December 2004

Technical Report

NREL/TP-550-36754

International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST)

Volume 2: Cases E300–E545

J. Neymark

J. Neymark & Associates, Golden, Colorado

R. Judkoff

National Renewable Energy Laboratory, Golden, Colorado

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Acknowledgments

The work described in this report was a cooperative effort involving the members of the International Energy Agency (IEA) Model Evaluation and Improvement Experts Group. The group was composed of experts from the IEA Solar Heating and Cooling (SHC) Programme, Task 22, and was chaired by R. Judkoff of the National Renewable Energy Laboratory (NREL) on behalf of the U.S. Department of Energy (DOE). We gratefully acknowledge the contributions from the modelers and the authors of sections on each of the computer programs used in this effort:

- CODYRUN: T. Mara, E. Fock, and F. Garde; University of Reunion Island, France
- ENERGYPLUS: R. Henninger and M. Witte; GARD Analytics, United States
- HOT3000: K. Haddad; CANMET Energy Technology Centre, Canada
- TRNSYS-TUD 14.2: H.-T. Le and G. Knabe; Technische Universität Dresden, Germany.

For assistance with our work with DOE-2.1E ESTSC (Energy Science and Technology Software Center, Oak Ridge National Laboratory, United States) version and DOE-2.2, we wish to thank F. Buhl of Lawrence Berkeley National Laboratory, United States, and J. Hirsch of James J. Hirsch & Associates, United States, respectively.

D. Barkley and J. Pegues of Carrier Corporation, United States, were very helpful with providing performance data for, and answering questions about, commercial air-cooled split-system space cooling equipment.

We appreciate the support and guidance of M. Holtz, operating agent for Task 22; and D. Crawley, DOE program manager for Task 22 and DOE representative to the IEA SHC Programme Executive Committee.

PREFACE

INTRODUCTION TO THE INTERNATIONAL ENERGY AGENCY

BACKGROUND

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 24 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development, and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security, and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation, and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centers.

SOLAR HEATING AND COOLING PROGRAMME

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its 20 members have been collaborating to advance active solar, passive solar, and photovoltaic technologies and their application in buildings.

The members are:

Australia	France	Portugal
Austria	Germany	Spain
Belgium	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	United Kingdom
European Commission	New Zealand	United States
Finland	Norway	

A total of 34 Tasks have been initiated, 25 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities – working groups, conferences, and workshops – have been organized.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:

Task 1	Investigation of the Performance of Solar Heating and Cooling Systems
Task 2	Coordination of Solar Heating and Cooling R&D
Task 3	Performance Testing of Solar Collectors
Task 4	Development of an Insolation Handbook and Instrument Package
Task 5	Use of Existing Meteorological Information for Solar Energy Application
Task 6	Performance of Solar Systems Using Evacuated Collectors
Task 7	Central Solar Heating Plants with Seasonal Storage
Task 8	Passive and Hybrid Solar Low Energy Buildings
Task 9	Solar Radiation and Pyranometry Studies
Task 10	Solar Materials R&D
Task 11	Passive and Hybrid Solar Commercial Buildings
Task 12	Building Energy Analysis and Design Tools for Solar Applications
Task 13	Advanced Solar Low Energy Buildings
Task 14	Advanced Active Solar Energy Systems
Task 16	Photovoltaics in Buildings
Task 17	Measuring and Modeling Spectral Radiation
Task 18	Advanced Glazing and Associated Materials for Solar and Building Applications
Task 19	Solar Air Systems
Task 20	Solar Energy in Building Renovation
Task 21	Daylight in Buildings
Task 22	Building Energy Analysis Tools
Task 23	Optimization of Solar Energy Use in Large Buildings
Task 24	Solar Procurement
Task 26	Solar Combisystems Working Group Materials in Solar Thermal Collectors
Task 30	Solar Cities – not initiated

Current Tasks:

Task 25	Solar Assisted Cooling Systems for Air Conditioning of Buildings
Task 27	Performance Assessment of Solar Building Envelope Components
Task 28	Solar Sustainable Housing
Task 29	Solar Crop Drying
Task 31	Daylight Buildings in the 21st Century
Task 32	Advanced Storage Concepts for Solar Thermal Systems in Low Energy Buildings
Task 33	Solar Heat for Industrial Processes
Task 34	Testing and Validation of Building Energy Simulation Tools
Task 35	PV/Thermal Systems

TASK 22: BUILDING ENERGY ANALYSIS TOOLS

Goal and Objectives of the Task

The overall goal of Task 22 was to establish a sound technical basis for analyzing solar and low-energy buildings with available and emerging building energy analysis tools. This goal was pursued by accomplishing the following objectives:

- Assessing the accuracy of available and emerging building energy analysis tools in predicting the performance of widely used solar and low-energy concepts
- Collecting and documenting engineering models of widely used solar and low-energy concepts for use in the next-generation building energy analysis tools
- Assessing and documenting the impact (value) of improved building analysis tools in analyzing solar and low-energy buildings, and widely disseminate research results and tools to industry and government agencies.

Scope of the Task

This Task investigated the availability and accuracy of building energy analysis tools and engineering models to evaluate the performance of solar and low-energy buildings. The scope of the Task was limited to whole-building energy analysis tools (including emerging modular type tools), and to widely used solar and low-energy design concepts. Tool evaluation activities included analytical, comparative, and empirical methods, with emphasis given to blind empirical validation using measured data from test rooms of full-scale buildings. Documentation of engineering models used existing standard reporting formats and procedures. The impact of improved building energy analysis was assessed from a building-owner perspective.

The audience for the results of the Task is developers of building energy analysis tools and national organizations that develop building energy standards. However, tool users such as architects, engineers, energy consultants, product manufacturers, and building owners and managers, are the ultimate beneficiaries of the research, and will be informed through targeted reports and articles.

Means

To accomplish the stated goal and objectives, the Participants carried out research under the framework of four Subtasks:

Subtask A: Tool Evaluation
Subtask B: Model Documentation
Subtask C: Comparative Evaluation
Subtask D: Empirical Evaluation

Participants

The participants in the Task were Australia, Canada, Finland, France, Germany, Spain, Sweden, Switzerland, the United Kingdom, and the United States. The United States served as Operating Agent for this Task, with Michael J. Holtz of Architectural Energy Corporation providing Operating Agent services on behalf of the U.S. Department of Energy.

This report documents work carried out under Subtask C: Comparative Evaluation.

Table of Contents

Electronic Media Contents

Files apply as they are called out in the test procedure.

README.DOC: Electronic media contents

NEW-ORL.TM2: TMY2 weather data for New Orleans, Louisiana, United States

E300MAP.XLS: Performance data (Tables 1-7a, 1-7b)

E300OUT2.XLS: Raw output data spreadsheet used by IEA participants

E300RESULTS.XLS: Results spreadsheet to assist users with plotting their results versus the example simulation results

E300RESULTS.DOC: Documentation for navigating E300RESULTS.XLS

\INPDECKS subdirectory (IEA SHC Task 22 participant simulation input decks)

\CODYRUN

\DOE-2.1E ESTSC

\DOE2.2

\ENERGYPLUS

\HOT3000

\TRNSYS-TUD

Executive Summary

This report is Volume 2 of the Building Energy Simulation Test for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST Volume 2). Volume 2 represents an extension of the tests in HVAC BESTEST Volume 1.[1] Volume 1 was limited to steady-state test cases that could be solved with analytical solutions. Volume 2 includes hourly dynamic effects, and other cases that cannot be solved analytically. This work was conducted by the National Renewable Energy Laboratory (NREL), United States in collaboration with the Tool Evaluation and Improvement Experts Group, under the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme Task 22. Other tool evaluation projects conducted in Task 22, and reported elsewhere, included work on empirical validation, comparative testing, and analytical verification (see front matter Introduction of this report for a list of references).

Background

The overall objective of the tool evaluation subtask is to develop a comprehensive and integrated set of tests for quality assurance during development of building energy simulation computer programs. These tests can also be used to certify software used to demonstrate performance-based code compliance in energy standards. Energy simulation tools are essential for evaluating solar energy and advanced energy efficiency technologies that are not normally addressed in prescriptive building energy standards and codes. Greater confidence in the accuracy and validity of predictions from building energy analysis tools can be established by developing these tests.

The development of practical procedures and data for tool evaluation and improvement is part of an overall IEA validation methodology that NREL[2,3] has been developing in collaboration with the IEA[4,5] for many years. The methodology combines empirical validation, analytical verification, and comparative analysis techniques; this is discussed in detail in the Background section of HVAC BESTEST Volume 1.[1]

NREL originally developed the BESTEST method in IEA SHC Task 12 and Energy Conservation in Buildings and Community Systems (ECBCS) Annex 21 to test building thermal fabric (envelope) models, and to diagnose sources of predictive disagreements.[6] This procedure was adopted with some refinements by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the American National Standards Institute (ANSI), and now forms the basis for ANSI/ASHRAE Standard 140, *Method of Test for the Evaluation of Building Energy Analysis Computer Programs*.[7] HVAC BESTEST extends the original BESTEST by adding the capability to test and diagnose mechanical system models. HVAC BESTEST Volume 1, cases E100–E200, are steady-state analytical verification tests that check the ability of simulation programs to apply basic performance map modeling techniques to simulation of unitary space cooling equipment on the working-fluid side of the cooling coil. These cases have been added to ANSI/ASHRAE Standard 140.[8]

This report documents an additional set of mechanical system test cases numbered E300–E545. These new cases, which are also planned for inclusion in ANSI/ASHRAE Standard 140, test a program's modeling capabilities on the working-fluid side of the coil, but in an hourly dynamic context over an expanded range of performance conditions. These cases help to scale the significance of disagreements that are less obvious in the steady-state cases. Cases E300–E440 also test the ability to model outside air mixing, infiltration, thermostat set up, overload conditions, and various economizer control schemes. The cases consist of a series of dynamic tests using a carefully specified mechanical cooling system applied to a highly simplified near-adiabatic building envelope. Because the mechanical equipment load is driven almost exclusively by sensible and latent internal gains, the response of the mechanical equipment models in simulation programs to a number of equipment performance parameters can be readily explored. Various output values—including energy consumptions, coil loads, and zone conditions—are compared and used in conjunction with a formal diagnostic method to determine the algorithms responsible for predictive differences.

Results

Field trials of the new HVAC BESTEST cases were conducted with a number of detailed state-of-the-art simulation programs from the United States and Europe as shown in Table ES-1. The process was iterative in that executing the simulations led to the refining of HVAC BESTEST, and the results of the tests led to improving and debugging the mechanical system models in the programs.

Table ES-1. Participating Organizations and Computer Programs

Simulation Program	Authoring Organization	Implemented by
CODYRUN/LGIMAT	Université de la Reunion Island, France	Université de la Reunion Island, France
DOE-2.1E-ESTSC version	LANL/LBNL/ESTSC/JJH,[a,b,c,d] United States	NREL/JNA,[e] United States
DOE-2.2 NT	LBNL/JJH,[b,d] United States	NREL/JNA,[e] United States
ENERGYPLUS	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-BT,[b,f,g,h,i,j] United States	GARD Analytics, United States
HOT3000	CETC/ESRU,[k,l] Canada/United Kingdom	CETC,[k] Canada
TRNSYS 14.2-TUD with real controller model	University of Wisconsin, United States; Technische Universität Dresden, Germany	Technische Universität Dresden, Germany

[a]LANL: Los Alamos National Laboratory, United States
[b]LBNL: Lawrence Berkeley National Laboratory, United States
[c]ESTSC: Energy Science and Technology Software Center (at Oak Ridge National Laboratory, United States)
[d]JJH: James J. Hirsch & Associates, United States
[e]NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates, United Sates
[f]UIUC: University of Illinois Urbana/Champaign, United States
[g]CERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, United States
[h]OSU: Oklahoma State University, United States
[i]FSEC: University of Central Florida, Florida Solar Energy Center, United States
[j]DOE-BT: U.S. Department of Energy, Office of Building Technologies, Energy Efficiency and Renewable Energy, United States
[k]CETC: CANMET Energy Technology Centre, Natural Resources Canada, Canada
[l]ESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

The agreement among simulation results improved with each iteration of the field trials. Improvements to the simulation programs are evident when the initial results set in Figure ES-1 is compared to the final results set in Figure ES-2. Improvements to simulation programs or simulation inputs made by participants must have a mathematical and physical basis, and must be applied consistently across tests. Also, all improvements were required to be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed.

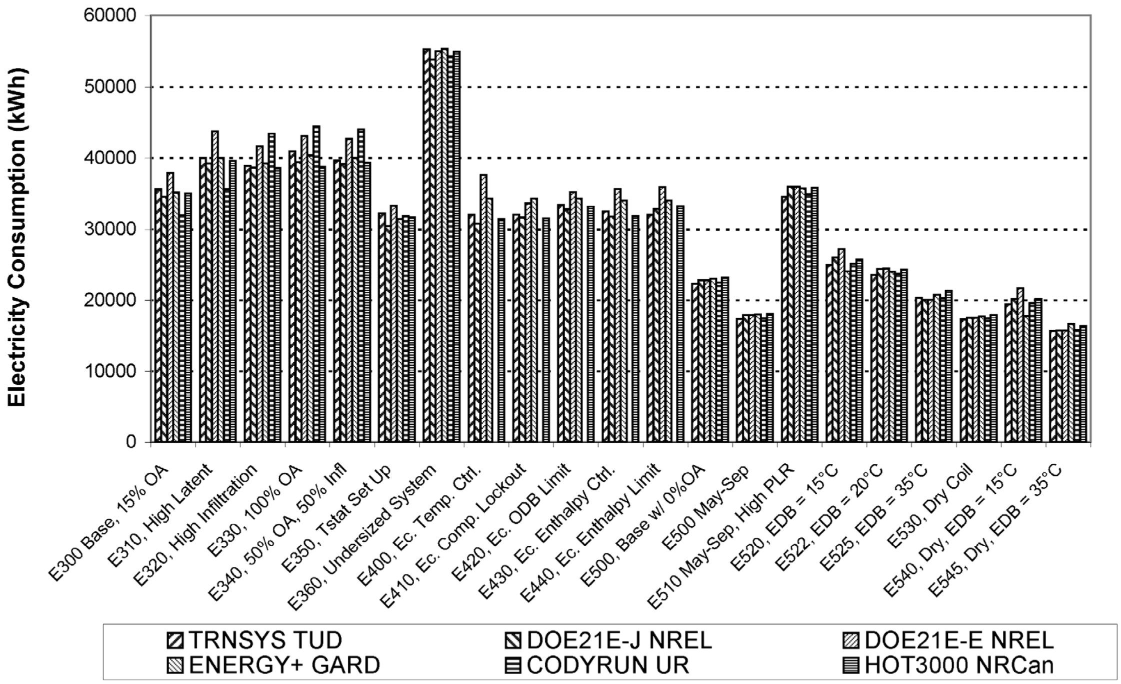

Figure ES-1. HVAC BESTEST E300–E545—total electricity consumption, before "BESTESTing"
(Abbreviations along the x-axis are shorthand for the case descriptions; see Part I for full case descriptions.)

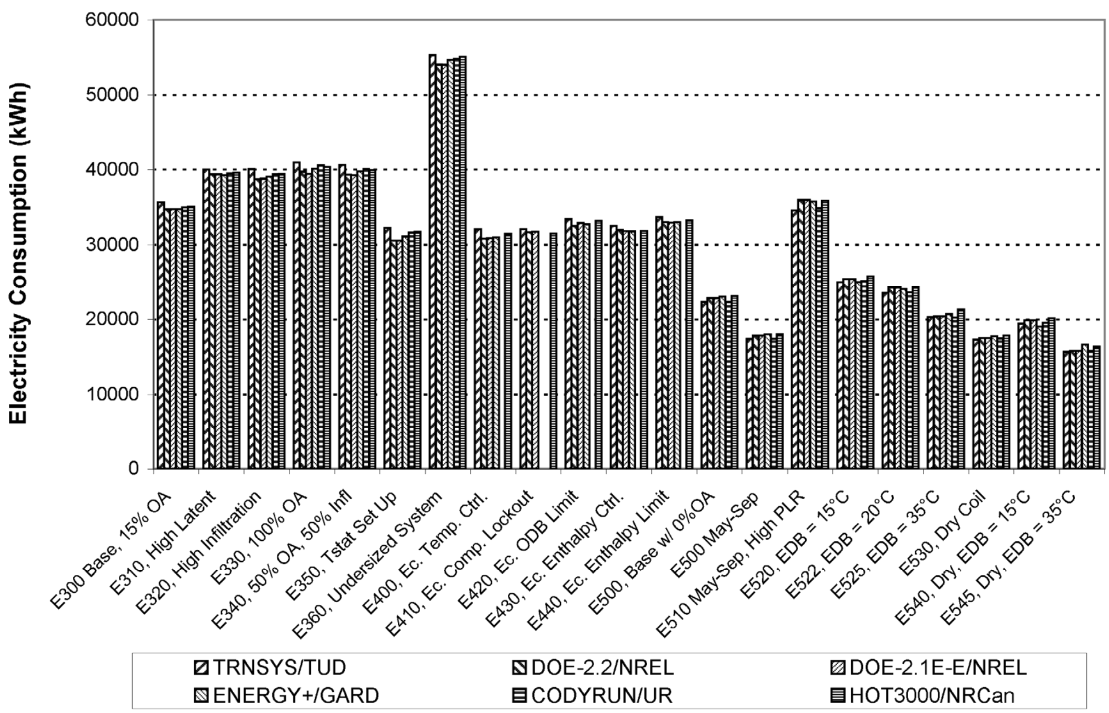

Figure ES-2. HVAC BESTEST E300–E545—total electricity consumption, after BESTESTing
(Abbreviations along the x-axis are shorthand for the case descriptions; see Part I for full case descriptions.)

These results indicate that there was initially a 3%–21% disagreement among the cases for the simulated energy consumption results, and that there was a lot of scatter among all the programs. Here disagreement is the difference between the maximum and minimum result for each case, divided by the mean of the results for each case ((max-min)/mean). The initial results disagreements are smaller for these results than for the E100–E200 cases (4%–40%) because TRNSYS-TUD, DOE-2.1E, and EnergyPlus were already improved during the earlier field trials of cases E100–E200.

After correcting software errors using HVAC BESTEST diagnostics, the remaining disagreements of results for annual total energy consumption for the programs are 2%–6% with very little scatter among the programs. This shows how the HVAC BESTEST method is used to diagnose and correct faulty algorithms in complex simulation programs.

Based on results *after* several iterations of HVAC BESTESTing, and on model improvements, the tested programs now appear reliable for performance-map modeling of space cooling equipment over an expanded range of dynamic performance conditions. The programs also appear reliable for modeling outside air mixing, infiltration, thermostat set up, overloaded conditions, and various economizer control schemes. This set of results may therefore be used as a reference or benchmark against which other software can be tested.

In contrast with steady-state cases E100–E200, which were solved analytically, the more realistic nature of cases E300–E545 allows us to gauge the importance of differences in simulation results in terms of annual energy performance, and if desired, annual energy cost (although not done here). This is a good way to understand the importance of the differences in results. For example, a large percentage difference for a given result that has only a very small impact on annual energy use may not be of concern, whereas a small percentage difference with a large impact on annual energy use may be deemed important. The internal gains schedules for cases E300–E545 combine aspects of both building thermal fabric loads and typical internal gains loading. Because there is almost no uncertainty regarding the load to which the mechanical system is responding, all disagreements in simulation results may be attributed to the HVAC system models. It is therefore apparent from the initial results for Case E300 that faulty algorithms in mechanical equipment models can easily account for 10%–20% errors in energy consumption estimates for real buildings. This was after many of the programs had already corrected errors found from running cases E100–E200.

Bugs Found in Simulation Programs

The results generated with the simulation programs used in this report are intended to be useful for evaluating other detailed or simplified building energy prediction tools. The collective experience of the IEA Experts Group has shown that when a program exhibits major disagreement with the results given in Part III of the report, the underlying cause is usually a bug, a faulty algorithm, or a documentation problem. During the field trials of cases E300–E545, the HVAC BESTEST diagnostic methodology was successful at exposing such problems in all but one of the simulation programs tested. The most notable examples for each program are listed below (in alphabetical order by program name); a listing of 21 problems found among the tested programs appears in Section 2.6 of Part II.

- CODYRUN. Isolation and correction of problems related to both inconsistent accounting of fan heat and neural network performance mapping for dry-coil conditions; this caused underestimated compressor annual consumption estimates of 14%, and underestimated peak-hour total consumption estimates of 9%. (CODYRUN is a detailed hourly simulation program sponsored by University of Reunion Island, France.)

- DOE-2.1E ESTSC version. Isolation of misleading documentation related to adjustment of bypass factor as a function of part-load ratio (PLR); this caused overestimation of latent coil loads and total energy consumption by 30%–115% and 7%–22%, respectively, in cases with continuous fan operation and typical ranges of PLR (Until recently, DOE-2 was the main building energy analysis program sponsored by the U.S. Department of Energy [DOE]; many of its algorithms are being incorporated into EnergyPlus.)
- DOE-2.2. Isolation and correction of an error in DOE-2.2 related to calculation of entering wet-bulb temperature; this caused 20%–50% overestimation of peak-hour latent coil loads in cases with high outside air fractions. (DOE-2.2 is based on DOE-2.1E, with further developments by James J. Hirsch & Associates.)
- ENERGYPLUS. Isolation and correction of an error related to calculating cooling coil outlet temperature and humidity ratio during dry-coil operation that caused the equipment not to operate during certain hours; this affected annual combined compressor and condenser fan annual energy consumption and total peak-hour consumptions by 1%–2% for cases E300–E360. (DOE recently released EnergyPlus as its next-generation building energy simulation program.)
- HOT3000. Isolation and correction of an error related to outside air modeling; this caused 4% underestimation of total consumption, 5% underestimation of sensible coil load, and 9% underestimation of latent coil load in the case with 100% outside air. (HOT3000 is developed and maintained by CANMET Energy Technology Centre at Natural Resources Canada; it is a modified version of ESP-r—authored by the University of Strathclyde, Scotland, United Kingdom—that retains ESP-r's modeling approach but includes some new models, such as those for unitary space cooling equipment.)

Conclusions

An advantage of BESTEST is that a program is examined over a broad range of parametric interactions based on a variety of output types, minimizing the possibility for concealment of problems by compensating errors. Performance of the tests resulted in quality improvements to all but one of the building energy simulation programs used in this study. Some of the bugs that were found may well have been present for many years. The fact that they have just now been uncovered shows the power of BESTEST and also suggests the importance of continuing to develop formalized validation and diagnostic methods.

Checking a building energy simulation program for the first time with HVAC BESTEST Volume 2 (cases E300–E545) requires about one person-week for an experienced simulation user, not including improvements to software if necessary. Subsequent program checks are faster because existing input decks may be reused. Because the simulation programs have taken many years to produce, HVAC BESTEST provides a very cost-effective way of testing them. As we continue to develop new test cases, we will adhere to the principle of parsimony so that the entire suite of BESTEST cases may be implemented by users within a reasonable time span.

Software developers, architects, engineers, and researchers can use these new HVAC BESTEST cases in a number of different ways, such as:

- To compare several building energy simulation programs to determine the degree of disagreement among them
- To diagnose the algorithmic sources of prediction differences among several building energy simulation programs

- To compare predictions from other building energy simulation programs to the simulation results in this report
- To check a program against a previous version of itself after internal code modifications to ensure that only the intended changes actually resulted
- To check a program against itself after a single algorithmic change to understand the sensitivity among algorithms.

Closing Remarks

The work presented in this report, and the work that has preceded it in IEA SHC Tasks 8, 12 (ECBCS Annex 21), and 22 is significant for two reasons. First, the methods have been extremely successful at correcting software errors in advanced building energy simulation programs throughout the world. Second, the methods are finding their way into industry by being adopted as the theoretical basis for formalized standard methods of test and software certification schemes; in this sense the work may be thought of as pre-normative research.

The previous IEA BESTEST envelope test cases[6] and the overall validation methodology[2,3] have been code-language adapted and formally approved as a standard method of test (ANSI/ASHRAE Standard 140).[7] ASHRAE Standard 90.1[9] requires that software used for demonstrating performance compliance with Standard 90.1 be tested using ASHRAE Standard 140. Standard 90.1 is ASHRAE's consensus energy code for commercial buildings and for non-low-rise residential buildings. IEA BESTEST is also being used for simulation certification tests in The Netherlands[10] and Australia.[11,12] The HVAC BESTEST Volume 1, cases E100–E200[1] have been code-language adapted and formally approved as Addendum *a* to ASHRAE Standard 140.[8] HVAC BESTEST Fuel-Fired Furnace Test Cases[13] are being code-language adapted for Standard 140. We anticipate that HVAC BESTEST Volume 2 cases E300–E545, other work from IEA SHC Task 22, and new work from a collaboration of IEA's SHC and ECBCS programmes (IEA SHC/ECBCS Task 34/Annex 43) will also be added to Standard 140 in the future. In the United States, the National Association of State Energy Officials (NASEO) Residential Energy Services Network (RESNET) has adopted Home Energy Rating System (HERS) BESTEST[14] as the basis for certifying software to be used for home energy rating systems under the NASEO/RESNET national accreditation standard.[15] HERS BESTEST is also being code-language adapted for future inclusion with ASHRAE Standard 140.[16] We hope that as the procedures become better known, developers will automatically run the tests as part of their normal in-house quality control efforts. The large number of requests (more than 1000) that we have received for the various BESTEST reports indicates that this is beginning to happen. For example, we recently learned that Carrier Corporation and Trane, which are among the largest suppliers of HVAC equipment in the world, are testing their respective software HAP and TRACE with Standard 140. Also, EnergyPlus, the United States Department of Energy's most advanced simulation program for building energy analysis, distributes their Standard 140 validation results with their CDs and from their website.

New energy-related technologies are continually being introduced into the buildings market. Thus, there will always be a need for further development of simulation models, combined with a substantial program of testing and validation. Such an effort should contain all the elements of an overall validation methodology (see HVAC BESTEST Volume 1:[1] Background Section), including:

- Analytical verification
- Comparative testing and diagnostics
- Empirical validation.

Future work should therefore encompass (see Section 2.5.2 for details):

- Continued production of a standard set of analytical tests
- Development of a set of diagnostic comparative tests that emphasize the modeling issues important in large commercial buildings, such as zoning, infiltration airflow rate determination, and more tests for heating, ventilating, and air-conditioning systems
- Development of a sequentially ordered series of high-quality data sets for empirical validation.

Continued support of model development and validation activities is essential because occupied buildings are not amenable to classical controlled, repeatable experiments. The few buildings that are truly useful for empirical validation studies have been designed primarily as test facilities. The energy, comfort, and lighting performance of buildings depend on the interactions among a large number of transfer mechanisms, components, and systems. Simulation is the only practical way to bring a systems integration problem of this magnitude within the grasp of designers. Greatly reducing the energy intensity of buildings through better design is possible with the use of simulation tools.[17] However, building energy simulation programs will not be widely used unless the design and engineering communities have confidence in these programs. Confidence and quality can best be encouraged by combining a rigorous development and validation effort with user-friendly interfaces.

Finally, the authors wish to acknowledge that the expertise available through IEA and the dedication of the participants were essential to the success of this project. Over the 4-year field trial effort, there were several revisions to the HVAC BESTEST specifications and subsequent re-executions of the computer simulations. This iterative process led to the refining of HVAC BESTEST, and the results of the tests led to improving and debugging of the programs. The process underscores the leveraging of resources for the IEA countries participating in this project. Such extensive field trials, and resulting enhancements to the tests, were much more cost effective with the participation of the IEA SHC Task 22 experts.

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Volume 1: Tier 1 and Tier 2 Tests User's Manual, NREL/TP-472-7332a, available from http://www.nrel.gov/docs/legosti/fy96/7332a.pdf (PDF 5.6 MB);
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Introduction

This report is Volume 2 of the Building Energy Simulation Test for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST Volume 2). Volume 2 represents an extension of the tests in HVAC BESTEST Volume 1 (Neymark and Judkoff 2002). Volume 1 was limited to test cases that could be solved with analytical solutions. Volume 2 includes dynamic effects, and other cases that cannot be solved analytically. This work was conducted by the National Renewable Energy Laboratory (NREL) in collaboration with the Tool Evaluation and Improvement Experts Group under International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme Task 22. Other tool evaluation projects conducted in Task 22, Subtasks A, C, and D, reported elsewhere, included work on empirical validation (Guyon and Moinard 1999; Maxwell, Loutzenhiser, and Klaassen 2003; Maxwell, Loutzenhiser, and Klaassen 2004; Palomo and Guyon 2002; Travesi et al. 2001); comparative testing (Achermann and Zweifel 2003; Purdy and Beausoleil-Morrison 2003; Deru, Judkoff, and Neymark 2003); and analytical verification (Neymark and Judkoff 2002; Purdy and Beausoleil-Morrison 2003; San Isidro 2000; Tuomaala 1999). In addition, Task 22, Subtask B has produced a report on the application of the Neutral Model Format in building energy simulation programs (Bring, Sahlin, and Vuolle 1999).

Background

The overall objective of the tool evaluation subtask is to develop a comprehensive and integrated set of tests for quality assurance during development of building energy simulation computer programs. These tests can also be used to certify software used to demonstrate performance-based code compliance in energy standards. Energy simulation tools are essential for evaluating solar energy and advanced energy efficiency technologies that are not normally addressed in prescriptive building energy standards and codes. Greater confidence in the accuracy and validity of predictions from building energy analysis tools can be established by developing these tests.

The development of practical procedures and data for tool evaluation and improvement is part of an overall IEA validation methodology that NREL (Judkoff et al. 1983; Judkoff 1988) and the IEA (e.g., Bloomfield 1989; Lomas 1991) have been developing for many years. The methodology combines empirical validation, analytical verification, and comparative analysis techniques; this is discussed in detail in the Background Section of HVAC BESTEST Volume 1 (Neymark and Judkoff 2002).

The BESTEST method was originally developed by NREL in IEA SHC Task 12 and Energy Conservation in Buildings and Community Systems Annex 21 to test building thermal fabric (envelope) models, and to diagnose sources of predictive disagreements (Judkoff and Neymark 1995a). This method of test was adopted with some refinements by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) in accordance with procedures of the American National Standards Institute (ANSI), and now forms the basis for ANSI/ASHRAE Standard 140, *Method of Test for the Evaluation of Building Energy Analysis Computer Programs* (ANSI/ASHRAE 2001). HVAC BESTEST extends the original BESTEST by adding the capability to test and diagnose mechanical system models. HVAC BESTEST Volume 1 cases E100–E200 are steady-state analytical verification tests that check the ability of simulation programs to apply basic performance-map modeling techniques to the simulation of unitary space cooling equipment on the working-fluid side of the cooling coil. These cases have been added to ANSI/ASHRAE Standard 140 (ANSI/ASHRAE 2004).

This report documents an additional set of mechanical system test cases numbered E300–E545. These new cases, which are also planned for inclusion in ANSI/ASHRAE Standard 140, test a program's modeling capabilities on the working-fluid side of the coil, but in an hourly dynamic context over an expanded range of performance conditions. These cases help to scale the importance of disagreements in simulation results that are less obvious in the steady-state cases. For example, a large percentage difference for a given result that has only a very small impact on annual energy use may not be of concern, whereas a small percentage difference with a large impact on annual energy use may be deemed important. Cases E300–E440 also test the ability to model outside air mixing, infiltration, thermostat set up, overloaded conditions, and various economizer control schemes. The cases consist of a series of dynamic tests using a carefully specified mechanical cooling system applied to a highly simplified near-adiabatic building envelope. Because the mechanical equipment load is driven almost exclusively by sensible and latent internal gains, the response of the mechanical equipment models in simulation programs to a number of equipment performance parameters can be readily explored. Various output values—including energy consumptions, coil loads, and zone conditions—are compared and used in conjunction with a formal diagnostic method to determine the algorithms responsible for predictive differences.

As a BESTEST user, if you have not already tested your software's ability to model envelope loads, we strongly recommend that you run the envelope-load tests in addition to HVAC BESTEST. A set of envelope-load tests is included in ASHRAE Standard 140 (ANSI/ASHRAE 2001); the Standard 140 test cases are based on IEA BESTEST (Judkoff and Neymark 1995a). Another set of envelope-load test cases, which were designed to test simplified tools such as those currently used for home energy rating systems (HERS), is included in HERS BESTEST (Judkoff and Neymark 1995b; Judkoff and Neymark 1997). HERS BESTEST has a more realistic base building than IEA BESTEST; however, its ability to diagnose sources of differences among results is not as detailed (Neymark and Judkoff 1997).

Final Report Structure

This report is divided into three parts. Part I is a user's manual that furnishes instructions on how to apply the HVAC BESTEST procedure. Part II describes the development, field-testing, and production of results data for the procedure. Part III presents the simulation program example results in tables and graphs along with disagreement statistics that compare the simulation programs to each other; these data can be used to compare results from other programs to Part III results.

An overview of validation methodology and a summary of previous NREL, IEA-related, and other validation work related to software that analyzes energy use in buildings is included in the Background Section of the front matter of Volume 1 (Neymark and Judkoff 2002).

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1.0 Part I: HVAC BESTEST User's Manual: Procedure and Specification Cases E300–E545

1.1 General Description of the Test Cases

There are 20 additional cases as summarized in Table 1-1 beyond those that were specified previously in *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 1* (Neymark and Judkoff 2002). These cases (E300–E545) test a program's ability to model mechanical equipment performance using realistic, dynamic, annual hourly weather data for a hot and humid climate.

The configuration of the base case building for these tests (Case E300) is a near-adiabatic rectangular single zone with user-specified internal gains, and outside air to drive dynamic loads. The mechanical system remains as vapor compression cooling equipment, but is a different system than for Cases E100–E200 and includes an expanded performance data set. Also, an air-mixing system has been added so that outside air mixing and economizer control can be included in the tests. As shown in Table 1-1, the following parameters are varied to develop the cases:

- Sensible internal gains
- Latent internal gains
- Infiltration rate
- Outside-air fraction
- Thermostat set points
- Economizer control settings.

The CD included with this document contains the following:

- NEW-ORL.TM2 (weather data for New Orleans, Louisiana, United States; typical meteorological year 2 [TMY2] format)
- E300MAP.XLS (performance data)
- E300OUT2.XLS (spreadsheet for recording output)
- E300RESULTS.XLS (example simulation results)
- E300RESULTS.DOC (navigation instructions for E300RESULTS.XLS)
- README.DOC (electronic media contents)
- \INPDECKS (participant input decks).

Table 1-1. HVAC BESTEST Case Descriptions (Cases E300–E545)

DYNAMIC TESTS - Hot and Humid Weather (New Orleans, LA), Near-Adiabatic Building Envelope

Case	Internal Gains Sensible	Internal Gains Latent	Cooling Setpoint (°C)	Infil. (ACH)	Outside Air (ACH)	Comments
Preliminary Series						
E300 Base Case (15% OA)	mid	mid	25	0	1.734	Supply fan runs continously, compressor cycles as needed, expanded performance data. Tests outside air versus E500.
E310 High latent load	mid	high	25	0	1.734	Tests high latent load versus E300.
E320 Infiltration	mid	mid	25	11.558 *	0.000	Tests high infiltration versus E300, E330.
E330 Outside air	mid	mid	25	0	11.558 *	Tests high outside air versus E300, E320.
E340 Infil./OA interaction	mid	mid	25	5.779 *	5.779 *	Tests infil./OA interaction versus E300, and E320 or E330.
E350 Thermostat set up	mid	mid	25/35	0	1.734	Tests thermostat set up control versus E300.
E360 Undersize	high	mid	25	0	1.734	Tests overloaded system versus E300.
Economizer Series					**Min OA**	**(Temperature control: E400, E410, E420)**
E400 Temperature control	mid	mid	25	0	1.734	Tests temperature economizer versus E300.
E410 Compressor lockout	mid	mid	25	0	1.734	Tests E400 with compressor lockout versus E300.
E420 ODB limit	mid	mid	25	0	1.734	Tests ODB limit (20°C) control versus E300.
						(Enthalpy control: E430, E440)
E430 Enthalpy control	mid	mid	25	0	1.734	Tests enthalpy control versus E300.
E440 Outdoor enthalpy limit	mid	mid	25	0	1.734	Tests outdoor enthalpy limit control versus E300.
0% OA Cases					**OA**	**(Wet coils: E500 - E525)**
E500 Base Case (0% OA)	mid2	mid2	25	0	0 **	Like E100 but with dynamics & expanded performance data. Supply fan cycles ON/OFF with compressor. Hourly output tests COP f(ODB).
E510 High PLR	high2	high2	25	0	0 **	High PLR. SHR same as E500. Tests PLR versus E500.
E520 Low EDB = 15°C	mid2	mid2	15	0	0 **	Tests EDB = 15°C versus E500.
E522 Low EDB = 20°C	mid2	mid2	20	0	0 **	Tests EDB = 20°C versus E500.
E525 High EDB	mid2	mid2	35	0	0 **	Tests EDB = 35°C versus E500, E520.
						(Dry coils: E530 - E545)
E530 Dry Coil	mid2	0	25	0	0 **	Tests dynamic dry-coil expanded performance versus E500. Hourly output tests COP f(ODB).
E540 Dry Coil, Low EDB	mid2	0	15	0	0 **	Tests EDB = 15°C versus E530.
E545 Dry Coil, High EDB	mid2	0	35	0	0 **	Tests EDB = 35°C versus E530.

Abbreviations: ACH = air changes per hour; COP = coefficient of performance; EDB = entering dry-bulb temperature; Infil. = infiltration; OA = outside air; ODB = outdoor dry-bulb temperature; PLR = part load ratio; SHR = sensible heat ratio.

Notes:
"mid" internal gains schedules are relatively high daytime and low nighttime periodically/seasonally adjusted values. See case descriptions for details.
"mid2" is similar to "mid" but with 0 cooler-month internal gains to get 0 cooling at ODB <55°F for 0 OA. See case descriptions.
"high" and "high2" are greater loads relative to "mid" and "mid2," respectively.

* Apr. 21 - Oct. 12, 8:00 - 20:00 only; see case descriptions for specific schedule.
**OA = 0 implies fan cycles ON/OFF with compressor.

e300case14.xls, d:a2..n47; Oct 27, 2004

1.2 Performing the Tests

1.2.1 Input Requirements

Building input data are organized case by case. The base case description (Case E300) is given in Section 1.3.1, with additional cases presented in Sections 1.3.2, 1.3.3, and 1.3.4. The additional cases are organized as modifications to the base case and ordered in a manner that will hopefully facilitate implementing the tests. In some instances (e.g., cases E400 and E500), a case developed from modifications to Case E300 will also serve as the base case for other cases.

Table 1-1 is a summary of the various parametric cases contained herein. These tables are provided only as an overview; use Section 1.3 to generate specific input decks. We recommend a quick look at Table 1-1 now to briefly study the base building and the other cases.

All of the cases utilize the New Orleans weather data; more detail on weather data is in Section 1.3.1.1.

1.2.2 Modeling Rules

(Note that these rules are the same as before for Cases E100–E200 except for the time convention, which indicates that weather data are binned into hours corresponding to the usual standard time.)

1.2.2.1 Consistent Modeling Methods

Where options exist within a simulation program for modeling a specific thermal behavior, consistent modeling methods shall be used for all cases. For example, if a software gives the user a choice of methods for modeling indoor air distribution fans, the same indoor fan modeling method shall be used for all cases. For the purpose of generating the example results, the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme, Task 22, participants used the most detailed level of modeling that was allowed by their simulation programs and that was consistent with the level of detail provided in this test specification.

1.2.2.2 Nonapplicable Inputs

In some instances the specification will include input values that do not apply to the input structure of your program. For example, your program may not allow the user to specify variation of cooling system sensible capacity with entering dry-bulb temperature, may not use the listed combined convective/radiative film coefficients, and/or may not apply other listed inputs. When nonapplicable input values are found, either use approximation methods suggested in your users manual, or simply disregard the nonapplicable inputs and continue. Such inputs are in the specification for those programs that may need them.

1.2.2.3 Time Convention

References to time in this specification are to local standard time. Assume that *hour 1 = 0:00–1:00 (the interval from midnight to 1 A.M.)*. Do not use daylight savings time or holidays for scheduling. The required TMY2 data are in hourly bins corresponding to standard time, consistent with all other schedules.

1.2.2.4 Geometry Convention

If your program includes the thickness of walls in a three-dimensional definition of the building geometry, then the wall, roof, and floor thicknesses should be defined such that the interior air volume of the building remains as specified (e.g., for Case E300, 14 m × 14 m × 3 m = 588 m^3). Make the thicknesses extend exterior to the currently defined internal volume.

1.2.2.5 Simulation Initialization

If your software allows, begin the simulation initialization process with zone air conditions that equal the outdoor air conditions.

1.2.2.6 Simulation Preconditioning

If your program allows for preconditioning (iterative simulation of an initial time period until temperatures or fluxes, or both, stabilize at initial values), use that capability.

1.2.2.7 Simulation Duration

Run the full annual simulation using the weather data provided. Give outputs as required per the test case descriptions in Section 1.3.

1.2.3 Comparing Your Output to the Example Simulation Results

You should compare your output with the example simulation results located in Part III, or with other results that were generated using this test procedure. Information about how example simulation results were produced is included in Part II. If you wish to plot or tabulate your results along with the example results, we have included for your convenience an electronic version of the example results with the file E300RESULTS.XLS on the accompanying CD.

1.2.3.1 Criteria for Determining Agreement between Results

For the E300 series we provide no formal criteria for when results agree or disagree. Determination of when results agree or disagree is left to the user. In making this determination the user should consider:

- Magnitude of results for individual cases
- Magnitude of difference in results between certain cases (e.g., Case E310–Case E300)
- Same direction of sensitivity (positive or negative) for difference in results between certain cases (e.g., Case E310–Case E300)
- Example results do <u>not</u> represent a truth standard
- Results that are logically counterintuitive with respect to known or expected physical behavior.

1.2.3.2 Diagnostic Logic for Determining Causes of Differences among Results

To help you identify which algorithm in the tested program is causing specific differences between programs, we have included diagnostic flow charts in Appendix G.

1.2.3.3 Rules for Modifying Simulation Programs or Simulation Inputs

Improvements to simulation programs or simulation inputs must have a mathematical and physical basis, and must be applied consistently across tests. Such improvements must be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed.

1.3 Input Specifications

1.3.1 Case E300: Base Case

Begin with Case E300. Case E300 shall be modeled as detailed in this section and its subsections. The bulk of the work for implementing this test is assembling an accurate base building model. We recommend that inputs for Case E300 be double-checked and that results disagreements diagnosed before going on to the other cases.

1.3.1.1 Weather Data

Use the TMY2 format weather data (NEW-ORL.TM2) provided on the CD. Site and weather characteristics are summarized in Table 1-2. The hourly time reference for TMY2 weather data is local standard time. See Appendix A for details about the TMY2 weather data file format.

Note regarding TMY2 data time convention. According to the weather data documentation included in Appendix A, solar radiation data represents energy received during the 60 minutes preceding the hour indicated. For meteorological elements, such as dry-bulb temperature, dew point temperature, relative humidity, and atmospheric pressure, data are spot measurements made at the hour indicated (Marion and Urban 1995). During the field trials, we observed that some simulation tools have adapted the meteorological element data to a preceding hour convention by averaging the listed point measurements for each hour. Other simulation tools have applied the meteorological element data as listed directly to their preceding hour time convention. These different applications give similar annual energy use results, but can cause variations among hourly and peak-hour load and consumption results. We conclude that both of these applications are reasonable interpretations for simulations that use preceding hour time conventions, and that different adaptations of the mixed conventions of TMY2 data cause legitimate disagreement among simulation results.

Table 1-2. Site and Weather Summary—New Orleans, Louisiana, United States

Climate Location	New Orleans
File name	NEW-ORL.TM2
Weather format	TMY2
Latitude	30.0° north
Longitude (local site)	90.3° west
Altitude	3 m
Time zone (standard meridian longitude)	6 (90° west)
Ground reflectivity	0.2
Site	Flat, unobstructed, located exactly at weather station
Mean annual outdoor dry-bulb temperature (ODB)	19.9°C
Minimum annual ODB	-4.4°C
Maximum annual ODB	35.0°C
Mean annual dew point temperature	14.7°C
Mean annual humidity ratio	0.0116
Mean annual wind speed	3.6 m/s
Maximum annual wind speed	13.9 m/s
Global horizontal solar radiation annual total	1680 kWh/m²
Direct normal solar radiation annual total	1498 kWh/m²

1.3.1.2 Output Requirements

Enter all your output data into the preformatted spreadsheet with the file name E300OUT2.XLS on the enclosed CD. Instructions for using the spreadsheet are included at the top of the spreadsheet and in Appendix B. Terms not defined directly below are defined in Appendix C (Glossary).

1.3.1.2.1 Annual Summations. The outputs listed immediately below are to include summed loads or consumptions (as appropriate) for the full annual simulation (full year).

- Cooling energy consumptions (kilowatt-hours [kWh] for annual sums, watt-hours [Wh] for hourly maxima)
    - Total consumption (compressor + outdoor condenser fan + indoor air distribution fan)
    - Disaggregated compressor consumption
    - Disaggregated outdoor condenser fan consumption
    - Disaggregated indoor air distribution fan consumption

- Evaporator coil loads (kWh for annual sums, Wh for hourly maxima)
  - Total evaporator coil load (sensible + latent)
  - Disaggregated sensible evaporator coil load
  - Disaggregated latent evaporator coil load.

1.3.1.2.2 Annual Hourly Maximum Values Only. The outputs listed immediately below are to include the hourly integrated maximum values for the full annual simulation. Maximum values are to include date and hour of occurrence; if there are multiple hours of occurrence for the maximum value, give the time and date for the first hour of the maximum value occurrence.

- Cooling energy consumptions (Wh)
  - Total consumption (compressor and both fans)
- Evaporator coil loads (Wh)
  - Total evaporator coil load (sensible + latent)
  - Disaggregated sensible evaporator coil load
  - Disaggregated latent evaporator coil load.

1.3.1.2.3 Annual Means, Maxima, and Minima. The outputs listed immediately below are to include the mean value for the full annual simulation and the hourly integrated maximum and minimum values for the full annual simulation. Maximum and minimum values are to include date and hour of occurrence. If there are multiple hours of occurrence for the maximum and/or minimum values, give the time and date for the first hour of the occurrence.

- Zone indoor dry-bulb temperature (IDB; °C)
- Zone humidity ratio (kg moisture/kg dry air)
- Zone relative humidity (%)
- Coefficient of performance excluding indoor fan energy consumption (COP_2, as defined below).

Relative humidity is the ratio of the mole fraction of water vapor in a given moist air sample to the mole fraction in an air sample that is saturated and at the same temperature and pressure. This is equivalent to the ratio of the partial pressure of the water vapor in a sample to the saturation pressure at the same temperature.

COP_2 is different from COP defined for cases E100–E200. Hourly COP_2 is calculated for each hour as

$$COP_2 = \text{(total coil load)} / (\text{(compressor energy)} + \text{(outdoor fan energy)}),$$

and is calculated for hours only when compressor energy > 0.

The mean value for COP_2 is calculated as

$$COP_{2,mean} = \Sigma\text{(total coil load)} / (\Sigma\text{(compressor energy)} + \Sigma\text{(outdoor fan energy)}),$$

where: Σ indicates annual summation of the given value
Total coil load is the sensible + latent evaporator coil load.

For example, if for an annual simulation

Total coil load (sensible + latent) = 28500 kWh thermal, and

Combined compressor and outdoor-fan energy is 6240 kWh electric, then

$COP_{2,mean}$ = 28500 kWh / 6240 kWh = 4.567.

Note that if your software does not output enough significant digits, maximum and minimum values for COP_2 can be generated by rounding uncertainty. If this is the case, when determining maximum and minimum COP_2 it will be necessary to filter out lower part-load ratio (PLR) outputs (e.g., for PLR < 0.01).

1.3.1.2.4 Additional Outputs for Case E300 Only.

- Annual means and maximum values (weather data checks)

  The outputs listed immediately below are to include the mean value for the full annual simulation and the hourly integrated maximum values for the full annual simulation. Maximum values are to include date and hour of occurrence. If there are multiple hours of occurrence for the maximum value, give the time and date for the first hour of the occurrence.

  - ODB (°C)
  - Outdoor humidity ratio (kg/kg)

- The following hourly outputs are for June 28 (all 24 hours):

  - Compressor electric consumption (Wh)
  - Outdoor condenser fan electric consumption (Wh)
  - Total evaporator coil load (Wh)
  - Sensible evaporator coil load (Wh)
  - Latent evaporator coil load (Wh)
  - COP_2
  - Zone humidity ratio (kg/kg)
  - ODB (°C)
  - Entering dry-bulb temperature (EDB), same as mixed air dry-bulb temperature (°C)
  - Entering wet-bulb temperature (EWB), same as mixed air wet-bulb temperature (°C)
  - Outdoor Humidity Ratio (kg/kg)

The hourly data are to consist of 24 values for each day. The first hour (hour 1) is defined to run from 00:00 to 01:00. To produce this output, run the program for a normal annual run. Do not run only the required days because the results could contain temperature history errors.

The June 28 hourly outputs are required only for Case E300. June 28 was chosen because of the relatively wide range of conditions occurring on that day. The purpose of including EDB, EWB, and ODB is to be able to check your model's use of the performance map when it is evaluating these hours.

1.3.1.3 Building Zone Description

1.3.1.3.1 Building Geometry. The base building is a 196-m² floor area, single-story building with rectangular-prism geometry as shown in Figure 1-1. Zone air volume is 588 m^3.

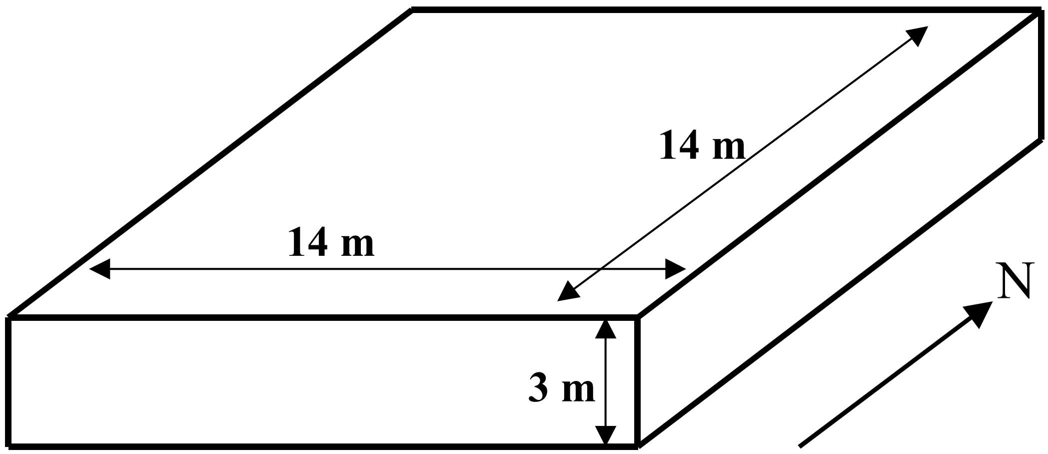

Figure 1-1. HVAC BESTEST Case E300: near-adiabatic envelope geometry

1.3.1.3.2 Building Envelope Thermal Properties. The base building zone is intended as a near-adiabatic test cell with cooling load driven by user-specified scheduled internal gains. Tables 1-3a and 1-3b list material properties in Système Internationale (SI) and English (IP) units, respectively; abbreviations used in these tables are listed in Appendix H. The building insulation has been made very thick to effectively thermally decouple the zone from ambient conditions. Materials of the space have no thermal or moisture capacitance and there is no moisture diffusion through them. If your software requires inputs for thermal capacitance, moisture capacitance, or moisture diffusion, use the minimum values your software allows.

If your software does not allow this much insulation, use the thickest insulation your program will permit and reduce the floor, roof, and wall areas to achieve the thermal conductance (UA) values listed in Table 1-3a (SI) or 1-3b (IP). The zone air volume, however, must remain at 588 m^3.

Air density at sea level is 1.201 kg/m^3.

The floor has the same exterior film coefficient as the other walls, as if the entire zone were suspended above the ground.

1.3.1.3.3 Infiltration. Infiltration rate = 0.0 air changes per hour (ACH), for the entire simulation period.

Table 1-3a. Material Specifications Base Case (SI Units)

EXTERIOR WALL (inside to outside)				
ELEMENT	**k (W/(m*K))**	**Thickness (m)**	**U (W/(m²*K))**	**R (m²*K/W)**
Int Surf Coef			8.290	0.121
Insulation (Note 1)	0.00308	1.000	0.00308	325.000
Ext Surf Coef			29.300	0.034
Total air - air			0.00308	325.155
Total surf - surf			0.00308	325.000

FLOOR (inside to outside)				
ELEMENT	**k (W/(m*K))**	**Thickness (m)**	**U (W/(m²*K))**	**R (m²*K/W)**
Int Surf Coef (Note 2)			8.290	0.121
Insulation (Note 1)	0.00308	1.000	0.00308	325.000
Ext Surf Coef			29.300	0.034
Total air - air			0.00308	325.155
Total surf - surf			0.00308	325.000

ROOF (inside to outside)				
ELEMENT	**k (W/(m*K))**	**Thickness (m)**	**U (W/(m²*K))**	**R (m²*K/W)**
Int Surf Coef (Note 2)			8.290	0.121
Insulation (Note 1)	0.00308	1.000	0.00308	325.000
Ext Surf Coef			29.300	0.034
Total air - air			0.00308	325.155
Total surf - surf			0.00308	325.000

SUMMARY		
COMPONENT	**AREA (m²)**	**UA (W/K)**
Wall	168.000	0.517
Floor	196.000	0.603
Roof	196.000	0.603
Infiltration (Note 3)		0.000
Total UA		1.722

ACH	**VOLUME (m³)**	**ALTITUDE (m)**
0.00	588.0	3.0

Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are < 1% of the total cooling load. If your software does not allow this much insulation, then reduce the floor, roof and wall areas to achieve the listed UA values, but keep volume as listed.
Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.
Note 3: Infiltration derived from:
ACH*Volume*(specific heat of air)*(density of air at specified altitude).

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Table 1-3b. Material Specifications Base Case (IP Units)

EXTERIOR WALL (inside to outside)				
ELEMENT	**k (Btu/(h*ft*F))**	**Thickness (ft)**	**U (Btu/(h*ft^2*F))**	**R (h*ft^2*F/Btu)**
Int Surf Coef			1.461	0.684
Insulation (Note 1)	0.00178	3.281	0.000542	1844.202
Ext Surf Coef			5.163	0.194
Total air - air			0.000542	1845.080
Total surf - surf			0.000542	1844.202

FLOOR (inside to outside)				
ELEMENT	**k (Btu/(h*ft*F))**	**Thickness (ft)**	**U (Btu/(h*ft^2*F))**	**R (h*ft^2*F/Btu)**
Int Surf Coef (Note 2)			1.461	0.684
Insulation (Note 1)	0.00178	3.281	0.000542	1844.202
Ext Surf Coef			5.163	0.194
Total air - air			0.000542	1845.080
Total surf - surf			0.000542	1844.202

ROOF (inside to outside)				
ELEMENT	**k (Btu/(h*ft*F))**	**Thickness (ft)**	**U (Btu/(h*ft^2*F))**	**R (h*ft^2*F/Btu)**
Int Surf Coef (Note 2)			1.461	0.684
Insulation (Note 1)	0.00178	3.281	0.000542	1844.202
Ext Surf Coef			5.163	0.194
Total air - air			0.000542	1845.080
Total surf - surf			0.000542	1844.202

SUMMARY		
COMPONENT	**AREA (ft^2)**	**UA (Btu/(h*F))**
Wall	1808.337	0.980
Floor	2109.726	1.143
Roof	2109.726	1.143
Infiltration		0.000
Total UA		3.267

	ACH	**VOLUME (ft^3)**	**ALTITUDE (ft)**	**UAinf (Note 3) (Btu/(h*F))**
	0.000	20765	9.84	0.000

Note 1: This level of insulation defines a near-adiabatic condition such that conduction gains are < 1% of the total cooling load. If your software does not allow this much insulation, then reduce the floor, roof and wall areas to achieve the listed UA values, but keep volume as listed.
Note 2: The interior film coefficient for floors and ceilings is a compromise between upward and downward heat flow for summer and winter.
Note 3: Infiltration derived from:
ACH*Volume*(specific heat of air)*(density of air at specified altitude).

e300env1.xls

1.3.1.3.4 Internal Heat Gains. Sensible and latent internal heat gains are as indicated in Table 1-4.

Table 1-4. Case E300 Hourly Internal Gains Schedule (IP and SI Units)

		SENSIBLE			LATENT		
Period	**Hours**	**Watts**	**Btu/h**	**frac v. max***	**Watts**	**Btu/h**	**frac v. max***
Jan. 1 thru Mar. 10	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 20:00	2931	10000	0.15625	366	1250	0.25
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00
Mar. 11 thru Apr. 10	0:00 - 9:00	2931	10000	0.15625	0	0	0.00
	9:00 - 18:00	7034	24000	0.37500	1466	5000	1.00
	18:00 - 24:00	2931	10000	0.15625	0	0	0.00
Apr. 11**	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 20:00	2931	10000	0.15625	366	1250	0.25
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00
Apr. 12 thru Apr. 20	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 19:00	9379	32000	0.50000	1466	5000	1.00
	19:00 - 24:00	2931	10000	0.15625	0	0	0.00
Apr. 21 thru Oct. 12	0:00 - 8:00	7034	24000	0.37500	0	0	0.00
	8:00 - 12:00	9379	32000	0.50000	1466	5000	1.00
	12:00 - 14:00	14069	48000	0.75000	1466	5000	1.00
	14:00 - 16:00	18758	64000	1.00000	1466	5000	1.00
	16:00 - 20:00	9379	32000	0.50000	1466	5000	1.00
	20:00 - 24:00	7034	24000	0.37500	0	0	0.00
Oct. 13 thru Oct. 18	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 16:00	9379	32000	0.50000	1466	5000	1.00
	16:00 - 24:00	2931	10000	0.15625	0	0	0.00
Oct. 19 thru Nov. 05	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 12:00	9379	32000	0.50000	1466	5000	1.00
	12:00 - 14:00	14069	48000	0.75000	1466	5000	1.00
	14:00 - 16:00	18758	64000	1.00000	1466	5000	1.00
	16:00 - 20:00	9379	32000	0.50000	1466	5000	1.00
	20:00 - 24:00	7034	24000	0.37500	0	0	0.00
Nov. 06 thru Dec. 31**	0:00 - 8:00	2931	10000	0.15625	0	0	0.00
	8:00 - 20:00	2931	10000	0.15625	366	1250	0.25
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00

Note: listed values are the internal gain for each hour within the specified period.

* "frac v. max" is the corresponding fraction for the given hourly value relative to the maximum value for the year. This is included for convenience of users who may need to provide this input.

** Same schedule as for Jan. 1 through Mar. 10.

e300intgains.xls e300sch!

Table 1-4 lists hourly values for a given period. In the first row of values, for example, the 2931 W of sensible gains and 0 W of latent gains are applied for each hour from 12 A.M. until 8 A.M. for the entire period from January 1 through March 10. Similarly, the second row of values indicates 2931 W of sensible gains and 366 W of latent gains for each hour from 8 A.M until 8 P.M for the same period. Values are provided in both SI and IP units. Additionally, the corresponding fraction of a given hourly value relative to the maximum hourly value for the year is given for the convenience of users who may need to provide input in such a format. In the first row of values for sensible gains, for example, the "frac v. max" value of 0.15625 comes from: (10,000 British thermal units [Btu]/h) / (64,000 Btu/h). Note that 64,000 Btu/h, which is the hourly sensible heat gain for the period from 14:00 until 16:00 for the period beginning April 21 and ending October 12, is also the maximum hourly sensible internal gain input for the year.

Sensible gains are 100% convective.

Zone sensible and latent internal gains are assumed to be distributed evenly throughout the zone air. These are internally generated sources of heat that are not related to the operation of the mechanical cooling system or its air distribution fan.

If your software requires input of water vapor mass flow rate rather than latent internal gains, use the heat of vaporization that your software assumes for condensation at the coil to convert the latent gains to water vapor mass flow rate for each listed time period.

If your software requires input of total internal gains, use the sum of sensible + latent internal gains for each listed time period.

The internal gains schedule for E300 was developed to serve the following purposes:

- To avoid extrapolations of performance data, the compressor is intended to be off when ODB < 12.78°C (55.0°F).
- The resulting E400 series (economizer) sensitivity tests are robust.
- Sensible internal gains variations are intended to correspond with additional building shell and solar loads toward midday when possible (this may allow for additional analysis that scales the significance of disagreements in software found here for real buildings); such shell loads would not otherwise be included in a near-adiabatic building model.

1.3.1.3.5 Opaque Surface Radiative Properties. Interior and exterior opaque surface solar (visible and ultraviolet wavelengths) absorptances and infrared emittances are included in Table 1-5.

Table 1-5. Opaque Surface Radiative Properties

	Interior Surface	Exterior Surface
Solar absorptance	0.6	0.1
Infrared emittance	0.9	0.9

1.3.1.3.6 Exterior Combined Radiative and Convective Surface Coefficients. If your program calculates exterior surface radiation and convection automatically, you may disregard this section. If your program does not calculate this effect, use 29.3 W/m²K for all exterior surfaces. This value is based on a mean annual wind speed of 4.02 m/s for a surface with roughness equivalent to rough plaster or brick.

1.3.1.3.7 Interior Combined Radiative and Convective Surface Coefficients. If your program calculates interior surface radiation and convection automatically, you may disregard this section. If your program does not calculate these effects, use the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) constant combined radiative and convective coefficients given in Table 1-6 (ASHRAE 2001: Chapter 24). (Note that the ASHRAE values are not exactly the same as the Chartered Institution of Building Services Engineers [CIBSE] values.)

Table 1-6. Interior Combined Surface Coefficient versus Surface Orientation

Orientation of Surface and Heat Flow	Interior Combined Surface Coefficient
Horizontal heat transfer on vertical surfaces	8.29 W/(m^2·K) (1.46 Btu/(h·ft^2·°F))
Upward heat transfer on horizontal surfaces	9.26 W/(m^2·K) (1.63 Btu/(h·ft^2·°F))
Downward heat transfer on horizontal surfaces	6.13 W/(m^2·K) (1.08 Btu/(h·ft^2·°F))

The radiative portion of these combined coefficients may be taken as 5.13 W/(m^2·K) (0.90 Btu/(h·ft^2·°F)) for an interior infrared emissivity of 0.9.

If your program does not allow scheduling of these coefficients, use 8.29 W/m^2K (1.46 Btu/(h·ft^2·°F)) for all horizontal surfaces. If you can justify using different values, go ahead and use them.

1.3.1.4 Mechanical System

The mechanical system represents a simple unitary vapor compression cooling system, or more precisely a split-system, air-cooled condensing unit with an indoor evaporator coil. Figure 1-2 is a schematic diagram of this system. See the Glossary (Appendix C) for definitions of some terminology used in this section.

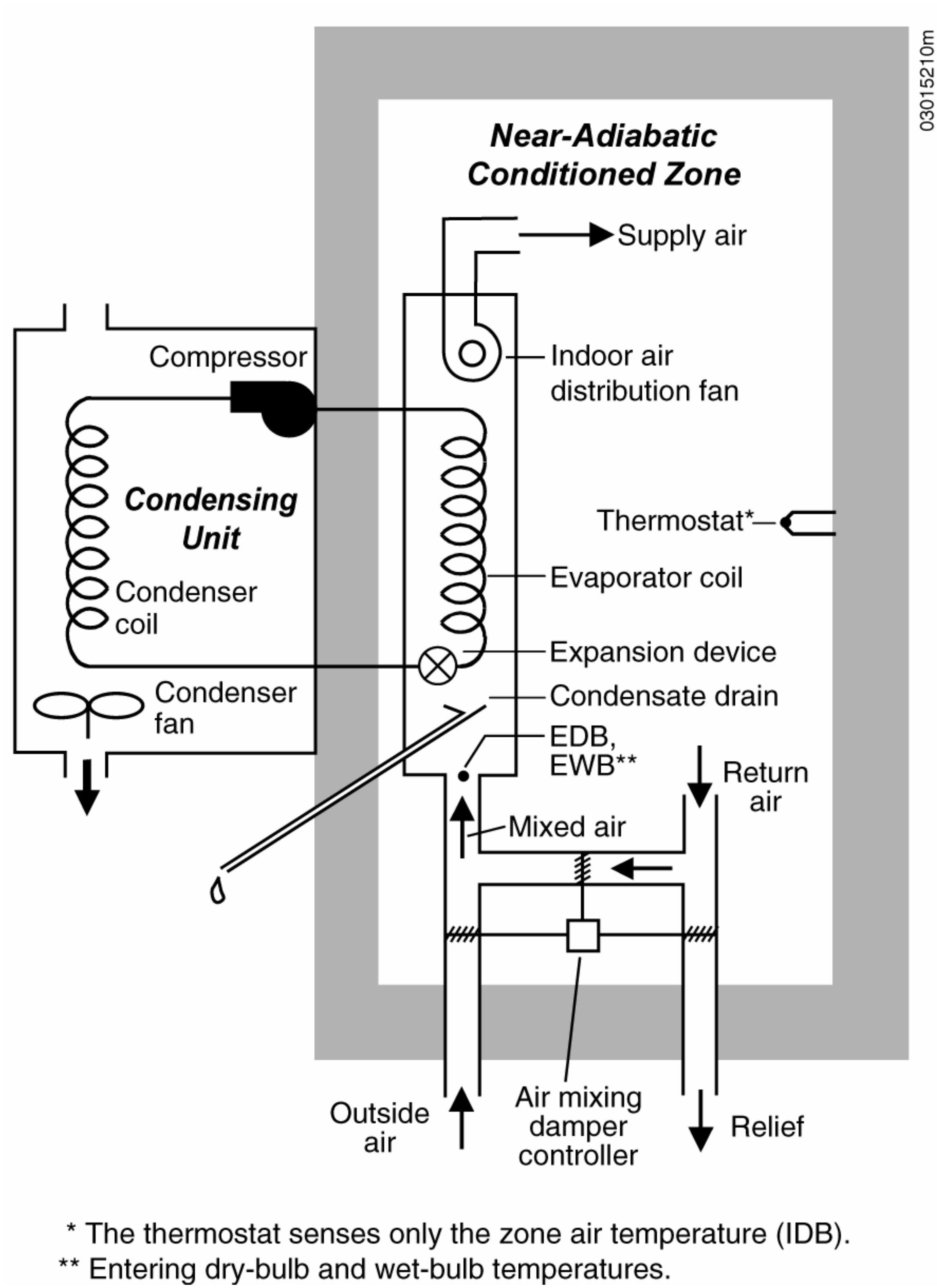

Figure 1-2. Unitary split-system, air-cooled condensing unit with indoor evaporator coil, and with outside-air mixing system

1.3.1.4.1 General Information.

- 100% convective air system
- Zone air perfectly mixed
- An outside-air mixing system included (as shown in Figure 1-2)
- Single-speed draw-through indoor-air distribution fan, continuous operation
- Outdoor condenser fan, cycling on and off together with compressor
- Air-cooled condenser
- Single-speed reciprocating compressor, R-22 refrigerant, no cylinder unloading
- No system hot-gas bypass
- The compressor, condenser, and condenser fan are located outside the conditioned zone
- All moisture that condenses on the evaporator coil (latent load) leaves the system through a condensate drain
- Crankcase heater and other auxiliary energy = 0.

1.3.1.4.2 Thermostat Control Strategy.

Heat = off
Cool = on if temperature > 25.0°C (77.0°F); otherwise Cool = off.

There is no zone humidity control. This means that the zone humidity level will float in accordance with zone latent loads and moisture removal by the mechanical system.

The thermostat senses only the zone air temperature; the thermostat itself does not sense any radiative heat transfer exchange with the interior surfaces.

The controls for this system are ideal in that the equipment is assumed to maintain the set point exactly, when it is operating and not overloaded. There are no minimum on or off time duration requirements for the unit, and no hysteresis control band (e.g., there is no ON at set point + x°C, or OFF at set point – y°C). If your software requires input for these, use the minimum values your software allows.

The thermostat is nonproportional in the sense that when the conditioned zone air temperature exceeds the thermostat cooling set point, the heat extraction rate is assumed to equal the maximum capacity of the cooling equipment corresponding to environmental conditions at the time of operation. A proportional thermostat model can be made to approximate a nonproportional thermostat model by setting a very small throttling range (the minimum allowed by your program). A COP = f(PLR) curve is given in Section 1.3.1.4.4 to account for equipment cycling.

1.3.1.4.3 Full-Load Cooling System Performance Data. Tables 1-7a and 1-7b give an expanded set of data for equipment full-load capacity and full-load performance data (Carrier Corporation 2001–2002). The tables contain gross capacity data, which are the full capacities of the unit without any fan heat subtracted out. Table 1-7a is in SI units; Table 1-7b is in IP units. Notes that also include specific units for various quantities presented in the tables are given on the last page of each table. Data are included for 2.78°C (5°F) increments of EDB and EWB, and 5.56°C (10°F) increments of ODB. Data are also included for typical rating conditions of ODB/EDB/EWB = 35.00°C/26.67°C/19.44°C (95°F/80°F/67°F).

For your convenience, an electronic file (E300MAP.XLS) containing Tables 1-7a and 1-7b is included on the accompanying CD.

Table 1-7a. Equipment Full-Load Performance with Gross Capacities (SI Units)

ODB (°C)	12.78	EDB (°C)								
EWB (°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
4.44	TC	*27.05*								
	SHC	*27.05*								
	kW	*6.0*								
7.22	TC	27.46	*28.81*	*30.60*						
	SHC	26.15	*28.81*	*30.60*						
	kW	6.0	*6.1*	*6.3*						
10.00	TC	29.81	29.86	*30.60*	*32.41*					
	SHC	20.54	26.27	*30.60*	*32.41*					
	kW	6.2	6.2	*6.3*	*6.4*					
12.78	TC	32.50	32.52	32.56	32.86	*34.23*				
	SHC	14.62	20.42	26.18	31.43	*34.23*				
	kW	6.4	6.4	6.4	6.4	*6.6*				
15.56	TC		35.31	35.44	35.42	35.58	36.25	*37.99*		
	SHC		14.41	20.20	25.86	31.38	35.94	*37.99*		
	kW		6.6	6.6	6.6	6.7	6.7	*6.8*		
18.33	TC			38.43	38.48	38.54	38.59	38.92	*39.91*	*41.83*
	SHC			14.14	19.83	25.49	31.04	36.18	*39.91*	*41.83*
	kW			6.9	6.9	6.9	6.9	6.9	*7.0*	*7.1*
21.11	TC				41.65	41.77	41.84	41.88	42.02	42.53
	SHC				13.74	19.40	25.00	30.53	35.85	36.36
	kW				7.1	7.1	7.1	7.1	7.2	7.2
23.89	TC					45.02	45.20	45.31	45.37	45.43
	SHC					13.27	18.87	24.42	29.91	35.26
	kW					7.4	7.4	7.4	7.4	7.4
26.67	TC						48.65	48.89	48.99	49.04
	SHC						12.73	18.29	23.79	29.20
	kW						7.7	7.7	7.7	7.7
29.44	TC							52.35	52.66	52.85
	SHC							12.13	17.63	23.09
	kW							8.0	8.0	8.0
32.22	TC								56.34	56.66
	SHC								11.50	16.95
	kW								8.3	8.3
35.00	TC									60.29
	SHC									10.84
	kW									8.6

ODB (°C)	18.33	EDB (°C)								
EWB (°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
4.44	TC	*26.00*								
	SHC	*26.00*								
	kW	*6.5*								
7.22	TC	26.26	*27.73*	*29.49*						
	SHC	25.36	*27.73*	*29.49*						
	kW	6.6	*6.7*	*6.9*						
10.00	TC	28.52	28.60	*29.49*	*31.27*					
	SHC	19.83	25.56	*29.49*	*31.27*					
	kW	6.8	6.8	*6.9*	*7.1*					
12.78	TC	31.13	31.17	31.19	31.58	*33.09*				
	SHC	13.92	19.74	25.46	30.63	*33.09*				
	kW	7.1	7.1	7.1	7.1	*7.3*				
15.56	TC		33.91	34.00	34.02	34.18	34.96	*36.80*		
	SHC		13.76	19.53	25.22	30.66	34.91	*36.80*		
	kW		7.3	7.3	7.3	7.4	7.4	*7.6*		
18.33	TC			36.87	36.99	37.05	37.10	37.49	*38.68*	
	SHC			13.49	19.21	24.87	30.39	35.41	*38.68*	
	kW			7.6	7.6	7.6	7.6	7.7	*7.8*	
21.11	TC				40.06	40.15	40.25	40.27	40.46	41.05
	SHC				13.14	18.79	24.40	29.91	35.18	39.82
	kW				7.9	7.9	7.9	7.9	8.0	8.0
23.89	TC					43.35	43.52	43.61	43.67	43.76
	SHC					12.70	18.30	23.85	29.34	34.67
	kW					8.2	8.2	8.2	8.3	8.3
26.67	TC						46.88	47.04	47.19	47.25
	SHC						12.20	17.74	23.25	28.67
	kW						8.6	8.6	8.6	8.6
29.44	TC							50.50	50.77	50.91
	SHC							11.65	17.13	22.57
	kW							8.9	8.9	8.9
32.22	TC								54.28	54.60
	SHC								11.05	16.47
	kW								9.2	9.3
35.00	TC									58.24
	SHC									10.43
	kW									9.6

Table 1-7a. Equipment Full-Load Performance with Gross Capacities (SI Units), continued

ODB (°C)	23.89									
EWB		EDB (°C)								
(°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
4.44	TC	*24.88*								
	SHC	*24.88*								
	kW	*7.1*								
7.22	TC	25.06	*26.59*	*28.31*						
	SHC	24.52	*26.59*	*28.31*						
	kW	7.1	*7.3*	*7.6*						
10.00	TC	27.20	27.29	*28.31*	*30.08*					
	SHC	19.12	24.80	*28.31*	*30.08*					
	kW	7.4	7.4	*7.6*	*7.8*					
12.78	TC	29.72	29.77	29.81	30.26	*31.86*				
	SHC	13.22	19.05	24.78	29.74	*31.86*				
	kW	7.7	7.7	7.7	7.8	*8.0*				
15.56	TC		32.44	32.48	32.52	32.74	*33.68*	*35.53*		
	SHC		13.09	18.83	24.54	29.94	*33.68*	*35.53*		
	kW		8.0	8.0	8.0	8.1	*8.2*	*8.4*		
18.33	TC			35.29	35.42	35.47	35.54	35.99	*37.39*	
	SHC			12.84	18.56	24.22	29.70	34.61	*37.39*	
	kW			8.4	8.4	8.4	8.4	8.4	*8.6*	
21.11	TC				38.38	38.48	38.56	38.57	38.83	39.51
	SHC				12.52	18.17	23.78	29.26	34.48	38.90
	kW				8.7	8.7	8.7	8.7	8.8	8.8
23.89	TC					41.59	41.75	41.85	41.89	41.97
	SHC					12.11	17.71	23.27	28.74	34.04
	kW					9.1	9.1	9.1	9.1	9.1
26.67	TC						44.96	45.17	45.30	45.37
	SHC						11.64	17.19	22.69	28.12
	kW						9.4	9.4	9.5	9.5
29.44	TC							48.48	48.76	48.92
	SHC							11.12	16.61	22.06
	kW							9.8	9.8	9.9
32.22	TC								52.09	52.49
	SHC								10.56	15.98
	kW								10.2	10.2
35.00	TC									55.98
	SHC									9.98
	kW									10.6

ODB (°C)	29.44									
EWB		EDB (°C)								
(°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
4.44	TC	*23.74*								
	SHC	*23.74*								
	kW	*7.7*								
7.22	TC	23.80	*25.40*	*27.11*						
	SHC	23.59	*25.40*	*27.11*						
	kW	7.7	*7.9*	*8.2*						
10.00	TC	25.82	25.94	*27.11*	*28.84*					
	SHC	18.39	24.02	*27.11*	*28.84*					
	kW	8.0	8.0	*8.2*	*8.4*					
12.78	TC	28.25	28.31	28.34	28.91	*30.60*				
	SHC	12.50	18.33	24.03	28.76	*30.60*				
	kW	8.3	8.4	8.4	8.4	*8.7*				
15.56	TC		30.89	30.95	30.98	31.24	*32.39*	*34.20*		
	SHC		12.39	18.15	23.85	29.17	*32.39*	*34.20*		
	kW		8.7	8.7	8.7	8.8	*8.9*	*9.2*		
18.33	TC			33.68	33.77	33.82	33.92	34.47	*36.04*	
	SHC			12.17	17.89	23.54	29.01	33.71	*36.04*	
	kW			9.1	9.1	9.1	9.1	9.2	*9.4*	
21.11	TC				36.64	36.75	36.83	36.87	37.15	*37.97*
	SHC				11.88	17.54	23.14	28.63	33.74	*37.82*
	kW				9.5	9.5	9.5	9.5	9.5	*9.7*
23.89	TC					39.74	39.90	40.01	40.03	40.15
	SHC					11.51	17.10	22.66	28.13	33.40
	kW					9.9	9.9	9.9	9.9	9.9
26.67	TC						43.01	43.20	43.33	43.41
	SHC						11.07	16.61	22.11	27.54
	kW						10.3	10.3	10.4	10.4
29.44	TC							46.40	46.67	46.81
	SHC							10.58	16.07	21.50
	kW							10.7	10.8	10.8
32.22	TC								49.93	50.27
	SHC								10.06	15.48
	kW								11.2	11.2
35.00	TC									53.64
	SHC									9.51
	kW									11.7

Table 1-7a. Equipment Full-Load Performance with Gross Capacities (SI Units), continued

ODB (°C)	35.00									
EWB		EDB (°C)								
(°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
7.22	TC	22.57	24.19	25.85						
	SHC	22.56	24.19	25.85						
	kW	8.6	8.5	8.8						
10.00	TC	24.42	24.56	25.85	27.56					
	SHC	17.66	23.20	25.85	27.56					
	kW	8.6	8.6	8.8	9.1					
12.78	TC	26.79	26.81	26.85	27.56	29.28				
	SHC	11.77	17.60	23.27	27.56	29.28				
	kW	9.0	9.0	9.0	9.1	9.4				
15.56	TC		29.32	29.37	29.39	29.72	31.05	32.82		
	SHC		11.68	17.46	23.15	28.33	31.05	32.82		
	kW		9.4	9.4	9.4	9.4	9.7	9.9		
18.33	TC			32.01	32.07	32.12	32.26	32.92	34.63	
	SHC			11.49	17.20	22.87	28.28	32.68	34.63	
	kW			9.8	9.8	9.8	9.9	10.0	10.2	
19.44*	TC						33.28			
	SHC						26.04			
	kW						10.0			
21.11	TC				34.82	34.94	35.02	35.05	35.41	36.45
	SHC				11.22	16.87	22.48	27.96	32.97	36.45
	kW				10.2	10.3	10.3	10.3	10.3	10.5
23.89	TC					37.81	37.96	38.07	38.10	38.28
	SHC					10.87	16.47	22.03	27.49	32.72
	kW					10.7	10.7	10.7	10.7	10.8
26.67	TC						40.96	41.15	41.29	41.33
	SHC						10.48	16.02	21.52	26.95
	kW						11.2	11.2	11.2	11.7
29.44	TC							44.23	44.49	44.64
	SHC							10.03	15.51	20.95
	kW							11.7	11.7	11.7
32.22	TC								47.66	47.92
	SHC								9.54	14.95
	kW								12.2	12.2
35.00	TC									51.18
	SHC									9.03
	kW									12.7

ODB (°C)	40.56									
EWB		EDB (°C)								
(°C)		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
7.22	TC	21.34	22.92	24.56						
	SHC	21.34	22.92	24.56						
	kW	8.8	9.1	9.4						
10.00	TC	22.95	23.16	24.56	26.23					
	SHC	16.89	22.33	24.56	26.23					
	kW	9.1	9.1	9.4	9.7					
12.78	TC	25.27	25.26	25.35	26.24	27.93				
	SHC	11.03	16.86	22.51	26.24	27.93				
	kW	9.6	9.5	9.6	9.7	10.1				
15.56	TC		27.68	27.73	27.75	28.17	29.65			
	SHC		10.96	16.74	22.42	27.41	29.65			
	kW		10.0	10.0	10.0	10.1	10.4			
18.33	TC			30.28	30.34	30.37	30.56	31.39	33.17	
	SHC			10.80	16.51	22.18	27.51	31.39	33.17	
	kW			10.5	10.5	10.5	10.6	10.7	11.0	
21.11	TC				32.98	33.12	33.17	33.21	33.67	34.97
	SHC				10.57	16.23	21.82	27.26	32.13	34.97
	kW				11.0	11.0	11.0	11.0	11.1	11.3
23.89	TC					35.85	36.01	36.08	36.13	36.37
	SHC					10.26	15.85	21.40	26.86	32.00
	kW					11.5	11.5	11.5	11.5	11.6
26.67	TC						38.86	39.07	39.18	39.22
	SHC						9.89	15.42	20.91	26.37
	kW						12.0	12.1	12.1	12.1
29.44	TC							42.00	42.24	42.38
	SHC							9.47	14.94	20.37
	kW							12.6	12.6	12.6
32.22	TC								45.27	45.55
	SHC								9.03	14.42
	kW								13.1	13.2
35.00	TC									48.65
	SHC									8.54
	kW									13.7

Table 1-7a. Equipment Full-Load Performance with Gross Capacities (SI Units), continued

ODB (°C)	46.11									
EWB (°C)		EDB (°C)								
		12.78	15.56	18.33	21.11	23.89	26.67	29.44	32.22	35.00
7.22	TC	20.08	21.64	23.24						
	SHC	20.08	21.64	23.24						
	kW	9.3	9.6	10.0						
10.00	TC	21.45	21.74	23.24	24.87					
	SHC	16.13	21.39	23.24	24.87					
	kW	9.6	9.6	10.0	10.4					
12.78	TC	23.68	23.69	23.80	24.87	26.53				
	SHC	10.27	16.12	21.71	24.87	26.53				
	kW	10.1	10.1	10.1	10.4	10.7				
15.56	TC		26.01	26.06	26.09	26.61	28.22			
	SHC		10.23	16.01	21.68	26.38	28.22			
	kW		10.6	10.6	10.6	10.7	11.1			
18.33	TC			28.52	28.57	28.58	28.84	29.93	31.67	
	SHC			10.10	15.83	21.49	26.69	29.93	31.67	
	kW			11.2	11.2	11.2	11.2	11.5	11.8	
21.11	TC				31.12	31.22	31.26	31.36	31.91	33.42
	SHC				9.89	15.56	21.15	26.57	31.16	33.42
	kW				11.7	11.7	11.7	11.8	11.9	12.2
23.89	TC					33.82	34.00	34.06	34.11	34.44
	SHC					9.62	15.22	20.78	26.21	31.23
	kW					12.3	12.3	12.3	12.3	12.4
26.67	TC						36.71	36.90	37.02	37.08
	SHC						9.29	14.81	20.32	25.75
	kW						12.8	12.9	12.9	12.9
29.44	TC							39.72	39.95	40.10
	SHC							8.91	14.36	19.82
	kW							13.4	13.5	13.5
32.22	TC								42.77	43.12
	SHC								8.50	13.88
	kW								14.0	14.1
35.00	TC									46.05
	SHC									8.04
	kW									14.7

Notes:
1. TC = gross total capacity (kW thermal)
2. SHC = gross sensible heat capacity (kW thermal)
3. kW = compressor power (kW)
4. ODB = ambient dry-bulb temperature = air temperature (°C) entering condenser
5. EDB = dry-bulb temperature (°C) entering indoor coil
6. EWB = wet-bulb temperature (°C) entering indoor coil
7. Airflow rate = indoor coil airflow rate (6796 m^3/h [4000 cubic feet per minute (CFM)] for all data)
8. Blue background (shaded upper left cells) = potential for freezing indoor coil
9. Red background (shaded lower right cells) = compressor outside operating envelope
CANNOT RUN HERE (for prolonged operation)
10. Each point has optimum charge (R22 charge not constant)
11. Computer model used to generate catalog data
12. Computer model based on test data
13. Computer model validated within the operating envelope of compressor
14. Computer model iterates and determines if the coil is wet or dry
15. Data are for 38AKS012 matched with a 40RM012 (6796 m^3/h indoors)
16. Original data provided 6/27/01; additional data provided 9/25/01 and 9/18/02
17. Data received from D. Barkley and J. Pegues of Carrier Corporation, Syracuse, New York, US.
18. SI data converted from original IP data by J. Neymark, J. Neymark & Associates, Golden, Colorado, US.

Table 1-7b. Equipment Full-Load Performance with Gross Capacities (IP Units)

ODB (°F)	55									
EWB (°F)		EDB (°F)								
		55	60	65	70	75	80	85	90	95
40	TC	*92.3*								
	SHC	*92.3*								
	kW	*6.0*								
45	TC	93.7	*98.3*	*104.4*						
	SHC	89.2	*98.3*	*104.4*						
	kW	6.0	*6.1*	*6.3*						
50	TC	101.7	101.9	*104.4*	*110.6*					
	SHC	70.1	89.6	*104.4*	*110.6*					
	kW	6.2	6.2	*6.3*	*6.4*					
55	TC	110.9	110.9	111.1	112.1	*116.8*				
	SHC	49.9	69.7	89.3	107.2	*116.8*				
	kW	6.4	6.4	6.4	6.4	*6.6*				
60	TC		120.5	120.9	120.9	121.4	123.7	*129.6*		
	SHC		49.2	68.9	88.2	107.1	122.6	*129.6*		
	kW		6.6	6.6	6.6	6.7	6.7	*6.8*		
65	TC			131.1	131.3	131.5	131.7	132.8	*136.2*	*142.7*
	SHC			48.2	67.7	87.0	105.9	123.4	*136.2*	*142.7*
	kW			6.9	6.9	6.9	6.9	6.9	*7.0*	*7.1*
70	TC				142.1	142.5	142.8	142.9	143.4	145.1
	SHC				46.9	66.2	85.3	104.1	122.3	124.0
	kW				7.1	7.1	7.1	7.1	7.2	7.2
75	TC					153.6	154.2	154.6	154.8	155.0
	SHC					45.3	64.4	83.3	102.0	120.3
	kW					7.4	7.4	7.4	7.4	7.4
80	TC						166.0	166.8	167.1	167.3
	SHC						43.4	62.4	81.2	99.6
	kW						7.7	7.7	7.7	7.7
85	TC							178.6	179.7	180.3
	SHC							41.4	60.1	78.8
	kW							8.0	8.0	8.0
90	TC								192.2	193.3
	SHC								39.3	57.8
	kW								8.3	8.3
95	TC									205.7
	SHC									37.0
	kW									8.6

ODB (°F)	65									
EWB (°F)		EDB (°F)								
		55	60	65	70	75	80	85	90	95
40	TC	*88.7*								
	SHC	*88.7*								
	kW	*6.5*								
45	TC	89.6	*94.6*	*100.6*						
	SHC	86.5	*94.6*	*100.6*						
	kW	6.6	*6.7*	*6.9*						
50	TC	97.3	97.6	*100.6*	*106.7*					
	SHC	67.7	87.2	*100.6*	*106.7*					
	kW	6.8	6.8	*6.9*	*7.1*					
55	TC	106.2	106.4	106.4	107.7	*112.9*				
	SHC	47.5	67.4	86.9	104.5	*112.9*				
	kW	7.1	7.1	7.1	7.1	*7.3*				
60	TC		115.7	116.0	116.1	116.6	119.3	*125.5*		
	SHC		47.0	66.6	86.0	104.6	119.1	*125.5*		
	kW		7.3	7.3	7.3	7.4	7.4	*7.6*		
65	TC			125.8	126.2	126.4	126.6	127.9	*132.0*	
	SHC			46.0	65.6	84.9	103.7	120.8	*132.0*	
	kW			7.6	7.6	7.6	7.6	7.7	*7.8*	
70	TC				136.7	137.0	137.3	137.4	138.0	140.1
	SHC				44.8	64.1	83.3	102.1	120.0	135.8
	kW				7.9	7.9	7.9	7.9	8.0	8.0
75	TC					147.9	148.5	148.8	149.0	149.3
	SHC					43.3	62.4	81.4	100.1	118.3
	kW					8.2	8.2	8.2	8.3	8.3
80	TC						159.9	160.5	161.0	161.2
	SHC						41.6	60.5	79.3	97.8
	kW						8.6	8.6	8.6	8.6
85	TC							172.3	173.2	173.7
	SHC							39.7	58.4	77.0
	kW							8.9	8.9	8.9
90	TC								185.2	186.3
	SHC								37.7	56.2
	kW								9.2	9.3
95	TC									198.7
	SHC									35.6
	kW									9.6

Table 1-7b. Equipment Full-Load Performance with Gross Capacities (IP Units), continued

ODB (°F)	75									
EWB (°F)		EDB (°F)								
		55	60	65	70	75	80	85	90	95
40	TC	84.9								
	SHC	84.9								
	kW	7.1								
45	TC	85.5	90.7	96.6						
	SHC	83.7	90.7	96.6						
	kW	7.1	7.3	7.6						
50	TC	92.8	93.1	96.6	102.6					
	SHC	65.2	84.6	96.6	102.6					
	kW	7.4	7.4	7.6	7.8					
55	TC	101.4	101.6	101.7	103.2	108.7				
	SHC	45.1	65.0	84.5	101.5	108.7				
	kW	7.7	7.7	7.7	7.8	8.0				
60	TC		110.7	110.8	110.9	111.7	114.9	121.2		
	SHC		44.7	64.3	83.7	102.2	114.9	121.2		
	kW		8.0	8.0	8.0	8.1	8.2	8.4		
65	TC			120.4	120.8	121.0	121.3	122.8	127.6	
	SHC			43.8	63.3	82.6	101.3	118.1	127.6	
	kW			8.4	8.4	8.4	8.4	8.4	8.6	
70	TC				131.0	131.3	131.6	131.6	132.5	134.8
	SHC				42.7	62.0	81.1	99.8	117.7	132.7
	kW				8.7	8.7	8.7	8.7	8.8	8.8
75	TC					141.9	142.4	142.8	142.9	143.2
	SHC					41.3	60.4	79.4	98.1	116.1
	kW					9.1	9.1	9.1	9.1	9.1
80	TC						153.4	154.1	154.5	154.8
	SHC						39.7	58.6	77.4	95.9
	kW						9.4	9.4	9.5	9.5
85	TC							165.4	166.4	166.9
	SHC							37.9	56.7	75.3
	kW							9.8	9.8	9.9
90	TC								177.7	179.1
	SHC								36.0	54.5
	kW								10.2	10.2
95	TC									191.0
	SHC									34.0
	kW									10.6

ODB (°F)	85									
EWB (°F)		EDB (°F)								
		55	60	65	70	75	80	85	90	95
40	TC	81.0								
	SHC	81.0								
	kW	7.7								
45	TC	81.2	86.7	92.5						
	SHC	80.5	86.7	92.5						
	kW	7.7	7.9	8.2						
50	TC	88.1	88.5	92.5	98.4					
	SHC	62.7	82.0	92.5	98.4					
	kW	8.0	8.0	8.2	8.4					
55	TC	96.4	96.6	96.7	98.6	104.4				
	SHC	42.6	62.5	82.0	98.1	104.4				
	kW	8.3	8.4	8.4	8.4	8.7				
60	TC		105.4	105.6	105.7	106.6	110.5	116.7		
	SHC		42.3	61.9	81.4	99.5	110.5	116.7		
	kW		8.7	8.7	8.7	8.8	8.9	9.2		
65	TC			114.9	115.2	115.4	115.7	117.6	123.0	
	SHC			41.5	61.0	80.3	99.0	115.0	123.0	
	kW			9.1	9.1	9.1	9.1	9.2	9.4	
70	TC				125.0	125.4	125.6	125.8	126.8	129.6
	SHC				40.5	59.8	78.9	97.7	115.1	129.0
	kW				9.5	9.5	9.5	9.5	9.5	9.7
75	TC					135.6	136.1	136.5	136.6	137.0
	SHC					39.3	58.4	77.3	96.0	114.0
	kW					9.9	9.9	9.9	9.9	9.9
80	TC						146.7	147.4	147.9	148.1
	SHC						37.8	56.7	75.4	94.0
	kW						10.3	10.3	10.4	10.4
85	TC							158.3	159.2	159.7
	SHC							36.1	54.8	73.4
	kW							10.7	10.8	10.8
90	TC								170.4	171.5
	SHC								34.3	52.8
	kW								11.2	11.2
95	TC									183.0
	SHC									32.4
	kW									11.7

Table 1-7b. Equipment Full-Load Performance with Gross Capacities (IP Units), continued

ODB (°F)	95									
EWB		EDB (°F)								
(°F)		55	60	65	70	75	80	85	90	95
45	TC	77.0	82.5	88.2						
	SHC	77.0	82.5	88.2						
	kW	8.6	8.5	8.8						
50	TC	83.3	83.8	88.2	94.0					
	SHC	60.2	79.2	88.2	94.0					
	kW	8.6	8.6	8.8	9.1					
55	TC	91.4	91.5	91.6	94.0	99.9				
	SHC	40.2	60.1	79.4	94.0	99.9				
	kW	9.0	9.0	9.0	9.1	9.4				
60	TC		100.0	100.2	100.3	101.4	105.9	112.0		
	SHC		39.9	59.6	79.0	96.7	105.9	112.0		
	kW		9.4	9.4	9.4	9.4	9.7	9.9		
65	TC			109.2	109.4	109.6	110.1	112.3	118.1	
	SHC			39.2	58.7	78.0	96.5	111.5	118.1	
	kW			9.8	9.8	9.8	9.9	10.0	10.2	
67	TC						113.5			
	SHC						88.9			
	kW						10.0			
70	TC				118.8	119.2	119.5	119.6	120.8	124.4
	SHC				38.3	57.6	76.7	95.4	112.5	124.4
	kW				10.2	10.3	10.3	10.3	10.3	10.5
75	TC					129.0	129.5	129.9	130.0	130.6
	SHC					37.1	56.2	75.1	93.8	111.6
	kW					10.7	10.7	10.7	10.7	10.8
80	TC						139.8	140.4	140.9	141.0
	SHC						35.8	54.6	73.4	91.9
	kW						11.2	11.2	11.2	11.7
85	TC							150.9	151.8	152.3
	SHC							34.2	52.9	71.5
	kW							11.7	11.7	11.7
90	TC								162.6	163.5
	SHC								32.5	51.0
	kW								12.2	12.2
95	TC									174.6
	SHC									30.8
	kW									12.7

ODB (°F)	105									
EWB		EDB (°F)								
(°F)		55	60	65	70	75	80	85	90	95
45	TC	72.8	78.2	83.8						
	SHC	72.8	78.2	83.8						
	kW	8.8	9.1	9.4						
50	TC	78.3	79.0	83.8	89.5					
	SHC	57.6	76.2	83.8	89.5					
	kW	9.1	9.1	9.4	9.7					
55	TC	86.2	86.2	86.5	89.5	95.3				
	SHC	37.6	57.5	76.8	89.5	95.3				
	kW	9.6	9.5	9.6	9.7	10.1				
60	TC		94.4	94.6	94.7	96.1	101.2			
	SHC		37.4	57.1	76.5	93.5	101.2			
	kW		10.0	10.0	10.0	10.1	10.4			
65	TC			103.3	103.5	103.6	104.3	107.1	113.2	
	SHC			36.8	56.3	75.7	93.9	107.1	113.2	
	kW			10.5	10.5	10.5	10.6	10.7	11.0	
70	TC				112.5	113.0	113.2	113.3	114.9	119.3
	SHC				36.0	55.4	74.4	93.0	109.6	119.3
	kW				11.0	11.0	11.0	11.0	11.1	11.3
75	TC					122.3	122.9	123.1	123.3	124.1
	SHC					35.0	54.1	73.0	91.7	109.2
	kW					11.5	11.5	11.5	11.5	11.6
80	TC						132.6	133.3	133.7	133.8
	SHC						33.7	52.6	71.3	90.0
	kW						12.0	12.1	12.1	12.1
85	TC							143.3	144.1	144.6
	SHC							32.3	51.0	69.5
	kW							12.6	12.6	12.6
90	TC								154.4	155.4
	SHC								30.8	49.2
	kW								13.1	13.2
95	TC									166.0
	SHC									29.1
	kW									13.7

Table 1-7b. Equipment Full-Load Performance with Gross Capacities (IP Units), continued

ODB (°F)	115									
EWB (°F)		EDB (°F) 55	60	65	70	75	80	85	90	95
45	TC	68.5	73.8	79.3						
	SHC	68.5	73.8	79.3						
	kW	9.3	9.6	10.0						
50	TC	73.2	74.2	79.3	84.9					
	SHC	55.0	73.0	79.3	84.9					
	kW	9.6	9.6	10.0	10.4					
55	TC	80.8	80.8	81.2	84.9	90.5				
	SHC	35.1	55.0	74.1	84.9	90.5				
	kW	10.1	10.1	10.1	10.4	10.7				
60	TC		88.7	88.9	89.0	90.8	96.3			
	SHC		34.9	54.6	74.0	90.0	96.3			
	kW		10.6	10.6	10.6	10.7	11.1			
65	TC			97.3	97.5	97.5	98.4	102.1	108.0	
	SHC			34.5	54.0	73.3	91.1	102.1	108.0	
	kW			11.2	11.2	11.2	11.2	11.5	11.8	
70	TC				106.2	106.5	106.7	107.0	108.9	114.0
	SHC				33.8	53.1	72.2	90.6	106.3	114.0
	kW				11.7	11.7	11.7	11.8	11.9	12.2
75	TC					115.4	116.0	116.2	116.4	117.5
	SHC					32.8	51.9	70.9	89.4	106.5
	kW					12.3	12.3	12.3	12.3	12.4
80	TC						125.3	125.9	126.3	126.5
	SHC						31.7	50.5	69.3	87.9
	kW						12.8	12.9	12.9	12.9
85	TC							135.5	136.3	136.8
	SHC							30.4	49.0	67.6
	kW							13.4	13.5	13.5
90	TC								145.9	147.1
	SHC								29.0	47.4
	kW								14.0	14.1
95	TC									157.1
	SHC									27.4
	kW									14.7

Notes:
1. TC = gross total capacity (kBtu/h)
2. SHC = gross sensible heat capacity (kBtu/h)
3. kW = compressor power (kW)
4. ODB = ambient dry-bulb temperature = air temperature (°F) entering condenser
5. EDB = dry-bulb temperature (°F) entering indoor coil
6. EWB = wet-bulb temperature (°F) entering indoor coil
7. CFM = indoor coil airflow rate in cubic feet per minute (4000 CFM for all data)
8. Blue background (shaded upper left cells) = potential for freezing indoor coil
9. Red background (shaded lower right cells) = compressor outside operating envelop
CANNOT RUN HERE (for prolonged operation)
10. Each point has optimum charge (R22 charge not constant)
11. Computer model used to generate catalog data
12. Computer model based on test data
13. Computer model validated within the operating envelope of compressor
14. Computer model iterates and determines if the coil is wet or dry
15. Data are for 38AKS012 matched with a 40RM012 (4000 CFM indoors)
16. Original data provided 6/27/01; additional data provided 9/25/01 and 9/18/02
17. Data received from D. Barkley and J. Pegues of Carrier Corporation, Syracuse New York, US.

These tables use ODB, EDB, and EWB as independent variables for performance data; the locations of EDB and EWB are shown in Figure 1-2. In these tables each block of data represents an f(EDB, EWB) data set for a different ODB.

The expanded data set was developed by a manufacturer, using the company's "in-house" engineering software for developing catalog data. This expanded data set goes outside the range of data that is normally available from typical published catalogs (as was used in the E100 series cases), and even outside the range of what can typically be obtained from the computer program that this manufacturer normally provides to design engineers for sizing equipment that frequently operates outside the range of typical design conditions. The computer model that was used to develop the expanded data set was generated to match the test data as perfectly as possible (in this case within 0.5%) at the rating condition of EDB/EWB/ODB = 26.67°C/19.44°C/35.00°C (80°F/67°F/95°F). Once the model is generated from the test data, the model is normalized to the compressor curve (provided by the compressor manufacturer).

The data set includes ranges where only limited system operation is recommended. These ranges are indicated by red and blue background shading in the tables (see the electronic version of E300MAP.XLS). The red shading indicates the range where the refrigerant temperature discharged from the compressor is higher than it should be. Prolonged operation in this region would shorten the life of the compressor. The blue shading indicates the range where frost may form on the coil, affecting the performance of the system.

The data set assumes that the refrigerant charge is always optimal at each listed full-load operating point. In reality, a refrigerant charge that is optimal for one point in the data may not be optimal for some other point in the data set. The manufacturer estimates that as a worst case the effect of the refrigerant charge makes about one-half to three-quarters of a percentage point difference (on the listed values). For the purpose of these tests, we are assuming that the refrigerant charge is always optimal.

The unit as described actually uses a 1242-W fan. So the "adjusted net capacity" (using same terminology as in the E100 series cases per Appendix C of this document) is

$$(\text{net cap})_{adj} = (\text{gross cap})_{listed} – (\text{fan power}).$$

Thus, for the net total (sensible + latent) capacity at ODB = 95°F, EDB = 75°F, and EWB = 65°F and 4000 CFM:

$$(\text{net cap})_{adj} = 32{,}122 \text{ W} – 1242 \text{ W} = 30{,}880 \text{ W}.$$

The technique for determining net sensible capacities is similar.

1.3.1.4.3.1 Validity of Listed Data (VERY IMPORTANT). EWB given for the listed compressor kW (kilowatts) and gross capacities given in Tables 1-7a and 1-7b are valid only for "wet" coils (when dehumidification is occurring). A dry-coil condition—no dehumidification—occurs when the entering air humidity ratio is decreased to the point where the entering air dew point temperature is less than the effective coil surface temperature (apparatus dew point). In Tables 1-7a and 1-7b, the dry-coil data (indicated with *italics*) are evident for conditions where the listed sensible capacity is equal to the corresponding total capacity. For a given EDB and ODB, the compressor power, total capacity, and sensible capacity for wet coils change with varying EWB. Once the coil becomes dry, for a given EDB, compressor power and capacities remain constant with decreasing EWB (Brandemuehl 1993; pp. 4-82–83).

For the purpose of interpolating data between listed wet-coil and dry-coil data points, it is necessary to evaluate the maximum EWB for the occurrence of the listed dry-coil data point. One method for establishing the maximum EWB where total and sensible capacities are equal is to linearly extrapolate EWB for a given EDB and ODB. For example, the data shown in Table 1-8 (extracted from Table 1-7b) can be used to determine the dry-coil compressor power for ODB/EDB = 95.0°F/80°F.

Table 1-8. Determination of Maximum Dry-Coil EWB Using Extrapolation

EWB (°F)	Gross Total Capacity (kBtu/h)	Gross Sensible Capacity (kBtu/h)	Compressor Power (kW)
62.77 (on TC) *62.63 (on SHC)*	**105.9**	**105.9**	**9.7**
65	**110.1**	**96.5**	**9.9**
70	**119.5**	**76.7**	**10.3**

* Italicized values are not specifically listed with the original performance data; they are determined based on the accompanying discussion. Data in bold font are from the original performance data.

At the dry-coil condition:

Gross total capacity = gross sensible capacity = 105.9 kBtu/h

where these data are listed in the row in Table 1-7b for EWB = 60°F.

Linear extrapolation based on gross total capacity gives

Maximum EWB for the dry-coil condition = 62.77°F.

Linear extrapolation based on gross sensible capacity gives

Maximum EWB for the dry-coil condition = 62.63°F.

Therefore, maximum dry-coil EWB ≈ 62.7°F.

(Because the values of maximum EWB based on extrapolation using total capacity versus sensible capacity are very close, but not exactly the same, there may be a small amount of error associated with assuming linearity in this determination, or there may be some uncertainty—perhaps from rounding—in the listed values. The listed compressor power data do not have as many significant digits as the capacity data, so these data were not used here for extrapolating EWB.)

1.3.1.4.3.2 Extrapolation of Performance Data. Allow your software to perform any necessary extrapolations. The need for doing extrapolations has been minimized by the inclusion of an expanded performance data set, and by specifying reduced internal gains during cooler weather.

1.3.1.4.3.3 Cooling Coil Bypass Factor. If your software does not require an input for bypass factor (BF), or automatically calculates it based on other inputs, ignore this information.

For this system:

BF = 0.070.

This value provided by the manufacturer (Pegues 2001). For this system, BF varies only with airflow rate, which is constant for these test cases.

1.3.1.4.3.4 Minimum Supply Air Temperature. This system is a variable temperature system, meaning that the supply air temperature varies with the operating conditions. If your software requires an input for minimum allowable supply air temperature, use

Minimum supply air temperature ≤ 1.66°C (34.6°F).

Appendix D contains calculation of minimum supply air temperature.

If your software does not require this input, ignore this information.

1.3.1.4.4 Part-Load Operation. The system efficiency degradation that results from part-load operation is described in Figure 1-3. This representation is the same as that for the E100 series cases. In this figure the COP degradation factor (CDF) is a multiplier to be applied to the full-load system COP (as defined in Appendix C) at a given PLR, where:

COP(PLR) = (full load COP(ODB,EWB,EDB)) * CDF(PLR).

It might be helpful to think of the efficiency degradation as being caused by additional compressor start-up run time required to bring the evaporator coil temperature down to its equilibrium temperature for the time(s) when the compressor is required to operate during an hour with part load. When the simplifying assumption is made that continuous operation of the air distribution fan has a negligible effect on the compressor's part-load energy use, CDF from Figure 1-3 applies similarly to COP_2 as to COP. That is,

(COP_2 at part load) = (CDF) × (COP_2 at full load),

where COP_2 at full load is determined as described in Section 1.3.1.2 (Output Requirements: Annual Means, Maxima, and Minima).

Because the compressor controller is ideal on/off cycling (see Section 1.3.1.4.2),

hourly fractional compressor and outdoor fan run time = PLR/CDF.

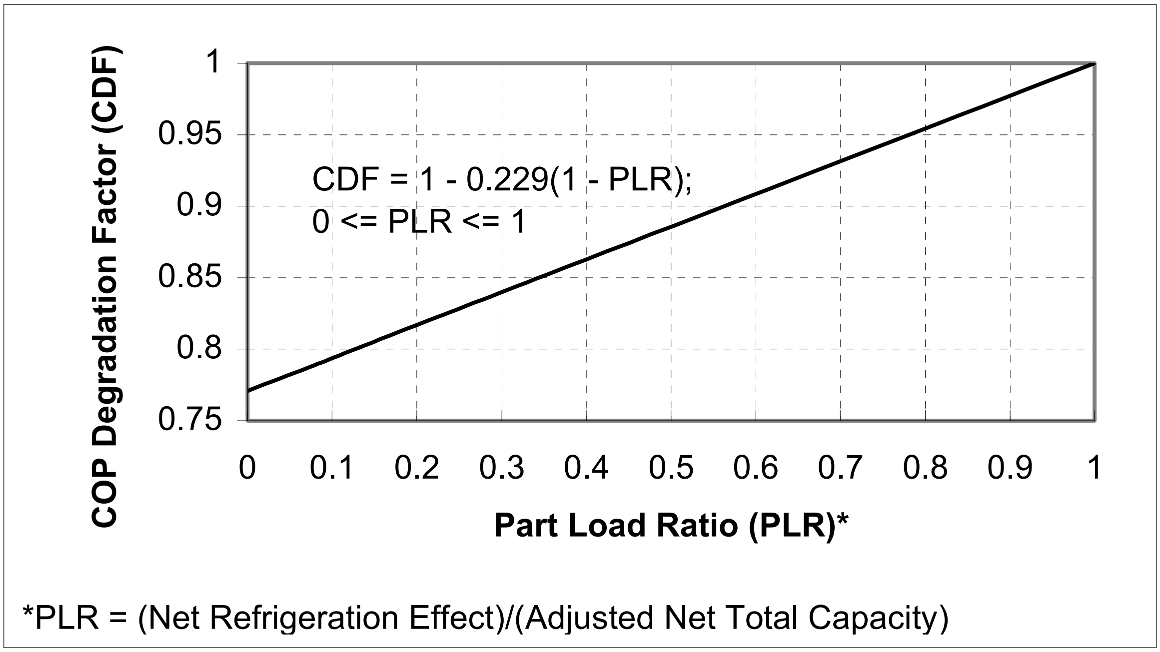

Figure 1-3. Cooling equipment part-load performance (COP degradation factor versus PLR)

In Figure 1-3, the PLR may be calculated by:

$$\frac{\text{(Gross Total Evaporator Coil Load)}}{\text{(Gross Total Capacity)}}$$

where the gross total evaporator coil load and gross total capacity are as defined in the Glossary (Appendix C). Per Appendix E, this definition is similar to the definition supplied in the E100 series cases:

$$\frac{\text{(Net Refrigeration Effect)}}{\text{(Adjusted Net Total Capacity)}}$$

where the net refrigeration effect and the adjusted net total capacity are as defined in the Glossary (Appendix C). Demonstration of the similarity of these definitions of PLR is included in Appendix E.

Simplifying assumptions in Figure 1-3 are

- There is no minimum on/off time for the compressor and outdoor condenser fan; they may cycle on/off as often as necessary to maintain the set point
- The decrease in efficiency with increased on/off cycling at very low PLR remains linear.

Because there is a continuously operating indoor air fan in the E300 and E400 series cases, the definition of PLR applying gross total evaporator coil load and gross total capacity is more convenient to apply. If you are defining PLR based on net refrigeration effect and adjusted net capacity, then for the E300 and E400 series cases indoor air distribution fan operation for times when the evaporator coil is not removing heat must still be considered in the simulation. Indoor air distribution fan operation for times when the evaporator coil is not removing heat does not affect the net refrigeration effect or the adjusted net total capacity.

For cases E300–E440, the CDF is not applicable to the continuously operating indoor air distribution fan energy consumption.

Appendix B of Volume 1 (Neymark and Judkoff 2002) includes additional details about how Figure 1-3 was derived.

If your software utilizes cooling coil bypass factor, model the BF as independent of (not varying with) the PLR (Cawley 1997).

1.3.1.4.5 Fans.

1.3.1.4.5.1 Indoor Air Distribution Fan.

- Airflow rate = 1.888 m^3/s = 6796 m^3/h = 4000 CFM
- Indoor fan electric power = 1242 W
- Indoor fan mechanical shaft power = 1167 W (1.565 brake horsepower [BHP])
- External static fan pressure = 74.7 Pa = 0.3 in. wg (water gauge)
- Fan static efficiency = 0.121
- Motor/drive efficiency = 0.940
- Supply air temperature rise from fan heat = 0.54°C = 0.97°F
- Air distribution efficiency = 100% (adiabatic ducts).

For further discussion of these inputs, see Appendix F.

The draw-through indoor air distribution fan operates continuously at 4000 CFM (6796.0 m^3/h) for the entire simulation period. For calculating additional heating of the distribution air related to waste heat from the indoor distribution fan, assume that the distribution fan motor is mounted in the distribution air stream so that 100% of the heat from fan energy use goes to the distribution (supply) air.

1.3.1.4.5.2 Outdoor Condenser Fan.

- Outdoor fan power = 930 W.

The draw-through outdoor condenser fan cycles on and off with the compressor.

1.3.1.4.6 Outside Air. The indoor air distribution fan operates continuously at 4000 CFM (6796.0 m^3/h). Dampers are adjusted to continuously supply 15% outside air mixed with the return air; that is, of the 4000 CFM (6796.0 m^3/h) of mixed supply air, 600 CFM (1019.4 m^3/h) is outside air and 3400 CFM (5776.6 m^3/h) is return air. As fresh air is introduced from the outside, a corresponding amount of zone air exits through the relief damper (see Figure 1-2).

1.3.2 Additional E300 Series Cases

This section describes sequential revisions to the base case required to model additional E300 series cases. Case E300 is the base case for all the E300 series cases. Unless otherwise noted, the required outputs for these cases are the same as for Case E300, but the hourly outputs for June 28 and the weather data checks are excluded.

1.3.2.1 Case E310: High Latent Gains

Case E310 is **exactly as Case E300 except** the latent internal heat gains are revised per Table 1-9. Only the latent internal gains are changed; sensible internal gains shown here are the same as for Case E300.

Table 1-9. Case E310 Hourly Internal Gains Schedule (IP and SI Units)

		SENSIBLE			LATENT		
Period	**Hours**	**Watts**	**Btu/h**	**frac v. max***	**Watts**	**Btu/h**	**frac v. max***
Jan. 1 thru Mar. 10	0:00 - 8:00	2931	10000	0.15625	0	0	0.00000
	8:00 - 20:00	2931	10000	0.15625	1466	5000	0.15625
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00000
Mar. 11 thru Apr. 10	0:00 - 9:00	2931	10000	0.15625	0	0	0.00000
	9:00 - 18:00	7034	24000	0.37500	7034	24000	0.75000
	18:00 - 24:00	2931	10000	0.15625	0	0	0.00000
Apr. 11**	0:00 - 8:00	2931	10000	0.15625	0	0	0.00000
	8:00 - 20:00	2931	10000	0.15625	1466	5000	0.15625
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00000
Apr. 12 thru Apr. 20	0:00 - 8:00	2931	10000	0.15625	0	0	0.00000
	8:00 - 19:00	9379	32000	0.50000	7034	24000	0.75000
	19:00 - 24:00	2931	10000	0.15625	0	0	0.00000
Apr. 21 thru Oct. 12	0:00 - 8:00	7034	24000	0.37500	7034	24000	0.75000
	8:00 - 12:00	9379	32000	0.50000	7034	24000	0.75000
	12:00 - 14:00	14069	48000	0.75000	9379	32000	1.00000
	14:00 - 16:00	18758	64000	1.00000	9379	32000	1.00000
	16:00 - 20:00	9379	32000	0.50000	7034	24000	0.75000
	20:00 - 24:00	7034	24000	0.37500	7034	24000	0.75000
Oct. 13 thru Oct. 18	0:00 - 8:00	2931	10000	0.15625	0	0	0.00000
	8:00 - 16:00	9379	32000	0.50000	7034	24000	0.75000
	16:00 - 24:00	2931	10000	0.15625	0	0	0.00000
Oct. 19 thru Nov. 05	0:00 - 8:00	2931	10000	0.15625	1466	5000	0.15625
	8:00 - 12:00	9379	32000	0.50000	7034	24000	0.75000
	12:00 - 14:00	14069	48000	0.75000	9379	32000	1.00000
	14:00 - 16:00	18758	64000	1.00000	9379	32000	1.00000
	16:00 - 20:00	9379	32000	0.50000	7034	24000	0.75000
	20:00 - 24:00	7034	24000	0.37500	7034	24000	0.75000
Nov. 06 thru Dec. 31**	0:00 - 8:00	2931	10000	0.15625	0	0	0.00000
	8:00 - 20:00	2931	10000	0.15625	1466	5000	0.15625
	20:00 - 24:00	2931	10000	0.15625	0	0	0.00000

Note: listed values are the internal gain for each hour within the specified period.

* "frac v. max" is the corresponding fraction for the given hourly value relative to the maximum value for the year. This is included for convenience of users who may need to provide this input.

** Same schedule as for Jan. 1 through Mar. 10.

e300intgains.xls e310sch!

Sensible gains remain as 100% convective.

These are internally generated sources of heat and humidity that are not related to operation of the mechanical cooling system or its air distribution fan.

If your software requires input of water vapor mass flow rate rather than latent internal gains, to convert the latent gains to water vapor mass flow rate for each listed time period, use the heat of vaporization that your software assumes for condensation at the coil.

If your software requires input of total internal gains, use the sum of sensible + latent internal gains for each listed time period.

1.3.2.2 Case E320: High Infiltration

Case E320 **is exactly as Case 300 except** infiltration and outside air are revised as follows.

1.3.2.2.1 Infiltration Schedule.

	Infiltration Rate	
From January 1 through April 20:	1.734 ACH	(1019.4 m^3/h, 600 CFM)
From April 21 through October 12:		
From 00:00 to 08:00	1.734 ACH	(1019.4 m^3/h, 600 CFM)
From 08:00 to 20:00	11.558 ACH	(6796.0 m^3/h, 4000 CFM)
From 20:00 to 24:00	1.734 ACH	(1019.4 m^3/h, 600 CFM)
From October 13 through December 31:	1.734 ACH	(1019.4 m^3/h, 600 CFM)

Infiltration is leakage of air through any building element (e.g., walls, windows, and doors). The listed infiltration rates are independent of factors such as wind speed, and indoor/outdoor temperature difference. This specific infiltration schedule was chosen to facilitate comparison between this case and Case E330 for outside air.

1.3.2.2.2 Outside Air. Outside air fraction = 0.0 (no outside air) for the full annual simulation period.

1.3.2.3 Case E330: High Outside Air

Case E330 **is exactly as Case E300 except** outside air fraction (as a percentage of total fan flow, OA%) is scheduled as follows.

	OA Fraction
From January 1 through April 20:	15%
From April 21 through October 12:	
From 00:00 to 08:00	15%
From 08:00 to 20:00	100%
From 20:00 to 24:00	15%
From October 13 through December 31:	15%

Note that an outside air fraction of 15% corresponds to 4000 CFM (6796.0 m^3/h) of mixed air containing 600 CFM (1019.4 m^3/h) of outside air and 3400 CFM (5776.6 m^3/h) of return air. Similarly, an outside air fraction of 100% corresponds to 4000 CFM (6796.0 m^3/h) of mixed air containing 4000 CFM (6796.0 m^3/h) of outside air and 0 CFM (0 m^3/h) of return air.

1.3.2.4 Case E340: Infiltration and Outside Air Interaction

Case E340 **is exactly as Case 300 except** infiltration and outside air are scheduled as follows.

1.3.2.4.1 Infiltration Schedule.

	Infiltration Rate	
From January 1 through April 20:	0 ACH	
From April 21 through October 12:		
From 00:00 to 08:00	0 ACH	
From 08:00 to 20:00	5.779 ACH	(3398.0 m^3/h; 2000 CFM)
From 20:00 to 24:00	0 ACH	
From October 13 through December 31:	0 ACH	

Infiltration is leakage of air through any building element (e.g., walls, windows, and doors). The listed infiltration rates are independent of factors such as wind speed, and indoor/outdoor temperature difference.

1.3.2.4.2 Outside Air Schedule.

	OA Fraction
From January 1 through April 20:	15%
From April 21 through October 12:	
From 00:00 to 08:00	15%
From 08:00 to 20:00	50%
From 20:00 to 24:00	15%
From October 13 through December 31:	15%

Note that an outside air fraction of 15% corresponds to 4000 CFM (6796.0 m^3/h) of mixed air containing 600 CFM (1019.4 m^3/h) of outside air and 3400 CFM (5776.6.0 m^3/h) of return air. Similarly, an outside air fraction of 50% corresponds to 4000 CFM (6796.0 m^3/h) of mixed air containing 2000 CFM (3398.0 m^3/h) of outside air and 2000 CFM (3398.0 m^3/h) of return air.

1.3.2.5 Case E350: Thermostat Set Up

Case E350 **is exactly as Case E300 except** the thermostat is scheduled as follows for the entire year:

	Cooling Set Point	
From January 1 through April 20:	25°C	(77°F)
From April 21 through October 12:		
From 00:00 to 07:00	35°C	(95°F)
From 07:00 to 20:00	25°C	(77°F)
From 20:00 to 24:00	35°C	(95°F)
From October 13 through December 31:	25°C	(77°F)

Note that set up begins at 07:00, which is 1 hour before the internal gains increase.

1.3.2.6 Case E360: Undersized System

Case E360 is **exactly as Case E300** except the internal heat gains are revised per Table 1-10. Only the sensible internal gains are changed for the period from April 21 through October 12; the latent internal gains and other sensible internal gains shown in the table are the same as for Case E300.

Sensible gains remain as 100% convective.

These are internally generated sources of heat and humidity that are not related to operation of the mechanical cooling system or its air distribution fan.

If your software requires input of water vapor mass flow rate rather than latent internal gains, to convert the latent gains to water vapor mass flow rate for each listed time period, use the heat of vaporization that your software assumes for condensation at the coil.

If your software requires input of total internal gains, use the sum of sensible + latent internal gains for each listed time period.

Table 1-10. Case E360 Hourly Internal Gains Schedule (IP and SI Units)

		SENSIBLE			LATENT		
Period	**Hours**	**Watts**	**Btu/h**	**frac v. max***	**Watts**	**Btu/h**	**frac v. max***
Jan. 1 thru Mar. 10	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 20:00	2931	10000	0.10000	366	1250	0.25
	20:00 - 24:00	2931	10000	0.10000	0	0	0.00
Mar. 11 thru Apr. 10	0:00 - 9:00	2931	10000	0.10000	0	0	0.00
	9:00 - 18:00	7034	24000	0.24000	1466	5000	1.00
	18:00 - 24:00	2931	10000	0.10000	0	0	0.00
Apr. 11**	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 20:00	2931	10000	0.10000	366	1250	0.25
	20:00 - 24:00	2931	10000	0.10000	0	0	0.00
Apr. 12 thru Apr. 20	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 19:00	9379	32000	0.32000	1466	5000	1.00
	19:00 - 24:00	2931	10000	0.10000	0	0	0.00
Apr. 21 thru Oct. 12	0:00 - 8:00	29310	100000	1.00000	0	0	0.00
	8:00 - 12:00	29310	100000	1.00000	1466	5000	1.00
	12:00 - 14:00	29310	100000	1.00000	1466	5000	1.00
	14:00 - 16:00	29310	100000	1.00000	1466	5000	1.00
	16:00 - 20:00	29310	100000	1.00000	1466	5000	1.00
	20:00 - 24:00	29310	100000	1.00000	0	0	0.00
Oct. 13 thru Oct. 18	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 16:00	9379	32000	0.32000	1466	5000	1.00
	16:00 - 24:00	2931	10000	0.10000	0	0	0.00
Oct. 19 thru Nov. 05	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 12:00	9379	32000	0.32000	1466	5000	1.00
	12:00 - 14:00	14069	48000	0.48000	1466	5000	1.00
	14:00 - 16:00	18758	64000	0.64000	1466	5000	1.00
	16:00 - 20:00	9379	32000	0.32000	1466	5000	1.00
	20:00 - 24:00	7034	24000	0.24000	0	0	0.00
Nov. 06 thru Dec. 31**	0:00 - 8:00	2931	10000	0.10000	0	0	0.00
	8:00 - 20:00	2931	10000	0.10000	366	1250	0.25
	20:00 - 24:00	2931	10000	0.10000	0	0	0.00

Note: listed values are the internal gain for each hour within the specified period.

* "frac v. max" is the corresponding fraction for the given hourly value relative to the maximum value for the year. This is included for convenience of users who may need to provide this input.

** Same schedule as for Jan. 1 through Mar. 10.

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1.3.3 Economizer Series (E400 Series) Cases

This section describes sequential revisions to the base case required to model the E400 economizer series cases. Most of the economizer series cases are based on Case E400; appropriate base cases for a given economizer case are

Case	**Basis for that case**
E400	E300
E410	E400
E420	E400
E430	E400
E440	E430

1.3.3.1 Case E400: Economizer with ODB/IDB Control and Integrated Compressor Control

Case E400 is **exactly as Case E300 except** the outside air and relief dampers (see Figure 1-2) are adjusted using economizer control based on ODB and return air temperature as described below. Because these cases assume no thermal losses or gains in the ducts, the return air temperature and the zone air temperature (IDB) may be assumed to be equal.

1.3.3.1.2 Economizer and Compressor Control Strategy (E400).

Economizer = ON AND Compressor = OFF IF
IDB > 25.0°C (77.0°F) AND ODB ≤ IDB AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND ODB ≤ IDB AND all cooling load for the given hour is NOT compensated by the economizer.
(In this configuration outside air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND ODB > IDB.

Economizer = OFF AND Compressor = OFF IF
IDB ≤ 25.0°C (77.0°F).

where for:

Economizer = ON, outside air is provided as needed up to 100% outside air for the entire hour, but not less than the 15% minimum outside air setting for any time during the hour

Economizer = OFF, outside air is provided at the 15% minimum outside air setting for that hour

Compressor = ON, the compressor and condenser fan will operate only as long as necessary to handle the sensible cooling load not compensated by the economizer

Compressor = OFF, the compressor and condenser fan do not operate for the hour.

Note that there is no lower limit temperature, which means that the economizer control strategy is not affected by how cold the outside air may become.

1.3.3.1.3 Outputs. Outputs are the same as for Case E300, but the hourly outputs for June 28 and the weather data checks are excluded.

1.3.3.2 Case E410: Economizer with ODB/IDB Control and Nonintegrated Compressor

Case E410 is **exactly as Case E400 except** while the economizer is operating, the compressor is not allowed to operate. The economizer takes precedence over the compressor but is only allowed to operate whenever it can satisfy the entire cooling load by itself.

Economizer and Compressor Control Strategy (E410)

Economizer = ON AND Compressor = OFF IF
IDB > 25.0°C (77.0°F) AND ODB ≤ IDB AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON NOT allowed.

Economizer = OFF AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND **{**(ODB > IDB) OR (all cooling load for the given hour CANNOT be compensated by the economizer)**}**.

Economizer = OFF AND Compressor = OFF IF
IDB ≤ 25.0°C (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case E400.

1.3.3.3 Case E420: Economizer with ODB Limit Control

Case E420 is **exactly as Case E400 except** when ODB > 20°C (68°F), the outside air and relief dampers are maintained at 15% outside air.

1.3.3.3.1 Economizer and Compressor Control Strategy (E420).

Economizer = ON AND Compressor = OFF IF
IDB > 25.0°C (77.0°F) AND ODB ≤ 20.0°C (68.0°F) AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND ODB ≤ 20.0°C (68.0°F) AND all cooling load for the given hour is NOT compensated by the economizer.
(In this configuration outside air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND ODB > 20.0°C (68.0°F).

Economizer = OFF AND Compressor = OFF IF
IDB ≤ 25.0°C (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case E400.

1.3.3.4 Case E430: Enthalpy Economizer with Integrated Compressor Control

Case E430 is **exactly as Case E400 except** the outside air and relief dampers are adjusted using economizer control based on outdoor air enthalpy (h_{amb}) and return air enthalpy (h_{ra}) as described below. Because these cases assume no thermal losses or gains in the ducts, the return air enthalpy and the zone air enthalpy may be assumed to be equal. Enthalpy has units of energy per mass of dry air.

1.3.3.4.1 Economizer and Compressor Control Strategy (E430).

Economizer = ON AND Compressor = OFF IF
IDB > 25.0°C (77.0°F) AND $h_{amb} \leq h_{ra}$ AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND $h_{amb} \leq h_{ra}$ AND all cooling load for the given hour is NOT compensated by the economizer.
(In this configuration outside air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND $h_{amb} > h_{ra}$.

Economizer = OFF AND Compressor = OFF IF
IDB ≤ 25.0°C (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case E400.

1.3.3.5 Case E440: Economizer with Enthalpy Limit Control

Case E440 is **exactly as Case E430 except** when h_{amb} > 47.25 kJ/kg (28.0 Btu/lb), the outside air and relief dampers are maintained at 15% outside air.

1.3.3.5.1 Economizer and Compressor Control Strategy (E440).

Economizer = ON AND Compressor = OFF IF
IDB > 25.0°C (77.0°F) AND $h_{amb} \leq$ 47.25 kJ/kg (28.0 Btu/lb) AND all cooling load for the given hour is compensated by the economizer.

Economizer = ON AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND $h_{amb} \leq$ 47.25 kJ/kg (28.0 Btu/lb) AND all cooling load for the given hour is NOT compensated by the economizer.
(In this configuration outside air is at the 100% maximum setting for the full hour.)

Economizer = OFF AND Compressor = ON IF
IDB > 25.0°C (77.0°F) AND h_{amb} > 47.25 kJ/kg (28.0 Btu/lb).

Economizer = OFF AND Compressor = OFF IF
IDB ≤ 25.0°C (77.0°F).

Economizer/Compressor ON/OFF are as defined for Case E400.

1.3.4 Cases with No Outside Air, Annual Simulation Context (E500 Series)

This section describes sequential revisions to the base case required to model the E500 series cases. Appropriate base cases for a given case are

Case	Basis for that case
E500	E300
E510	E500
E520	E500
E522	E520
E525	E520
E530	E500
E540	E530
E545	E540

1.3.4.1 Case E500: Base Case with No Outside Air

Case E500 is **exactly as Case E300 except** for the changes related to internal heat gains and thermostat control strategy as described in the subsections below.

1.3.4.1.1 Internal Heat Gains. The hourly internal gains are as indicated in Table 1-11. For this case the "frac v. max" values in Table 1-11 are the same for both sensible and latent loads.

Sensible internal gains remain as 100% convective.

These are internally generated sources of heat that are not related to operation of the mechanical cooling system or its air distribution fan.

If your software requires input of water vapor mass flow rate rather than latent internal gains, to convert the latent gains to water vapor mass flow rate for each listed time period, use the heat of vaporization that your software assumes for condensation at the coil.

Table 1-11. Case E500 Hourly Internal Gains Schedule (IP and SI Units)

		SENSIBLE			LATENT		
Period	**Hours**	**Watts**	**Btu/h**	**frac v. max***	**Watts**	**Btu/h**	**frac v. max***
Jan. 1 thru Mar. 10	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 20:00	0	0	0.00000	0	0	0.000
	20:00 - 24:00	0	0	0.00000	0	0	0.000
Mar. 11 thru Apr. 10	0:00 - 9:00	0	0	0.00000	0	0	0.000
	9:00 - 16:00	7034	24000	0.37500	2858	9750	0.375
	16:00 - 24:00	0	0	0.00000	0	0	0.000
Apr. 11**	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 20:00	0	0	0.00000	0	0	0.000
	20:00 - 24:00	0	0	0.00000	0	0	0.000
Apr. 12 thru Apr. 20	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 17:00	9379	32000	0.50000	3810	13000	0.500
	17:00 - 24:00	0	0	0.00000	0	0	0.000
Apr. 21 thru Oct. 11	0:00 - 8:00	7034	24000	0.37500	2858	9750	0.375
	8:00 - 12:00	9379	32000	0.50000	3810	13000	0.500
	12:00 - 14:00	14069	48000	0.75000	5715	19500	0.750
	14:00 - 16:00	18758	64000	1.00000	7621	26000	1.000
	16:00 - 20:00	9379	32000	0.50000	3810	13000	0.500
	20:00 - 24:00	7034	24000	0.37500	2858	9750	0.375
Oct. 12 thru Oct. 18	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 14:00	9379	32000	0.50000	3810	13000	0.500
	14:00 - 24:00	0	0	0.00000	0	0	0.000
Oct. 19 thru Nov. 05	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 12:00	9379	32000	0.50000	3810	13000	0.500
	12:00 - 14:00	14069	48000	0.75000	5715	19500	0.750
	14:00 - 16:00	18758	64000	1.00000	7621	26000	1.000
	16:00 - 20:00	9379	32000	0.50000	3810	13000	0.500
	20:00 - 24:00	7034	24000	0.37500	2858	9750	0.375
Nov. 06 thru Dec. 31**	0:00 - 8:00	0	0	0.00000	0	0	0.000
	8:00 - 20:00	0	0	0.00000	0	0	0.000
	20:00 - 24:00	0	0	0.00000	0	0	0.000

Note: listed values are the internal gain for each hour within the specified period.

* "frac v. max" is the corresponding fraction for the given hourly value relative to the maximum value for the year. This is included for convenience of users who may need to provide this input.

** Same schedule as for Jan. 1 through Mar. 10.

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If your software requires input of total internal gains, use the sum of sensible + latent internal gains for each listed time period.

The internal gains schedule for E500 was developed to serve the following purposes:

- To avoid extrapolations of performance data, the compressor is intended to be off when ODB < 12.78°C (55.0°F).

- Sensible internal gains variations are intended to correspond with additional building shell and solar loads toward midday when possible (this may allow for additional analysis that scales the significance of disagreements in software found here for real buildings); such shell loads would not otherwise be included in a near-adiabatic building model.
- The latent gains schedule allows for a PLR test versus E510 using constant sensible heat ratio (SHR) between E510 and E500.

1.3.4.1.2 Indoor Fan Control and Part-Load Operation. The indoor air distribution fan cycles on and off with the compressor. For this type of control CDF applies to the indoor fan energy consumption (see Section 1.3.1.4.4 and Figure 1-3). Although the fan now cycles rather than operating continuously, the equivalence still holds for using gross total capacity to calculate PLR as an alternative to using net refrigeration effect and adjusted net capacity. See Appendix E for more discussion.

1.3.4.1.3 Outside Air. Outside air fraction = 0.0 (no outside air) for the full annual simulation period. Note that setting both infiltration and outside air to 0 may cause anomalous results for some software. If problems occur, use the lowest values that your software allows (e.g., 1×10^{-x}). (We found in NREL's DOE-2 simulations that simultaneous use of "0" outside air and "0" infiltration caused an error in the simulations. We worked around this by specifying minimum outside air = 0.000001 ft^3/min. We recommend that you run a sensitivity test to ensure that using 0 for both these inputs does not cause a problem.)

1.3.4.1.4 Outputs.

1.3.4.1.4.1 Annual Maxima and Minima. For cases E500–E545 the outputs listed immediately below are to include the hourly integrated maximum and minimum values for the period of April 1 through December 31.

- Minimum zone IDB (°C)
- Minimum zone humidity ratio (kg/kg)
- Maximum zone relative humidity (%)
- Minimum zone relative humidity (%)

Extract this output from a normal annual run. Do not do an additional simulation beginning on April 1 because the above results could contain temperature history errors. These four values are selected after the first three months of simulation to avoid differences in results that could be caused by differences in zone initialization techniques.

Include the other required maximum and minimum value outputs as usual for the entire simulation period (January 1 through December 31).

1.3.4.1.4.2 ODB Sensitivity. For obtaining a sensitivity test of performance as a function of ODB, in addition to the usual outputs (for cases E310–E440), include the following daily average per hour outputs (consumptions and coil loads are full day sums divided by 24 [hours]) for April 30 and June 25 (0:00–24:00):

- Total consumption (compressor + outdoor condenser fan + indoor air distribution fan, Wh)
- Compressor electric consumption (Wh)
- Outdoor condenser fan electric consumption (Wh)
- Indoor air distribution fan electric consumption (Wh)

- Total evaporator coil load (sensible + latent), (Wh)
- Sensible evaporator coil load (Wh)
- Latent evaporator coil load (Wh)
- COP_2 = Σ(total coil load) / (Σ(compressor energy) + Σ(outdoor fan energy)), for the given day
- Zone humidity ratio (kg/kg)
- ODB (°C)
- EDB (°C).

1.3.4.1.4.3 PLR Sensitivity. For developing a sensitivity test of performance as a function of PLR versus Case E510, also include the following summed, mean, and other outputs only for the period of May 1 through September 30. Extract this output from a normal annual run. Do not run only the required months because the results could contain temperature history errors.

- Summed Values
  - Total consumption (compressor + outdoor condenser fan + indoor air distribution fan, kWh)
  - Compressor electric consumption (kWh)
  - Outdoor condenser fan electric consumption (kWh)
  - Indoor air distribution fan electric consumption (kWh)
  - Total evaporator coil load (sensible + latent), (kWh)
  - Sensible evaporator coil load (kWh)
  - Latent evaporator coil load (kWh)
- Mean Values
  - COP_2
  - Zone IDB (°C)
  - Zone humidity ratio (kg/kg)
  - Zone relative humidity (%).

1.3.4.2 Case E510: High Part-Load Ratio

Case E510 **is exactly as Case E500 except** for the internal gains and outputs as described below.

1.3.4.2.1 Internal Heat Gains. The hourly internal gains are as indicated in Table 1-12. The loads are only changed from Case E500 for the period of April 21 through October 11. This results, however, in changes to the listed "frac v. max" multipliers for the other time periods. For this case the "frac v. max" values in Table 1-12 are the same for both sensible and latent loads.

Sensible gains remain as 100% convective.

These are internally generated sources of heat that are not related to operation of the mechanical cooling system or its air distribution fan.

If your software requires input of water vapor mass flow rate rather than latent internal gains, to convert the latent gains to water vapor mass flow rate for each listed time period, use the heat of vaporization that your software assumes for condensation at the coil.

If your software requires input of total internal gains, use the sum of sensible + latent internal gains for each listed time period.

Table 1-12. Case E510 Hourly Internal Gains Schedule (IP and SI Units)

		SENSIBLE			LATENT		
Period	**Hours**	**Watts**	**Btu/h**	**frac v. max***	**Watts**	**Btu/h**	**frac v. max***
Jan. 1 thru Mar. 10	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 20:00	0	0	0.00000	0	0	0.00000
	20:00 - 24:00	0	0	0.00000	0	0	0.00000
Mar. 11 thru Apr. 10	0:00 - 9:00	0	0	0.00000	0	0	0.00000
	9:00 - 16:00	7034	24000	0.33333	2858	9750	0.33333
	16:00 - 24:00	0	0	0.00000	0	0	0.00000
Apr. 11**	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 20:00	0	0	0.00000	0	0	0.00000
	20:00 - 24:00	0	0	0.00000	0	0	0.00000
Apr. 12 thru Apr. 20	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 17:00	9379	32000	0.44444	3810	13000	0.44444
	17:00 - 24:00	0	0	0.00000	0	0	0.00000
Apr. 21 thru Oct. 11	0:00 - 8:00	21103	72000	1.00000	8573	29250	1.00000
	8:00 - 12:00	21103	72000	1.00000	8573	29250	1.00000
	12:00 - 14:00	21103	72000	1.00000	8573	29250	1.00000
	14:00 - 16:00	21103	72000	1.00000	8573	29250	1.00000
	16:00 - 20:00	21103	72000	1.00000	8573	29250	1.00000
	20:00 - 24:00	21103	72000	1.00000	8573	29250	1.00000
Oct. 12 thru Oct. 18	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 14:00	9379	32000	0.44444	3810	13000	0.44444
	14:00 - 24:00	0	0	0.00000	0	0	0.00000
Oct. 19 thru Nov. 05	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 12:00	9379	32000	0.44444	3810	13000	0.44444
	12:00 - 14:00	14069	48000	0.66667	5715	19500	0.66667
	14:00 - 16:00	18758	64000	0.88889	7621	26000	0.88889
	16:00 - 20:00	9379	32000	0.44444	3810	13000	0.44444
	20:00 - 24:00	7034	24000	0.33333	2858	9750	0.33333
Nov. 06 thru Dec. 31**	0:00 - 8:00	0	0	0.00000	0	0	0.00000
	8:00 - 20:00	0	0	0.00000	0	0	0.00000
	20:00 - 24:00	0	0	0.00000	0	0	0.00000

Note: listed values are the internal gain for each hour within the specified period.

* "frac v. max" is the corresponding fraction for the given hourly value relative to the maximum value for the year. This is included for convenience of users who may need to provide this input.

** Same schedule as for Jan. 1 through Mar. 10.

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1.3.4.2.2 Outputs. The outputs are as for E500 except the following summed, mean, and other outputs are included only for the period of May 1 through September 30:

- Summed Values
  - Total consumption (compressor + outdoor condenser fan + indoor air distribution fan, kWh)
  - Compressor electric consumption (kWh)

- Outdoor condenser fan electric consumption (kWh)
  - Indoor air distribution fan electric consumption (kWh)
  - Total evaporator coil load (sensible + latent), (kWh)
  - Sensible evaporator coil load (kWh)
  - Latent evaporator coil load (kWh)
- Mean Values
  - COP_2
  - Zone IDB (°C)
  - Zone humidity ratio (kg/kg)
  - Zone relative humidity (%).

Extract this output from a normal annual run. Do not run only the required months because the results could contain temperature history errors. Do not include these outputs for the period from January 1 through December 31 (as is required for all the other cases).

Include the other required maximum and minimum value outputs as described for Case E500. Do not include average daily outputs for April 30 and June 25.

1.3.4.3 Case E520: Reduced Thermostat Set Point (EDB = 15°C)

Case E520 is **exactly as Case E500 except** the thermostat control strategy and outputs are as described below.

1.3.4.3.1 Thermostat Control Strategy.

Heat = off.
Cool = on if zone air temperature > 15.0°C (59.0°F); otherwise Cool = off.

All other features of the thermostat remain as before.

1.3.4.3.2 Outputs.

The required outputs are the typical outputs required for cases E310–E440. As in Case E500, however, the outputs listed immediately below are to include the hourly integrated maximum and minimum values for the period from April 1 through December 31.

- Minimum zone IDB (°C)
- Minimum zone humidity ratio (kg/kg)
- Maximum zone relative humidity (%)
- Minimum zone relative humidity (%)

Extract this output from a normal annual run. Do not do an additional simulation beginning on April 1 because the above results could contain temperature history errors. These four values are selected after the first three months of simulation to avoid differences in results that could be caused by differences in zone initialization techniques.

Include the other required maximum and minimum value outputs as usual for the entire simulation period (January 1–December 31).

1.3.4.4 Case E522: Reduced Thermostat Set Point (EDB = 20°C)

Case E522 is **exactly as Case E520 except** the thermostat control strategy is as described below.

Heat = off.
Cool = on if zone air temperature > 20.0°C (68.0°F); otherwise Cool = off.

All other features of the thermostat remain as before.

1.3.4.5 Case E525: Increased Thermostat Set Point (EDB Sensitivity)

Case E525 is **exactly as Case E520 except** the thermostat control strategy is as described below.

Heat = off.
Cool = on if zone air temperature > 35.0°C (95.0°F); otherwise Cool = off.

All other features of the thermostat remain as before.

1.3.4.6 Case E530: Dry Coil

Case E530 is **exactly as Case E500 except** the latent internal gains and outputs are as described below.

1.3.4.6.1 Internal Gains. The latent internal gains are 0 for the entire annual simulation period. The sensible internal gains remain as in Case E500. If your software requires input of total internal gains, use the sensible internal gains for each listed time period.

1.3.4.6.2 Outputs. For obtaining a sensitivity test of performance as a function of ODB, in addition to the usual outputs (for Case E520), include the following daily average per hour outputs (consumptions and coil loads are full day sums divided by 24 [hours]) for April 30 and June 25 (0:00–24:00):

- Total consumption (compressor + outdoor condenser fan + indoor air distribution fan), (Wh)
- Compressor electric consumption (Wh)
- Outdoor condenser fan electric consumption (Wh)
- Indoor air distribution fan electric consumption (Wh)
- Total evaporator coil load (sensible + latent, Wh)
- Sensible evaporator coil load (Wh)
- Latent evaporator coil load (Wh)
- COP_2 = Σ(total coil load) / (Σ(compressor energy) + Σ(outdoor fan energy)), for the given day
- Zone humidity ratio (kg/kg)
- ODB (°C)
- EDB (°C).

1.3.4.7 Case E540: Reduced Thermostat Set Point (EDB Sensitivity)

Case E540 is **exactly as Case E530 except** the thermostat control strategy and outputs are as described below.

1.3.4.7.1 Thermostat Control Strategy.

Heat = off.
Cool = on if zone air temperature > 15.0°C (59.0°F); otherwise Cool = off.

All other features of the thermostat remain as before.

1.3.4.7.2 Outputs.

The required outputs are only the typical outputs required for Case E520.

1.3.4.8 Case E545: Increased Thermostat Set Point (EDB Sensitivity)

Case E545 is **exactly as Case E540 except** the thermostat control strategy is as described below.

Heat = off.
Cool = on if zone air temperature > 35.0°C (95.0°F); otherwise Cool = off.

All other features of the thermostat remain as before.

APPENDIX A

TMY2 Weather Data Format Description

The following TMY2 format description is extracted from Section 3 of the TMY2 user manual (Marion and Urban 1995).

For each station, a TMY2 file contains 1 year of hourly solar radiation, illuminance, and meteorological data. The files consist of data for the typical calendar months during 1961–1990 that are concatenated to form the typical meteorological year for each station.

Each hourly record in the file contains values for solar radiation, illuminance, and meteorological elements. A two-character source and uncertainty flag is attached to each data value to indicate whether the data value was measured, modeled, or missing, and to provide an estimate of the uncertainty of the data value.

Users should be aware that the format of the TMY2 data files is different from the format used for the NSRDB and the original TMY data files.

File Convention

File naming convention uses the Weather Bureau Army Navy (WBAN) number as the file prefix, with the characters TM2 as the file extension. For example, 13876.TM2 is the TMY2 file name for Birmingham, Alabama. The TMY2 files contain computer readable ASCII characters and have a file size of 1.26 MB.

File Header

The first record of each file is the file header that describes the station. The file header contains the WBAN number, city, state, time zone, latitude, longitude, and elevation. The field positions and definitions of these header elements are given in Table A-1, along with sample FORTRAN and C formats for reading the header. A sample of a file header and data for January 1 is shown in Figure A-1.

Hourly Records

Following the file header, 8,760 hourly data records provide 1 year of solar radiation, illuminance, and meteorological data, along with their source and uncertainty flags. Table A-2 provides field positions, element definitions, and sample FORTRAN and C formats for reading the hourly records.

Each hourly record begins with the year (field positions 2-3) from which the typical month was chosen, followed by the month, day, and hour information in field positions 4-9. *The times are in local standard time (previous TMYs based on SOLMET/ERSATZ data are in solar time).*

```
 14944 SIOUX_FALLS            SD  -6 N 43 34 W  96 44   435
 850101010000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-211A7060A70975A7360A7052A70161A700945A70999099999004E7050F8000A700E7
 850101020000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-206A7060A70975A7350A7077A70161A700914A70999099999004E7050F8000A700E7
 850101030000000000000?00000?00000?00000?00000?00000?00000?010A710A7-144A7-200A7063A70975A7340A7062A70161A700732A70999099999004E7050F8000A700E7
 850101040000000000000?00000?00000?00000?00000?00000?00000?010A710A7-150A7-206A7063A70976A7330A7072A70161A700640A70999099999004E7050F8000A700E7
 850101050000000000000?00000?00000?00000?00000?00000?00000?010A710A7-156A7-217A7060A70976A7330A7067A70161A700640A70999099999003E7050F8000A700E7
 850101060000000000000?00000?00000?00000?00000?00000?00000?010A710A7-167A7-222A7062A70976A7340A7067A70161A700640A70999099999003E7050F8000A700E7
 850101070000000000000?00000?00000?00000?00000?00000?00000?004A704A7-183A7-233A7065A70977A7300A7052A70193A777777A70999999999003E7050F8000A700E7
 850101080000000000000?00000?00000?00000?00000?00000?00000?002A702A7-194A7-244A7065A70978A7310A7036A70193A777777A70999999999003E7050F8000A700E7
 850101090102129700037G50173G40024G50038I50071I40033I50043I604A700A7-200A7-256A7062A70978A7330A7046A70193A777777A70999999999003E7050F8000A700E7
 850101100287141500157G50560G40043G50159I50444I40069I50079I600A700A7-189A7-256A7056A70979A7310A7067A70193A777777A70999999999003E7050F8000A700E7
 850101110436141500276G40714G40056G50286I40642I40088I50111I500A700A7-172A7-250A7051A70979A7310A7062A70161A777777A70999999999003E7050F8000A700E7
 850101120530141500357G40782G40064G50374I40735I40098I50131I500A700A7-167A7-244A7051A70978A7300A7062A70161A777777A70999999999003E7050F8000A700E7
 850101130562141500387G40806G40067G50407I40767I40101I50139I500A700A7-156A7-244A7047A70978A7320A7067A70193A777777A70999999999003E7050F8000A700E7
 850101140530141500359G40788G40064G50377I40742I40098I50131I500A700A7-144A7-239A7045A70978A7310A7062A70193A777777A70999999999003E7050F8000A700E7
 850101150436141500277G40716G40056G50289I40645I40088I50111I500A700A7-139A7-239A7043A70978A7330A7052A70193A777777A70999999999003E7050F8000A700E7
 850101160286141500157G50564G40043G50162I50450I40069I50080I600A700A7-139A7-233A7045A70978A7300A7052A70161A777777A70999999999003E7050F8000A700E7
 850101170104127300038G50209G40021G50038I50104I40030I50038I600A700A7-150A7-233A7049A70978A7290A7041A70241A777777A70999999999003E7050F8000A700E7
 850101180000000000000?00000?00000?00000?00000?00000?00000?000A700A7-167A7-233A7057A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
 850101190000000000000?00000?00000?00000?00000?00000?00000?000A700A7-172A7-233A7059A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
 850101200000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-233A7062A70978A7000A7000A70241A777777A70999999999003E7050F8000A700E7
 850101210000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70978A7260A7015A70241A777777A70999999999003E7050F8000A700E7
 850101220000000000000?00000?00000?00000?00000?00000?00000?000A700A7-183A7-239A7062A70977A7220A7021A70241A777777A70999999999003E7050F8000A700E7
 850101230000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7220A7015A70241A777777A70999999999003E7050F8000A700E7
 850101240000000000000?00000?00000?00000?00000?00000?00000?000A700A7-178A7-239A7059A70977A7240A7010A70241A777777A70999999999003E7050F8000A700E7

                                                                                                   1         1         1         1         1
         1         2         3         4         5         6         7         8         9         0         1         2         3         4
1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789012
                                             (for field position identification only)
```

Figure A-1. Sample file header and data in the TMY2 format for January 1

Table A-1. Header Elements in the TMY2 Format
(For First Record of Each File)

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1 of Marion and Urban [1995])
008 - 029	City	City where the station is located (maximum of 22 characters)
031 - 032	State	State where the station is located (abbreviated to two letters)
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time is ahead of or behind Universal Time. For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time.
038 - 044 038 040 - 041 043 - 044	Latitude	Latitude of the station N = North of equator Degrees Minutes
046 - 053 046 048 - 050 052 - 053	Longitude	Longitude of the station W = West, E = East Degrees Minutes
056 - 059	Elevation	Elevation of station in meters above sea level

FORTRAN Sample Format:
`( 1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4 )`
C Sample Format:
`( %s %s %s %d %s %d %d %s %d %d %d )`		

Table A-2. Data Elements in the TMY2 Format
(For All Except the First Record)

Field Position	Element	Values	Definition
002 - 009 002 - 003 004 - 005 006 - 007 008 - 009	Local Standard Time Year Month Day Hour	 61 - 90 1 - 12 1 - 31 1 - 24	 Year, 1961-1990 Month Day of month Hour of day in local standard time
010 - 013	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
014 - 017	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in Wh/m^2 received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
018 - 023 018 - 021 022 023	Global Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1200 A - H, ? 0 - 9	Total amount of direct and diffuse solar radiation in Wh/m^2 received on a horizontal surface during the 60 minutes preceding the hour indicated
024 - 029 024 - 027 028 029	Direct Normal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1100 A - H, ? 0 - 9	Amount of solar radiation in Wh/m^2 received within a 5.7° field of view centered on the sun, during the 60 minutes preceding the hour indicated

Table A-2. Data Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
030 - 035 030 - 033 034 035	Diffuse Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 700 A - H, ? 0 - 9	Amount of solar radiation in Wh/m^2 received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
036 - 041 036 - 039 040 041	Global Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1,300 I, ? 0 - 9	Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1,300 = 0 to 130,000 lux
042 - 047 042 - 045 046 047	Direct Normal Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1,100 I, ? 0 - 9	Average amount of direct normal illuminance in hundreds of lux received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1,100 = 0 to 110,000 lux
048 - 053 048 - 051 052 053	Diffuse Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 800 I, ? 0 - 9	Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
054 - 059 054 - 057 058 059	Zenith Luminance Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 7,000 I, ? 0 - 9	Average amount of luminance at the sky's zenith in tens of Cd/m^2 during the 60 minutes preceding the hour indicated. 0 to 7,000 = 0 to 70,000 Cd/m^2
060 - 063 060 - 061 062 063	Total Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F, ? 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
064 - 067 064 - 065 066 067	Opaque Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated
068 - 073 068 - 071 072 073	Dry-Bulb Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -500 to 500 A - F 0 - 9	Dry-bulb temperature in tenths of °C at the hour indicated. -500 to 500 = -50.0 to 50.0 degrees C
074 - 079 074 - 077 078 079	Dew Point Temperature Data Value Flag for Data Source Flag for Data Uncertainty	 -600 to 300 A - F 0 - 9	Dew point temperature in tenths of °C at the hour indicated. -600 to 300 = -60.0 to 30.0 °C
080 - 084 080 - 082 083 084	Relative Humidity Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Relative humidity in percent at the hour indicated

Table A-2. Data Elements in the TMY2 Format (Continued)

Field Position	Element	Values	Definition
085 - 090 085 - 088 089 090	Atmospheric Pressure Data Value Flag for Data Source Flag for Data Uncertainty	 700 - 1100 A - F 0 - 9	Atmospheric pressure at station in millibars at the hour indicated
091 - 095 091 - 093 094 095	Wind Direction Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 360 A - F 0 - 9	Wind direction in degrees at the hour indicated. (N = 0 or 360, E = 90, S = 180, W = 270). For calm winds, wind direction equals zero.
096 - 100 096 - 98 99 100	Wind Speed Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 400 A - F 0 - 9	Wind speed in tenths of meters per second at the hour indicated. 0 to 400 = 0 to 40.0 m/s
101 - 106 101 - 104 105 106	Visibility Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1609 A - F, ? 0 - 9	Horizontal visibility in tenths of kilometers at the hour indicated. 7777 = unlimited visibility 0 to 1609 = 0.0 to 160.9 km 9999 = missing data
107 - 113 107 - 111 112 113	Ceiling Height Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 30450 A - F, ? 0 - 9	Ceiling height in meters at the hour indicated. 77777 = unlimited ceiling height 88888 = cirroform 99999 = missing data
114 - 123	Present Weather	See Appendix B of Marion and Urban (1995)	Present weather conditions denoted by a 10-digit number. See Appendix B of Marion and Urban (1995) for key to present weather elements.
124 - 128 124 - 126 127 128	Precipitable Water Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 100 A - F 0 - 9	Precipitable water in millimeters at the hour indicated
129 - 133 129 - 131 132 133	Aerosol Optical Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 240 A - F 0 - 9	Broadband aerosol optical depth (broad-band turbidity) in thousandths on the day indicated. 0 to 240 = 0.0 to 0.240
134 - 138 134 - 136 137 138	Snow Depth Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 150 A - F, ? 0 - 9	Snow depth in centimeters on the day indicated. 999 = missing data
139 - 142 139 - 140 141 142	Days Since Last Snowfall Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 88 A - F, ? 0 - 9	Number of days since last snowfall 88 = 88 or greater days 99 = missing data

FORTRAN Sample Format:

```
(1X,4I2,2I4,7(I4,A1,I1),2(I2,A1,I1),2(I4,A1,I1),1(I3,A1,I1),
 1(I4,A1,I1),2(I3,A1,I1),1(I4,A1,I1),1(I5,A1,I1),10I1,3(I3,A1,I1),
 1(I2,A1,I1))
```

C Sample Format:

```
(%2d%2d%2d%2d%4d%4d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s%1d%4d%1s
 %1d%4d%1s%1d%2d%1s%1d%2d%1s%1d%4d%1s%1d%4d%1s%1d%3d%1s%1d%4d%1s%1d%3d
 %1s%1d%3d%1s%1d%4d%1s%1d%5ld%1s%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%1d%3d%1s
 %1d%3d%1s%1d%3d%1s%1d%2d%1s%1d)
```

Note: For ceiling height data, integer variable should accept data values as large as 99999.

For solar radiation and illuminance elements, the data values represent the energy received during the 60 minutes *preceding the hour indicated*. For meteorological elements (with a few exceptions), observations or measurements were made *at the hour indicated*. A few of the meteorological elements had observations, measurements, or estimates made at daily, instead of hourly, intervals. Consequently, the data values for broadband aerosol optical depth, snow depth, and days since last snowfall represent the values available for the day indicated.

Missing Data

Data for some stations, times, and elements are missing. The causes for missing data include such things as equipment problems, some stations not operating at night, and a National Oceanic and Atmospheric Administration (NOAA) cost-saving effort from 1965 to 1981 that digitized data for only every third hour.

Although both the National Solar Radiation Database (NSRDB) and the TMY2 data sets used methods to fill data where possible, some elements, because of their discontinuous nature, did not lend themselves to interpolation or other data-filling methods. Consequently, data in the TMY2 data files may be missing for horizontal visibility, ceiling height, and present weather for up to 2 consecutive hours for Class A stations and for up to 47 hours for Class B stations. For Colorado Springs, Colorado, snow depth and days since last snowfall may also be missing. No data are missing for more than 47 hours, except for snow depth and days since last snowfall for Colorado Springs, Colorado. As indicated in Table A-2, missing data values are represented by 9's and the appropriate source and uncertainty flags.

Source and Uncertainty Flags

With the exception of extraterrestrial horizontal and extraterrestrial direct radiation, the two field positions immediately following the data value provide source and uncertainty flags both to indicate whether the data were measured, modeled, or missing, and to provide an estimate of the uncertainty of the data. Source and uncertainty flags for extraterrestrial horizontal and extraterrestrial direct radiation are not provided because these elements were calculated using equations considered to give exact values.

For the most part, the source and uncertainty flags in the TMY2 data files are the same as the ones in NSRDB, from which the TMY2 files were derived. However, differences do exist for data that were missing in the NSRDB, but then filled while developing the TMY2 data sets. Uncertainty values apply to the data with respect to when the data were measured, and not as to how "typical" a particular hour is for a future month and day. More information on data filling and the assignment of source and uncertainty flags is found in Appendix A of Marion and Urban (1995).

Tables A-3 through A-6 define the source and uncertainty flags for the solar radiation, illuminance, and meteorological elements.

Table A-3. Solar Radiation and Illuminance Source Flags

Flag	Definition
A	Post-1976 measured solar radiation data as received from NCDC or other sources
B	Same as "A" except the global horizontal data underwent a calibration correction
C	Pre-1976 measured global horizontal data (direct and diffuse were not measured before 1976), adjusted from solar to local time, usually with a calibration correction
D	Data derived from the other two elements of solar radiation using the relationship, global = diffuse + direct × cosine (zenith)
E	Modeled solar radiation data using inputs of *observed* sky cover (cloud amount) and aerosol optical depths derived from direct normal data collected at the same location
F	Modeled solar radiation data using *interpolated* sky cover and aerosol optical depths derived from direct normal data collected at the same location
G	Modeled solar radiation data using *observed* sky cover and aerosol optical depths estimated from geographical relationships
H	Modeled solar radiation data using *interpolated* sky cover and estimated aerosol optical depths
I	Modeled illuminance or luminance data derived from measured or modeled solar radiation data
?	Source does not fit any of the above categories. Used for nighttime values, calculated extraterrestrial values, and missing data

Table A-4. Solar Radiation and Illuminance Uncertainty Flags

Flag	Uncertainty Range (%)
1	Not used
2	2 - 4
3	4 - 6
4	6 - 9
5	9 - 13
6	13 - 18
7	18 - 25
8	25 - 35
9	35 - 50
0	Not applicable

Table A-5. Meteorological Source Flags

Flag	Definition
A	Data as received from NCDC, converted to SI units
B	Linearly interpolated
C	Non-linearly interpolated to fill data gaps from 6 to 47 hours in length
D	Not used
E	Modeled or estimated, except: precipitable water, calculated from radiosonde data; dew point temperature calculated from dry-bulb temperature and relative humidity; and relative humidity calculated from dry-bulb temperature and dew point temperature
F	Precipitable water, calculated from surface vapor pressure; aerosol optical depth, estimated from geographic correlation
?	Source does not fit any of the above. Used mostly for missing data

Table A-6. Meteorological Uncertainty Flags

Flag	Definition
1 - 6	Not used
7	Uncertainty consistent with NWS practices and the instrument or observation used to obtain the data
8	Greater uncertainty than 7 because values were interpolated or estimated
9	Greater uncertainty than 8 or unknown
0	Not definable

Appendix B
Output Spreadsheet Instructions

E300OUT2.XLS
Output spreadsheet for HVAC BESTEST, Cases E300 - E545

INSTRUCTIONS

1. Use specified units.

2. Data entry is restricted to the following ranges:

B62..L82:	Annual Sums, Annual Means, and Other
M62..N62:	Annual Means, E300 Only
B89..L112:	June 28 Hourly Output, Case E300
B120..L121:	Case E500 Average Daily Outputs
B129..L130:	Case E530 Average Daily Outputs
Q62..AB81:	Annual Hourly Integrated Maxima, Consumptions and Loads
AC62..AH62:	Annual Hourly Integrated Maxima, Case E300 - Weather Check
Q89..AN108:	Annual Hourly Integrated Maxima and Minima, COP2 and Zone

3. Annual totals are consumption and/or loads just for the entire annual simulation. Similarly, annual means, maxima, and minima are those values that occur for the entire annual simulation. "May-Sep" results are taken using May 1 - September 30 data extracted from a full annual simulation.

4. Output terminology is defined in the output section of the specification for each case where applicable or in the Glossary (Appendix C).

5. Format dates using the appropriate two-digit date followed by a three-letter month code and two-digit hour code (24-hour clock) as shown below.

MONTH CODES:

MONTH	CODE
JANUARY	Jan
FEBRUARY	Feb
MARCH	Mar
APRIL	Apr
MAY	May
JUNE	Jun
JULY	Jul
AUGUST	Aug
SEPTEMBER	Sep
OCTOBER	Oct
NOVEMBER	Nov
DECEMBER	Dec

For example a maximum value occuring on August 16 during the 15th hour interval (2-3 P.M.), should be input as:

Date	Hour
16-Aug	15

Appendix C
Glossary

Glossary terms used in the definitions of other terms are highlighted with italics.

References for terms listed here that are not specific to this test procedure include ANSI/ARI 210/240-89 (1989); *ASHRAE Handbook of Fundamentals* (2001); *ASHRAE Psychrometric Chart No. 1* (1992); *ASHRAE Terminology of Heating, Ventilation, Air-Conditioning, and Refrigeration* (1991); Brandemuehl (1993); Cawley (1997); Lindeburg (1990); McQuiston and Parker (1994); and Van Wylen and Sonntag (1985).

Adjusted net sensible capacity is the *gross sensible capacity* less the actual fan power.

Adjusted net total capacity is the *gross total capacity* less the actual fan power.

Apparatus dew point (ADP) is the effective coil surface temperature when there is dehumidification; this is the temperature to which all the supply air would be cooled if 100% of the supply air contacted the coil. On the psychrometric chart, this is the intersection of the condition line and the saturation curve, where the condition line is the line passing through the entering air conditions with the slope defined by the sensible heat ratio ((sensible capacity)/(total capacity)).

Bypass factor (BF) can be thought of as the percentage of the distribution air that does not come into contact with the cooling coil; the remaining air is assumed to exit the coil at the average coil temperature (*apparatus dew point*).

Coefficient of performance (COP) for a cooling (refrigeration) system is the ratio, using the same units, of the *net refrigeration effect* to the corresponding energy input. For the purpose of calculating COP, corresponding energy input is the related *cooling energy consumption*, except for cases E300–E440 where the indoor air distribution fan energy is included only during times when heat is being extracted by the evaporator coil.

Cooling energy consumption is the site electric energy consumption of the mechanical cooling equipment including the compressor, air distribution fan (regardless of whether the compressor is on or off), condenser fan, and related auxiliaries.

COP_2 (or COP2) is the ratio, using the same units, of the *gross total evaporator coil load* to the sum of the compressor and outdoor condenser fan energy consumptions.

COP degradation factor (CDF) is a multiplier (≤1) applied to the full-load system COP or COP2. CDF is a function of *part-load ratio*.

Dew point temperature is the temperature of saturated air at a given *humidity ratio* and pressure. As moist air is cooled at constant pressure, the dew point is the temperature at which condensation begins.

Economizer is a control system that conserves energy, usually by using outside air and control logic to maintain a fixed minimum of outside air when increased outside-air flow rates are not called for.

Entering dry-bulb temperature (EDB) is the temperature that a thermometer would measure for air entering the evaporator coil. For a draw-through fan configuration with no heat gains or losses in the ductwork and no outside air mixed with return air, EDB equals the indoor (or zone-air) dry-bulb temperature. For a similar configuration but when outside air is mixed with return air, EDB equals the mixed air dry-bulb temperature.

Entering wet-bulb temperature (EWB) is the temperature that the wet-bulb portion of a psychrometer would measure if exposed to air entering the evaporator coil. For a draw-through fan with no heat gains or losses in the ductwork and no outside air mixed with return air, this would also be the zone-air wet-bulb temperature. For a similar configuration but when outside air is mixed with return air, EWB equals the mixed air wet-bulb temperature. For mixtures of water vapor and dry air at atmospheric temperatures and pressures, the wet-bulb temperature is approximately equal to the adiabatic saturation temperature (temperature of the air after undergoing a theoretical adiabatic saturation process). The wet-bulb temperature given in psychrometric charts is really the adiabatic saturation temperature.

Evaporator coil loads are the actual *sensible heat* and *latent heat* removed from the distribution air by the evaporator coil. Sensible evaporator coil load applies only to sensible heat removal. Latent evaporator coil load applies only to latent heat removal.

Gross sensible capacity is the rate of *sensible heat* removal by the cooling coil for a given set of operating conditions. This value varies as a function of performance parameters such as EWB, ODB, EDB, and airflow rate.

Gross total capacity is the total rate of both *sensible heat* and *latent heat* removal by the cooling coil for a given set of operating conditions. This value varies as a function of performance parameters such as EWB, ODB, EDB, and airflow rate.

Gross total evaporator coil load is the sum of the *sensible heat* and *latent heat* removed from the distribution air by the evaporator coil.

Humidity ratio is the ratio of the mass of water vapor to the mass of dry air in a moist air sample.

Indoor dry-bulb temperature (IDB) is the temperature that a thermometer would measure if exposed to indoor air.

Infiltration is leakage of air through any building element (e.g., walls, windows, and doors).

Latent heat is the change in enthalpy associated with a change in *humidity ratio*, caused by the addition or removal of moisture.

Net refrigeration effect is the rate of heat removal (sensible + latent) by the evaporator coil, as regulated by the thermostat (i.e., not necessarily the full-load capacity), after deducting internal and external heat transfers to air passing over the evaporator coil. For cases E500–E545 (and cases E100–E200), the net refrigeration effect is the *evaporator coil load* less the air distribution fan heat. For cases E300–E440, the net refrigeration effect is the *evaporator coil load* less the air distribution fan heat for times when the evaporator coil is removing heat.

Outdoor dry-bulb temperature (ODB) is the temperature that a thermometer would measure if exposed to outdoor air. This is the temperature of air entering the condenser coil.

Part-load ratio (PLR) is the ratio of the *net refrigeration effect* to the *adjusted net total capacity* for the cooling coil. As shown in Appendix E, for the purpose of calculating the *COP degradation factor (CDF),* defining PLR as the ratio of the *gross total evaporator coil load* to the *gross total capacity* produces an equivalent CDF.

Relative humidity is the ratio of the mole fraction of water vapor in a given moist air sample to the mole fraction in an air sample that is saturated and at the same temperature and pressure. This is equivalent to the ratio of partial pressure of the water vapor in a sample to the saturation pressure at the same temperature.

Sensible heat is the change in enthalpy associated with a change in dry-bulb temperature, caused by the addition or removal of heat.

Sensible heat ratio (SHR), also known as sensible heat factor (SHF), is the ratio of sensible heat transfer to total (sensible + latent) heat transfer for a process. See also *sensible heat* and *latent heat*.

Appendix D
Calculation of Minimum Supply Air Temperature

$T_{sa,min} = EDB + \Delta T,$ (1)

where $T_{sa,min}$ ≡ minimum supply air temperature
EDB ≡ entering dry-bulb temperature
ΔT ≡ temperature change through coil/air-handling system (value is negative for cooling).

ΔT is determined from

$q = m\, c_p\, \Delta T,$ (2)

where q ≡ cooling capacity
c_p ≡ specific heat of air
m ≡ mass flow rate of entering air = ρ Q
where ρ ≡ density of air
Q ≡ airflow rate.

For $\rho = 0.075$ lb/ft^3, $c_p = 0.24$ Btu/lb°F implies that (2) can be rewritten as

$\Delta T = q / 1.08\,(CFM),$ (3)

where CFM = entering airflow rate in ft^3/min.

Then for Q = 4000 CFM, and q = –92,300 Btu/h (maximum sensible cooling capacity for EDB = 55°F), and using equation (3), gives

$\Delta T_{coil} = -21.37$°F.

However, there is draw-through fan heat of 1242 W (4238 Btu/h), which causes a temperature increase using equation (3) of

$\Delta T_{fan} = 0.98$°F,

Then

$\Delta T = \Delta T_{coil} + \Delta T_{fan} = -20.38$°F.

Returning to equation (1), the internal gains have been scheduled so that the lowest EDB that should occur is EDB = 55°F (in Case E330), so that from (1)

$T_{sa,min}$ = 55°F – 20.38°F = 34.62°F (1.46°C).

Note that this calculation assumes typical dry air properties. Using moist air properties at actual entering conditions would give minor variation. For example, EWB = 40°F and EDB = 55°F at sea level gives υ = 13.1 ft^3/lb and ω = 0.0018 kg/kg, resulting in $T_{sa,min}$ = 35.06°F (1.70°C).

Appendix E
PLR Definition Similarity

We have defined PLR in cases E100–E200 based on guidance from an equipment manufacturer as

PLR1 = Qnet / CAPnet,

where

Qnet = net refrigeration effect
CAPnet = adjusted net total capacity.

For the E300 series cases we wish to define PLR as

PLR2 = Qgtc / CAPgtc,

where
Qgtc = gross total coil load
CAPgtc = gross total capacity.

The net refrigeration effect = Qgtc – Qfan

where Qfan is the air distribution fan heat.

For cases E500–E545 (and cases E100–E200), the net refrigeration effect is the *evaporator coil load* less the air distribution fan heat. For cases E300–E440, the net refrigeration effect is the *evaporator coil load* less the air distribution fan heat for times when the evaporator coil is removing heat.

The adjusted net capacity = CAPgtc – Pfan

where Pfan = fan rated power.

Then for PLR1 = PLR2 to be true implies

Qgtc / CAPgtc = (Qgtc – Qfan) / (CAPgtc – Pfan),

which is true if

Qfan / Pfan = Qgtc / CAPgtc,

that is, if the fan heat for a given period is the fan's run-time fraction for that period multiplied by the fan power, where Qgtc/CAPgtc inherently defines the required fraction of a time period that the evaporator coil is to be removing heat at a given capacity. The above relation is true if there is no additional fan run time (and fan heat) associated with additional compressor start-up run time that occurs during part-load operation. This is true for Case E300 where the fan is always on and may be thought of as only being accounted for in the net refrigeration effect term when the coil is actually cold enough to remove heat (i.e. additional start-up run time not included). (For this discussion we are ignoring that the coil removes heat at a small rate during start-up, a rate that gradually increases until the evaporator coil temperature reaches stability.) Then for Case E300,

$$Qfan = Pfan * PLR2 = Pfan * Qgtc / CAPgtc,$$

and it would follow that PLR1 = PLR2.

For cases E100–E200, because the indoor fan cycles on/off with the compressor, we originally defined the net refrigeration effect to subtract out fan heat for the time when the compressor is operating (which is longer than the time that the coil is actually removing heat at rated capacity).

For that situation, which also applies to cases E500–E545, it is useful to think of

$$Qfan / Pfan = PLR / CDF.$$

This relation, however, implies

$$Qfan / Pfan \neq Qgtc / CAPgtc,$$

with the theoretical result that PLR1 ≠ PLR2.

Table E-1 provides an analysis of the difference between PLR1 and PLR2 and corresponding resultant CDF1 and CDF2 that could be used in evaluating part-load performance for cases where the air distribution fan operates continuously and where the fan cycles on/off with the compressor. This analysis applies reasonable hypothetical values of coil capacity and fan power. The analysis indicates (see far right column of Table E-1) that the resulting difference between CDF1 and CDF2 and, therefore, the compressor energy consumptions related to applying those CDFs, is < 0.1%, which is negligible. Thus, for the purpose of calculating CDF, either PLR1 or PLR2 may be used.

Table E-1. Comparison of PLR Definitions

Continuously operating fan, compressor cycling (start-up) does not create any additional fan ON time.

PLR2	CAPgtc (Btu/h)	Qgtc (Btu/h)	Pfan (Btu/h)	CDF2	Qfan (Btu/h)	Qfan/ Pfan	net refr (Btu/h)	adjnetcap (Btu/h)	PLR1 = net refr/ CAPnet	PLR2/ PLR1	CDF1	CDF2/ CDF1
0.1	100000	10000	4000	0.7939	400	0.100	9600	96000	0.1000	1.0000	0.7939	1.00000
0.5	100000	50000	4000	0.8855	2000	0.500	48000	96000	0.5000	1.0000	0.8855	**1.00000**
0.9	100000	90000	4000	0.9771	3600	0.900	86400	96000	0.9000	1.0000	0.9771	1.00000

So for E300 the ratio of net refr effect to adj net cap exactly equals the ratio of Qgtc to CAPgtc, as shown previously.

Fan cycles ON/OFF with compressor, compressor cycling creates additional fan ON time.

PLR2	CAPgtc (Btu/h)	Qgtc (Btu/h)	Pfan (Btu/h)	CDF2	Qfan (Btu/h)	Qfan/ Pfan	net refr (Btu/h)	adjnetcap (Btu/h)	PLR1 = net refr/ CAPnet	PLR2/ PLR1	CDF1	CDF2/ CDF1
0.1	100000	10000	4000	0.7939	504	0.126	9496	96000	0.0989	0.9892	0.7937	1.000312
0.35	100000	35000	4000	0.8512	1645	0.411	33355	96000	0.3474	0.9927	0.8506	1.000687
0.4	100000	40000	4000	0.8626	1855	0.464	38145	96000	0.3973	0.9934	0.8620	1.000705
0.45	100000	45000	4000	0.8741	2059	0.515	42941	96000	0.4473	0.9940	0.8734	**1.000708**
0.5	100000	50000	4000	0.8855	2259	0.565	47741	96000	0.4973	0.9946	0.8849	**1.000697**
0.55	100000	55000	4000	0.897	2453	0.613	52547	96000	0.5474	0.9952	0.8963	1.000673
0.9	100000	90000	4000	0.9771	3684	0.921	86316	96000	0.8991	0.9990	0.9769	1.000206

Notes regarding Table E-1:

Bold font indicates value of CDF2/CDF1 at PLR2 = 0.5, and value of PLR2 at maximum value of CDF2/CDF1.

For the case where the fan cycles on/off with the compressor, the total fan run-time fraction, including the additional start-up run time during which little or no cooling occurs, = PLR/CDF. Actually, fan heat should be slightly higher because the additional fan run time resulting from CDF creates a slight amount of additional fan heat that, in turn, causes slightly more additional run time. In accord with an analytical solution by Technische Universität Dresden, Germany for mid-PLR case E170 (see HVAC BESTEST Volume 1 [Neymark and Judkoff 2002: Section 2.3.1]), the additional run time (fan heat) is 0.5% greater if this effect is taken into account. Because this is a 0.5% effect on a quantity that makes up at most 4% of the coil load (i.e., 0.02% effect overall), for the purpose of calculating CDF = f(PLR), we ignore it.

Appendix F
Indoor Fan Data Equivalence

Fan performance data for indoor fan electric power (1242 W), mechanical shaft power (1.565 BHP = 1167 W) and airflow rate (4000 CFM = 1.888 m^3/s) are based on dry air at standard fan rating conditions. ASHRAE defines a standard condition as 1 atmosphere (101.325 kPa or 14.696 psi) and 68°F (20°C) with a density of 0.075 lb/ft^3 (1.204 kg/m^3) (Howell, Sauer, and Coad 1998: p. 3.4).

The static pressure of 0.3 in. wg (74.7 Pa) is based on the Air-Conditioning and Refrigeration Institute (ARI) rating condition (Pegues 2001).

The **fan static efficiency** is based on:

$$Eff_s = Q * \Delta P_s / W_{sh,}$$

(McQuiston and Parker 1994: p. 463; ANSI/AMCA 210-85, ANSI/ASHRAE 51, 1985: pp. 4, 40, 46–48)

where

Q ≡ indoor fan airflow rate (m^3/s)
ΔP_s ≡ static fan pressure (Pa)
W_{sh} ≡ fan shaft power input (W)
Eff_s ≡ static fan efficiency.

Solving for Eff_s

$$Eff_s = 1.888 \text{ m}^3/\text{s} * 74.7 \text{ Pa} / 1167 \text{ W} = 0.121 = 12.1\%.$$

The **motor/drive efficiency** is based on

$$Eff_m = W_{sh} / W,$$

where

Eff_m ≡ motor/drive efficiency
W_{sh} ≡ fan shaft power input (W)
W ≡ fan electric power input (W)

Solving for Eff_m

$$Eff_m = 1167 \text{ W} / 1242 \text{ W} = 0.940 = 94.0\%.$$

The **supply air temperature rise from fan heat** is based on

$$q_{fan} = \rho * c_p * Q * \Delta T * C$$

where

q_{fan} ≡ fan heat (Btu/h or W), motor/drive in air stream
ρ ≡ standard air density = 0.075 lb/ft^3 (1.204 kg/m^3)

c_p ≡ specific heat of air (Btu/(lb°F) or kJ/(kgK))
Q ≡ indoor fan airflow rate (ft^3/min or m^3/s)
ΔT ≡ supply air temperature rise from fan heat (°F or °C)
C ≡ units conversion constant.

Solving for ΔT

$$\Delta T = q_{fan} / (\rho * c_p * Q * C),$$

where

q_{fan} = 1242 W = 4237 Btu/h; Q = 4000 CFM = 1.888 m^3/s
c_p = 0.24 Btu/lb F for dry air, or
c_p = 0.2445 Btu/lb F when humidity ratio = 0.01 (Howell, Sauer, and Coad 1998; p. 3.5).

Then, ΔT = 4237 Btu/h / { 0.075 lb/ft^3 * 4000 ft^3/min * 60 min/h * 0.2445 Btu/(lb°F) }

ΔT = 0.963°F (0.535°C), or

for c_p = 0.24 Btu/(lb°F), gives ΔT = 0.981°F (0.545°C).

Appendix G
Diagnosing the Results Using the Flow Diagrams

G.1 General Description

Figures G-1, G-2, and G-3 contain a set of flow diagrams that serve as a guide for diagnosing the cause of disagreeing results that may arise from using this test. These flow diagrams list the feature(s) being tested, thus indicating potential sources of algorithmic differences. Flow diagrams are included here for both the Volume 1 cases E100–E200 (Figure G-1) and the Volume 2 cases E300–E545 (Figures G-2 and G-3). Cases E100–E200 (Neymark and Judkoff 2002) are to be run first. These are steady-state cases that test basic performance-map modeling capabilities, and utilize comparisons with analytical solutions that constitute a mathematical truth standard. It is very important to have confidence in your results for cases E100–E200 before proceeding to the other cases.

After successfully completing cases E100–E200, go on to cases E300–E545. These cases test additional model features under more dynamic conditions. Example simulation results (see Part III) for cases E300–E545 do not include analytical solutions, so analytical verification versus a mathematical truth standard is not possible for those cases. The flow diagrams for cases E300–E545 may be used in two ways. The most powerful but time-consuming way is to perform all cases E300–E545, and then use the diagnostic logic in the flow diagrams to analyze the results. The least time-consuming way is to perform the tests in sequence according to the flow diagrams, beginning with Figure G-2.

G.2 Comparing Tested Software Results to Analytical Solution Results (cases E100–E200)

See the discussion in Appendix F of Volume 1 (Neymark and Judkoff 2002).

G.3 Comparing Tested Software Results to Other Example Results (cases E300–E545)

"Example results" are either results presented in Part III of this document or other results that were generated using this test procedure.

For cases E300–E545 we provide no formal criteria for when results agree or disagree. Determination of agreement or disagreement of results is left to the user. In making this determination the user should consider:

- Magnitude of results for individual cases
- Magnitude of difference in results between certain cases (e.g., "Case E310–Case E300")
- Same direction of sensitivity (positive or negative) for difference in results between certain cases (e.g., "Case E310–Case E300")
- Example results do <u>not</u> represent a truth standard
- Results that are logically counterintuitive with respect to known or expected physical behavior.

Check the program being tested for agreement (see above) with example results for both the absolute outputs and the sensitivity (or "delta") outputs. For example, when comparing to the example results, for

Case "E310–E300" in Figure G-2, the program results are compared with both the Case E310 example results and the Case E310–E300 example sensitivity results.

Compare all available output types specified for each case that can be produced by the program being tested. This includes appropriate energy consumption, coil load, zone temperature results, humidity ratio results, and so forth for all of the required outputs that the software is capable of producing. A disagreement with any one of the output types may be cause for concern.

The flow diagram of Figure G-2 begins with a basic performance test (Case E300). It is very important to have confidence in your Case E300 results before proceeding to the other cases. If output from the tested program agrees satisfactorily with other example results for Case E300, then continue to check output for the remaining cases according to the flow diagram. If output from the tested program disagrees with other example results for Case E300, then follow the diagnostic logic accordingly. The diagnostic logic for cases E500–E545 is presented in Figure G-3. Cases E500–E545 test similar effects as cases E100–E200, but in an hourly dynamic context using expanded performance data without analytical verification. The sensitivity result "E500–E300" isolates the effect of outside air, but with some noise because of varying internal gains schedules between Case E300 and Case E500, and because the air distribution fan cycles with the compressor in Case E500. In contrast with steady-state cases E100–E200 that were solved analytically, the more realistic nature of cases E300–E545 allows us to gauge the importance of being able to simulate various effects accurately in terms of annual energy performance. For example, a large percentage difference for a given result that has only a very small impact on annual energy use may not be of concern, whereas a small percentage difference with a large impact on annual energy use may be deemed important.

There are some cases where it is possible to proceed even if disagreements were uncovered in the previous case. For example, in Case E410, inability to model an economizer with compressor lockout does not necessarily affect the usefulness of the program (or the ability to further test the program) for modeling other types of economizer controls or other mechanical equipment features. Thus the flow diagram has an extra arrow connecting Case E410 and Case E420, which denotes that you may proceed regardless of the results for Case E410. Where cases are connected by a single arrow, a satisfactory result is required in order to proceed to the next case. For example, in Case E310, the inability to model latent load removal makes it difficult to proceed with these tests until the disagreement is reconciled.

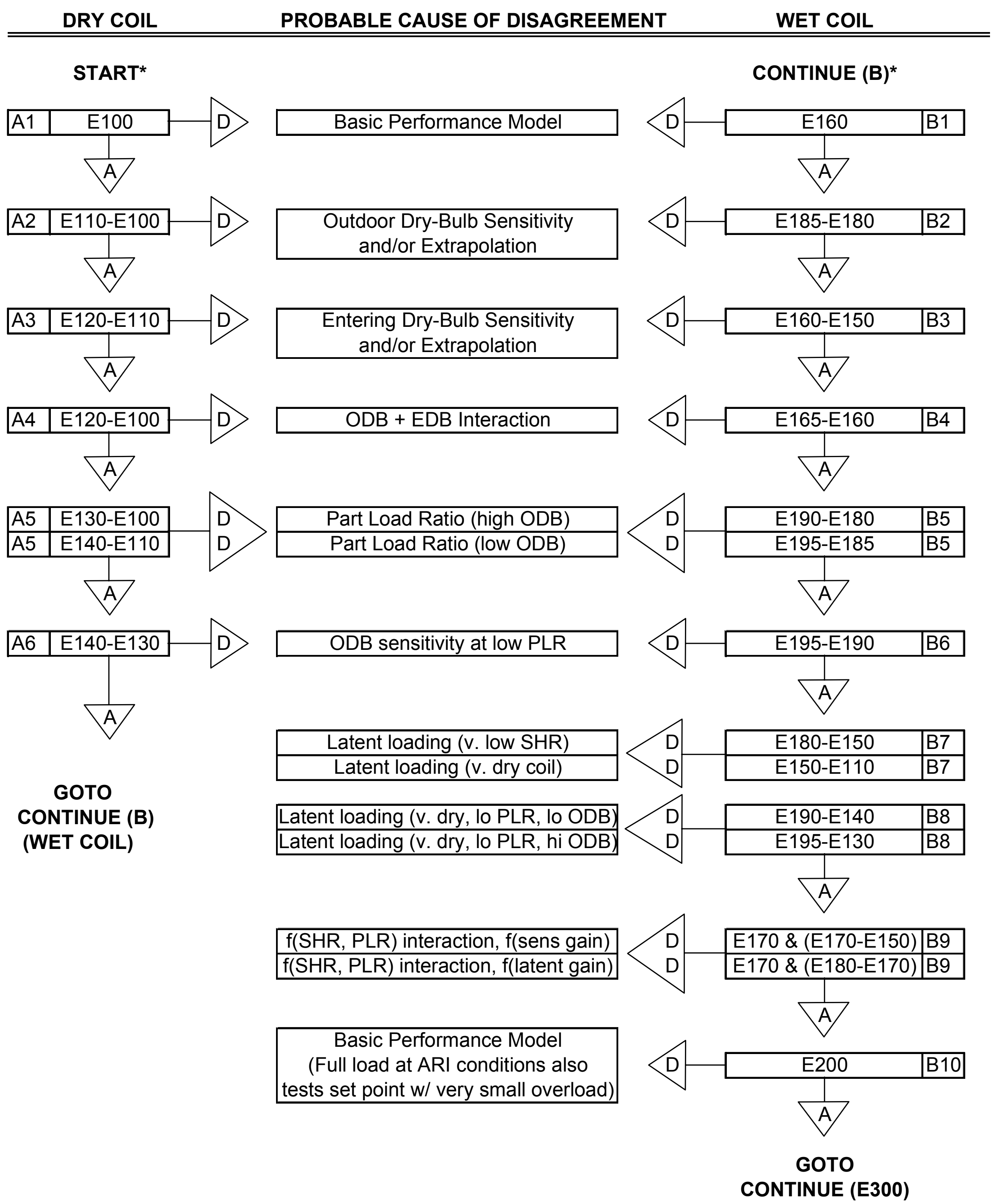
G.3.1 If Tested Software Results Disagree with Example Results

If the tested program shows disagreement (as defined above) with the example results, then recheck the inputs against the specified values. Use the diagnostic logic flow diagrams to help isolate the source of the difference; in some cases it may be useful to recheck E100 series results. If no input error can be found, then look for an error in the software. If an error is found, then fix it and rerun the tests. If in the engineering judgment of the user the disagreement is caused by a reasonable difference in algorithms between the tested software and the example results, then continue with the next test case.

G.3.2 Example

A program shows disagreement with E300. Because this is the base case for the E300 series, Figure G-2 suggests a number of potential sources of algorithmic differences including dynamic variation of load, 15% outside air (mixed with return air), continuous indoor fan operation, or hourly dynamic equipment performance as f(EDB, EWB, ODB, PLR). The user is directed to check diagnostics C1 and C2. If the disagreement persists for C1 and/or C2, this likely eliminates outside air mixing and continuous fan operation as the cause of the problem. The user is then directed to recheck results from cases E100–E200. If the E100 results are still satisfactory, then the problem is likely isolated to performance-map parameter f(ODB, EWB, EDB) sensitivity over the expanded range of performance data or some other problem related to hourly dynamic modeling.

Section 2.4 (Part II) gives examples of how the tests were used to trace and correct specific algorithmic and input errors in the programs used in the field trials.



ABBREVIATIONS

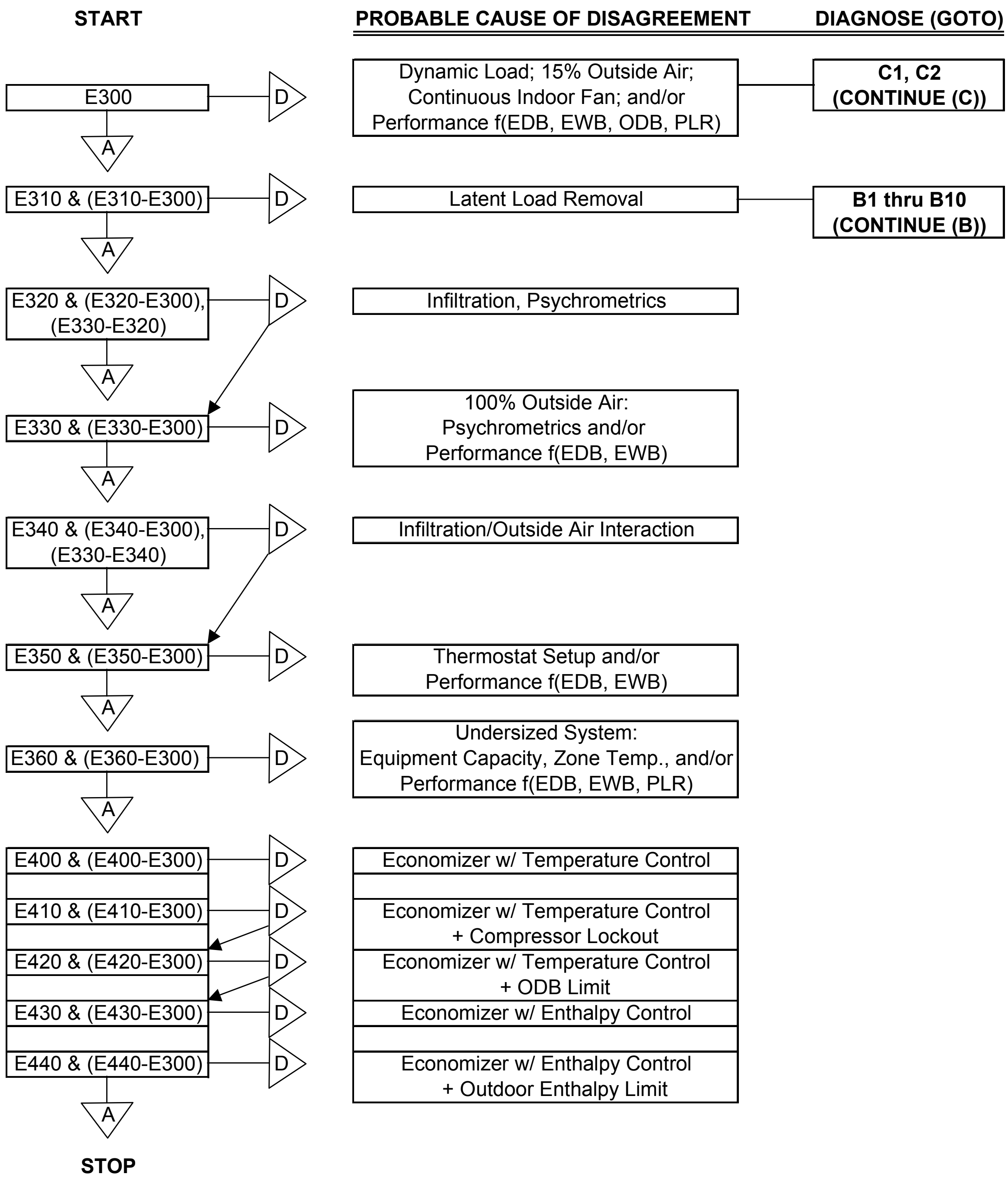
A = Agree; i.e., agree with analytical solution results for the case itself and the sensitivity case. E.g., to check for agreement regarding Case E130, compare example results for Case E130 and E130-E100 sensitivity.

D = Disagree; i.e., show disagreement with analytical solution results.

NOTES

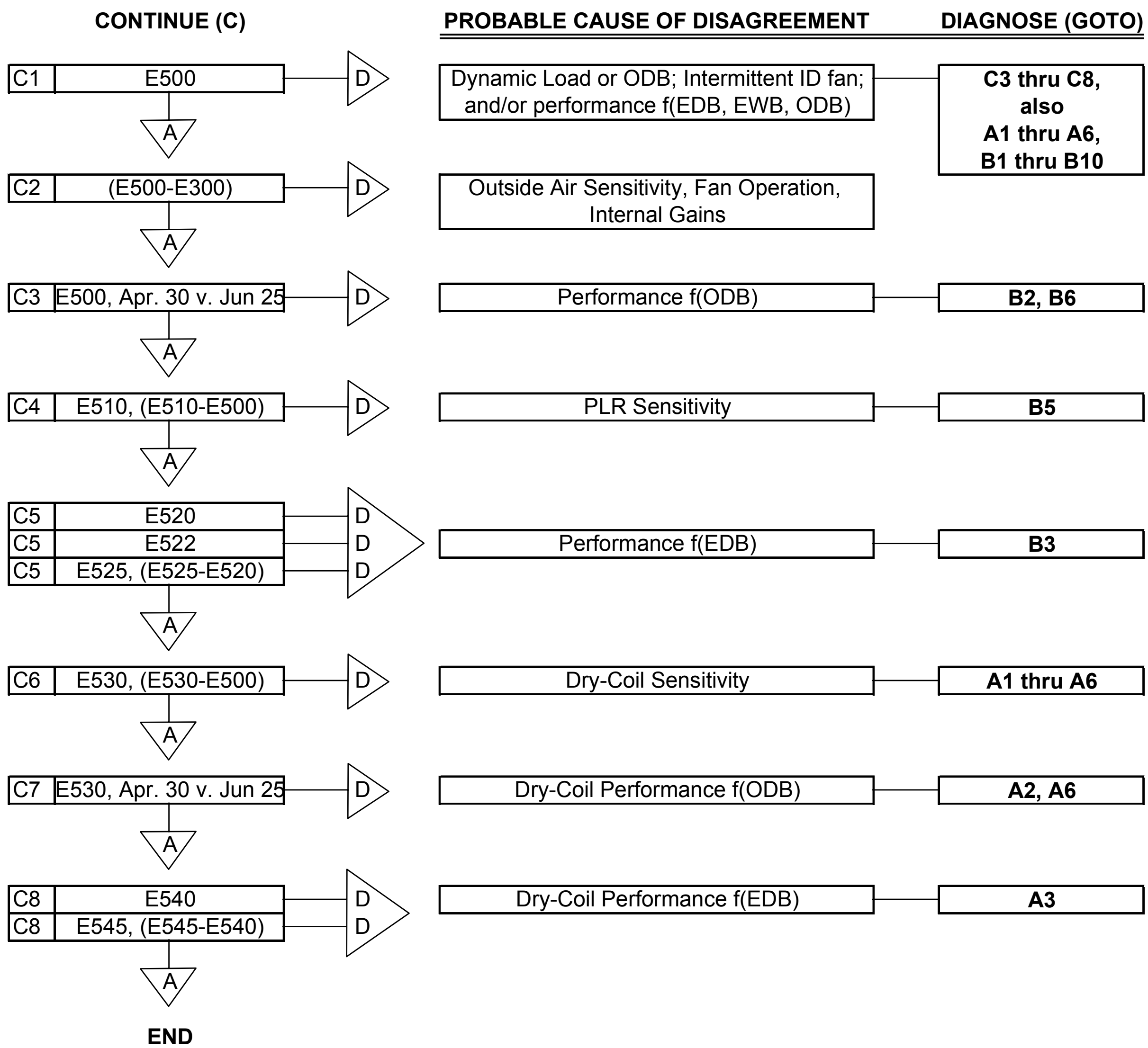
* It is better to perform/analyze results of these tests in blocks such as E100-E140 and E150-E200.

Figure G-1. Cases E100–E200 (steady-state analytical verification) diagnostic logic flow diagram



ABBREVIATIONS
A = Agree; D = Disagree. For the E300 series, agreement/disagreement is determined relative to example simulation results or other user-provided results and the sensitivity case.

Figure G-2. Cases E300–E440 (dynamic dases with outside air) diagnostic logic flow diagram



ABBREVIATIONS
A = Agree; D = Disagree. For the E300 series, agreement/disagreement is determined relative to example simulation results or other user-provided results and the sensitivity case.

Figure G-3. Cases E500–E545 (dynamic cases without outside air) diagnostic logic flow diagram

Appendix H
Abbreviations and Acronyms

Terms denoted with "" are defined in the glossary (Appendix C).*

ACH	air changes per hour
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BF*	bypass factor
BHP	brake horsepower
Btu	British thermal unit
CDF*	coefficient of performance degradation factor
CFM	cubic feet per minute
Coef	coefficient
COP*	coefficient of performance
COP_2*	alternative coefficient of performance
EDB*	entering dry-bulb temperature
EWB*	entering wet-bulb temperature
Ext	exterior
HVAC	heating, ventilating, and air-conditioning
HVAC BESTEST	International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models
ID	indoor
IDB*	indoor dry-bulb temperature
IEA	International Energy Agency
Int	interior
IP	inch-pound
k	thermal conductivity (W/(m·K))
kW	compressor power (kW), *as used in Tables 1-7a and 1-7b only*
kWh	kilowatt-hour
NSRDB	National Solar Radiation Database
ODB*	outdoor dry-bulb temperature
PLR*	part-load ratio
R	unit thermal resistance (m^2·K/W)
SHC	Solar Heating and Cooling Programme
SHC*	gross sensible capacity (kW thermal)
SHR*	sensible heat ratio
SI	Système Internationale
Surf	surface

TC*	gross total capacity (kW thermal)
TMY2	typical meteorological year 2
U	unit thermal conductance or overall heat transfer coefficient (W/(m²·K))
UA	thermal conductance (W/K)
WBAN	Weather Bureau Army Navy
wg	water gauge
Wh	watt-hour

References for Part I

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2.0 Part II: Production of Simulation Results

2.1 Introduction

In this section we describe what the working group members did to produce example results with several detailed programs that were considered to represent the state of the art for building energy simulation in Europe and the United States. The objectives of developing the simulation results were

- To demonstrate the applicability and usefulness of the Building Energy Simulation Test for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST) test suite
- To improve the test procedure through field trials
- To identify the range of disagreement that may be expected for simulation programs relative to each other (see Part III).

The field trial effort took about 4 years and involved several revisions to the HVAC BESTEST specifications and subsequent reexecution of the computer simulations. The process was iterative in that executing the simulations led to the refinement of HVAC BESTEST, and the results of the tests led to improving and debugging the mechanical system models in the programs. This process underscores the importance of International Energy Agency (IEA) participation in this project; such extensive field trials, and resulting enhancements to the tests, were much more cost-effective with the participation of the IEA Solar Heating and Cooling (SHC) Programme Task 22 experts.

Table 2-1 describes the programs used to generate the simulation results. Appendix II (Section 2.9) presents reports written by the modelers for each simulation program.

The tables and graphs in Part III present the final results from all the simulation programs used in this study.

Abbreviations and acronyms used in Sections 2.2 through 2.6 are given in Section 2.7. References cited in Section 2.2 through 2.6 are given in Section 2.8.

Table 2-1. Participating Organizations and Computer Programs

Simulation Program	Authoring Organization	Implemented by
CODYRUN/LGIMAT	Université de la Reunion Island, France	Université de la Reunion Island, France
DOE-2.1E-ESTSC version	LANL/LBNL/ESTSC/JJH,[a,b,c,d] United States	NREL/JNA,[e] United States
DOE-2.2 NT	LBNL/JJH,[b,d] United States	NREL/JNA,[e] United States
ENERGYPLUS	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-BT,[b,f,g,h,i,j] United States	GARD Analytics, United States
HOT3000	CETC/ESRU,[k,l] Canada/United Kingdom	CETC,[k] Canada
TRNSYS 14.2-TUD with real controller model	University of Wisconsin, United States; Technische Universität Dresden, Germany	Technische Universität Dresden, Germany

[a]LANL: Los Alamos National Laboratory, United States
[b]LBNL: Lawrence Berkeley National Laboratory, United States
[c]ESTSC: Energy Science and Technology Software Center (at Oak Ridge National Laboratory, United States)
[d]JJH: James J. Hirsch & Associates, United States

[e]NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates, United Sates
[f]UIUC: University of Illinois Urbana/Champaign, United States
[g]CERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, United States
[h]OSU: Oklahoma State University, United States
[i]FSEC: University of Central Florida, Florida Solar Energy Center, United States
[j]DOE-BT: U.S. Department of Energy, Office of Building Technologies, Energy Efficiency and Renewable Energy, United States
[k]CETC: CANMET Energy Technology Centre, Natural Resources Canada, Canada
[l]ESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

2.2 Selection of Simulation Programs and Modeling Rules for Simulations

The countries participating in this IEA task made the initial selections of the simulation programs used in this study. The selection criteria required that

- A program be a true simulation based on hourly weather data and calculative time increments of 1 hour or less
- A program be representative of the state of the art in whole-building energy simulation as defined by the country making the selection.

The modeling rules were somewhat different (more stringent) for the simulation programs used for Part III example results than for a given program to be normally tested with HVAC BESTEST (see Section 1.2.2, Modeling Rules). For the Part III simulation results, we allowed a variety of modeling approaches. However, we required that these cases be modeled in the most detailed way possible for each simulation program within the limits of the test specification (e.g., detailed component data are not given for the compressor, condenser, and thermal expansion device).

To minimize the potential for user error, we encouraged more than one modeler to develop input files for each program. Where only a single modeler was involved, we strongly recommended that another modeler familiar with the program check the inputs carefully.

Where improvements to simulation programs or simulation inputs were made as a result of running the tests, such improvements must have a mathematical and physical basis, and must be applied consistently across tests. In addition, all improvements were required to be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed. The diagnostic process of trapping bugs discussed in Section 2.4 also isolated input errors that were corrected, as noted there and in the modeler reports (Section 2.9).

2.3 Improvements to the Test Specification as a Result of the Field Trials

Based on comments by the other IEA SHC Task 22 participants during the field trials, observations from our own DOE-2.1E.simulations, and comments by industry engineers, we made a number of improvements and revisions to the test specification. Although researching the comments and communicating specification revisions to the field trial participants was very time-consuming, the importance of the accuracy and clarity of the test specification for this type of work cannot be overstated.

The contribution of the IEA SHC Task 22 participating countries was particularly valuable because the Task 22 experts supplied continuous feedback throughout the 4-year field trial effort. Their feedback resulted in several revisions to the HVAC BESTEST specifications and subsequent reexecution of the computer simulations. This iterative process led to refinement of HVAC BESTEST, and the results of the tests led to the improvement and debugging of the programs. The process underscores the leveraging of resources for the IEA countries participating in this project. Such extensive field trials, and resulting enhancements to the tests, would not have occurred without the participation of the IEA SHC Task 22 experts.

2.3.1 Major Revisions to Initially Proposed Test Specification

The initial specification of these test cases was issued in May 1999. The parametric sensitivity tests were mostly similar to the current E300–E545 tests, but the base case was significantly different: using the same full-load performance data as in the Volume 1 (E100–E200) cases, and a realistic building envelope similar to that of IEA BESTEST (Judkoff and Neymark 1995a). Observations of the initial results based on simulations performed by some of the E100–E200 field trial participants indicated the following issues.

- The range of disagreement (max-min/mean) regarding electricity use (compressor + outdoor fan) among the simulation programs for these cases was:

  E300 series: 13%–24%
  E400 series: 4%–23%
  E500 series: 8%–36%.

- Disagreement caused by the more realistic building shell, based on a case developed specifically to evaluate that, appeared to be about 25%. Much of this disagreement may have been caused either by a bug or an input error in one of the simulations. Even excluding the one suspect simulation result, the disagreement is 8%, much of which may have been from differences in window models. In any case, it was apparent that for the purpose of testing mechanical equipment models, applying a realistic building envelope was adding unnecessary complexity (i.e., increased potential for user input error) to the tests.

- Results differences related to variations in performance data extrapolation techniques and different extrapolation boundaries in the various programs were significant.

Based on these observations, the following revisions were made:

- Utilization of a near-adiabatic envelope with dynamic internal gains schedules; this removed disagreements caused by variation among building envelope models.

- Utilization of an expanded performance data set that we were able to obtain for a larger unitary system, along with establishment of internal gains schedules that required little or no extrapolation of the performance data; this removed disagreements caused by variations in extrapolation techniques.

2.3.2 Second Round of Revisions

Field trials of the revised test specification engendered further revisions as listed below.

- Case E320 revised to exclude outside air, has scheduled infiltration only
- Case E340 added for outside air/infiltration interaction
- Revised output requirements
    - Added outputs
        - Total annual (compressor + indoor [ID] fan + outdoor [OD] fan) consumption
        - Total annual coil (sensible + latent); previously these were only disaggregated
        - Annual mean and maximum outdoor dry-bulb temperature (ODB) and outdoor humidity ratio (OHR), E300 only (weather data checks)
        - June 28 hourly total coil load and OHR, E300 only
        - Daily outputs for April 30 and June 25 for Case E500 and Case E530: total consumption, total coil load, ODB, and entering dry-bulb temperature (EDB)
    - Revised output requirement period as April 1 to December 31 for minimum indoor dry-bulb temperature (IDB), humidity ratio and relative humidity (RH), and maximum relative humidity (to exclude results caused by initialization differences)
    - Deleted outputs that did not enhance diagnostic capability
        - Peak compressor + OD fan only
        - Annual compressor operating hours
        - Annual number of under cooled hours
        - Annual number of hours with RH > 60%
- Glossary revisions
    - Coefficient of performance (COP): clarified for when to include ID fan with energy input (E300–E440)
    - Evaporator coil loads: clarifications of definitions of sensible and latent coil loads
    - Net refrigeration effect: clarifications of accounting for air distribution fan (especially cases E300–E440)
    - Deleted a number of terms that were previously useful for Volume 1 cases E100–E200, but not applicable for cases E300–E545
- Other changes
    - Added discussions explaining the purposes of various internal gains schedules
    - Added discussion about the relationship between latent internal gains and heat of vaporization
    - Deleted unnecessary text discussion about when fan heat is accounted in coil load (coil load is whatever heat the coil removes)
    - COP degradation factor (CDF) discussion better emphasizes the option to use gross total coil load/gross total capacity (Qgtc/CAPgtc) for defining part-load ratio (PLR) in E300–E440 when there is continuously operating indoor fan
    - Improved version of weather data appendix (Appendix A) transferred over from E100 cases
    - Clarifications to appendices
        - Appendix E (PLR definition equivalence)
        - Appendix G (diagnostic logic)
    - More units as both Système Internationale (SI) and English (IP)
    - Other minor edits.

2.3.3 Third Round of Revisions

Additional field trials of the revised test specification engendered further revisions as listed below.

- Added discussion to weather data appendix noting that solar data and meteorological data included within typical meteorological year 2 (TMY2) data utilize different time conventions.
- Manufacturer provided system performance data were added for typical rating conditions (ODB/EDB/entering wet-bulb temperature [EWB] = 95°F/80°F/67°F, and corresponding SI units).

2.3.4 Fourth Round of Revisions

Disagreeing results for TRNSYS-TUD uncovered an error in the test specification regarding IP and SI unit equivalent values for enthalpy limits given in Case E440. SI enthalpies were changed from 65.13 kJ/kg to 47.25 kJ/kg to account for different reference temperatures used in IP versus SI psychrometric charts that were not initially considered.

2.4 Examples of Error Trapping with HVAC BESTEST Diagnostics

This section summarizes a few examples that demonstrate how the HVAC BESTEST procedure was used to isolate and correct bugs in the reference programs. Further description may be found in the individual code reports presented in Appendix II (see Section 2.9).

Simulations were performed for each test case with the participating computer programs using hourly TMY2 weather data. At each stage of the exercise, output data from the simulations were compared to each other according to the diagnostic logic of the test cases (see Part I, Appendix G). The test diagnostics revealed (and led to the correction of) bugs, faulty algorithms, input errors, or some combination of those in all but one of the programs. Several examples follow.

2.4.1 EnergyPlus

EnergyPlus is the program recently released by the United States Department of Energy (DOE), and is the department's next-generation building energy simulation program. GARD Analytics (GARD) used the "Unitary Air-to-Air Heat Pump" system in EnergyPlus for its model.

GARD submitted eight iterations of simulation results. Table 2-2 describes input file and software modifications for each iteration; a single results set was submitted corresponding to changes described in each row of the table. Version 1.0.2.004 was used for the initial results set.

Table 2-2. Summary of EnergyPlus Changes That Were Implemented

Version	Input File Changes	Code Changes
1.0.2.004	• ARI performance data point interpolated	• Error message improvement
1.0.3.001		• Latent cooling load: hg function replace previous hfg function
1.0.3.005		• Dry-coil condition coil outlet condition calculation error fixed
1.0.3.005	• New curve fits generated for given ARI data point performance in revised test specification	
1.0.3.006	• Initialization with small amount of infiltration during first simulation week for 0 OA dry-coil cases (E530, E540, and E545); to achieve initialization specified in modeling requirements	• Weather data subhourly time step interpolation method
1.0.3.013	• Fan outlet node name related to economizer control fixed (E400–E440) • E410 deleted; compressor lockout capability not yet included in the program • Economizer high-temperature-limit specification fixed (E420) • Relaxation of temperature limits associated with use of performance curves	
1.1.0.004	• External output reporting error fixed	• Space internal loads accounted for before system simulation
1.1.0.020	• For Case E440, set economizer enthalpy limit to 47,250 J/kg per change to specification	

2.4.1.1 Documentation Improvement Regarding Input Requirements at ARI Rating Conditions

The initial test specification did not give equipment performance at Air-Conditioning and Refrigeration Institute (ARI) rating conditions (ODB/EDB/EWB = 35°C/26.67°C/19.44°C [= 95°F/80°F/67°F]). Initially the EnergyPlus testing team assumed that performance curves could be normalized to some other point as long as such normalization was consistent for all performance curves, and implemented this in their system inputs. This input caused a fatal error as described in the EnergyPlus modeler report (see Section 2.9). Because of this the source code was changed to include an improved error message to assist users if detailed performance-map data do not identify performance at ARI rating conditions.

2.4.1.2 Latent Cooling Load Calculation

As shown in Figure 2-1, the space temperature was not always maintained at 25°C in cases E300 (base case) and E310 (high latent loads), or went above the 35°C set-up set point in Case E350 (thermostat set up). Additionally, Figure 2-2 indicates a substantial disagreement for minimum COP_2 for Case E350 (COP_2 is defined in Section 2.7). In the first attempt at correcting this, the program authors replaced an hfg function with an hg function in the psychrometric routines. According to GARD, this change produced only a small change in results; the GARD modeling team did not document this change in their intermediate results set.

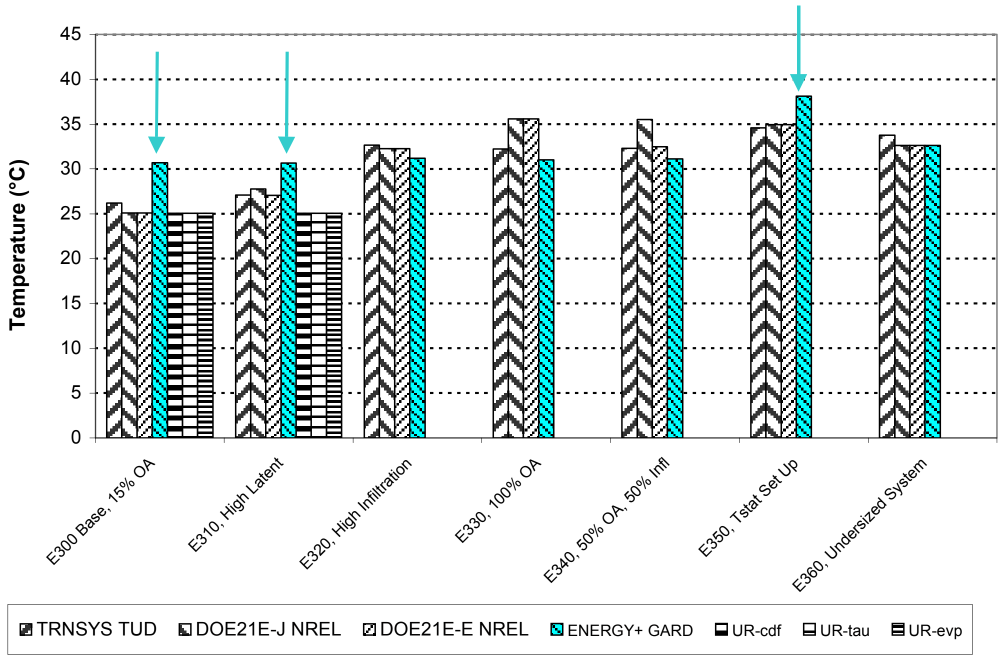

Figure 2-1. Maximum indoor dry-bulb temperature disagreement, initial results

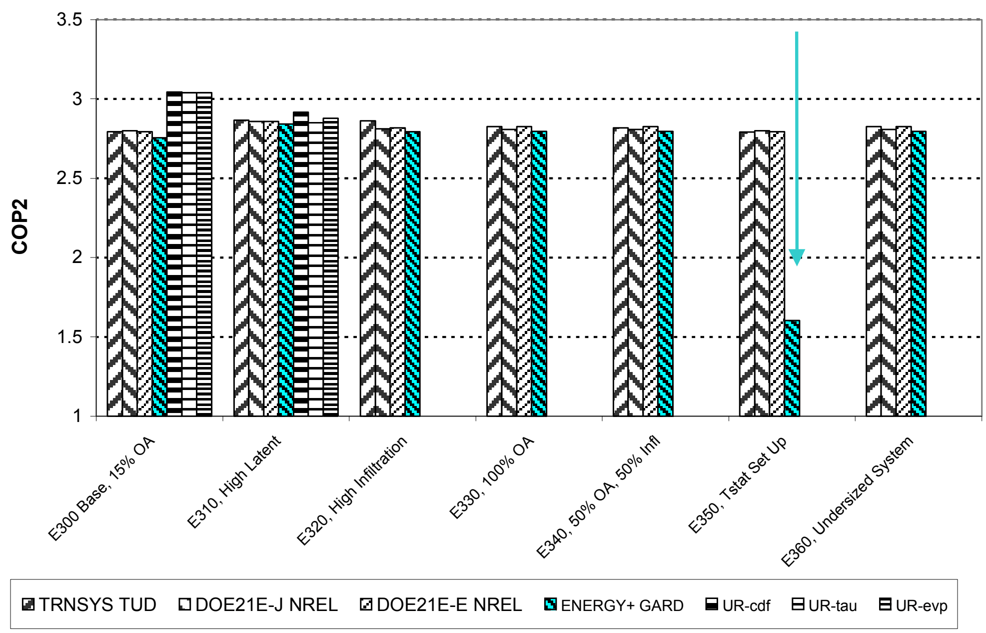

Figure 2-2. Minimum COP2 disagreement, initial results

2.4.1.3 System Control during Low Part Loading (1%–2% compressor + OD fan consumption decrease for E300 series cases)

On further review of the disagreement indicated in Figure 2-1 by the code authors, the temperature control problems were found to be occurring during periods of low or no internal loads when the air conditioner did not cycle on to provide cooling. Detailed review isolated an error related to calculating cooling coil outlet temperature and humidity ratio during dry-coil conditions (before GARD had run the E500 series cases, so we do not know what the dry-coil cases [E530–E545] would have indicated). This error caused the heat pump not to operate during certain hours. After this error was corrected, the illustrated disagreements were ameliorated. The corrections decreased combined compressor and OD fan annual energy consumption and total peak-hour consumption by 1%–2 % for the E300 series cases.

2.4.1.4 Weather Data Interpolation When Using Subhourly Time Steps (0%–1% compressor + OD fan consumption increase and 0%–2% total peak-hour consumption increase for E300 series cases)

For fourth iteration results compiled during July 2002, it was noticed that the hourly COP2 for June 28 was 1 hour out of phase with the other programs as shown in Figure 2-3. Further review indicated that hourly ODB was also out of phase as shown in Figure 2-4, and that based on the given weather data, the listed hourly ODB results for the other programs are more logical than those for EnergyPlus. A similar disagreement was apparent in the hourly outdoor humidity ratio results. The code authors traced this problem to weather data interpolations that are performed when subhourly time steps are implemented in the model. This interpolation method was revised so that the EnergyPlus hourly results now show better agreement with the other results. The corrections increased combined compressor and OD fan energy consumption 0.0%–0.8% and increase total peak-hour consumption by 0.0%–2.1% for the E300 series cases.

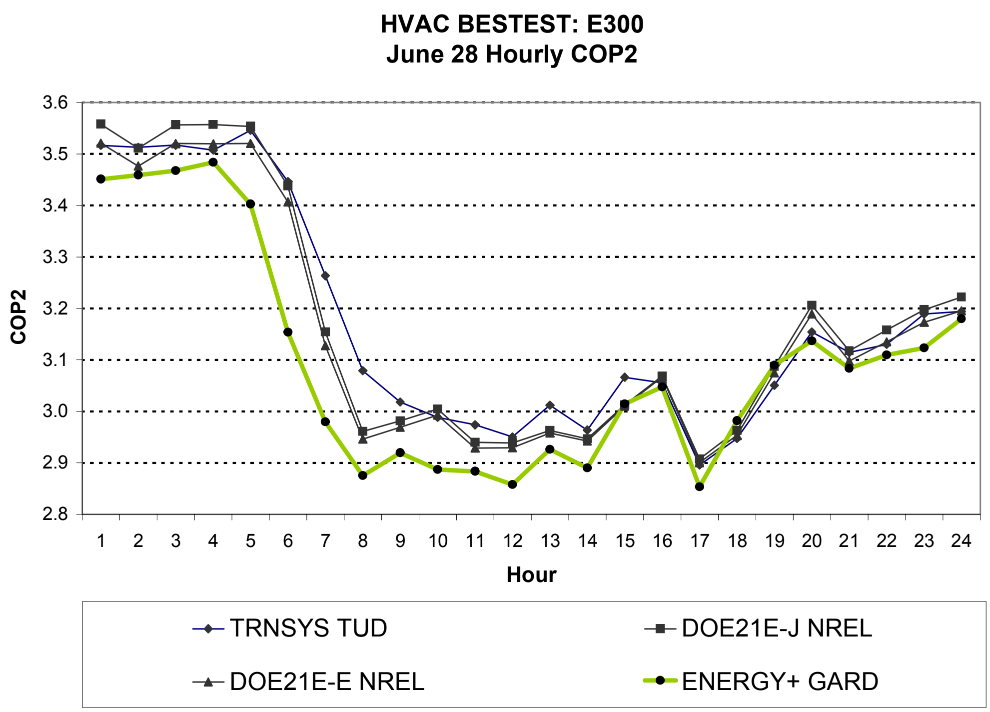

Figure 2-3. Hourly COP2 out of phase

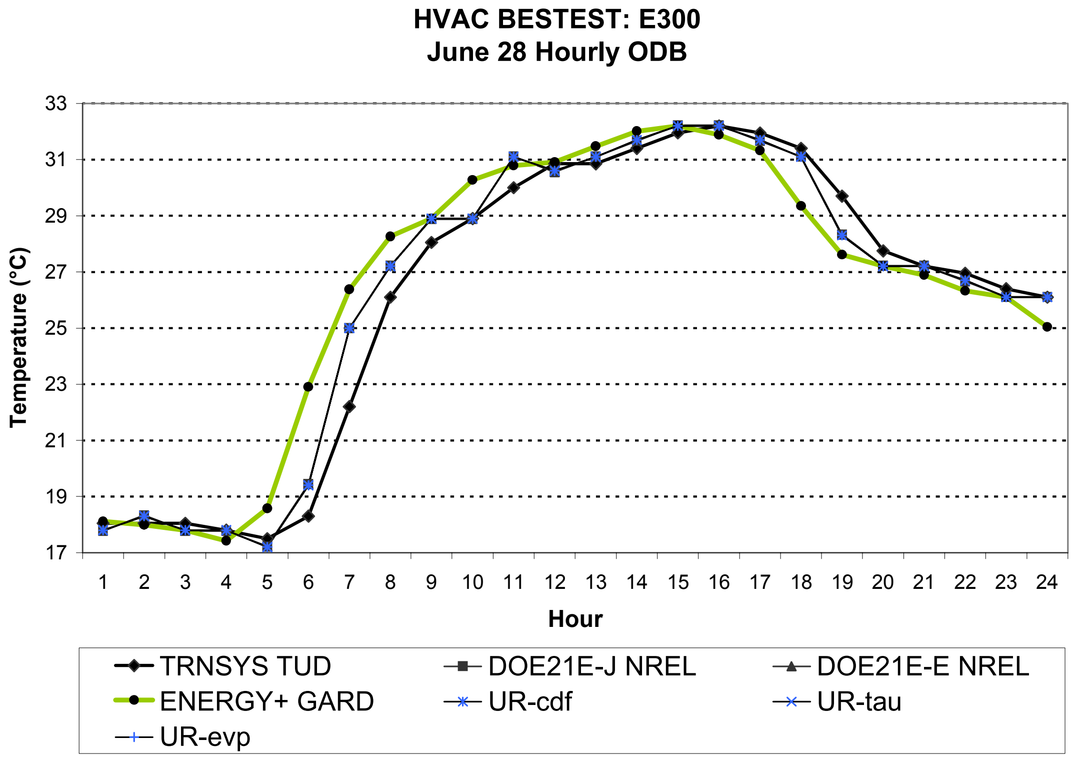

Figure 2-4. Weather data out of phase (interpolation error)

2.4.1.5 Economizer Compressor Lockout Feature Allows Input for Algorithm Not Yet Implemented (Modeling feature to be added, code authors notified)

In the first iteration of E400 and E500 series cases, the results for cases E410 and E400 were identical. EnergyPlus indicates the availability of an optional compressor lockout feature, but it has not yet been implemented within the code.

2.4.1.6 Moisture Balance (Negligible effect on annual and peak-hour total consumptions)

After addressing previous errors (6th iteration overall, 2nd iteration of E500 series), it was found that maximum space humidity ratios were high for cases E500–E545 as shown in Figure 2-5. Further investigation into the problem indicated that these maximum humidity ratios were occurring 1 to 2 hours after the scheduled internal gains and the HVAC system were off. The error was traced to a problem in the moisture balance algorithm, where internal loads during each time step were being accounted for *after* the HVAC system simulation, rather than before. Fixing this error corrected the maximum humidity ratio results, but had negligible effect on annual consumption results for all cases, and peak-hour consumption results for cases E300–E440. It was not possible to identify the effect on peak load results for the E500 series cases because of a simultaneous correction to a reporting error for those results from the previous iteration.

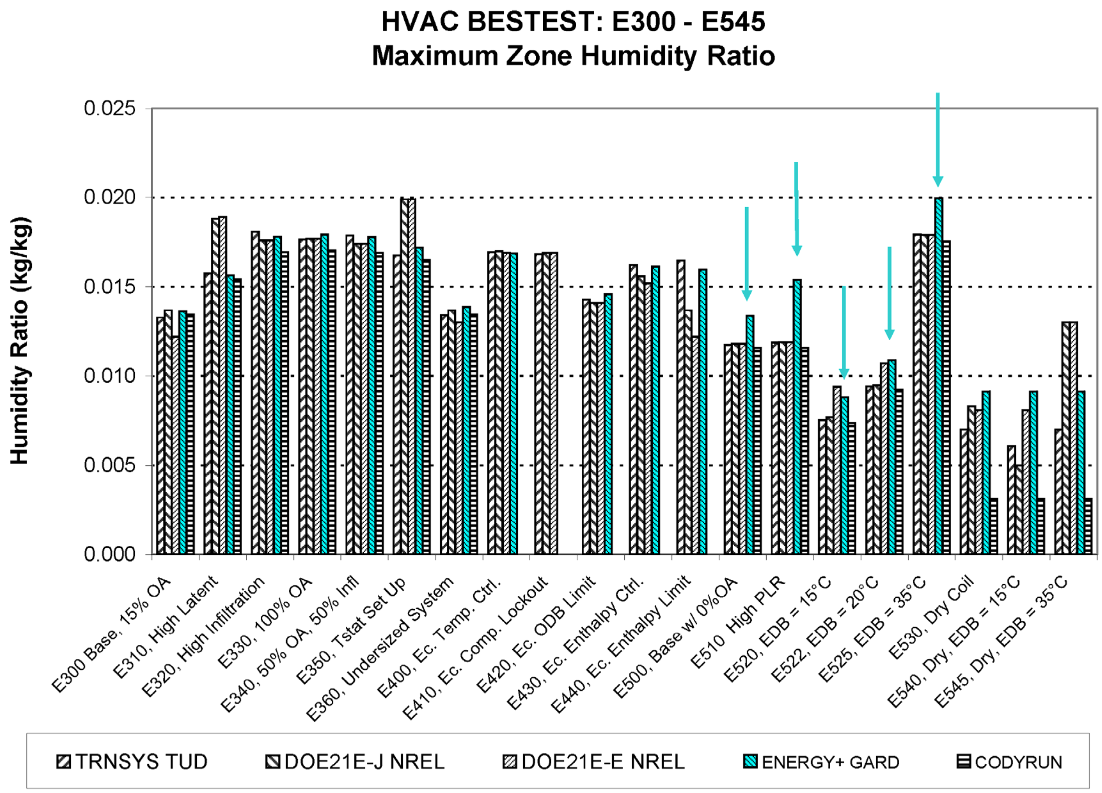

Figure 2-5. Maximum zone humidity ratio disagreement (moisture balance error)

2.4.1.7 Input Error Summary

A number of input errors were also documented in the EnergyPlus modeler report. These related to description of economizer operation for cases E400, E420, E430, and E440, and performance-curve operation boundaries (at low EDB) for cases E520 and E540.

2.4.2 CODYRUN

CODYRUN is a whole-building simulation program under development at Laboratoire de Génie Industriel (Industrial Engineering Laboratory) of University of Reunion Island (UR), France. UR submitted seven iterations of simulation results. Table 2-3 describes input file and software modifications for each iteration; a single results set was submitted corresponding to changes described in each row of the table.

Table 2-3. Summary of CODYRUN Changes That Were Implemented

Iteration	Input File Changes	Code Changes
1 (E300, E310)		
2 (E300–E360)		• Fix of inconsistent use of gross versus net capacities in different subroutines (building loads versus coil loads) • Allow extrapolation of dry-coil performance in neural network performance map model
3	• Internal gains corrected	• Inclusion of subhourly iterative loop for moisture balance (entering air humidity ratio) solution
4 (E300–E360, E500–E545)		• Allow IDB to be greater than set point if system capacity is less than the load (e.g. in Case E360)
5	• Decreased thermal capacitance of walls	• Inclusion of subhourly iterative loop for thermal balance (entering air humidity ratio) solution • Fixed an amalgamation of air infiltration and outside air mixing
6		• Fixed improper accounting of CDF/PLR in fan calculations • Neural network equipment performance calculation improvement
7		• Improved iterative balance of zone air conditions and equipment performance parameters

2.4.2.1 Inconsistent Accounting of Fan Heat in Building Loads Calculations versus Coil Loads Calculations, and Dry-Coil Performance-Map Modeling Improvement (14% underestimation of annual compressor consumption, 9% underestimation of peak-hour total consumption)

In the initial runs (done only for cases E300 and E310) using three different modeling techniques, the annual average COP2 disagreed with those of the other programs by about 30% as shown in Figure 2-6. The main source of disagreement was found to be inconsistent accounting of indoor air distribution fan heat in the calculation of sensible building loads, evaporator coil loads, and compressor consumption. In addition, the neural network performance-mapping model did not allow the calculation of EWB at the "intersection point" (greatest value of dry-coil EWB for given EDB and ODB) where dry-coil conditions occur. Fixing this error in cases E300 and E310 caused annual compressor consumption to increase by 14% and peak-hour total consumption to increase by 9% in both cases.

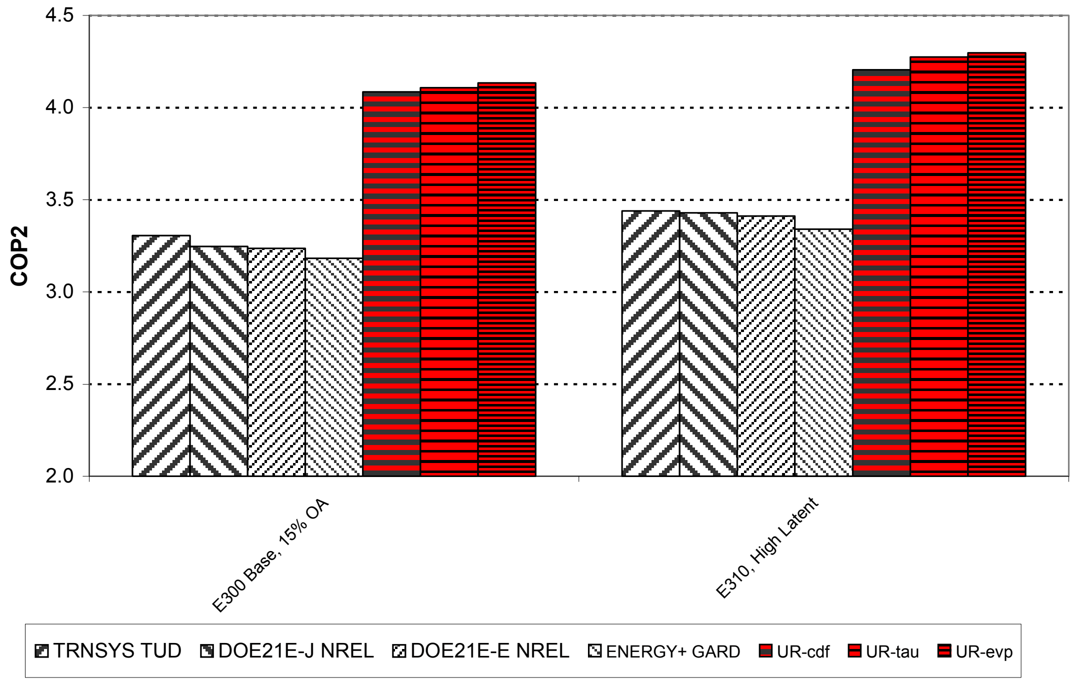

Figure 2-6. COP2 disagreement (fan heat accounting inconsistencies)

2.4.2.2 Moisture Balance Calculation Problem (1% underestimation of compressor consumption for E360, 4%–5% overestimation of peak-hour total consumption for E300, E310, E320, and E360)

Analysis by the code authors of hourly zone humidity ratio results (see Figure 2-7) indicated greater oscillations than expected, especially for Case E360. This problem was traced to not accounting for latent loading during the appropriate time step. The problem was fixed by including a subhourly iterative loop for moisture balance calculation within each time step. Zone air humidity ratio predictions became more stable, as shown in Figure 2-8. Fixing this error caused an increase in annual compressor consumption of 1.3% in Case E360 (other cases negligible), and a 4%–5% decrease in peak-hour total consumption for cases E300, E310, E350, and E360 (high infiltration and/or outside air (OA) cases E320–E340 were not significantly affected).

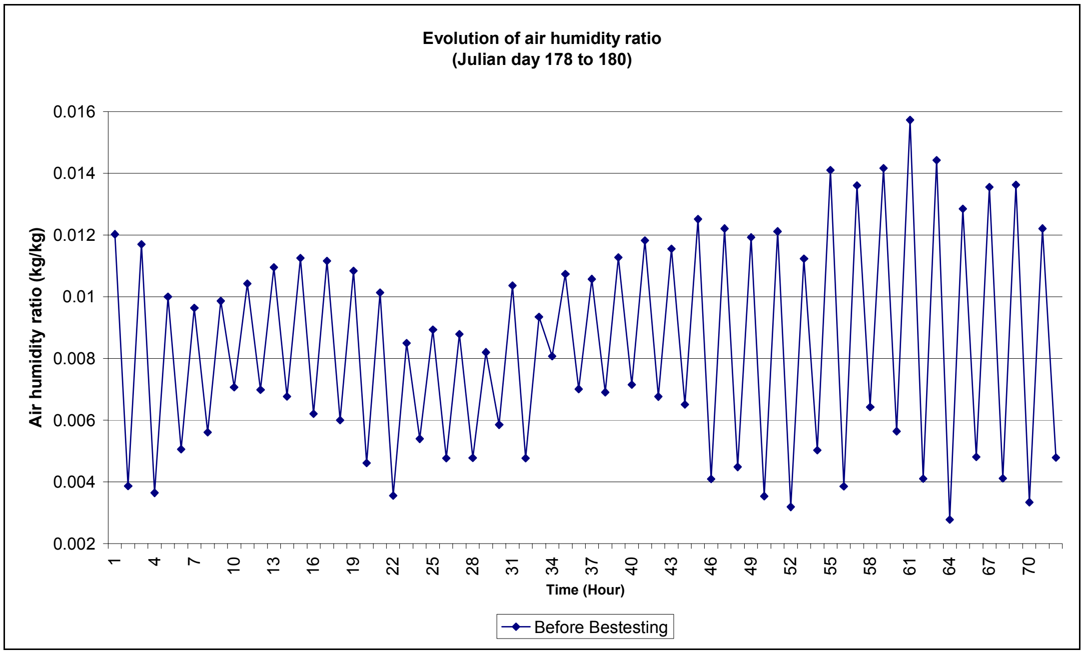

Figure 2-7. Case E360 hourly zone air humidity ratio oscillations before fixing moisture balance calculation

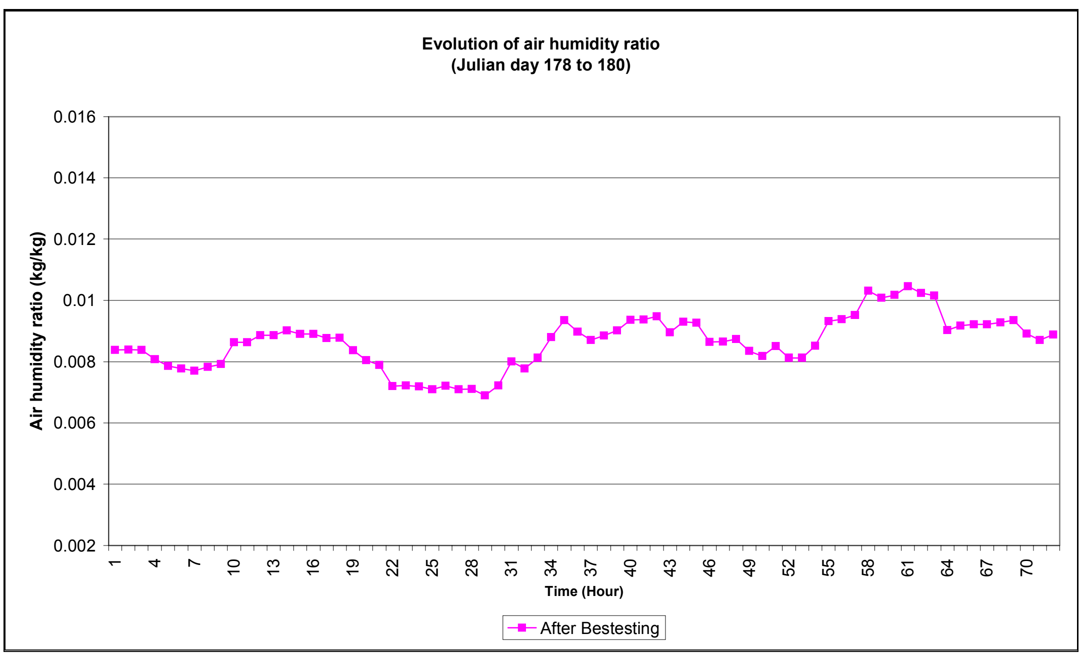

Figure 2-8. Case E360 hourly zone air humidity ratio oscillations after fixing moisture balance calculation

2.4.2.3 IDB Not Allowed above Set Point When Equipment Overloaded (0.5%–14% overestimation of annual compressor consumption, 0%–1% underestimation of peak-hour total consumption)

Review of the next set of results for November 2002 indicated high total consumptions for cases E320, E330, and E340, which were most clearly apparent from consumption sensitivity disagreements illustrated in Figure 2-9. Further review indicated high sensible cooling loads for these cases but a low sensible cooling load for Case E360 as shown in Figure 2-10. Latent cooling loads (not shown) were similarly high for E320 through E340 and also high for E360. Figure 2-11 (maximum IDB) indicates a possible cause for the problem in that CODYRUN does not allow IDB to go above the set point during hours when equipment is overloaded, as indicated by maximum IDB for the other programs. This wrongly locates performance in a less efficient part of the performance map during overloaded hours. Fixing the software to allow IDB to float above the set point when equipment is overloaded caused a 13%–14% overestimation of compressor consumption in the cases with high infiltration and outside-air flow rates (cases E320–E340) and a 0.5%–1.5% variation in compressor consumptions for the remaining E300 series cases. This was accompanied by negligible peak-hour total consumption variation for cases E320, E330, E340, and E360, and by about 1% peak-hour total consumption increase for cases E300, E310, and E350.

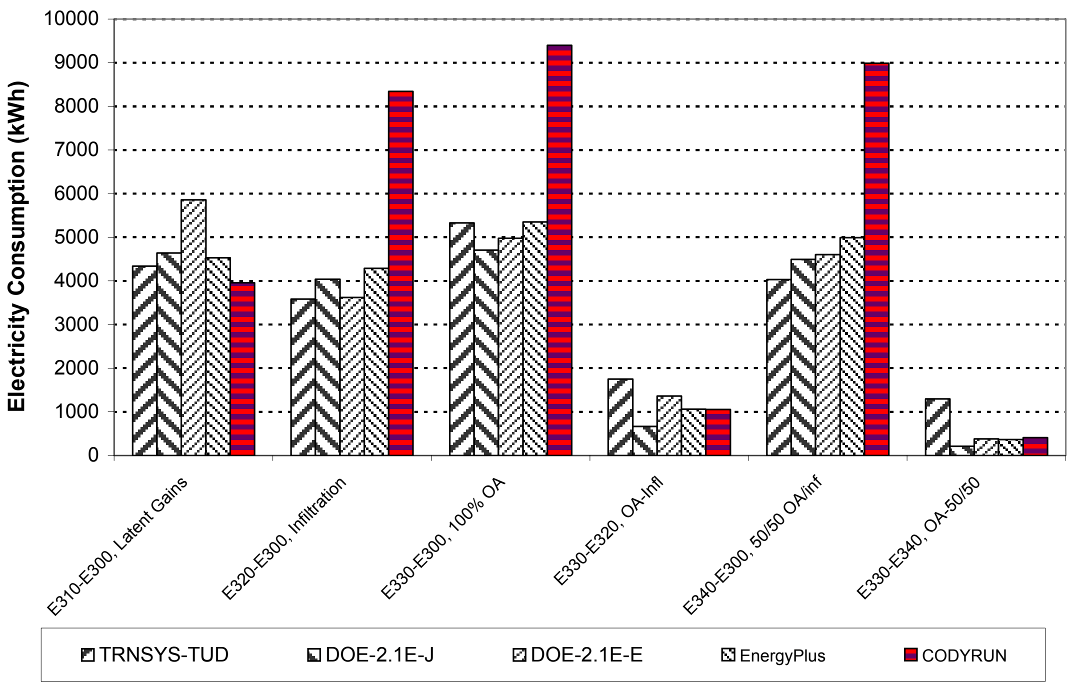

Figure 2-9. CODYRUN total space cooling electricity consumption sensitivity disagreements (E320–E300, E330–E300, E340–E300)

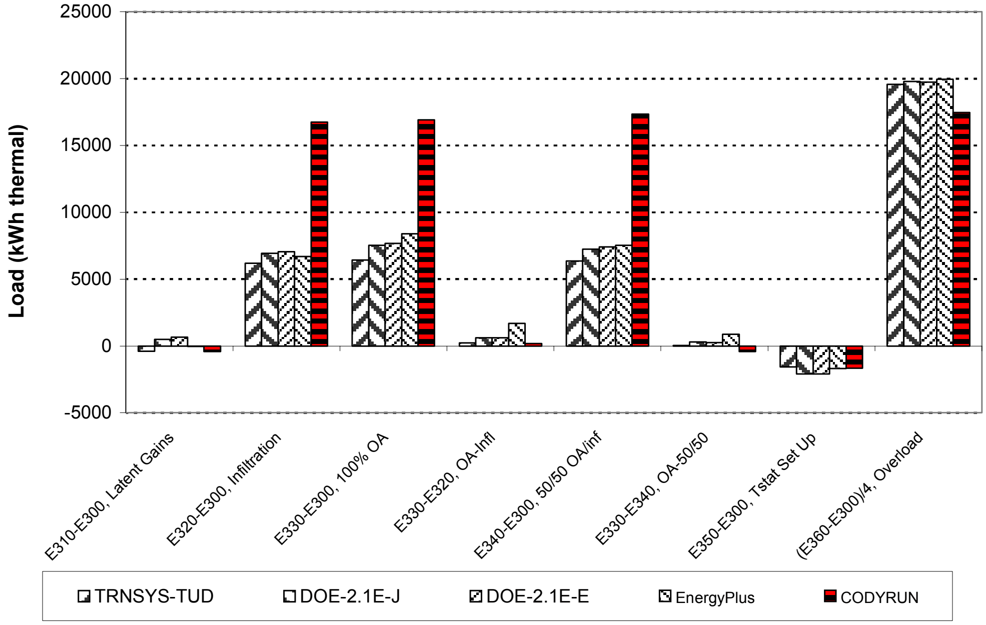

Figure 2-10. CODYRUN sensible coil load sensitivity disagreements (E320–E300, E330–E300, E340–E300)

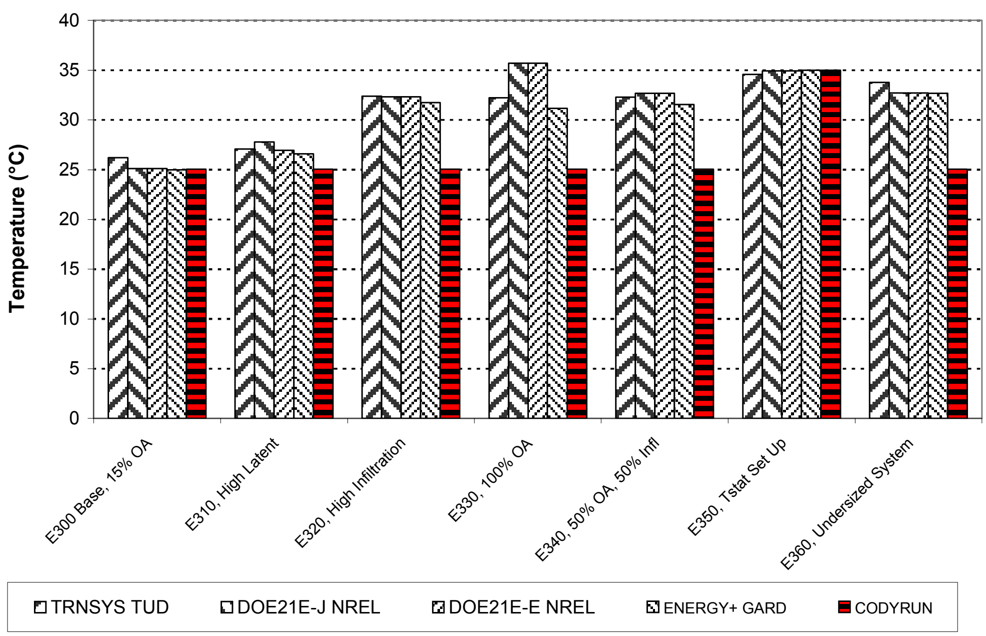

Figure 2-11. CODYRUN maximum IDB not floating when overloaded

2.4.2.4 Thermal Balance Calculation Improvement, Amalgamation of Air Infiltration and Outside Air Mixing, and Input-Reduced Thermal Capacitance (Affects annual total and peak-hour total consumptions by up to 3.2% and 4.3%, respectively)

After fixing the previous bugs, some further disagreements were uncovered. Figure 2-12 illustrates a variety of disagreements versus other programs for Case E360, including that peak-hour total consumption is 3% low, annual sensible coil load is 7% low, annual average IDB is 3°C high, and peak-hour IDB is 17°C high. Interestingly, with all of these disagreements, the annual total consumption is in agreement with the other programs. Additional disagreements for Case E320 (illustrated using sensitivity disagreements for E320–E300 as shown in Figure 2-13) indicate that sensible coil load sensitivity is 42% low, latent coil load sensitivity is 86% high, and maximum IDB sensitivity is 4.1°C high, with good agreement for annual total consumption.

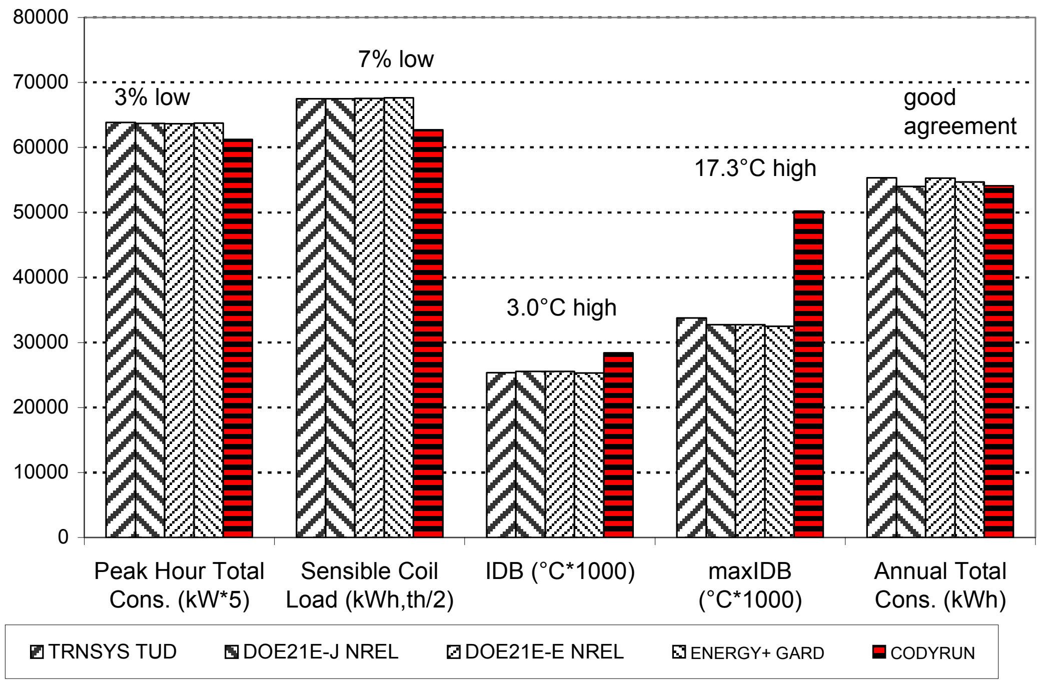

Figure 2-12. Remaining disagreements for Case E360 from 4th simulation iteration

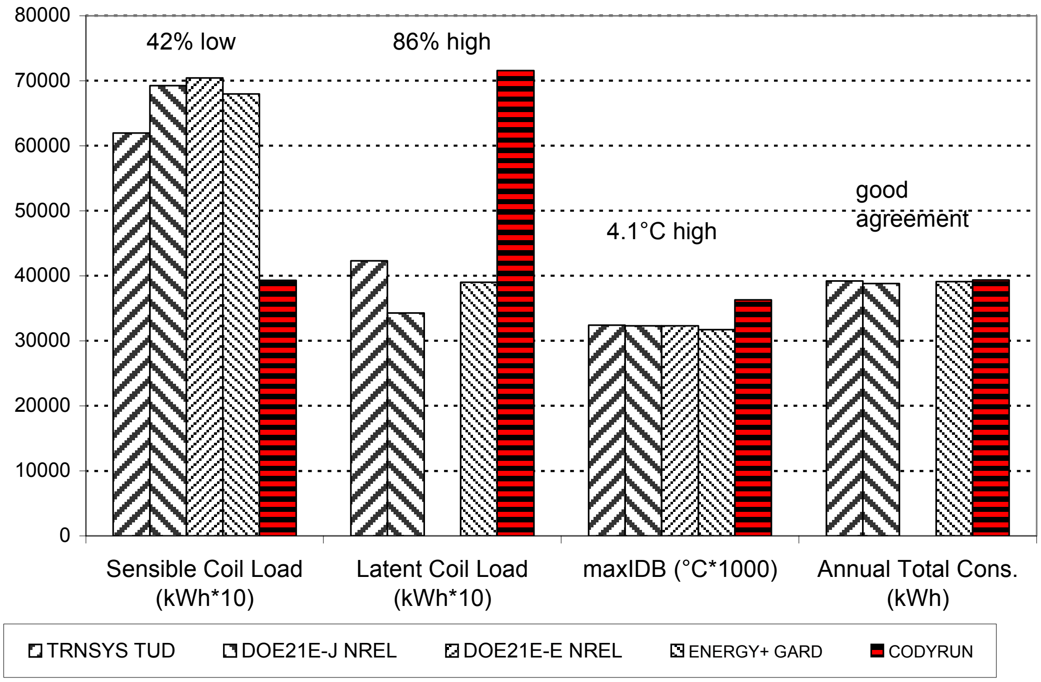

Figure 2-13. Remaining disagreements for Case E320–E300 from 4th simulation iteration

This fourth overall iteration of simulations also included initial results for cases E500–E545 (not shown). These results had generally good agreement except for cases with low EDB (15°–20°C, cases E520, E522, and E540), where maximum COP2 was 10%–50% high and minimum COP2 was about 10% lower than the other programs. Additionally, annual average zone humidity ratio was 0.002–0.004 kg/kg lower than the other programs.

Identification of these three sets of disagreements led to the following software improvements:

- Inclusion of a subhourly iterative loop for thermal balance calculation within each time step (addressed the E360–E300 disagreements)
- Fixing of an error in the program that corresponded to an amalgamation of air infiltration and outside air mixing (addressed the E320–E300 disagreements).

Additionally, the input for thermal capacitance of wall materials (previously input as polystyrene) was reduced.

The code authors did not disaggregate the effect of each case in their results. The aggregate effect of these changes, however, was to fix the above disagreements with overall effect on annual and peak-hour total consumptions of up to 3.2% and 4.3%, respectively.

2.4.2.5 CDF/PLR Not Properly Accounted for in Fan Energy Consumptions

After correction of previous errors, the second iteration of results for cases E500–E545 (fifth iteration for cases E300–E360) indicated low OD fan energy consumption for wet-coil case results E500–E525, as shown in Figure 2-14. This disagreement was not apparent in early results, indicating the presence of compensating errors and the importance of rechecking all results after each iteration of software correction.

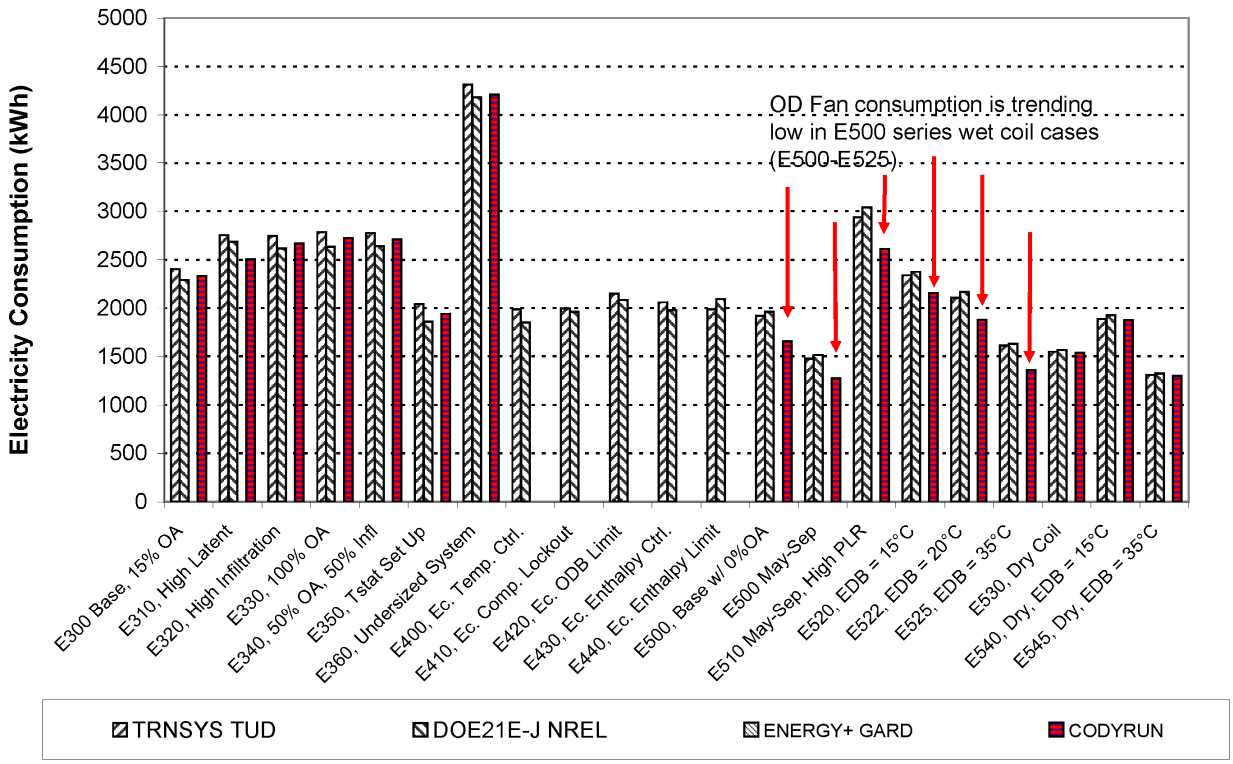

Figure 2-14. OD fan consumption disagreements for Cases E500–E525 from 5th simulation iteration

Based on these disagreements, the code authors discovered that CDF/PLR was not properly accounted for in the calculation of fan energy consumptions. Improvement of the software to eliminate these disagreements resulted in an 8%–18% increase in both ID and OD fan annual energy consumptions (1%–3% increase in annual total energy consumption) for wet-coil cases E500–E525. The dry-coil cases E530–E545 fan energy consumption results indicated no disagreement in the previous results iteration, and were not affected by this software improvement.

2.4.2.6 Neural Network Equipment Performance Calculation Improvement (for Case E360 only: 21% decrease in peak-hour sensible coil load, 1% increase in total annual energy consumption)

After previous errors were corrected, the fifth iteration of results indicated a disagreement for peak-hour sensible coil load results for Case E360, as shown in Figure 2-15. This disagreement was traced to a problem with the accuracy of the neural network algorithm used for calculating performance parameters at temperatures above 33°C; see CODYRUN modeler report. Improvement of the neural network algorithm gave better agreement for peak sensible coil load results (15% decrease from previous results), and caused a

1.1% increase in annual total energy consumption for Case E360 (because of simultaneous adjustment to resulting performance parameters at EDB < 33°C).

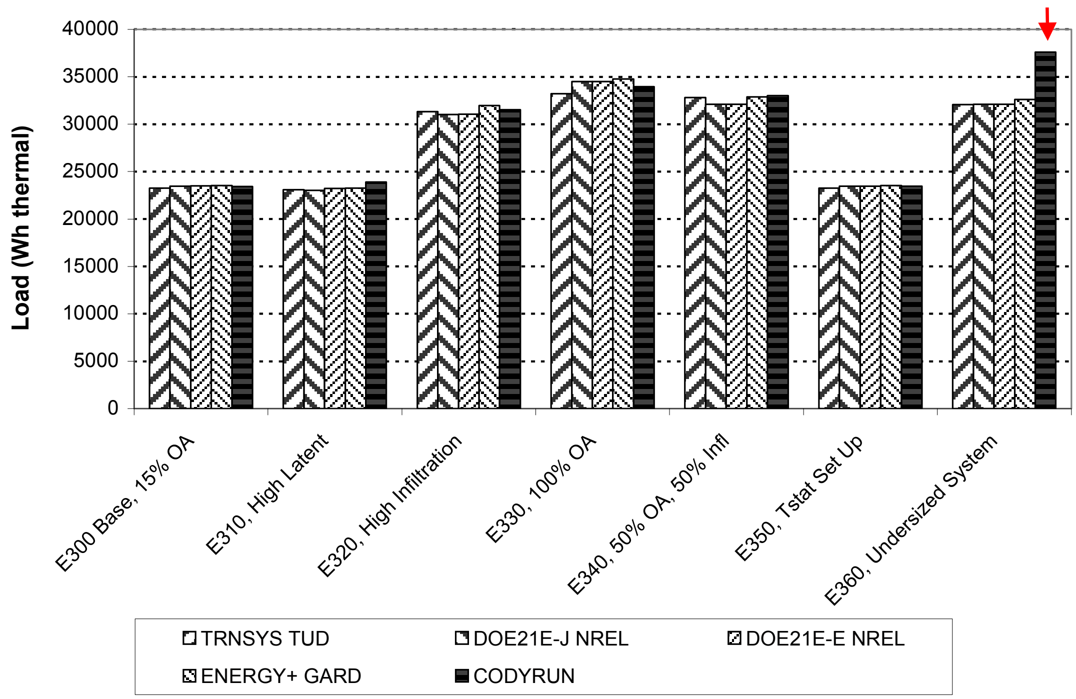

Figure 2-15. Peak-hour sensible coil load disagreement, Case E360

2.4.2.7 Algorithm for Iterative Balance of Zone Air Conditions and Equipment Performance Parameters (36% and 53% overestimation of peak latent coil loads in cases E520 and E522, respectively; 2% underestimation and 6.5% overestimation of peak-hour total consumption loads in cases E520 and E522, respectively)

The fifth and sixth iterations of results indicated disagreements for peak latent coil loads for cases E520 and E522 (low EDB), as shown in Figure 2-16. Discrepancies in zone air humidity were also noted for these cases. The code authors traced this problem to a basic thermal balance calculation, and wrote a new algorithm for iterative balance of zone air conditions and equipment performance parameters, as documented in their modeler report. Application of this new algorithm resulted in 36% and 53% decreases in peak-hour latent coil load results for cases E520 and E522, respectively. This was accompanied by a 2% increase and 6.5% decrease in peak-hour total consumption for cases E520 and E522, respectively. The effect on annual total consumption was negligible. CODYRUN now shows better agreement with other simulation results for all results.

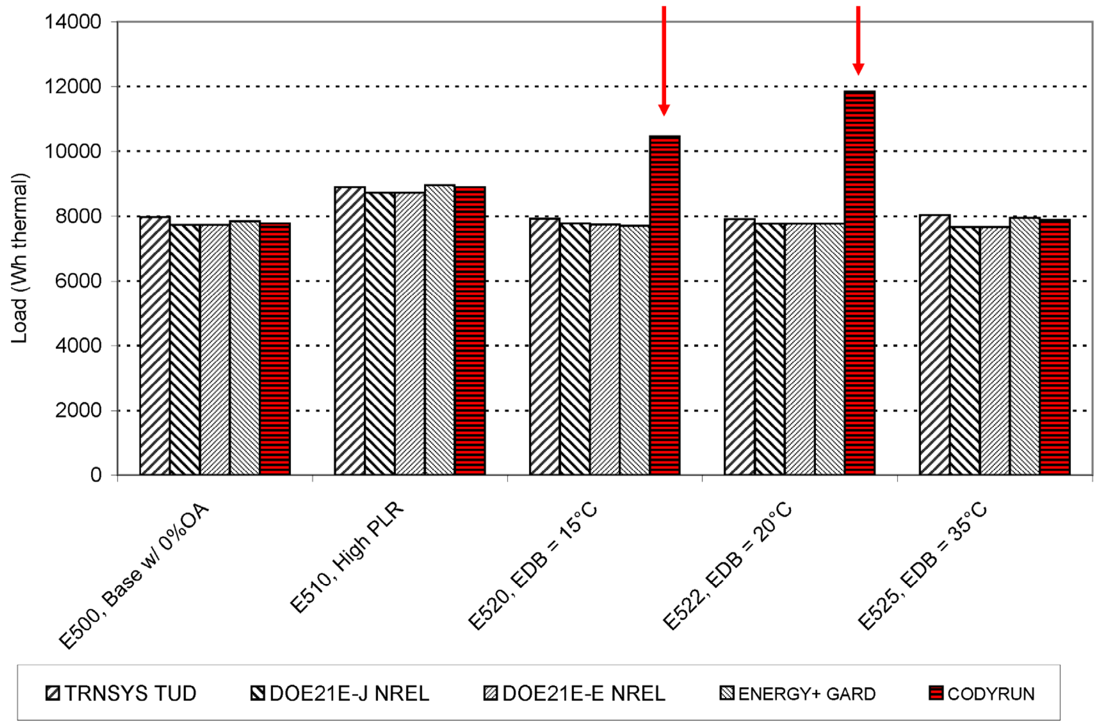

Figure 2-16. Peak-hour latent coil load disagreement, cases E520 and E522.

2.4.2.8 Input Error Summary

The CODYRUN modeler report also documents the correction of one additional input error after the third iteration of results. This was evident from analysis of hourly results and was related to a 1-hour offset of internal gains.

2.4.3 TRNSYS-TUD with Realistic Controller

TRNSYS is considered to be the most advanced program that DOE has sponsored for simulating active solar systems. The program was originally written at the University of Wisconsin. Technische Universität Dresden (TUD) acquired a license for the source code and has since developed new source code for TUD's own calculation routines. This new version is designated TRNSYS-TUD, and some new routines developed at TUD were tested for this project. For this project TUD ran TRNSYS-TUD using a realistic controller.

No software errors were found in the simulations. Errors previously discovered and corrected using HVAC BESTEST cases E100–E200 were documented in HVAC BESTEST Volume 1 (Neymark and Judkoff 2002).

2.4.3.1 External Post-Processor Error Summary

Illogical results (shown in Figure 2-17) in the high outside air cases (E320–E340) led to the discovery of an output post-processor error. In these cases consumption results for E340 (50% OA and 50% OA as infiltration) should fall in between those for E320 (100% OA) and E330 (100% OA as infiltration). This post-processor error was fixed.

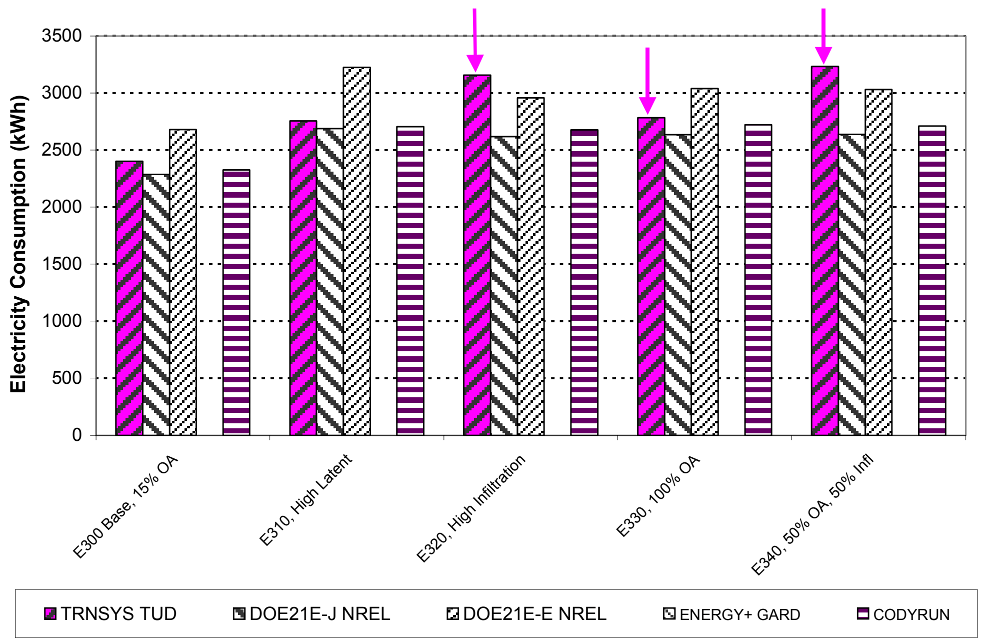

Figure 2-17. Illogical outdoor fan consumption results, post-processor error

2.4.4 DOE-2.1E ESTSC Version

Until recently, DOE-2 was the main building energy analysis program supported by DOE; many of its algorithms have been incorporated into DOE's next-generation simulation software, EnergyPlus.

2.4.4.1 Bypass Factor f(PLR) Curve, Misleading Documentation (30%–115% overestimation of annual latent coil loads resulting in 7%–22% overestimation of total annual consumption for continuous fan operation in cases with typical range of PLR)

In DOE-2.1E ESTSC version 119, cases E300–E350 and E400–E440 annual latent coil loads were overestimated by 30%–115% (see Figure 2-18), resulting in overestimation of annual total energy consumption of 7%–22% (see Figure 2-19). This problem was traced to detailed input for DOE-2's equipment performance curve (COIL-BF-FPLR) that adjusts bypass factor (BF) as a function of PLR. Initially, curve-fit data were specified according to DOE-2's documentation to achieve no variation of bypass factor as a function of PLR, as indicated in the test specification. This caused the disagreements shown in Figures 2-18 and 2-19 for cases with continuously operating air distribution fan and typical ranges of PLR. No related disagreements occurred for the E500 series cases because the BF = f(PLR) adjustment is applied differently in the DOE-2.1E ESTSC version for intermittent (cycling) operation versus for continuous fan operation; for intermittent operation, variation of input for COIL-BF-FPLR has a negligible effect. After reviewing DOE-2's documentation of COIL-BF-FPLR and NREL's input decks, the code authors concluded that, "the documentation for this algorithm is misleading and will lead to incorrect results if a fixed [bypass factor] is applied with a continuously operating fan" (Buhl 2003). Use of DOE-2's default curve for COIL-BF-FPLR gave results with better agreement.

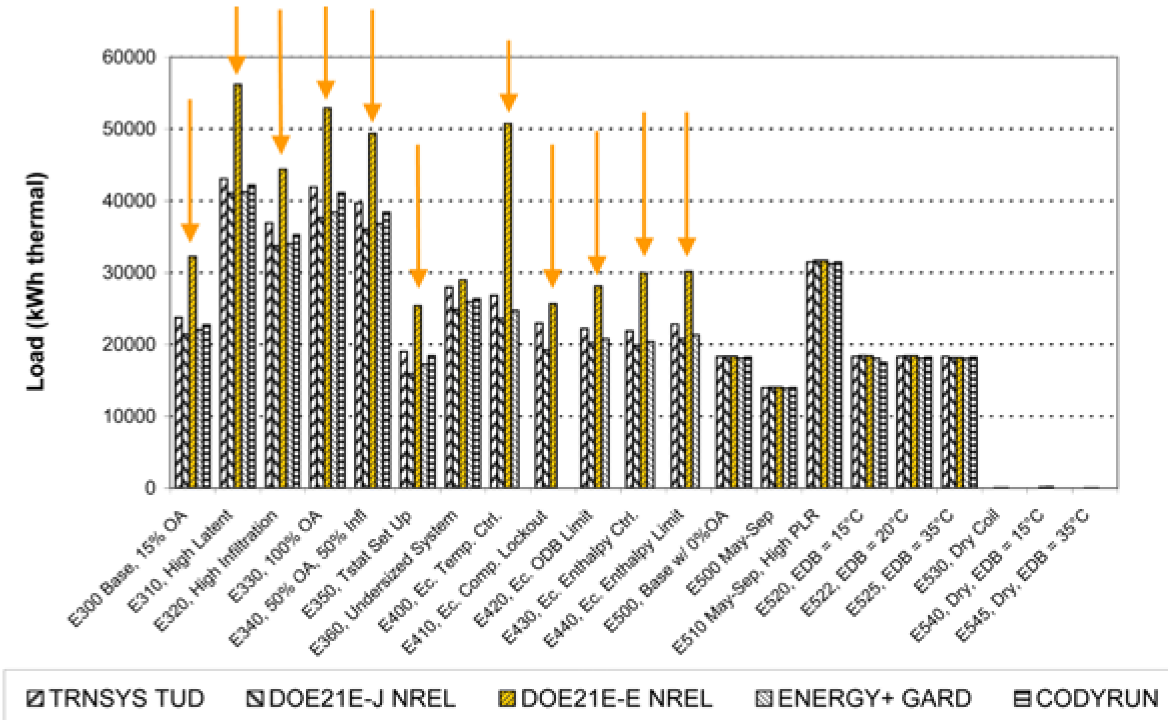

Figure 2-18. Latent coil load disagreements for DOE-2.1E, ESTSC version 119

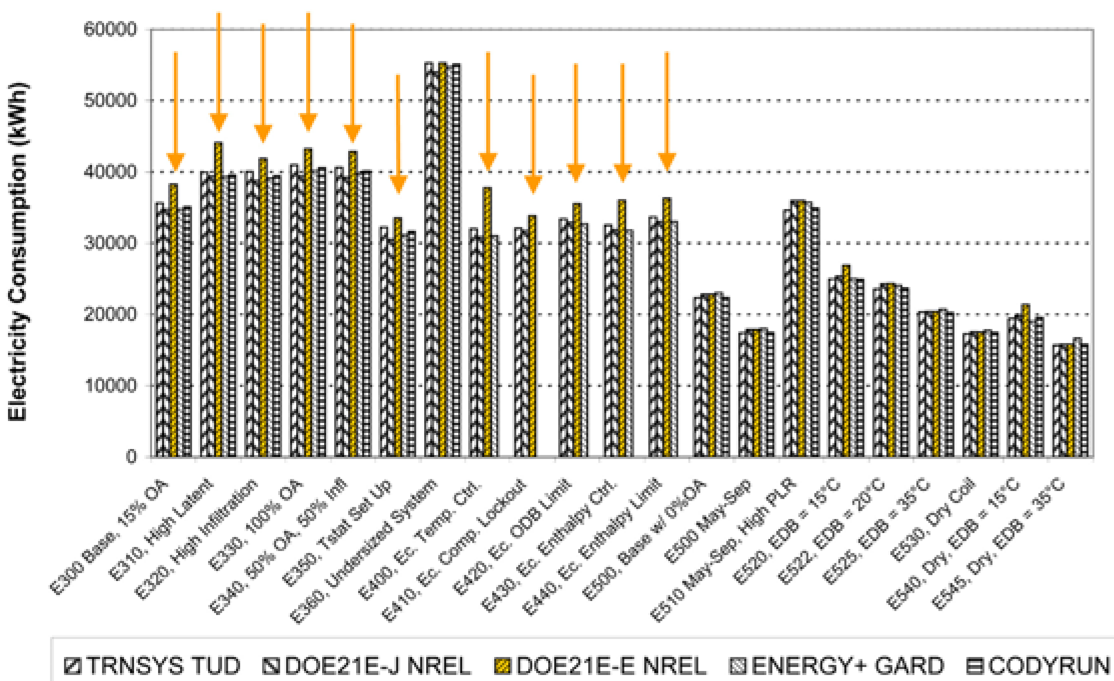

Figure 2-19. Total energy consumption disagreements for DOE-2.1E, ESTSC version 119, cases E300–E350 and E400–E440

2.4.4.2 Hard-Wired Lower Limit of 60°F (15.6°C) on the Coil Entering Wet-Bulb Temperature (Low EDB cases E520 and E540 only: 65%–109% overestimation of annual indoor fan electricity, 6%–13% underestimation of annual condenser fan electricity, and 1%–4% underestimation of annual compressor electricity, resulting in 6%–8% overestimation of annual total electricity consumption)

After applying DOE-2's default curve for COIL-BF-FPLR, further disagreements remained for the indoor fan electricity consumption of cases E520 and E540, as shown in Figure 2-20. Cases E520 and E540 have relatively low entering dry-bulb temperature of 15°C for wet- and dry-coil conditions, respectively. Other disagreements for cases E520 and E540 (not shown) also occurred for the outdoor fan electricity consumption and maximum IDB. As discussed in the modeler report (see Appendix II-E), the reason for this difference was a hard-wired lower limit of 60°F (15.6°C) on coil EWB. For cases E520 and E540 only, versus previous results, modification of the EWB lower limit caused 39%–52% decrease in indoor fan electricity, 7%–15% increase in outdoor fan electricity, and 1%–5% increase in compressor electricity, resulting in a 6%–7% decrease in total energy consumption. All this resulted in better agreement with the other programs (see Part III).

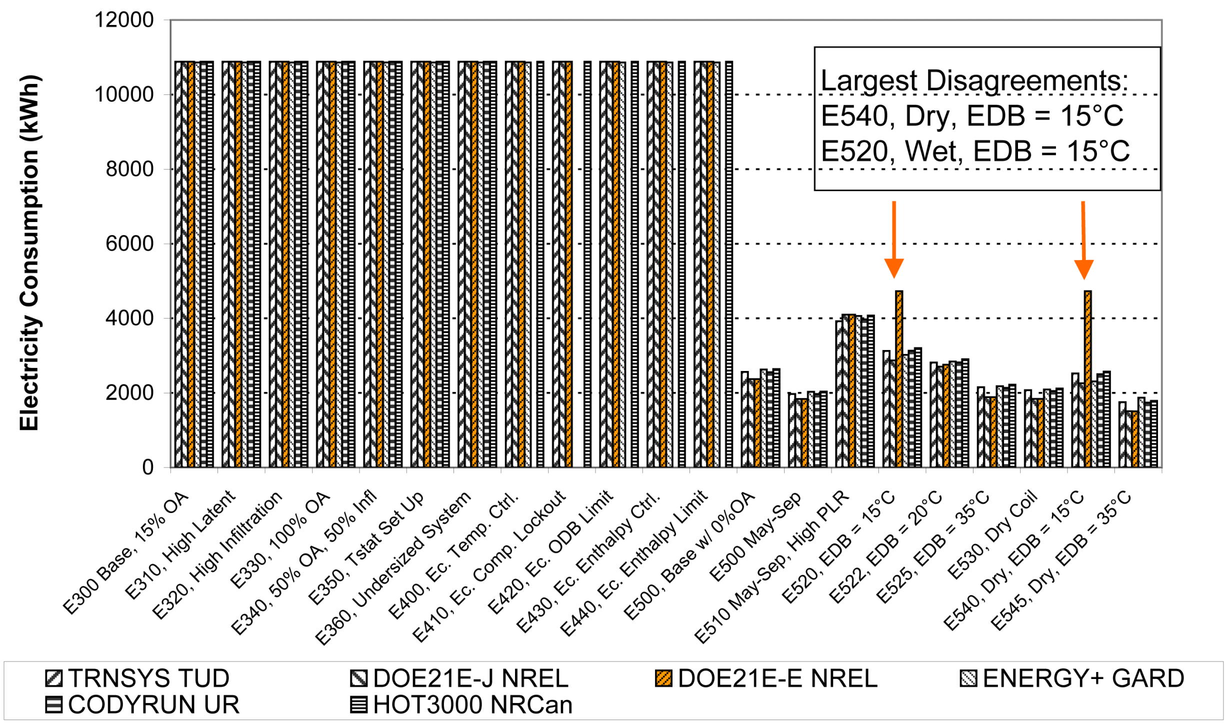

Figure 2-20. Indoor fan electricity consumption disagreements for DOE-2.1E, ESTSC version 119, cases E520 and E540

2.4.4.3 Single-Pass HVAC Calculation with 1-Hour Time Step (20%–50% overestimation of peak-hour latent coil loads for cases E320, E330, E340, and E400; 20%, 18%, and 80% overestimation of peak-hour zone humidity ratio for cases E310, E350, and E545, respectively)

After fixing the low EWB limit problem, there are still some disagreements in DOE-2.1E ESTSC version 120.

A 20%–50% overestimation of peak latent coil loads for cases E320, E330, E340, and E400 is apparent in Figure 2-21. As discussed in the modeler report (see Appendix II-E), the basis of the disagreement is that DOE-2 does a single-pass HVAC calculation with a 1-hour time step. To obtain good annual energy use estimates in this calculation environment and to save execution time, the code authors had previously chosen to use the previous hour's mixed air wet-bulb temperature in DOE-2's performance curve that modifies sensible capacity as a function of EWB and ODB. When the entering humidity ratio changes abruptly between adjacent hours, as occurs because of the scheduling of high rates of infiltration or outside air in cases E320–E340 and because of economizer operation in Case E400, the sensible capacity is misestimated. This leads to a misestimate of minimum supply temperature that ultimately leads to a misestimate of moisture removal. If DOE-2.1E is used for sizing equipment, the current disagreement regarding peak-hour latent coil loads could affect comfort-related equipment selection decisions for buildings in humid climates with high amounts of outside air, natural ventilation, and/or infiltration. There do not appear to be any corresponding disagreements for annual or peak-hour energy consumption estimates.

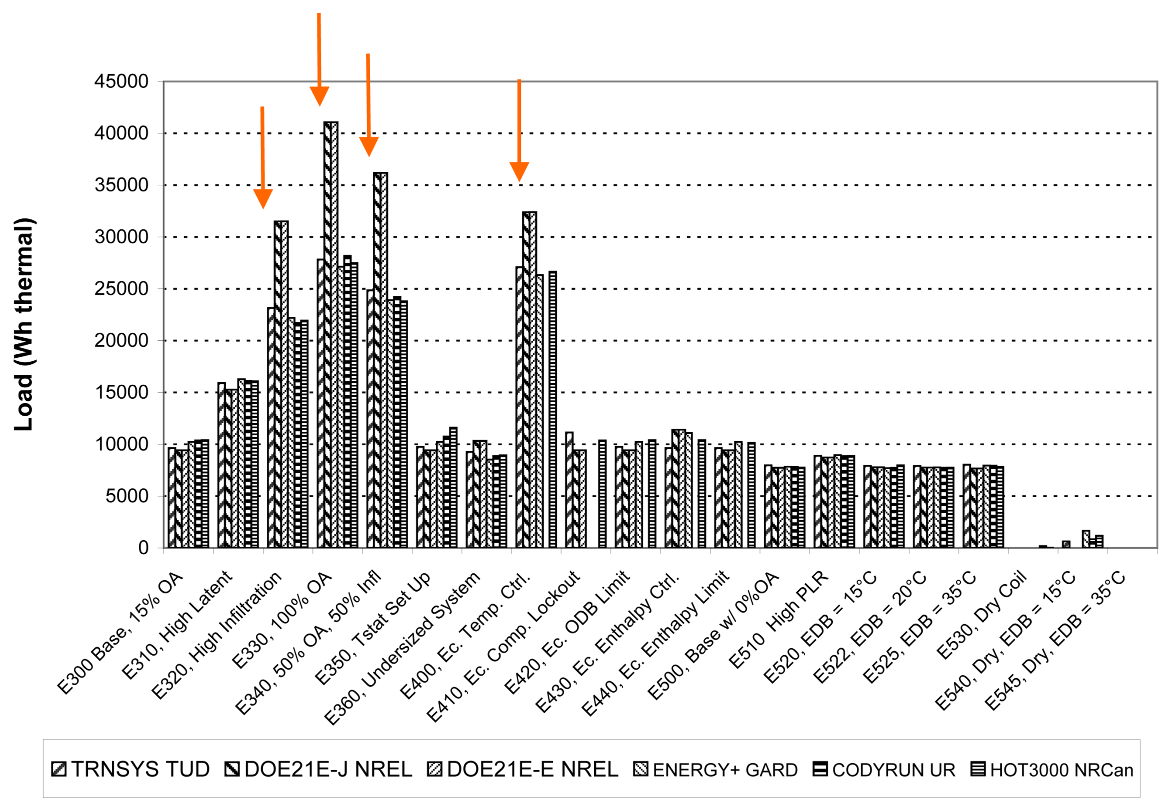

Figure 2-21. Peak-hour latent coil load disagreements for DOE-2.1E, ESTSC version 120, cases E320–E340 and E400

Another set of remaining disagreements for peak-hour humidity ratio is shown in Figure 2-22. The peak-hour zone humidity ratios for cases E310, E350, and E545 are overestimated by 20%, 18%, and 80%, respectively. Examination of this disagreement for Case E310 by one of the code authors indicates the following cause for the disagreement. During the hour where the peak humidity ratio is occurring in DOE-2, sensible and latent gains have increased, but the cooling system remains off; for the other programs, the cooling system comes on during that hour. This occurs because during the hour, the average zone temperature is below the cooling set point, and the cooling system remains off for DOE-2. Other programs that use smaller time steps, however, can switch the system on during the hour and remove some moisture from the zone. There do not appear to be any corresponding disagreements in annual or peak-hour energy consumption or coil loads, or in annual mean or hourly maximum or minimum zone temperature.

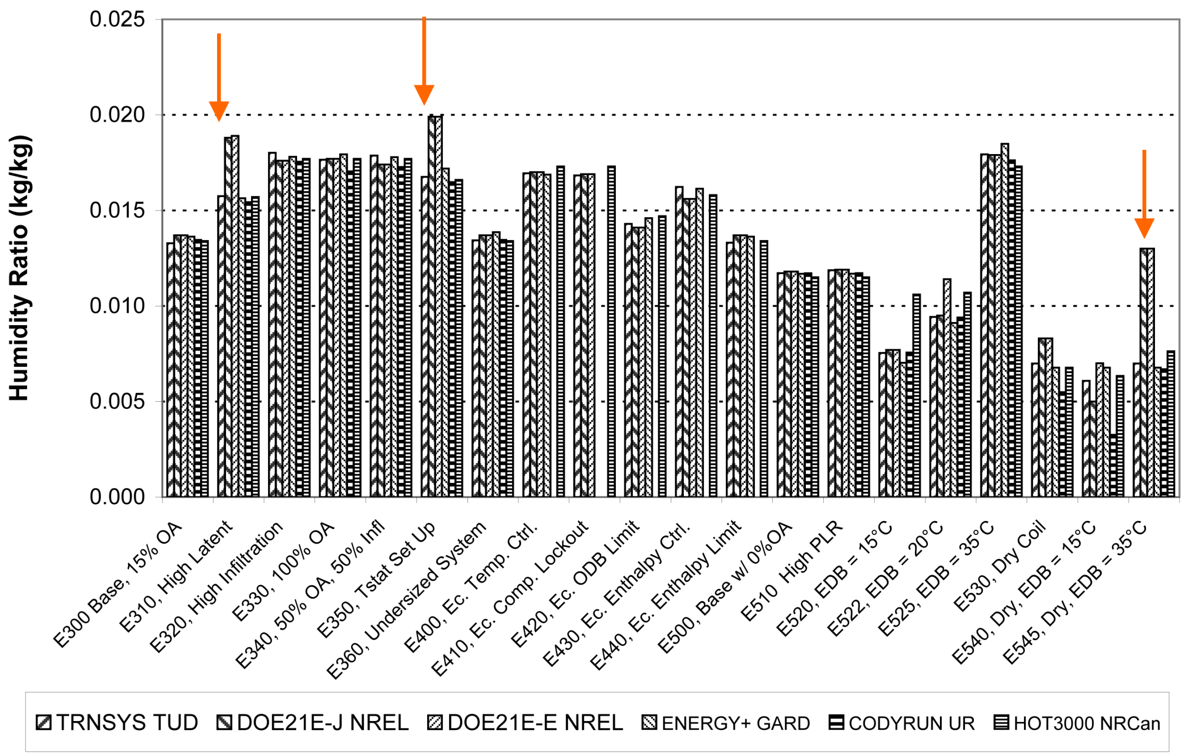

Figure 2-22. Maximum zone humidity ratio disagreements for DOE-2.1E, ESTSC version 120, cases E310, E350, and E545

The disagreements noted in Figures 2-21 and 2-22 would decrease with decreasing time steps, if that were possible in DOE-2 (Buhl 2003). But the authors do not plan any changes to the DOE-2.1E ESTSC version, as it would involve rewriting DOE-2's HVAC calculation, and DOE has already resolved these disagreements in its next-generation software (EnergyPlus).

2.4.4.4 Variation of Zone Humidity Ratio in Dry-Coil Cases at Constant Set Point with Cooling On (10%–25% overestimation of humidity ratio in E530)

Figure 2-23 indicates a variation of zone humidity ratio for dry-coil case E530 that is not present in the other programs. For this case we expect—during the simulation period of April 21 through October 11 (when the cooling system is always on)—that the simulation programs would establish a zone humidity ratio that corresponds to the set point, and that because there are no zonal moisture gains or losses, that humidity ratio would remain fixed. For DOE-2, however, the zone humidity ratio is set to the humidity ratio that would occur assuming 100% relative humidity air at the coil surface temperature. Because the coil surface temperature varies with the load, so does the zone humidity ratio. The code authors do not plan to make any changes to DOE-2.1E ESTSC version 120 related to this issue. There do not appear to be any corresponding disagreements in specific day energy consumption or coil loads.

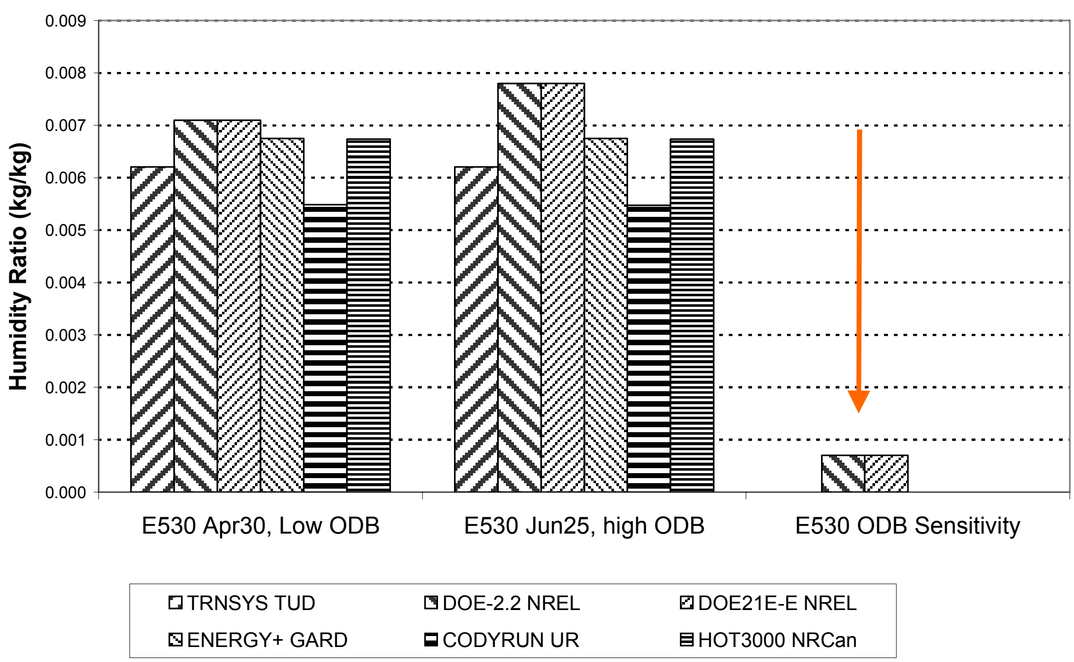

Figure 2-23. Specific day humidity ratio, Case E530

2.4.5 HOT3000/ESP-r

HOT3000 was developed and is maintained by CANMET Energy Technology Centre at Natural Resources Canada. HOT3000 is a modified version of ESP-r (developed and maintained at the University of Strathclyde, Scotland, United Kingdom) that retains ESP-r's modeling approach but includes new models for ground coupling, air infiltration, furnace, unitary space cooling equipment, air- and ground-source heat pumps, domestic hot water, and fuel cells.

2.4.5.1 Outside Air Modeling (4% underestimation of total consumption, 5% underestimation of sensible coil load, and 9% underestimation of latent coil load in Case E330; 0.3% underestimation of total consumption in Case E300)

After early input errors were corrected, the initial results for HOT3000 total consumption sensitivities disagreed for all comparisons involving Case E330, as shown in Figure 2-24. These disagreements were accompanied by observed disagreements in sensible cooling load sensitivities (see Figure 2-25) and similar latent cooling load sensitivity disagreements (not shown). The code authors traced the disagreements to modeling the sensible effect of outside air on the space load in a manner similar to modeling a sensible internal gain/loss from lights or another source (see modeler report, Appendix II-D). This problem has been fixed, and the revised software now models the effect of outdoor air on the space *load* the same as infiltration air; effects of outside air on resulting coil performance are modeled separately. This improvement gives a better account of the effect of outdoor air on the space load, and gives better agreement with the other simulation programs.

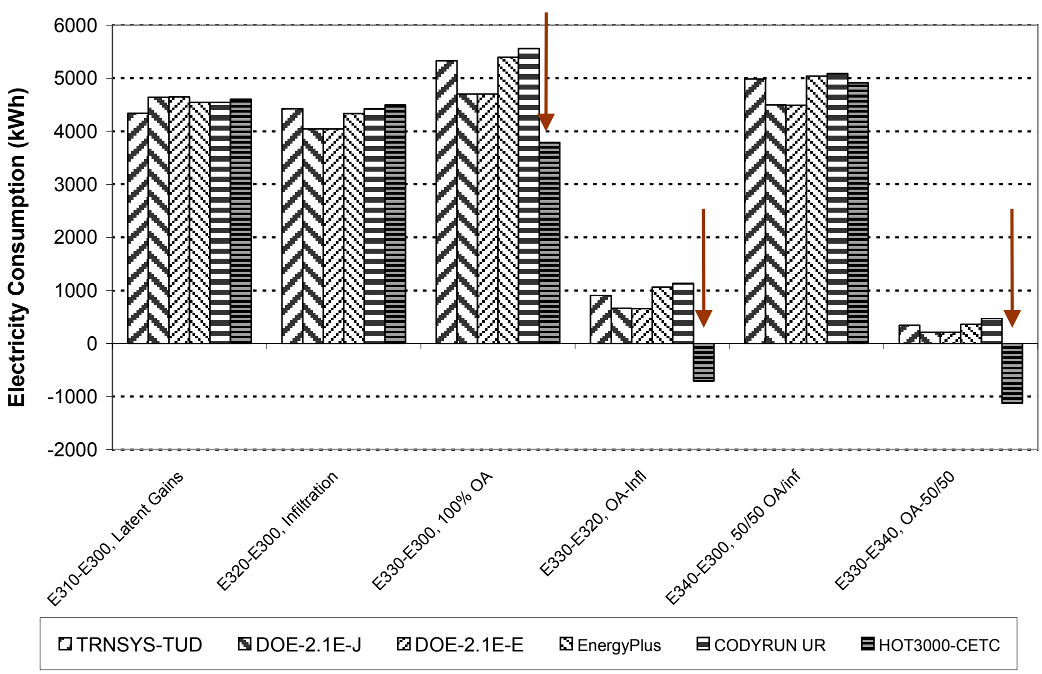

Figure 2-24. Total space cooling electricity consumption sensitivity disagreements for HOT3000, cases E330–E300, E330–E320, and E330–E340

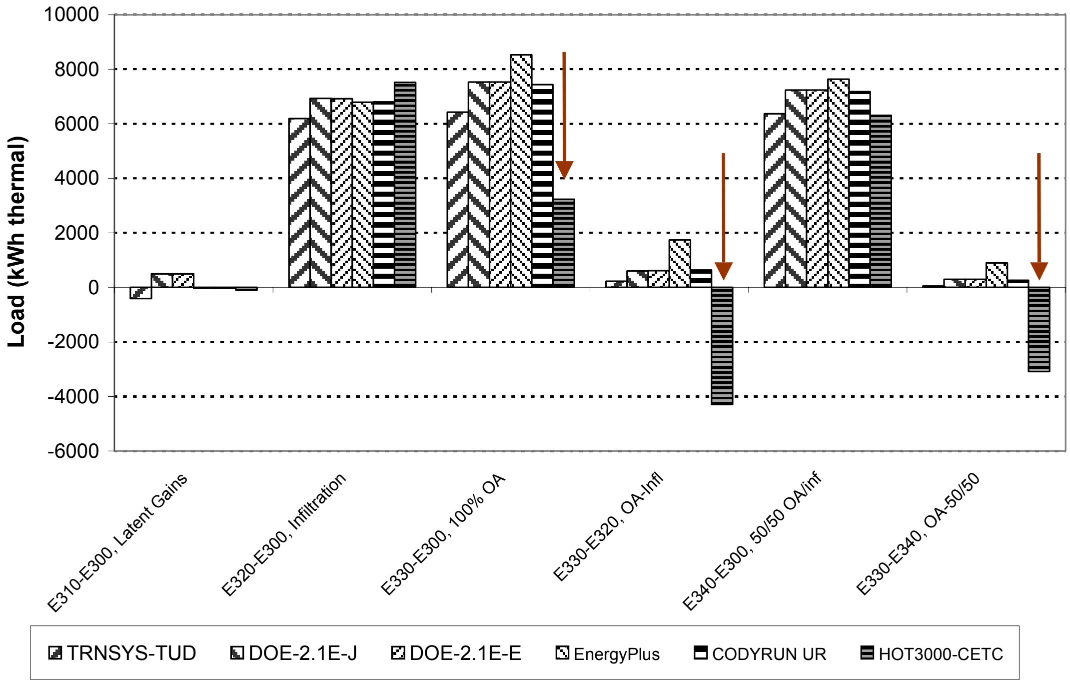

Figure 2-25. Total sensible cooling load sensitivity disagreements for HOT3000, cases E330–E300, E330–E320, and E330–E340

2.4.5.2 Does Not Calculate Loads and Energy Use within the Same Time Step (Likely 3% underestimation of peak-hour total consumption for cases E310 and E520; code authors could not complete software improvement in time for publication of this report)

After fixing the previous problem related to outside air modeling, a few disagreements remained related to some of the peak consumption, load, and zone condition results. The peak-hour total consumption disagreements for cases E310 and E520 are illustrated in Figure 2-26. If HOT3000 is used for estimating utility peak demand charges, the current disagreement regarding peak-hour electricity consumption could affect energy-cost-related equipment selection decisions for buildings with high latent loads. There do not appear to be any corresponding disagreements in annual total consumption, or in annual or peak-hour coil loads.

As shown in Table 2-4, the peak-hour consumptions for economizer cases E400 and E440 did not match that for E300. Those peak-hour results should match E300 because high-temperature outside air conditions that cause the peak load also cause the outside air dampers to be at the minimum setting (15% OA as in E300) during peak load hours; this is evident in the results for the other programs (see Part III). There do not appear to be any corresponding disagreements in annual or peak-hour total consumption or coil loads, or in annual mean or hourly maximum or minimum zone temperature or humidity. Other disagreements for zone temperature and humidity ratio extremes for some of the E500 series cases (not shown) were also observed. Except for the remaining peak-hour total consumption disagreement previously described for Case E520, there appear to be no corresponding disagreements in annual or peak-hour total consumption or coil loads.

As noted in the modeler report (see Appendix II-D), the code authors have determined that the likely cause of these disagreements is related to the software not iteratively calculating building loads and system operation within the same time step. The modeler report notes that for a given time step, system operating parameters are based on zone conditions determined during the previous time step. The code authors plan to revise HOT3000 so that loads and systems calculations are performed iteratively within the same time step. Because of unavoidable delays in getting started with their field trials, the code authors were unable to complete this software revision in time for final publication of this report.

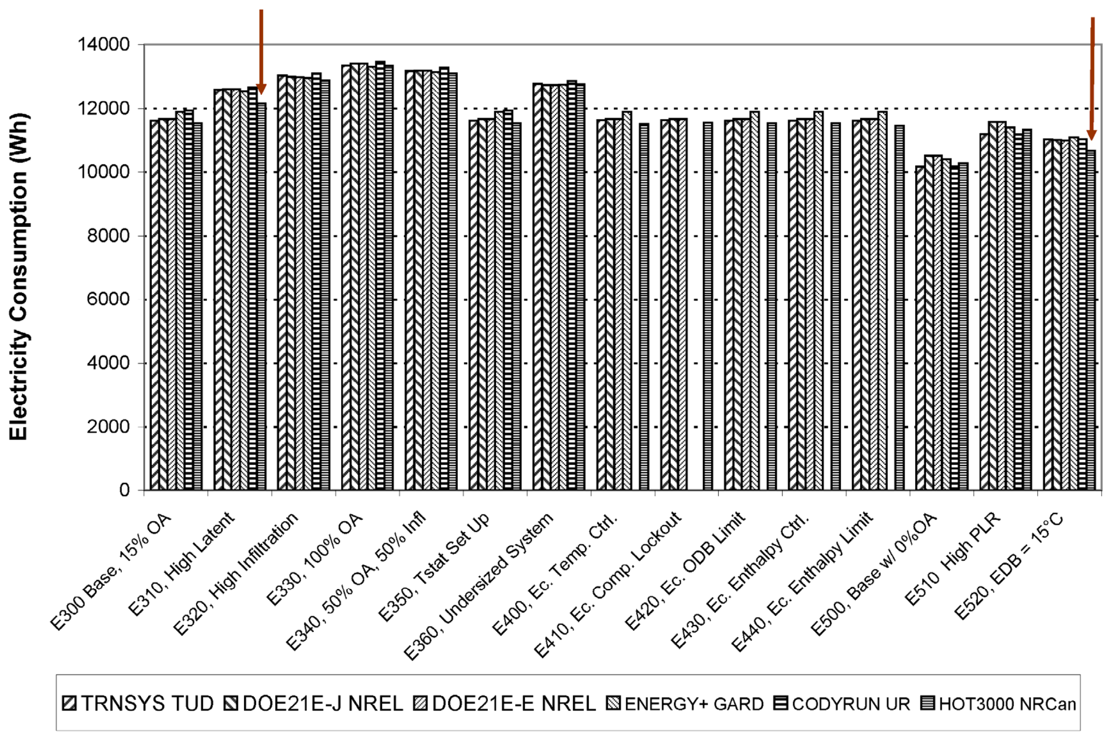

Figure 2-26. Peak-hour total electricity consumption disagreements for HOT3000, cases E310 and E520

Table 2-4. Economizer Peak Consumption Disagreements for HOT3000, Cases E400 and E440

Case	Peak Consumption (Wh)	Date	Hour
E300	11,548	Jul. 20	15
E400	11,519	Jul. 20	15
E410	11,549	Jul. 20	15
E420	11,548	Jul. 20	15
E430	11,548	Jul. 20	15
E440	11,461	Aug. 16	16

2.4.6 DOE-2.2

DOE-2.2 was developed by Lawrence Berkeley National Laboratory (LBNL) and James J. Hirsch & Associates, and is distributed by James J. Hirsch & Associates. DOE-2.2 is based on DOE-2.1E, which was developed by LBNL with the assistance of James J. Hirsch & Associates.

2.4.6.1 Incorrect Entering Wet-Bulb Temperature Used for Estimating Capacity and Supply Temperature (50%, 20%, and 20% overestimation of peak-hour latent coil loads in cases E330, E340, and E400, respectively; 1.0% effect on annual energy consumption in Case E330)

Figure 2-27 indicates approximately 20%–50% overestimation of peak-hour latent coil loads for DOE-2.2 NT41n for cases E320–E340 and E400 versus the other programs (except the DOE-2.1E ESTSC version). Based on these results one of the code authors found an incorrect line of logic in DOE-2.2. This logic caused DOE-2.2 to use the previous-hour entering wet-bulb temperature for estimating current-hour system capacity and supply temperature, without correcting for current-hour conditions. The code author noted that this problem would only affect hours of simulation where both the internal and external conditions (load, dry-bulb temperature, and humidity) change abruptly during 2 consecutive hours when the system fans are operating (Hirsch 2003). Correction of this error in an updated version of DOE-2.2 (DOE-2.2 NT42j) caused 35%, 16%, and 21% reductions of peak-hour latent coil loads in cases E330, E340, and E400, respectively; these cases have high continuous or controlled high outside-air flows. Other effects of this improvement are noted in Table 2-5. There was negligible effect on results for Case E320, which has zero outside air but high infiltration airflow.

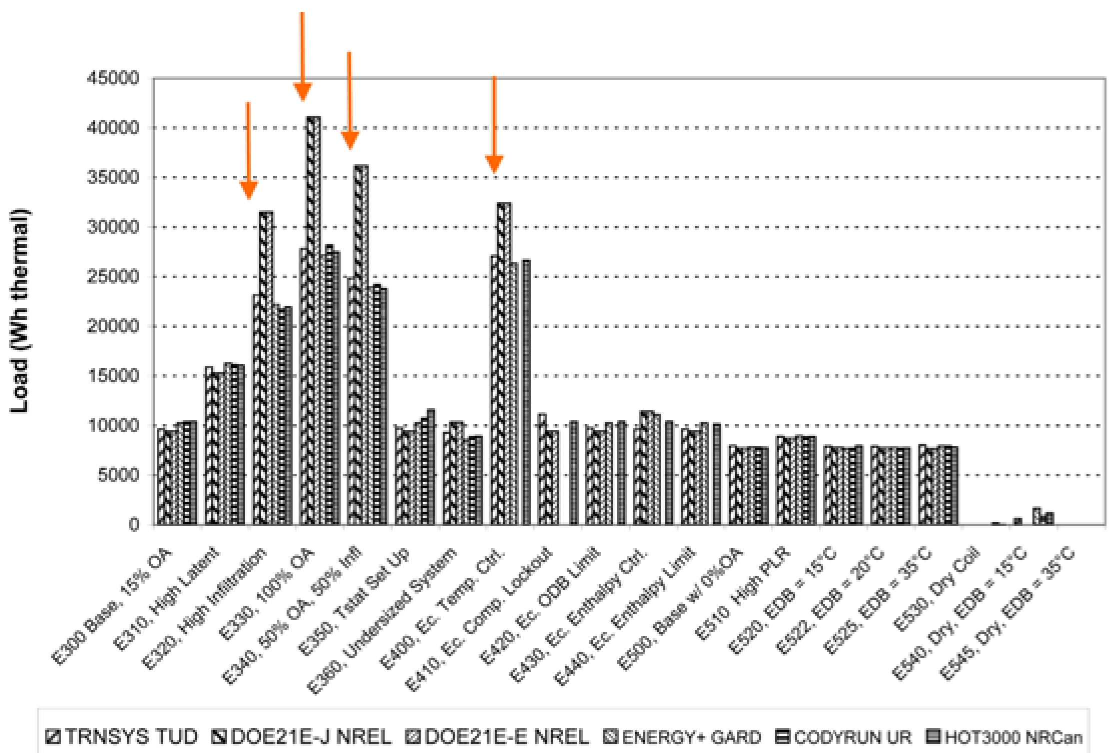

Figure 2-27. DOE-2.2 NT41n, peak-hour latent coil load disagreements, cases E320, E330, E340, and E400

Table 2-5. Effects of Improvement to DOE-2.2 Regarding Calculation of Entering Wet-Bulb Temperature for Estimating System Capacity and Supply Air Temperature

Version	NT41n		NT42j		
Output	Value	Date (mm/dd/hh)	Value	Date (mm/dd/hh)	Change
Peak-hour latent coil load (kW)	41.065	10/02/09	26.491	09/18/15	35%
Peak-hour sensible coil load (kW)	34.490	06/14/15	33.410	06/14/14	3%
Peak-hour total consumption (kW)	13.317	07/20/15	13.212	07/20/15	1%
Annual total consumption (kWh)	39.315	---	39.708	---	1%

2.4.6.2 Remaining Disagreements

Figure 2-28 indicates approximately 40% and 25% overestimation of peak-hour latent coil loads for DOE-2.2 NT42j for cases E320 and E340, respectively, versus the other programs (except the DOE-2.1E ESTSC version). These disagreements occur during the same hour (October 2, hour 9) as disagreements described in Figure 2-27, meaning that a similar problem may be occurring here related to calculation of EWB with high infiltration airflow, as was previously found for calculation of EWB with high OA flow as described in Section 2.4.6.1.

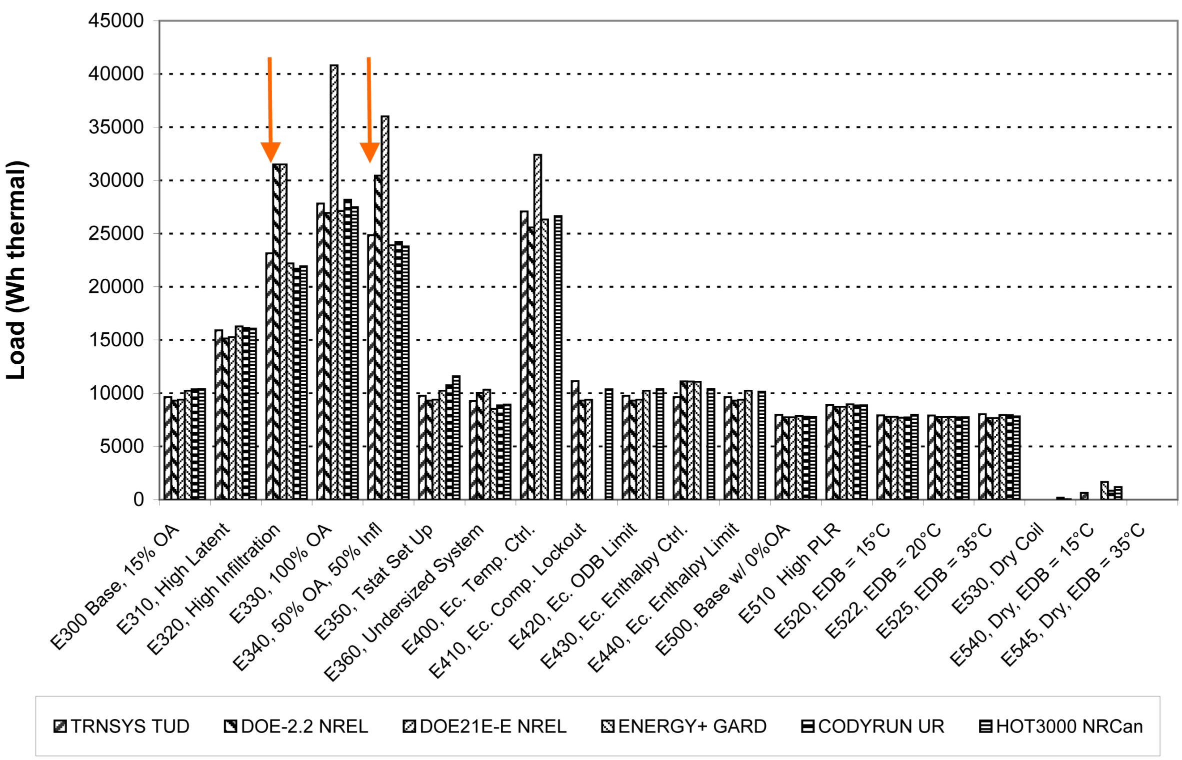

Figure 2-28. DOE-2.2NT42j, peak-hour latent coil load disagreements, cases E320 and E340

If DOE-2.2 is used for sizing equipment, the current disagreement regarding peak-hour latent coil loads could affect related equipment-selection decisions for buildings in humid climates with high amounts of infiltration or zone-based natural ventilation. Based on Table 2-5, the corresponding disagreements for annual and peak-hour energy consumption estimates may be roughly 1%.

Figure 2-29 indicates up to approximately 75% overestimation of maximum hour COP2 in the E500 series (zero outside air) wet-coil cases, as well as approximately 25% and 10% disagreements for cases E320 and E340, respectively. There appear to be no corresponding disagreements in annual or peak-hour energy consumption or coil loads, or in annual mean or hourly maximum or minimum zone temperature or zone humidity. Figure 2-30 indicates approximately 20%, 20%, and 90% overestimation of maximum hour zone humidity ratio for cases E310, E350, and E545, respectively. There do not appear to be any corresponding disagreements in annual or peak-hour energy consumption or coil loads, or in annual mean or hourly maximum or minimum zone temperature or zone humidity. Additionally, the apparently minor disagreement regarding variation of specific day zone humidity ratio in dry-coil cases at constant set point with cooling on (10%–25% overestimation of humidity ratio in E530)—described for the DOE-2.1E ESTSC version (see Section 2.4.4.4)—also occurred for DOE-2.2. Based on the current results sets, the code authors are planning to examine remaining disagreements and revise their software if necessary, but were not able to address the remaining disagreements in time for publication of this report.

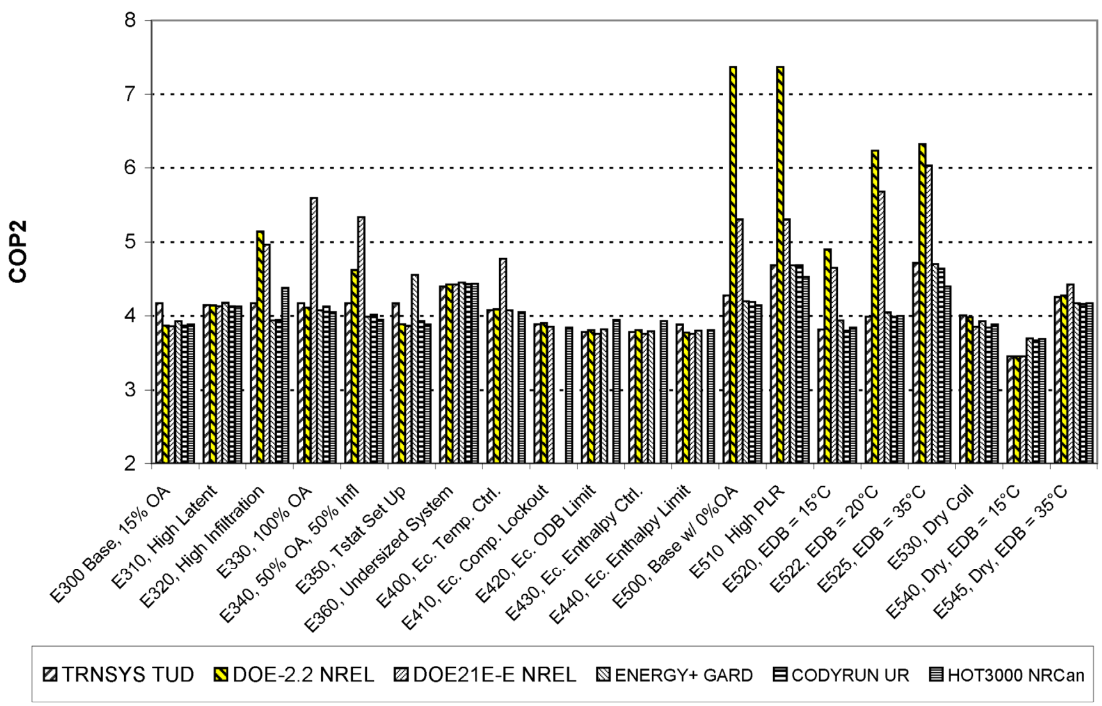

Figure 2-29. DOE-2.2NT42j, maximum COP2 disagreements, cases E320, E340, and E500 series

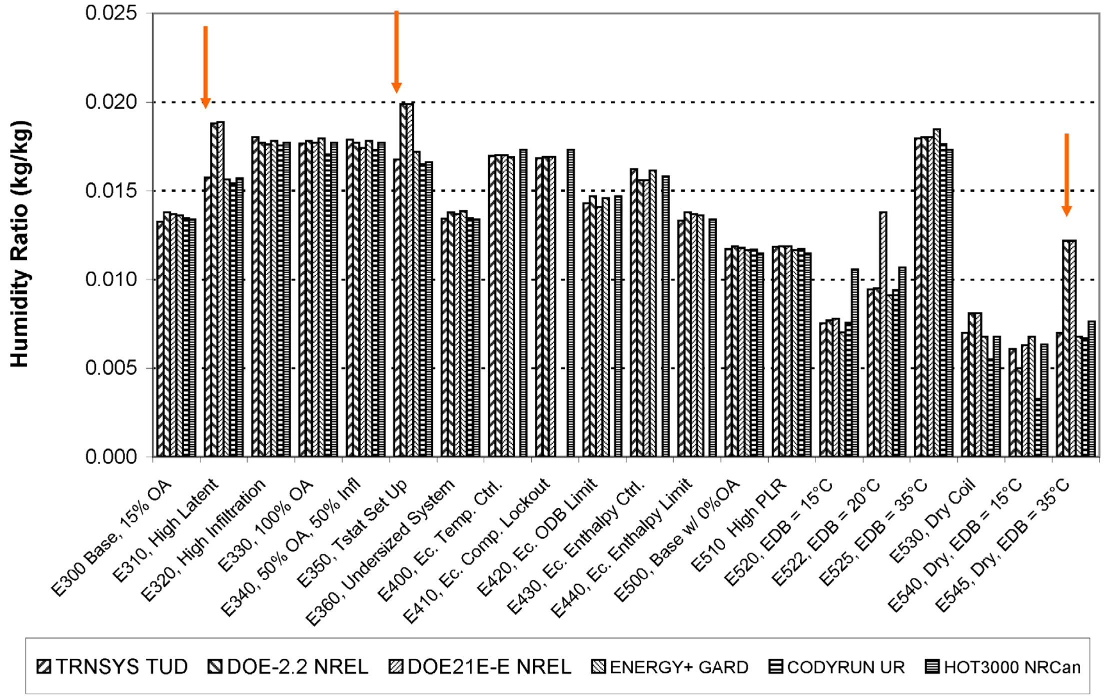

Figure 2-30. DOE-2.2 NT42j, peak-hour humidity ratio disagreements for cases E310, E350, and E545

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2.5 Interpretation of Results

The tables and graphs in Part III present the final results from all the simulation programs used in this study. Unlike the results of cases E100–E200, these cases do not have analytical solution results. Therefore, this set of simulation results does not establish either an absolute or a mathematical truth standard (see *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating and Air-Conditioning Equipment Models, (HVAC BESTEST) Volume 1* [Neymark and Judkoff 2002: Section 3.5]). These reference results do represent the best current state of the art in whole-building energy simulation predictions as defined by our group of international experts. Because there is no truth standard, for any given case a program that yields values in the middle of the range of the reference results should not be perceived as better or worse than a program that yields values at the borders of the range. The ranges represent algorithmic differences in the current state of the art.

Programs that fall outside the ranges of reference results are producing results that differ from the current state of the art in whole-building energy simulation. One must rely on engineering judgment to assess the significance of results that disagree. For simulation results that disagree significantly with the reference simulation results, investigating the source(s) of the difference(s) is worthwhile, but the existence of a difference does not necessarily mean that a program is faulty. However, our collective experience in this task has indicated that when programs show disagreement, we often find a bug, a questionable algorithm, or a documentation problem.

Because of iterative correction of input errors, software bugs, and clarification of the test specifications, the agreement among simulation results improved with each iteration of the field trials. Improvements to the simulation programs are evident when the initial results set in Figure 2-31 is compared to the final results set in Figure 2-32. (In these figures abbreviations along the x-axis are shorthand for the case descriptions given in Part I.) Improvements to simulation programs or simulation inputs made by participants must have a mathematical and physical basis, and must be applied consistently across tests. Also, all improvements were required to be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed.

For Figure 2-31, the participants submitted their initial results as follows. Initial results submitted for CODYRUN and EnergyPlus were only for cases E300–E310 and E300–E360 respectively. The EnergyPlus results for E400–E545 were submitted after several iterations of fixing errors in cases E300–E360; the initial E400–E545 results then indicated that a few disagreements remained for those cases. The CODYRUN results for E320–E360 were submitted after one iteration of error correction for cases E300 and E310; these results indicate disagreements for E320–E340. CODYRUN results for E500–E545 were submitted after errors for cases E320–E340 were addressed, so no new disagreements for total consumption are indicated for E500–E545, although a few disagreements for other outputs were observed (see Section 2.4). Initial results for DOE-2.2 (distributed by James J. Hirsch & Associates) are represented by the DOE21E-J results, which use a James J. Hirsch & Associates version of DOE-2.1E. Initial results for DOE21E-J, DOE21E-E (DOE-2.1E ESTSC version), and TRNSYS-TUD were submitted for the full set of test cases. All results for TRNSYS-TUD use a realistic controller (time step = 90 seconds) and interpolated weather data (based on the given hourly data) within each time step. For HOT3000, results were initially submitted only for cases E300–E320 and E340–E350. The next set of HOT3000 results was submitted for E300–E360. HOT3000 results for cases E400–E545 were submitted after a software improvement to fix a problem with HOT3000's Case E330 results.

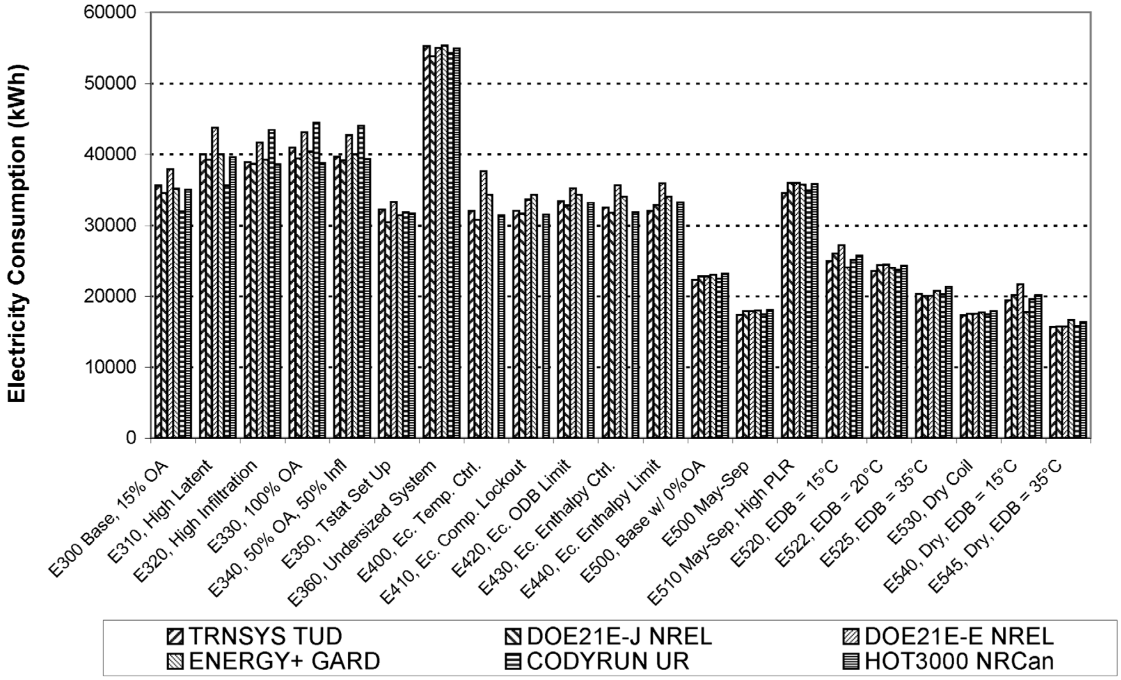

Figure 2-31. HVAC BESTEST E300–E545—total electricity consumption, before BESTESTing
(Abbreviations along the x-axis are shorthand for the case descriptions; see Part I for full case descriptions.)

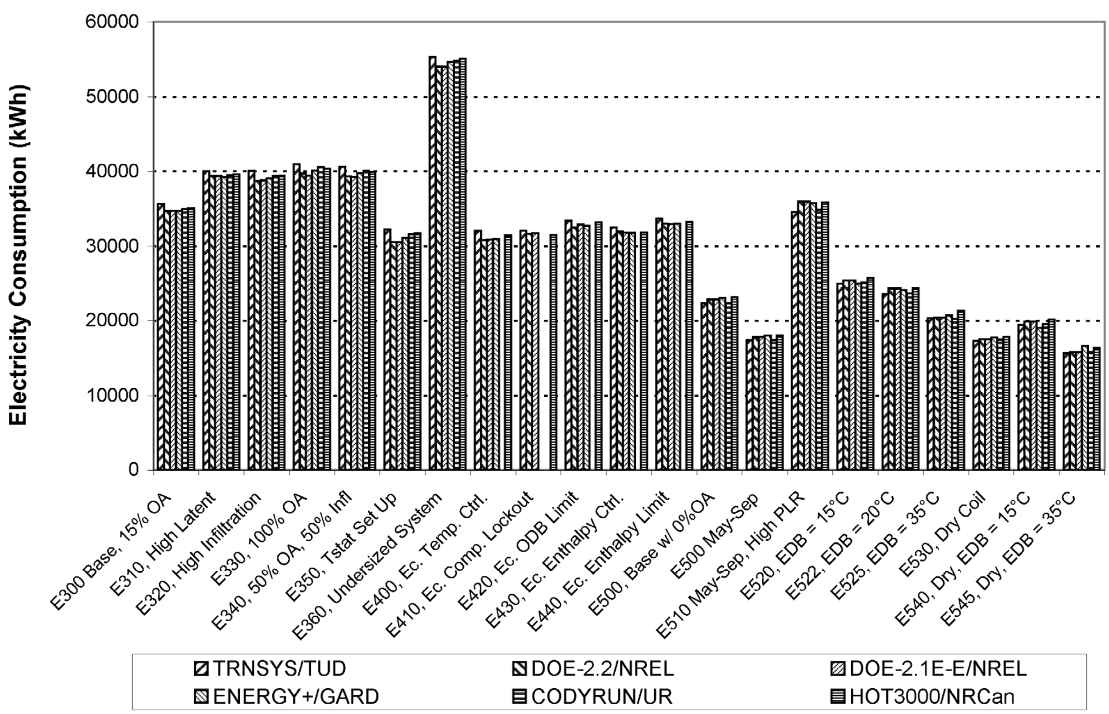

Figure 2-32. HVAC BESTEST E300–E545—total electricity consumption, after BESTESTing
(Abbreviations along the x-axis are shorthand for the case descriptions; see Part I for full case descriptions.)

The results shown in Figure 2-31 indicate that there was initially a 3%–21% disagreement among the cases for the simulated energy consumption results, and that there was a lot of scatter among the programs. Here disagreement is the difference between the maximum and minimum result for each case, divided by the mean of the results for each case ((max-min)/mean). The initial results disagreements are smaller for these results than for the E100–E200 cases (4%–40%) possibly because TRNSYS-TUD, DOE-2.1E, and EnergyPlus were already improved during the earlier field trials of cases E100–E200.

Figure 2-32 shows that after correcting software errors using HVAC BESTEST diagnostics, the remaining disagreements of results for annual total energy consumption for the programs are 2%–6%, with very little scatter among the programs. This shows how the HVAC BESTEST method is used to diagnose and correct faulty algorithms in complex simulation programs.

Final ranges of disagreement are further summarized in Table 2-6 for predictions of various outputs. The outputs are disaggregated for cases E300-E440 (continuous outside air and/or infiltration, and continuous fan operation) and for cases E500–E545 (no outside air nor infiltration, indoor fan cycles on/off with compressor). The higher level of indoor dry-bulb temperature (IDB) and humidity ratio disagreement in cases E500–E545 may be caused by the wider range of thermostat set points that was used in those cases.

Table 2-6. Ranges of Disagreement among Simulation Results

Cases	**E300-E440**	**E500-E545**
Annual total electric consumption	2%–5%	3%–6%
Annual mean zone humidity ratio	2%–3%	4%–23%
Annual mean zone temperature	0.1°C–0.6°C	0.4°C–4.1°C*

* Higher IDB by HOT3000 for cases E500–E545 was attributed by the HOT3000 modelers to the use of an adiabatic zone in their model, versus the near-adiabatic zone specified in Part I.

Based on results *after* several iterations of HVAC BESTESTing, and resulting model improvements, the tested programs now appear reliable for performance-map modeling of space-cooling equipment over an expanded range of dynamic performance conditions. The programs also appear reliable for modeling outside air mixing, infiltration, thermostat set up, overloaded conditions, and various economizer control schemes. This set of results may therefore be used as a reference or benchmark against which other software can be tested.

The current set of reference results applies a simplifying assumption in the test specification (Part I, Section 1.3.1.4.1) that, "All moisture that condenses on the evaporator coil … leaves the system through a condensate drain." This simplifying assumption is common to the simulation tools used in the field trials. Recently published work (Shirey and Henderson 2004) indicates that this simplification deviates from reality at a part-load condition, and especially for single-stage systems where the indoor air distribution fan operates continuously, as in cases E300-E440. This is because of latent performance degradation caused by evaporation of condensate from the evaporator coil during the compressor off-cycle, which effectively causes a trade-off of reduced latent capacity for increased sensible capacity (or sensible zone-load reduction) because of the evaporative cooling that results. The latent performance degradation effect is greatly reduced when the air distribution fan cycles on/off with the compressor, as in the E100 and E500 series cases. Shirey and Henderson (2004) note that most mainstream hourly whole-building energy simulation programs do not consider part-load latent performance degradation and therefore tend to overestimate moisture removal. Their article cites a study that showed 5%–10% underprediction of relative humidity levels in a typical small office application for a single-stage system with continuous air distribution fan operation in a humid climate. Personal communications with the authors indicate that the corresponding overprediction in energy use may also be 5%–10%, and that they are working to incorporate the part-load latent degradation model that they have been using into EnergyPlus (Shirey 2004; Henderson 2004). One issue with the use of the model is that parameters necessary to accurately estimate latent performance degradation exist only for a limited number of cooling coils and equipment configurations. To address this, the authors are working to develop guidelines for selecting model parameters for a greater variety of cooling coils and equipment configurations.

2.5.1 Importance of Simulated Effects on Real Buildings

The E500 series cases repeat some of the tests of cases E100–E200, but use dynamic loading, dynamic weather data, and expanded mechanical equipment performance data to test the ability to model the effects of variation of part-load ratio (PLR), and outdoor dry-bulb temperature (ODB) and entering dry-bulb temperature (EDB) performance sensitivities.

In addition to testing these effects in a dynamic context, there is also value in having these tests to scale the importance of being able to simulate these effects for real buildings. For example, a large percentage difference for a given result that has only a very small impact on annual energy use may not be of concern, whereas a small percentage difference with a large impact on annual energy use may be deemed important. The same is true for features tested in the E300 series and E400 series cases. The internal gains schedules for cases E300–E545 combine aspects of both building thermal fabric and typical internal gains loading. Because there is almost no uncertainty regarding the load to which the mechanical system is responding, all disagreements in simulation results may be attributed to HVAC system models. It is therefore apparent from the initial results for Case E300 that improper modeling of mechanical equipment can easily account for 10%–20% errors in energy consumption estimates for real buildings; this was after some of the programs had already corrected errors found from running cases E100–E200. Similar initial disagreements were likely not found for the initial results of the E500 series cases either because all the participating programs had found bugs from running the E100–E200 series cases or because the E300 series cases had been run before they began field testing the E500 series cases.

2.5.2 Test Cases for Future Work

We suggest that additional work related to model testing and validation, outlined in the sections that follow, be considered.

2.5.2.1 Mechanical Equipment

For the current set of all HVAC BESTEST cases, it would be interesting to include:

- Heat pumps
- A test of the ability to extrapolate from a set of typical manufacturer catalog performance data (using a limited set of performance data with smaller increments of ODB, entering wet-bulb temperature [EWB], and EDB over a typical design range for the same equipment for which the current expanded performance data have been obtained)

- Variation of part-load performance based on more detailed data
- Five-minute minimum on/off or hysteresis control, or both; preliminary work by TUD documented in the Volume 1 TRNSYS-TUD modeler report suggests that it might be interesting to try:
    - Case E140 with 5-minute minimum on and 5-minute minimum off
    - Case E130 with 2°C hysteresis
    - Five-minute minimum off (a common manufacturer setting)
    - Combination of minimum on/off and hysteresis
    - Proportional control
    - Adding equipment run time to outputs.

Additional possible cases include:

- Variable-air volume fan performance and control
- Repeat one or two of the E100–E200 series cases using expanded performance data
- Fan heat test using continuous fan operation at low compressor part load
- Latent capacity degradation test using continuous fan operation at low compressor part load
- PLR effect test using Air-Conditioning and Refrigeration Instiute (ARI) conditions for ODB, EWB, and EDB
- Outside dew point temperature (humidity ratio) effect on performance (see the DOE-2.1E/NREL modeler report of Volume 1 [Appendix III-A])
- Combination of mechanical equipment tests with a realistic building envelope (although combining these adds noise, which makes diagnostics more difficult).

Obtaining additional simulation results would also be useful. Possible additional programs to test include FSEC 3.0, HVACSIM+, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) HVAC2 Toolkit, and others.

Other BESTEST-type test suites that have been developed within International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC) Task 22 include:

- HVAC BESTEST Fuel-Fired Furnace Test Cases (Purdy and Beausoleil-Morrison 2003)
- RADTEST Radiant Heating and Cooling Test Cases [hydronic system model test cases] (Achermann and Zweifel 2003).

For the longer term, there has been discussion of trying to gather data that would allow highly detailed equivalent primary-loop component models of, for example, compressors, condensers, evaporators, and expansion valves, to be incorporated into the test specification. Incorporating and verifying data for such models to enhance the current HVAC BESTEST specification is expected to be a major effort. Additional long-term work would also include:

- Thermal storage equipment
- Air-to-air heat exchanger
- Fuel-fired domestic hot water
- Combination hot water/space-heating systems
- Solar domestic hot water systems
- More complex systems associated with larger buildings including:
    - Large chillers
    - Chilled water loops
    - Cooling towers and related circulation loops

  - More complex air-handling systems
  - Other "plant" equipment
- Field trials of ASHRAE RP-865 air-side analytical tests (Yuill and Haberl 2002).

Within IEA SHC Task 22, economizer model empirical validation tests have been completed. (Maxwell, Loutzenhiser, and Klaassen 2004). Empirical studies being developed within new IEA SHC/Energy Conservation in Buildings and Community Systems (ECBCS) Task 34/Annex 43 are aimed at better characterizing HVAC systems, controls, and components. Development of additional empirical validation test cases related to mechanical equipment models may be proposed in the future.

2.5.2.2 Building Thermal Fabric (envelope)

IEA SHC Task 22 began developing improvements to existing IEA BESTEST (Judkoff and Neymark 1995a) and HERS BESTEST (Judkoff and Neymark 1995b) cases related to ground-coupled heat transfer through floor slabs and basement walls. This work is described in an IEA Working Document (Deru, Judkoff, and Neymark 2003), and is being continued within new IEA SHC/ECBCS Task 34/Annex 43 (IEA 34/43). Additional building thermal fabric test cases being developed within IEA 34/43 are for testing the ability to model multizone envelope heat transfer (Neymark and Judkoff 2004). Cases for testing models of single- and multizone airflow (including infiltration) based on structural and weather conditions are also being proposed for development within IEA 34/43.

A number of other interesting areas relating to envelope models for which BESTEST cases could be developed include:

- Variation of radiant fraction of heat sources
- Moisture adsorption/desorption
- Daylighting controls.

ASHRAE has developed a series of building thermal fabric analytical verification tests under RP-1052 (Spitler, Rees, and Xiao 2001). Future work could also include field trials of these tests.

The current IEA BESTEST envelope tests should be updated periodically to include:

- New simulation results for the current set of programs, and simulation results for other detailed hourly simulation programs not currently shown
- Application of updated weather data (e.g., TMY2 or other)
- Additional radiative exchange tests (see IEA BESTEST [Judkoff and Neymark 1995a: Table 2-51])
- Other improvements that may be recommended by users.

Within IEA SHC Task 22, daylighting control empirical validation tests have been completed (Maxwell, Loutzenhiser, and Klaassen 2003). Empirical validation tests being developed within IEA 34/43 include tests for models of:

- Daylighting, shading, and related load interaction
- Double-skin buildings.

Based on the outcome of the IEA 34/43 projects, development of additional empirical validation test cases related to modeling the building thermal fabric may be proposed in the future.

2.6 Conclusions and Recommendations

2.6.1 Conclusions

Additional test cases for mechanical space cooling equipment have been added to the International Energy Agency's (IEA)'s existing method for systematically comparing whole-building energy software and determining the algorithms responsible for prediction differences. Similar to previous test suites that applied the Building Energy Simulation Test and Diagnositc Method (BESTEST), these new cases have a variety of uses, including:

- Comparing several building energy simulation programs to determine the degree of disagreement among them
- Diagnosing the algorithmic sources of prediction differences among several building energy simulation programs
- Comparing predictions from other building energy programs to the simulation results in this report
- Checking a program against a previous version of itself after the internal code has been modified, to ensure that only the intended changes actually resulted
- Checking a program against itself after a single algorithmic change to understand the sensitivity among algorithms.

Previous BESTEST procedures have been adopted by codes and standards authorities in the United States. (e.g., American National Standards Institue [ANSI]/American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE] Standard 140-2001 [2001]), and adopted as software qualification tests for agencies in Europe and Australia. Further details are discussed in Section 2.6.2.

Adding new mechanical equipment tests to the existing set of envelope and mechanical equipment tests gives building energy software developers and users an expanded ability to test a program for reasonableness of results and to determine if a program is appropriate for a particular application. The current set of steady-state tests (cases E100–E200) and dynamic tests (E300–E545) represent the beginning of work in this area. Additional cases for future consideration beyond these were discussed in Section 2.5.2.

The procedure has been field-tested using a number of advanced building energy simulation programs from the United States and Europe. The method has proven effective at isolating the sources of predictive differences. The diagnostic procedures revealed bugs, faulty algorithms, limitations, and input errors in all but one of the building energy computer programs tested in this study. Table 2-7 summarizes the notable examples.

Many of the errors listed in Table 2-7 were significant, with up to 22% effect on total annual electricity consumption for some cases. Some errors had relatively minor (<2%) effect on total consumption. Where a program had multiple errors of smaller magnitude, such errors did not necessarily compensate for each other, and may have been cumulative in some cases. Therefore, correcting the minor errors as well as the major errors was important.

Table 2-7. Summary of Software Problems Found Using HVAC BESTEST Cases E300–E545

Software	Error Description[a]	% Disagreement[a,b]	Resolution
CODYRUN	Inconsistent accounting of fan heat (main issue), and dry-coil modeling in neural network performance mapping	14% compressor consumption 9% peak power (E300, E310)	Fixed
CODYRUN	Moisture balance calculation	1% compressor consumption (E360) 4%–5% peak power (E360,E300–E320)	Fixed
CODYRUN	IDB does not float above set point when equipment is overloaded	14% compr. consumption (E320–E340) 1% compressor consumption. (other E3xx) 0%–1% peak power (E300 series)	Fixed
CODYRUN	Thermal balance calculation, amalgamation of air infiltration and outside air mixing, and thermal capacitance input error	Up to 4% total consumption Up to 3% peak consumption	Fixed
CODYRUN	CDF/PLR not properly accounted for in ID and OD fan consumptions	8%–18% ID and OD fan consumption 1%–3% total consumption (E500–E525)	Fixed
CODYRUN	Neural network performance calculation	21% peak-hour sensible load (E360) 1% total consumption (E360)	Fixed
CODYRUN	Balancing of zone air conditions and equipment performance parameters	36%–53% peak latent coil load 2%–6.5% peak consumption (E520, E522)	Fixed
DOE-2.1E-ESTSC	Misleading documentation for BF = f(PLR) curve, affects cases with continuous fan operation and typical range of PLRs	30%–115% latent coil loads 7%–22% total consumption (E300–E350, E400–E440)	Authors notified, input fixed
DOE-2.1E-ESTSC	Hard-wired lower limit on EWB used with performance data	65%–109% fan consumption 6%–8% total consumption (low EDB E520, E540 only)	Fixed
DOE-2.1E-ESTSC	Single-pass HVAC calculation with 1-hour time step	20%–50% peak latent coil load (E320–E340, E400); 20%–80% peak humidity (E310, E350, E545)	No change, fixed in EnergyPlus
DOE-2.1E-ESTSC	Variation of zone humidity ratio in dry-coil cases with constant set point and cooling on	10%–25% daily humidity ratio (E530 specific day results)	No change, fixed in EnergyPlus
DOE-2.2	Incorrect entering wet-bulb temperature for high outside air with abrupt changes in conditions	20%–50% peak latent coil loads (E330, E340, E400) 1.0% total consumption (E340)	Fixed
DOE-2.2	Possible incorrect entering wet-bulb temperature for high infiltration air with abrupt changes in conditions	20%–50% peak latent coil loads (E320, E340)	Authors notified
ENERGYPLUS	Documentation improvement for when performance data for ARI rating conditions not included	Possible fatal error[c]	Fixed
ENERGYPLUS	Latent cooling load calculation	Negligible	Fixed
ENERGYPLUS	System control during part loading	1%–2% consumption[d] and total peak power (E300 series)	Fixed
ENERGYPLUS	Weather data interpolation with subhourly time steps	0%–1% consumption[d] (E300 series) 0%–2% total peak power (E300 series)	Fixed
ENERGYPLUS	Economizer compressor lockout allowed as input, but not implemented in the software	E410 gives same results as E400	Authors notified
ENERGYPLUS	Moisture balance	8%–32% humidity ratio (E500-E525); negligible consumption	Fixed
HOT3000	Outside air not properly modeled	4% total consumption, 5% sensible coil, 9% latent coil (E330 only)	Fixed
HOT3000	System performance parameters based on zone conditions from previous time step	3% peak consumption (E310, E520 only)	Authors notified

[a] Acronyms and abbreviations used in this column are defined in Section 2.7.
[b] Specific cases or conditions relevant to the described disagreement(s) are included in parentheses.
[c] Fatal error occurs if ARI-condition data point is not used for curve fit normalization.
[d] Compressor + OD fan.

Some of the errors were discovered in programs that had already corrected errors found during the HVAC BESTEST Volume 1 tests (cases E100–E200; Neymark and Judkoff 2002)—e.g., DOE-2.1E and EnergyPlus. The Volume 1 cases are in-depth diagnostic, steady-state, test cases over a limited range of operation, which have quasi-analytical solutions formulated outside of a whole-building energy simulation program. The Volume 2 test cases employ operating conditions that vary hourly and over a wider range than for Volume 1, as well as additional parametric sensitivities. Therefore, the discovery of remaining software errors using HVAC BESTEST Volume 2, after testing software with Volume 1, indicates the importance of also testing the programs with the Volume 2 test cases.

Performance of the Volume 2 tests resulted in quality improvements to all the building energy simulation programs used in the field trials except for TRNSYS-TUD (which did have software corrections in the Volume 1 tests). Some of the bugs that were found may well have been present for many years. The fact that they have just now been uncovered shows the power of BESTEST and also suggests the importance of continuing to develop formalized validation and diagnostic methods. It is only after coding bugs have been eliminated that the assumptions and approximations in the algorithms can be evaluated where necessary.

Checking a building energy simulation program for the first time with HVAC BESTEST Volume 2 (cases E300–E545) requires about 1 person-week for an experienced simulation user, not including any necessary improvements to the software. Subsequent program checks are faster because existing input decks may be reused. Because the simulation programs have taken many years to produce, HVAC BESTEST provides a very cost-effective way of testing them. As we continue to develop new test cases, we will adhere to the principle of parsimony so that the entire suite of BESTEST cases may be implemented by users within a reasonable time span.

After correcting software errors using HVAC BESTEST diagnostics, the remaining disagreements of results for annual total energy consumption for the programs are 2%–6% with very little scatter among the programs. This shows how the HVAC-BESTEST method is used to diagnose and correct faulty algorithms in complex simulation programs.

Based on results *after* several iterations of HVAC BESTESTing and resulting model improvements, the tested programs now appear reliable for performance-map modeling of space-cooling equipment over an expanded range of dynamic performance conditions. The programs also appear reliable for modeling outside air mixing, infiltration, thermostat set up, overloaded conditions, and various economizer control schemes. This set of results may therefore be used as a reference or benchmark against which other software can be tested.

In contrast with steady-state cases E100–E200, which were solved analytically, the more realistic nature of cases E300–E545 allows us to gauge the importance of differences in simulation results, and if desired, annual energy cost (although not done here). This is a good way to understand the importance of the differences in results. For example, a large percentage difference for a given result that has only a very small impact on annual energy use may not be of concern, whereas a small percentage difference with a large impact on annual energy use may be deemed important. The internal gains schedules for cases E300–E545 combine aspects of both building thermal fabric loads and typical internal gains loading. Because there is almost no uncertainty regarding the load to which the mechanical system is responding, all disagreements in simulation results may be attributed to the HVAC system models. It is therefore apparent from the initial results for Case E300 that faulty algorithms in mechanical equipment models can easily account for 10%–20% errors in energy consumption estimates for real buildings; this was after some of the programs had already corrected errors found from running cases E100–E200.

In practice, simulation tools often use data from the manufacturer to predict energy performance. Manufacturers typically supply catalog equipment performance data for equipment selection at given common design load conditions. Data for atypical conditions, which can commonly occur in buildings with outside air requirements or high internal gains, are not generally included. Significant effort was required to obtain the expanded performance data set needed for cases E300–E545. We reviewed three manufacturer equipment selection software packages typically used by HVAC engineers for specifying equipment. None of these, however, were satisfactory for developing the range of data we desired; the performance data we ultimately obtained were custom-generated by a manufacturer. In general if the state of the art in annual simulation of mechanical systems is to improve, manufacturers need to either readily provide expanded data sets on the performance of their equipment, or improve existing equipment selection software to facilitate generation of such data sets.

Within the BESTEST structure, there is room to add new test cases when required. BESTEST is better developed in areas related to energy flows and energy storage in the architectural fabric of the building. BESTEST work related to mechanical equipment is still in its early phases. Other BESTEST-type test suites that have been developed within IEA Solar Heating and Cooling Programme (SHC) Task 22 include

- HVAC BESTEST Fuel-Fired Furnace Test Cases (Purdy and Beausoleil-Morrison 2003)
- RADTEST Radiant Heating and Cooling Test Cases for hydronic systems (Achermann and Zweifel 2003).

IEA SHC Task 22 began developing improvements to existing BESTEST building thermal fabric test cases with ground-coupled heat transfer through floor slabs and basement walls (Deru, Judkoff, and Neymark 2003). This work is continuing under new IEA SHC/Energy Conservation in Buildings and Community Systems (ECBCS) Task 34/Annex 43 (Judkoff and Neymark 2004).

For the longer term we hope to add test cases that emphasize special modeling issues associated with more complex building types and HVAC systems as listed in Section 2.5.2.

2.6.2 Recommendations

The work presented in this report, and the work that has preceded it in IEA SHC Tasks 8, 12 (ECBCS Annex 21), and 22 is significant for two reasons. First, the methods have been extremely successful at correcting software errors in advanced building energy simulation programs throughout the world. Second, the methods are finding their way into industry by being adopted as the theoretical basis for formalized standard methods of test and software certification schemes; in this sense the work may be thought of as pre-normative research.

The previous IEA BESTEST envelope test cases (Judkoff and Neymark 1995a) and the overall validation methodology (Judkoff et al. 1983; Judkoff 1988) have been code-language adapted and formally approved as a standard method of test, ASHRAE Standard 140-2001 (ANSI/ASHRAE 2001). ASHRAE Standard 90.1 (ANSI/ASHRAE/Illuminating Engineering Society of North America [IESNA] 2004) requires that software used for demonstrating performance compliance with Standard 90.1 be tested using ASHRAE Standard 140. Standard 90.1 is ASHRAE's consensus energy code for commercial buildings, and other non-low-rise residential buildings. IEA BESTEST is also being used for simulation certification tests in The Netherlands (ISSO 2003) and Australia (SEDA 2003; Pears 1998).

The HVAC BESTEST Volume 1, cases E100–E200 (Neymark and Judkoff 2002) have been code-language adapted and formally approved as Addendum *a* to ASHRAE Standard 140 (ANSI/ASHRAE 2004). HVAC BESTEST Fuel-Fired Furnace Test Cases (Purdy and Beausoleil-Morrison 2003) are being code-language adapted for Standard 140. We anticipate that HVAC BESTEST Volume 2 cases E300–E545, other work from IEA SHC Task 22, and new work from IEA SHC/ECBCS Task 34/Annex 43 will also be added to Standard 140 in the future. In the United States, the National Association of State Energy Officials (NASEO) Residential Energy Services Network (RESNET) has adopted HERS BESTEST (Judkoff and Neymark 1995b) as the basis for certifying software to be used for Home Energy Rating Systems under the NASEO/RESNET national accreditation standard (NASEO/RESNET 2002). HERS BESTEST is also being code-language adapted for future inclusion with ASHRAE Standard 140 (SSPC-140 2004).

The BESTEST procedures are also being used as teaching tools for simulation courses at universities in the United States and Europe. We hope that as the procedures become better known, developers will automatically run the tests as part of their normal in-house quality control efforts. The large number of requests (more than 1000) that we have received for the various BESTEST reports indicates that this is beginning to happen. For example, we recently learned that Carrier Corporation and Trane, which are among the largest suppliers of HVAC equipment in the world, are testing their respective software HAP and TRACE with Standard 140. Also, EnergyPlus, the United States Department of Energy’s most advanced simulation program for building energy analysis, distributes their Standard 140 validation results with their CDs and from their website.

Because new energy-related technologies are continually being introduced into the buildings market, there will always be a need for further development of simulation models, combined with a substantial program of testing and validation. Such an effort should contain all the elements of an overall validation methodology (see HVAC BESTEST Volume 1 [Neymark and Judkoff 2002: Background Section]), including:

- Analytical verification
- Comparative testing and diagnostics
- Empirical validation.

Future work should therefore encompass:

- Continued production of a standard set of analytical tests
- Development of a set of diagnostic comparative tests that emphasize the modeling issues important in large commercial buildings, such as zoning, infiltration airflow rate determination, and more tests for heating, ventilating, and air-conditioning systems
- Development of a sequentially ordered series of high-quality data sets for empirical validation.

Continued support of model development and validation activities is essential because occupied buildings are not amenable to classical controlled, repeatable experiments. The few buildings that are truly useful for empirical validation studies have been designed primarily as test facilities. The energy, comfort, and lighting performance of buildings depend on the interactions among a large number of transfer mechanisms, components, and systems. Simulation is the only practical way to bring a systems integration problem of this magnitude within the grasp of designers. Greatly reducing the energy intensity of buildings through better design is possible with the use of simulation tools (Torcellini, Hayter, and Judkoff 1999). However, building energy simulation programs will not be widely used unless the design and engineering communities have confidence in these programs. Confidence and quality can best be encouraged by combining a rigorous development and validation effort with user-friendly interfaces.

Development and validation of whole-building energy simulation programs is one of the most important activities meriting the support of national energy research programs. The IEA Executive Committees for Solar Heating and Cooling and for Energy Conservation in Buildings and Community Systems should diligently consider what sort of future collaborations would best support this essential research area.

2.7 Abbreviations and Acronyms for Part II

These acronyms are used in Sections 2.2 through 2.6.

ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BESTEST	Building Energy Simulation Test
BF	bypass factor
CAPgtc	gross total capacity
CDF	COP degradation factor is a multiplier (≤1) applied to the full-load system COP; CDF is a function of PLR
CETC	CANMET Energy Technology Centre, Natural Resources Canada
Compr.	compressor
COP	coefficient of performance; for definition, see Part I, Appendix C (Glossary)
COP2	(or COP_2) is the ratio, using same units, of the gross total evaporator coil load to the sum of the compressor and outdoor condenser fan energy consumptions
Ctrl	control
DOE	U.S. Department of Energy
Ec.	economizer
ECBCS	Energy Conservation in Buildings and Community Systems programme (of the IEA)
EDB	entering dry-bulb temperature, the temperature that a thermometer would measure for air entering the evaporator coil
ESTSC	Energy Science and Technology Software Center (of the U.S. Department of Energy)
EWB	entering wet-bulb temperature; for definition, see Part I, Appendix C (Glossary)
GARD	GARD Analytics
HERS	Home Energy Rating System
HVAC	heating, ventilating, and air-conditioning
ID	indoor
IDB	indoor dry-bulb temperature; for definition, see Part I, Appendix C (Glossary)
IEA	International Energy Agency

IEA 34/43	International Energy Agency joint Solar Heating and Cooling Programme Task 34 and Energy Conservation in Buildings and Community Systems Programme Annex 43
IESNA	Illuminating Engineering Society of North America
Inf	infiltration
Infl	infiltration
IP	inch-pound
ISSO	Instituut voor Studie en Stimulering van Onderzoek op het Gebied van Gebouwinstallaties (Netherlands)
LBNL	Lawrence Berkeley National Laboratory
Max	maximum
Min	minimum
NASEO	National Association of State Energy Officials
NREL	National Renewable Energy Laboratory
OA	outside air
OD	outdoor
ODB	outdoor dry-bulb temperature; for definition, see Part I, Appendix C (Glossary)
OHR	outdoor humidity ratio
PLR	part-load ratio; for definition, see Part I, Appendix C (Glossary)
Qgtc	gross total coil load
RADTEST	radiant heating and cooling test cases
RESNET	Residential Energy Services Network
RH	relative humidity
SEDA	Sustainable Energy Development Authority (Australia)
SHC	Solar Heating and Cooling Programme (of the IEA)
SI	Système Internationale
SSPC	Standing Standard Project Committee (of ASHRAE)
TMY2	Typical Meteorological Year 2
Tstat	thermostat
TUD	Technische Universität Dresden
UR	University of Reunion Island

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2.9 APPENDIX II: Simulation Modeler Reports

In Appendix II, we present reports written by the modeler(s) for each simulation program. The modelers were asked to document:

- Modeling assumptions (required inputs not explicitly described in the test specification)
- Modeling options (alternative modeling techniques)
- Difficulties experienced in developing input files for the test cases with their program
- Bugs, faulty algorithms, documentation problems, or input errors uncovered using the HVAC BESTEST diagnostics
- Source code or input modifications made because of the diagnostic results
- Comments on agreement or disagreement of results compared to other simulation results
- Any odd results obtained with their programs
- Sensitivity studies conducted to further understand the sources of differences between their programs and the others
- Conclusions and recommendations about their simulation programs, HVAC BESTEST, or both.

Modelers also filled out a pro-forma description that defines many of the algorithms within their programs. These pro-forma reports, which appear as they were submitted with minimal reformatting and editing, are presented at the end of each modeler report, except for Appendix II-D.

Appendix II-A

HVAC BESTEST MODELER REPORT FOR CASES E300–E545 ENERGYPLUS VERSION 1.1.0.020

PREPARED BY
R. HENNINGER AND M. WITTE, GARD ANALYTICS, INC.
D. CRAWLEY, U.S. DEPT. OF ENERGY

JULY 2003

1. Introduction

Software:	EnergyPlus Version 1.1.0.020
Authoring Organization:	Lawrence Berkeley National Laboratory, U.S. Department of Energy; University of Illinois
Authoring Country:	United States

This report describes the modeling methodology and results for several rounds of testing done for the IEA HVAC BESTEST Cases E300 through E545 that were simulated using the EnergyPlus software. During the early rounds of testing only cases E300–E360 were analyzed. Beginning with Round 3C, the results for cases E400–E440 and cases E500–E545 are also included. The specifications for the model building and HVAC equipment for each case are described in *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 2: Cases E300–E545,* J. Neymark and R. Judkoff, National Renewable Energy Laboratory, September 2002 (referred to as the BESTEST specification in this report).

2. Modeling Methodology

For modeling of the simple unitary vapor compression cooling system, the EnergyPlus Unitary Air-to-Air Heat Pump model was utilized. The Heat Pump model was the only DX cooling system available in EnergyPlus that allowed a draw-through fan configuration. Since cooling only was required during the simulation, the heat pump controls were set to prevent operation of the heat pump in the heating mode. As configured for this test series, the following heat pump modules were exercised: a DX cooling coil, an indoor fan and outside air mixer.

The building envelope loads and internal loads were calculated each hour to determine the zone load that the mechanical HVAC system must satisfy. The EnergyPlus DX coil model then uses performance information at rated conditions along with curve fits for variations in total capacity, energy input ratio and part-load fraction to determine performance at part-load conditions. Sensible/latent capacity splits are determined by the rated sensible heat ratio (SHR) and the apparatus dew point/bypass factor approach.

The EnergyPlus DX coil model requires that the rated total cooling capacity, rated sensible heat ratio, rated COP and rated air volume flow rate be specified for the ARI rating condition of 35°C outside air dry-bulb, 26.7°C entering evaporator dry-bulb and 19.4°C entering evaporator wet-bulb. Since the equipment performance data as provided in the BESTEST specification dated March 2002 did not include equipment performance data at the ARI rating point, the performance data were first curve fit and then the resulting curves were used to determine the cooling capacity, energy consumption and SHR at the ARI rating condition. In September 2002, revised specifications were provided which included performance at the ARI rating point. The revised rating point was used in Round 3B and later.

Five equipment performance curves were required:

1) The Total Cooling Capacity Modifier Curve (function of temperature) is a bi-quadratic curve with two independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and outdoor dry-bulb temperature (ODB) of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated total cooling capacity to give the total cooling capacity at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

2) The Total Cooling Capacity Modifier Curve (function of flow fraction) is a quadratic curve with the independent variable being the ratio of the actual airflow rate across the cooling coil to the rated airflow rate (i.e., fraction of full-load flow). The output of this curve is multiplied by the rated total cooling capacity and the total cooling capacity modifier curve (function of temperature) to give the total cooling capacity at the specific temperature and airflow conditions at which the coil is operating.

3) The Energy Input Ratio (EIR) Modifier Curve (function of temperature) is a bi-quadratic curve with two independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and outdoor dry-bulb temperature (ODB) of the air entering the air-cooled condenser. The output of this curve is multiplied by the rated EIR (inverse of the rated COP) to give the EIR at specific temperature operating conditions (i.e., at temperatures different from the rating point temperatures).

4) The Energy Input Ratio (EIR) Modifier Curve (function of flow fraction) is a quadratic curve with the independent variable being the ratio of the actual airflow rate across the cooling coil to the rated airflow rate (i.e., fraction of full-load flow). The output of this curve is multiplied by the rated EIR (inverse of the rated COP) and the EIR modifier curve (function of temperature) to give the EIR at the specific temperature and airflow conditions at which the coil is operating.

5) The part-load fraction correlation (function of part-load ratio) is a quadratic curve with the independent variable being part-load ratio (sensible cooling load/steady-state sensible cooling capacity). The output of this curve is used in combination with the rated EIR and EIR modifier curves to give the "effective" EIR for a given simulation time step. The part-load fraction correlation accounts for efficiency losses due to compressor cycling.

3. Modeling Assumptions

Thermostat Control

Ideal thermostat control was assumed with no throttling range.

ARI Rating Point Conditions

Since the modeling specifications (March 2002) did not list the equipment performance at the ARI rated conditions of 35°C outside air dry-bulb, 26.7°C entering evaporator dry-bulb and 19.4°C entering evaporator wet-bulb, an initial set of performance curves were developed using 35°C/26.7°C/18.33°C as the nominal point. This, however, caused problems with the simulation (see Section 5). These initial curve fits were then used to interpolate and determine the following estimated ARI standard rated performance:

Rated gross cooling capacity	33.084 kW
Rated sensible heat ratio	0.8043
Rated COP	3.028
Rated energy consumption	10.924 kW

The rated energy consumption includes the compressor (9.994 kW) and outdoor condenser fans (0.93 kW). These values were revised in Round 3B when an updated HVAC BESTEST E300-E400-E500 test specification was issued in March 2002, which contained the manufacturer performance data for ARI standard conditions.

DX Coil Curve Fits

Equipment performance data from Table 1-7b [Part I] Equipment Full-Load Performance with Gross Capacities – SI Units of the BESTEST specification were used to develop the input parameters required for the EnergyPlus performance curves. Although performance data for a range of entering dry-bulb temperatures (EDB) is given in the table, the EnergyPlus performance curves were developed for the ARI rated condition of 26.67°C EDB. The resulting coefficients are presented below. These curves are normalized around the standard ARI rating conditions of 35°C outside air dry-bulb, 26.7°C entering evaporator dry-bulb and 19.4°C entering evaporator wet-bulb.

1) **Total cooling capacity modifier curve** (function of temperature)
Form: Bi-quadratic curve
curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
Independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and dry-bulb temperature of the air entering (ODB) the air-cooled condenser.

a =	0.953441251
b =	-0.000938414
c =	0.000932679
d =	-0.001299058
e =	-2.67478E-05
f =	-0.000306850

These values were revised in Round 3B.

2) **Total cooling capacity modifier curve** (function of flow fraction)
Form: Quadratic curve
curve = a + b*FF + c*FF**2
Independent variables: ratio of the actual airflow rate across the cooling coil to the rated airflow rate (i.e., fraction of full-load flow, FF).

Since indoor fan always operates at constant volume flow, modifier will be 1.0, therefore:

a = 1.0
b = 0.0
c = 0.0

3) **Energy input ratio (EIR) modifier curve** (function of temperature)
Form: Bi-quadratic curve
curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
Independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and dry-bulb temperature of the air entering (ODB) the air-cooled condenser.

a = 0.537791667
b = -0.000895849
c = -0.000154388
d = 0.012700780
e = 0.000162966
f = -0.000157276

These values were revised in Round 3B.

4) **Energy input ratio (EIR) modifier curve** (function of flow fraction)
Form: Quadratic curve
curve = a + b*FF + c*FF**2
Independent variables: ratio of the actual airflow rate across the cooling coil to the rated airflow rate (i.e., fraction of full-load flow, FF).

Since indoor fan always operates at constant volume flow, modifier will be 1.0, therefore:

a = 1.0
b = 0.0
c = 0.0

5) **Part-load fraction correlation** (function of part-load ratio, PLR)
Form: Quadratic curve
curve = a + b*PLR + c*PLR**2
Independent variable: part-load ratio (sensible cooling load/steady state sensible cooling capacity)

Part-load performance specified in Figure 1-3 [Part I] of the BESTEST specification, therefore:

a = 0.771
b = -0.229
c = 0.0

4. Modeling Difficulties

Building Envelope Construction

The BESTEST specification for the building envelope indicates that the exterior walls, roof and floor are made up of one opaque layer of insulation (R=325, SI units) with differing radiative properties for the interior surface and exterior surface (ref. Table 1-5 [Part I] of BESTEST specification). To allow the surface radiative properties to be set at different values, the exterior wall, roof and floor had to be simulated as two insulation layers, each with an R=162.5. The EnergyPlus description for this construction was as follows:

```
MATERIAL:Regular-R,
        INSULATION-EXT,             ! Material Name
        VerySmooth,                 ! Roughness
        162.5,                      ! Thermal Resistance {m2-K/W}
        0.9000,                     ! Thermal Absorptance
        0.1000,                     ! Solar Absorptance
        0.1000;                     ! Visible Absorptance

MATERIAL:Regular-R,
        INSULATION-INT,             ! Material Name
        VerySmooth,                 ! Roughness
        162.5,                      ! Thermal Resistance {m2-K/W}
        0.9000,                     ! Thermal Absorptance
        0.6000,                     ! Solar Absorptance
        0.6000;                     ! Visible Absorptance

CONSTRUCTION,
        LTWALL,                     ! Construction Name
              ! Material layer names follow:
        INSULATION-EXT,
        INSULATION-INT;
```

Compressor and Condenser Fan Breakout

The rated COP required as input by the EnergyPlus DX coil model requires that the input power be the combined power for the compressor and condenser fans. As such, there are no separate input variables or output variables available for the compressor or condenser fan. The only output variable available for reporting in EnergyPlus is the DX coil electricity consumption, which includes compressor plus condenser fan.

5. Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 1

1) Rated Performance and Bypass Factor Calculations

As mentioned in Section 3, the initial set of performance data was based on using 18.33°C EWB, because this was directly available from the performance data tables. Even though the EnergyPlus documentation stated clearly that the rated performance inputs were to be entered for rated ARI conditions (19.4°C

EWB), it was wrongly assumed that a different entering condition could be used as long as the performance curves were normalized around the same condition. This caused a fatal error, because EnergyPlus attempts to calculate a rated bypass factor by starting with entering air at ARI standard conditions and then applying the nominal total capacity and SHR. Using a data point corresponding to a drier entering condition caused the leaving air to be supersaturated and the bypass factor search algorithm failed. Further investigation by the EnergyPlus development team resulted in source code changes for additional error checking in the DX coil routines and an improved error message to help users know how to solve this problem.

2) Temperatures Out of Control

The draft BESTEST specification dated March 2002 did not contain any empirical results or results from other programs to compare to, so it is not possible to determine for certain if any software errors exist. One potential problem was identified, however. For cases E300 and E310, the air-conditioner did not maintain the space temperature at the required 25°C. There were hours during periods of low or no internal loads, November 6 for example, when the air-conditioner did not cycle on to provide cooling and subsequently the space temperature rose to as high as 30°C. A change request (bug report) was submitted. The software will be examined to determine why the air-conditioner would not operate during low part-load conditions.

6. Results – Round 1

Results from the Round 1 modeling with EnergyPlus Version 1.0.2.004 are presented below.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Evaporator Coil Load Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	35149	24287	Note 1	10862	77308	55108	22199	3.18	24.11	0.0093	48.7	19.9	0.0116
E310	39999	29137	Note 1	10862	97350	55157	42193	3.34	24.10	0.0114	59.0		
E320	39274	28411	Note 1	10862	94961	61250	33712	3.34	24.26	0.0101	52.0		
E330	40373	29511	Note 1	10862	101066	62845	38221	3.42	24.29	0.0100	51.3		
E340	39997	29135	Note 1	10862	98579	62053	36526	3.38	24.31	0.0100	51.2		
E350	31447	20585	Note 1	10862	65640	48271	17369	3.19	26.26	0.0100	45.3		
E360	55351	44489	Note 1	10862	160883	134944	25940	3.62	25.41	0.0088	42.4		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima: Weather Data Checks					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads: Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11841	07/08	15:00	23280	08/16	15:00	10406	09/03	15:00	32620	07/08	15:00	34.775	07/20	14:00	0.0218	10/02	08:00
E310	12574	08/16	15:00	22975	07/11	16:00	16529	09/18	15:00	37342	09/03	16:00						
E320	13049	07/20	14:00	31697	04/24	15:00	21150	10/01	20:00	39583	09/03	16:00						
E330	13436	07/20	14:00	34709	06/14	13:00	27032	09/18	15:00	42547	10/02	09:00						
E340	13265	07/20	14:00	32657	05/16	15:00	23236	10/02	09:00	40741	09/03	15:00						
E350	11841	07/08	15:00	23280	08/16	15:00	10425	10/02	08:00	32620	07/08	15:00						
E360	12910	07/20	14:00	32542	04/24	15:00	8471	09/03	17:00	38331	09/03	12:00						

Hour	June 28 Hourly Output - Case E300											
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor	Cond Fan	Total	Sensible	Latent	Hum. Rat.	COP2	ODB	EDB	EWB	Hum. Rat.
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	2175	Note 1	7507	5853	1653	0.0094	3.45	18.1	24.0		0.0113
2	2155	Note 1	7454	5809	1645	0.0094	3.46	18.0	23.9		0.0112
3	2116	Note 1	7338	5744	1594	0.0093	3.47	17.8	23.9		0.0111
4	2037	Note 1	7096	5614	1482	0.0092	3.48	17.4	23.9		0.0105
5	2184	Note 1	7430	6015	1415	0.0090	3.40	18.6	24.0		0.0106
6	2924	Note 1	9221	7531	1689	0.0093	3.15	22.9	24.7		0.0123
7	3563	Note 1	10614	8756	1859	0.0096	2.98	26.4	25.2		0.0118
8	3862	Note 1	11106	9419	1687	0.0096	2.88	28.3	25.5		0.0116
9	4928	Note 1	14389	11995	2393	0.0099	2.92	28.9	25.6		0.0124
10	5467	Note 1	15785	12488	3297	0.0105	2.89	30.3	25.8		0.0140
11	5729	Note 1	16519	12671	3848	0.0109	2.88	30.8	25.9		0.0138
12	5605	Note 1	16018	12705	3312	0.0107	2.86	30.9	25.9		0.0120
13	7212	Note 1	21103	17594	3508	0.0102	2.93	31.5	26.0		0.0115
14	7259	Note 1	20979	17785	3194	0.0100	2.89	32.0	26.1		0.0121
15	8968	Note 1	27032	22559	4472	0.0100	3.01	32.2	26.1		0.0135
16	9036	Note 1	27537	22458	5079	0.0102	3.05	31.9	26.0		0.0145
17	5818	Note 1	16600	12868	3733	0.0108	2.85	31.3	26.0		0.0153
18	5620	Note 1	16757	12171	4586	0.0112	2.98	29.4	25.7		0.0149
19	5353	Note 1	16539	11556	4983	0.0113	3.09	27.6	25.4		0.0159
20	5429	Note 1	17030	11414	5616	0.0117	3.14	27.2	25.3		0.0168
21	4416	Note 1	13615	8952	4663	0.0118	3.08	26.9	25.3		0.0168
22	4273	Note 1	13287	8753	4534	0.0117	3.11	26.3	25.2		0.0168
23	4236	Note 1	13230	8674	4556	0.0117	3.12	26.1	25.2		0.0171
24	4007	Note 1	12742	8297	4444	0.0117	3.18	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	C O P 2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	4.33	11/06	17:00	2.75	06/14	12:00	30.7	11/06	16:00	8.7	01/06	05:00
E310	4.31	11/06	17:00	2.84	12/01	14:00	30.7	11/06	16:00	8.7	01/06	05:00
E320	4.26	11/06	17:00	2.79	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.33	11/06	17:00	2.80	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	4.33	11/06	17:00	2.80	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.59	10/13	01:00	1.60	04/28	07:00	38.1	10/12	07:00	8.7	01/06	05:00
E360	4.40	10/04	23:00	2.80	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00
E310	0.0159	10/02	08:00	0.0020	01/05	07:00	79.9	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	13.2	11/06	15:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	13.0	11/06	15:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	13.0	11/06	15:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.4	11/16	16:00	13.0	11/06	15:00

7. Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 3A

Note: Other whole-building energy analysis simulation programs participating in this IEA comparative study have gone through two rounds of testing while EnergyPlus, which joined in later, has only gone through one round of testing. To be consistent with results that will be reported by other program participants, the latest round of testing with EnergyPlus as reported below is being referred to as Round 3 testing and results.

As a result of testing done during Round 1, two changes were made to the EnergyPlus code to correct algorithm errors and bring results more in line with what the BESTEST specification called for.

1) Latent Cooling Loads
In EnergyPlus Version 1.0.3.001, an hg function replaced the hfg function in the psychrometric routines. This change produced only small changes in the results.

2) Dry-Coil Conditions
An error found during Round 1 with calculating outlet conditions (humidity ratio and temperature) from the cooling coil when dry conditions (no dehumidification) occurred was corrected in EnergyPlus Version 1.0.3.005. This error was causing the heat pump not to operate during certain hours. NREL also noted this problem with the EnergyPlus results in their report and discussion on the latest results dated July 11, 2002. The change made to the code to correct this problem in EnergyPlus Version 1.0.3.005 corrected the zone temperature control problems in cases E300 and E310 and corrected the low minimum COP that had occurred in case E350.

8. Results – Round 3A

Results from the Round 3A modeling with EnergyPlus Version 1.0.3.005 are presented below.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34879	24016	Note 1	10862	77352	55255	22097	3.22	24.09	0.0093	48.6	19.9	0.0116
E310	39445	28583	Note 1	10862	96434	55232	41201	3.37	24.09	0.0113	58.6		
E320	38983	28121	Note 1	10862	95107	61455	33652	3.38	24.24	0.0101	51.9		
E330	40074	29212	Note 1	10862	101239	63043	38196	3.47	24.27	0.0100	51.2		
E340	39694	28832	Note 1	10862	98715	62234	36482	3.42	24.29	0.0100	51.2		
E350	31256	20394	Note 1	10862	65804	48541	17263	3.23	26.24	0.0099	45.2		
E360	54849	43987	Note 1	10862	160937	135106	25831	3.66	25.38	0.0088	42.3		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads									Weather Data Checks					
				Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11703	07/08	15:00	23280	08/16	15:00	10355	09/03	15:00	32570	07/08	15:00	34.775	07/20	14:00	0.0218	10/02	08:00
E310	12423	08/16	15:00	23003	07/11	16:00	16224	09/18	15:00	37073	09/03	16:00						
E320	12907	07/20	14:00	31693	04/24	15:00	21134	10/01	20:00	39574	09/03	16:00						
E330	13291	07/20	14:00	34709	06/14	13:00	27032	09/18	15:00	42547	10/02	09:00						
E340	13121	07/20	14:00	32676	05/16	15:00	23232	10/02	09:00	40738	10/02	09:00						
E350	11703	07/08	15:00	23280	08/16	15:00	10425	10/02	08:00	32570	07/08	15:00						
E360	12766	07/20	14:00	32539	04/24	15:00	8426	09/03	17:00	38300	09/03	12:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2149	Note 1	7506	5853	1653	0.0094	3.49	18.1	24.0		0.0113
2	2129	Note 1	7454	5809	1645	0.0094	3.50	18.0	23.9		0.0112
3	2091	Note 1	7338	5744	1594	0.0093	3.51	17.8	23.9		0.0111
4	2013	Note 1	7096	5614	1482	0.0092	3.53	17.4	23.9		0.0105
5	2158	Note 1	7430	6015	1415	0.0090	3.44	18.6	24.0		0.0106
6	2889	Note 1	9221	7531	1689	0.0093	3.19	22.9	24.7		0.0123
7	3520	Note 1	10614	8756	1859	0.0096	3.02	26.4	25.2		0.0118
8	3817	Note 1	11106	9419	1687	0.0096	2.91	28.3	25.5		0.0116
9	4868	Note 1	14383	11995	2388	0.0099	2.95	28.9	25.6		0.0124
10	5395	Note 1	15758	12488	3270	0.0105	2.92	30.3	25.8		0.0140
11	5651	Note 1	16484	12671	3813	0.0109	2.92	30.8	25.9		0.0138
12	5529	Note 1	15983	12705	3277	0.0107	2.89	30.9	25.9		0.0120
13	7115	Note 1	21059	17594	3465	0.0101	2.96	31.5	26.0		0.0115
14	7163	Note 1	20939	17785	3154	0.0100	2.92	32.0	26.1		0.0121
15	8850	Note 1	26984	22559	4424	0.0100	3.05	32.2	26.1		0.0135
16	8918	Note 1	27492	22458	5034	0.0101	3.08	31.9	26.0		0.0145
17	5740	Note 1	16570	12868	3702	0.0108	2.89	31.3	26.0		0.0153
18	5544	Note 1	16721	12171	4550	0.0112	3.02	29.4	25.7		0.0149
19	5280	Note 1	16502	11557	4946	0.0113	3.13	27.6	25.4		0.0159
20	5355	Note 1	16992	11414	5578	0.0116	3.17	27.2	25.3		0.0168
21	4357	Note 1	13589	8952	4637	0.0118	3.12	26.9	25.3		0.0168
22	4220	Note 1	13279	8753	4525	0.0117	3.15	26.3	25.2		0.0168
23	4185	Note 1	13227	8674	4553	0.0117	3.16	26.1	25.2		0.0171
24	3959	Note 1	12741	8297	4444	0.0117	3.22	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.89	04/30	16:00	2.79	06/14	12:00	25.0	09/23	07:00	8.7	01/06	05:00
E310	4.12	04/30	15:00	2.87	12/01	14:00	26.4	07/08	16:00	8.7	01/06	05:00
E320	3.89	09/16	15:00	2.83	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.06	06/17	16:00	2.83	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	3.96	09/16	16:00	2.83	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.57	10/13	01:00	2.79	06/14	12:00	35.0	09/23	07:00	8.7	01/06	05:00
E360	4.45	10/04	23:00	2.83	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00
E310	0.0158	10/02	08:00	0.0020	01/05	07:00	79.4	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	14.7	11/06	05:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	14.5	11/06	05:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	14.5	11/06	05:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.3	11/16	16:00	14.5	11/06	05:00

9. Input Changes – Round 3B

As was discussed in Section 3, the equipment performance data provided in the March 2002 version of the HVAC BESTEST, Volume 2 specification did not contain data for the ARI rating condition of 35°C ODB/26.7°C EDB/19.4°C EWB. EnergyPlus uses this data point to normalize the performance data and produce curve fits for capacity and energy input. The September 2002 version of the specification now includes performance for the ARI rating point. A new set of curve fits was therefore generated for EnergyPlus based on this new data point. The coefficients for those curves that changed are shown below. The coefficients for the other EnergyPlus curves as described in Section 3 remained unchanged.

1) **Total cooling capacity modifier curve** (function of temperature)
Form: Bi-quadratic curve
curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
Independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and dry-bulb temperature of the air entering (ODB) the air-cooled condenser.

a = 0.952735372
b = -0.000932873
c = 0.000927172
d = -0.001291389
e = -2.65899E-05
f = -0.000305038

2) **Energy input ratio (EIR) modifier curve** (function of temperature)
Form: Bi-quadratic curve
curve = a + b*EWB + c*EWB**2 + d*ODB + e*ODB**2 + f*EWB*ODB
Independent variables: wet-bulb temperature of the air entering (EWB) the cooling coil, and dry-bulb temperature of the air entering (ODB) the air-cooled condenser.

a = 0.535665387
b = -0.000900699
c = -0.000155223
d = 0.012769543
e = 0.000163848
f = -0.000158128

Use of the new curve fits lowered the annual cooling energy consumption slightly, which resulted in a correspondingly small increase in the COP.

10. Results – Round 3B

Results from the Round 3B modeling with EnergyPlus Version 1.0.3.005 are presented below.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone	Zone		Outdoor
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Humidity Ratio (kg/kg)	Relative Humidity (%)	ODB (°C)	Humidity Ratio (kg/kg)
E300	34719	23857	Note 1	10862	77332	55255	22077	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39250	28388	Note 1	10862	96412	55231	41181	3.40	24.09	0.0113	58.6		
E320	38785	27923	Note 1	10862	95041	61439	33601	3.40	24.25	0.0101	51.9		
E330	39859	28997	Note 1	10862	101146	63023	38122	3.49	24.27	0.0100	51.2		
E340	39486	28624	Note 1	10862	98636	62216	36420	3.45	24.29	0.0100	51.2		
E350	31119	20257	Note 1	10862	65782	48540	17241	3.25	26.24	0.0099	45.2		
E360	54530	43668	Note 1	10862	160828	135068	25760	3.68	25.39	0.0088	42.3		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads									Weather Data Checks					
				Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11643	07/08	15:00	23280	08/16	15:00	10350	09/03	15:00	32565	07/08	15:00	34.775	07/20	14:00	0.0218	10/02	08:00
E310	12349	08/16	15:00	23004	07/11	16:00	16215	09/18	15:00	37057	09/03	16:00						
E320	12825	07/20	14:00	31671	04/24	15:00	21097	10/01	20:00	39512	09/03	16:00						
E330	13200	07/20	14:00	34708	06/14	13:00	26976	09/18	15:00	42458	10/02	09:00						
E340	13034	07/20	14:00	32676	05/16	15:00	23182	10/02	09:00	40665	10/02	09:00						
E350	11643	07/08	15:00	23280	08/16	15:00	10424	10/02	08:00	32565	07/08	15:00						
E360	12689	07/20	14:00	32527	04/24	15:00	8403	09/03	17:00	38262	09/03	12:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2133	Note 1	7503	5853	1650	0.0094	3.52	18.1	24.0		0.0113
2	2113	Note 1	7451	5809	1642	0.0094	3.53	18.0	23.9		0.0112
3	2075	Note 1	7335	5744	1591	0.0093	3.54	17.8	23.9		0.0111
4	1997	Note 1	7093	5614	1479	0.0092	3.55	17.4	23.9		0.0105
5	2141	Note 1	7427	6015	1412	0.0090	3.47	18.6	24.0		0.0106
6	2869	Note 1	9217	7531	1686	0.0093	3.21	22.9	24.7		0.0123
7	3497	Note 1	10611	8756	1855	0.0096	3.03	26.4	25.2		0.0118
8	3793	Note 1	11102	9419	1684	0.0096	2.93	28.3	25.5		0.0116
9	4838	Note 1	14379	11995	2383	0.0099	2.97	28.9	25.6		0.0124
10	5362	Note 1	15754	12488	3266	0.0105	2.94	30.3	25.8		0.0140
11	5617	Note 1	16480	12671	3809	0.0109	2.93	30.8	25.9		0.0138
12	5496	Note 1	15979	12705	3273	0.0107	2.91	30.9	25.9		0.0120
13	7074	Note 1	21054	17594	3460	0.0101	2.98	31.5	26.0		0.0115
14	7121	Note 1	20935	17785	3150	0.0100	2.94	32.0	26.1		0.0121
15	8799	Note 1	26978	22559	4419	0.0100	3.07	32.2	26.1		0.0135
16	8866	Note 1	27488	22458	5029	0.0101	3.10	31.9	26.0		0.0145
17	5707	Note 1	16567	12868	3699	0.0108	2.90	31.3	26.0		0.0153
18	5509	Note 1	16717	12171	4546	0.0112	3.03	29.4	25.7		0.0149
19	5246	Note 1	16498	11557	4942	0.0113	3.14	27.6	25.4		0.0159
20	5320	Note 1	16988	11414	5574	0.0116	3.19	27.2	25.3		0.0168
21	4328	Note 1	13586	8952	4634	0.0118	3.14	26.9	25.3		0.0168
22	4192	Note 1	13275	8753	4522	0.0117	3.17	26.3	25.2		0.0168
23	4157	Note 1	13224	8674	4550	0.0117	3.18	26.1	25.2		0.0171
24	3932	Note 1	12737	8297	4440	0.0117	3.24	25.0	25.0		0.0165

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.92	04/30	16:00	2.80	06/14	12:00	25.0	09/23	07:00	8.7	01/06	05:00
E310	4.15	04/30	15:00	2.89	12/01	14:00	26.4	07/08	16:00	8.7	01/06	05:00
E320	3.92	09/16	15:00	2.84	03/31	14:00	31.2	07/08	15:00	7.8	01/06	05:00
E330	4.08	06/17	16:00	2.85	03/31	14:00	31.0	08/16	16:00	8.7	01/06	05:00
E340	3.99	09/16	16:00	2.85	03/31	14:00	31.1	08/16	16:00	8.7	01/06	05:00
E350	4.61	10/13	01:00	2.80	06/14	12:00	35.0	09/23	07:00	8.7	01/06	05:00
E360	4.49	10/04	23:00	2.85	03/31	14:00	32.6	07/10	12:00	8.7	01/06	05:00

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0136	11/16	16:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00
E310	0.0158	10/02	08:00	0.0020	01/05	07:00	79.4	10/02	08:00	16.1	11/06	08:00
E320	0.0178	07/10	11:00	0.0019	01/05	06:00	82.7	09/16	20:00	14.7	11/06	05:00
E330	0.0181	07/10	11:00	0.0019	01/05	06:00	77.0	09/16	20:00	14.5	11/06	05:00
E340	0.0178	07/10	11:00	0.0019	01/05	06:00	80.7	09/16	20:00	14.5	11/06	05:00
E350	0.0172	10/01	24:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00
E360	0.0139	07/10	12:00	0.0019	01/05	06:00	68.4	11/16	16:00	14.5	11/06	05:00

11. Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 3C

Change in Weather Data Interpolation

In a report by NREL dated July 11, 2002, prepared for the IEA SHC Task 22, Subtask A2 working group, the results of the second round of testing for Cases E300–E545 are presented and discussed. One of the comments made by the authors was that the outdoor dry-bulb temperature seemed to be one hour out of phase with some of the other programs and that the method of "weather averaging" that EnergyPlus uses may be at fault. EnergyPlus does not do any weather averaging but rather uses "weather interpolation" to estimate the value of outdoor parameters when simulation time steps less than one hour are used. The EnergyPlus simulations performed for the HVAC BESTEST E300–E360 test series used a TIMESTEP = 4, which means the building envelope time step is 15 minutes, or 4 time steps per hour. In EnergyPlus Version 1.0.3.006, the interpolation method was changed. Further testing needs to be performed before this technique is accepted as a permanent change in the code, but for now it does seem to give better agreement with what other programs are using.

12. Results – Round 3C

Results from the Round 3C modeling with EnergyPlus Version 1.0.3.006 are presented below. During Round 3C testing the following additional test cases were simulated for the first time: cases E400–E440 and cases E500–E545. The following comments are provided regarding certain input parameters, assumptions and results related to modeling of these new cases with EnergyPlus:

1) Case E410, Compressor Lockout
   Case E410 required the air conditioning compressor to be locked out from operation anytime the economizer was operating. The EnergyPlus CONTROLLER:OUTSIDE AIR input object does have an optional compressor lockout feature but it has not been implemented yet within the code. The EnergyPlus results for cases E400 and E410 are therefore identical.

2) Cases E500–E545, No Outside Air
   For cases E500 through E545, during the initial period of simulation there is no sensible heat gain in the space due to the adiabatic building envelope, no outside air or infiltration, no fan heat because fan operates in a cycling mode, and no sensible internal load due to the schedule, which does not allow either a sensible or latent internal load until March 11. During the simulation of these cases EnergyPlus issued a warning that "Loads initialization did not converge." Putting a sensible load as small as 750 W for the first hour of the simulation or even changing to a continuous fan operation eliminated this error. The results reported below for cases E500 through E525 were simulated as per the specification with no sensible or latent loads from January 1 through March 10. The initialization warning issued by EnergyPlus appears to have very minimal impact on the results. For cases E530, E540 and E545, see discussion that follows in item (3) below.

3) Dry-Coil cases E530, E540, and E545
   Initial simulations with EnergyPlus for these cases resulted in very low humidity levels in the space. This situation is due to EnergyPlus' initialization methodology and was alleviated by introducing a small amount of infiltration during the first week of the simulation. Even though EnergyPlus initializes all nodes to the outdoor humidity ratio at the beginning of the simulation, conditions during the simulation warmup days overdry the zone for these cases. Without the infiltration during the first week, there is no source of moisture to overcome the overdrying and establish the desired equilibrium. For cases E330, E340, and E345, a constant infiltration load of 1.0 m^3/s was turned on for January 1 through January 7 and then turned off.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone	Zone		Outdoor
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Humidity Ratio	Relative Humidity	ODB	Humidity Ratio
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)	(°C)	(kg/kg)
E300	34728	23866	Note 1	10862	77323	55252	22071	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39260	28398	Note 1	10862	96409	55220	41189	3.39	24.09	0.0113	58.6		
E320	39017	28154	Note 1	10862	95927	61950	33977	3.41	24.26	0.0101	51.8		
E330	40079	29217	Note 1	10862	102038	63648	38390	3.49	24.28	0.0100	51.2		
E340	39719	28856	Note 1	10862	99548	62780	36768	3.45	24.30	0.0100	51.1		
E350	31125	20263	Note 1	10862	65775	48543	17232	3.25	26.24	0.0099	45.2		
E360	54533	43670	Note 1	10862	160834	135067	25767	3.68	25.39	0.0088	42.3		
E400	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E410	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E420	34331	23469	Note 1	10862	76779	48627	28151	3.27	24.09	0.0098	51.3		
E430	34035	23173	Note 1	10862	74860	52808	22052	3.23	24.09	0.0093	48.7		
E440	34035	23173	Note 1	10862	74860	52808	22052	3.23	24.09	0.0093	48.7		
E500	23055	20410	Note 1	2645	65621	47507	18114	3.22	20.38	0.0096	60.5		
E500 May-Sep	18006	15965	Note 1	2041	50369	36487	13882	3.15	24.98	0.0113	57.4		
E510 May-Sep	35720	31637	Note 1	4083	112814	81586	31228	3.57	24.96	0.0113	57.4		
E520	24051	21203	Note 1	2848	65968	47815	18153	3.11	13.57	0.0063	63.6		
E522	24027	21183	Note 1	2845	65904	47759	18145	3.11	16.99	0.0079	62.9		
E525	20718	18525	Note 1	2194	65013	46943	18070	3.51	27.10	0.0140	55.6		
E530	17738	15639	Note 1	2099	46953	46953	0	3.00	20.58	0.0067	48.9		
E540	17789	15683	Note 1	2106	47094	47084	10	3.00	13.79	0.0039	41.9		
E545	16643	14762	Note 1	1882	46622	46622	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads									E300 Only, Maxima Weather Data Checks			
	Energy Consumption Compr + Both Fans		Evaporator Coil Loads: Sensible		Latent		Sensible + Latent			ODB		Outdoor Humidity Ratio	
	Wh	Date Hour	Wh	Date Hour	Wh	Date Hour	Wh	Date Hour		°C	Date Hour	kg/kg	Date Hour
E300	11887	07/20 15:00	23531	07/20 15:00	10238	07/10 13:00	32738	07/20 15:00		34.775	07/20 15:00	0.0218	10/02 09:00
E310	12479	07/20 15:00	23209	07/11 16:00	16234	08/04 15:00	37009	09/17 15:00					
E320	12889	07/20 15:00	31800	04/24 15:00	22072	10/02 10:00	39559	09/03 16:00					
E330	13200	07/20 15:00	34709	06/14 14:00	26976	09/18 16:00	42458	10/02 10:00					
E340	13066	07/20 15:00	32753	04/24 15:00	23767	10/02 10:00	41085	10/02 10:00					
E350	11887	07/20 15:00	23531	07/20 15:00	10239	07/10 13:00	32738	07/20 15:00					
E360	12690	07/20 15:00	32528	04/24 16:00	8448	10/02 11:00	38319	10/02 11:00					
E400	11887	07/20 15:00	23531	07/20 15:00	26261	09/16 14:00	40488	09/16 15:00					
E410	11887	07/20 15:00	23531	07/20 15:00	26261	09/16 14:00	40488	09/16 15:00					
E420	11887	07/20 15:00	23531	07/20 15:00	26261	09/16 14:00	40488	09/16 15:00					
E430	11887	07/20 15:00	23531	07/20 15:00	10344	05/21 15:00	32738	07/20 15:00					
E440	11887	07/20 15:00	23531	07/20 15:00	10344	05/21 15:00	32738	07/20 15:00					
E500	9223	07/20 15:00	19845	07/29 16:00	7750	06/29 16:00	27563	06/29 16:00					
E510	10230	07/20 15:00	22296	07/20 15:00	10439	04/21 01:00	32485	04/21 01:00					
E520	9485	07/20 15:00	19936	07/29 16:00	7661	06/29 16:00	27560	06/29 16:00					
E522	9487	07/20 15:00	19927	07/29 16:00	7698	06/29 16:00	27589	06/29 16:00					
E525	8581	07/20 15:00	19660	07/20 15:00	7812	06/29 16:00	27445	06/29 16:00					
E530	7301	07/20 15:00	19643	07/20 15:00	2	03/16 10:00	19643	07/20 15:00					
E540	7315	07/20 15:00	19663	07/20 15:00	1791	03/11 10:00	19663	07/20 15:00					
E545	6975	07/20 15:00	19544	07/20 15:00	0	09/21 13:00	19544	07/20 15:00					

Hour	June 28 Hourly Output - Case E300											
	Energy Consumption		Evaporator Coil Load			Zone						Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)		Hum. Rat. (kg/kg)
1	2119	Note 1	7476	5811	1666	0.0094	3.53	18.0	23.9			0.0112
2	2131	Note 1	7497	5853	1644	0.0094	3.52	18.1	24.0			0.0113
3	2113	Note 1	7449	5809	1639	0.0094	3.53	18.0	23.9			0.0112
4	2075	Note 1	7334	5744	1590	0.0093	3.54	17.8	23.9			0.0111
5	1997	Note 1	7093	5614	1479	0.0092	3.55	17.4	23.9			0.0105
6	2141	Note 1	7427	6015	1412	0.0090	3.47	18.6	24.0			0.0106
7	2869	Note 1	9218	7532	1686	0.0093	3.21	22.9	24.7			0.0123
8	3497	Note 1	10611	8756	1855	0.0096	3.03	26.4	25.2			0.0118
9	4650	Note 1	13922	11767	2156	0.0097	2.99	28.3	25.5			0.0116
10	4929	Note 1	14720	11997	2723	0.0102	2.99	28.9	25.6			0.0124
11	5399	Note 1	15889	12488	3401	0.0106	2.94	30.3	25.8			0.0140
12	5628	Note 1	16519	12671	3848	0.0109	2.94	30.8	25.9			0.0138
13	7127	Note 1	21590	17401	4189	0.0104	3.03	30.9	25.9			0.0120
14	6978	Note 1	20681	17592	3089	0.0100	2.96	31.5	26.0			0.0115
15	8564	Note 1	26137	22481	3657	0.0098	3.05	32.0	26.1			0.0121
16	8724	Note 1	26669	22557	4111	0.0099	3.06	32.2	26.1			0.0135
17	5715	Note 1	16347	13062	3285	0.0106	2.86	31.9	26.0			0.0145
18	5877	Note 1	17196	12870	4326	0.0112	2.93	31.3	26.0			0.0153
19	5552	Note 1	16881	12170	4710	0.0113	3.04	29.4	25.7			0.0149
20	5256	Note 1	16539	11556	4983	0.0113	3.15	27.6	25.4			0.0159
21	4354	Note 1	13565	9063	4502	0.0117	3.12	27.2	25.3			0.0168
22	4292	Note 1	13448	8953	4495	0.0116	3.13	26.9	25.3			0.0168
23	4175	Note 1	13210	8753	4457	0.0116	3.16	26.3	25.2			0.0168
24	4152	Note 1	13204	8674	4530	0.0117	3.18	26.1	25.2			0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.18	04/30	15:00	2.89	12/01	15:00	26.6	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.8	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.85	03/31	15:00	31.2	07/20	15:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.85	03/31	15:00	31.6	07/20	15:00	8.7	01/06	06:00
E350	4.58	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.49	10/05	01:00	2.85	03/31	15:00	32.7	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E420	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E430	3.80	04/30	14:00	2.78	06/13	17:00	25.0	10/10	09:00	8.7	01/06	06:00
E440	3.80	04/30	14:00	2.78	06/13	17:00	25.0	10/10	09:00	8.7	01/06	06:00
E500	4.17	04/30	16:00	2.71	07/30	12:00	25.0	03/31	18:00	14.5	11/23	09:00
E510	4.69	10/05	01:00	2.90	03/31	18:00	25.0	03/31	18:00	14.5	11/23	09:00
E520	4.06	04/30	16:00	2.62	07/30	12:00	15.0	03/25	08:00	12.8	11/14	08:00
E522	4.06	04/30	16:00	2.62	07/30	12:00	20.0	04/02	08:00	13.8	11/23	09:00
E525	4.65	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	15.4	12/01	01:00
E530	3.88	03/16	11:00	2.53	07/30	12:00	25.0	04/17	18:00	14.5	11/23	09:00
E540	3.88	03/16	10:00	2.53	07/30	12:00	15.0	04/16	01:00	12.8	11/14	08:00
E545	4.10	03/16	11:00	2.66	07/30	12:00	35.0	07/09	22:00	15.4	12/01	01:00

Humidity Ratio						Relative Humidity						Cases
Maximum			Minimum*			Maximum*			Minimum*			
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.6	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.7	11/06	06:00	E320
0.0181	07/10	12:00	0.0019	01/11	03:00	76.8	09/17	12:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E400
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E410
0.0160	09/07	01:00	0.0019	01/11	03:00	80.4	09/07	01:00	14.2	11/06	06:00	E420
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.2	11/06	06:00	E430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.2	11/06	06:00	E440
0.0134	04/18	19:00	0.0102	11/23	10:00	100.0	11/13	09:00	54.4	04/30	13:00	E500
0.0154	10/12	02:00	0.0102	11/23	10:00	100.0	11/13	09:00	55.2	11/04	13:00	E510
0.0087	04/18	19:00	0.0064	04/30	13:00	84.1	10/18	08:00	60.7	04/30	13:00	E520
0.0108	04/18	19:00	0.0084	04/30	13:00	100.0	11/22	02:00	57.9	04/30	13:00	E522
0.0199	04/18	19:00	0.0109	11/30	24:00	100.0	11/12	01:00	47.3	04/30	13:00	E525
0.0091	01/03	15:00	0.0067	10/18	12:00	66.3	11/23	09:00	33.9	09/28	18:00	E530
0.0091	01/03	15:00	0.0033	10/17	09:00	36.0	11/22	10:00	30.8	09/28	18:00	E540
0.0091	01/03	15:00	0.0068	04/01	01:00	62.3	11/30	23:00	19.2	04/18	17:00	E545

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	4032	3510	Note 1	522	13659	9887	3773	0.0110	3.85	16.8	24.98
June 25	5232	4663	Note 1	569	13737	9956	3781	0.0115	2.95	29.5	24.98

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3094	2681	Note 1	413	9775	9775	0	0.0067	3.45	16.8	25.00
June 25	4030	3578	Note 1	453	9838	9838	0	0.0067	2.78	29.5	25.00

13. Input Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 4

A comparison of EnergyPlus results from Round 3C with results from other programs (Ref: *HVAC BESTEST Cases E300-E545, Summary of 3rd Set of Results*, 12 Nov. 2002, J. Neymark) indicated that there were disagreements with regard to economizer control results (Cases E400–E440) and DX cooling system performance for Cases E500–E545. Further investigation into the reasons for these differences indicated that several input errors had been made:

1) Cases 400–440
A fan outlet node name for the mixed air set point manager had been incorrectly identified and caused the economizer control to operate not in accordance with the specification.

2) Case 410
This case required that the DX cooling compressor be locked out from operating whenever the economizer was in operation. This capability has not yet been implemented in EnergyPlus so no results are being shown for this case.

3) Case 420
The economizer high temperature limit of 20°C for this case had not been specified as required and was defaulting to a different setting.

4) Cases 500–545
The EnergyPlus total electricity consumption results for these cases are consistently low compared to the results of other programs. The DX coil model may be imposing some temperature limits on the use of the performance curves. During Round 4 the input temperature limits that defined the boundaries of the performance curves were opened up and some slight improvement in results occurred for Cases 520 and 540. This problem will be further investigated.

The results for Round 4, which are presented below, were produced using EnergyPlus 1.0.3.013.

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34743	23881	Note 1	10862	77307	55252	22055	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39282	28420	Note 1	10862	96404	55225	41179	3.39	24.09	0.0113	58.6		
E320	39084	28222	Note 1	10862	96103	62045	34058	3.41	24.25	0.0101	51.9		
E330	40151	29289	Note 1	10862	102242	63778	38463	3.49	24.27	0.0100	51.2		
E340	39789	28927	Note 1	10862	99731	62887	36844	3.45	24.30	0.0100	51.2		
E350	31138	20276	Note 1	10862	65763	48545	17218	3.24	26.24	0.0099	45.2		
E360	54703	43841	Note 1	10862	161241	135286	25955	3.68	25.32	0.0088	42.4		
E400	31009	20147	Note 1	10862	65399	40691	24708	3.25	24.09	0.0101	52.5		
E410			Note 1										
E420	32734	21872	Note 1	10862	70343	49527	20816	3.22	24.09	0.0094	49.4		
E430	31769	20907	Note 1	10862	67129	46733	20396	3.21	24.09	0.0095	49.6		
E440	31770	20908	Note 1	10862	67131	46734	20397	3.21	24.09	0.0095	49.6		
E500	23049	20419	Note 1	2630	65605	47492	18113	3.21	20.38	0.0096	60.5		
E500 May-Sep	18001	15972	Note 1	2030	50357	36476	13881	3.15	24.98	0.0113	57.4		
E510 May-Sep	35732	31669	Note 1	4063	112793	81566	31226	3.56	24.96	0.0113	57.4		
E520	25043	22021	Note 1	3022	66154	47989	18165	3.00	13.58	0.0064	64.7		
E522	24099	21254	Note 1	2845	65904	47760	18144	3.10	16.99	0.0079	63.0		
E525	20710	18529	Note 1	2181	65000	46930	18069	3.51	27.10	0.0140	55.7		
E530	17742	15652	Note 1	2090	46944	46944	0	3.00	20.58	0.0067	49.0		
E540	19061	16752	Note 1	2309	47296	47288	9	2.82	13.79	0.0043	46.3		
E545	16636	14765	Note 1	1871	46612	46612	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads									Weather Data Checks					
				Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11900	07/20	15:00	23531	07/20	15:00	10234	07/10	13:00	32734	07/20	15:00	34.775	07/20	15:00	0.0218	10/02	09:00
E310	12541	07/20	15:00	23276	07/11	16:00	16272	08/04	15:00	37125	09/17	15:00						
E320	12954	07/20	15:00	31972	04/24	15:00	22198	10/02	10:00	39765	09/03	16:00						
E330	13314	07/20	15:00	34765	06/14	15:00	27134	09/18	16:00	43445	10/02	09:00						
E340	13134	07/20	15:00	32888	04/24	15:00	23911	10/02	10:00	41327	10/02	10:00						
E350	11900	07/20	15:00	23531	07/20	15:00	10235	07/10	13:00	32734	07/20	15:00						
E360	12744	07/20	15:00	32621	04/24	16:00	8514	10/02	11:00	38451	10/02	11:00						
E400	11900	07/20	15:00	23531	07/20	15:00	26317	09/16	14:00	40728	09/16	15:00						
E410																		
E420	11900	07/20	15:00	23531	07/20	15:00	10234	07/10	13:00	32734	07/20	15:00						
E430	11900	07/20	15:00	23531	07/20	15:00	11074	10/24	13:00	32734	07/20	15:00						
E440	11900	07/20	15:00	23531	07/20	15:00	11074	10/24	13:00	32734	07/20	15:00						
E500	10286	07/20	15:00	19839	07/29	16:00	7751	06/29	16:00	27558	06/29	16:00						
E510	11410	07/20	15:00	22291	07/20	15:00	10425	04/21	01:00	32466	04/21	01:00						
E520	10968	07/20	15:00	19990	07/29	16:00	7661	06/29	16:00	27616	06/29	16:00						
E522	10640	07/20	15:00	19924	07/29	16:00	7707	06/29	16:00	27596	06/29	16:00						
E525	9476	07/20	15:00	19656	07/20	15:00	7812	06/29	16:00	27440	06/29	16:00						
E530	8171	07/20	15:00	19639	07/20	15:00	1	03/16	10:00	19639	07/20	15:00						
E540	8678	07/20	15:00	19727	07/20	15:00	1650	03/11	10:00	19727	07/20	15:00						
E545	7763	07/20	15:00	19540	07/20	15:00	0	05/03	16:00	19540	07/20	15:00						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor	Cond Fan	Total	Sensible	Latent	Hum. Rat.	COP2	ODB	EDB	EWB	Hum. Rat.
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	2119	Note 1	7475	5811	1664	0.0094	3.53	18.0	23.9		0.0112
2	2132	Note 1	7496	5853	1643	0.0094	3.52	18.1	24.0		0.0113
3	2113	Note 1	7447	5809	1638	0.0094	3.52	18.0	23.9		0.0112
4	2075	Note 1	7332	5744	1589	0.0093	3.53	17.8	23.9		0.0111
5	1997	Note 1	7091	5614	1477	0.0092	3.55	17.4	23.9		0.0105
6	2142	Note 1	7425	6015	1410	0.0090	3.47	18.6	24.0		0.0106
7	2869	Note 1	9215	7532	1683	0.0093	3.21	22.9	24.7		0.0123
8	3498	Note 1	10609	8756	1853	0.0096	3.03	26.4	25.2		0.0118
9	4652	Note 1	13919	11767	2152	0.0097	2.99	28.3	25.5		0.0116
10	4931	Note 1	14717	11997	2720	0.0102	2.98	28.9	25.6		0.0124
11	5401	Note 1	15886	12488	3398	0.0106	2.94	30.3	25.8		0.0140
12	5631	Note 1	16516	12671	3845	0.0109	2.93	30.8	25.9		0.0138
13	7132	Note 1	21586	17401	4185	0.0104	3.03	30.9	25.9		0.0120
14	6983	Note 1	20677	17592	3086	0.0100	2.96	31.5	26.0		0.0115
15	8572	Note 1	26133	22481	3652	0.0098	3.05	32.0	26.1		0.0121
16	8733	Note 1	26665	22557	4107	0.0099	3.05	32.2	26.1		0.0135
17	5718	Note 1	16345	13062	3283	0.0106	2.86	31.9	26.0		0.0145
18	5881	Note 1	17194	12870	4324	0.0112	2.92	31.3	26.0		0.0153
19	5555	Note 1	16878	12170	4708	0.0113	3.04	29.4	25.7		0.0149
20	5259	Note 1	16537	11556	4981	0.0113	3.14	27.6	25.4		0.0159
21	4356	Note 1	13563	9063	4500	0.0117	3.11	27.2	25.3		0.0168
22	4294	Note 1	13446	8953	4493	0.0116	3.13	26.9	25.3		0.0168
23	4177	Note 1	13208	8753	4455	0.0116	3.16	26.3	25.2		0.0168
24	4153	Note 1	13202	8674	4528	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
E350	4.56	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410												
E420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E440	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E500	4.22	03/16	10:00	2.71	07/30	12:00	25.0	03/31	18:00	14.5	11/23	09:00
E510	4.68	10/05	01:00	2.91	03/31	18:00	25.0	03/31	18:00	14.5	11/23	09:00
E520	3.93	04/30	16:00	2.53	07/30	12:00	15.0	03/25	08:00	12.8	11/14	08:00
E522	4.06	03/16	10:00	2.61	07/30	12:00	20.0	04/02	08:00	13.8	11/23	09:00
E525	4.73	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	15.4	12/01	01:00
E530	3.92	03/16	10:00	2.53	07/30	12:00	25.0	04/17	18:00	14.5	11/23	09:00
E540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	04/16	01:00	12.8	11/14	08:00
E545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/09	22:00	15.4	12/01	01:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone												Cases
Humidity Ratio						Relative Humidity						
Maximum			Minimum*			Maximum*			Minimum*			
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.6	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.7	11/06	06:00	E320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.9	09/03	10:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	E400
												E410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	E420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.8	04/02	05:00	13.9	11/06	06:00	E430
0.0160	04/02	05:00	0.0019	01/11	03:00	79.9	04/02	05:00	13.9	11/06	06:00	E440
0.0134	04/18	19:00	0.0102	11/23	10:00	100.0	11/13	09:00	54.4	04/30	13:00	E500
0.0154	10/12	02:00	0.0102	11/23	10:00	100.0	11/13	09:00	55.3	11/04	13:00	E510
0.0088	04/18	19:00	0.0066	04/30	13:00	85.7	10/18	08:00	62.4	04/30	13:00	E520
0.0109	04/18	19:00	0.0085	04/30	13:00	100.0	11/22	02:00	58.2	04/30	13:00	E522
0.0199	04/18	19:00	0.0109	11/30	24:00	100.0	11/11	24:00	47.4	04/30	13:00	E525
0.0091	01/03	15:00	0.0067	10/18	12:00	66.5	11/23	09:00	34.0	09/28	18:00	E530
0.0091	01/03	15:00	0.0038	10/18	09:00	42.1	11/22	10:00	36.0	09/28	16:00	E540
0.0091	01/03	15:00	0.0068	04/01	01:00	62.3	11/30	23:00	19.2	04/18	17:00	E545

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	4030	3511	Note 1	519	13656	9884	3772	0.0110	3.85	16.8	24.98
June 25	5230	4665	Note 1	566	13734	9953	3781	0.0115	2.94	29.5	24.98

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3102	2689	Note 1	412	9775	9775	0	0.0067	3.44	16.8	25.00
June 25	4029	3579	Note 1	450	9835	9835	0	0.0067	2.78	29.5	25.00

14. Software Errors Discovered and/or Comparison Between Different Versions of the Same Software – Round 5

Error in Reporting Round 4 Results

An error was made in the Round 4 "Energy Consumption – Compr + Both Fans" results reported in the "Annual Hourly Integrated Maxima Consumptions and Loads" table for Cases E500 through E545. The indoor fan energy consumption had been omitted from the totals. This error has been corrected in the results reported below for Round 5.

Error in Space Humidity Ratio Algorithm

A comparison of EnergyPlus results from Round 4 to the results of other programs indicated that the maximum space humidity ratios for Cases E500 through E545 were high. Further investigation into the problem indicated that these maximum values were actually happening one to two hours after the internal loads and HVAC system had been scheduled off. This was occurring because of the way the moisture balance algorithm had been set up. Internal loads during each time step of the simulation in EnergyPlus were being accounted for after the HVAC system simulation. With EnergyPlus version 1.1.0.004 and subsequent releases the space internal loads are now accounted for before the system simulation. This brought the EnergyPlus results more in line with the results of the other programs. Also, for cases E530, E540 and E545 the maximum space humidity ratio was occurring during the beginning of the year before the AC unit came on for the first time (March 11). The period for determining maximum space humidity ratio was therefore changed to March 11 through December 31. This then brought the EnergyPlus results for cases E530 and E540 closer to results for the other programs. The Round 5 results that follow present the revised results.

Change in Economizer Enthalpy Limit for Case E440

In accordance with changes to the test suite specification, the economizer enthalpy limit for case E440 was changed from 65.13 kJ/kg to 47.25 kJ/kg.

The results for Round 5, which are presented below, were produced using EnergyPlus 1.1.0.020.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone	Zone		Outdoor
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Humidity Ratio	Relative Humidity	ODB	Humidity Ratio
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)	(°C)	(kg/kg)
E300	34746	23884	Note 1	10862	77318	55252	22066	3.24	24.09	0.0093	48.6	19.9	0.0116
E310	39290	28428	Note 1	10862	96448	55225	41222	3.39	24.09	0.0113	58.6		
E320	39079	28217	Note 1	10862	96084	62043	34040	3.41	24.25	0.0101	51.8		
E330	40143	29281	Note 1	10862	102211	63779	38433	3.49	24.27	0.0100	51.2		
E340	39783	28921	Note 1	10862	99709	62886	36823	3.45	24.30	0.0100	51.1		
E350	31145	20283	Note 1	10862	65790	48545	17245	3.24	26.24	0.0099	45.2		
E360	54705	43843	Note 1	10862	161248	135287	25961	3.68	25.32	0.0088	42.4		
E400	31013	20151	Note 1	10862	65414	40688	24726	3.25	24.09	0.0101	52.5		
E410			Note 1										
E420	32736	21873	Note 1	10862	70349	49524	20826	3.22	24.09	0.0094	49.4		
E430	31772	20910	Note 1	10862	67141	46739	20403	3.21	24.09	0.0095	49.6		
E440	33032	22170	Note 1	10862	71417	50060	21357	3.22	24.09	0.0093	48.8		
E500	23035	20406	Note 1	2628	65571	47491	18080	3.21	20.38	0.0094	59.2		
E500 May-Sep	17996	15967	Note 1	2029	50354	36476	13879	3.15	24.98	0.0113	57.3		
E510 May-Sep	35732	31669	Note 1	4063	112793	81566	31226	3.56	24.96	0.0113	57.4		
E520	25017	21999	Note 1	3019	66088	47986	18101	3.00	13.58	0.0060	61.4		
E522	24078	21235	Note 1	2843	65851	47758	18093	3.10	17.00	0.0076	60.8		
E525	20702	18522	Note 1	2180	64973	46930	18044	3.51	27.10	0.0138	55.0		
E530	17742	15652	Note 1	2090	46944	46944	0	3.00	20.59	0.0067	49.0		
E540	19061	16752	Note 1	2309	47297	47288	9	2.82	13.79	0.0043	46.3		
E545	16636	14765	Note 1	1871	46612	46612	0	3.16	27.31	0.0067	38.6		

Note 1: Condenser fan energy consumption included with compressor energy consumption; cannot break out.

Cases	Annual Hourly Integrated Maxima Consumptions and Loads								E300 Only, Maxima			
									Weather Data Checks			
	Energy Consumption Compr + Both Fans		Evaporator Coil Loads: Sensible		Latent		Sensible + Latent		ODB		Outdoor Humidity Ratio	
	Wh	Date Hour	Wh	Date Hour	Wh	Date Hour	Wh	Date Hour	°C	Date Hour	kg/kg	Date Hour
E300	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00	34.775	07/20 15:00	0.0218	10/02 09:00
E310	12541	07/20 15:00	23276	07/11 16:00	16275	08/04 15:00	37126	09/17 15:00				
E320	12954	07/20 15:00	31972	04/24 15:00	22195	10/02 10:00	39765	09/03 16:00				
E330	13314	07/20 15:00	34765	06/14 15:00	27134	09/18 16:00	43445	10/02 09:00				
E340	13134	07/20 15:00	32888	04/24 15:00	23911	10/02 10:00	41328	10/02 10:00				
E350	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00				
E360	12744	07/20 15:00	32621	04/24 16:00	8520	10/02 11:00	38460	10/02 11:00				
E400	11900	07/20 15:00	23531	07/20 15:00	26317	09/16 14:00	40728	09/16 15:00				
E410												
E420	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00				
E430	11900	07/20 15:00	23531	07/20 15:00	11074	10/24 13:00	32733	07/20 15:00				
E440	11900	07/20 15:00	23531	07/20 15:00	10235	07/10 13:00	32733	07/20 15:00				
E500	10399	07/20 15:00	19849	07/20 15:00	7839	06/29 16:00	27646	06/29 16:00				
E510	11410	07/20 15:00	22290	07/20 15:00	8955	06/17 14:00	31178	06/17 14:00				
E520	11101	07/20 15:00	19999	07/20 15:00	7699	06/29 16:00	27653	06/29 16:00				
E522	10762	07/20 15:00	19934	07/20 15:00	7770	06/29 16:00	27659	06/29 16:00				
E525	9570	07/20 15:00	19664	07/20 15:00	7947	06/29 16:00	27577	06/29 16:00				
E530	8171	07/20 15:00	19639	07/20 15:00	1	03/16 10:00	19639	07/20 15:00				
E540	8677	07/20 15:00	19726	07/20 15:00	1655	03/11 10:00	19726	07/20 15:00				
E545	7763	07/20 15:00	19540	07/20 15:00	0	05/23 15:00	19540	07/20 15:00				

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	2119	Note 1	7472	5811	1661	0.0094	3.53	18.0	23.9		0.0112
2	2131	Note 1	7494	5853	1641	0.0094	3.52	18.1	24.0		0.0113
3	2113	Note 1	7447	5809	1637	0.0094	3.52	18.0	23.9		0.0112
4	2075	Note 1	7332	5744	1588	0.0093	3.53	17.8	23.9		0.0111
5	1997	Note 1	7091	5614	1477	0.0092	3.55	17.4	23.9		0.0105
6	2142	Note 1	7425	6015	1410	0.0090	3.47	18.6	24.0		0.0106
7	2870	Note 1	9216	7532	1684	0.0093	3.21	22.9	24.7		0.0123
8	3499	Note 1	10609	8757	1853	0.0096	3.03	26.4	25.2		0.0118
9	4682	Note 1	14032	11767	2265	0.0098	3.00	28.3	25.5		0.0116
10	4948	Note 1	14778	11996	2781	0.0102	2.99	28.9	25.6		0.0124
11	5407	Note 1	15905	12488	3417	0.0106	2.94	30.3	25.8		0.0140
12	5632	Note 1	16522	12671	3851	0.0109	2.93	30.8	25.9		0.0138
13	7133	Note 1	21588	17401	4187	0.0104	3.03	30.9	25.9		0.0120
14	6983	Note 1	20678	17592	3086	0.0100	2.96	31.5	26.0		0.0115
15	8572	Note 1	26133	22481	3652	0.0098	3.05	32.0	26.1		0.0121
16	8733	Note 1	26665	22557	4107	0.0099	3.05	32.2	26.1		0.0135
17	5718	Note 1	16345	13061	3283	0.0106	2.86	31.9	26.0		0.0145
18	5881	Note 1	17193	12870	4324	0.0112	2.92	31.3	26.0		0.0153
19	5555	Note 1	16878	12170	4708	0.0113	3.04	29.4	25.7		0.0149
20	5259	Note 1	16536	11556	4981	0.0113	3.14	27.6	25.4		0.0159
21	4326	Note 1	13445	9063	4383	0.0116	3.11	27.2	25.3		0.0168
22	4279	Note 1	13387	8953	4434	0.0116	3.13	26.9	25.3		0.0168
23	4173	Note 1	13191	8753	4437	0.0116	3.16	26.3	25.2		0.0168
24	4152	Note 1	13196	8674	4522	0.0117	3.18	26.1	25.2		0.0171

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	℃	Date	Hour	℃	Date	Hour
E300	3.93	04/30	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E310	4.17	04/30	15:00	2.89	12/01	15:00	26.5	07/20	16:00	8.7	01/06	06:00
E320	3.94	09/16	15:00	2.84	03/31	15:00	31.7	07/20	15:00	7.8	01/06	06:00
E330	4.07	09/16	14:00	2.84	03/31	15:00	31.1	07/08	16:00	8.7	01/06	06:00
E340	3.99	09/16	15:00	2.84	03/31	15:00	31.5	07/20	15:00	8.7	01/06	06:00
E350	4.56	10/13	01:00	2.78	06/13	17:00	35.0	10/01	02:00	8.7	01/06	06:00
E360	4.46	10/04	24:00	2.84	03/31	15:00	32.5	07/10	13:00	8.7	01/06	06:00
E400	4.07	09/16	14:00	2.78	06/13	17:00	26.9	09/16	16:00	8.7	01/06	06:00
E410												
E420	3.82	05/21	15:00	2.78	06/13	17:00	25.0	09/23	08:00	8.7	01/06	06:00
E430	3.79	05/21	16:00	2.78	06/13	17:00	25.0	05/18	19:00	8.7	01/06	06:00
E440	3.80	05/21	15:00	2.78	06/13	17:00	25.0	04/24	19:00	8.7	01/06	06:00
E500	4.20	03/16	10:00	2.71	07/30	12:00	25.0	03/31	18:00	8.9	12/21	02:00
E510	4.68	10/05	01:00	2.87	03/31	18:00	25.0	03/31	18:00	8.9	12/21	02:00
E520	3.94	04/30	15:00	2.53	07/30	12:00	15.0	04/16	01:00	8.8	12/21	01:00
E522	4.04	04/30	15:00	2.61	07/30	12:00	20.0	04/16	20:00	8.9	12/21	01:00
E525	4.70	03/16	10:00	2.94	07/30	12:00	35.0	03/11	12:00	9.0	12/21	02:00
E530	3.93	03/16	10:00	2.53	07/30	12:00	25.0	03/30	17:00	8.9	12/21	02:00
E540	3.70	03/16	10:00	2.38	07/30	12:00	15.0	03/25	08:00	8.8	12/21	01:00
E545	4.17	03/16	10:00	2.66	07/30	12:00	35.0	07/09	22:00	9.0	12/21	02:00

Annual Hourly Integrated Maxima and Minima - COP2 and Zone												
Humidity Ratio						Relative Humidity						
Maximum			Minimum*			Maximum*			Minimum*			Cases
kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E300
0.0156	10/01	08:00	0.0019	01/05	07:00	78.6	10/02	08:00	15.5	11/06	08:00	E310
0.0178	07/10	13:00	0.0019	01/11	03:00	83.0	09/18	10:00	14.6	11/06	06:00	E320
0.0179	07/10	12:00	0.0019	01/11	03:00	76.9	09/03	10:00	14.4	11/06	06:00	E330
0.0178	07/10	12:00	0.0019	01/11	03:00	80.8	09/18	10:00	14.4	11/06	06:00	E340
0.0172	10/02	01:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E350
0.0139	07/10	13:00	0.0019	01/11	03:00	68.4	11/16	17:00	14.4	11/06	06:00	E360
0.0169	04/05	22:00	0.0019	01/11	03:00	84.6	04/05	22:00	13.9	11/06	06:00	E400
												E410
0.0146	04/02	18:00	0.0019	01/11	03:00	73.3	04/02	18:00	13.9	11/06	06:00	E420
0.0161	04/02	05:00	0.0019	01/11	03:00	80.7	04/02	05:00	13.9	11/06	06:00	E430
0.0136	11/16	17:00	0.0019	01/11	03:00	68.4	11/16	17:00	13.9	11/06	06:00	E440
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	09:00	55.2	04/30	04:00	E500
0.0117	07/20	15:00	0.0070	12/20	12:00	100.0	11/21	09:00	55.3	05/04	03:00	E510
0.0070	07/20	15:00	0.0065	11/10	09:00	93.8	12/20	11:00	61.7	11/27	24:00	E520
0.0091	07/20	15:00	0.0070	12/20	12:00	100.0	12/15	22:00	59.2	04/30	04:00	E522
0.0185	07/20	15:00	0.0070	12/20	12:00	100.0	11/12	19:00	47.9	10/05	02:00	E525
0.0068	03/11	01:00	0.0067	10/18	12:00	96.2	12/20	11:00	34.0	04/18	18:00	E530
0.0068	03/11	01:00	0.0038	10/18	09:00	55.2	12/20	11:00	36.0	09/28	16:00	E540
0.0068	12/31	07:00	0.0068	04/01	02:00	96.2	12/20	11:00	19.2	04/18	17:00	E545

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	4029	3510	Note 1	519	13655	9884	3772	0.0110	3.85	16.8	24.98
June 25	5229	4663	Note 1	566	13733	9953	3781	0.0115	2.94	29.5	24.98

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3101	2689	Note 1	412	9775	9775	0	0.0068	3.44	16.8	25.00
June 25	4029	3579	Note 1	450	9835	9835	0	0.0068	2.78	29.5	25.00

Program name (please include version number)

EnergyPlus Version 1.1.0.004

Your name, organisation, and country

Robert H. Henninger, GARD Analytics, Inc., United States

In this description "x" denotes used in the model; "a" denotes available, but not used for modeling the test cases.

Program name (please include version number)

EnergyPlus Version 1.1.0.004

Your name, organisation, and country

Robert H. Henninger, GARD Analytics, Inc., United States

Program status

	Public domain
	Commercial
	Research
x	Other (please specify) *Government-sponsored, end-user license is no charge, other license types have fees associated with them*

Solution method for unitary space cooling equipment

x	Overall Performance Maps
	Individual Component Models
	Constant Performance (no possible variation with entering or ambient conditions)
	Other (please specify)

Interaction between loads and systems calculations

x	Both are calculated during the same time step
	First, loads are calculated for the entire simulation period, then equipment performance is calculated separately
	Other (please specify)

Time step

	Fixed within code (please specify time step):
x	User-specified (please specify time step): *one hour for envelope*
x	Other (please specify): *program automatically adjusts HVAC time step, <= envelope time step*

Timing convention for meteorological data: sampling interval

	Fixed within code (please specify interval)
x	User-specified: *one hour*

Timing convention for meteorological data: period covered by first record

x	Fixed within code (please specify period or time which meteorological record covers): *0:00 - 1:00*
	User-specified

Meteorological data reconstitution scheme

	Climate assumed stepwise constant over sampling interval
x	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
x	Produces average outputs for each hour (please specify period to which value relates): *user-specified, hourly data are average or sum for previous hour, can specify output at each time step*

Treatment of zone air

x	Single temperature (i.e., good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Zone air initial conditions

x	Same as outside air
	Other (please specify)

Internal gains output characteristics

	Purely convective
	Radiative/Convective split fixed within code
x	Radiative/Convective split specified by user: *100% convective for these tests*
	Detailed modeling of source output

Mechanical systems output characteristics

x	Purely convective
	Radiative/Convective split fixed within code
a	Radiative/Convective split specified by user: *for types of equipment not used in these tests*
	Detailed modeling of source output

Control temperature

x	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control properties

x	Ideal control as specified in the user's manual
	On/Off thermostat control
	On/Off thermostat control with hysteresis
	On/Off thermostat control with minimum equipment on and/or off durations
	Proportional control
	More comprehensive controls (please specify)

Performance Map: characteristics

	Default curves
x	Custom curve fitting
	Detailed mapping not available
	Other (please specify)

Performance Map: independent variables

	Entering Dry-Bulb Temperature: *program calculates adjustments internally*
x	Entering Wet-Bulb Temperature
x	Outdoor Dry-Bulb Temperature
x	Part-Load Ratio
a	Indoor Fan Airflow Rate: *always=1, because fan always operates at rated conditions*
	Other (please specify)

Performance Map: dependent variables

x	Coefficient of Performance (or other ratio of load to electricity consumption)
x	Total Capacity
	Sensible Capacity: *program calculates internally based on user-specified nominal SHR*
	Bypass Factor: *program calculates internally based on nominal SHR and current conditions*
x	Other (please specify) *indoor fan power (function of PLR)*

Performance Map: available curve fit techniques

x	Linear, f(one independent variable): *flow fraction curves set to constant=1*
x	Quadratic, f(one independent variable): *PLF-FPLR (cycling loss)*
a	Cubic, f(one independent variable):
a	Bi-Linear, f(two independent variables)
x	Bi-Quadratic, f(two independent variables): *CAP-FT, EIR-FT*
	Other (please specify)

Performance Map: extrapolation limits

x	Limits independent variables: *27.4 <= ODB <= 48.1; 13.0 <= EWB <= 23.7, 0.0 <= PLR <= 1.0*
	Limits dependent variables
	No extrapolation limits
	Extrapolation not allowed
	Other (please specify)

Cooling coil and supply air conditions model

	Supply air temperature = apparatus dew point (ADP); supply air humidity ratio = humidity ratio of saturated air at ADP
	Bypass factor model using listed ADP data
x	Bypass factor model with ADP calculated from extending condition line: *nominal BF is calculated from user-specified nominal SHR*
x	Fan heat included
	More comprehensive model (please specify)

Disaggregation of fans' electricity use directly in the simulation and output

x	Indoor fan only
	Outdoor fan only
	Both indoor and outdoor fans disaggregated in the output
	None - disaggregation of fan outputs with separate calculations by the user

Economizer settings available (for E400 series)

x	Temperature, outdoor dry-bulb temperature versus return air temperature (E400, E410)
x	Temperature, outdoor dry-bulb temperature high limit setting (E420)
x	Enthalpy, outdoor air enthalpy versus return air enthalpy (E430)
x	Enthalpy, outdoor air enthalpy high limit setting (E440)
	Compressor Lockout (E410) *(Could not run E410, capability not added yet)*
	Other (please specify)

Appendix II-B

HVAC BESTEST MODELER REPORT FOR CASES E300–E360 AND E500–E545 CODYRUN

PREPARED BY
T. A. MARA, E. FOCK, AND F. GARDE
UNIVERSITY OF REUNION ISLAND

MAY 2003

1. Introduction

Software: CODYRUN
Authoring Organization: Laboratoire de Génie Industriel, 15 Avenue René Cassin, BP 7151 97715 Saint-Denis Messag Cedex 9, La Réunion
Authoring Country: FRANCE

This report describes the modeling methodology and results for several rounds of testing done for the IEA HVAC BESTEST Cases E300 through E360, which were simulated using the CODYRUN software. Only cases E300–E360 are analyzed. The specifications for the model building and HVAC equipment for each case are described in *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 2: Cases E300-E545, J. Neymark and R. Judkoff, National Renewable Energy Laboratory, September 2002* (referred to as the BESTEST specification in this report).

Nomenclature

Bl	Hourly building load	(W)	**Subscripts**	
C_r	Cycling rate	(h^{-1})	*ai*	Indoor air
CI	Internal loads	(W)	*tot*	Total
CDF	Cooling Degradation Factor		*sens*	Sensible
λ	Fractional on-time (= t_0/t_{cyc})		*lat*	Latent
Ω	Nondimensionnal time (t_0/τ)		*cyc*	Cycle
P_{abs}	Electric power	(kW)	*ss*	Steady state
PLR	Part-Load ratio		*odb*	Outdoor dry-bulb
$\dot{Q}$	Cooling capacity	(kW)	*edb*	Entering dry-bulb
T	Temperature	(°C)	*ewb*	Entering wet-bulb
t	Time	(s)		
τ	Time constant	(s)		
t_0	On-time cycle	(s)		
t_{cyc}	Cycle time	(s)		
q_L	Constant evaporative cooling rate	(kW)		
ΔT_c	Dead band	(°C)		
w	Zone humidity ratio	(kg/kg)		
HR	Relative humidity	(%)		

2. Description of the dynamic model

2.1 Classical approaches

We assume a first order model for both total and sensible capacities of the form:

$$\begin{aligned}
\dot{Q}_{tot,cyc} &= \dot{Q}_{tot,ss}(1-e^{-t/\tau}) \\
\dot{Q}_{sens,cyc} &= \dot{Q}_{sens,ss}(1-e^{-t/\tau}) \quad \text{when } t \le t_0 \\
\dot{Q}_{lat,cyc} &= \dot{Q}_{tot,cyc} - \dot{Q}_{sens,cyc}
\end{aligned} \tag{1}$$

Concerning the electrical power, the authors agree that there is no time constant for P_{abs} and that the dynamic regime value is the same as its steady-state value. At steady state the capacities are given by an empirical model, which is a function of the interior and exterior conditions. This model is built from the manufacturers' data.

Under the assumption that the steady-state capacities are unchanged during the operation, it can be proved that the coefficients of performance of the system have the following expressions:

$$PLR = \lambda\left(1+\frac{1}{\Omega}(e^{-\Omega}-1)\right) \tag{2}$$

$$CDF = 1+\frac{1}{\Omega}(e^{-\Omega}-1) \tag{3}$$

where $\Omega = \frac{t_0}{\tau} = \frac{\lambda t_{cyc}}{\tau}$ is a nondimensional time and $\lambda = \frac{t_0}{t_{cyc}}$ is the run-time fraction. From the previous equations, we deduce a first relationship between the two performance coefficients that is,

$$PLR = \lambda * CDF \tag{4}$$

The *PLR* is assumed to be the ratio of the cooling load and air conditioner capacity. Consequently, in a hourly simulation, the *PLR* can be calculated with a building energy simulation program. So evaluating the *CDF* and λ another relationship that takes into account the thermostat characteristics is necessary. McQuiston (1988) derived an empirical relationship of the form:

$$CDF = 1 - C_d(1-PLR) \tag{5}$$

C_d is called the degradation coefficient and is in the range of [0.1,0.25]. The advantage of this approach is that it is easy to implement in a hourly building thermal simulation program. The main drawback is that the approach is parametric because it requires the knowledge of the parameter C_d. Such an approach also assumes an ideal system where $\tau = 0$ seconds.

2.2 Our approach

The factors that mainly affect the dynamic regime are the operating time t_0 and the cycling time t_{cyc}. We have, therefore, developed an hourly HVAC model that allows the calculation of t_0 and t_{cyc}. Then, the model is improved to take into account the effect of the evaporative cooling on the system performances in case of constant fan mode.

t_0 is estimated from the following relationship,

$$-2C_{th}\Delta T_c = Bl_{sens}.t_0 - \dot{Q}_{sens,ss}\left(t_0 + \tau\left(e^{-t_0/\tau} - 1\right)\right).$$

This equation can be rearranged in form of:

$$f(t_0) = b + at_0 + K\left(e^{-t_0/\tau} - 1\right) = 0 \quad (6)$$

with $b = 2C_{th}\Delta T_c$, $a = Bl_{sens}$ - $\dot{Q}_{sens,ss}$ and $K = -\tau\dot{Q}_{sens,ss}$ and t_0 being the root of f. Let us note that $f(t) = 0$ has a root only if $a < 0$; in other words $Bl_{sens} < \dot{Q}_{sens,ss}$; otherwise, the system operates all the time without bringing T_{idb} to $T_c - \Delta T_c$.

The analytical expression to calculate the cycle time is:

$$t_{cyc} = t_0 + \left(2C_{th}\Delta T_c + q_L t_w\right)\Big/Bl_{sens} \quad (7)$$

q_L is the constant evaporative cooling rate. As far as t_w is concerned, we have the following inequality which translates to the fact that the moisture added to the air stream during the off-cycle is at the most equal to the moisture removed from the air during the compressor operation:

$$t_w = \min\left(\dot{Q}_{lat,ss}\left(t_0 + \tau\left(e^{-t_0/\tau} - 1\right)\right)\Big/q_L, \left(t_{cyc} - t_0\right)\right)$$

$t_w = \dot{Q}_{lat,ss}\left(t_0 + \tau\left(e^{-t_0/\tau} - 1\right)\right)\Big/q_L$ means that the entire moisture removed (condensate on the coil) are added in the room, whereas $t_w = (t_{cyc} - t_0)$ means that only a part of the condensate is evaporated in the air stream during the off-cycle. Therefore, the modelers can tune the value of the evaporation capacity to fix the amount of moisture that stays on the coil after the off-cycle (and that, for instance, leaves the system through a condensate drain).

Given a system unit, its regulators' characteristics and a constant evaporation capacity, both equations (6) and (7) embedded in a building energy simulation program allow the modelers to determine the unit performances during an hourly simulation. Indeed, once t_0 and t_{cyc} are determined, the *PLR* and the *CDF* can be hourly estimated and so on (the *COP*, C_d, λ, ...).

3. Identification of the equivalent set of parameters

The HVAC BESTEST procedure only concerns ideal systems. The thermostat is represented by the relationship (5) with C_d = 0.229. As a consequence, for our model we have first to determine an equivalent set of parameters value for the couple $(\tau,\ \Delta T_c)$. This was done by applying the HVAC BESTEST E100–200 series cases. We found τ = 0.8 sec and ΔT_c = 0.05°C which gave C_d = 0.226 (instead of 0.229 for the idealistic model) and *CDF* = 0.9805 (instead of 0.981). The same set of parameters is used to perform the E300–360 series cases.

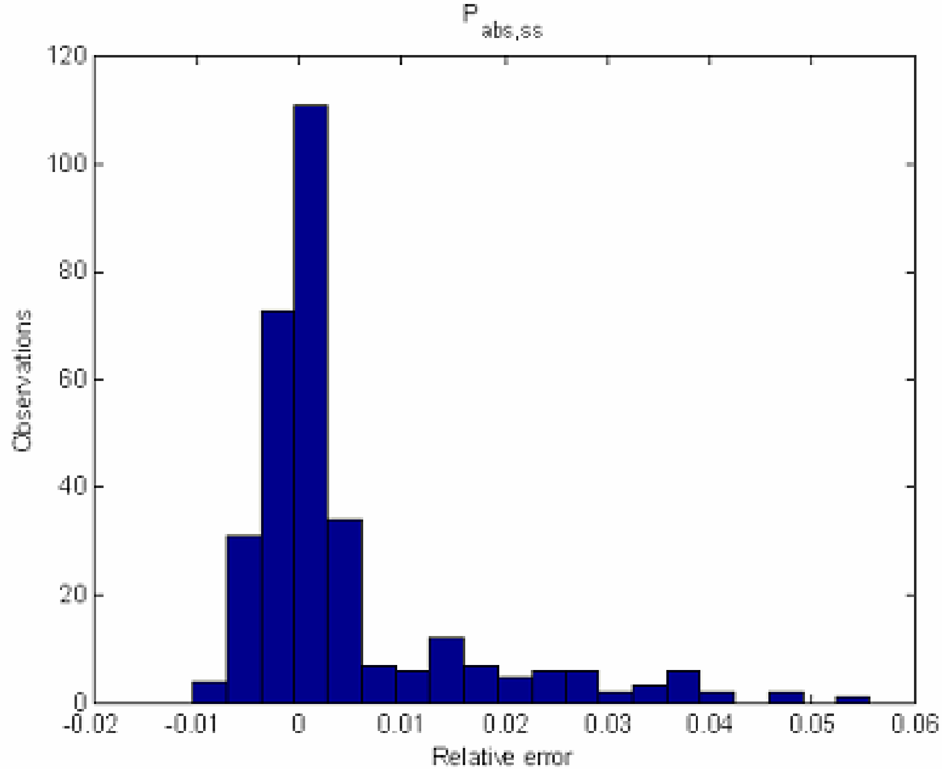
4. Modeling the steady-state capacities with neural networks

The steady-state performances of the split-system are predicted using a neural network. This model was obtained using manufacturer data. Indeed, starting from the HVAC performances in extreme conditions (measured), a database was built in order to allow a neural network to learn the behavior of the system under several conditions. With such a model, the coil loads are obtained for values of the model inputs varying between the minimal and the maximal value of the learning database (no extrapolation).

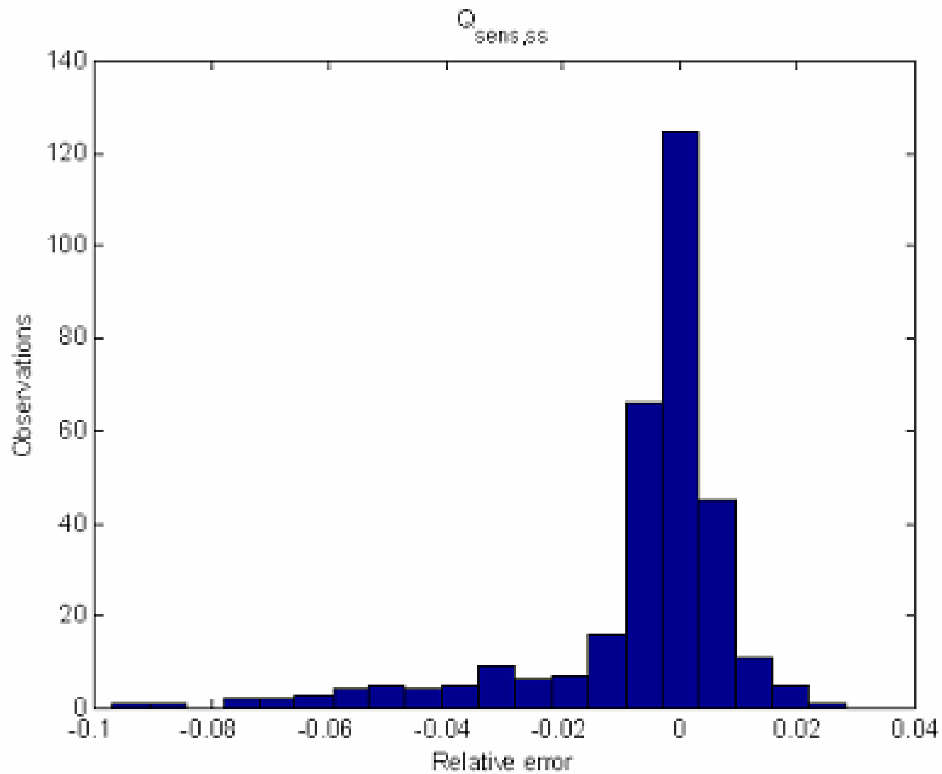
	EDB	EWB	ODB
Min	12.78	4.4	12.78
Max	35.00	35.00	46.11

However, the neural networks are unable to extrapolate in the case of dry-coil conditions. In such a case, the following expressions are used:

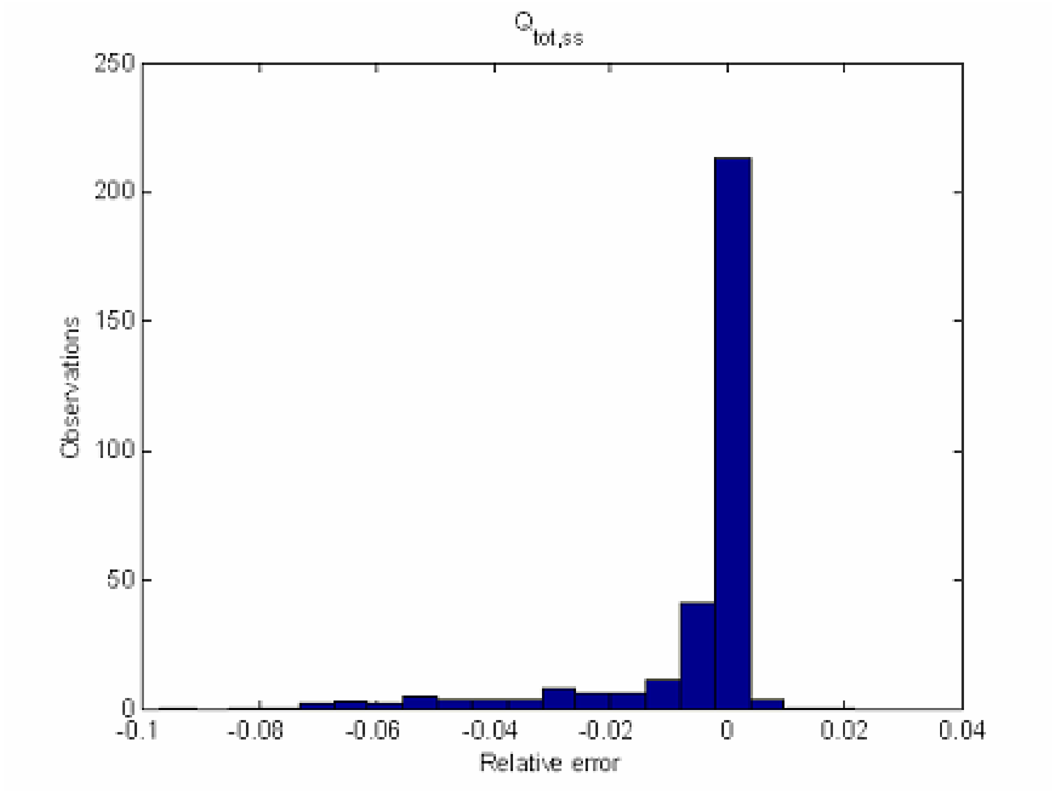
Tewb = ((17.8823 - 23.5512) + (- 0.1128*Todb + 0.3226*Todb) + (1.9688*Tedb - 0.0046*Tedb))/(1.0882 + 2.1011);
$Q_{tot,ss}$ = 23.5512 - 0.3226*Todb + 0.0046*Tedb + 1.0882*Tewb;
$P_{sens,ss}$ = 17.8823 - 0.1128*Todb + 1.9688*Tedb - 2.1011*Tewb;
$P_{abs,ss}$ = 2.3926 + 0.1390*Todb + 0.0056*Tedb + 0.1376*Tewb;
These relationships ensure that $Q_{tot,ss} = Q_{sens,ss}$.



$P_{abs,ss}$
Observations
Relative error



$Q_{sens,ss}$
Observations
Relative error



These figures show the distribution of the relative errors between the neural networks prediction and the manufacturer's data. The neural network model is quite accurate.

5. Results

5.1 Round 1

In the first round only cases 300 and 310 were tested (July 2002).

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	31988.103	18768.339	2339.844	10879.92	86713.7	52954.9	22878.8	4.10806	24.088	0.00915	0.47663	19.91	0.01165
E310	35627.559	22075.852	2671.787	10879.92	105792	51681.17	43231	4.27484	24.085	0.01105	0.57179		

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks					
	Compr + Both Fans			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11.176	201	15	22.095	155	15	19.765	255	15	36.486	255	15	35	201	15	0.0224	275	9
E310	11.734	201	14	22.456	201	15	29.453	216	14	40.751	275	14						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	1600	240	7296	5539	1757	0.009098	3.96522	17.8	23.92	17.166	0.0111
2	1650	245	7401	5705	1695	0.009301	3.90554	18.3	24	17.088	0.01146
3	1599	240	7289	5539	1750	0.009104	3.96357	17.8	23.92	17.157	0.0111
4	1583	238	7184	5541	1643	0.009114	3.94509	17.8	23.92	17.017	0.0111
5	1501	229	6893	5346	1547	0.008608	3.98439	17.2	23.83	16.886	0.01018
6	1737	253	7485	6075	1410	0.009048	3.76131	19.4	24.16	16.737	0.011
7	2572	332	9856	7907	1950	0.010153	3.39394	25	25	17.599	0.01314
8	3004	368	11126	8616	2510	0.008819	3.29953	27.2	25.33	18.228	0.01108
9	3742	451	13312	11445	1867	0.010527	3.17482	28.9	25.59	17.44	0.012
10	4107	485	15203	11394	3809	0.010152	3.31076	28.9	25.59	18.755	0.01276
11	4480	509	15799	12118	3681	0.011412	3.16677	31.1	25.91	18.845	0.01481
12	4608	523	16744	11924	4820	0.010016	3.2633	30.6	25.84	19.43	0.01325
13	5658	648	20570	16616	3954	0.008947	3.26197	31.1	25.91	18.361	0.01133
14	5496	630	19324	16852	2472	0.009942	3.15442	31.7	26	17.682	0.01173
15	7120	800	26438	21451	4988	0.008796	3.33813	32.2	26.08	18.471	0.01238
16	6854	777	25042	21489	3553	0.010649	3.28161	32.2	26.08	17.917	0.01423
17	4682	525	16439	12302	4136	0.011196	3.1571	31.7	26	19.148	0.01473
18	4769	535	17238	12079	5160	0.011219	3.25	31.1	25.91	19.636	0.01568
19	4222	499	16171	11165	5006	0.010619	3.42533	28.3	25.5	19.383	0.01454
20	3991	482	15609	10810	4799	0.012041	3.4896	27.2	25.33	19.211	0.01688
21	3508	417	13804	8544	5260	0.011089	3.51694	27.2	25.33	20.111	0.01688
22	3244	394	12662	8406	4256	0.011478	3.48048	26.7	25.25	19.493	0.01683
23	3218	393	12844	8199	4645	0.011359	3.55691	26.1	25.16	19.728	0.01689
24	3207	392	12786	8200	4586	0.01164	3.55265	26.1	25.16	19.691	0.01733

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zo											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	4.4302	110	5	3.039	164	17	25.04	81	2	8.03	6	5
E310	4.9232	124	14	2.8509	210	17	25.04	81	2	8.02	6	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zo											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0144	247	16	0.0008	255	15	0.72	174	16	0.04	255	15
E310	0.0201	161	15	0.0019	11	2	1	112	15	0.13	226	16

The results showed high gaps as compared to the other programs. It was found that the main error of the model was due to an amalgam between gross and net capacities. Indeed, the sensible building loads were calculated by accounting for the sensible gain due to the indoor ventilator (1.242 kW), whereas in the calculation of the evaporator coil loads net capacities were considered. We also noticed that the neural networks did not allow extrapolation in case of dry-coil conditions.

5.2 Round 2

Round 2 is an improvement of the previous program as it properly takes into account the gross capacities and also allows extrapolation at dry-coil conditions. For extrapolation the polynomials described earlier are used (see page 3).

Results from the Round 2 modeling with CODYRUN are presented below.

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity	Zone Relative		Outdoor Humidity
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Ratio (kg/kg)	Humidity (%)	ODB (°C)	Ratio (kg/kg)
E300	35085.893	21866.098	2339.875	10879.92	78549.4	55589.32	22847.1	3.24504	24.087	0.00913	0.47593	19.91	0.01165
E310	39050.576	25511.567	2659.089	10879.92	97696.8	54371.42	43055	3.46803	24.086	0.01107	0.57302		
E320	43422.252	29447.726	3094.606	10879.92	113767	71993.22	41409.7	3.49596	24.087	0.00989	0.51302		
E330	44428.791	30432.139	3116.732	10879.92	120527	72733.48	47364	3.59257	24.087	0.00965	0.50159		
E340	44038.555	30040.44	3118.195	10879.92	117554	72814.27	44615.8	3.5452	24.087	0.00971	0.50416		
E350	31849.319	18972.872	1996.527	10879.92	67649.6	48835.15	18611.7	3.22611	26.276	0.00971	0.43858		
E360	53712.926	38596.307	4236.699	10879.92	153566	113395	31251.9	3.58522	24.086	0.00798	0.41797		

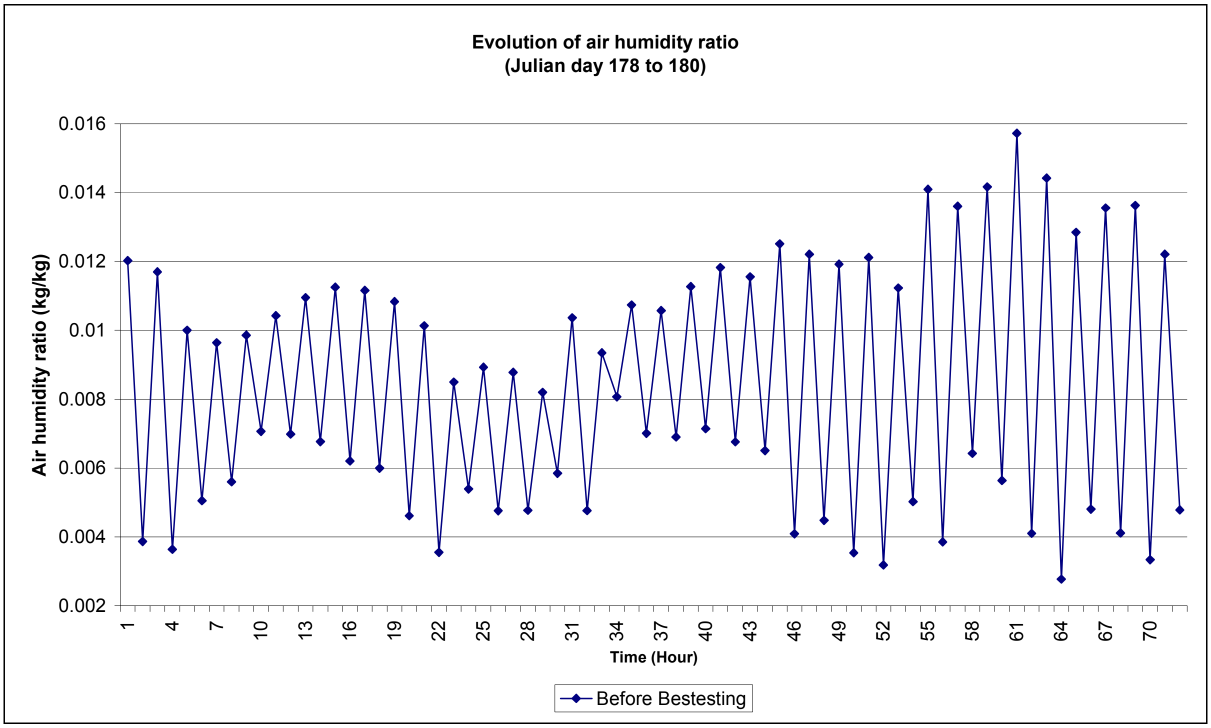
Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
	Energy Consumption			Evaporator Coil Loads									Weather Data Checks					
	Compr + Both Fans			Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	12270	189	16	23056	155	16	19145	227	15	37709	227	17	35	201	15	26.5	201	15
E310	12855	189	18	22925	195	17	29984	275	16	42209	275	16						
E320	12629	201	15	34388	285	17	28976	275	10	40994	275	10						
E330	13474	201	15	34789	114	13	28234	204	13	43778	275	9						
E340	13066	201	15	32731	114	14	26477	275	10	41447	275	10						
E350	12448	189	16	23062	155	16	18218	246	16	37458	246	16						
E360	12701	201	15	31841	214	20	25549	219	21	40594	219	21						

Hour	June 28 Hourly Output - Case E300											
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	1921	240	7555	5800	1755	0.009097	3.49607	17.8	23.92	17.163	0.0111
2	1977	245	7667	5972	1695	0.009301	3.4505	18.3	24	17.088	0.01146
3	1920	240	7550	5800	1750	0.009104	3.49537	17.8	23.92	17.157	0.0111
4	1901	238	7443	5800	1643	0.009114	3.47966	17.8	23.92	17.017	0.0111
5	1806	229	7141	5593	1547	0.008608	3.50909	17.2	23.83	16.886	0.01018
6	2076	253	7759	6350	1410	0.009048	3.33147	19.4	24.16	16.737	0.011
7	3015	332	10225	8276	1950	0.010153	3.05497	25	25	17.599	0.01314
8	3496	368	11542	9032	2510	0.008819	2.98706	27.2	25.33	18.228	0.01108
9	3575	371	11118	9617	1501	0.009686	2.81754	28.9	25.59	17.44	0.012
10	4565	469	14868	11962	2906	0.010535	2.95352	28.9	25.59	18.186	0.01276
11	5261	517	16858	12718	4140	0.011202	2.91762	31.1	25.91	19.104	0.01481
12	5268	520	17184	12546	4638	0.010078	2.9689	30.6	25.84	19.336	0.01325
13	4995	496	15651	12718	2933	0.00975	2.8503	31.1	25.91	18.389	0.01133
14	6574	649	21191	17615	3576	0.009392	2.93382	31.7	26	18.243	0.01173
15	6598	648	20963	17787	3176	0.009979	2.89304	32.2	26.08	18.102	0.01238
16	8331	811	28151	22476	5676	0.009459	3.0793	32.2	26.08	18.716	0.01423
17	8056	794	27230	22304	4926	0.010158	3.07684	31.7	26	18.393	0.01473
18	5201	513	16587	12718	3868	0.011827	2.90287	31.1	25.91	18.952	0.01568
19	5054	513	17565	11756	5809	0.010227	3.1552	28.3	25.5	19.784	0.01454
20	4540	474	15711	11377	4333	0.012254	3.13343	27.2	25.33	18.951	0.01688
21	5074	520	18361	11377	6983	0.01097	3.28227	27.2	25.33	20.268	0.01688
22	3745	391	12993	8860	4133	0.011528	3.14144	26.7	25.25	19.413	0.01683
23	3737	393	13270	8654	4616	0.0114	3.21308	26.1	25.16	19.709	0.01689
24	3743	393	13299	8654	4645	0.01161	3.21543	26.1	25.16	19.728	0.01733

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.9766	263	1	2.7401	227	18	25.04	81	2	8.03	6	5
E310	4.4114	110	5	2.6334	189	19	25.04	81	2	8.03	6	5
E320	4.565	120	10	2.7483	335	14	25.04	81	2	8.03	6	5
E330	4.3703	120	9	2.7483	335	14	25.04	81	2	8.03	6	5
E340	4.4495	120	9	2.7483	335	14	25.04	81	2	8.03	6	5
E350	3.9428	101	19	2.6385	163	9	35	111	1	8.03	6	5
E360	4.7579	110	4	2.7304	90	15	25.04	81	2	8.03	6	5

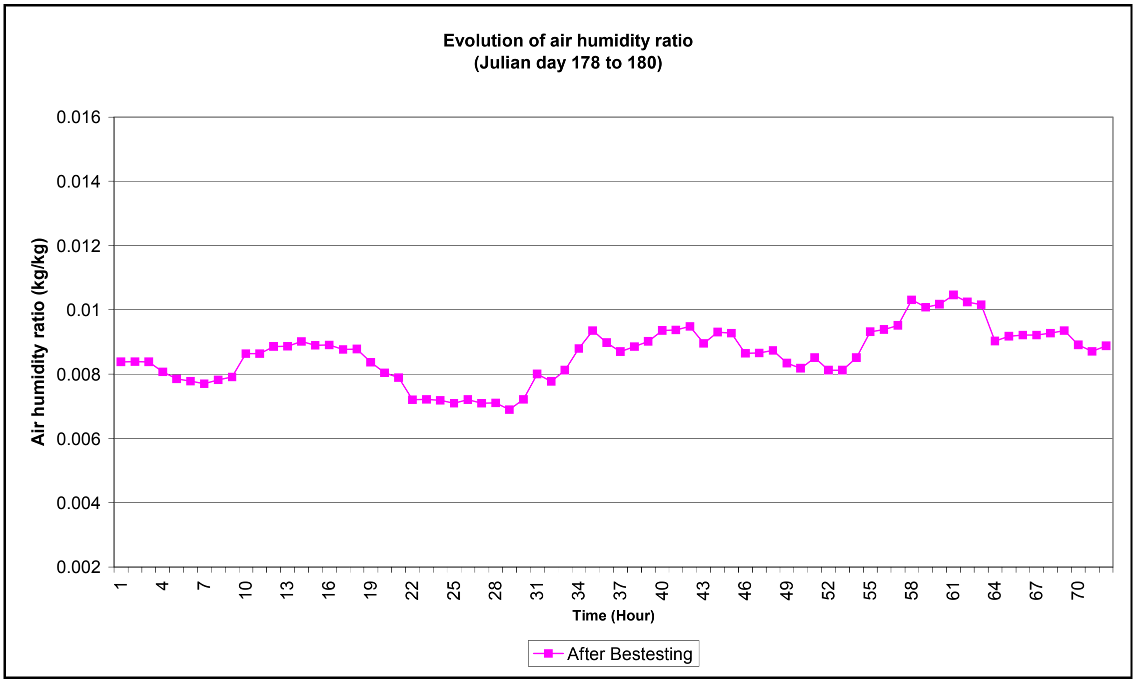
Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0146	227	18	0.0019	11	2	0.73	227	16	0.13	310	5
E310	0.0201	112	17	0.0019	11	2	1	112	17	0.13	310	5
E320	0.0197	275	9	0.0019	11	2	0.98	275	9	0.13	310	5
E330	0.0179	191	12	0.0019	11	2	0.89	191	12	0.13	310	5
E340	0.0182	275	9	0.0019	11	2	0.91	275	9	0.13	310	5
E350	0.0173	213	21	0.0019	11	2	0.79	275	9	0.13	310	5
E360	0.0164	274	11	-0.0006	219	21	0.82	191	12	-0.03	219	21

By analyzing the results in-depth, we noticed that the predicted indoor air humidity was not satisfactory. Indeed, as shown on the figure below, the predicted indoor humidity ratio strongly oscillates, especially for the case E360 (in this case, the minimal indoor air humidity ratio was negative). This is explained by the fact that the system capacities depend on the air humidity entering the evaporator coil. But in the original program, the air humidity entering the evaporator coil was calculated from the indoor air humidity estimated at the preceding time step (the previous hour). Consequently, the predicted steady-capacities were underestimated as the current internal latent load was not accounted for.



5.3 Round 3

To take into account the latent loads properly, an iterative loop at a short-time step (some minutes) was used to solve the humidity equation balance. The aim of the loop is to determine the appropriate entering air humidity for the hourly simulation. As expected, the predicted indoor air humidity ratio is improved.



Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	35086.586	21866.916	2339.75	10879.92	78568.1	55621.82	22856.6	3.24572	24.087	0.00913	0.47601	19.91	0.01165
E310	39044.396	25505.057	2659.419	10879.92	97518.4	55202.41	42299.5	3.46246	24.086	0.01118	0.57904		
E320	43434.026	29456.575	3097.531	10879.92	113750	72369.42	41029	3.49419	24.087	0.00989	0.51354		
E330	44483.545	30483.373	3120.252	10879.92	120828	72548.49	47852.3	3.59568	24.087	0.00964	0.50094		
E340	44076.572	30074.487	3122.165	10879.92	117707	72965.69	44619.9	3.54576	24.087	0.0097	0.50394		
E350	31861.866	18984.607	1997.339	10879.92	67674.3	48971.95	18591.4	3.22536	26.276	0.00971	0.44024		
E360	54305.655	39138.762	4286.973	10879.92	155663	125505.8	30077.4	3.58457	24.086	0.00814	0.42673		

Cases	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
													Weather Data Checks					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads: Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11825	189	16	23064	228	16	11480	246	16	33409	246	16	35	201	15	26.5	201	15
E310	12392	228	16	22821	164	16	18290	261	16	38196	261	16						
E320	12634	201	15	34388	285	17	23034	275	11	39513	275	12						
E330	13480	201	15	34789	114	13	28246	112	18	43932	275	9						
E340	13072	201	15	32731	114	16	24898	246	17	40705	246	17						
E350	11821	189	16	23072	228	16	16521	275	8	33421	246	16						
E360	12236	201	15	31300	136	10	10749	246	17	35827	258	11						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	1923	240	7566	5800	1766	0.009202	3.49792	17.8	23.92	17.178	0.0111
2	1989	246	7734	5972	1762	0.009245	3.4604	18.3	24	17.173	0.01146
3	1916	240	7530	5800	1730	0.009172	3.49258	17.8	23.92	17.131	0.0111
4	1909	239	7489	5800	1690	0.009138	3.4865	17.8	23.92	17.079	0.0111
5	1809	229	7157	5593	1564	0.008871	3.51178	17.2	23.83	16.91	0.01018
6	2102	256	7909	6350	1559	0.00895	3.35411	19.4	24.16	16.931	0.011
7	3002	330	10163	8276	1888	0.009557	3.05012	25	25	17.538	0.01314
8	3397	360	11068	9032	2036	0.00926	2.94597	27.2	25.33	17.813	0.01108
9	3660	378	11511	9617	1894	0.009404	2.85067	28.9	25.59	17.805	0.012
10	4506	464	14592	11962	2630	0.010023	2.93602	28.9	25.59	17.999	0.01276
11	5132	507	16270	12718	3552	0.010743	2.88526	31.1	25.91	18.769	0.01481
12	5150	511	16642	12546	4096	0.010534	2.93976	30.6	25.84	19.042	0.01325
13	5106	505	16153	12718	3435	0.010034	2.87881	31.1	25.91	18.699	0.01133
14	6664	656	21607	17615	3993	0.009606	2.95178	31.7	26	18.44	0.01173
15	6664	653	21268	17787	3482	0.009715	2.90666	32.2	26.08	18.252	0.01238
16	8234	804	27683	22476	5207	0.009718	3.06296	32.2	26.08	18.551	0.01423
17	8166	802	27764	22304	5461	0.009781	3.0959	31.7	26	18.586	0.01473
18	5110	505	16174	12718	3456	0.010892	2.8805	31.1	25.91	18.712	0.01568
19	4812	492	16394	11756	4638	0.010836	3.09087	28.3	25.5	19.187	0.01454
20	4693	487	16465	11377	5088	0.011368	3.17857	27.2	25.33	19.365	0.01688
21	4831	499	17149	11377	5772	0.01147	3.21745	27.2	25.33	19.712	0.01688
22	3854	401	13527	8860	4666	0.011387	3.17908	26.7	25.25	19.752	0.01683
23	3726	392	13216	8654	4562	0.011388	3.20932	26.1	25.16	19.676	0.01689
24	3742	393	13294	8654	4640	0.011499	3.21499	26.1	25.16	19.725	0.01733

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.9428	101	19	2.7483	335	14	25.04	81	2	8.03	6	5
E310	4.287	110	6	2.7621	335	15	25.04	81	2	8.03	6	5
E320	4.5616	277	20	2.7277	335	14	25.04	81	2	8.03	6	5
E330	4.3717	120	9	2.7483	335	14	25.04	81	2	8.03	6	5
E340	4.445	120	9	2.7483	335	14	25.04	81	2	8.03	6	5
E350	3.9428	101	19	2.7497	335	14	35.00	111	1	8.03	6	5
E360	4.6285	110	3	2.7483	335	14	25.04	81	2	8.03	6	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0135	320	16	0.0020	11	3	0.68	320	16	0.15	310	5
E310	0.0157	275	9	0.0020	5	7	0.78	246	9	0.15	310	5
E320	0.0173	191	12	0.0020	11	3	0.86	191	12	0.15	310	5
E330	0.0171	191	13	0.0020	11	3	0.85	191	12	0.15	310	5
E340	0.0171	191	12	0.0020	11	3	0.85	191	12	0.15	310	5
E350	0.0166	275	2	0.0020	11	3	0.68	320	16	0.15	310	5
E360	0.0135	320	16	0.0020	11	3	0.68	320	16	0.15	310	5

However, the predictions of CODYRUN strongly disagreed with those of the other programs. The sensitivity tests and the comparisons proposed by the procedure brought us to doubt about the internal loads file. Indeed, a shift in the hourly electrical consumption has been noticed. The internal loads files were checked and corrected. Then we performed the next round.

5.4 Round 4

We also modified CODYRUN so that the IDB value could be greater than the set point when the system is undersized. Previously, the IDB was fixed to the set point when the system was on. The results were then more in accordance with the other codes except for case E360. We think that this difference can be explained by the neural network performance. Even though its accuracy was assessed with the available data, we are unable to affirm that the neural networks perform well in the "blank cases conditions." These cases probably occur more frequently in the E360 case (undersized system).

	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity Ratio	Zone Relative Humidity		Outdoor Humidity Ratio
Cases	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	(kg/kg)	(%)	ODB (°C)	(kg/kg)
E300	34958.787	21754.282	2324.585	10879.92	77684.4	55162.02	22520.9	3.22625	24.084	0.00918	0.47829	19.91	0.01165
E310	39500.164	25916.972	2703.272	10879.92	97202.6	55089.64	42111.7	3.39629	24.108	0.01117	0.57781		
E320	39361.996	25804.156	2677.92	10879.92	96499.3	59094.11	37403.5	3.38807	24.472	0.00999	0.50372		
E330	40518.956	26918.215	2720.821	10879.92	103678	62613.01	41063.4	3.49802	24.297	0.00981	0.50079		
E340	40019.637	26430.125	2709.592	10879.92	100381	60887.75	39491.6	3.44481	24.383	0.00984	0.49927		
E350	31638.101	18793.412	1964.769	10879.92	66965.2	48539.4	18424.1	3.22597	26.271	0.00974	0.44207		
E360	54073.58	38923.953	4269.707	10879.92	155126	125449	29675.4	3.5914	28.402	0.00816	0.34749		

	Annual Hourly Integrated Maxima Consumptions and Loads												E300 Only, Maxima					
													Weather Data Checks					
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads: Sensible			Latent			Sensible + Latent			ODB			Outdoor Humidity Ratio		
Cases	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	°C	Date	Hour	kg/kg	Date	Hour
E300	11914	20-juil	15	23441	20-juil	15	10331	3-sept	15	32462	20-juil	15	35	20-juil	15	0.0224	2-oct	9
E310	12544	20-juil	15	22973	10-sept	15	16377	3-sept	15	36938	3-sept	15						
E320	12628	20-juil	15	30816	24-avr	16	22837	10-juil	12	39008	18-sept	15						
E330	13467	20-juil	15	33969	24-avr	16	28184	18-sept	15	43978	2-oct	9						
E340	13083	20-juil	15	32835	24-avr	16	24719	2-oct	9	41022	2-oct	9						
E350	11930	20-juil	15	23449	20-juil	15	10787	2-oct	8	32613	20-juil	15						
E360	12243	20-juil	15	31156	16-mai	10	10329	2-oct	9	35375	22-sept	19						

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load			Zone					Outdoor
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Hum. Rat. (kg/kg)
1	1890	236	7488	5800	1689	0.009271	3.52211	17.8	23.92	17.114	0.0111
2	1968	245	7722	5972	1750	0.009297	3.48938	18.3	24	17.249	0.01146
3	1886	236	7466	5800	1666	0.009232	3.51838	17.8	23.92	17.096	0.0111
4	1881	236	7445	5800	1645	0.009196	3.51677	17.8	23.92	17.084	0.0111
5	1761	223	7023	5593	1429	0.008962	3.53982	17.2	23.83	16.683	0.01018
6	2077	254	7922	6350	1573	0.009007	3.39854	19.4	24.16	17.049	0.011
7	3031	338	10434	8276	2158	0.009493	3.09706	25	25	18.106	0.01314
8	3303	350	10814	9032	1782	0.009314	2.96031	27.2	25.33	17.572	0.01108
9	4477	467	14605	11962	2644	0.009714	2.95409	28.9	25.59	18.274	0.012
10	4588	476	15074	11962	3112	0.010051	2.9767	28.9	25.59	18.567	0.01276
11	5234	523	16708	12718	3990	0.010595	2.90221	31.1	25.91	19.351	0.01481
12	5063	504	16247	12546	3701	0.010584	2.91845	30.6	25.84	18.935	0.01325
13	6442	633	21090	17408	3682	0.009973	2.98092	31.1	25.91	18.092	0.01133
14	6519	642	21051	17615	3436	0.009777	2.93967	31.7	26	18.193	0.01173
15	7994	782	26610	22476	4135	0.009582	3.03213	32.2	26.08	18.162	0.01238
16	8167	801	27407	22476	4931	0.009733	3.05609	32.2	26.08	18.614	0.01423
17	5300	528	16681	12925	3756	0.010442	2.86222	31.7	26	19.329	0.01473
18	5377	534	17296	12718	4578	0.010915	2.92607	31.1	25.91	19.636	0.01568
19	4790	491	16225	11756	4469	0.010917	3.07233	28.3	25.5	19.199	0.01454
20	4807	504	16860	11377	5483	0.011272	3.17454	27.2	25.33	19.78	0.01688
21	3936	409	13471	9032	4438	0.011354	3.10035	27.2	25.33	19.73	0.01688
22	3851	402	13319	8860	4458	0.011387	3.13167	26.7	25.25	19.709	0.01683
23	3751	396	13137	8654	4483	0.011418	3.16783	26.1	25.16	19.706	0.01689
24	3793	400	13319	8654	4664	0.01151	3.17648	26.1	25.16	19.841	0.01733

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.8753	30-avr	16	2.7825	13-juin	17	25.04	22-mars	2	8.03	6-janv	5
E310	4.1343	30-avr	15	2.873	1-déc	15	29.71	8-juil	16	8.03	6-janv	5
E320	3.9249	16-sept	15	2.8027	1-déc	15	36.29	20-juil	15	8.03	6-janv	5
E330	4.1219	17-juin	16	2.8225	31-mars	15	31.89	20-juil	15	8.03	6-janv	5
E340	4.0096	16-sept	16	2.8225	31-mars	15	34.24	20-juil	15	8.03	6-janv	5
E350	3.8805	27-avr	5	2.7862	13-juin	17	35	21-avr	1	8.03	6-janv	5
E360	4.4335	4-oct	24	2.8225	31-mars	15	50.19	10-juil	13	8.03	6-janv	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.0135	30-avr	16	0.002	13-juin	3	68%	22-mars	16	15%	6-janv	5
E310	0.0154	30-avr	8	0.002	1-déc	7	77%	8-juil	8	16%	6-janv	8
E320	0.0169	16-sept	12	0.002	1-déc	3	82%	20-juil	18	15%	6-janv	5
E330	0.017	17-juin	13	0.002	31-mars	3	76%	20-juil	18	15%	6-janv	5
E340	0.0169	16-sept	12	0.002	31-mars	3	79%	20-juil	19	15%	6-janv	5
E350	0.0165	27-avr	2	0.002	13-juin	3	70%	21-avr	8	15%	6-janv	5
E360	0.0135	4-oct	16	0.002	31-mars	3	68%	10-juil	16	14%	6-janv	13

5.5 Cases E500–E545

We have tested the E500 cases series. It was the first round for this case. We noticed sensitivities to humidity ratio and COP2 for cases E530, E540, and E545. In the cases the building is perfectly closed (no indoor/outdoor air exchange) and no latent load is supplied; the results are sensitive to the initial indoor air conditions. For instance, we obtained for case E520 a maximum COP2 between 5 to 6 by setting the initial indoor air conditions equal to the outdoor air conditions at the first time step.

Cases	Annual Sums							Annual Means			
	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity	Zone Relative
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Ratio (kg/kg)	Humidity (%)
E500	22438.141	17954.355	1919.891	2563.895	63341.4	45033.53	18307.8	3.18711	20.806	0.00959	0.57911
E500 May-Sep	17459.032	14012.297	1475.843	1970.892	48424.4	34432.96	13991.5	3.12655	25	0.01121	0.56475
E510 May-Sep	34907.785	27958.63	2975.449	3973.706	108964	77483.79	31479.9	3.52245	25	0.01121	0.56479
E520	25161.221	19681.536	2346.402	3133.283	63193.2	44956.2	18232.4	2.86878	13.409	0.00654	0.67188
E522	23741.477	18790.149	2120.039	2831.289	63400.2	45090.12	18310	3.03202	17.254	0.0078	0.60079
E525	20303.238	16561.751	1602.045	2139.442	63224.5	44921.62	18303	3.4808	27.851	0.01403	0.53952
E530	17447.262	13859.917	1536.021	2051.324	44856.7	44836.58	0	2.91354	20.805	0.0031	0.23506
E540	19566.37	15186.767	1875.244	2504.359	44964.4	44956.24	0.493	2.63535	13.405	0.00269	0.30076
E545	15780.848	12742.127	1301.089	1737.632	44738.8	44724.75	0.486	3.18579	27.847	0.00274	0.17162

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3904.875	3024	377.0833	503.7917	13164.9	9359.917	3804.63	0.01089	3.8316	16.8833	25
June 25	5067.08333	4107.04167	411.0833	548.9583	13187.8	9376.917	3810.38	0.01134	2.9174	29.5167	25

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
April 30	3090.91667	2377.83333	305.3333	407.75	9362.17	9359.917	0	0.0031	3.46	16.8833	25
June 25	3936.375	3167.04167	329.4167	439.9167	9383.08	9376.917	0	0.0031	2.6877	29.5167	25

Cases	Annual Hourly Integrated Maxima Consumptions and Loads											
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads: Sensible			Latent			Sensible + Latent		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour
E500	10154	20-juil	15	18762	14-août	15	7833	29-juin	16	26590	29-juin	16
E510	11157	20-juil	15	21107	14-août	12	8891	17-juin	14	29990	17-juin	14
E520	11008	20-juil	15	18865	20-juil	16	7716	30-juin	16	26578	20-juil	16
E522	10611	20-juil	15	18770	29-juil	15	7770	29-juin	16	26536	30-juin	16
E525	9411	20-juil	15	18745	22-août	16	7990	29-juin	16	26729	29-juin	16
E530	8003	20-juil	15	18762	14-août	15	0	1-janv	1	18777	16-août	15
E540	8866	20-juil	15	18779	3-août	15	90	11-mars	14	18784	13-août	15
E545	7367	20-juil	15	18745	22-août	16	57	11-mars	11	18756	16-août	15

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2: Maximum			Minimum			Indoor Drybulb Temperature: Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E500	4.1702	16-mars	10	2.6702	29-juil	12	25	11-mars	10	18.2	31-déc	21
E510	4.6883	4-oct	24	2.8773	31-mars	15	25	11-mars	10	18.2	31-déc	21
E520	4.4	22-nov	1	2.2857	8-nov	11	17.26	16-août	16	14.34	31-mars	9
E522	5	10-nov	12	2.3333	16-nov	13	20.05	19-oct	7	16.99	31-déc	23
E525	4.6018	16-mars	10	2.8966	29-juil	12	35	11-mars	10	20.51	31-déc	24
E530	3.7304	16-mars	10	2.4701	29-juil	12	25	11-mars	10	18.2	31-déc	21
E540	6	16-déc	2	2.1429	15-oct	15	15.05	12-nov	6	14.34	31-mars	9
E545	4.1396	16-mars	10	2.6918	29-juil	12	35	11-mars	10	20.51	31-déc	23

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio: Maximum			Minimum*			Relative Humidity: Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E500	0.0116	16-mars	15	0.0107	29-juil	1	83%	11-mars	14	54%	31-déc	3
E510	0.0116	4-oct	15	0.0107	31-mars	24	83%	11-mars	14	54%	31-déc	5
E520	0.0074	22-nov	15	0.007	8-nov	24	71%	16-août	10	60%	31-mars	16
E522	0.0092	10-nov	15	0.0086	16-nov	9	71%	19-oct	4	59%	31-déc	2
E525	0.0175	16-mars	15	0.0152	29-juil	24	100%	11-mars	11	44%	31-déc	23
E530	0.0031	16-mars	1	0.0031	29-juil	1	24%	11-mars	22	16%	31-déc	10
E540	0.0031	16-déc	1	0.0026	15-oct	1	26%	12-nov	1	25%	31-mars	1
E545	0.0031	16-mars	1	0.0026	29-juil	24	17%	11-mars	23	7%	31-déc	24

5.6 Polynomial approximations of the whole manufacturer's data

Neural networks are not easy to implement. Therefore, the steady-state capacities have been approximated by polynomial functions. The results obtained with those functions are close to the predictions from neural networks (see the tables below). We just noticed a slight shift in the calculation of the humidity ratio.

$$P_{abs} = a_1 + a_2 T_{EWB} + a_3 T_{EDB} + a_4 T_{ODB} + a_5 T_{EWB}^2 + a_6 T_{ODB}^2 + a_7 T_{EWB} T_{ODB} + a_8 T_{EWB}^2 T_{EDB}$$

$$\begin{aligned} P_{tot} = {} & a_1 + a_2 T_{EWB} + a_3 T_{EDB} + a_4 T_{ODB} + a_5 T_{EWB}^2 + a_6 T_{EDB}^2 + a_7 T_{ODB}^2 + a_8 T_{EWB} T_{ODB} \\ & + a_9 T_{EWB}^3 + a_{10} T_{EWB}^2 T_{EDB} + a_{11} T_{EDB}^2 T_{EWB} + a_{12} T_{EDB} T_{EWB} T_{ODB} + a_{13} T_{EWB}^3 T_{EDB} \\ & + a_{14} T_{EWB}^4 T_{EDB} + a_{15} T_{EWB}^3 T_{EDB}^2 \end{aligned}$$

$$\begin{aligned} P_{sens} = {} & a_1 + a_2 T_{EWB} + a_3 T_{EDB} + a_4 T_{ODB} + a_5 T_{EWB}^2 + a_6 T_{EDB}^2 + a_7 T_{ODB}^2 + a_8 T_{EWB} T_{ODB} \\ & + a_9 T_{EWB}^3 + a_{10} T_{EWB}^2 T_{EDB} + a_{11} T_{EDB}^2 T_{EWB} + a_{12} T_{EDB} T_{EWB} T_{ODB} + a_{13} T_{EWB}^3 T_{EDB} \\ & + a_{14} T_{EWB}^4 T_{EDB} + a_{15} T_{EWB}^3 T_{EDB}^2 + a_{16} T_{EDB}^3 T_{EWB}^2 + a_{17} T_{EDB}^3 \end{aligned}$$

Coefficients	Pabs	Ptot	Psens
a1	9.3254	35.5299	20.1656
a2	1.6426	15.051	-31.222
a3	0.1589	1.0087	21.9428
a4	2.2504	-5.0211	-1.4393
a5	0.1867	2.0888	-1.0333
a6	-0.0684	-0.2118	-0.1579
a7	0.7169	-0.262	-0.1157
a8	0.4376	-1.8029	0.6444
a9		-3.1211	8.5271
a10		6.1887	-19.6709
a11		-3.3151	11.0309
a12		-0.4909	-1.2676
a13		0.5559	0.0358
a14		-2.8045	6.3097
a15		2.7819	-7.3674
a16			3.4213
a17			-2.2501

5.7 Major improvements during round 5 (February 2003)

To improve the performance of the model:

- We have included the thermal balance equation into the reduced time step loop just like we did with the humidity balance equation in the last round.
- Since we participated in the test, the walls of the building were modeled using a real material: polystyrene. But, we noticed that the discrepancies in the E500 series cases (max. COP2, min. indoor dry-bulb temp. …) were due to the thermal capacitance of the building. Consequently, we decreased the thermal capacitance of the walls.
- We have also modified an error in the program that corresponded to an amalgam between the air infiltration and the mixing air rate at the entering of the evaporator.

Cases	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity	Zone Relative
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Ratio	Humidity
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)
E300	35063.45	21853.18	2330.35	10879.92	77923.15	55162.02	22761.12	3.222157	24.08404	0.009144	47.66267
E310	38909.80	25526.73	2503.15	10879.92	95296.76	55106.53	40190.14	3.399827	24.10236	0.011439	59.09224
E320	39435.10	25887.97	2667.21	10879.92	97187.60	61764.30	35423.29	3.403502	24.33958	0.010035	51.00776
E330	40584.02	26980.64	2723.46	10879.92	103741.72	62621.23	41120.49	3.492504	24.29694	0.009799	50.01804
E340	40106.50	26518.12	2708.47	10879.92	100696.95	62204.86	38492.10	3.445389	24.31765	0.009853	50.19532
E350	31480.67	18658.44	1942.31	10879.92	66558.03	48539.40	18018.60	3.230855	26.27149	0.009793	44.48505
E360	54477.23	39387.32	4209.99	10879.92	159621.60	133190.04	26431.50	3.661272	25.80300	0.008622	41.28904

Cases	Annual Sums							Annual Means			
	Cooling Energy Consumption				Evaporator Coil Load					Zone Humidity	Zone Relative
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Ratio	Humidity
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)
E500	21749.36	17880.80	1656.37	2212.18	63100.77	44873.82	18227.01	3.22978	20.88422	0.010147	61.74658
E500 May-	16983.69	14004.70	1275.49	1703.50	48439.62	34448.18	13991.48	3.170093	25.00000	0.012364	62.18655
E510 May-	34015.29	27919.70	2610.00	3485.59	108978.87	77498.98	31479.87	3.569601	25.00826	0.012856	64.58660
E520	24700.50	19675.10	2151.91	2873.49	63208.03	44976.28	18231.77	2.895862	14.04710	0.006621	65.18699
E522	23100.03	18716.63	1876.91	2506.49	63152.87	44923.54	18229.28	3.066634	17.56455	0.008314	63.80925
E525	19667.36	16496.76	1357.59	1813.01	62995.93	44774.47	18221.45	3.528323	27.51462	0.014429	55.84966
E530	17457.77	13867.97	1537.19	2052.61	44874.21	44873.82	0.39	2.912934	21.01572	0.006293	44.70753
E540	19572.27	15191.38	1875.81	2505.08	44979.00	44976.55	2.45	2.635407	14.15885	0.004515	46.11461
E545	15791.06	12750.28	1302.05	1738.74	44774.47	44774.47	0.00	3.186267	27.64612	0.006597	36.53242

Hour	Energy Consumption Compressor (Wh)	Cond Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Outdoor Hum. Rat. (kg/kg)
	June 28 Hourly Output - Case E300										
1	1903	237	7524	5800	1724	0.009222	3.515888	17.80	23.92	17.084	0.011100
2	1981	246	7760	5972	1788	0.009249	3.484508	18.30	24.00	17.220	0.011462
3	1898	237	7502	5800	1702	0.009186	3.513817	17.80	23.92	17.067	0.011100
4	1894	237	7481	5800	1682	0.009150	3.510558	17.80	23.92	17.055	0.011100
5	1773	224	7054	5593	1461	0.008918	3.532298	17.20	23.83	16.659	0.010180
6	2091	255	7960	6350	1611	0.008963	3.393009	19.40	24.16	17.020	0.011001
7	3056	340	10498	8276	2222	0.009438	3.091284	25.00	25.00	18.069	0.013140
8	3325	351	10859	9032	1827	0.009259	2.954026	27.20	25.33	17.541	0.011075
9	4507	469	14687	11962	2726	0.009645	2.951568	28.90	25.59	18.224	0.011995
10	4620	478	15165	11962	3203	0.009969	2.974696	28.90	25.59	18.511	0.012760
11	5265	526	16818	12718	4100	0.010497	2.904162	31.10	25.91	19.288	0.014809
12	5092	506	16341	12546	3795	0.010481	2.919078	30.60	25.84	18.866	0.013253
13	6465	635	21161	17408	3752	0.009876	2.980423	31.10	25.91	18.035	0.011329
14	6539	643	21116	17615	3502	0.009686	2.940128	31.70	26.00	18.136	0.011729
15	8012	783	26678	22476	4202	0.009494	3.033314	32.20	26.08	18.111	0.012379
16	8195	803	27525	22476	5049	0.009627	3.059013	32.20	26.08	18.544	0.014232
17	5327	530	16776	12925	3851	0.010334	2.864265	31.70	26.00	19.259	0.014730
18	5404	536	17390	12718	4672	0.010805	2.927609	31.10	25.91	19.566	0.015684
19	4818	494	16301	11756	4546	0.010812	3.068712	28.30	25.50	19.143	0.014539
20	4830	505	16911	11377	5534	0.011181	3.169822	27.20	25.33	19.730	0.016878
21	3956	410	13521	9032	4488	0.011273	3.096885	27.20	25.33	19.693	0.016878
22	3872	404	13368	8860	4507	0.011313	3.126286	26.70	25.26	19.672	0.016832
23	3772	397	13184	8654	4530	0.011350	3.162389	26.10	25.16	19.676	0.016889
24	3813	402	13363	8654	4709	0.011446	3.170344	26.10	25.16	19.811	0.017329

Day	Energy Consumption Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
	Case E500 Average Daily Outputs - f(ODB) sensitivity										
April 30	3802.75	3023.63	333.58	445.54	13167.25	9365.50	3801.79	0.011789	3.883338	16.88333	25
June 25	4929.71	4106.08	352.75	470.88	13197.96	9387.38	3810.63	0.012585	2.959242	29.51667	25

Day	Energy Consumption Total (Wh)	Compressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
	Case E530 Average Daily Outputs - f(ODB) sensitivity										
April 30	3091.71	2378.54	305.42	407.75	9365.50	9365.50	0.00	0.006206	3.46022	16.88333	25
June 25	3937.75	3168.33	329.42	440.00	9387.38	9387.38	0.00	0.006206	2.687874	29.51667	25

Cases	Energy Consumption Compr + Both Fans Wh	Date	Hour	Evaporator Coil Loads: Sensible Wh	Date	Hour	Latent Wh	Date	Hour	Sensible + Latent Wh	Date	Hour
	Annual Hourly Integrated Maxima Consumptions and Loads											
E300	11930	20-juil	15	23441	20-juil	15	10461	03-sept	15	32612	20-juil	15
E310	12560	20-juil	15	23907	08-juil	16	16862	03-sept	15	37105	03-sept	15
E320	12996	20-juil	15	31514	24-avr	16	22501	02-oct	9	40393	20-juil	16
E330	13480	20-juil	15	33969	24-avr	16	28111	18-sept	15	43942	02-oct	9
E340	13233	20-juil	15	33006	24-avr	16	24625	02-oct	9	41242	02-oct	10
E350	11934	20-juil	15	23449	20-juil	15	11915	02-oct	9	32632	20-juil	15
E360	12793	20-juil	14	37614	10-juil	14	12800	03-sept	17	39688	01-oct	10

Cases	Annual Hourly Integrated Maxima Consumptions and Loads											
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads: Sensible			Latent			Sensible + Latent		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour
E500	9825	20-juil	15	18770	10-juil	16	7972	29-juin	16	26739	29-juin	16
E510	10825	20-juil	15	21170	14-juil	19	9185	17-juin	14	30292	17-juin	14
E520	11037	20-juil	15	19640	20-juil	16	8227	20-juil	15	26476	05-mai	16
E522	10309	20-juil	15	18778	25-juin	16	7925	29-juin	16	26701	29-juin	16
E525	9079	20-juil	15	18752	25-juin	15	8100	29-juin	16	26849	29-juin	16
E530	7999	20-juil	15	18770	10-juil	16	139	16-mars	10	18770	10-juil	16
E540	8864	20-juil	15	18787	10-juil	16	1133	11-mars	10	18787	10-juil	16
E545	7365	20-juil	15	18752	25-juin	15	0	01-janv	1	18752	25-juin	15

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2: Maximum			Minimum			Indoor Drybulb Temperature: Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.864536	30-avr	16	2.785981	13-juin	17	25.04	22-mars	2	8.03	06-janv	5
E310	4.132477	30-avr	15	2.854977	01-déc	15	30.15	20-juil	15	8.03	06-janv	5
E320	3.935372	18-sept	16	2.804582	01-déc	15	33.25	20-juil	15	8.03	06-janv	5
E330	4.114632	17-juin	16	2.795699	28-avr	9	31.89	20-juil	15	8.03	06-janv	5
E340	4.016122	16-sept	16	2.804582	01-déc	14	32.66	20-juil	15	8.03	06-janv	5
E350	3.883092	30-avr	8	2.786090	13-juin	17	35.00	21-avr	1	8.03	06-janv	5
E360	4.415068	04-oct	24	2.803367	01-déc	15	45.31	20-juil	15	8.03	06-janv	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio: Maximum			Minimum*			Relative Humidity: Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.013576	16-nov	16	0.001968	11-janv	3	68.00	16-nov	16	15	06-nov	5
E310	0.016887	02-oct	8	0.002019	05-janv	7	84.00	03-août	8	16	06-nov	8
E320	0.017391	10-juil	12	0.001968	11-janv	3	86.00	03-sept	17	15	06-nov	5
E330	0.017054	10-juil	13	0.001968	11-janv	3	77.00	16-août	20	15	06-nov	5
E340	0.017172	10-juil	13	0.001968	11-janv	3	83.00	03-sept	17	15	06-nov	5
E350	0.016495	02-oct	2	0.001968	11-janv	3	82.00	02-oct	8	15	06-nov	5
E360	0.014708	20-juil	14	0.001968	11-janv	3	74.00	20-juil	14	15	06-nov	5

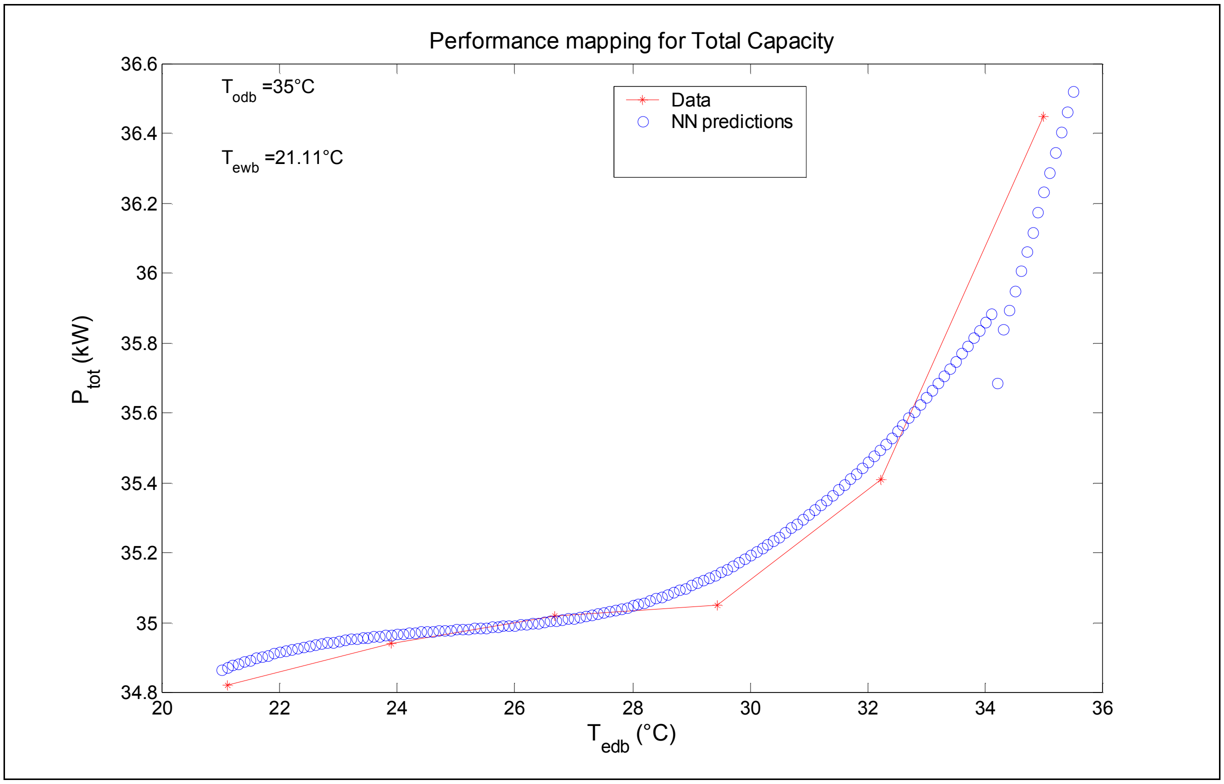
Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2: Maximum			Minimum			Indoor Drybulb Temperature: Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E500	4.264286	16-mars	10	2.705858	29-juil	12	25.00	11-mars	10	8.86	20-déc	24
E510	4.745364	04-oct	24	2.916962	31-mars	15	25.30	10-juil	15	8.86	20-déc	24
E520	3.818576	30-avr	16	2.000000	30-janv	14	19.30	20-juil	15	8.82	21-déc	1
E522	4.018273	30-avr	16	2.555556	31-mars	18	20.11	04-juin	16	8.86	20-déc	24
E525	4.710872	16-mars	10	2.936880	29-juil	12	35.00	11-mars	10	8.86	21-déc	1
E530	3.853005	16-mars	10	2.470263	29-juil	12	25.00	11-mars	10	8.86	20-déc	24
E540	4.000000	22-mars	1	2.000000	08-avr	17	15.05	29-janv	24	8.82	21-déc	1
E545	4.162586	16-mars	10	2.692043	30-juil	12	35.00	11-mars	10	8.86	21-déc	1

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone													
	Humidity Ratio						Relative Humidity						Hum	
	Maximum			Minimum*			Maximum*			Minimum*			Maximum	
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour	kg/kg	Date
E500	0.013389	20-juil	15	0.007061	21-déc	1	100.00	12-avr	7	58	29-avr	3	0.013389	20-juil
E510	0.013690	20-juil	15	0.007061	21-déc	1	100.00	12-avr	7	58	01-nov	22	0.013690	20-juil
E520	0.010663	20-juil	16	0.006640	28-nov	5	100.00	02-avr	19	53	20-juil	15	0.010663	20-juil
E522	0.010627	20-juil	15	0.007061	21-déc	1	100.00	12-avr	7	63	27-avr	5	0.010627	20-juil
E525	0.020246	20-juil	15	0.007062	21-déc	1	100.00	08-nov	8	48	29-avr	4	0.020246	20-juil
E530	0.006206	01-avr	1	0.006167	05-oct	2	87.00	13-déc	6	31	04-oct	22	0.006206	01-avr
E540	0.004044	01-avr	1	0.004036	04-oct	24	58.00	12-nov	7	38	01-avr	1	0.004044	01-avr
E545	0.006575	01-avr	1	0.006575	01-avr	1	93.00	13-déc	5	19	01-avr	10	0.006575	01-avr

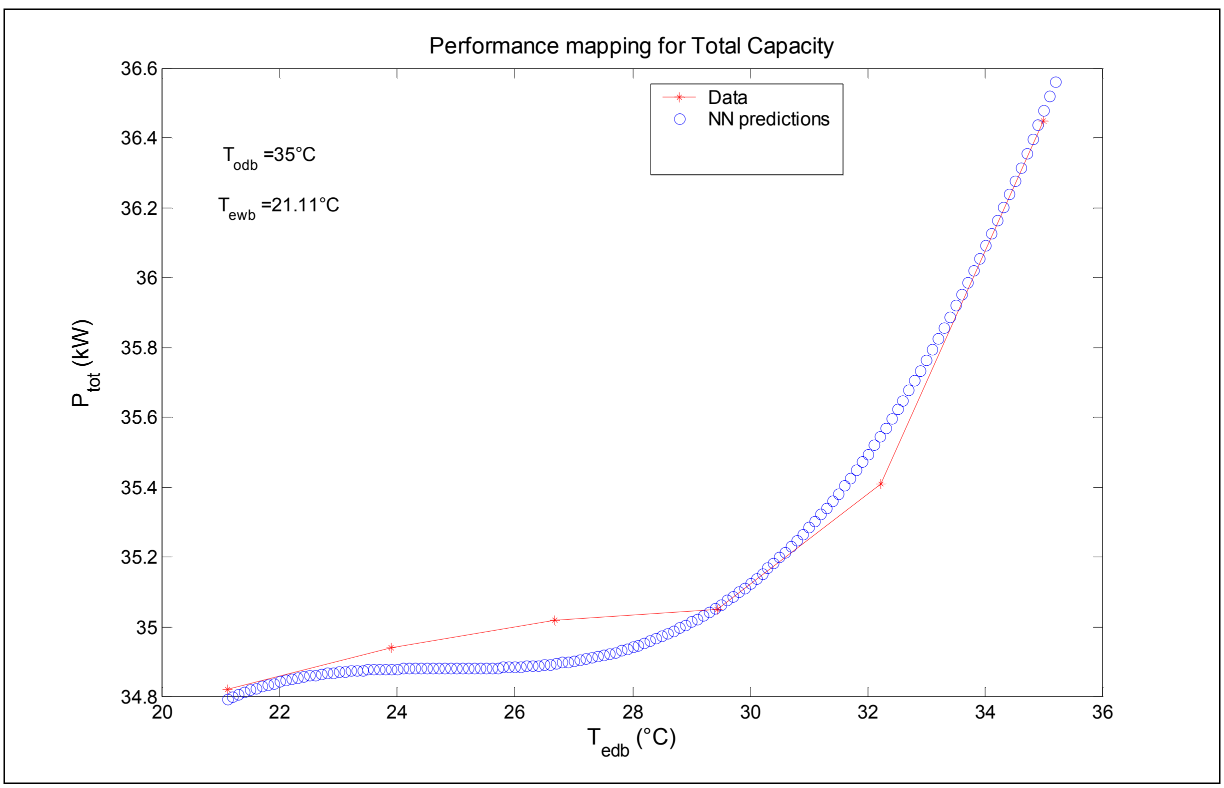
5.8 Major improvements during round 6 (March 2003)

First improvement: The discrepancies observed in the previous round concerning the fan consumption are explained by the fraction on-time (λ) that was not properly taken into account in their calculation. More exactly, we used the value of λ obtained at the end of the subhourly loop instead of the average value. This was fixed. Then, the results for some cases remain (almost) unchanged whereas some others were improved. This can be explained by the fact that, in the latter cases, the value of λ changed during the simulation time step (average value of λ is different from value of λ at the end of the subhourly loop).

Second improvement: The case E360 exploring the extreme value of the performance map, we tested the neural networks predictions. The neural network employed so far performs accurately for values of Tedb included in the interval [21°C, 33°C] but performs poorly above 33°C (see figure below). During this step, we improved the neural network as shown on the figure below.



Performance mapping of the previous neural network



Performance mapping of the new neural network (Round March 2003)

Cases	Annual Sums							Annual Means			
	Cooling Energy Consumption				Evaporator Coil Load					Zone	Zone
	Total	ompressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Humidity Ratio	Relative Humidity
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)
E300	35079.16	21867.04	2332.19	10879.92	77974.17	55209.47	22764.77	3.222175	24.0816473	0.009143	47.66587
E310	39566.54	25982.00	2704.62	10879.92	97369.97	55200.14	42169.85	3.394265	24.0847374	0.011167	57.82215
E320	39478.13	25919.80	2678.41	10879.92	97283.51	61987.47	35296.07	3.401734	24.3284064	0.010036	51.04304
E330	40601.04	26990.56	2730.56	10879.92	103776.95	62657.66	41119.33	3.49169	24.2950594	0.009799	50.02637
E340	40136.47	26540.55	2716.00	10879.92	100774.48	62366.01	38408.51	3.444511	24.3095742	0.009855	50.22477
E350	31664.21	18811.57	1972.72	10879.92	67030.24	48588.80	18441.51	3.225044	26.2685993	0.009735	44.20457
E360	55131.58	39985.34	4266.32	10879.92	162781.40	136401.93	26379.48	3.678537	24.7554007	0.008642	43.12763

Cases	Annual Sums							Annual Means			
	Cooling Energy Consumption				Evaporator Coil Load					Zone	Zone
	Total	ompressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	COP2	IDB	Humidity Ratio	Relative Humidity
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)		(°C)	(kg/kg)	(%)
E500	22363.07	17895.73	1912.86	2554.48	63102.07	44874.22	18227.81	3.185592	20.86661	0.009374	57.83984
E500 May-Sep	17464.42	14016.66	1476.30	1971.47	48439.66	34448.15	13991.49	3.12656	25.00000	0.011211	56.47032
E510 May-Sep	34912.47	27962.28	2975.86	3974.33	108979.12	77498.99	31480.01	3.522485	25.00000	0.01121	56.47549
E520	24923.62	19501.61	2321.67	3100.34	62484.52	44976.74	17507.61	2.863204	14.0194075	0.006457	63.73379
E522	23656.19	18724.26	2111.81	2820.12	63153.72	44924.11	18229.83	3.03098	17.5525868	0.007749	59.92374
E525	20239.61	16511.06	1596.51	2132.04	62997.97	44775.10	18222.87	3.479096	27.487395	0.013162	52.23995
E530	17458.19	13868.35	1537.28	2052.56	44874.52	44874.22	0.29	2.912864	20.9980582	0.006275	44.50639
E540	19573.05	15192.28	1875.77	2505.00	44979.08	44976.75	2.33	2.63528	14.1406473	0.004494	45.85959
E545	15790.84	12750.39	1301.78	1738.67	44775.10	44775.10	0.00	3.186349	27.6188436	0.006495	36.17683

Hour	Energy Consumption ompressor (Wh)	Cond Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Outdoor Hum. Rat. (kg/kg)
	June 28 Hourly Output - Case E300										
1	1898	237	7505	5788	1717	0.009227	3.515222	17.80	23.92	17.12	0.011100
2	1977	245	7743	5961	1782	0.009255	3.484698	18.30	24.00	17.20	0.011462
3	1895	237	7487	5788	1700	0.009190	3.511726	17.80	23.92	17.10	0.011100
4	1890	237	7465	5788	1677	0.009155	3.509638	17.80	23.92	17.07	0.011100
5	1768	225	7033	5580	1453	0.008925	3.528851	17.20	23.83	16.76	0.010180
6	2088	254	7949	6341	1608	0.008969	3.394108	19.40	24.16	17.00	0.011001
7	3060	335	10514	8277	2237	0.009436	3.096907	25.00	25.00	17.87	0.013140
8	3324	353	10856	9038	1818	0.009261	2.952407	27.20	25.33	17.61	0.011075
9	4511	464	14703	11971	2732	0.009644	2.955377	28.90	25.59	18.07	0.011995
10	4623	474	15176	11971	3205	0.009968	2.977438	28.90	25.59	18.38	0.012760
11	5269	518	16830	12731	4098	0.010497	2.908243	31.10	25.91	19.08	0.014809
12	5096	506	16359	12559	3800	0.010479	2.920207	30.60	25.84	18.87	0.013253
13	6465	643	21158	17422	3736	0.009881	2.976646	31.10	25.91	18.26	0.011329
14	6542	646	21129	17629	3500	0.009690	2.939482	31.70	26.00	18.21	0.011729
15	8017	787	26695	22491	4204	0.009496	3.032144	32.20	26.08	18.18	0.012379
16	8196	801	27526	22491	5035	0.009634	3.059464	32.20	26.08	18.49	0.014232
17	5336	521	16810	12939	3871	0.010331	2.870070	31.70	26.00	19.00	0.014730
18	5408	530	17405	12729	4676	0.010802	2.931122	31.10	25.91	19.39	0.015684
19	4818	493	16299	11761	4538	0.010813	3.068914	28.30	25.50	19.13	0.014539
20	4832	500	16917	11381	5536	0.011181	3.172731	27.20	25.33	19.59	0.016878
21	3957	409	13521	9036	4484	0.011274	3.096885	27.20	25.33	19.65	0.016878
22	3873	403	13372	8864	4509	0.011313	3.127222	26.70	25.25	19.65	0.016832
23	3771	396	13180	8656	4524	0.011352	3.162947	26.10	25.16	19.65	0.016889
24	3811	400	13357	8656	4701	0.011451	3.171931	26.10	25.16	19.76	0.017329

Day	Energy Consumption Total (Wh)	ompressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
	Case E500 Average Daily Outputs - f(ODB) sensitivity										
April 30	3906.50	3025.25	377.33	503.92	13170.92	9365.46	3805.50	0.010888	3.83164106	16.88333	25
June 25	5070.54	4109.79	411.33	549.42	13197.96	9387.63	3810.50	0.011340	2.91775448	29.51667	25

Day	Energy Consumption Total (Wh)	ompressor (Wh)	Cond Fan (Wh)	Indoor Fan (Wh)	Evaporator Coil Load Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum Rat (kg/kg)	COP2	ODB (°C)	EDB (°C)
	Case E530 Average Daily Outputs - f(ODB) sensitivity										
April 30	3091.63	2378.54	305.33	407.75	9365.46	9365.46	0.00	0.006209	3.46034391	16.88333	25
June 25	3937.75	3168.38	329.42	439.96	9387.63	9387.63	0.00	0.006209	2.68788687	29.51667	25

Cases	Energy Consumption Compr + Both Fans Wh	Date	Hour	Evaporator Coil Loads: Sensible Wh	Date	Hour	Latent Wh	Date	Hour	Sensible + Latent Wh	Date	Hour
	Annual Hourly Integrated Maxima Consumptions and Loads											
E300	11945	20-juil	15	23457	20-juil	15	10480	03-sept	15	32641	20-juil	15
E310	12682	20-juil	15	23122	20-juil	15	16148	04-août	15	37396	03-sept	15
E320	13103	20-juil	15	31640	24-avr	16	21623	17-sept	12	39862	03-sept	16
E330	13480	20-juil	15	33997	24-avr	16	28111	18-sept	15	43942	02-oct	9
E340	13281	20-juil	15	33102	24-avr	16	24054	03-sept	17	41309	03-sept	15
E350	11951	20-juil	15	23457	20-juil	15	10756	02-oct	8	32665	20-juil	15
E360	13011	20-juil	15	32792	20-juil	15	8583	03-sept	17	39320	10-juil	12

Cases	Annual Hourly Integrated Maxima Consumptions and Loads											
	Energy Consumption Compr + Both Fans			Evaporator Coil Loads Sensible			Latent			Sensible + Latent		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour
E500	10152	20-juil	15	18776	04-juin	15	7783	29-juin	16	26545	29-juin	16
E510	11169	20-juil	15	21121	04-juin	13	8895	30-juin	16	30003	30-juin	16
E520	10820	10-sept	15	18804	12-juil	16	10470	28-sept	15	29243	28-sept	15
E522	11333	25-juil	16	18785	04-juin	15	11848	25-juil	16	30630	25-juil	16
E525	9412	20-juil	15	18759	04-juin	15	7886	29-juin	16	26631	29-juin	16
E530	8002	20-juil	15	18776	04-juin	15	107	16-mars	10	18776	04-juin	15
E540	8867	20-juil	15	18794	04-juin	15	834	11-mars	10	18794	04-juin	15
E545	7367	20-juil	15	18759	04-juin	15	0	01-janv	1	18759	04-juin	15

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2 Maximum			Minimum			Indoor Drybulb Temperature Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.861217	30-avr	16	2.788429	13-juin	17	25.05	21-févr	17	8	06-janv	5
E310	4.124828	30-avr	15	2.854701	01-déc	15	25.62	20-juil	15	8	06-janv	5
E320	3.936881	16-sept	15	2.805108	01-déc	14	32.34	20-juil	15	8	06-janv	5
E330	4.114644	17-juin	16	2.805108	01-déc	14	31.9	20-juil	15	8	06-janv	5
E340	4.011976	16-sept	16	2.805108	01-déc	14	32.17	20-juil	15	8	06-janv	5
E350	3.884146	04-oct	24	2.788429	13-juin	17	35	21-avr	1	8	06-janv	5
E360	4.41361	04-oct	24	2.805108	01-déc	14	28.48	20-juil	15	8	06-janv	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio Maximum			Minimum*			Relative Humidity Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.01345	16-nov	16	0.001968	11-janv	3	68.00	16-nov	16	15	06-nov	5
E310	0.015467	02-oct	8	0.002019	05-janv	7	77.00	12-juin	7	16	06-nov	8
E320	0.017549	10-juil	12	0.001968	11-janv	3	83.00	03-sept	17	15	06-nov	5
E330	0.017054	10-juil	13	0.001968	11-janv	3	77.00	16-août	20	15	06-nov	5
E340	0.01728	10-juil	13	0.001968	11-janv	3	80.00	03-sept	17	15	06-nov	5
E350	0.016487	03-août	7	0.001968	11-janv	3	70.00	02-oct	8	15	06-nov	5
E360	0.013718	10-juil	13	0.001968	11-janv	3	68.00	16-nov	16	15	06-nov	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2 Maximum			Minimum			Indoor Drybulb Temperature Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E500	4.18151	16-mars	10	2.670385	29-juil	12	25.02	30-mars	17	8.54	20-déc	20
E510	4.687263	04-oct	24	2.876418	31-mars	15	25.02	30-mars	17	8.54	20-déc	20
E520	3.705593	30-avr	15	2.142857	30-janv	17	15.06	12-juil	15	8.51	20-déc	20
E522	3.980778	30-avr	16	2.411388	25-juil	17	20.05	13-mars	22	8.54	20-déc	20
E525	4.615458	16-mars	10	2.897192	29-juil	12	35	11-mars	10	8.54	20-déc	20
E530	3.844617	16-mars	10	2.470681	29-juil	12	25.02	30-mars	17	8.54	20-déc	20
E540	3.666667	11-mars	22	2.142857	05-avr	20	15.05	28-janv	20	8.51	20-déc	20
E545	4.161783	16-mars	10	2.692794	29-juil	12	35	11-mars	10	8.54	20-déc	20

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E500	0.011713	20-juil	15	0.006908	20-déc	20	100.00	12-avr	5	54	04-oct	24
E510	0.011716	20-juil	15	0.006908	20-déc	20	100.00	12-avr	5	54	04-oct	23
E520	0.007566	20-juil	15	0.006525	27-nov	23	95.00	08-nov	17	61	27-nov	22
E522	0.009398	20-juil	15	0.006908	20-déc	20	100.00	12-avr	1	60	04-oct	23
E525	0.017626	20-juil	15	0.006909	20-déc	20	100.00	08-nov	23	44	04-mai	4
E530	0.00549	01-avr	1	0.005453	01-nov	21	79.00	06-déc	8	28	01-avr	10
E540	0.003256	01-avr	1	0.003253	29-avr	23	47.00	12-avr	6	31	01-avr	1
E545	0.006689	01-avr	1	0.006685	20-juil	15	97.00	07-déc	4	19	01-avr	10

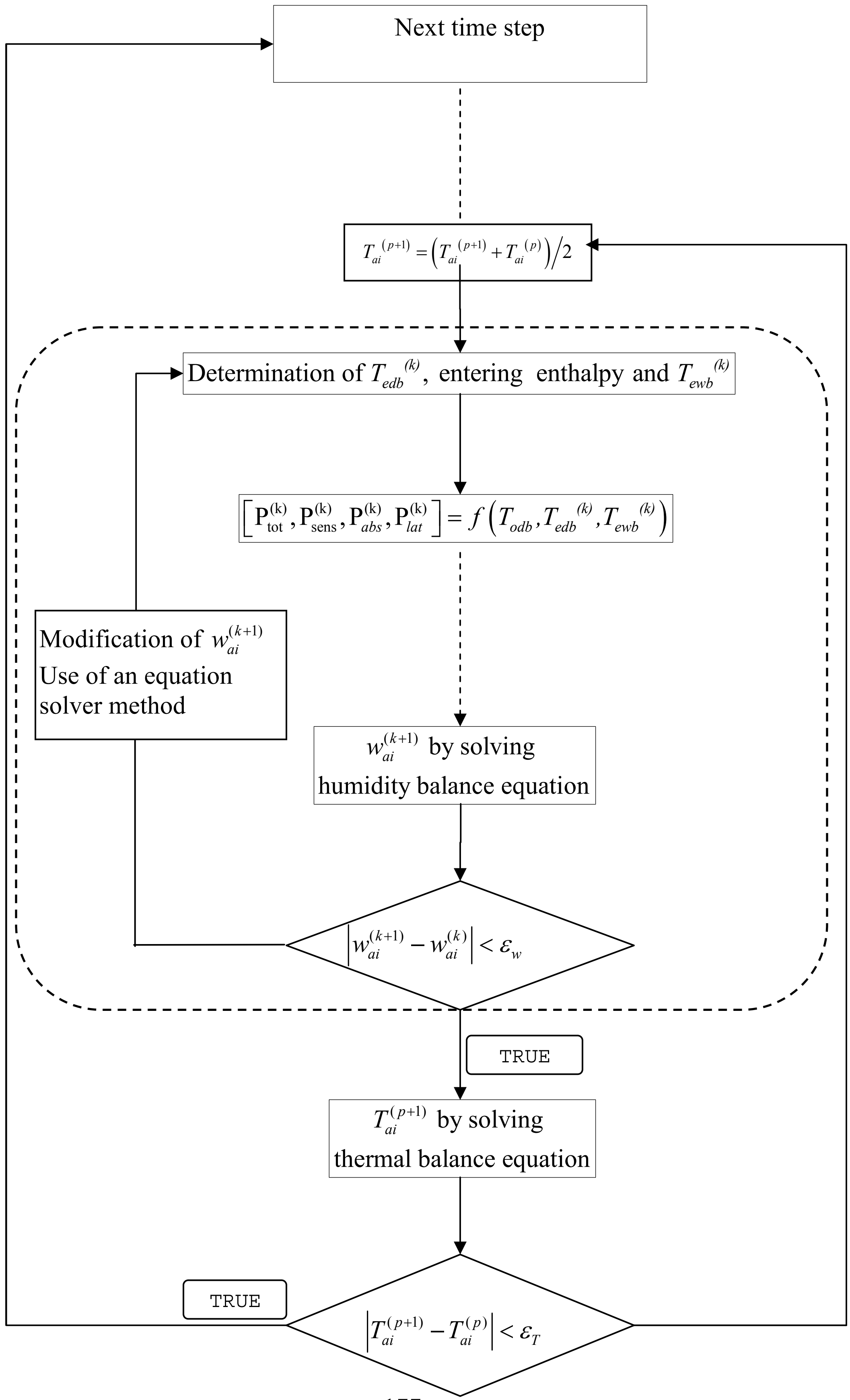
5.9 Major improvements during round 7 (April 2003)

By using the short time step loop, we were unable to find the same results as those of the other participants (specially for cases E500–E545 and E360). The discrepancies seem to result from the calculation of the indoor air humidity. Moreover, the short time step approach induces long calculation time. Consequently, we decided to derive a new algorithm, described on the chart below. At a given time step (1 hour), once the building sensible load is calculated, the new algorithm runs as follows:

1) The first loop consists of fixing the indoor air temperature to the average value of the temperatures obtained in the previous iteration and the current one (at the beginning of the loop, the indoor air temperature is fixed to the value of the previous hour).
2) The second loop, embedded in the previous one, consists of searching the optimal value of indoor air humidity (by exploring the performance map and solving the humidity balance equation).
3) Once the second loop has converged, the indoor air temperature is calculated (by solving the thermal balance equation). Then, a new iteration (step 1) is performed if the indoor air temperature has changed.

The iterations stop once both values of indoor air temperature and humidity have converged.

With the new approach, our results are globally close to those of the other programs. However, some non-negligible gaps still remain in the predictions of relative humidity ratio in the E530–E545 cases (dry coil). We explained that behavior by the fact that our building was less insulated than the other models.


Next time step
$T_{ai}^{(p+1)} = \left(T_{ai}^{(p+1)} + T_{ai}^{(p)}\right)/2$
Determination of $T_{edb}^{(k)}$, entering enthalpy and $T_{ewb}^{(k)}$
$\left[P_{tot}^{(k)}, P_{sens}^{(k)}, P_{abs}^{(k)}, P_{lat}^{(k)}\right] = f\left(T_{odb}, T_{edb}^{(k)}, T_{ewb}^{(k)}\right)$
Modification of $w_{ai}^{(k+1)}$
Use of an equation solver method
$w_{ai}^{(k+1)}$ by solving humidity balance equation
$\left|w_{ai}^{(k+1)} - w_{ai}^{(k)}\right| < \varepsilon_w$
TRUE
$T_{ai}^{(p+1)}$ by solving thermal balance equation
TRUE
$\left|T_{ai}^{(p+1)} - T_{ai}^{(p)}\right| < \varepsilon_T$

Cases	Annual Sums							Annual Means				Annual Means E300 Only	
	Cooling Energy Consumption				Evaporator Coil Load								
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)	ODB (°C)	Outdoor Humidity Ratio (kg/kg)
E300	34976.41	21770.001	2326.49	10879.92	77744.59	55209.47	22535.14	3.226386	24.0816473	0.009175	47.82614	19.91445	0.011649
E310	39519.57	25936.821	2702.828	10879.92	97295.87	55185.07	42110.84	3.397244	24.0897089	0.011175	57.84098		
E320	39400.82	25846.026	2674.869	10879.92	97141.31	62008.8	35132.59	3.40597	24.3273539	0.010049	51.10342		
E330	40535.14	26927.733	2727.484	10879.92	103712.9	62649.46	41063.37	3.497291	24.2954692	0.009812	50.08482		
E340	40065.26	26472.79	2712.551	10879.92	100676.2	62380.56	38295.62	3.449547	24.308863	0.009868	50.29669		
E350	31586.59	18738.055	1968.617	10879.92	66860.16	48588.8	18271.39	3.228919	26.2685993	0.009759	44.31621		
E360	54843.26	39697.162	4266.176	10879.92	161200.2	134205.7	26994.48	3.666696	25.4808767	0.008552	40.871		

Cases	Annual Sums							Annual Means			
	Cooling Energy Consumption				Evaporator Coil Load						
	Total (kWh)	Compressor (kWh)	Cond Fan (kWh)	Indoor Fan (kWh)	Total (kWh)	Sensible (kWh)	Latent (kWh)	COP2	IDB (°C)	Zone Humidity Ratio (kg/kg)	Zone Relative Humidity (%)
E500	22322.95	17857.852	1911.869	2553.232	63105.37	44874.22	18231.14	3.192021	21.09783	0.010218	65.94189
E500 Ma	17434.54	13988.512	1475.528	1970.497	48439.57	34448.15	13991.42	3.132401	25.00000	0.011329	57.07217
E510 Ma	34848.64	27901.957	2974.4	3972.28	108979	77498.99	31479.86	3.52953	25.00000	0.011328	57.06155
E520	25131.07	19654.972	2344.827	3131.271	63212.1	44976.72	18235.13	2.873304	14.1420811	0.007023	70.22683
E522	23619.74	18689.799	2110.833	2819.112	63157.03	44924.11	18233.15	3.036303	17.7290274	0.00858	68.23139
E525	20241.71	16506.802	1599.203	2135.708	63001.56	44775.1	18226.51	3.479595	27.7709395	0.01398	60.1387
E530	17442.5	13855.961	1535.685	2050.858	44875.41	44874.22	1.182	2.915569	21.0958482	0.00577	41.25776
E540	19536.57	15163.82	1872.336	2500.416	44979.84	44976.75	3.09	2.640258	14.1406473	0.003855	40.05091
E545	15791.08	12750.623	1301.791	1738.667	44775.11	44775.1	0.004	3.186293	27.7166336	0.006749	36.87466

Hour	June 28 Hourly Output - Case E300										
	Energy Consumption		Evaporator Coil Load								
	Compressor (Wh)	Cond Fan (Wh)	Total (Wh)	Sensible (Wh)	Latent (Wh)	Zone Hum. Rat. (kg/kg)	COP2	ODB (°C)	EDB (°C)	EWB (°C)	Outdoor Hum. Rat. (kg/kg)
1	1886	237	7472	5788	1684	0.009276	3.519548	17.8	23.92	17.155	0.0111
2	1964	244	7707	5961	1747	0.009302	3.490489	18.3	24	17.238	0.011462
3	1881	236	7445	5788	1657	0.009239	3.516769	17.8	23.92	17.12	0.0111
4	1878	236	7432	5788	1644	0.009201	3.51561	17.8	23.92	17.102	0.0111
5	1756	224	7000	5580	1420	0.008969	3.535354	17.2	23.83	16.787	0.01018
6	2075	253	7915	6341	1574	0.009012	3.399914	19.4	24.16	17.032	0.011001
7	3035	334	10450	8277	2173	0.00949	3.101811	25	25	17.911	0.01314
8	3303	352	10813	9038	1775	0.009314	2.958413	27.2	25.33	17.646	0.011075
9	4483	463	14631	11971	2660	0.009708	2.958148	28.9	25.59	18.118	0.011995
10	4594	472	15099	11971	3128	0.010041	2.980458	28.9	25.59	18.442	0.01276
11	5238	516	16722	12731	3991	0.010588	2.906152	31.1	25.91	19.142	0.014809
12	5066	504	16258	12559	3699	0.01058	2.918851	30.6	25.84	18.935	0.013253
13	6442	642	21090	17422	3669	0.009975	2.977132	31.1	25.91	18.326	0.011329
14	6523	645	21067	17629	3438	0.009778	2.939035	31.7	26	18.269	0.011729
15	8000	785	26636	22491	4145	0.009579	3.031986	32.2	26.08	18.239	0.012379
16	8169	799	27416	22491	4925	0.009733	3.057092	32.2	26.08	18.557	0.014232
17	5306	519	16702	12939	3763	0.01044	2.867296	31.7	26	19.063	0.01473
18	5381	528	17312	12729	4582	0.010912	2.929768	31.1	25.91	19.458	0.015684
19	4791	492	16232	11761	4470	0.010914	3.072497	28.3	25.5	19.199	0.014539
20	4809	498	16867	11381	5486	0.011269	3.178255	27.2	25.33	19.65	0.016878
21	3939	408	13484	9036	4447	0.011348	3.101909	27.2	25.33	19.706	0.016878
22	3852	402	13322	8864	4459	0.011383	3.131641	26.7	25.25	19.697	0.016832
23	3752	395	13139	8656	4482	0.011416	3.168314	26.1	25.16	19.694	0.016889
24	3794	399	13323	8656	4666	0.011507	3.177439	26.1	25.16	19.805	0.017329

Day	Case E500 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3901.04167	3020.0417	377.25	503.75	13169.54	9365.458	3804.375	0.010938	3.83716004	16.88333	25
June 25	5066.5	4105.9583	411.3333	549.2083	13198.08	9387.625	3810.417	0.011479	2.92126537	29.51667	25

Day	Case E530 Average Daily Outputs - f(ODB) sensitivity										
	Energy Consumption				Evaporator Coil Load			Zone			
	Total	Compressor	Cond Fan	Indoor Fan	Total	Sensible	Latent	Hum Rat	COP2	ODB	EDB
	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)
April 30	3091.54167	2378.4583	305.3333	407.75	9365.458	9365.458	0	0.005484	3.46043506	16.88333	25
June 25	3934.625	3165.5833	329.25	439.7917	9387.625	9387.625	0	0.005478	2.69003883	29.51667	25

Cases	Annual Hourly Integrated Maxima Consumptions and Loads											
	Energy Consumption			Evaporator Coil Loads								
	Compr + Both Fans			Sensible			Latent			Sensible + Latent		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour
E300	11932	20-juil	15	23457	20-juil	15	10375	03-sept	15	32502	20-juil	15
E310	12653	20-juil	15	23078	10-sept	15	16112	04-août	15	37261	03-sept	15
E320	13104	20-juil	15	31134	03-juin	16	21697	17-sept	12	39904	03-sept	16
E330	13467	20-juil	15	33997	24-avr	16	28184	18-sept	15	43978	02-oct	9
E340	13277	20-juil	15	32940	24-avr	16	24225	03-sept	17	41366	03-sept	15
E350	11932	20-juil	15	23457	20-juil	15	10755	02-oct	8	32502	20-juil	15
E360	12863	20-juil	15	31981	24-avr	16	8859	03-sept	17	38322	02-oct	10

Cases	Annual Hourly Integrated Maxima Consumptions and Loads											
	Energy Consumption			Evaporator Coil Loads								
	Compr + Both Fans			Sensible			Latent			Sensible + Latent		
	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour	Wh	Date	Hour
E500	10177	20-juil	15	18776	04-juin	15	7805	29-juin	16	26567	29-juin	16
E510	11186	20-juil	15	21121	04-juin	13	8850	17-juin	14	29948	17-juin	14
E520	11044	20-juil	15	18969	20-juil	16	7726	30-juin	16	26675	20-juil	16
E522	10639	20-juil	15	18785	04-juin	15	7743	29-juin	16	26514	29-juin	16
E525	9419	20-juil	15	18759	04-juin	15	7938	29-juin	16	26683	29-juin	16
E530	7992	20-juil	15	18776	04-juin	15	179	11-mars	11	18776	04-juin	15
E540	8846	20-juil	15	18794	04-juin	15	845	11-mars	10	18794	04-juin	15
E545	7351	20-juil	15	18759	04-juin	15	4	20-juil	15	18764	20-juil	15

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E300	3.870611	30-avr	16	2.785629	13-juin	17	25.05	21-févr	17	8	06-janv	5
E310	4.12764	30-avr	15	2.872645	01-déc	15	26.62	20-juil	15	8	06-janv	5
E320	3.943305	16-sept	15	2.814522	31-mars	15	32.32	20-juil	15	8	06-janv	5
E330	4.121946	17-juin	16	2.823325	31-mars	15	31.9	20-juil	15	8	06-janv	5
E340	4.017161	16-sept	16	2.823325	31-mars	15	32.15	20-juil	15	8	06-janv	5
E350	3.932099	04-oct	24	2.785909	13-juin	17	35	21-avr	1	8	06-janv	5
E360	4.43201	04-oct	24	2.823325	31-mars	15	33	20-juil	15	8	06-janv	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E300	0.013457	16-nov	16	0.001968	11-janv	3	68.00	16-nov	16	15	06-nov	5
E310	0.015432	02-oct	8	0.002019	05-janv	7	77.00	12-juin	8	16	06-nov	8
E320	0.017547	10-juil	12	0.001968	11-janv	3	83.00	03-sept	17	15	06-nov	5
E330	0.017045	10-juil	13	0.001968	11-janv	3	76.00	10-juin	18	15	06-nov	5
E340	0.017272	10-juil	13	0.001968	11-janv	3	80.00	03-sept	17	15	06-nov	5
E350	0.016479	02-oct	2	0.001968	11-janv	3	70.00	02-oct	8	15	06-nov	5
E360	0.013457	16-nov	16	0.001968	11-janv	3	68.00	16-nov	16	15	06-nov	5

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	COP2						Indoor Drybulb Temperature					
	Maximum			Minimum			Maximum			Minimum*		
	COP2	Date	Hour	COP2	Date	Hour	°C	Date	Hour	°C	Date	Hour
E500	4.184622	16-mars	10	2.666464	30-juil	12	25.02	30-mars	17	8.54	20-déc	20
E510	4.689584	04-oct	24	2.881736	31-mars	15	25.02	30-mars	17	8.54	20-déc	20
E520	3.801729	30-avr	16	2.333333	29-janv	10	15.98	20-juil	15	8.51	20-déc	20
E522	3.985798	30-avr	16	2.428571	30-mars	17	20.05	13-mars	22	8.54	20-déc	20
E525	4.638054	16-mars	10	2.894073	29-juil	12	35	11-mars	10	8.54	20-déc	20
E530	3.840045	16-mars	10	2.473282	29-juil	12	25.02	30-mars	17	8.54	20-déc	20
E540	3.666667	11-mars	22	2.142857	05-avr	20	15.05	28-janv	20	8.51	20-déc	20
E545	4.156489	16-mars	10	2.692021	29-juil	12	35	11-mars	10	8.54	20-déc	20

Cases	Annual Hourly Integrated Maxima and Minima - COP2 and Zone											
	Humidity Ratio						Relative Humidity					
	Maximum			Minimum*			Maximum*			Minimum*		
	kg/kg	Date	Hour	kg/kg	Date	Hour	%	Date	Hour	%	Date	Hour
E500	0.011713	20-juil	15	0.006908	20-déc	20	100.00	14-nov	5	54	04-oct	24
E510	0.011716	20-juil	15	0.006908	20-déc	20	100.00	14-nov	5	54	04-oct	23
E520	0.007566	20-juil	15	0.006525	27-nov	23	95.00	20-déc	17	61	27-nov	22
E522	0.009398	20-juil	15	0.006908	20-déc	20	100.00	15-déc	1	60	04-oct	23
E525	0.017626	20-juil	15	0.006909	20-déc	20	100.00	11-nov	23	44	04-mai	4
E530	0.005491	01-avr	1	0.005454	01-nov	21	79.00	20-déc	8	28	01-avr	10
E540	0.003256	01-avr	1	0.003253	29-avr	23	47.00	20-déc	6	31	01-avr	1
E545	0.006689	01-avr	1	0.006685	20-juil	15	97.00	20-déc	4	19	01-avr	10

Program name (please include version number
CODYRUN
Your name, organisation, and country
Thierry MARA, Eric FOCK, François GARDE and Harry BOYER
Laboratory of Industrial Engineering, University of La Reunion, FRANCE

Program status

	Public domain
	Commercial
X	Research
	Other (please specify)

Solution method for unitary space cooling equipment

X	Overall Performance Maps
	Individual Component Models
	Constant Performance (no possible variation with entering or ambient conditions)
a	Other: First order model for dynamic modeling and performance mapping for steady-state modeling

Interaction between loads and systems calculations

X	Both are calculated during the same time step
	First, loads are calculated for the entire simulation period, then equipment performance is calculated separately
	Other (please specify)

Time step

X	Fixed within code: the same as the meteorological data sampling interval
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data: sampling interval

X	Fixed within code: it is fixed in the meteorological data file
	User-specified

Timing convention for meteorological data: period covered by first record

X	Fixed within code (please specify period or time which meteorological record covers): 0:00–1:00
	User-specified

Meteorological data reconstitution scheme

X	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
X	Produces average outputs for each hour (please specify period to which value relates): same as time step

Treatment of zone air

X	Single temperature (i.e., good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Zone air initial conditions

X	Same as outside air
a	Other (please specify): user specified

Internal gains output characteristics

	Purely convective
	Radiative/Convective split fixed within code
X	Radiative/Convective split specified by user
	Detailed modeling of source output

Mechanical systems output characteristics

X	Purely convective
	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modeling of source output

Control temperature

X	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control properties

	Ideal control as specified in the user's manual
a	On/Off thermostat control
X	On/Off thermostat control with hysteresis: and a first order model. The hysteresis control band was fixed to +- 0.05°C and the time constant to 0.8 sec so that Cd = 0.229 (CDF = 1 – Cd(1 – PLR)).
	On/Off thermostat control with minimum equipment on and/or off durations
	Proportional control
	More comprehensive controls (please specify)

Performance Map: characteristics

a	Default curves
X	Custom curve fitting
	Detailed mapping not available
	Other (please specify)

Performance Map: independent variables

X	Entering Dry-Bulb Temperature
X	Entering Wet-Bulb Temperature
X	Outdoor Dry-Bulb Temperature
	Part-Load Ratio
	Indoor Fan Airflow Rate
	Other (please specify)

Performance Map: dependent variables

	Coefficient of Performance (or other ratio of load to electricity consumption)
X	Total Capacity
X	Sensible Capacity
	Bypass Factor
X	Other (please specify) Compressor power

Performance Map: available curve fit techniques

	Linear, f(one independent variable)
	Quadratic, f(one independent variable)
	Cubic, f(one independent variable)
	Bi-Linear, f(two independent variables)
	Bi-Quadratic, f(two independent variables)
X	Other (please specify) Non Linear: neural networks or multivariate polynomial

Performance Map: extrapolation limits

	Limits independent variables
	Limits dependent variables
X	No extrapolation limits
	Extrapolation not allowed
	Other (please specify)

Cooling coil and supply air conditions model

	Supply air temperature = apparatus dew point (ADP); supply air humidity ratio = humidity ratio of saturated air at ADP
	Bypass factor model using listed ADP data
	Bypass factor model with ADP calculated from extending condition line
	Fan heat included
X	More comprehensive model: only the capacities (sensible and latent) supplied by the system are considered.

Disaggregation of fans' electricity use directly in the simulation and output

	Indoor fan only
	Outdoor fan only
X	Both indoor and outdoor fans disaggregated in the output
	None - disaggregation of fan outputs with separate calculations by the user

Economizer settings available (for E400 series)

	Temperature, outdoor dry-bulb temperature versus return air temperature (E400, E410)
	Temperature, outdoor dry-bulb temperature high limit setting (E420)
	Enthalpy, outdoor air enthalpy versus return air enthalpy (E430)
	Enthalpy, outdoor air enthalpy high limit setting (E440)
	Compressor Lockout (E410)
X	Other (please specify) no object

Appendix II-C

TRNSYS-TUD Modeler Report for HVAC BESTEST E300–545

by

Gottfried Knabe and Huu-Thoi Le

Institute for Thermodynamics and Technical Building Services
Dresden University of Technology
February 2003

1. Introduction

TRNSYS (A Transient System Simulation Program) [1] is a program for solar simulation written by the University of Wisconsin, USA. Since applying for a license of this program the Dresden University of Technology has changed the program codes, especially the building module TYPE 56. Additional modules have also been written, therefore, the TUD has developed a new program for the simulation of heating systems and air conditioning. It is designated TRNSYS-TUD. Physical and empirical models for each component of a system are available at the TU Dresden. The loads and the system can be simultaneously calculated. Since program code has been changed by the TU Dresden it is now possible to run the simulation with a time step of a thousandth of an hour.

It is necessary to prepare a dek-file for running a simulation with TRNSYS-TUD. This dek-file contains all information the TRNSYS-TUD needs to run a particular simulation; that is, the time step, run time, tolerances, user specified equations, declared types, etc. Therefore, this file is named input-file or management-file for the TRNSYS simulation. As mentioned above, the TRNSYS-TUD consists of a main program and several modules (types). A type is represented as a component of the HVAC system with defined inputs and outputs as well as parameters. A type describes the behaviors of a certain component of the HVAC system.

The IEA SHC Task 22 offers different methods to test the whole program system for energy building simulation. There are analytical validation, comparison test and empirical verification. Therefore, the Task 22 is a good opportunity to improve the modules available in the program package TRNSYS-TUD. This report is to document the HVAC BESTEST [2] made by TU Dresden.

2. Modeling

In order to run a simulation with TRNSYS-TUD the building as well as the HVAC system has to be modeled. As known, the more precise the modeling the more simulation results are reached in good agreement with precise measurements. Consequently, the modeling is made under consideration of the behaviors at full load as well as at part-load operation and the possible frame conditions. As shown in [3] a HVAC system operates for over 80% of the total operating hours in part-load field. Therefore, the modeling of a system with only the characteristic curves given by manufacturers at full-load operation is not precise enough to determine the energy consumptions and to diagnose the zone parameters (temperature, humidity, etc.). An analysis of the system behavior at part-load operation is always necessary to fulfill the requirements mentioned above [3].

In the current HVAC BESTEST [2] there is a coupled simulation of a zone (building) with a HVAC split system. In contrast to the HVAC BESTEST E100 series [4] the system is tested now under real boundary conditions. That means the real building fabrics and the real weather data are used to test the ability of the whole system for energy building simulation. Therefore, the transient processes of the building envelope the thermal storages in the walls and in the zone air are also taken into consideration. The modeling of each component is described in detail as follows.

2.1 Modeling: Building

A detailed description of the building fabrics as well as the weather data are available in [2]. All this information (wall materials, heat transfer coefficients, thermal and moisture storages in the walls and in the zone air, etc.) is exactly taken into account to model the applied zone for running the HVAC BESTEST Task 22 cases E300-E545.

This model assumes that the zone air temperature is homogenous within the zone. In the program TRNSYS-TUD the CFD model is available. That makes it possible to evaluate the distribution of the zone air temperature. The reasons for not applying this CFD model are the long computing time and the dependence on the location of the supply air, etc.

2.2 Modeling: HVAC Split System

Compared to HVAC BESTEST cases E100–E200 the split system with higher capacity is here utilized for the cases E300–E545 because the cooling zone loads are larger now. Similar to the preparation for the E100 series [5, 6] the analysis of the split system behavior is carried out at first. For that the given measurements data from manufacturers at full-load operation [2] are applied. As shown in [5, 6], the different behavior of the split system at wet-coil conditions and at dry-coil conditions are taken into account as well.

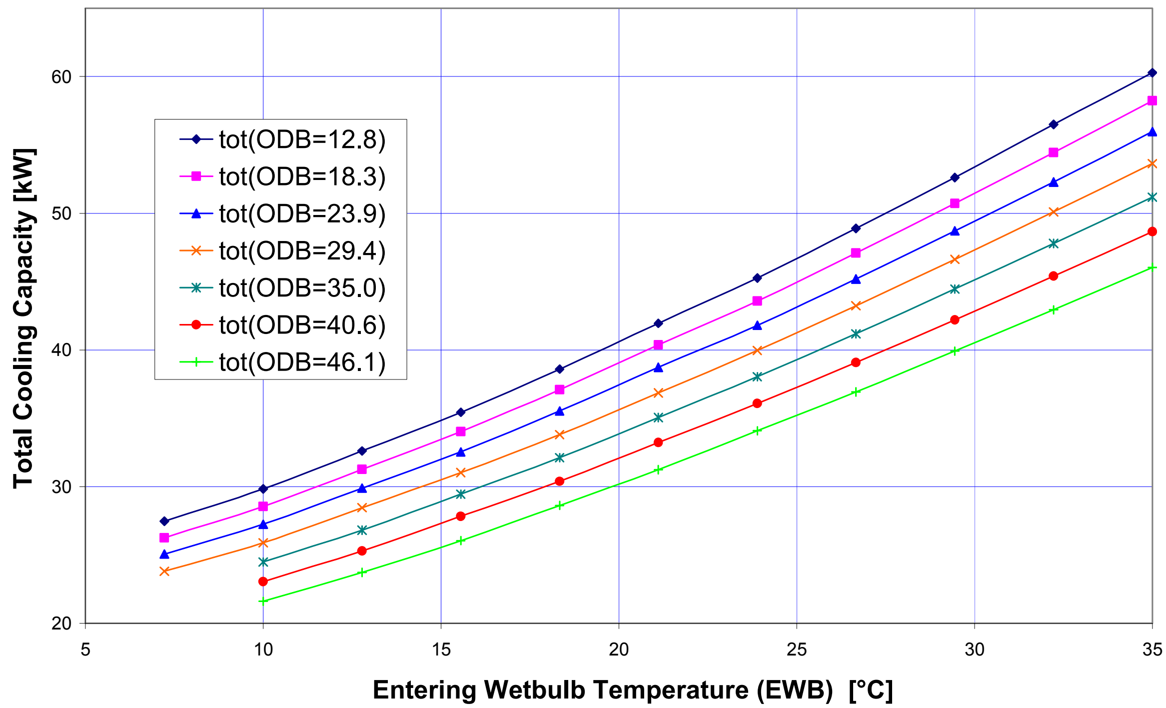


Figure 2C-1. Total cooling capacity at full-load operation with different ODB as a function of EWB

Figure 2C-1 shows the total cooling capacity of the applied split system at different ODB as a function of EWB. Compared to HVAC BESTEST series E100 the characteristics curves of the total cooling capacity do not behave linearly to the entering wet-bulb temperature (EWB) but quadratically to the EWB. The characteristics curves for the sensible cooling capacity are shown in Figure 2C-2. There are similar behaviors to the BESTEST cases E100–E200. In Figure 2C-3 the system behaviors at dry-coil and at wet -coil condition are represented for ODB = 35°C. The characteristic curves of the sensible and total cooling capacity crosses in a point that is named transition cooling point (TCP). On the right of this TCP (EWB > TCP) the split system operates with wet coil. That means that the latent cooling capacity is higher than zero and a part of the water content of the zone air is taken away. Otherwise, the dry-coil conditions will occur. In this case the total cooling capacity as well as the sensible cooling capacity are constant and independent of the EWB. Their values are equal to the values at the TCP.

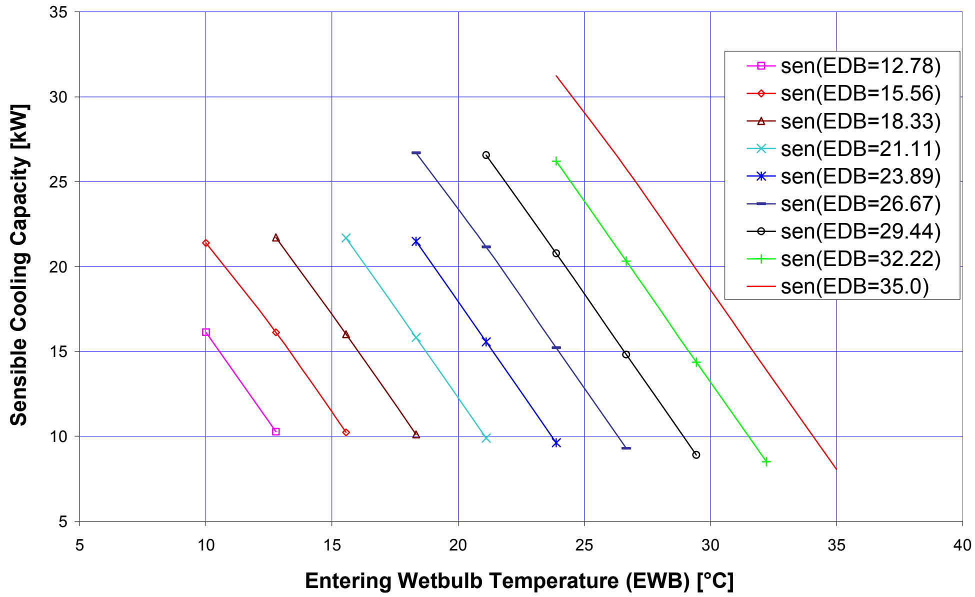


Figure 2C-2. Sensible cooling capacity at full-load operation with different EDB; ODB = 46.1°C as a function of EWB

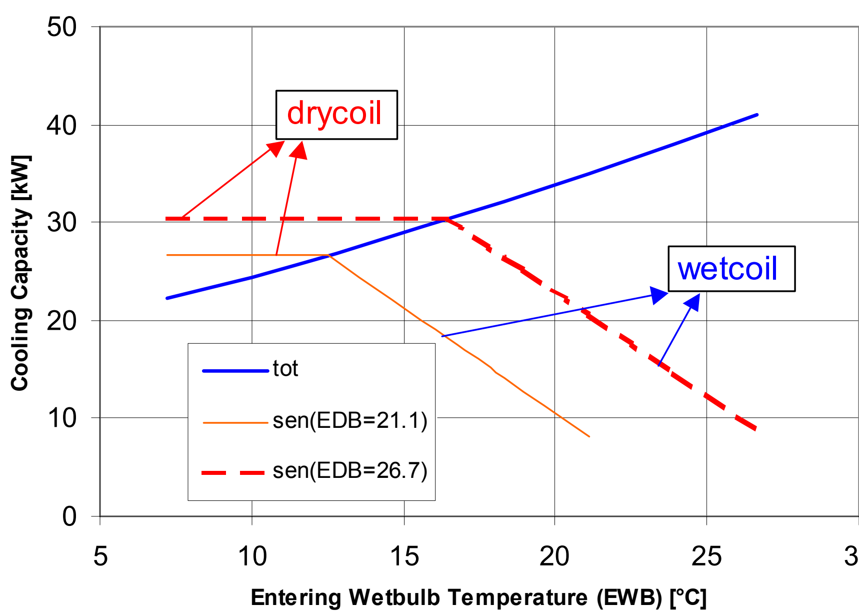


Figure 2C-3. Dry-coil and wet-coil behavior of the used split system at full-load operation with different EDB (21.1°C; 26.7°C) and ODB = 35°C as a function of EWB

As shown in Figures 2C-1 to 2C-3, the characteristics curves are approximated with the equations shown below.

$$\dot{Q}_{N,tot} = (A_1 \cdot ODB + A_2)(A_3 \cdot EWB^2 + A_4 \cdot EWB + A_5) + (A_6 \cdot ODB + A_7) \quad (1)$$

$$\dot{Q}_{N,sen} = (B_1 \cdot ODB + B_2 \cdot EDB + B_3) \cdot EWB + (B_4 \cdot ODB + B_5 \cdot EDB + B_6) \quad (2)$$

$$\dot{Q}_{N,lat} = \dot{Q}_{N,tot} - \dot{Q}_{N,sen} \quad (3)$$

The behavior of the compressor power is similar to the one of the total cooling capacity. Therefore, one can calculate the compressor power with the following equation.

$$P_{comp} = (C_1 \cdot ODB + C_2)(C_3 \cdot EWB^2 + C_4 \cdot EWB + C_5) + (C_6 \cdot ODB + C_7) \quad (4)$$

To control the cooling capacity to maintain the temperature set point, a two-point-controller is taken into operation. At part-load operation an extent of run time of the compressor as well as the outdoor fan is required. This behavior is illustrated in detail in the test description [2]. The CDF factor is applied for these components to calculate the energy consumptions. This behavior is not valid for the indoor fan in case this fan runs continuously.

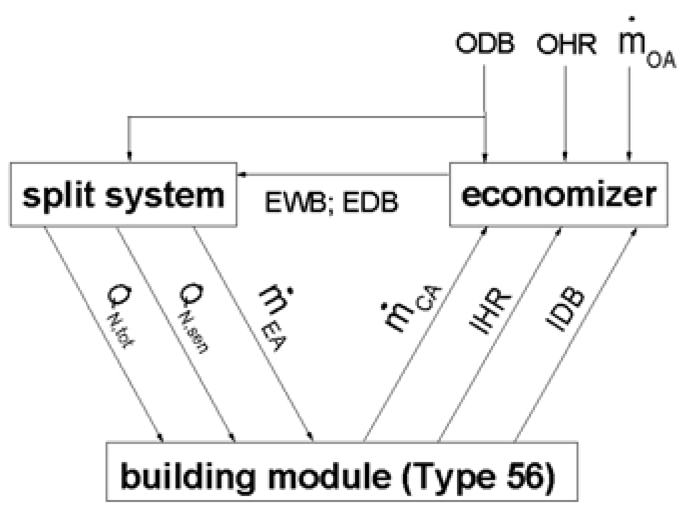


Figure 2C-4: Coupling of the split system with the building module (Type 56) in TRNSYS-TUD

2.3 Coupling of building with HVAC split system

At first, Figure 2C-4 shows the scheme how the split system is coupled into the program TRNSYS-TUD. The economizer is applied. The economizer is controlled by a given strategy to fulfill the hygienic requirements as well as the energy saving during the operating time at low outdoor dry-bulb temperatures. The mixed air conditions (entering air) are determined by the zone air and the outdoor air as well as by their mass flow rates. Depending on the ODB, EDB, and EWB, the split system supplies its cooling capacities to the building module (Type 56). In Type 56, heat and moisture are balanced. Of course, this Type 56 considers the heat and moisture transfers through the walls and the windows, the radiations of the sun, the infiltration, etc. It results in the zone air conditions that are used to calculate the entering air by the economizer. Therefore, iteration is necessary for the calculating procedures in Figure 2C-4. As a result, this calculation takes a long time. To avoid this iteration, the results of the previous time step (zone air conditions) are introduced into the calculation for the current time step. This is equivalent to a digital controller used for the control of HVAC systems in practice. The time step chosen for the simulation should be very short to reduce the deviation caused by this consideration.

To determine the cooling capacities, the characteristic curves at full-load operation described in Eq. 1 to Eq. 3 are used. As mentioned above, the total cooling capacity consists of a sensible and a latent part. The sensible cooling capacity is responsible for the maintenance of the set point temperature, whereas part of the water content of the zone air condenses due to the latent cooling capacity. After a short run time, the steady-state operating point adjusts and the latent cooling capacity exactly matches the latent cooling zone loads.

Because of a direct input of latent cooling capacity or latent cooling zone loads into the program TRNSYS-TUD is not allowed, so a conversion from latent capacity into mass flow rate of water vapor needs to be done. This input is available in this program. The vapor rate is calculated with the following equation.

$$\dot{m}_{vapour} = \frac{\dot{Q}_{lat}}{2501 + 1.86 \cdot EDB} \qquad (5)$$

2.4 Control Strategy

The current series E300 of BESTEST consists of a total of 20 cases with different frame conditions to test the whole program system. The control strategy varies from case to case as described in [2]. In addition to the description in [2], a real controller is adapted into operation in the program TRNSYS-TUD to model the system behavior as realistically as possible. As shown in [6], the differential gap has a large influence on the state parameters, especially at small part-load ratio. To avoid this effect and to enable a comparison of TRNSYS-TUD results with other programs, the differential gap is set to zero.

On the one hand, there is a simulation period of 1 year for the test series E300. That means that the run time and the results data are essentially higher compared to the test series E100. On the other hand, as mentioned above, the time step chosen for the simulation should be short to reduce the deviation due to the calculation algorithm described above. As a compromise for that, a time step of 90 seconds is utilized for all simulation cases in the test series.

3. Results

Experiences from the HVAC BESTEST series E100 show that the careful preparations for the simulation—handling of the frame conditions, the input files, the output files, and especially the dek-file—are much recommended. In case errors occur in the simulation or remarkable disagreements among the simulation programs are obtained by comparison to each other or big differences between the simulation results and analytical solution appear, the simulation program used has to be checked from one component to the others until the errors are found. The whole procedure would take a lot of time. Due to very careful preparations and some errors that were already discovered in the program TRNSYS-TUD in the test series E100, no errors have been found in this round.

It should be noted in the test series E300 that first the program TRNSYS-TUD gives simulation results in files. Because the result files are very large and contain a lot of values due to applying of the real controller with a time step of 90 seconds, a manual compiling of these results would take a very long time. Consequently, a module was written in Excel to determine the values required in [2] from the result files of TRNSYS-TUD. Unfortunately, the prior (untested) version of this module in Excel containing an error was used for the determination of updated results in the meantime. Therefore, these updated results contained an error. This error is fixed now.

Further, the compiled results presented in the 15th meeting of the Task 22 showed a difference between annual COP_2 and seasonal COP_2. The pure definition of COP_2 is available in the test description [2]. The annual COP_2 is calculated as arithmetic average value of the hourly COP_2 over the year, whereas the seasonal COP_2 is the ratio of the sum of the hourly total cooling capacity in a season to the total energy consumption of the given season.

In the end, the results were submitted to the project coordinator to be compared with other simulation programs. It shows very good agreement with other simulation programs.

4. Conclusion

In the HVAC BESTEST a model of the split system was developed and integrated in the program package TRNSYS-TUD. The BESTEST series E100 and E300 enable testing of the model of the split system applied as well as other models of the whole program for the energy building simulation.

In the cases of the first test series E100 some errors were found in the program TRNSYS-TUD, which have now been fixed. In the second series, the program shows good agreements with other programs tested.

The HVAC BESTEST is very useful to improve the program package TRNSYS-TUD.

5. Nomenclature

CDF	Coefficient of Performance Degradation Factor
CFD	Computing Fluid Dynamics
COP	Coefficient of Performance
EDB	Entering Dry-Bulb Temperature
EWB	Entering Wet-Bulb Temperature
TCP	Transition Cooling Point
IDB	Indoor Dry-Bulb Temperature
IHR	Indoor Humidity Ratio
ODB	Outdoor Dry-Bulb Temperature
OHR	Outdoor Humidity Ratio
$\dot{Q}_{N,lat}$	Latent Cooling Capacity
$\dot{Q}_{N,sen}$	Sensible Cooling Capacity
$\dot{Q}_{N,tot}$	Total Cooling Capacity
P_{comp}	Compressor Power
$\dot{m}_{CA}$	Mass Flow Rate of Recirculation Air
$\dot{m}_{EA}$	Mass Flow Rate of Entering Air
$\dot{m}_{OA}$	Mass Flow Rate of Outside Air
$\dot{m}_{vapor}$	Mass Flow Rate of Vapor

6. References

[1] TRNSYS: A Transient System Simulation Program, Solar Energy Laboratory, University of Wisconsin, Madison, USA 1983; Internet: http://sel.me.wisc.edu/trnsys/default.html
[2] Neymark, J.; Judkoff, R.: International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilation and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 2: Cases E300–E545, National Renewable Energy Laboratory, Golden, Colorado, USA, March 2002.
[3] Steimle, F.: Integrierte Planung – Vorraussetzung für gute Klimatechnik, KI Luft- und Kältetechnik, February 2003, S. 47.
[4] Neymark, J.; Judkoff, R.: International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilation and Air-Conditioning Equipment Models (HVAC BESTEST), Volume 1: Cases E100–E200, National Renewable Energy Laboratory, Golden, Colorado, USA, November 2000.
[5] Le, H.-T.; Knabe, G.: HVAC BESTEST Modeler Report analytical solutions for cases E100-E200, Dresden, September 2000.
[6] Le, H.-T.; Knabe, G.: HVAC BESTEST Modeler Report simulation model with TRNSYS TUD for cases E100-E200, Dresden, September 2000.

Program name (please include version number)
TRNSYS-TUD
Your name, organisation, and country
Gottfried Knabe, Huu-Thoi Le, Dresden University of Technology, Germany

TRNSYS-TUD Pro-Forma Model description is included with Volume 1, Appendix III-B. The information below was not included previously.

Economizer settings available (for E400 series)

x	Temperature, outdoor dry-bulb temperature versus return air temperature (E400, E410)
x	Temperature, outdoor dry-bulb temperature high limit setting (E420)
x	Enthalpy, outdoor air enthalpy versus return air enthalpy (E430)
x	Enthalpy, outdoor air enthalpy high limit setting (E440)
x	Compressor Lockout (E410)
	Other (please specify)

Appendix II-D

APPLICATION OF IEA COOLING TEST CASES SERIES 300–500 TO THE HOT3000 BUILDING ENERGY SIMULATION COMPUTER PROGRAM

Prepared by

Kamel Haddad, Ph.D.
Building Energy Simulation Researcher

SIMULATION GROUP
CANMET ENERGY TECHNOLOGY CENTRE
OTTAWA, ONTARIO K1A 0E4

September 9, 2003

1. Summary

The IEA Cooling Test Cases E300–E545 are applied to the HOT3000 building energy simulation program. The zone description is modified from the test specifications so that the boundary condition on the outside of the building envelope is adiabatic. This is needed to overcome convergence issues associated with using low thermal mass. The HOT3000 cooling model is capable of handling all the situations described in the test specification, which include effects of outdoor air and economizer control. One of the limitations with HOT3000 is that only one day type can be defined for internal gains and infiltration. To overcome this, these two simulation inputs are read for each time step from an ASCII file.

The simulation results from HOT3000 agree well with those from other programs. The largest differences are observed in the predicted values of zone air temperature, humidity ratios, and relative humidity for cases E500–E545. This can be attributed to the fact that in the HOT3000 simulations the zone is modeled with adiabatic boundary conditions. Other differences between the HOT3000 results and those from the other programs are due to the fact that the current model performs a successive rather than a simultaneous solution of the loads and HVAC systems.

Initially it is found that there is a discrepancy between the relative difference between the results for case E330 and cases E320 and E340 predicted by HOT3000 and the other simulation programs included with the kit. A modification is made to the way the effect of outdoor air is accounted for in the HOT3000 model and a better agreement is obtained. The simulation results also indicate the need to upgrade the HOT3000 model so that a simultaneous solution of the loads and HVAC domains is performed instead of the successive solution method currently employed.

2. Modeling Assumptions

Description of HOT3000 Air-Conditioning Model

The model is based on the use of performance curves to predict the energy consumption of the equipment. One of the major inputs to the model is the space sensible load, which is predicted by the HOT3000 load module. When the indoor circulation fan is in the continuous mode, the fan power is included as part of the sensible internal gains to the space. In the case where the fan is in the auto or intermittent mode, its effect is accounted for by reducing the capacity of the equipment when computing the part-load ratio for the time step. After the sensible loads of the zones served by the cooling equipment are predicted by the HOT3000 load module, the air-conditioning model subroutine is called and the following main steps are then performed:

- If economizer control exists, determine proper outdoor airflow and updated sensible cooling load to be supplied by compressor-based system.
- Determine cooling coil inlet air conditions. This accounts for any outdoor air effects.
- For the inlet dry-bulb temperature, determine the maximum wet-bulb temperature for dry-coil conditions.
- Set the gross capacity and the sensible heat ratio of the equipment based on the inlet air conditions to the coil and the maximum wet-bulb temperature for dry-coil operation.
- Determine equipment part-load ratio and part-load factor. The space latent load is determined in the process.
- Determine coefficient of performance.
- Predict energy consumption of compressor, outdoor fan, and indoor fan.
- Set airflow and moisture content to include in the zone moisture balance.
- Determine conductance of outdoor air to include as part of space infiltration.
- Set proper sensible capacity for ideal temperature controller.

In the last step listed above, the indoor and outdoor conditions for the current time step are used to find the sensible cooling capacity of the air-conditioner. This sensible cooling capacity is set equal to the controller capacity for the next time step. In other words, the sensible loads and conditions of the space for a certain time step are determined using a controller capacity from the previous time step. The model currently does not include an iterative procedure within each time step, to update the controller capacity once the current conditions within the space are found, until convergence of the solution.

Weather Data

The TMY2 weather files provided with the test suite are used to generate binary weather files for HOT3000. Hourly weather data required for HOT3000 are:

- Outdoor dry-bulb temperature
- Direct normal radiation
- Diffuse solar radiation on horizontal surface
- Wind speed
- Wind direction
- Relative humidity.

All of these variables are given directly in the TMY2 weather files.

Building Zone Description

The building zone description is as specified in section 1.3.1.3 [Part I] except for the material specifications in Table 1-3a [Part I]. Initially the material specifications in the table are used, but this results in a convergence problem due to the very low specific heat, density, and conductivity specified when the envelope elements are declared as exposed to ambient conditions. To resolve the convergence problems, an adiabatic boundary condition for the envelope is used instead. In this case it is possible to specify a very low material density and specific heat to eliminate any thermal mass effects. This modification will impact the predicted values of temperature, relative humidity, and humidity ratio when the cooling load within the zone is zero (absence of internal gains) for an extended period of time, as is the case for test cases E500–E545. For these cases, an adiabatic boundary condition will result in constant zone air conditions in the absence of sensible and latent gains to the space.

Internal Gains and Infiltration

One of the limitations of HOT3000 for specifying sensible gains, latent gains, and infiltration is that the user is able to specify only one day type for the whole simulation. Given this limitation, the time step sensible gains, latent gains, and infiltration are stored in an ASCII file and then read during the simulation. This ASCII file contained information for the full year as well as the start-up period of the month of December.

Equipment Performance Curves

The HOT3000 cooling model uses correlations for the gross equipment capacity and the power input to the compressor. The equipment data in Table 1-7b [Part I] of the report are used to develop the correlations used.

The gross cooling capacity of the air-conditioner under wet conditions is correlated to the outdoor dry-bulb temperature and the coil entering wet-bulb temperature:

$$Total\ Cooling\ Capacity\ (kW) = a1 + a2 \times Todb + a3 \times Todb^2 + a4 \times Tewb + a5 \times Tewb^2 + a6 \times Todb \times Tewb$$

a1 = 23.49707981
a2 = -0.1076915531
a3 = -0.001612289548
a4 = 0.8052200912
a5 = 0.008864708391
a6 = -0.004824135037

The power input to the compressor under wet conditions is also correlated to the outdoor dry-bulb temperature and the coil inlet wet-bulb temperature:

$$Compressor\ Power\ (kW) = b1 + b2 \times Todb + b3 \times Todb^2 + b4 \times Tewb + b5 \times Tewb^2 + b6 \times Todb \times Tewb$$

b1 = 4.157768999
b2 = 0.1136096948
b3 = -0.0003236709368

b4 = 0.01115838853
b5 = 0.002180347593
b6 = 0.001799048516

The HOT3000 cooling model includes a method for calculating the coil sensible heat ratio under wet conditions. Therefore the sensible capacity equipment data in Table 1-7b [Part I] are not used to generate the simulation results. The sensible heat ratio is determined based on the coil bypass factor at rating conditions. The model also includes a method for determining whether the coil is dry or wet. Given the entering dry-bulb temperature to the coil, the maximum coil inlet wet-bulb temperature associated with dry conditions is determined. If the actual inlet wet-bulb temperature to the coil is greater than this cutoff wet-bulb temperature, it is assumed the coil is wet; otherwise it is dry.

Part-Load Performance

The part-load performance is based on the equation given in the test specification:

$$CDF = 1 - 0.229 \times (1 - PLR)$$

This part-load factor is also used to find the energy consumption of the outdoor and indoor fan when used in the intermittent mode.

Ideal Controller

An ideal controller with no throttling range is used. The controller cools the space back to the set point temperature when air temperature inside the space rises above the set point. For cases E300–E360, the maximum sensible cooling capacity of the controller for the time step is set to the gross sensible cooling capacity of the equipment for the previous time step. In this case the fan power is included as part of the sensible internal gains to the space.

For cases E400–E440, when the air-conditioner and the economizer can operate together to meet the load, the maximum controller capacity is set to the gross sensible cooling capacity for the previous time step plus any sensible cooling capacity associated with the operation of the economizer. If the air-conditioner and the economizer can not operate together to meet the load, then the controller maximum cooling capacity is set to the gross equipment sensible cooling capacity for the previous time step. Also in this case the fan power is included as part of the sensible internal gains to the space.

For cases E500–E545 the maximum sensible capacity of the controller is set to the sensible gross cooling capacity of the equipment for the previous time step minus the fan power. In this case the fan power is not included as an internal gain to the space, but its effect will show up in higher part-load ratios due to the lower equipment capacity.

Effect of Indoor Circulation Fan

When the indoor circulation fan is in continuous mode, it is specified as a sensible internal gain to the space. Its effect is then accounted for through the effect on the sensible cooling load of the space and an increased part-load ratio of the air-conditioner.

When the indoor circulation fan is in auto mode, the capacity of the equipment is degraded by the fan power. As a result, the predicted part-load ratio is higher due to the effect of the indoor fan. In this case the fan power is not included as internal gain to the space.

Start-up Simulation Period

A start-up period of 31 days is used corresponding to the full month of December.

Simulation of Infiltration and Outdoor Air Effects

Given that HOT3000 does not allow for more than one day type of infiltration during the simulation, the conductance associated with infiltration for cases E320 and E340 is read from an ASCII file. For each time step, this conductance is set equal to the product of the outdoor air density, volume flow rate, and specific heat:

$$C_{\inf} = \rho_{oa} \dot{V}_{oa} Cp_{oa}$$

This conductance is then automatically used in HOT3000 as part of the air-point energy balance.

HOT3000 performs a zone moisture balance for each time step. This moisture balance accounts for vapor addition or removal within the space due to infiltration and/or ventilation air, and the operation of any mechanical system such as an air conditioner. Any moisture generation within the space is also accounted for. In case there is control of the humidity level within the space, then the action of the controller is also modeled.

Initially, the sensible gain/loss from the introduction of outdoor air through the HVAC system is accounted for as part of the sensible internal gains of the space. In this case the sensible effect of outdoor air for the time step is treated like a sensible gain from lights or any other source of internal gain. The space air-point moisture balance is modified to include an extra moist air supply term at the actual exit air conditions from the coil. The model accounts for the effect of outdoor air on the inlet conditions to the coil. These inlet conditions are needed to predict the correct steady-state total capacity and COP of the air-conditioner. Using this approach and the previous approach for infiltration, the annual sums predicted for cases E320–E340 are shown in the following table:

Table 2D-1: HOT3000 Predictions of Annual Sums for Cases E320–E340 with Original Modeling Approach of Outdoor Air Effects

Cases	Energy Consumption (kWh)				Coil Loads (kWh)		
	Total	Compressor	Compressor Fan	Indoor Fan	Total	Sensible Load	Latent Load
E320	39475	25928	2683	10880	97036	62720	34315
E330	38770	25338	2568	10880	94992	58428	36562
E340	39892	26349	2680	10880	99404	61509	37895

These results indicate a decrease in the total and sensible evaporator coil loads for case E330 relative to cases E320 and E340. This is in contradiction to all the results from the other simulation programs, which predict an increase in the total and sensible coil loads for case E330 relative to E320 and E340. It can therefore be concluded that the original modeling approach in HOT3000 does not effectively predict the relative differences between simulation results when both outdoor air and infiltration are present.

The initial approach for modeling the outdoor air through the HVAC system is then modified. Its effect on the air-point energy and moisture balance is now accounted for in the same way infiltration is accounted for within the HOT3000 loads module. In this case then outside air is included as another airflow into the conditioned space within the HOT3000 numerical solution scheme. The moisture removal at the cooling coil is still accounted for in the space moisture balance. When there is outdoor air through the HVAC system, it is accounted for to find the proper inlet conditions to the cooling coil. Infiltration also affects inlet conditions to the coil through its effect on the space energy and moisture balances. With this modification, the results for case E330 show the same kind of relative differences with cases E320 and E340 as that predicted by the other simulation programs as shown in the following table. This approach for treating outdoor air is then used to generate the results for all the test cases involving the introduction of outdoor air through the HVAC system.

Table 2D-2: HOT3000 Predictions of Annual Sums for Cases E320–E340 with Modified Modeling Approach of Outdoor Air Effects

Cases	Energy Consumption (kWh)			Coil Loads (kWh)			
	Total	Compressor	Compressor Fan	Indoor Fan	Total	Sensible Load	Latent Load
E320	39457	25912	2681	10880	96957	62734	34224
E330	40330	26775	2693	10880	102008	61822	40186
E340	39947	26400	2684	10880	99753	61406	38346

3. Discussion of Remaining Differences in Results Between HOT3000 and Other Programs

The following discussion addresses several differences between the HOT3000 results and those from the other programs that were highlighted (Neymark 2003).

For cases E310 and E520, the peak-hour total electricity consumption from HOT3000 is slightly lower than in the case of the other programs. For these two cases, there are instances when the total space sensible + latent loads for the time step are very close to the total equipment capacity. The HOT3000 model sets the maximum controller capacity for the time step equal to the sensible equipment capacity from the previous time step. The model does not include at this time an iterative process within the time step to update the controller capacity once new space conditions are found for the time step. It is then possible with the current model to have a sensible space load for the time step that is slightly higher than the present sensible equipment capacity. When this happens, the model reduces the sensible load and sets it equal to the equipment sensible capacity for the time step, which explains the lower peak consumptions observed in these cases.

For cases E400 and E440, the peak hourly consumption is slightly lower than for case E300. The other programs show the same peak hourly consumption for all these cases. For these two cases (E400 and E440) also, there are instances when the space sensible load is very close to the equipment sensible capacity. As explained in the previous paragraph this can cause slight reductions in the peak consumption.

The total sensible cooling load and peak hourly COP for case E330 are lower than those for case E320 for HOT3000, whereas for the other simulation programs they are higher. For many time steps the sensible cooling load for cases E320 and E330 are also very close to the sensible equipment capacity. Therefore, as described in the previous paragraph, for these cases also there are some minor uncertainties in the results associated with setting the present controller capacity equal to the sensible equipment capacity from the previous time step. This can be corrected by including an iterative process within each time step so that the controller capacity is updated after each solution of the space conditions until there is convergence. This model upgrade is planned for the future.

For cases E520 and E522 HOT3000 predicts higher peak zone temperatures and humidity ratios than most of the other programs. For these cases also, there are instances when the sensible space load is very close to the sensible equipment capacity. As mentioned previously, the maximum controller sensible capacity is not updated within the time step simulation to reflect the exact equipment capacity. As a result, the space temperature and humidity ratios can be higher than they actually are.

4. Conclusions

Overall, a good agreement is obtained between the simulation results from HOT3000 and the other computer programs included in the kit. The largest differences are observed in the predicted values of the temperature, humidity ratio, and relative humidity for cases E500–E545. This can be attributed to the use of adiabatic boundary conditions instead of the material construction given in Table 1-3a [Part I]. Cases E500–E545 have an extended period of time where there are no internal gains with the air temperature free floating inside the space. It is expected that the assumed adiabatic boundary conditions will have an impact on the predicted results for these cases. Other differences are found to be attributed to the fact that the HOT3000 model performs a successive solution of the loads and systems parts rather than a simultaneous solution.

The application of the test cases illustrated their algorithm validation benefits. In the present case, the relative differences between the predicted annual sums for case E330 relative to cases E320 and E340 were not in agreement with the predictions from the other simulation programs. Originally the sensible effect of the introduction of outdoor air through the HVAC system on the space load was accounted for by including it as part of the space sensible internal gains. This was then modified so that the sensible effect on the space load of the HVAC outdoor air was treated the same way as infiltration is treated in the HOT3000 numerical simulation scheme. In both cases though, the HOT3000 air-conditioning model accounts properly for the effect of condensation at the coil on the space moisture balance and for the effect of outdoor air on the inlet conditions to the coil. With this change, a better agreement was obtained with the other simulation programs for cases E320–E340.

The simulation results also show the need to upgrade the HOT3000 model so that the loads and HVAC domains are solved simultaneously. Currently, the space loads and conditions for a given time step are determined using a controller capacity equal to the sensible equipment capacity from the previous time step. The model can be improved by taking the space conditions for the time step to update the equipment sensible capacity and then determining the space loads and conditions again. Such an upgrade to the HOT3000 model is planned for the future.

5. Reference

Neymark, J. (2003). Email communication, 25 July 2003.

Appendix II-E

DOE-2.1E
National Renewable Energy Laboratory/J. Neymark & Associates
United States
June 17, 2004

1. Introduction

Software: DOE-2.1E ESTSC version 120 *(Pre-release version; the output file designation indicating "version 2.1E-119" will be corrected by the code authors.)*

Authoring Organization: Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, and James J. Hirsch & Associates

Authoring Country: USA

Referencing of DOE-2.1E Modeler Report Included with Volume 1 of HVAC BESTEST and Input Decks Included with Accompanying CD

HVAC BESTEST Volume 1 (Neymark and Judkoff 2002), Appendix III-A includes a modeler report for an earlier version of DOE-2.1E that was distributed by James J. Hirsch & Associates rather than by the U.S. government's Energy Science and Technology Software Center (ESTSC). Because there are numerous similarities between the DOE-2.1E programs issued by these sources, only additions and modifications to the DOE-2.1E modeler report of HVAC BESTEST Volume 1 are included herein. The most complete source regarding current modeling details are the input decks included with the accompanying electronic media. Input decks for cases E300–E545 were developed from the input decks for cases E100–E200; they contain some commentary notes from that earlier work as well as comments added for running the current set of test cases.

Modeling Methodology

Recall from the Volume 1 modeler report that DOE2 assumes that total coil capacity and compressor power do not vary with EDB.

Extrapolation of curve fits can be limited in DOE2, using either a limit on the dependent variable results, or limit cap on ODB and EWB. The lower-end limit on EWB for versions 119 and earlier was hard-wired at EWB = 60°F (15.6°C); that was changed (per the testing for this project) to EWB = ODB – 10 (°F).

DOE-2.1E automatically identifies when a dry-coil condition has occurred and does calculations accordingly. f(EWB,ODB) curve fit data used in DOE-2 are meant for wet coils only. Where possible f(T) data points assume EDB = 80°F; however, at lower EWB, it was necessary to use data for EDB < 80°F (and normalize those data to be consistent with EDB – 80°F data) to give proper information to curve fit routines. The methodology is described in the input decks included with the accompanying CD; the spreadsheet used to implement this methodology (e300MAP-doe2-1102.XLS) is also included. For HVAC BESTEST volume 2 cases, 55°F ≤ ODB ≤ 95°F. Maximum ODB for New Orleans TMY2 is 95°F, and by design of the cases system operation below ODB = 55°F should not occur. Also 55°F < EWB < 75°F is the most common range of operation for the cases, although some operation occurs outside of that range, especially in specific cases with specified higher or lower EDB (set point).

The COIL-BF-FT curve fit was set so that bypass factor remains constant throughout the simulations. Bypass factor was allowed to vary as f(ODB,EWB) in cases E100–E200.

2. Modeling Assumptions

Modeling assumptions that vary from those for cases E100–E200 are listed below. Fullest detail is included with the input decks.

- FLOOR-WEIGHT = 0.74 (lb/ft^2): This accounts for the mass of air in the zone. Custom weighting factors (set by entering "0") will not run with zero-mass construction. 0.1 lb/ft^2—the lowest value allowed per the *DOE-2 Reference Manual Version 2.1A* (1981), p. III-51—was used in runs with ESTSC version 119 and initial runs with version 120, and then corrected to 0.74 lb/ft^2 to account for the mass of zone air in a second set of runs using version 120.
- MIN-SUPPLY-T = 35: lowest allowed value. Per test specification, Appendix D, 34.6 < MST < 35.1°F; depending on air properties, 35.1°F may be a more precise value.
- SUPPLY-DELTA-T = 0.960 (temperature difference from fan heat): This value is based on Qfan = m(cp)(deltaT), 1242 W, 4000 cfm. This value was calculated to match the assumptions of DOE-2 documented on p. IV.28 of the *DOE-2 Engineers Manual* (1982), and utilizes the following air properties: density = 0.075 lb/ft^3 and cp = 0.244 Btu/(lb°F) for humidity ratio = 0.01 lb/lb.
- COOL-FT-MIN = 50 (°F; used for calculations defining lower limit temperatures for performance calculations using curve-fit data [e.g. as COOL-FT-MIN – 10], if not hard-wired elsewhere in the software): This value allows performance calculations down to ODB = 50°F and EWB = 40°F in ESTSC version 120; version 119 had hard-wired lower limit of EWB = 60°F (15.6°C) for performance calculations.
- OUTDOOR-FAN-T = 24 (°F): limit below which fans do not run. The minimum hour ODB for New Orleans TMY2 annual weather data is 24°F.

3. Modeling Options

SYSTEM-TYPE: PSZ model

A number of SYSTEM-TYPEs are possible and reasonable for modeling the HVAC BESTEST DX system, including RESYS2, RESYS, PSZ, and PTAC. Choice of system type affects default performance curves and features available with the system. Of these, according to a DOE-2 documentation supplement (James J. Hirsch & Associates 1996), neither PTAC nor RESYS had the improved part-load (cycling) model for packaged systems incorporated (the improved model uses the COOL-CLOSS-FPLR curve rather than the COOL-EIR-FPLR curve). Either the PSZ or RESYS2 models could have worked since custom performance curves are applied. PSZ was chosen because the system used in the test cases is larger than what would normally be used in a single-family detached residence.

4. Modeling Difficulties

COIL-BF-FPLR was originally specified such that bypass factor would not vary with part-load ratio. However, this caused erroneous results in cases with continuously operating fans as noted further below. Based on advice of one of the code authors (Buhl 2003), input for this curve fit was set to default (i.e., the final input decks are silent regarding this input).

DOE-2.1E does not provide hourly output of zone humidity ratio. An output for return air humidity ratio (which is equivalent to zone humidity ratio for a single zone case with no duct leakage) is available, but this value is only enabled when the air distribution fan is operating. Zone relative humidity was calculated with a post-processor based on hourly outputs for zone temperature, return air humidity ratio, and atmospheric pressure. For cases with intermittent fan operation (E500–E545) it was not possible to obtain annual average zone humidity ratio and relative humidity, maximum relative humidity, and minimum humidity ratios and relative humidity. It was possible to obtain average humidity ratios and post-processed relative humidity for results taken for the period from May 1–Sep 30 for cases E500 and E510 because the cooling system is required to operate during all hours of that time period for those cases.

5. Software Errors Discovered

In the process of testing DOE-2.1E ESTSC version, we found two documentation problems, one bug that resulted in a new version, and three other disagreements that the code authors are not planning to fix in DOE-2.1E because these disagreements do not occur in their next-generation software EnergyPlus. These are all discussed below.

Documentation Problems

There is a problem with misleading documentation related to use of the COIL-BF-FPLR curve that adjusts bypass factor (BF) as a function of part-load ratio. This caused 30%–115% overestimation of annual latent coil loads resulting in a 7%–22% overestimation of total annual consumption for cases with continuous fan operation (E300–E440). Detailed discussion of this problem is included in the main body of the report, Part II, Section 2.4.4.1.

Another documentation problem relates to that DOE-2.1E provides two possibilities for zone temperature output (*DOE-2 Supplement* 1994):

TNOW: "Current hour zone temperature (°F)"
TAVE: "The average zone air temperature during the hour (°F). This is the value used for the energy calculation."

For the Volume 1 steady-state cases (E100–E200), there was no difference in results for TNOW versus TAVE, and TNOW was used in the input decks for those cases. For the Volume 2 cases TNOW and TAVE give the same annual average results, but different hourly results. Per discussions with one of the DOE-2 authors, TAVE is representative of the average zone conditions over the hour and should be used; TNOW may not be representative of average zone conditions for certain hours (Hirsch 2003). Revising from TNOW to TAVE caused mostly minor variations to the maximum and minimum IDB results and maximum and minimum relative humidity results (because the relative humidity results are developed using a separate post processor outside of DOE-2); by far the biggest change was a 4°C decrease in maximum IDB for Case E330.

Fixed Bug Resulting from this Work

After addressing the above documentation problem a number of other disagreements remained, and were transmitted to the code authors. Figure 2E-1 illustrates the remaining fan electric consumption disagreement for cases E520 and E540 using DOE-2.1E ESTSC version 119 (Neymark 2003).

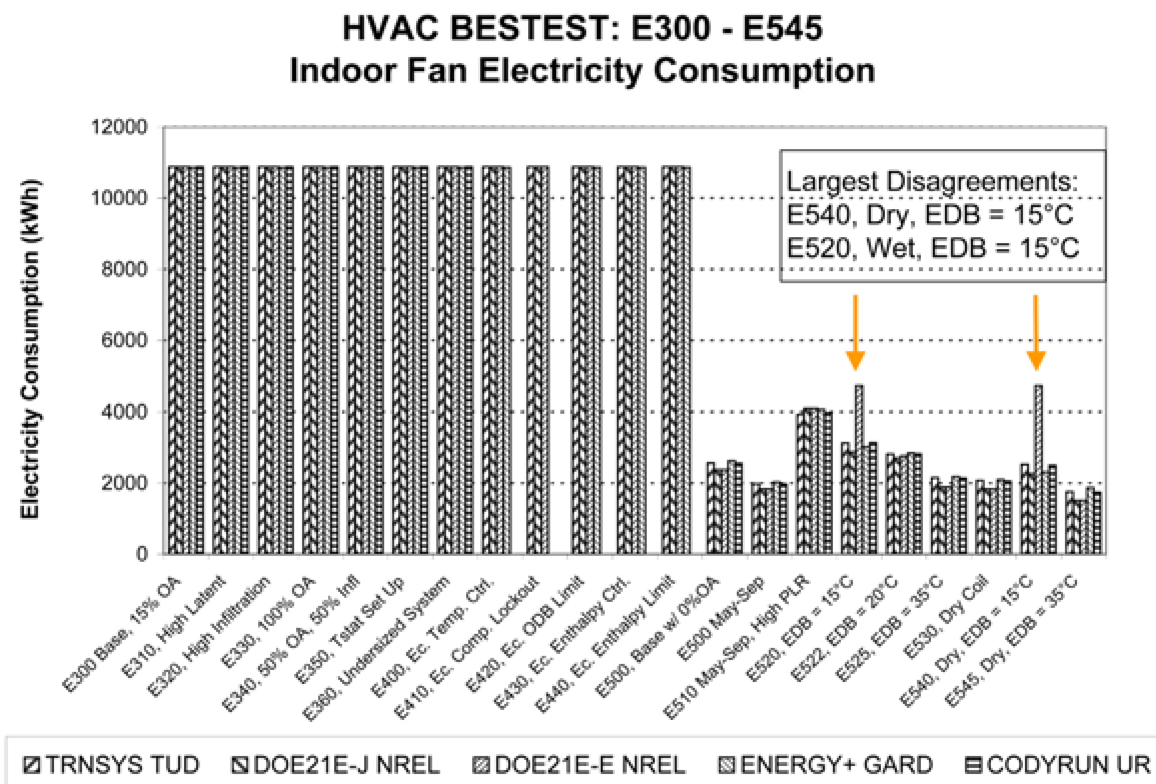


Figure 2E-1. DOE-2.1E ESTSC 119, indoor fan electricity disagreements for E520 and E540

Based on the observation that these disagreements were occurring only for cases with low EDB, some sort of performance data limiting issue was suspected as the cause. Upon further analysis by one of the code authors, he responded with the following (Buhl 2003):

> "The reason for this difference is a hard lower limit of 60F on the coil entering wet-bulb temperature. Changing
>
> EWB = AMAX1(<PASTMIXW.,60.)
>
> to
>
> EWB = AMAX1(<PASTMIXW>,<COOL-FT-MIN>-10.)
>
> causes the difference to go away and the ESTSC and Hirsch versions [of DOE-2.1E] to get [an agreeing] result.

Note: <COOL-FT-MIN> is the minimum outside air or entering air temperature for the capacity and EIR modification curves; <PASTMIXW> is the previous hour's value for mixed air wet-bulb temperature.

This change will be incorporated in the next ESTSC version of DOE-2.1E."

For cases E520 and E540 only, for ESTSC version 119 versus version 120 results, modification of the EWB lower limit caused a 39%–52% decrease in indoor fan electricity, a 7%–15% increase in outdoor fan electricity, and a 1%–5% increase in compressor electricity, resulting in a 6%–7% decrease in total energy consumption; also there was a 6°–7°C decrease in maximum IDB (using TNOW). The DOE-2.1E ESTSC version 120 results are included in Part III.

Other Disagreements Transmitted to Code Authors

The disagreements noted for DOE-2.1E ESTSC version 119 in Figures 2E-2, 2E-3, 2E-4, and 2E-5 were also transmitted to the code authors along with other figures and comments not included here (Neymark 2003).

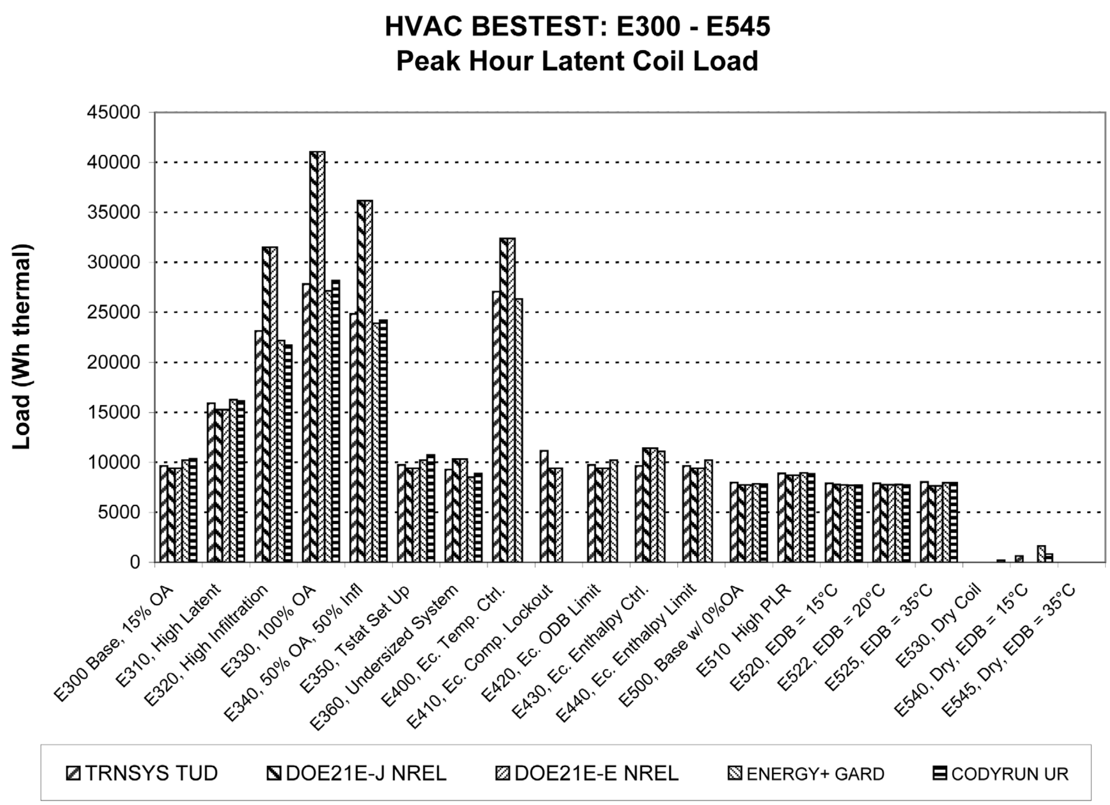


Figure 2E-2. DOE-2.1E ESTSC 119, peak-hour latent coil load disagreement for cases E320, E330, E340, and E400

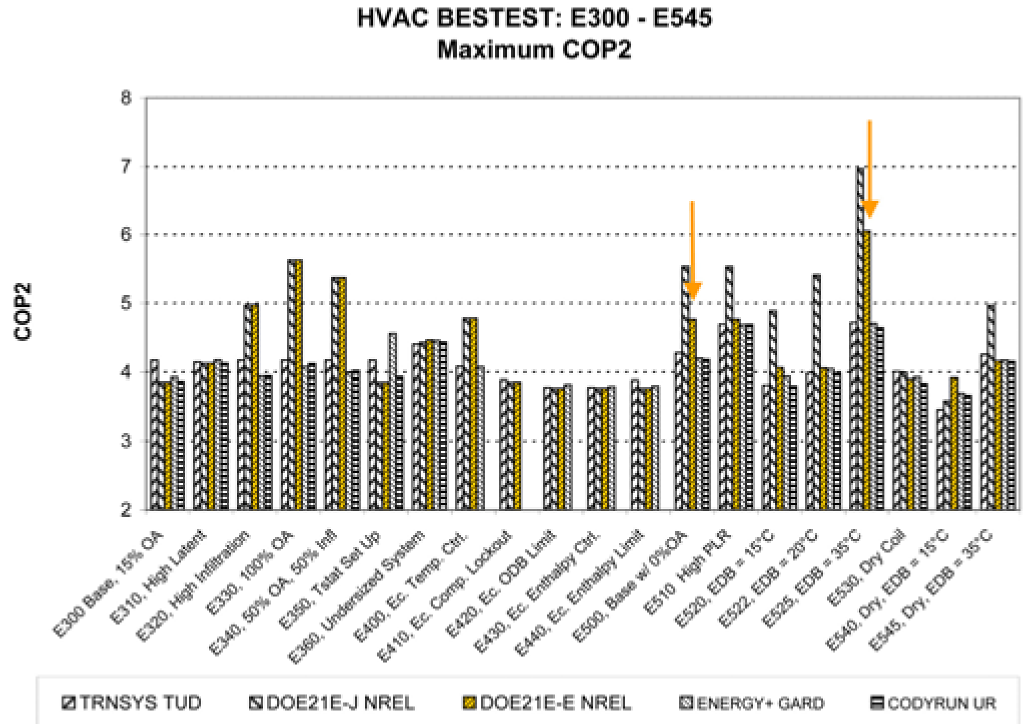


Figure 2E-3. DOE-2.1E ESTSC 119, maximum COP2 disagreements

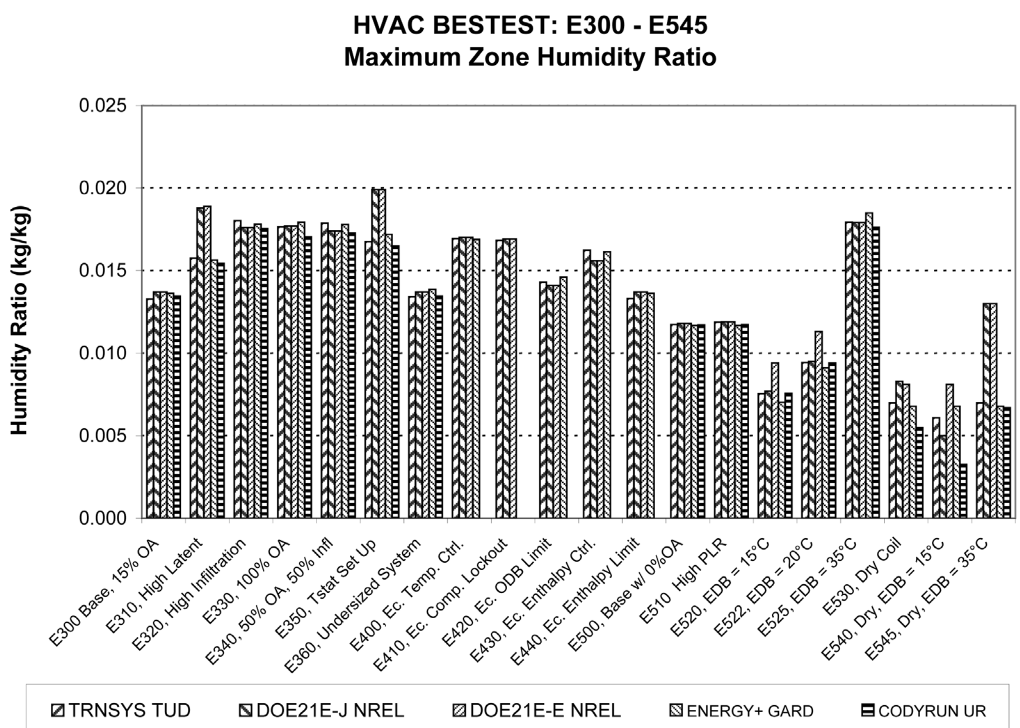


Figure 2E-4. DOE-2.1E ESTSC 119, peak-hour humidity ratio disagreements for cases E310, E350, and E545

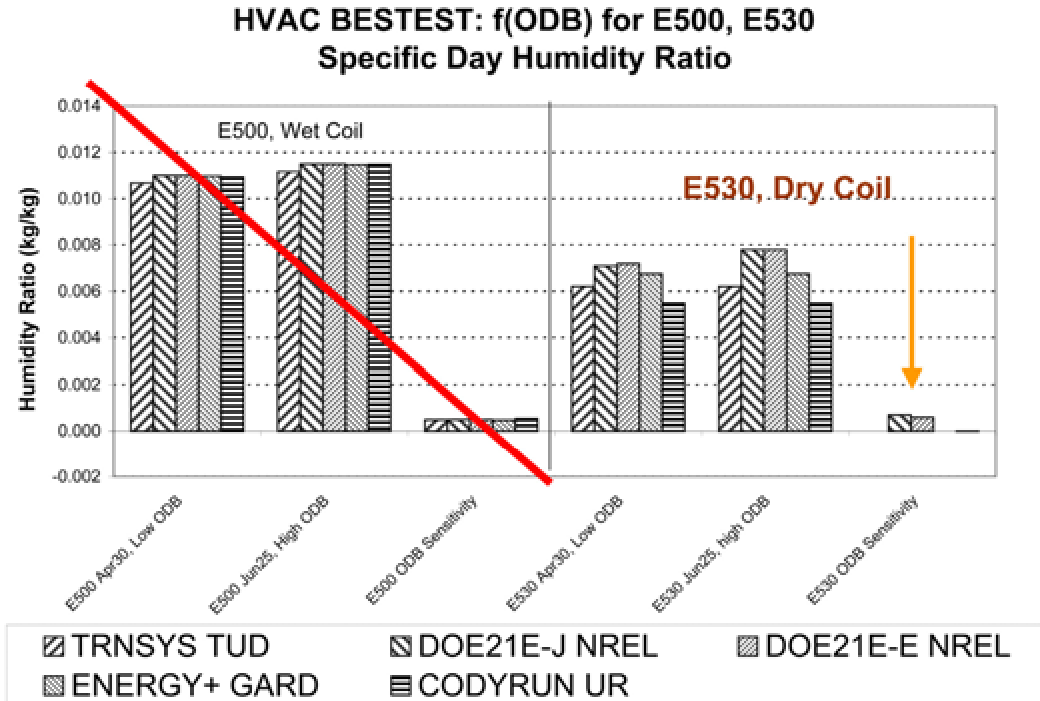


Figure 2E-5. Is DOE-2 "inhaling moisture" in dry-coil Case E530?

Responses from one of the code authors may be categorized according to the above figures (Buhl 2003). Regarding Figure 2E-2, which indicates a 20%–50% overestimation of peak-hour latent coil loads for cases E320, E330, E340, and E400:

> "… High peak-hour coil load for cases E330, E340, E350, E400.
>
> This difference between DOE-2 and the other programs is due to DOE-2's use of the previous hour's mixed air wet-bulb temperature in the COOL-SH-FT sensible capacity modification curve. When entering humidity jumps abruptly in one hour this results in a misestimate of the sensible capacity, which gives a misestimate of the minimum supply temperature leading finally to a misestimate of the moisture removal capability.
>
> DOE-2 employs a single-pass HVAC calculation with a 1-hour time step. Entering conditions are estimated from the previous time step values. As a consequence the program does not do well in the time step after an abrupt change in load or conditions. Note that this has nothing to do with the coupling of the envelope and the HVAC calculation; it is strictly a consequence of the HVAC solution method which was chosen years ago for execution speed with good annual energy numbers, not for detailed equipment performance calculations in rapidly varying conditions. In steady-state conditions the program will of course do well. If the HVAC calculation were iterated or run at a smaller time step, the problem would go away. However, no change to the program

is contemplated to resolve this issue: it would involve rewriting the DOE-2 HVAC calculation."

Regarding Figure 2E-3:

> "… High COP2, cases E320, E330, E340, E500, E525.
>
> The difference between DOE-2 and the other programs (E320, E330, E340) is due to [the issue discussed with Figure 2E-2]. The difference between the 2 versions of DOE-2 (E500, E520) is probably due to [the issue discussed with Figure 2E-1]."

Regarding Figure 2E-4, which indicates 20%, 18%, and 80% overestimations of peak-hour zone humidity ratio for cases E310, E350, and E545, respectively:

> " … High maximum humidity ratio for cases E310, E350, E545.
>
> Only case E310 was examined. For E310 the peak "zone" humidity ratio occurs on October 15, hour 9. For this hour the cooling is off, but the latent heat gain has started. The fan is running and there is no infiltration. For this simple case we can calculate the humidity balance by hand. The outside air fraction is 0.15, outside humidity ratio is 0.0104, latent load is 24008 (Btu/h), CFM is 4000. The hand calculation gives a return humidity ratio of 0.0189, the same as reported by DOE-2.
>
> Why is the cooling off? In EnergyPlus it is on for this hour. The answer is that DOE-2 uses a 1-hour time step and the average zone temperature for the hour is well below the cooling set point: the thermostat is in the deadband and cooling is off. In EnergyPlus the HVAC calculation time step drops to 1 minute as the load ramps up; the cooling switches on during the hour and there is significant moisture removal. Thus the difference in zone max humidity is just a result of comparing a program with a fixed 1-hour time step to a program with a varying time step. With a 1-hour time step, on/off decisions have to be made for the whole hour at the start of the hour. Lack of iteration means that the decision cannot be changed.
>
> No code change is planned to deal with this issue. Fixing it would require rewriting DOE-2 HVAC."

Regarding Figure 2E-5:

> " … DOE-2 'inhaling' moisture? E530, April 30 versus June 25.
>
> As far as I can tell, this case has no source for moisture during the entire year. In this case there is no "correct" answer for the humidity ratio anywhere in the system. I suppose it would be nice if whatever humidity ratio is chosen would remain fixed. DOE-2's varies a bit: it is set to WSURF, the presumed coil surface humidity ratio—actually

the humidity ratio obtained assuming 100% relative humidity at the coil surface temperature. The coil surface temperature varies with the load, thus so does WSURF. DOE-2 expels as well as inhales moisture in this zero source of moisture case.

No code change is planned to deal with this issue."

6. Results

Unlike the analytical verification tests of cases E100–E200, cases E300–E545 do not have analytical solutions and therefore provide no mathematical truth standard for comparison of results. Therefore, simulation results are assumed to be in agreement with other simulation results unless a disagreement is obviously noticeable. In cases where the range of results is relatively wide with noticeable relative disagreement among all the results, the criteria for disagreement are looser. Additionally where all results are reasonably agreeing, there is no certainty that a result in the center of a range of results is any better than a result that defines the extreme of a range of results.

In general DOE-2.1E exhibits a good level of agreement with the other programs for annual energy use, loads, and other annual average results. There are some notable disagreements for peak-hour results, however, as discussed above. A compilation of what appear to be obviously disagreeing results based on Part III is included below; these disagreements should all be related to the problems discussed above, although there is no way to be certain because the code authors do not plan to rewrite the HVAC calculations for DOE-2.1E.

Remaining disagreements:

- Peak-hour total coil load: E320, E330, E340, E400
- Peak-hour total coil load sensitivity: E320–E300, E330–E300, E330–E320, E340–E300, E400–E300
- Peak-hour latent coil load: E320, E330, E340, E400
- Peak-hour latent coil load sensitivity: E320–E300, E330–E300, E330–E320, E340–E300, E400–E300
- Maximum COP2: E320, E330, E340, E350, E400, E500 through E525
- Maximum COP2 sensitivity: many cases
- Minimum COP2 sensitivity: E400–E300, E430–E300, E440–E300, E510–E500
- Minimum IDB: E320
- Maximum humidity ratio: E310, E350, E522, E545
- Maximum humidity ratio sensitivity: E310–E300, E350–E300
- Maximum relative humidity: E310, E350
- Maximum relative humidity sensitivity: E310–E300
- Humidity ratio f(ODB): E530.

7. Other

There is some disagreement regarding hourly latent coil load for Case E300, June 28, hours 7, 8, 11, and 13 (see Figure 2F-7 of Appendix II-F). This is related to differences in handling of weather data in DOE-2 versus the other programs as shown in Figure 2F-8 of Appendix II-F. Here DOE-2 is applying original raw weather data values for the entire hour, while other programs appear to be performing some type of averaging. Justification for interpreting weather data differently is given in Section 1.3.1.1 of Part I.

8. Conclusions and Recommendations

Regarding the DOE-2.1E Results

Working with DOE-2.1E during the development of HVAC BESTEST Volume 2, cases E300–E545, allowed additional examination of the DOE-2 results and identified the following issues relating to accuracy of the software. The list includes the significance of the problem and related actions.

- COIL-BF-FPLR documentation problem (7%–22% overestimation of total consumption for cases with continuous fan operation [E300–E440]), authors notified and input revised.
- Minimum EWB was 60°F (low EDB cases E520 and E540 only: 65%–109% overestimation of indoor fan electricity, 6%–8% overestimation of total energy consumption), fixed in ESTSC version 120.
- Single-pass HVAC calculation with 1-hour time step using previous hour's EWB (20%–50% overestimation of peak-hour latent coil loads for cases E320, E330, E340, and E400; 20%, 18%, and 80% overestimation of peak-hour zone humidity ratio for cases E310, E350, and E545, respectively). Authors do not plan to fix in DOE-2.1E; these issues are addressed in their next-generation software EnergyPlus, which can iterate between loads and systems calculations within subhourly time steps.
- Zone humidity ratio for dry-coils assumes 100% relative-humidity air at the coil surface temperature resulting in unexpected variations of zone humidity ratio (10%–25% overestimation of humidity ratio for dry-coil case E530). Authors do not plan to fix DOE-2.1E; this problem does not exist in their next-generation software EnergyPlus.

For DOE-2.1E the annual summed or averaged results for system performance and zone conditions appear satisfactory when compared with other programs. See Part III for detailed results. The inability of DOE-2.1E to iterate systems and loads calculations within a time step, and the inability to apply subhourly time steps appear to be related to a number of disagreements versus the other programs for hourly extreme values and perhaps some hourly estimates in general (see Sections 5 and 6 above).

Regarding HVAC BESTEST

After improvements to earlier versions of DOE-2.1E documented in Volume 1, the James J. Hirsch & Associates version of DOE-2.1E (version 133) showed good agreement for the Volume 1 steady-state cases E100–E200; this was before that program was applied to the Volume 2 cases that have more realistic dynamics and apply additional mechanical equipment features. For the Volume 2 test cases, both the Hirsch and ESTSC versions of DOE-2.1E exhibit similar overall results and similar disagreements versus the other programs. The disagreements are related to use of calculation techniques that were originally developed to save execution time. This discovery of further disagreements for both versions of DOE-2.1E, after testing one of the versions with Volume 1, indicates the importance of also having tested the programs over a wider range of varying conditions and applying additional mechanical features in the test cases.

9. References

Buhl, W.F. (2003). Email communications, May 25, 2003, October 7, 2003. Lawrence Berkeley National Laboratory, Berkeley, California, US. Discussion related to COIL-BF-FPLR documentation problem is from May 15, 2003; discussion related to Figures 2E-1 through 2E-5 is from October 7, 2003.

DOE-2 Reference Manual (Version 2.1A) Part 1. (May 1981). D. York, C. Cappiello, eds. Berkeley, California, US: Lawrence Berkeley Laboratory.

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DOE-2 Supplement (Version 2.1E). (January 1994). Berkeley, California, US: Lawrence Berkeley Laboratory.

Hirsch, J. (June 2003). Personal telephone communication. June 2003. Camarillo, California, US: James J. Hirsch & Associates.

JJHirsch DOE-2.1E Documentation ERRATA and ADDITIONS. Part III: ADDITIONS to the JJ Hirsch DOE-2.1E Program. (January 1996). Included with DOE-2.1E as "C:\DOE21E\DOC\21EDOC.DOC." Camarillo, California, US: James J. Hirsch & Associates,.

Neymark, J. (2003). Email communication with W.F. Buhl, sent May 19, 2003. J. Neymark & Associates, Golden, Colorado, US. Results shown in Figures 2E-1 through 2E-5 are from spreadsheet: *E300results0503.xls* (HVAC BESTEST Vol. 2 results summary May 2003, with revisions to charts afterward.)

Neymark, J.; Judkoff, R. (2002). *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Mechanical Equipment (HVAC BESTEST), Volume 1: Cases E100–E200.* NREL/TP-550-30152. Golden, Colorado, US: National Renewable Energy Laboratory.

Program name (please include version number)

DOE-2.1E ESTSC version 120

Your name, organisation, and country

Joel Neymark, National Renewable Energy Laboratory/J. Neymark & Associates, United States

In tables below:
x = *method used*

a = *method available, but not used*

Program status

	Public domain
x	Commercial: *purchased from Energy Science and Technology Software Center, Oak Ridge TN, USA.*
	Research
	Other (please specify)

Solution method for unitary space cooling equipment

x	Overall Performance Maps
	Individual Component Models
	Constant Performance (no possible variation with entering or ambient conditions)
	Other (please specify)

Interaction between loads and systems calculations

	Both are calculated during the same time step
x	First, loads are calculated for the entire simulation period, then equipment performance is calculated separately
	Other (please specify)

Time step

x	Fixed within code (please specify time step): *one hour*
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data: sampling interval

x	Fixed within code (please specify interval): *one hour*
	User-specified

Timing convention for meteorological data: period covered by first record

x	Fixed within code (please specify period or time which meteorological record covers): *0:00 - 1:00*
	User-specified

Meteorological data reconstitution scheme

x	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
x	Produces average outputs for each hour (please specify period to which value relates): *same as time step*

Treatment of zone air

x	Single temperature (i.e., good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Zone air initial conditions

x	Same as outside air
	Other (please specify)

Internal gains output characteristics

	Purely convective
	Radiative/Convective split fixed within code
x	Radiative/Convective split specified by user
	Detailed modeling of source output

Mechanical systems output characteristics

x	Purely convective
	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modeling of source output

Control temperature

x	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control properties

	Ideal control as specified in the user's manual
	On/Off thermostat control
	On/Off thermostat control with hysteresis
	On/Off thermostat control with minimum equipment on and/or off durations
x	Proportional control: *a throttling range setting of 0.1°F was input along with a “TWO-POSITION” thermostat type.*
	More comprehensive controls (please specify)

Performance Map: characteristics

a	Default curves
x	Custom curve fitting
	Detailed mapping not available
	Other (please specify)

Performance Map: independent variables

x	Entering Dry-bulb Temperature: *The effect of EDB is “hardwired” in DOE-2, and only affects sensible capacity.*
x	Entering Wet-bulb Temperature
x	Outdoor Dry-bulb Temperature
x	Part-Load Ratio
a	Indoor Fan Airflow Rate: *did not use; fan air-flow was always at rated conditions when the fan was operating.*
	Other (please specify)

Performance Map: dependent variables

x	Coefficient of Performance (or other ratio of load to electricity consumption)
x	Total Capacity
x	Sensible Capacity
x	Bypass Factor
	Other (please specify)

Performance Map: available curve fit techniques

x	Linear, f(one independent variable): *COIL-BF-FPLR using default linear curve*
a	Quadratic, f(one independent variable)
x	Cubic, f(one independent variable): *CLOSS-FPLR*
x	Bi-Linear, f(two independent variables): *COIL-BF-FT input as constant (multiplier always = 1)*
x	Bi-Quadratic, f(two independent variables): *SCAP-FT, CAP-FT, BF-FT, EIR-FT*
x	Other (please specify)

Performance Map: extrapolation limits

x	Limits independent variables: *ODB (input setting = 50°F); EWBmin = ODBmin – 10; before work with HVAC BESTEST EWB lower limit was 60°F, which caused problems*
a	Limits dependent variables: *available for all curves*
x	No extrapolation limits: *available dependent variable limits were not applied*
	Extrapolation not allowed
	Other (please specify)

Cooling coil and supply air conditions model

	Supply air temperature = apparatus dew point (ADP); supply air humidity ratio = humidity ratio of saturated air at ADP
a	Bypass factor model using listed ADP data
x	Bypass factor model with ADP calculated from extending condition line
x	Fan heat included
	More comprehensive model (please specify)

Disaggregation of fans' electricity use directly in the simulation and output

a	Indoor fan only
a	Outdoor fan only
x	Both indoor and outdoor fans disaggregated in the output
a	None - disaggregation of fan outputs with separate calculations by the user

Economizer settings available (for E400 series)

x	Temperature
x	Enthalpy
x	Compressor Lockout
	Other (please specify)

Appendix II-F

DOE-2.2
National Renewable Energy Laboratory/J. Neymark & Associates
United States
June 17, 2004

1. Introduction

Software: DOE-2.2 version NT42j
Authoring Organization: Lawrence Berkeley National Laboratory/University of California, and James J. Hirsch & Associates (distributed by James J. Hirsch & Associates)

Authoring Country: United States

Referencing of DOE-2.1E Modeler Report Included with Volume 1 of HVAC BESTEST and Input Decks Included with Accompanying CD

HVAC BESTEST Volume 1 (Neymark and Judkoff 2002), Appendix III-A includes a modeler report for an earlier version of DOE-2.1E that was distributed by James J. Hirsch & Associates. DOE-2.2 is the Hirsch update of their version of DOE-2.1E. Because many similarities remain between DOE-2.1E and DOE-2.2, only additions and modifications to the DOE-2.1E modeler report of HVAC BESTEST Volume 1 are included herein. The most complete source regarding current modeling details are the input decks included with the accompanying electronic media. Input decks for cases E300–E545 were developed from the input decks for cases E100–E200; they contain some commentary notes from that earlier work as well as comments added for running the current set of test cases. DOE-2 simulations for this project originally began with both the Hirsch and ESTSC versions of DOE-2.1E. James J. Hirsch & Associates assisted with conversion of input decks from DOE-2.1E to DOE-2.2 (Hirsch 2003a).

Modeling Methodology

Recall from the Volume 1 modeler report that DOE-2 assumes that total coil capacity and compressor power do not vary with EDB. Extrapolation of curve fits can be limited in DOE-2, using either a limit on the dependent variable results, or a limit cap on ODB and EWB.

DOE-2.1E automatically identifies when a dry-coil condition has occurred and does calculations accordingly. f(EWB,ODB) curve fit data used in DOE-2 are meant for wet coils only. Where possible f(T) data points assume EDB = 80°F; however, at lower EWB, it was necessary to use data for EDB < 80°F (and normalize those data to be consistent with EDB – 80°F data) to give proper information to curve fit routines. The methodology is described in the input decks included with the accompanying CD; the spreadsheet used to implement this methodology (e300MAP-doe2-1102.XLS) is also included. For HVAC BESTEST Volume 2 cases, 55°F ≤ ODB ≤ 95°F. The maximum ODB for New Orleans TMY2 is 95°F, and by design of the cases, system operation below ODB = 55°F should not occur. Also 55°F < EWB < 75°F is the most common range of operation for the cases, although some operation occurs outside of that range, especially in specific cases with specified higher or lower EDB (set point).

The COIL-BF-FT curve fit was set so that bypass factor remains constant throughout the simulations. Bypass factor was allowed to vary as f(ODB,EWB) in cases E100–E200.

2. Modeling Assumptions

Modeling assumptions that vary from those for cases E100–E200 are listed below. Fullest detail is included with the input decks.

- FLOOR-WEIGHT = 0.74 (lb/ft^2): This accounts for the mass of air in the zone. Custom weighting factors (set by entering "0") will not run with zero-mass construction. 0.1 lb/ft^2—the lowest value allowed per the *DOE-2 Reference Manual Version 2.1A* (1981), p. III-51—was used in runs with version NT41n and initial runs with version NT42j, and then corrected to 0.74 lb/ft^2 in a second set of runs using version NT42j.
- MIN-SUPPLY-T = 35: lowest allowed value. Per test specification, Appendix D, 34.6 < MST < 35.1°F; depending on air properties, 35.1°F may be a more precise value.
- SUPPLY-DELTA-T = 0.960 (temperature difference from fan heat): This value is based on Qfan = m(cp)(deltaT), 1242 W, 4000 cfm. This value calculated to match the assumptions of DOE-2 documented on p. IV.28 of the *DOE-2 Engineers Manual* (1982), and utilizes the following air properties: density = 0.075 lb/ft^3 and cp = 0.244 Btu/(lb°F) for humidity ratio = 0.01 lb/lb.
- COOL-FT-MIN = 50 (°F; used for calculations defining lower limit temperatures for performance calculations using curve-fit data [e.g., as COOL-FT-MIN – 10]): This value allows performance calculations down to ODB = 50°F and EWB = 40°F.
- OUTDOOR-FAN-T = 24 (°F): limit below which fans do not run. The minimum hour ODB for New Orleans TMY2 annual weather data is 24°F.

3. Modeling Options

SYSTEM-TYPE: PSZ model

A number of SYSTEM-TYPEs are possible and reasonable for modeling the HVAC BESTEST DX system, including RESYS2, RESYS, PSZ, and PTAC. Choice of system type affects default performance curves and features available with the system. Of these, according to a DOE-2 documentation supplement (J.J. Hirsch and Associates 1996), neither PTAC nor RESYS had the improved part-load (cycling) model for packaged systems incorporated (the improved model uses the COOL-CLOSS-FPLR curve rather than the COOL-EIR-FPLR curve) into DOE-2.1E. Either the PSZ or RESYS2 models could have worked since custom performance curves are applied. PSZ was chosen because the system used in the test cases is larger than what would normally be used in a single-family detached residence.

4. Modeling Difficulties

Neither DOE-2.1E nor DOE-2.2 provide hourly output of zone humidity ratio. An output for return air humidity ratio (which is equivalent to zone humidity ratio for a single zone case with no duct leakage) is available, but this value is enabled only when the air distribution fan is operating. Zone relative humidity was calculated with a post-processor based on hourly outputs for zone temperature, return air humidity ratio, and atmospheric pressure. For cases with intermittent fan operation (E500–E545) it was not possible to obtain annual average zone humidity ratio and relative humidity, maximum relative humidity, and minimum humidity ratios and relative humidity. It was possible to obtain average humidity ratios and post-processed relative humidity for results taken for the period from May 1–Sep 30 for cases E500 and E510 because the cooling system is required to operate during all hours of that time period for those cases.

5. Software Errors Discovered

In the process of testing James J. Hirsch & Associates DOE-2.1E and DOE-2.2 we found one documentation problem, one fixed bug, and other results disagreements that have been transmitted to the code authors. These are discussed below.

Documentation Problem

DOE-2.2 provides 2 possibilities for zone temperature (*DOE-2.2 Volume 4* 2002)

TNOW: "Current hour zone temperature (°F)"
TAVE: "The average zone air temperature during the hour (°F). This is the value used for the energy calculation."

For the Volume 1 steady-state cases (E100–E200), there was no difference in results for TNOW versus TAVE, and TNOW was used in the input decks for those cases. For the Volume 2 cases, TNOW and TAVE give the same annual average results, but different hourly results. Per discussions with one of the DOE-2 authors, TAVE is representative of the average zone conditions over the hour and should be used; TNOW may not be representative of average zone conditions for certain hours (Hirsch 2003b). Revising from TNOW to TAVE caused mostly minor variations to the maximum and minimum IDB results in the DOE-2.1E ESTSC version as documented in Appendix II-E.

Disagreements Transmitted to Code Authors November 13, 2003 (Includes 1 Fixed Bug)

The disagreements noted for DOE-2.2 NT41n in Figures 2F-1 through 2F-4 are similar to those documented in Appendix II-E for DOE-2.1E ESTSC version 120. These disagreements were transmitted to the DOE-2.2 code authors (Neymark 2003a).

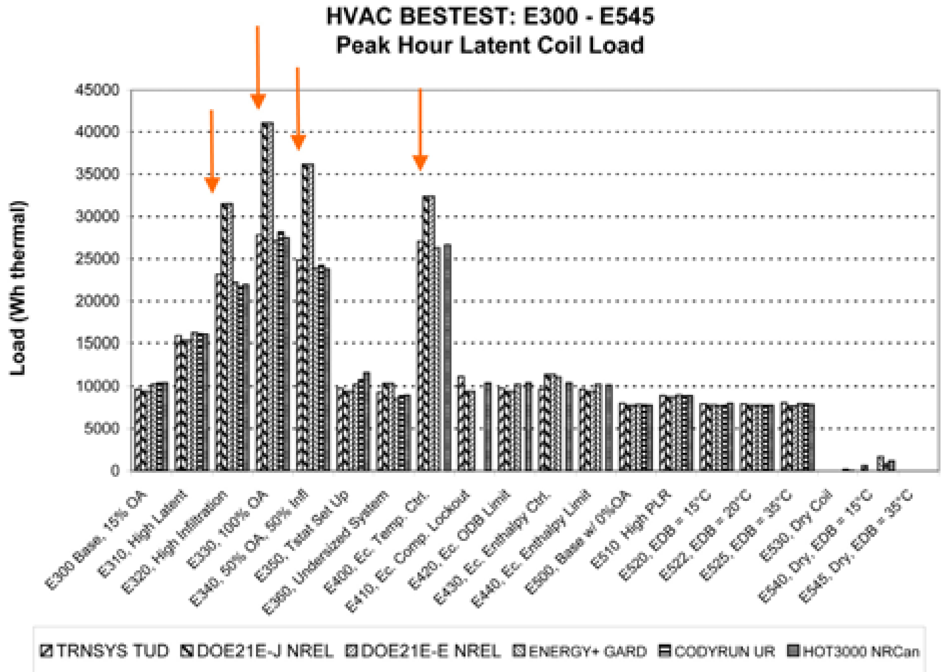

Figure 2F-1. DOE-2.2 NT41n, peak-hour latent coil load disagreements: cases E320, E330, E340, and E400

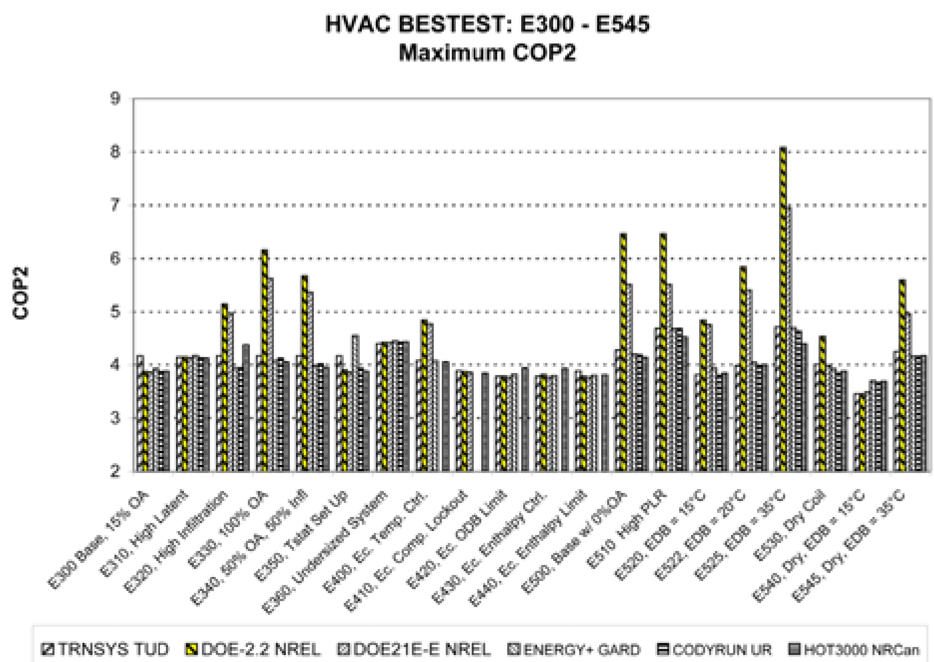

Figure 2F-2. DOE-2.2 NT41n, maximum COP2 disagreements

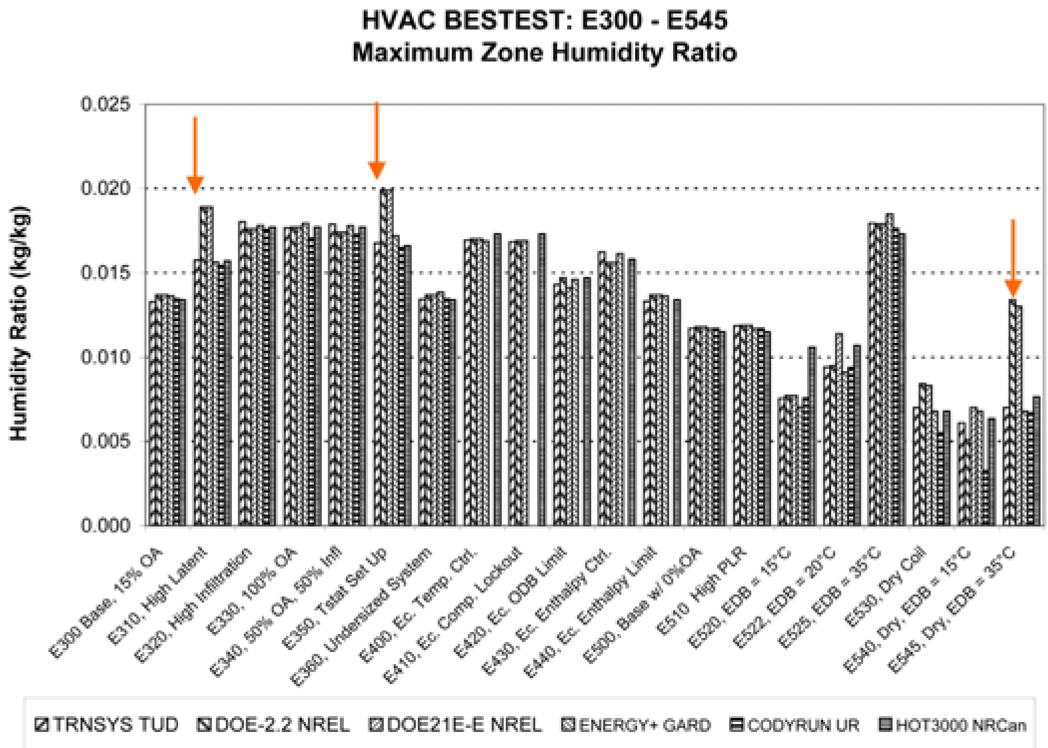

Figure 2F-3. DOE-2.2 NT41n, peak-hour humidity ratio disagreements for cases E310, E350, and E545

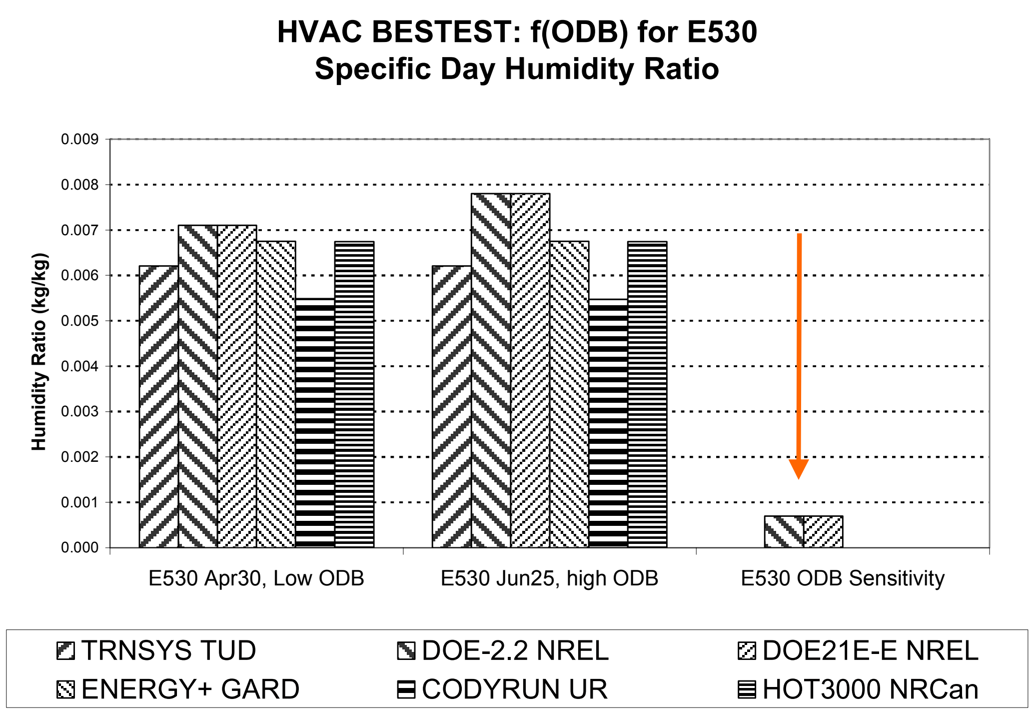

Figure 2F-4. DOE-2.2 NT41n, Is DOE-2 "inhaling" moisture in dry-coil Case E530?

One of the code authors responded by first addressing the problem in Case E330 (see Figures 2F-1 and 2F-2), which has 100% outside air and no infiltration. His response is included below (Hirsch 2003c):

> "The problem was a single hour anomaly where the total and particularly the latent cooling removal for the unit was way over the unit actual capacity. This happened in the hour (using 100% OA in New Orleans LA) when the OA fraction was changed to 100% at the same time a latent and sensible load appeared in the space. This hour highlighted a incorrect line of logic in the code … where for the case of fans being on in the previous hour the wet-bulb temperature used in the first iteration (really the first estimation as DOE-2 does not do 'true' iterations) for the estimation of unit capacity and supply temperature incorrectly used the previous hour[']s unit entering wet-bulb with no correction for the current hour[']s conditions. At this point of the code it had correctly updated the estimated dry-bulb entering condition but skipped around the entering wet-bulb correction only if the fans were on the previous hour. I removed that skip to cause the unit entering wet-bulb to always be updated using current conditions. This problem would only have a bad effect in the case where both the internal and external conditions (load and wet-/dry-bulb) change abruptly during two consecutive hours when the unit fans were operating."

Correction of the coding error that caused the use of the previous hour EWB as the current hour EWB results in a 34% decrease in peak-hour latent coil load for Case E340. Cases E330 and E400 show a decrease in peak-hour latent coil load of 16% and 21%, respectively; for Case E300 the decrease is only 1%, and there is no effect on the E500 series cases (which have no outside air). The greatest effect on annual energy consumption is a 1.0% increase going from versions NT41n to NT42j that occurs for Case E330. Regarding the disagreements noted above, after this correction good agreement was achieved only for the peak latent coil load and maximum COP2 for Case E330. Figure 2F-5 indicates remaining latent coil load disagreements for cases E320 and E340 where infiltration is also occurring. Figure 2F-6 indicates remaining maximum COP2 disagreements for cases E320 and E340, as well as for many of the E500 series cases.

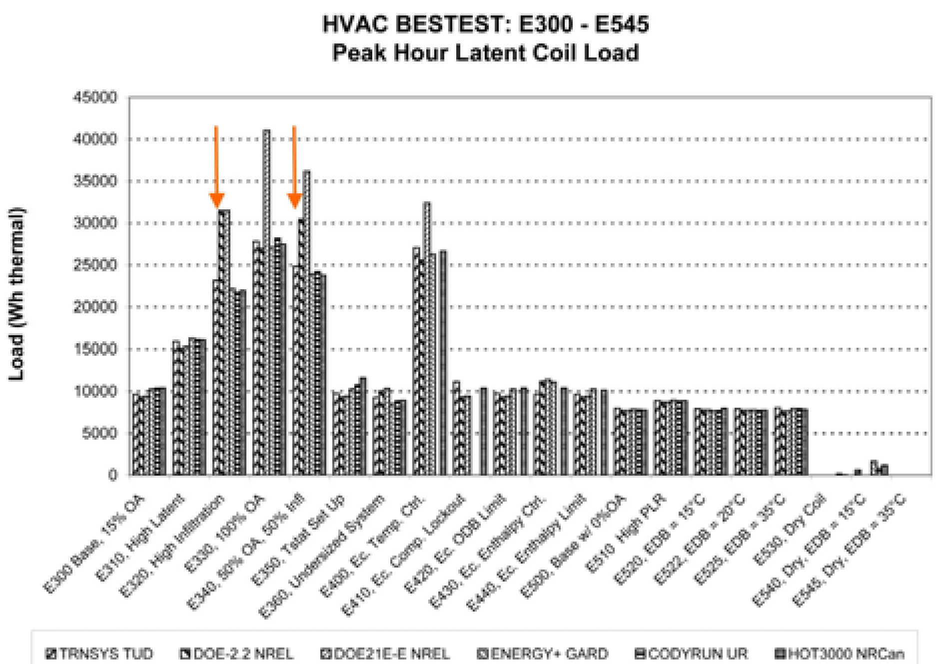

Figure 2F-5. DOE-2.2NT42j, peak-hour latent coil load disagreements: E320 and E340

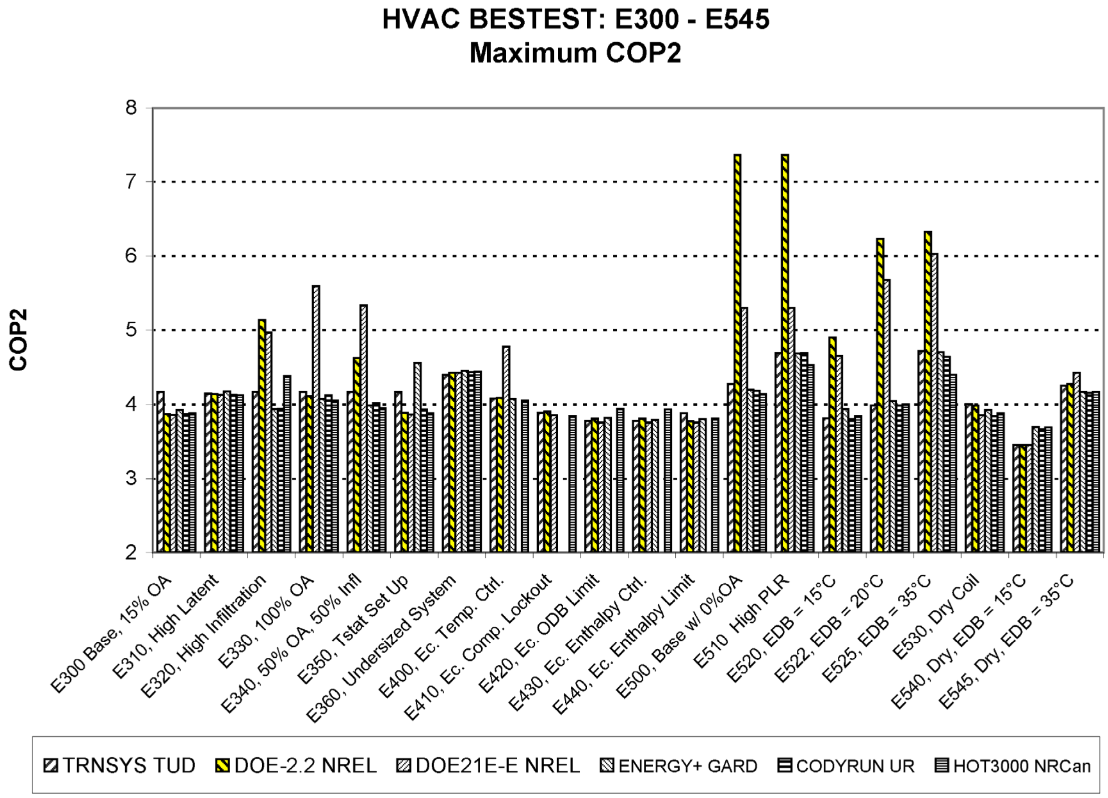

Figure 2F-6. DOE-2.2NT42j, maximum COP2 disagreements: E320, E340, and E500–E525

Remaining Disagreements Transmitted to Code Authors

Disagreements documented above for DOE-2.2 NT41n in Figures 2F-3 and 2F-4 remain in NT42j. The disagreements noted in Figures 2F-3 through 2F-6 were transmitted to the code authors (Neymark 2003a). Based on the current results sets, the code authors are planning to examine remaining disagreements and revise their software if necessary, but were not able to address the remaining disagreements in time for publication of this report.

6. Results

Unlike the analytical verification tests of cases E100–E200, cases E300–E545 do not have analytical solutions and therefore provide no mathematical truth standard for comparison of results. Therefore, simulation results are assumed to be in agreement with other simulation results unless a disagreement is obviously noticeable. In cases where the range of results is relatively wide with noticeable relative disagreement among all the results, the criteria for disagreement are looser. Additionally, where all results are reasonably agreeing, there is no certainty that a result in the center of a range of results is any better than a result that defines the extreme of a range of results.

In general DOE-2.2 exhibits a good level of agreement with the other programs for annual energy use, loads, and other annual average results. There are some notable disagreements for peak-hour results, however, as discussed above. A compilation of what appear to be disagreeing results based on Part III is included below.

Remaining disagreements:

- Peak-hour total coil load: E320, E340
- Peak-hour total coil load sensitivity: E320–E300, E330–E320, E340–E300, E330–E340
- Peak-hour latent coil load: E320, E340
- Peak-hour latent coil load sensitivity: E320–E300, E330–E320, E340–E300, E330–E340
- Maximum COP2: E320, E340; E500 through E525
- Maximum COP2 sensitivity: E330–E320, E340–E300, E330–E340, E500–E300, E510–E500, E530–E500
- Minimum COP2 sensitivity: E400–E300, E430–E300, E440–E300
- Minimum IDB: E320
- Maximum humidity ratio: E310, E350, E545
- Maximum humidity ratio sensitivity: E310–E300, E350–E300
- Maximum relative humidity: E310, E350
- Maximum relative humidity sensitivity: E310–E300
- Humidity ratio f(ODB): E530.

7. Other

There is some disagreement regarding hourly latent coil load for Case E300, June 28 hours 7, 8, 11, 13 (see Figure 2F-7 [Neymark 2003b]). This is related to differences in handling of weather data in DOE-2 versus the other programs as shown in Figure 2F-8. Here DOE-2 is applying original raw weather data values for the entire hour, while other programs appear to be performing some type of averaging. Justification for interpreting weather data differently is given in Section 1.3.1.1 of Part I.

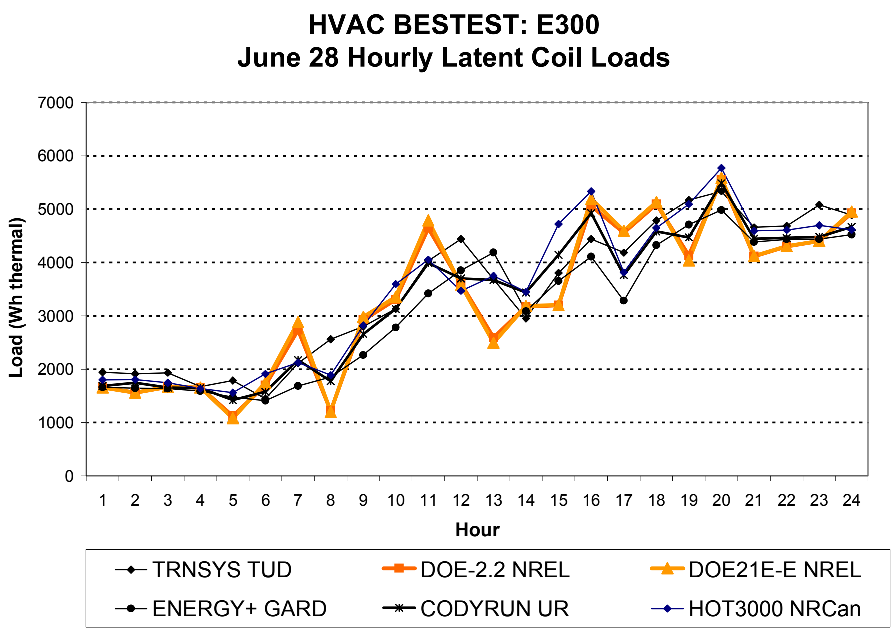

Figure 2F-7. DOE-2 latent coil load disagreements for hours 7, 8, 11, and 13

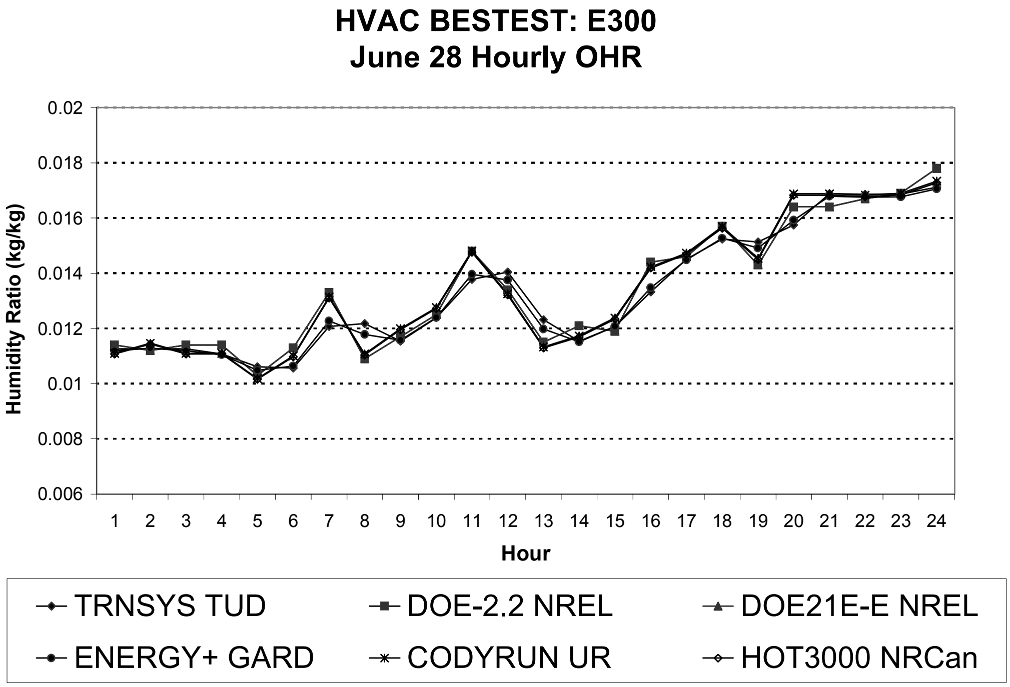

Figure 2F-8. June 28 outdoor humidity ratio, all simulations

8. Conclusions and Recommendations

Regarding the DOE-2.2 Results

Working with DOE-2.1E and DOE-2.2 during the development of HVAC BESTEST Volume 2, cases E300–E545, allowed additional examination of the DOE-2 results and identified the following fixed bug.

- Correction of the coding error that caused the use of the previous hour EWB as the current hour EWB (34%, 16%, and 21% decreases in peak-hour latent coil load for cases E330, E340, and E400, respectively; 1.4% increase in annual energy consumption for E340.)

For DOE-2.2 the annual summed or averaged results for system performance and zone conditions appear satisfactory when compared with other programs. Disagreements relating to specific maximum-hour values that were transmitted to the code authors were described in Section 5 of this modeler report and cover:

- Maximum-hour latent coil loads for high zone-air infiltration rates (E320, E340)
- Maximum-hour COP2 calculations when there are no outside air and no infiltration (E500 series wet-coil cases [E500 through E525])
- Maximum-hour zone humidity ratio calculation for cases with very high latent loads (E310), thermostat set up (E350), and dry coil with high EDB (E545).

Based on the current results sets, the code authors are planning to examine remaining disagreements and revise their software if necessary, but were not able to address the remaining disagreements in time for publication of this report.

Regarding HVAC BESTEST

After improvements to earlier versions of DOE-2.1E documented in Volume 1, the James J. Hirsch & Associates version of DOE-2.1E (version 133) showed good agreement for the Volume 1 steady-state cases E100–E200; this was before DOE-2.2 (which evolved from DOE-2.1E) was applied to the Volume 2 cases that have more realistic dynamics and also apply additional mechanical equipment features. For the Volume 2 test cases, fixing of a bug and discovery of further disagreements for DOE-2.2 after testing of DOE-2.1E with Volume 1 indicates the importance of also having tested the programs over a wider range of varying conditions and applying additional mechanical features in the test cases.

9. References

DOE-2 Reference Manual (Version 2.1A) Part 1. (May 1981). D. York, C. Cappiello, eds. Berkeley, California, US: Lawrence Berkeley Laboratory.

DOE-2 Engineer's Manual (Version 2.1A). (November 1982). D. York, C. Cappiello, eds. Berkeley, California, US: Lawrence Berkeley Laboratory.

DOE-2.2 Building Energy Use and Cost Analysis Program, Volume 4: Libraries and Reports. (March 2002). Camarillo, California, US: James J. Hirsch & Associates.

JJHirsch DOE-2.1E Documentation ERRATA and ADDITIONS. Part III: ADDITIONS to the JJ Hirsch DOE-2.1E Program. (January 1996). Included with DOE-2.1E as "C:\DOE21E\DOC\21EDOC.DOC." Camarillo, California, US: James J. Hirsch & Associates.

Hirsch, J. (2003a). E-mail communications, May 21–22, 2003. Camarillo, California, US: James J. Hirsch & Associates.

Hirsch, J. (2003b). Personal telephone communication, June 2003. Camarillo, California, US: James J. Hirsch & Associates.

Hirsch, J. (2003c). E-mail communication, 14 November 2003. Camarillo, California, US: James J. Hirsch & Associates.

Neymark, J. (2003a). E-mail communications with J. Hirsch, November 17, 2003. J. Neymark & Associates, Golden, Colorado, US. Results shown in Figures 2F-1 through 2F-4 are from spreadsheet *E300results111203.xls* (HVAC BESTEST Vol. 2 results summary, November 12, 2003). Results shown in Figures 2F-5 through 2F-6 are from spreadsheet: *E300results111703.xls* (HVAC BESTEST Vol. 2 results summary, November 17, 2003).

Neymark, J. (2003b). *E300results111703.xls*. (HVAC BESTEST Vol. 2 results summary, November 2003.)

Neymark, J.; Judkoff, R. (2002). *International Energy Agency Building Energy Simulation Test and Diagnostic Method for Mechanical Equipment (HVAC BESTEST), Volume 1: Cases E100–E200.* NREL/TP-550-30152. Golden, Colorado, US: National Renewable Energy Laboratory.

Program name (please include version number)

DOE-2.2 version NT42j

Your name, organisation, and country

Joel Neymark, National Renewable Energy Laboratory/J. Neymark & Associates, United States

In tables below:

x = *method used*

a = *method available, but not used*

Program status

	Public domain
x	Commercial: *obtained from James J. Hirsch & Associates, Camarillo, Callifornia, US.*
	Research
	Other (please specify)

Solution method for unitary space cooling equipment

x	Overall Performance Maps
	Individual Component Models
	Constant Performance (no possible variation with entering or ambient conditions)
	Other (please specify)

Interaction between loads and systems calculations

	Both are calculated during the same time step
x	First, loads are calculated for the entire simulation period, then equipment performance is calculated separately
	Other (please specify)

Time step

x	Fixed within code (please specify time step): *one hour*
	User-specified (please specify time step)
	Other (please specify)

Timing convention for meteorological data: sampling interval

x	Fixed within code (please specify interval): *one hour*
	User-specified

Timing convention for meteorological data: period covered by first record

x	Fixed within code (please specify period or time which meteorological record covers): *0:00 - 1:00*
	User-specified

Meteorological data reconstitution scheme

x	Climate assumed stepwise constant over sampling interval
	Linear interpolation used over climate sampling interval
	Other (please specify)

Output timing conventions

	Produces spot predictions at the end of each time step
	Produces spot output at end of each hour
x	Produces average outputs for each hour (please specify period to which value relates): *same as time step*

Treatment of zone air

x	Single temperature (i.e., good mixing assumed)
	Stratified model
	Simplified distribution model
	Full CFD model
	Other (please specify)

Zone air initial conditions

x	Same as outside air
	Other (please specify)

Internal gains output characteristics

	Purely convective
	Radiative/Convective split fixed within code
x	Radiative/Convective split specified by user
	Detailed modeling of source output

Mechanical systems output characteristics

x	Purely convective
	Radiative/Convective split fixed within code
	Radiative/Convective split specified by user
	Detailed modeling of source output

Control temperature

x	Air temperature
	Combination of air and radiant temperatures fixed within the code
	User-specified combination of air and radiant temperatures
	User-specified construction surface temperatures
	User-specified temperatures within construction
	Other (please specify)

Control properties

	Ideal control as specified in the user's manual
	On/Off thermostat control
	On/Off thermostat control with hysteresis
	On/Off thermostat control with minimum equipment on and/or off durations
x	Proportional control: *a throttling range setting of 0.1°F was input along with a "TWO-POSITION" thermostat type*
	More comprehensive controls (please specify)

Performance Map: characteristics

a	Default curves
x	Custom curve fitting
	Detailed mapping not available
	Other (please specify)

Performance Map: independent variables

x	Entering Dry-bulb Temperature: *The effect of EDB is "hard-wired" in DOE-2, and only affects sensible capacity.*
x	Entering Wet-bulb Temperature
x	Outdoor Dry-bulb Temperature
x	Part-Load Ratio
a	Indoor Fan Airflow Rate: *did not use; fan airflow was always at rated conditions when the fan was operating*
	Other (please specify)

Performance Map: dependent variables

x	Coefficient of Performance (or other ratio of load to electricity consumption)
x	Total Capacity
x	Sensible Capacity
x	Bypass Factor
	Other (please specify)

Performance Map: available curve fit techniques

x	Linear, f(one independent variable): *COIL-BF-FPLR using default linear curve*
a	Quadratic, f(one independent variable)
x	Cubic, f(one independent variable): *CLOSS-FPLR*
x	Bi-Linear, f(two independent variables): *COIL-BF-FT input as constant (multiplier always = 1)*
x	Bi-Quadratic, f(two independent variables): *SCAP-FT, CAP-FT, BF-FT, EIR-FT*
x	Other (please specify)

Performance Map: extrapolation limits

x	Limits independent variables: *ODB (input setting = 50°F); EWBmin = ODBmin - 10*
a	Limits dependent variables: *available for all curves*
x	No extrapolation limits: *available dependent variable limits were not applied*
	Extrapolation not allowed
	Other (please specify)

Cooling coil and supply air conditions model

	Supply air temperature = apparatus dew point (ADP); supply air humidity ratio = humidity ratio of saturated air at ADP
a	Bypass factor model using listed ADP data
x	Bypass factor model with ADP calculated from extending condition line
x	Fan heat included
	More comprehensive model (please specify)

Disaggregation of fans' electricity use directly in the simulation and output

a	Indoor fan only
a	Outdoor fan only
x	Both indoor and outdoor fans disaggregated in the output
a	None - disaggregation of fan outputs with separate calculations by the user

Economizer settings available (for E400 series)

x	Temperature
x	Enthalpy
x	Compressor Lockout
	Other (please specify)

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3.0 Part III: Simulation Field Trial Results

Here we present the simulation results for the field trials of cases E300–E545. These are results after numerous iterations to incorporate clarifications to the test specification, simulation input deck corrections, and simulation software improvements. Where improvements to simulation programs or simulation inputs were made as a result of running the tests, such improvements must have mathematical and physical bases and must be applied consistently across tests. Also, all improvements were required to be documented in modeler reports. Arbitrary modification of a simulation program's input or internal code just for the purpose of more closely matching a given set of results is not allowed. The diagnostic process of trapping bugs discussed in Section 2.4 of Part II also isolated input errors that were corrected, as noted there and in the modeler reports (Part II, Section 2.9).

An electronic version of these results is included on the accompanying CD in the file E300RESULTS.XLS, with its navigation instructions included in E300RESULTS.DOC. This section presents graphs of the results first, followed by tables of the results.

We have attempted to give a brief description of the cases in the x-axis labels of the accompanying graphs. See Section 2.7 of Part II for definitions of the abbreviations and acronyms. Case descriptions are summarized in Table 1-1 in Part I. The results tables include dates and hours of occurrences for hourly maxima and minima; times of occurrence are not indicated in the graphs depicting hourly maxima and minima.

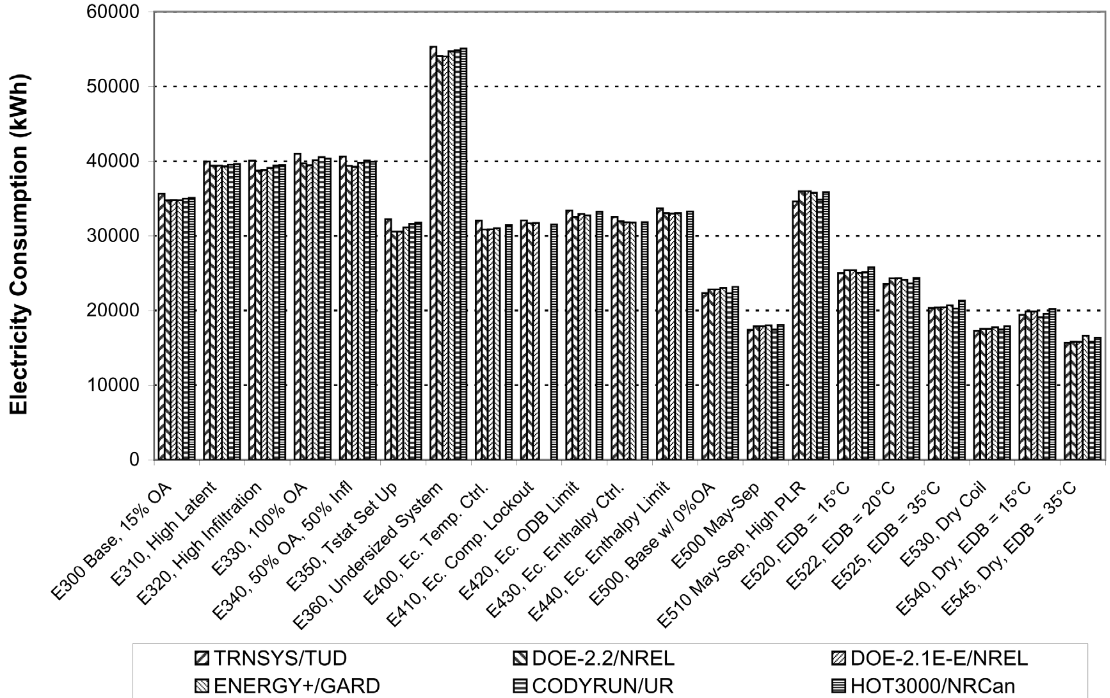
Table 3-1 summarizes the following information for the six models that were implemented by the five organizations that participated in this project: model-authoring organization, model testing organization ("Implemented by"), and abbreviation labels used in the results graphs and tables.

Table 3-1. Participating Organizations and Computer Programs

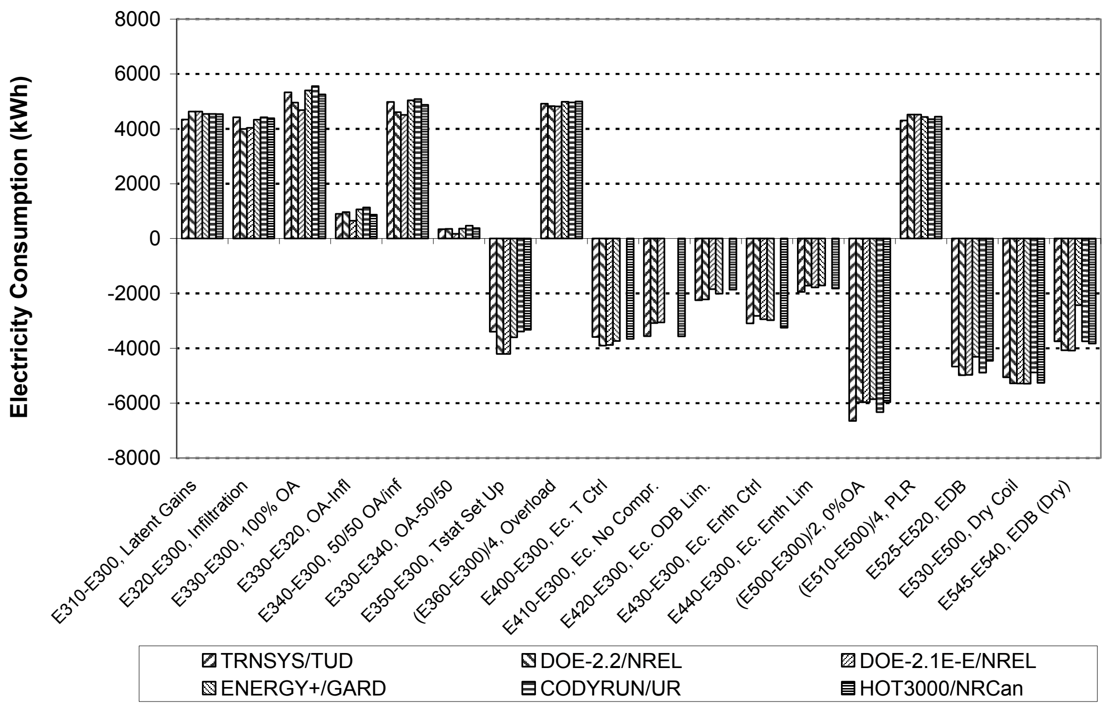
Simulation Program	Authoring Organization	Implemented by	Abbreviation
CODYRUN/LGIMAT	Université de la Reunion Island, France	Université de la Reunion Island, France	CODYRUN/UR
DOE-2.1E-ESTSC version	LANL/LBNL/ESTSC/JJH,[a,b,c,d] United States	NREL/JNA,[e] United States	DOE-2.1E-E/NREL DOE21E-E
DOE-2.2 NT	LBNL/JJH,[b,d] United States	NREL/JNA,[e] United States	DOE-2.2/NREL
ENERGYPLUS	LBNL/UIUC/CERL/OSU/GARD Analytics/FSEC/DOE-BT,[b,f,g,h,i,j] United States	GARD Analytics, United States	ENERGY+/GARD
HOT3000	CETC/ESRU,[k,l] Canada/United Kingdom	CETC,[k] Canada	HOT3000/NRCan
TRNSYS 14.2-TUD with real controller model	University of Wisconsin, United States; Technische Universität Dresden, Germany	Technische Universität Dresden, Germany	TRNSYS-TUD/TUD

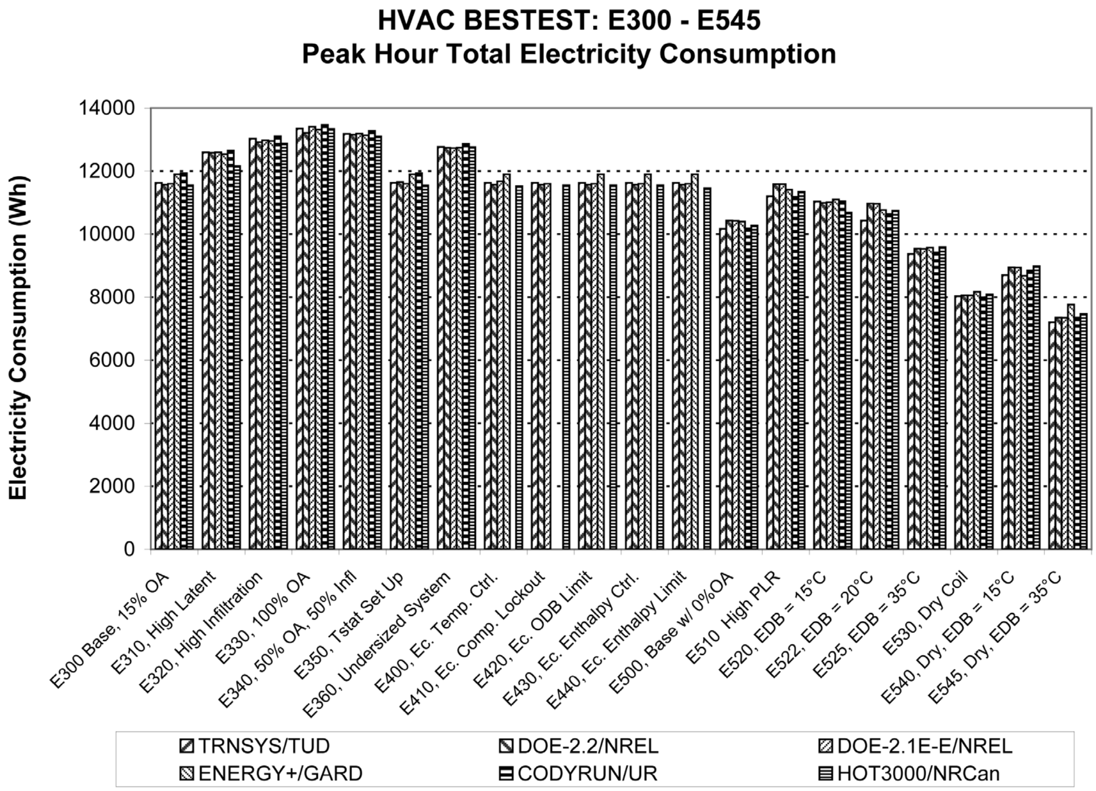
[a]LANL: Los Alamos National Laboratory, United States
[b]LBNL: Lawrence Berkeley National Laboratory, United States
[c]ESTSC: Energy Science and Technology Software Center (at Oak Ridge National Laboratory, United States)
[d]JJH: James J. Hirsch & Associates, United States
[e]NREL/JNA: National Renewable Energy Laboratory/J. Neymark & Associates, United Sates
[f]UIUC: University of Illinois Urbana/Champaign, United States
[g]CERL: U.S. Army Corps of Engineers, Construction Engineering Research Laboratories, United States
[h]OSU: Oklahoma State University, United States
[i]FSEC: University of Central Florida, Florida Solar Energy Center, United States
[j]DOE-BT: U.S. Department of Energy, Office of Building Technologies, Energy Efficiency and Renewable Energy, United States
[k]CETC: CANMET Energy Technology Centre, Natural Resources Canada, Canada
[l]ESRU: Energy Systems Research Unit, University of Strathclyde, Scotland, United Kingdom

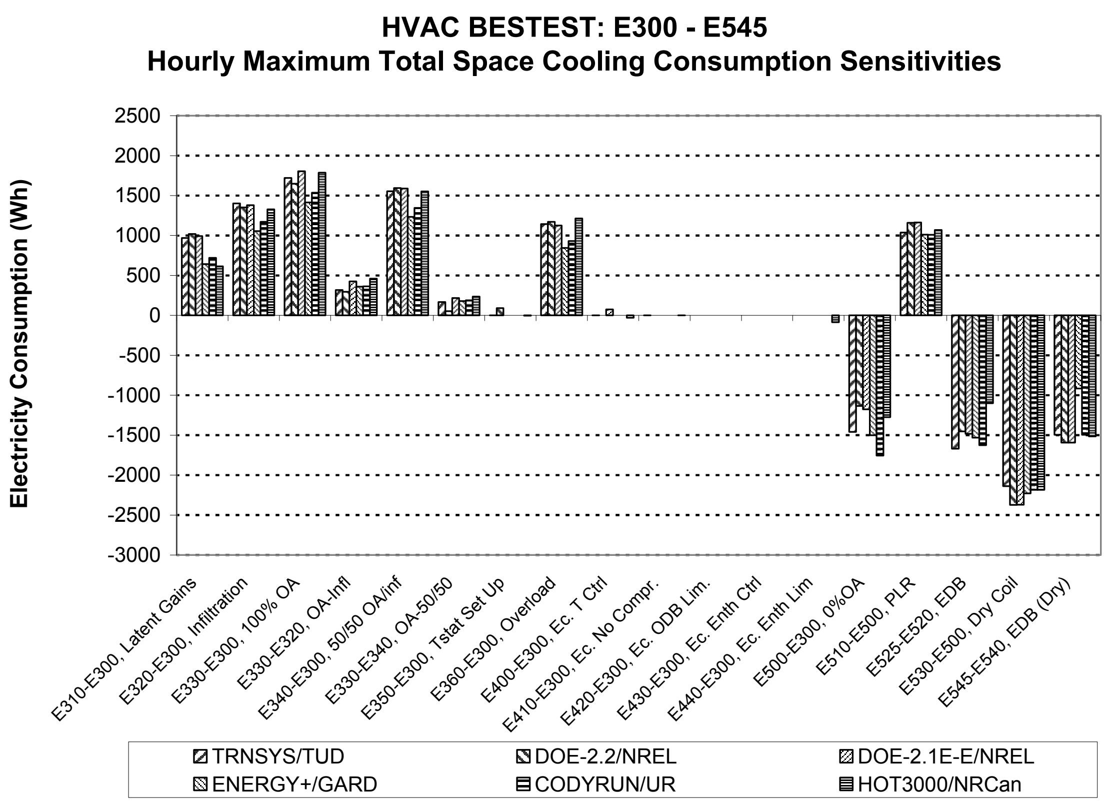
HVAC BESTEST: E300 - E545
Total Electricity Consumption

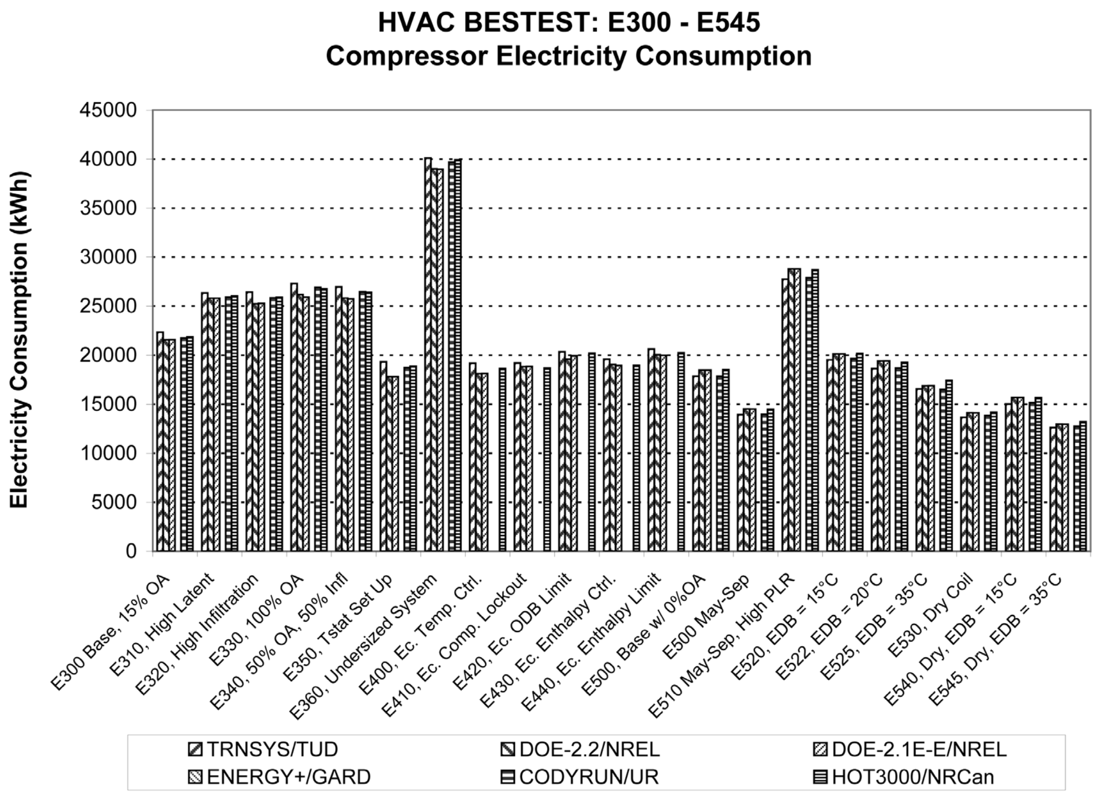


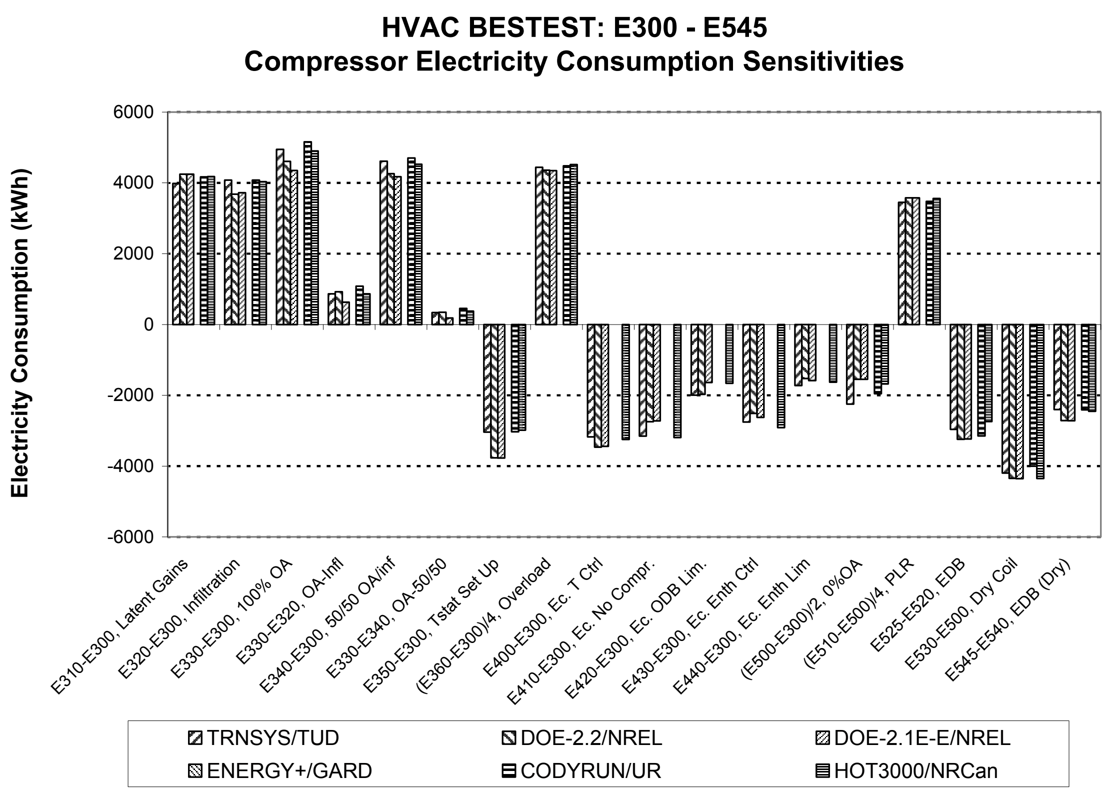
HVAC BESTEST: E300 - E545
Total Space Cooling Electricity Consumption Sensitivities

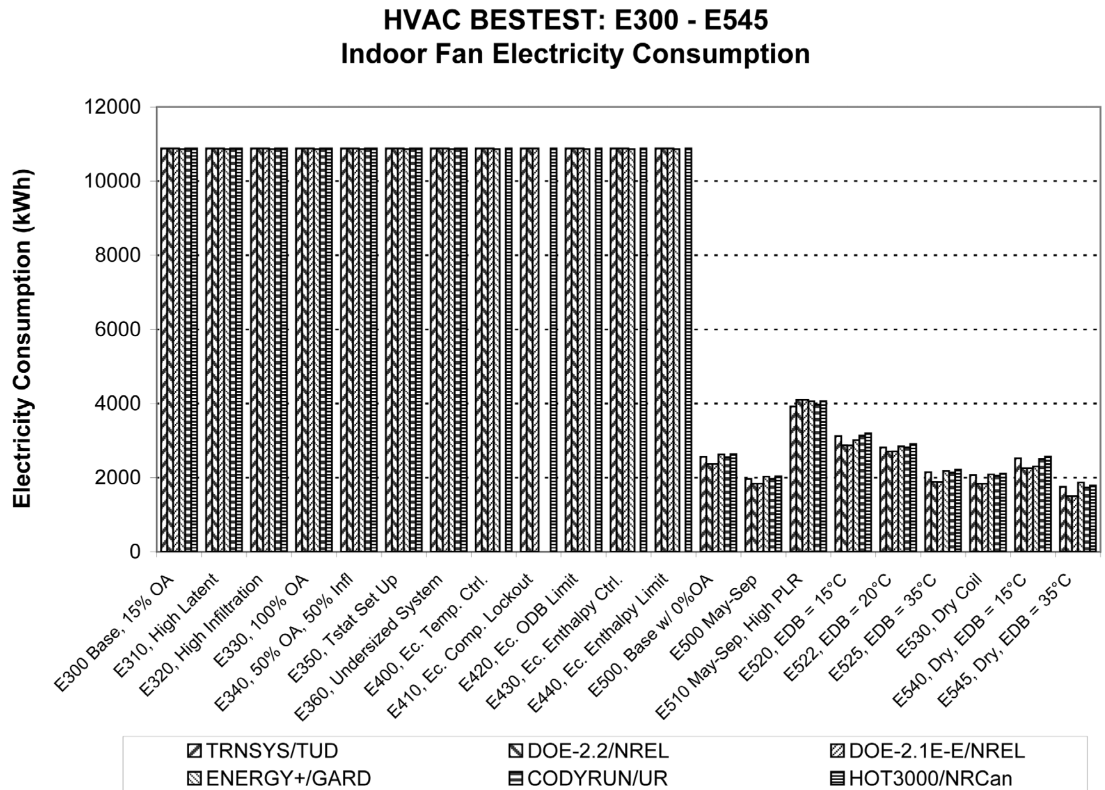


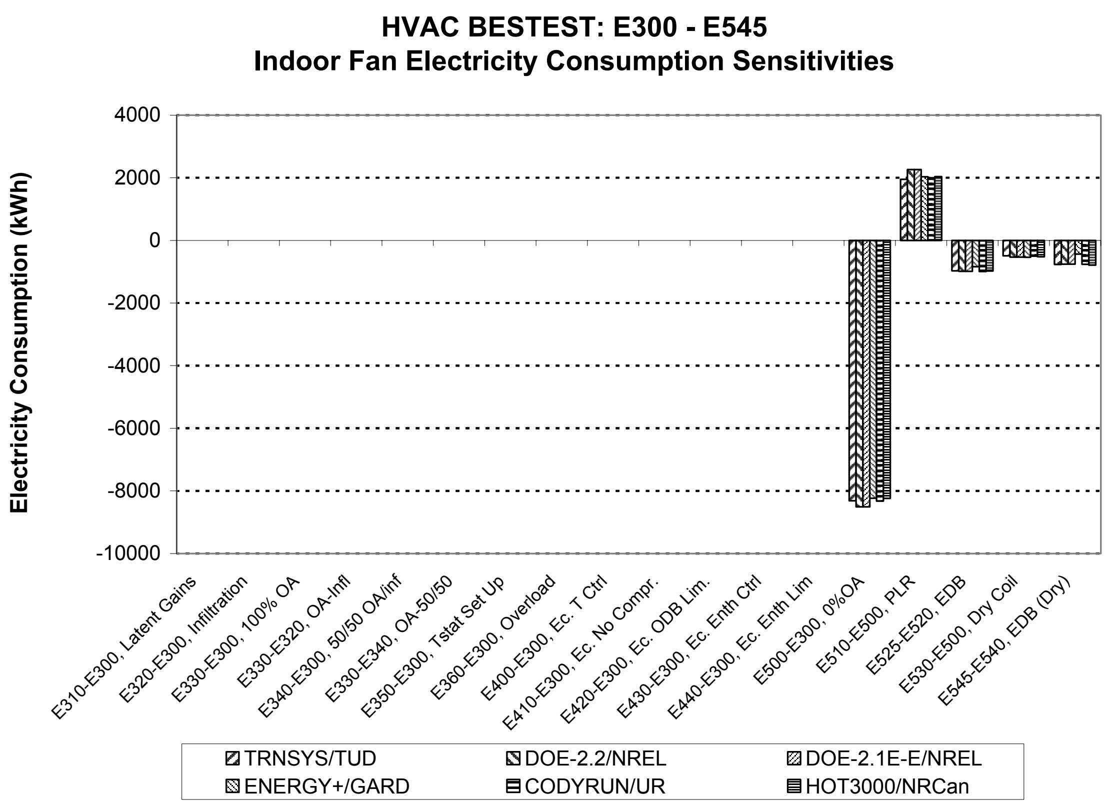

HVAC BESTEST: E300 - E545
Peak Hour Total Electricity Consumption
Electricity Consumption (Wh)
14000
12000
10000
8000
6000
4000
2000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

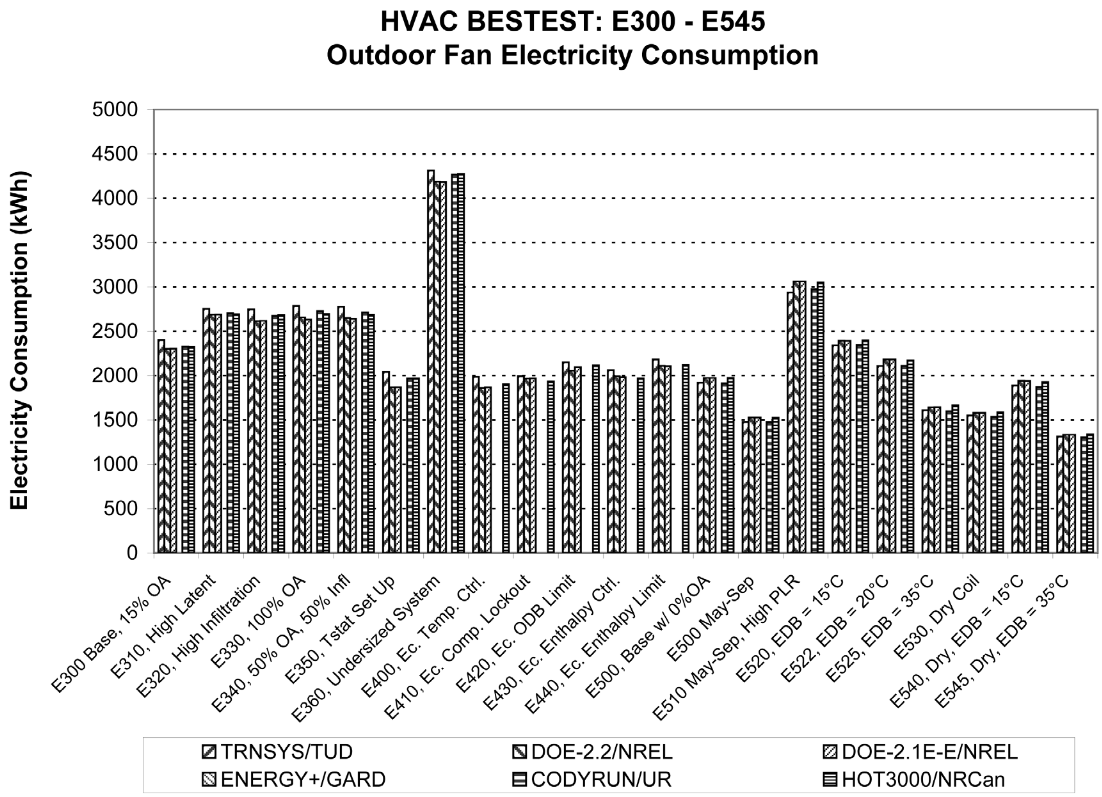

HVAC BESTEST: E300 - E545
Hourly Maximum Total Space Cooling Consumption Sensitivities
Electricity Consumption (Wh)
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

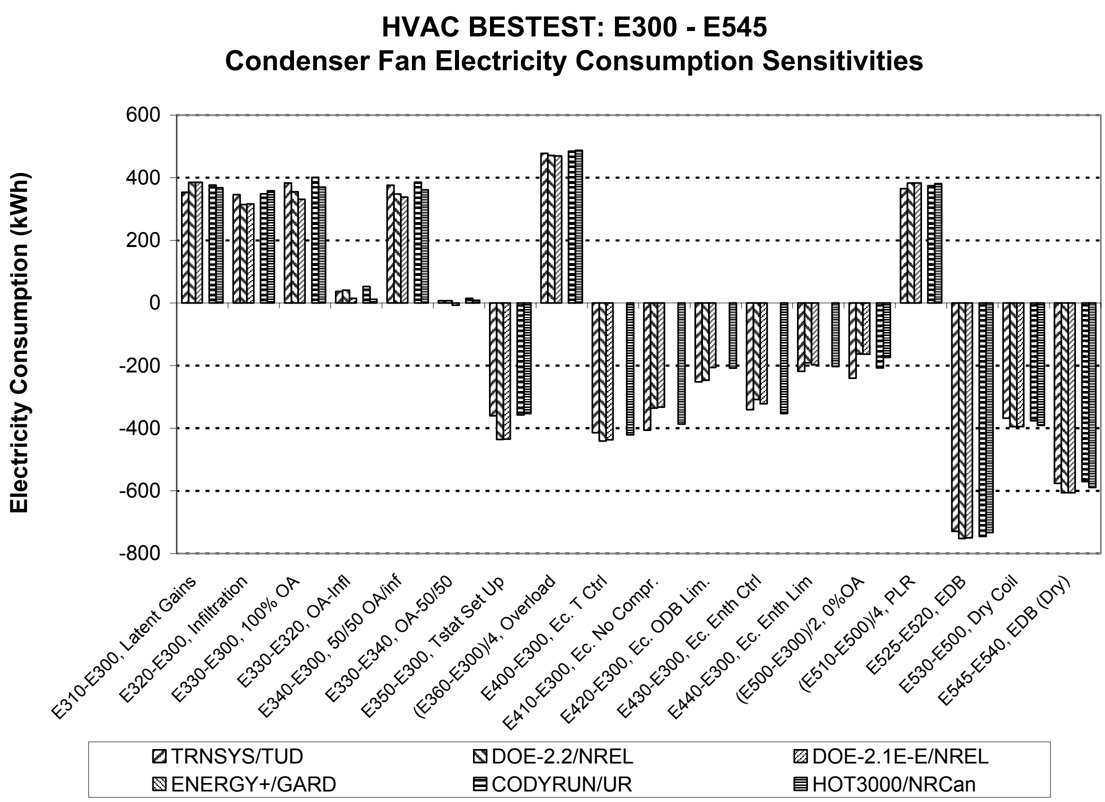

HVAC BESTEST: E300 - E545
Compressor Electricity Consumption
Electricity Consumption (kWh)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

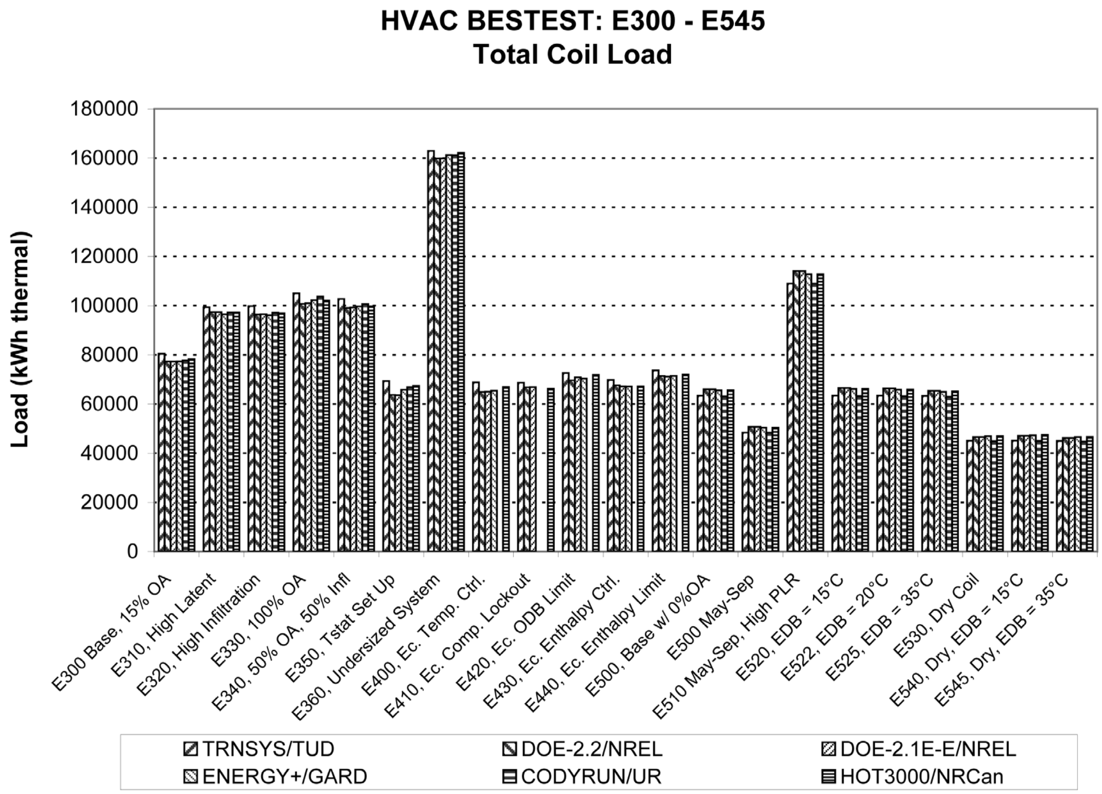

HVAC BESTEST: E300 - E545
Compressor Electricity Consumption Sensitivities
Electricity Consumption (kWh)
6000
4000
2000
0
-2000
-4000
-6000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
(E360-E300)/4, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
(E500-E300)/2, 0%OA
(E510-E500)/4, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

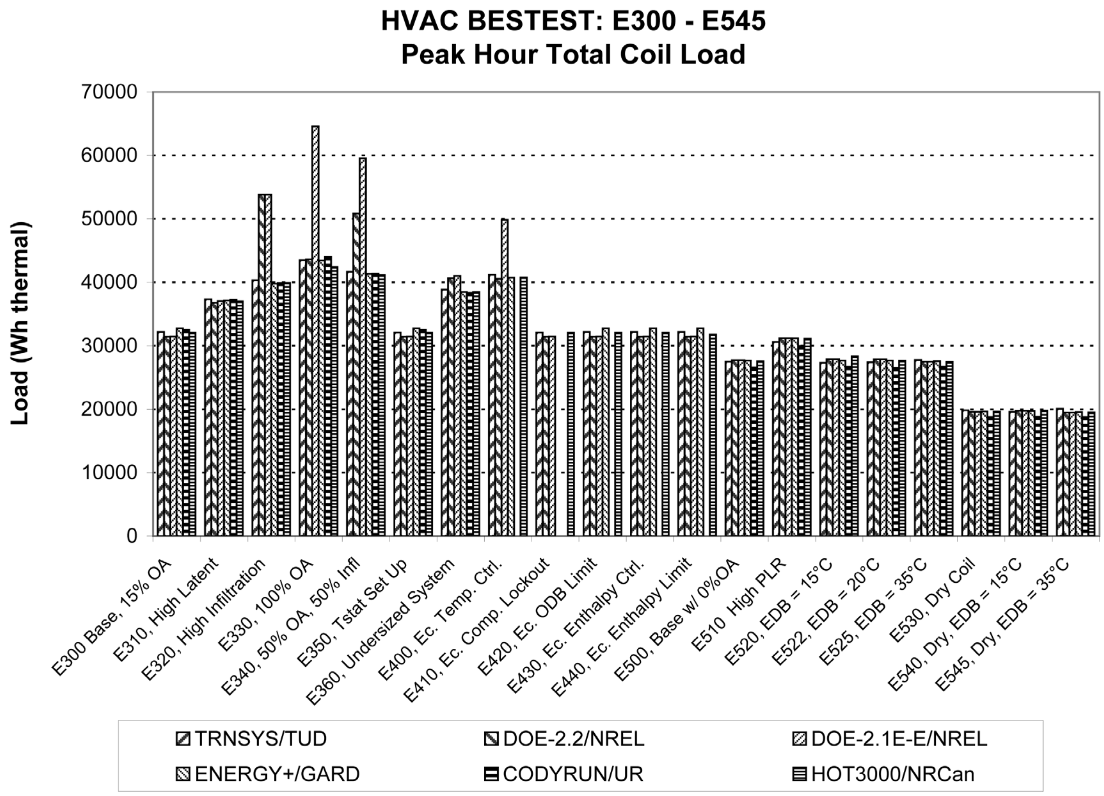

HVAC BESTEST: E300 - E545
Indoor Fan Electricity Consumption
Electricity Consumption (kWh)
0
2000
4000
6000
8000
10000
12000
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

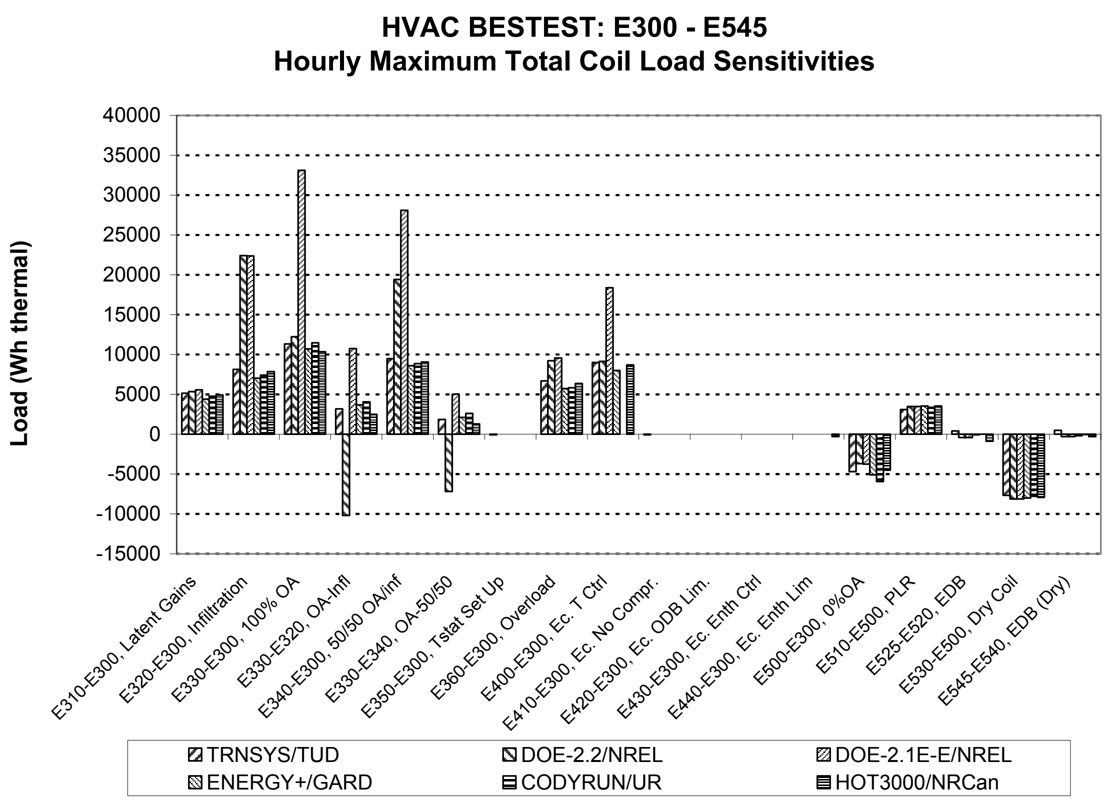

HVAC BESTEST: E300 - E545
Indoor Fan Electricity Consumption Sensitivities
Electricity Consumption (kWh)
4000
2000
0
-2000
-4000
-6000
-8000
-10000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

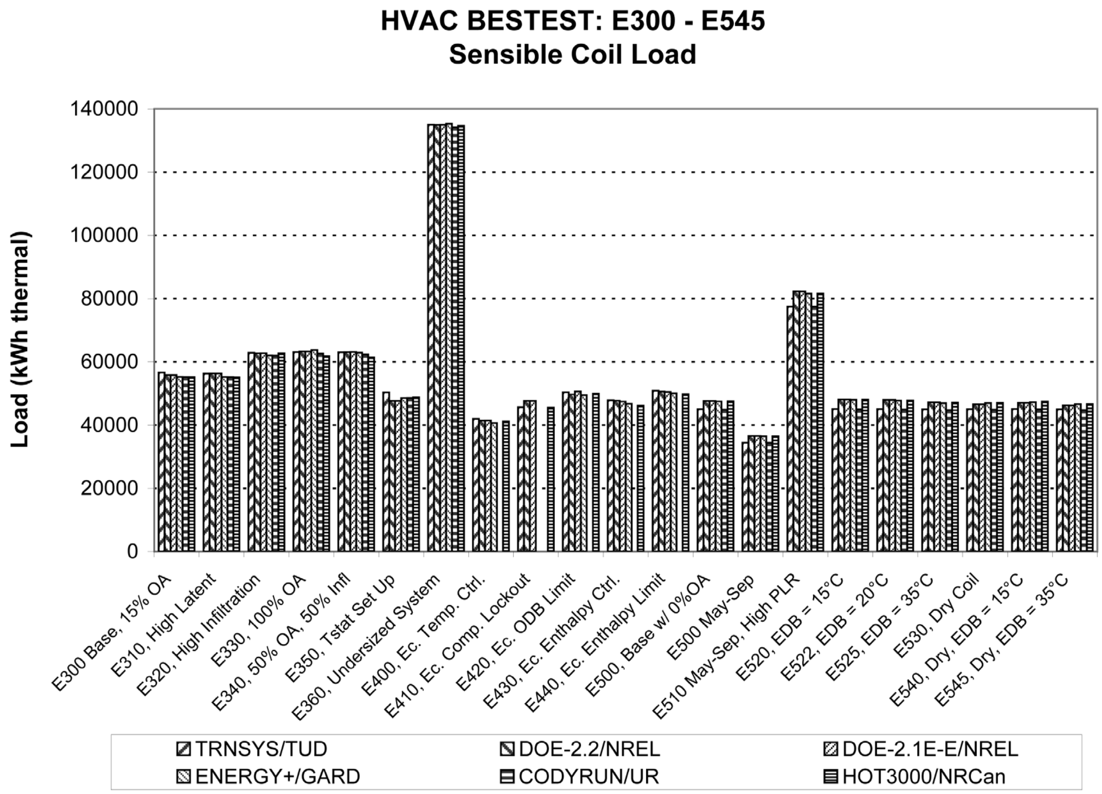

HVAC BESTEST: E300 - E545
Outdoor Fan Electricity Consumption
Electricity Consumption (kWh)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

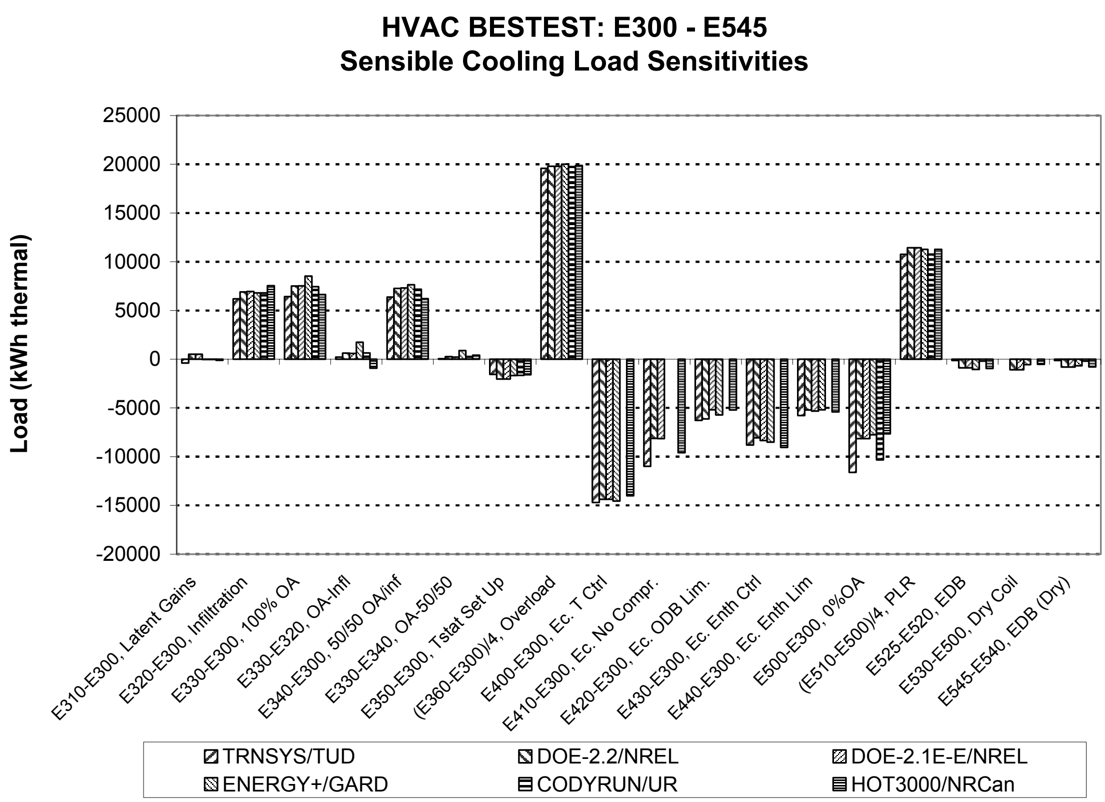

HVAC BESTEST: E300 - E545
Condenser Fan Electricity Consumption Sensitivities
Electricity Consumption (kWh)
600
400
200
0
-200
-400
-600
-800
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
(E360-E300)/4, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
(E500-E300)/2, 0%OA
(E510-E500)/4, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

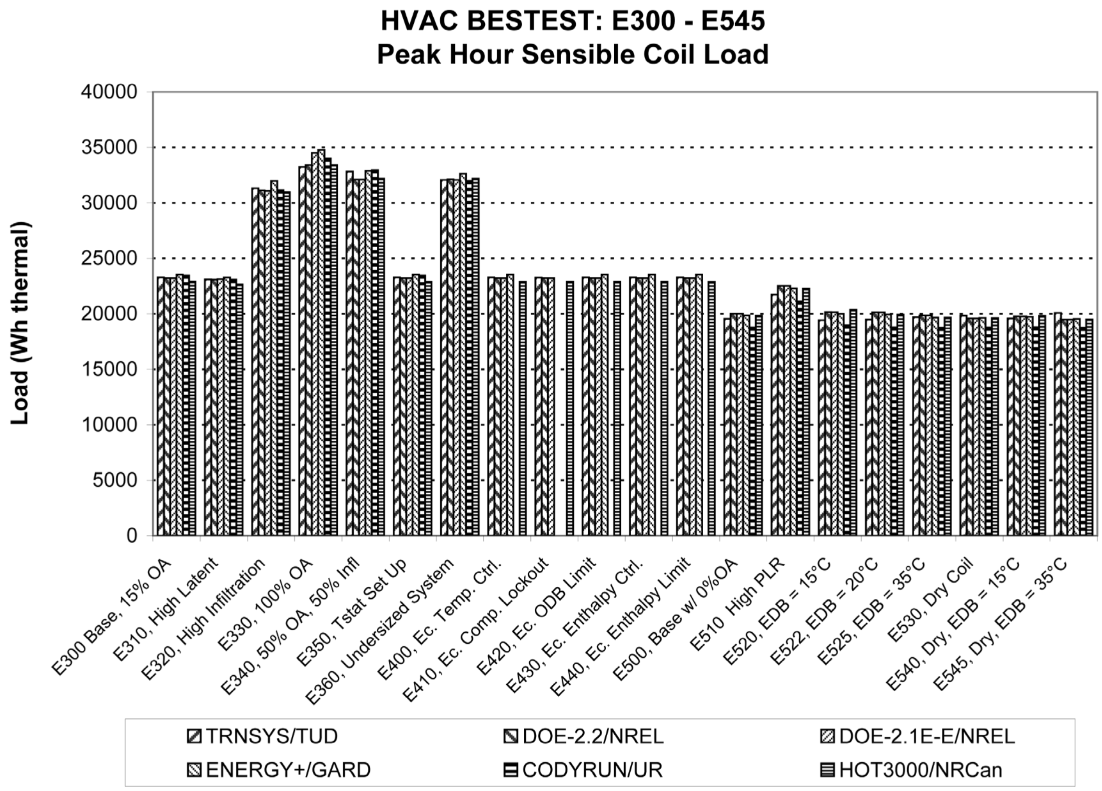

HVAC BESTEST: E300 - E545
Total Coil Load
Load (kWh thermal)
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300 - E545
Peak Hour Total Coil Load
Load (Wh thermal)
70000
60000
50000
40000
30000
20000
10000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

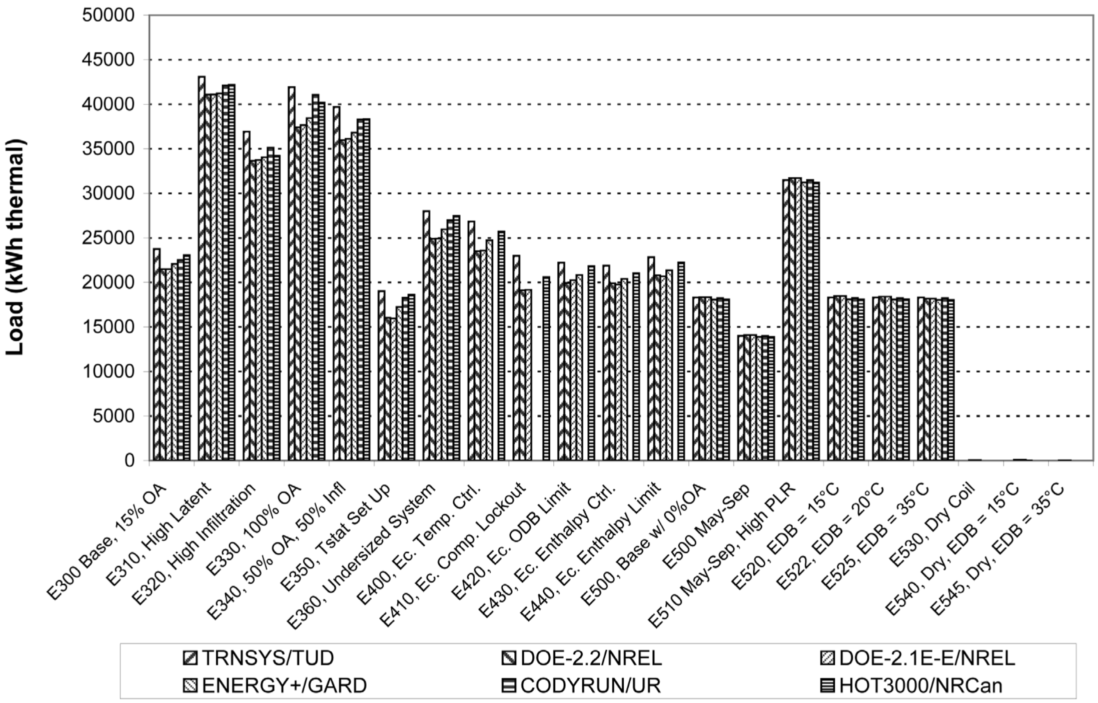

HVAC BESTEST: E300 - E545
Hourly Maximum Total Coil Load Sensitivities
Load (Wh thermal)
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
-10000
-15000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300 - E545
Sensible Coil Load
Load (kWh thermal)
140000
120000
100000
80000
60000
40000
20000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

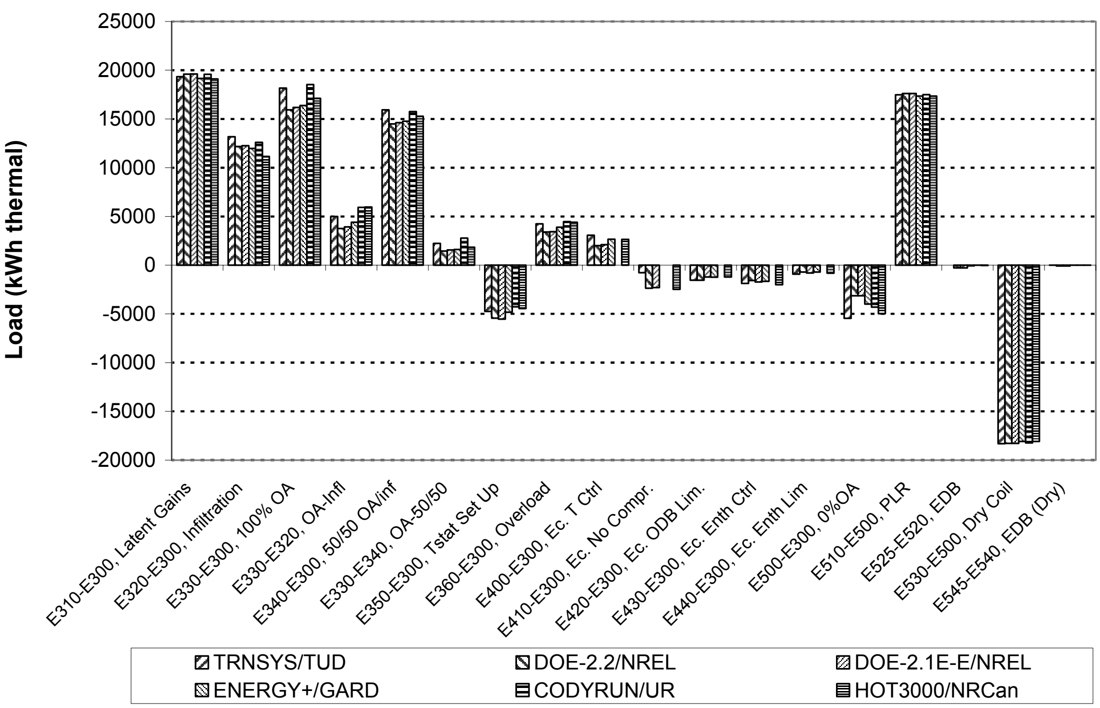

HVAC BESTEST: E300 - E545
Sensible Cooling Load Sensitivities
Load (kWh thermal)
25000
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
(E360-E300)/4, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
(E510-E500)/4, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

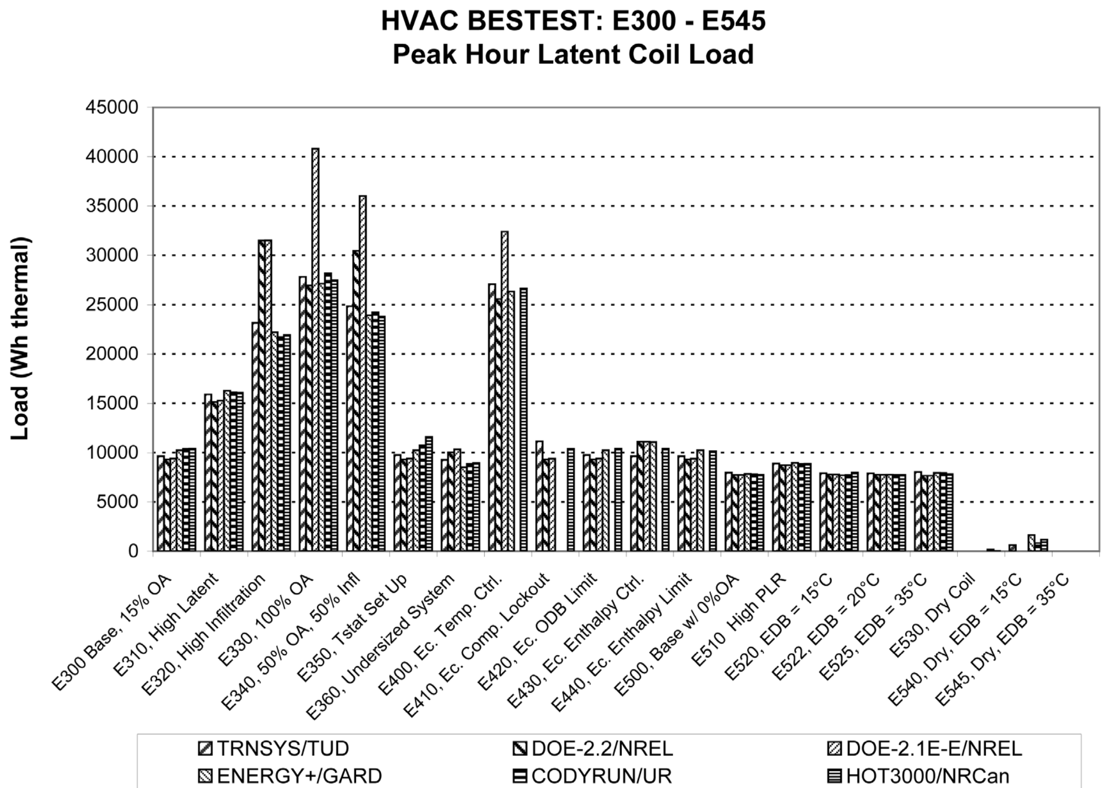

HVAC BESTEST: E300 - E545
Peak Hour Sensible Coil Load
Load (Wh thermal)
40000
35000
30000
25000
20000
15000
10000
5000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

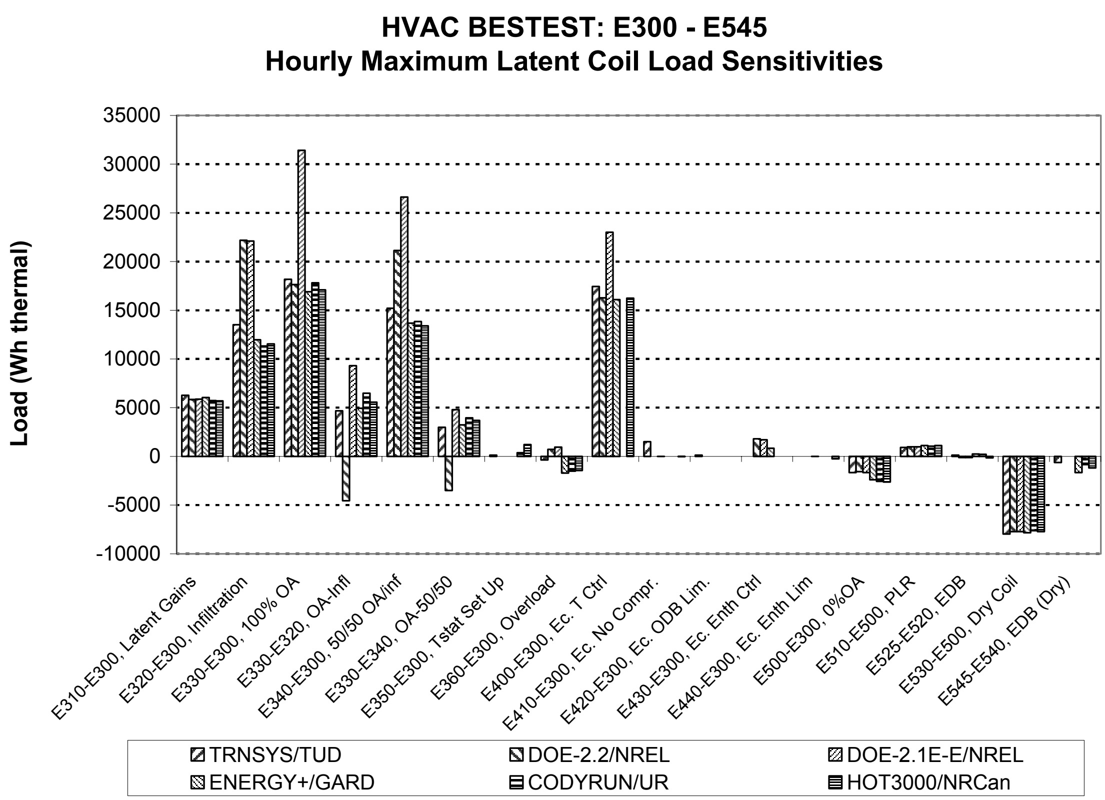
HVAC BESTEST: E300 - E545
Latent Coil Load



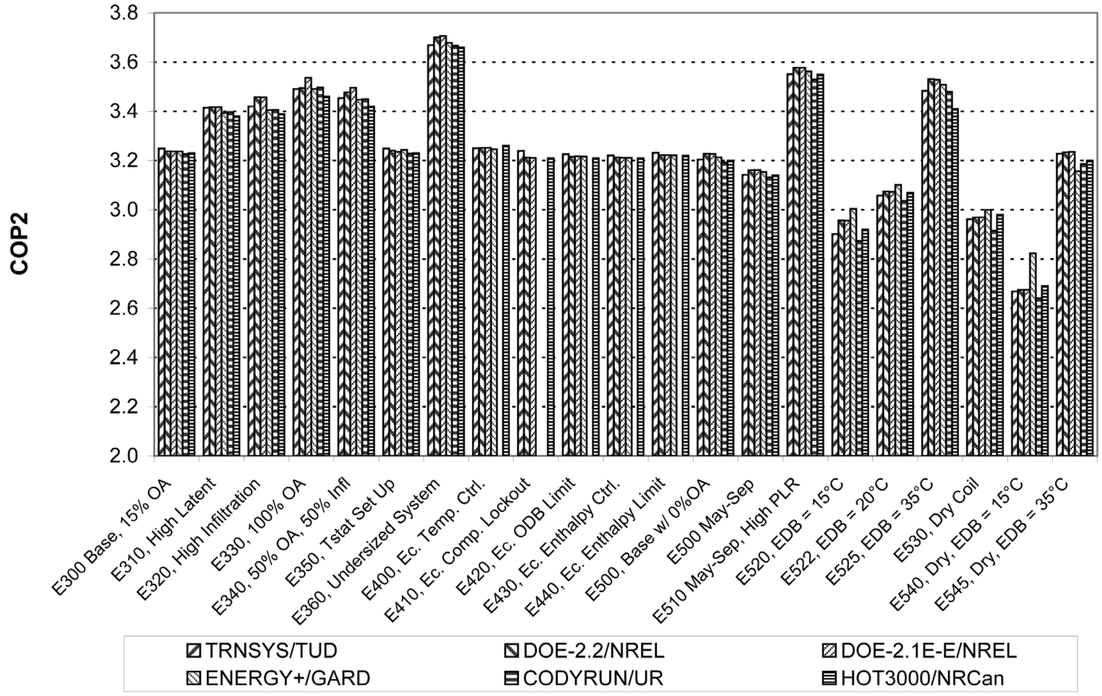
HVAC BESTEST: E300 - E545
Latent Cooling Load Sensitivities



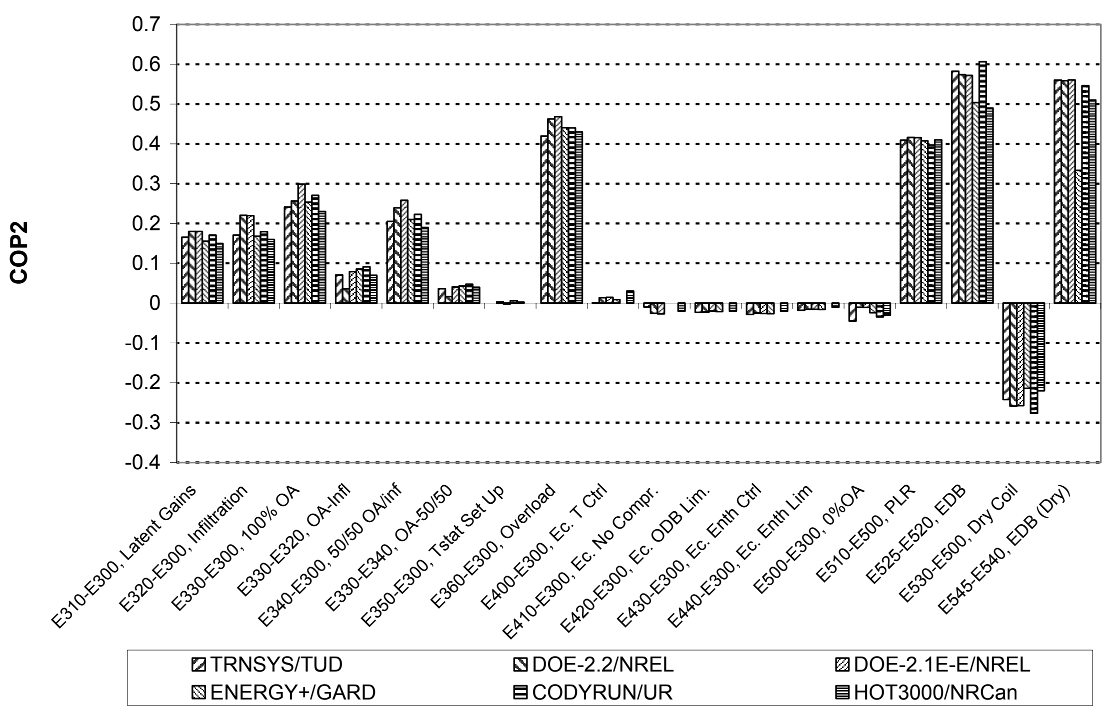

HVAC BESTEST: E300 - E545
Peak Hour Latent Coil Load
Load (Wh thermal)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

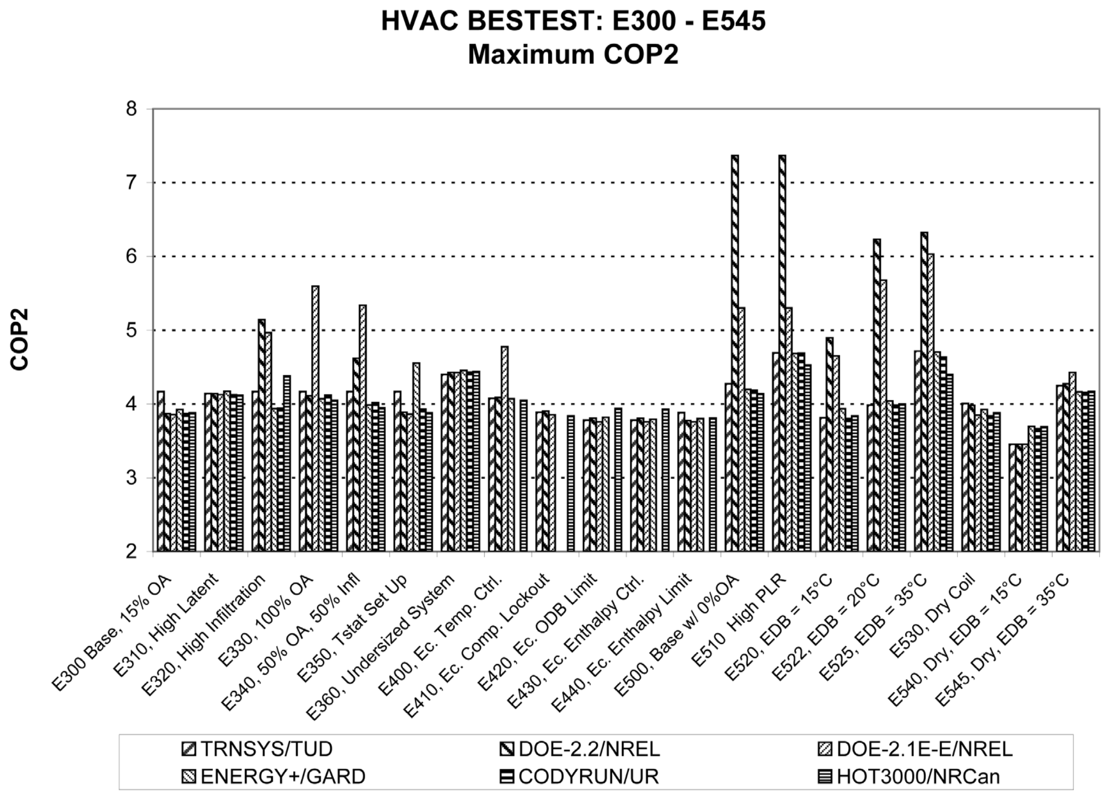

HVAC BESTEST: E300 - E545
Hourly Maximum Latent Coil Load Sensitivities
Load (Wh thermal)
35000
30000
25000
20000
15000
10000
5000
0
-5000
-10000
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

HVAC BESTEST: E300 - E545
COP2

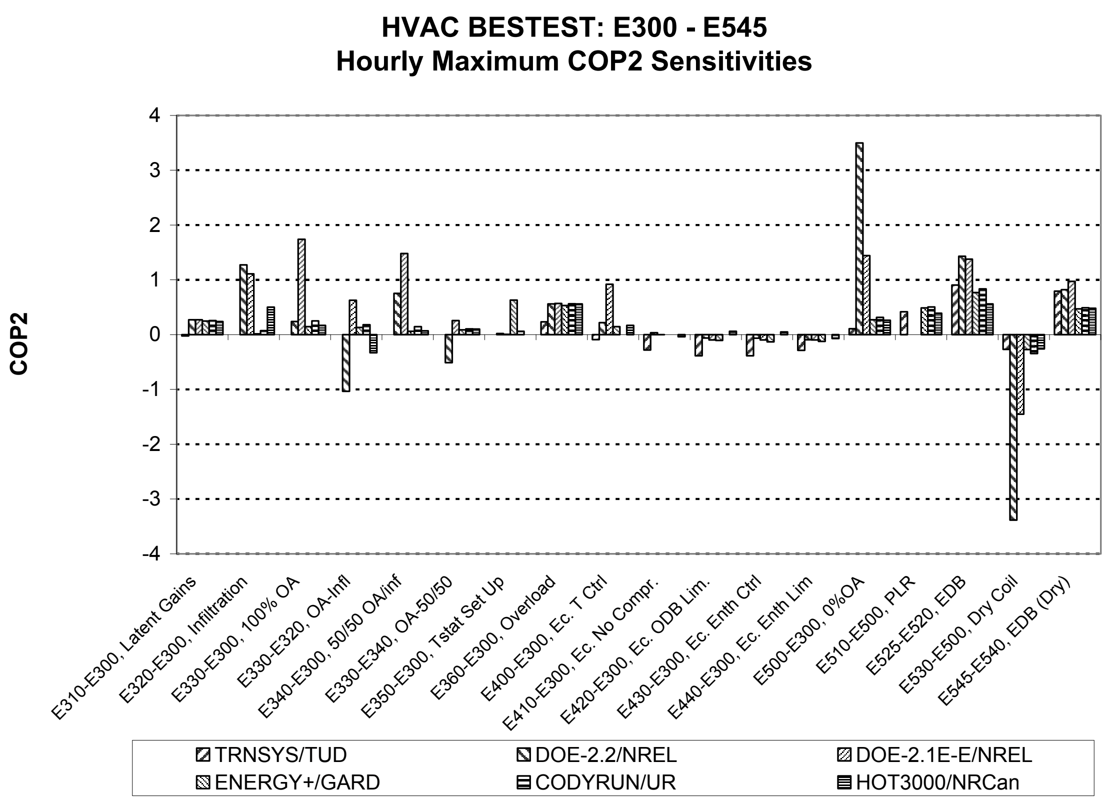


HVAC BESTEST: E300 - E545
COP2 Sensitivities

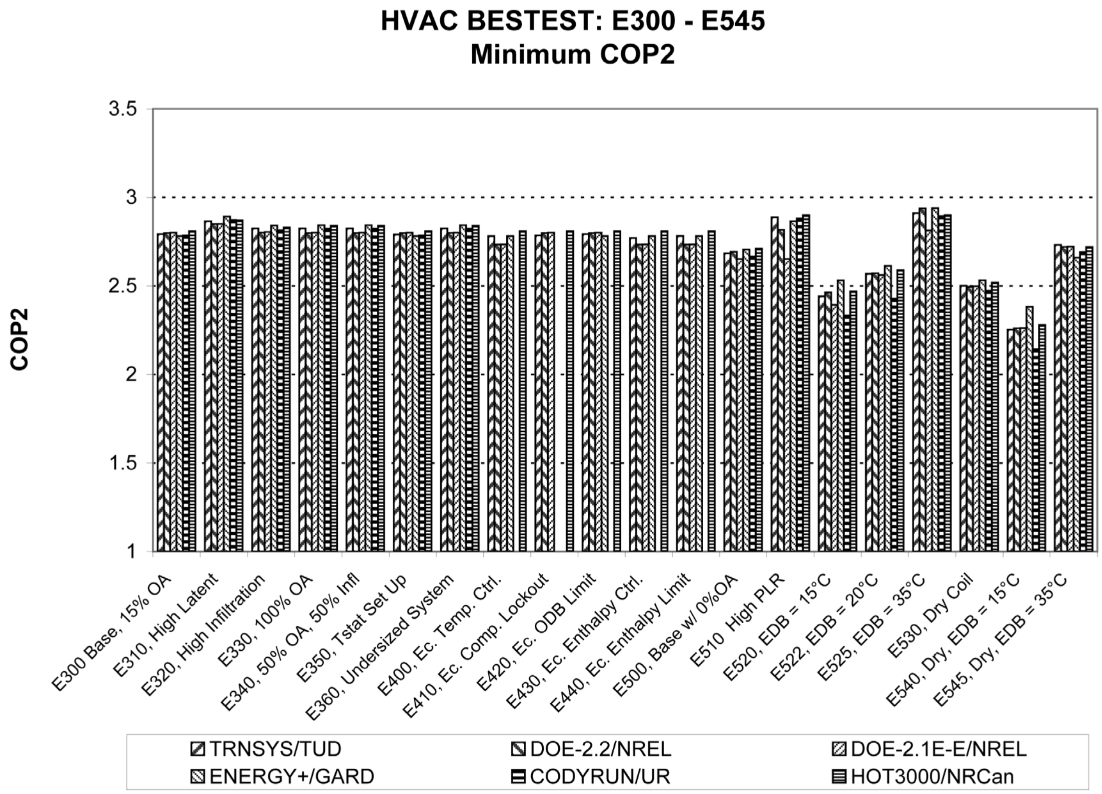




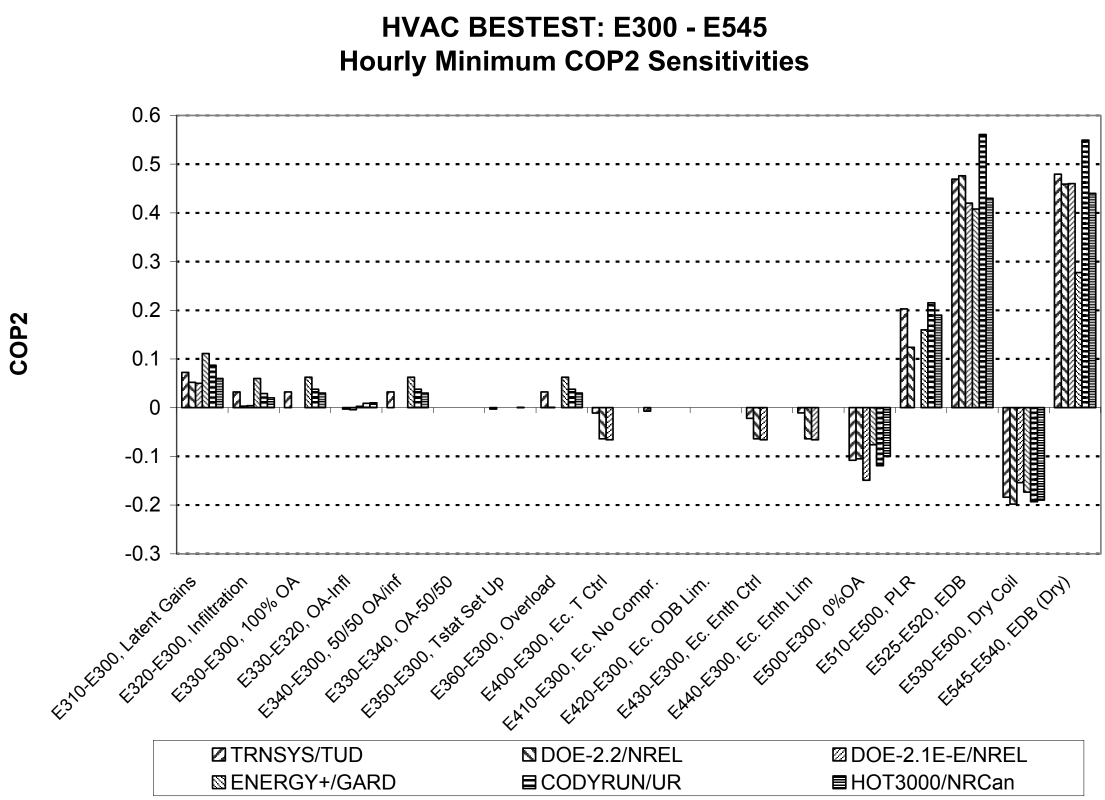
HVAC BESTEST: E300 - E545
Maximum COP2
COP2
8
7
6
5
4
3
2
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan



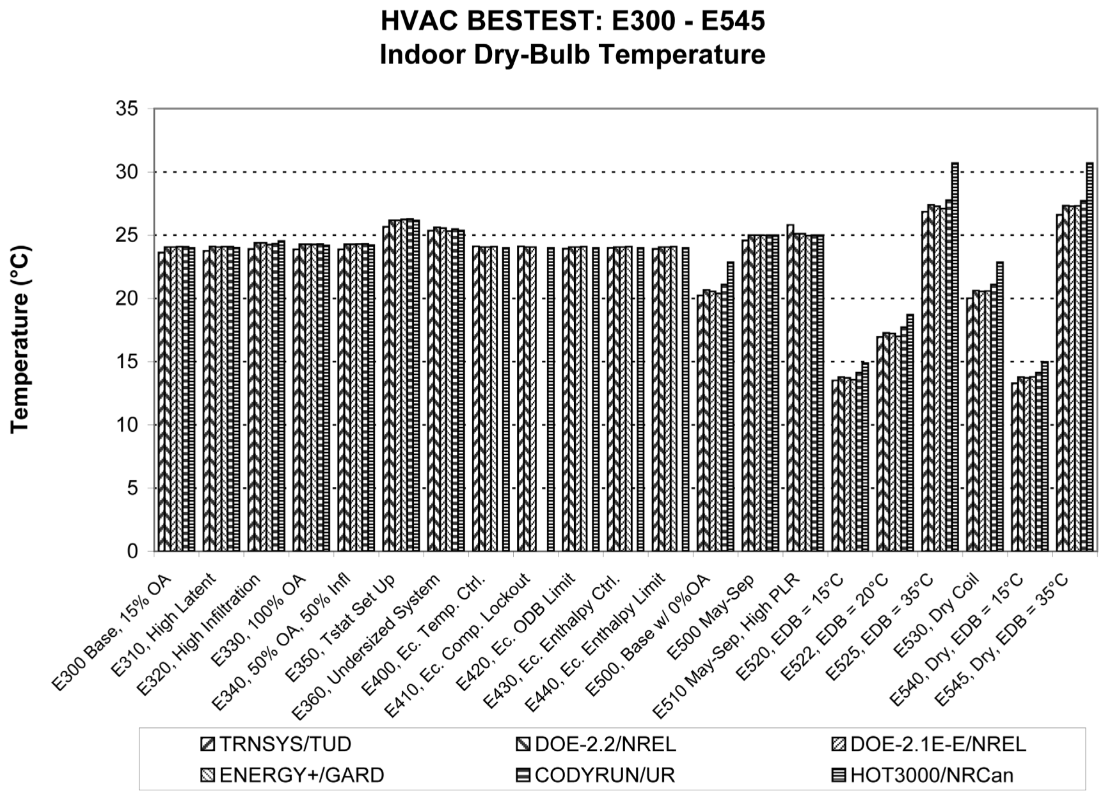
HVAC BESTEST: E300 - E545
Hourly Maximum COP2 Sensitivities
COP2
4
3
2
1
0
-1
-2
-3
-4
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

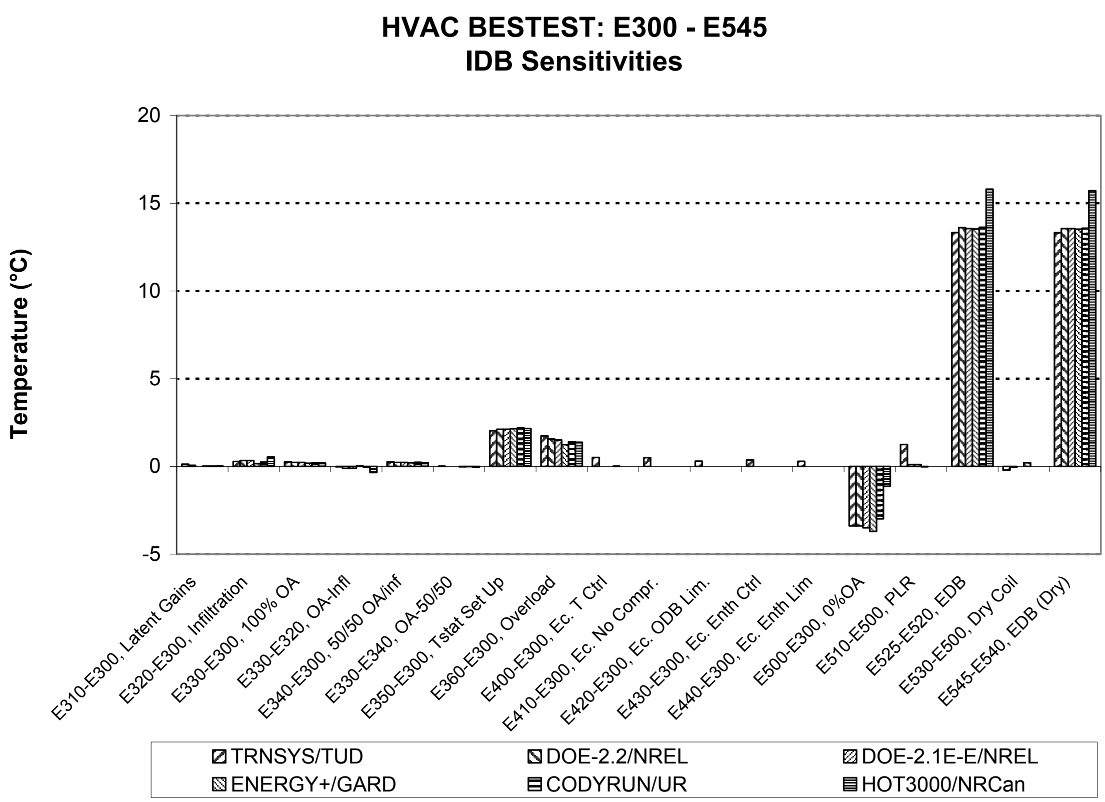


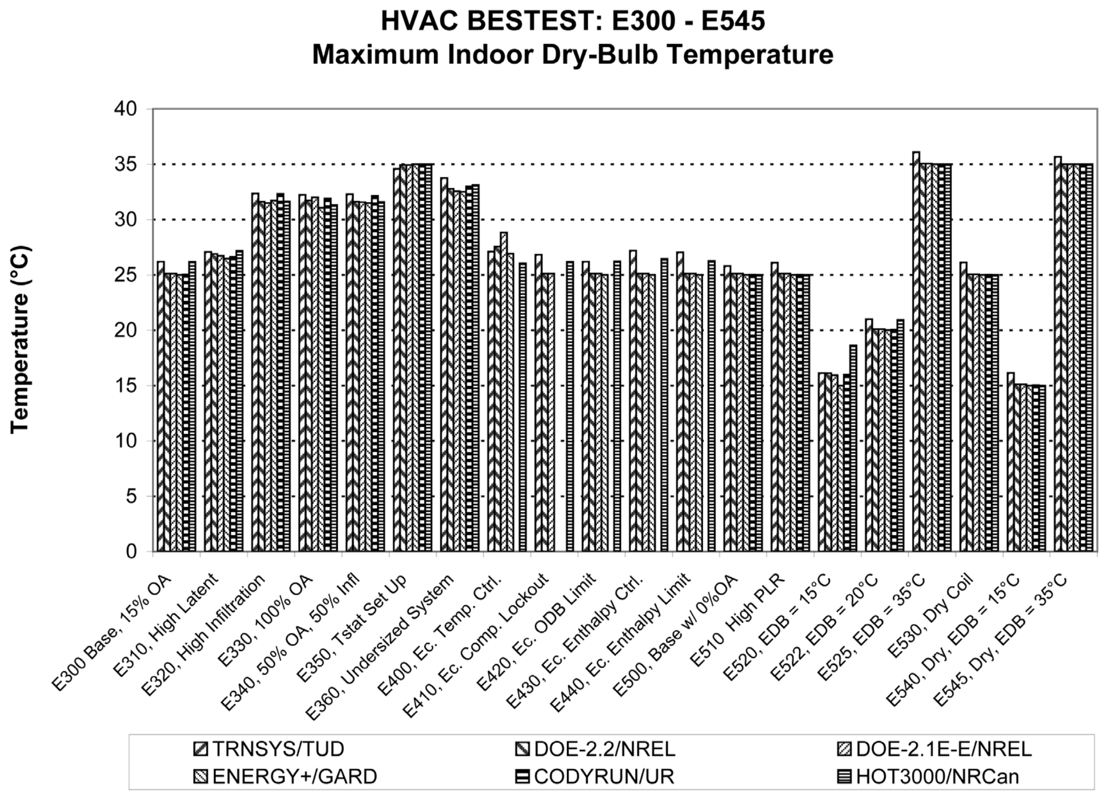
HVAC BESTEST: E300 - E545
Minimum COP2
COP2
3.5
3
2.5
2
1.5
1
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

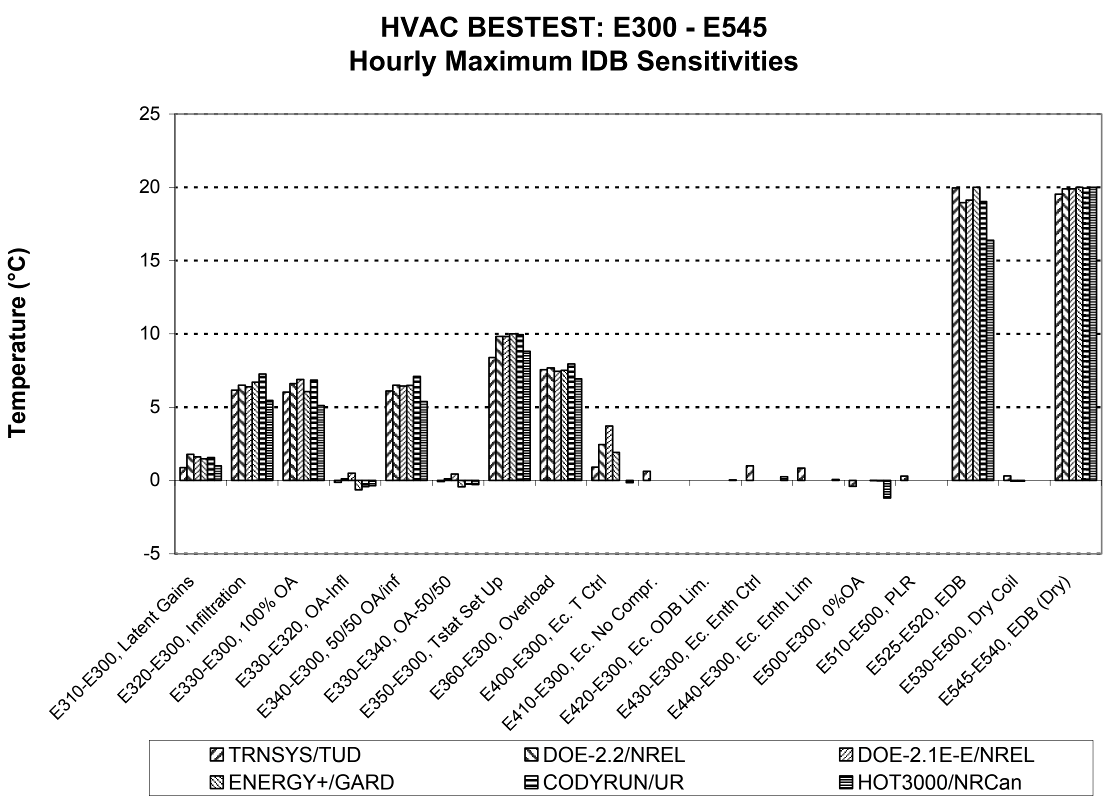


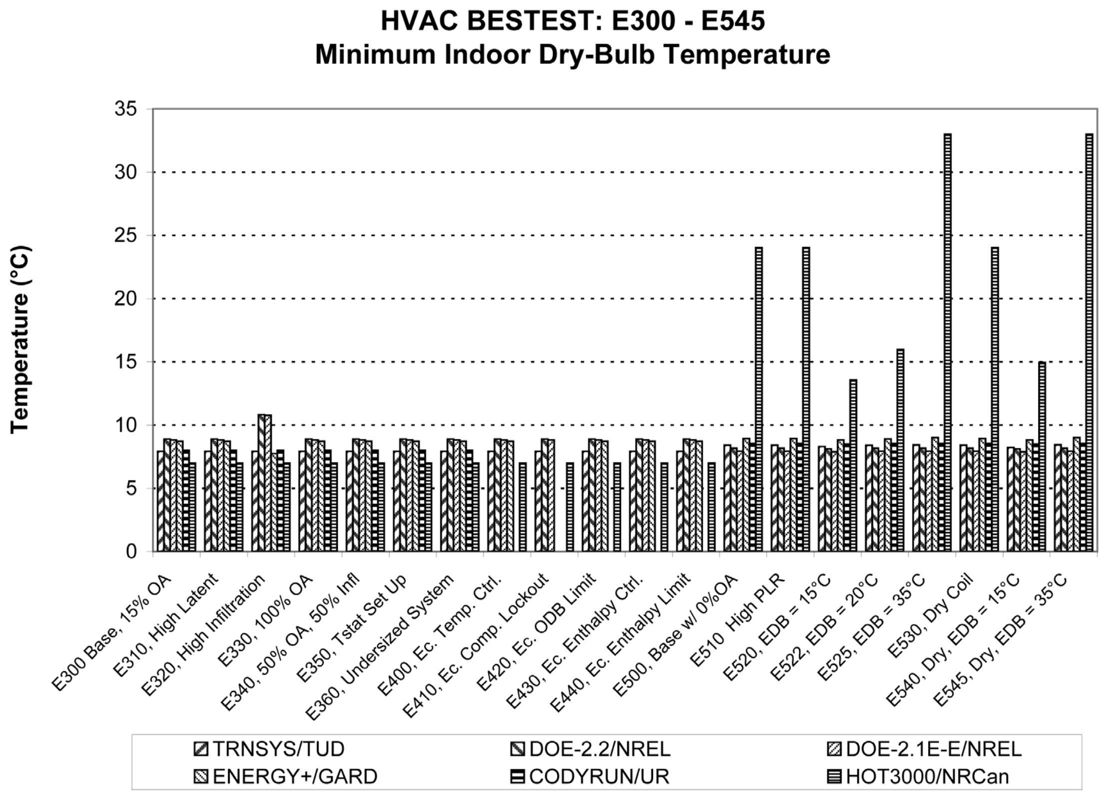
HVAC BESTEST: E300 - E545
Hourly Minimum COP2 Sensitivities
COP2
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

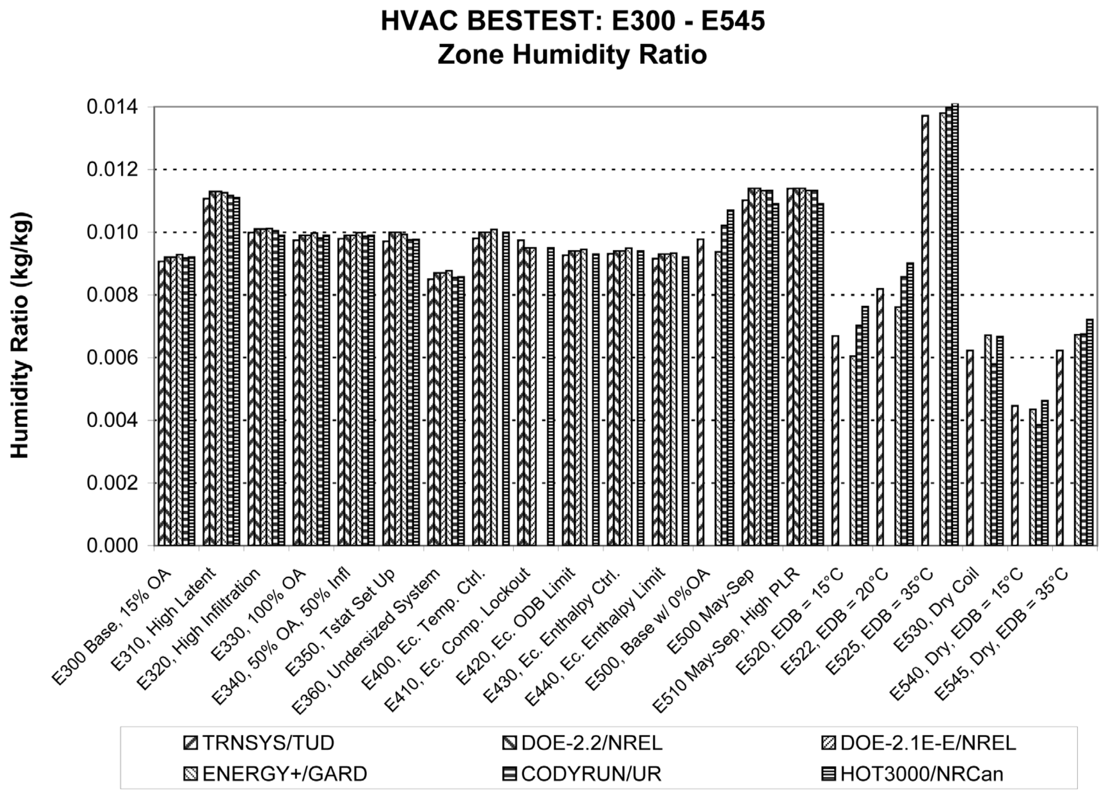

HVAC BESTEST: E300 - E545
Indoor Dry-Bulb Temperature
Temperature (°C)
0
5
10
15
20
25
30
35
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

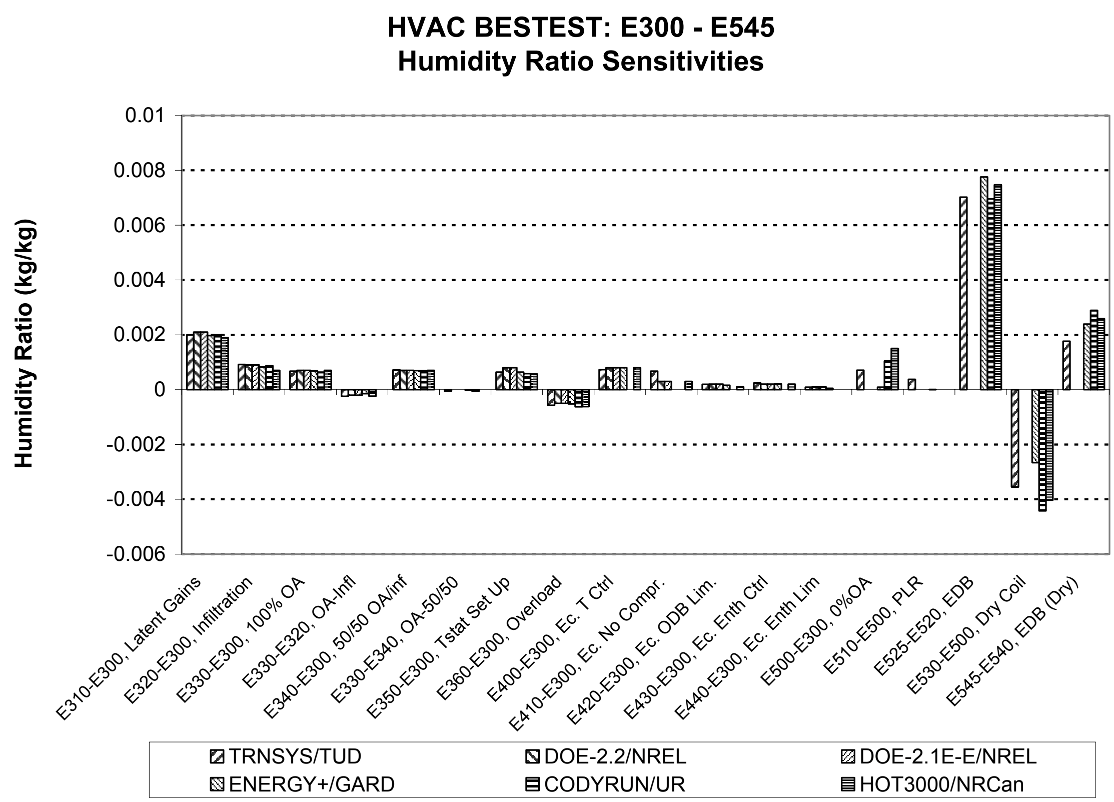

HVAC BESTEST: E300 - E545
IDB Sensitivities
Temperature (°C)
-5
0
5
10
15
20
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

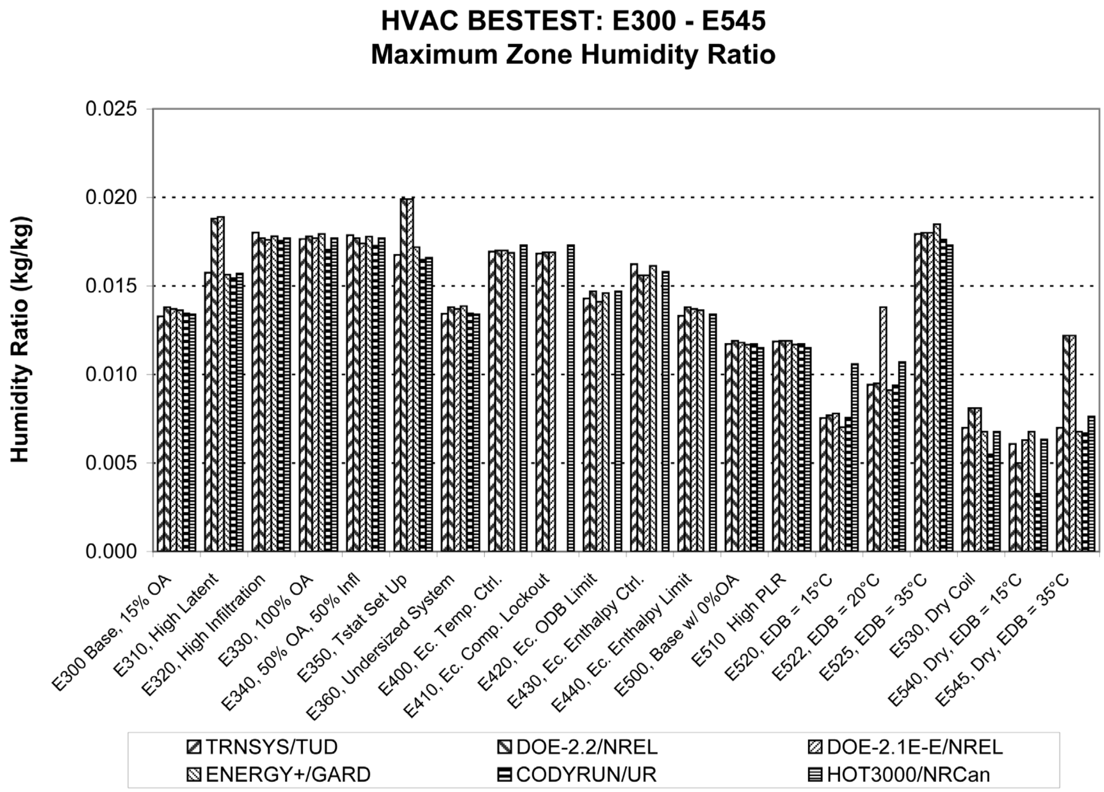

HVAC BESTEST: E300 - E545
Maximum Indoor Dry-Bulb Temperature
Temperature (°C)
40
35
30
25
20
15
10
5
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

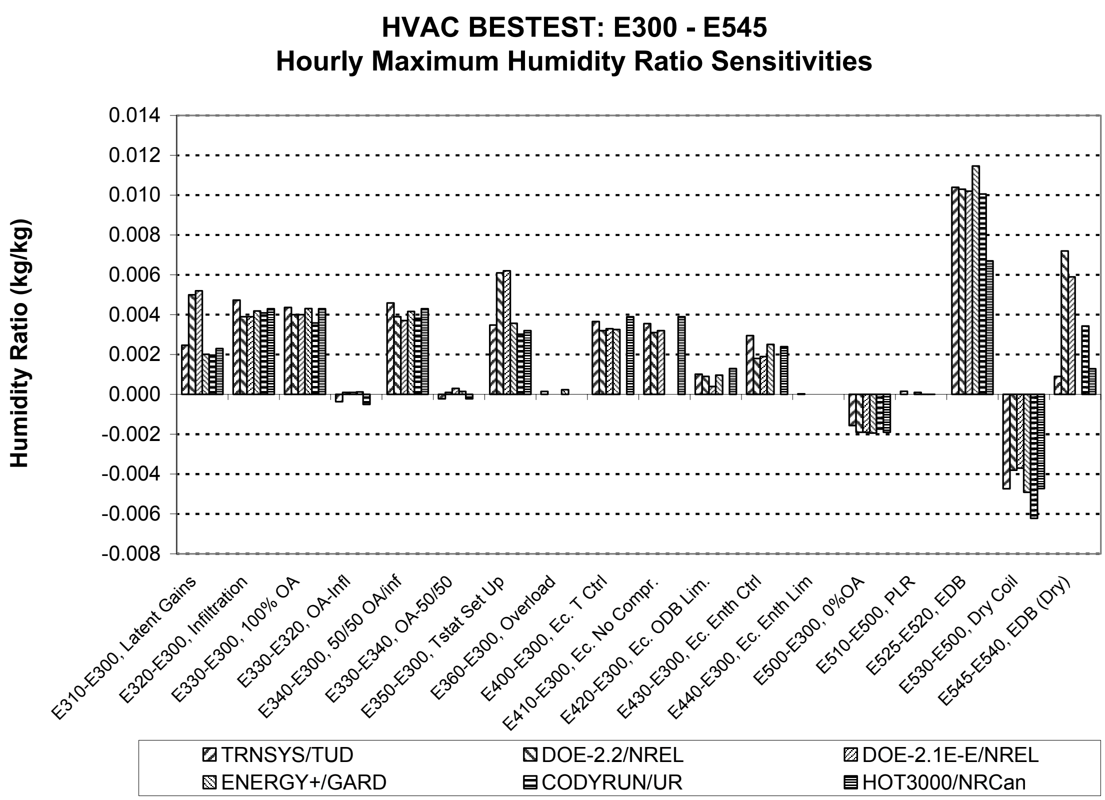

HVAC BESTEST: E300 - E545
Hourly Maximum IDB Sensitivities
Temperature (°C)
25
20
15
10
5
0
-5
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

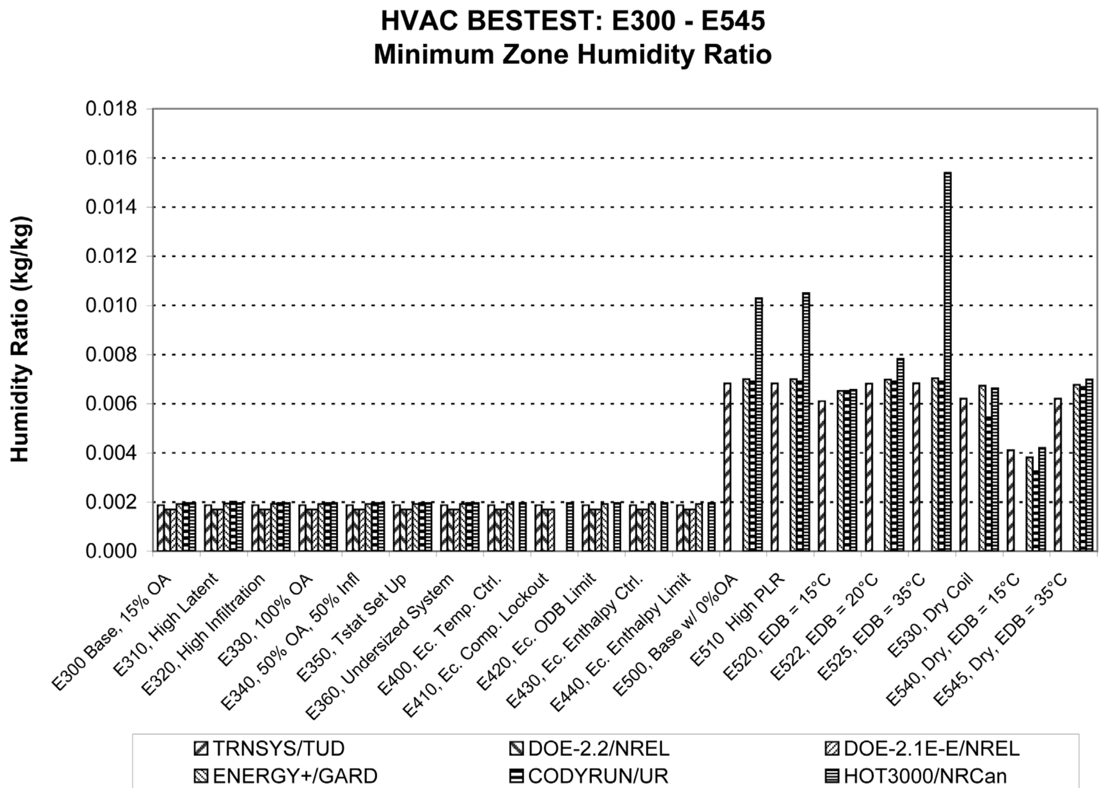

HVAC BESTEST: E300 - E545
Minimum Indoor Dry-Bulb Temperature
Temperature (°C)
35
30
25
20
15
10
5
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300 - E545
Zone Humidity Ratio
Humidity Ratio (kg/kg)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

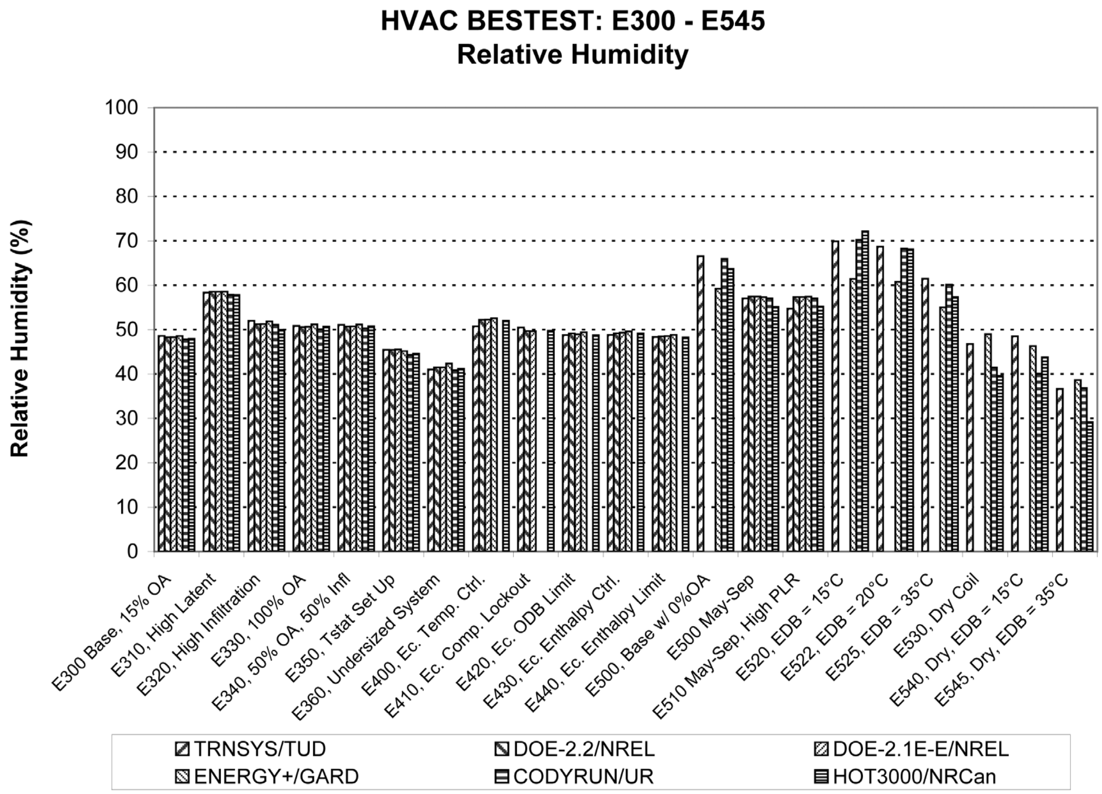

HVAC BESTEST: E300 - E545
Humidity Ratio Sensitivities
Humidity Ratio (kg/kg)
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

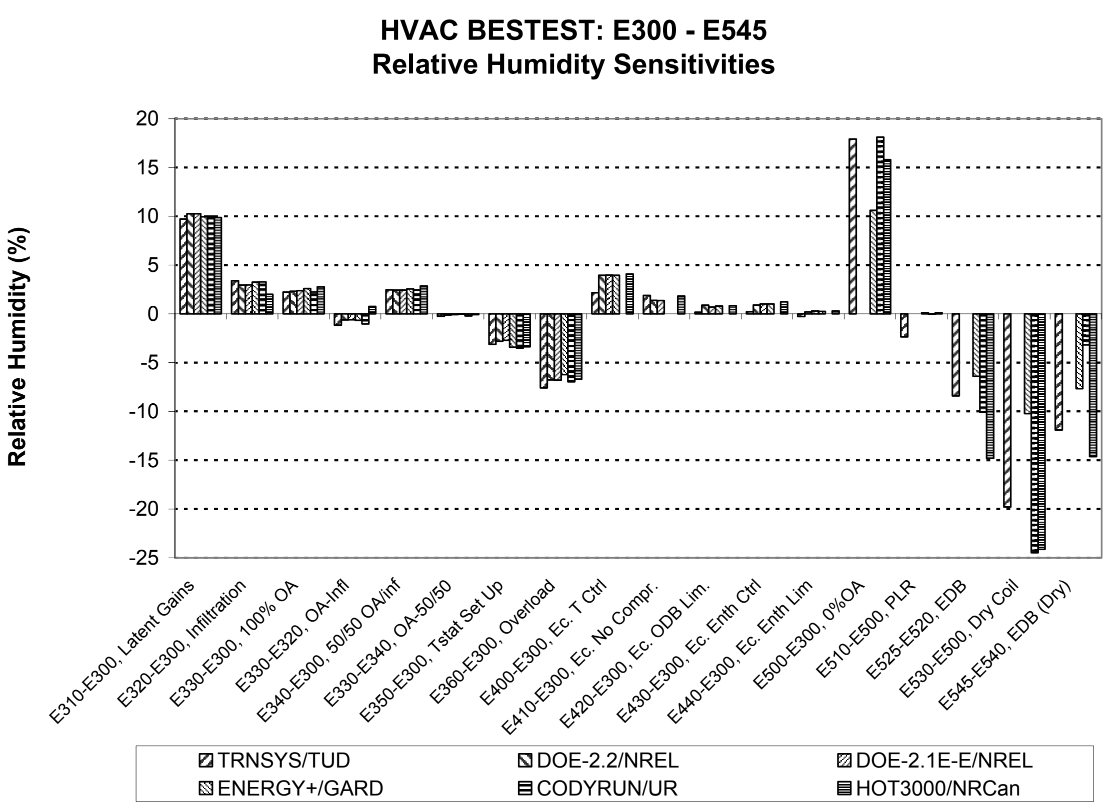

HVAC BESTEST: E300 - E545
Maximum Zone Humidity Ratio
Humidity Ratio (kg/kg)
0.025
0.020
0.015
0.010
0.005
0.000
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300 - E545
Hourly Maximum Humidity Ratio Sensitivities
Humidity Ratio (kg/kg)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

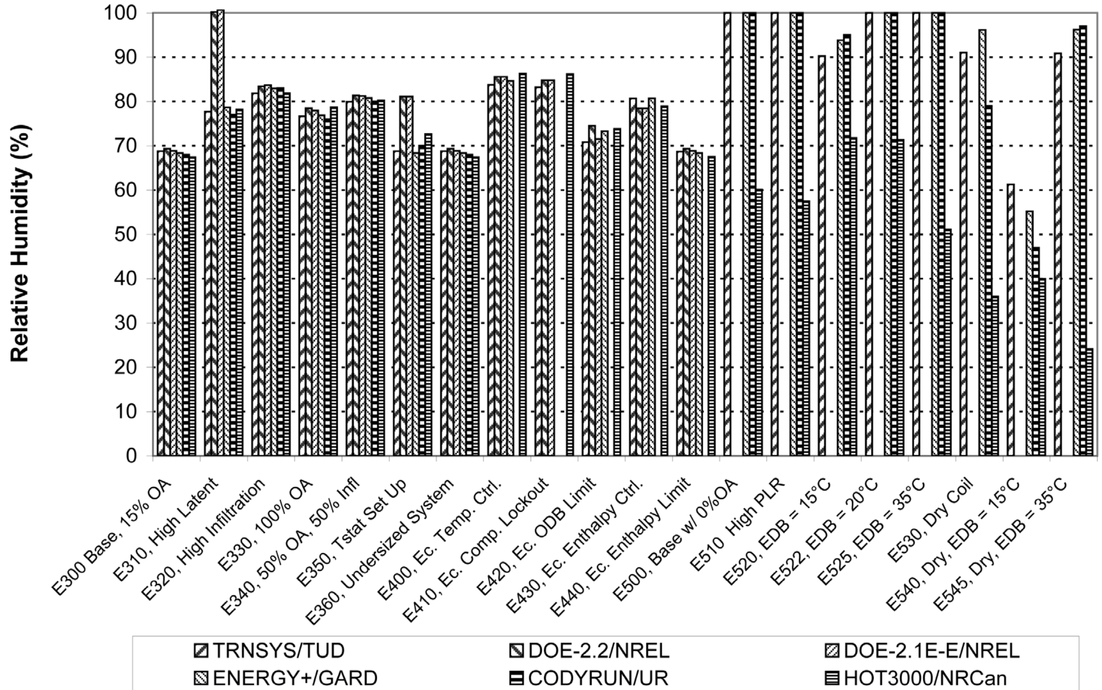


HVAC BESTEST: E300 - E545
Minimum Zone Humidity Ratio
Humidity Ratio (kg/kg)
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

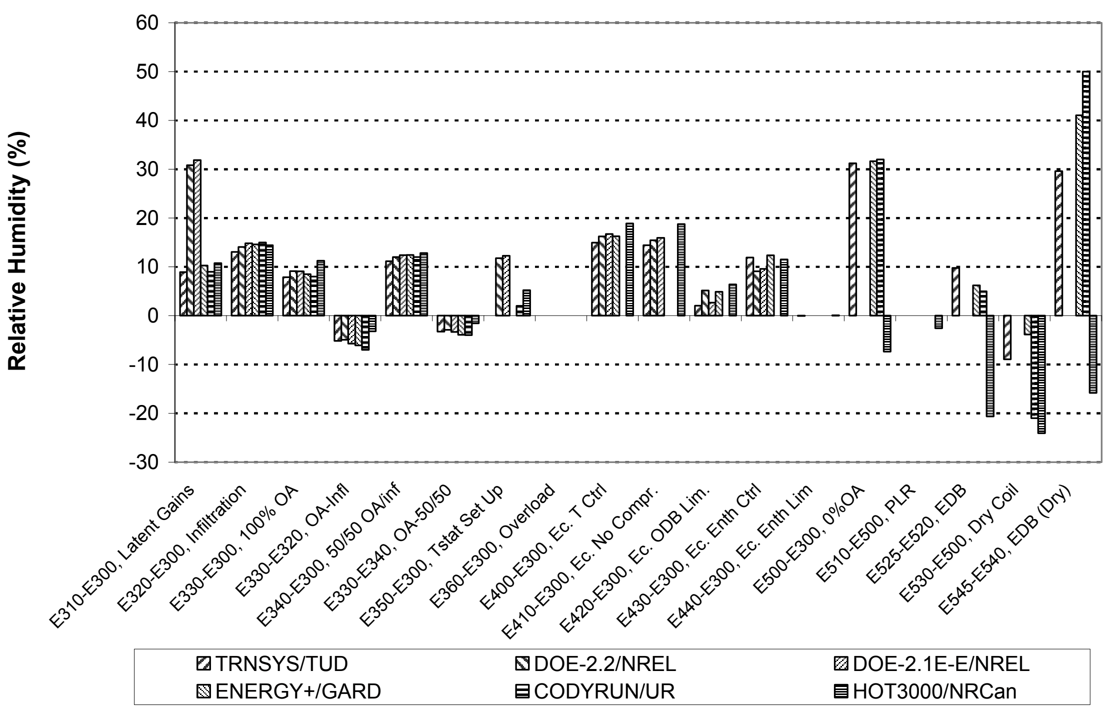

HVAC BESTEST: E300 - E545
Relative Humidity
Relative Humidity (%)
100
90
80
70
60
50
40
30
20
10
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E500 May-Sep
E510 May-Sep, High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

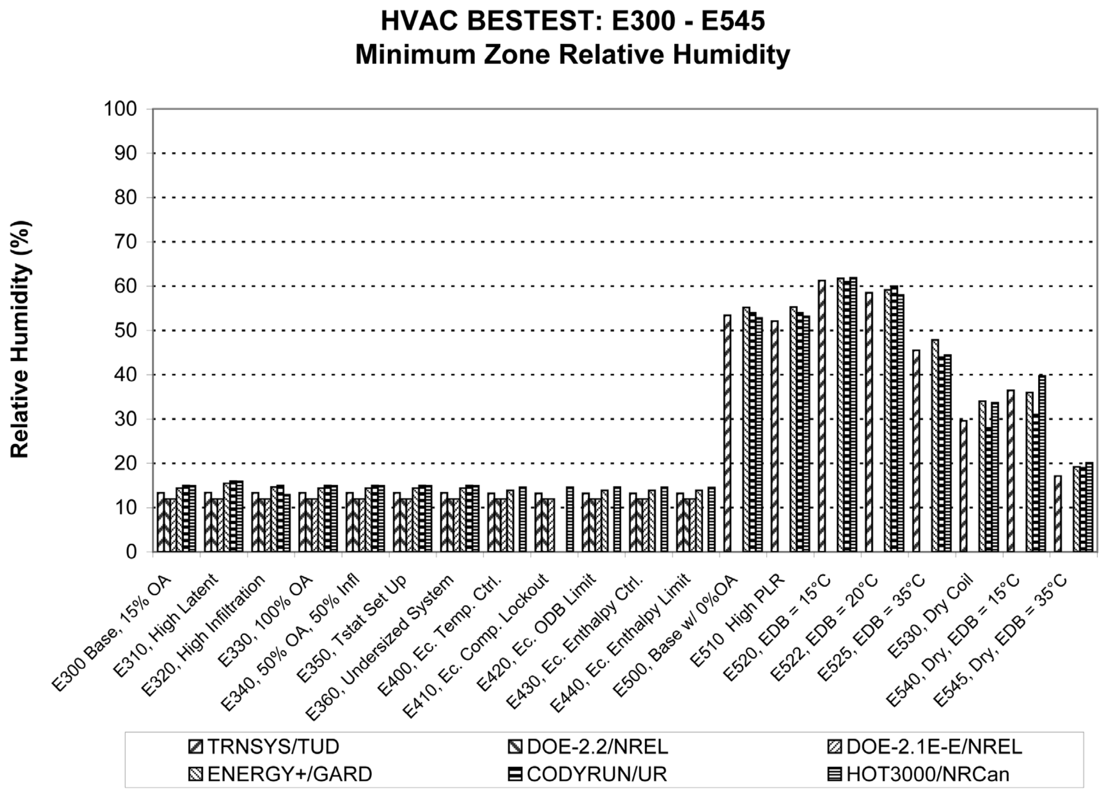

HVAC BESTEST: E300 - E545
Relative Humidity Sensitivities
Relative Humidity (%)
20
15
10
5
0
-5
-10
-15
-20
-25
E310-E300, Latent Gains
E320-E300, Infiltration
E330-E300, 100% OA
E330-E320, OA-Infl
E340-E300, 50/50 OA/inf
E330-E340, OA-50/50
E350-E300, Tstat Set Up
E360-E300, Overload
E400-E300, Ec. T Ctrl
E410-E300, Ec. No Compr.
E420-E300, Ec. ODB Lim.
E430-E300, Ec. Enth Ctrl
E440-E300, Ec. Enth Lim
E500-E300, 0%OA
E510-E500, PLR
E525-E520, EDB
E530-E500, Dry Coil
E545-E540, EDB (Dry)
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

HVAC BESTEST: E300 - E545
Maximum Zone Relative Humidity

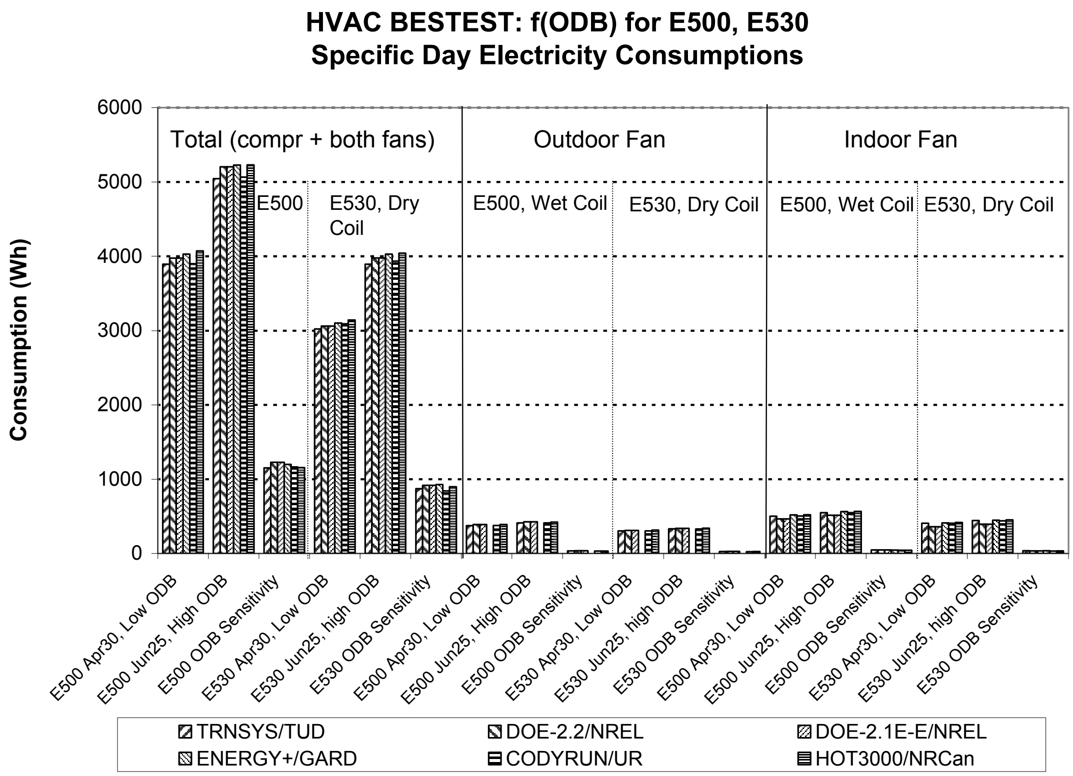


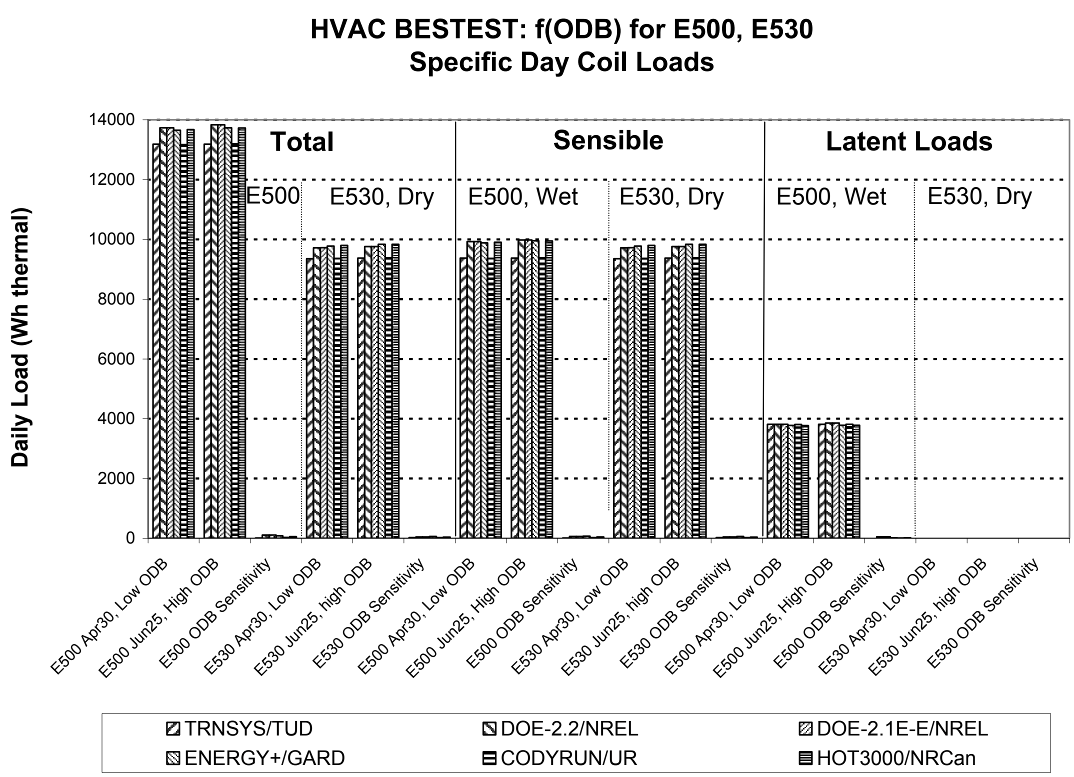
HVAC BESTEST: E300 - E545
Hourly Maximum Relative Humidity Sensitivities



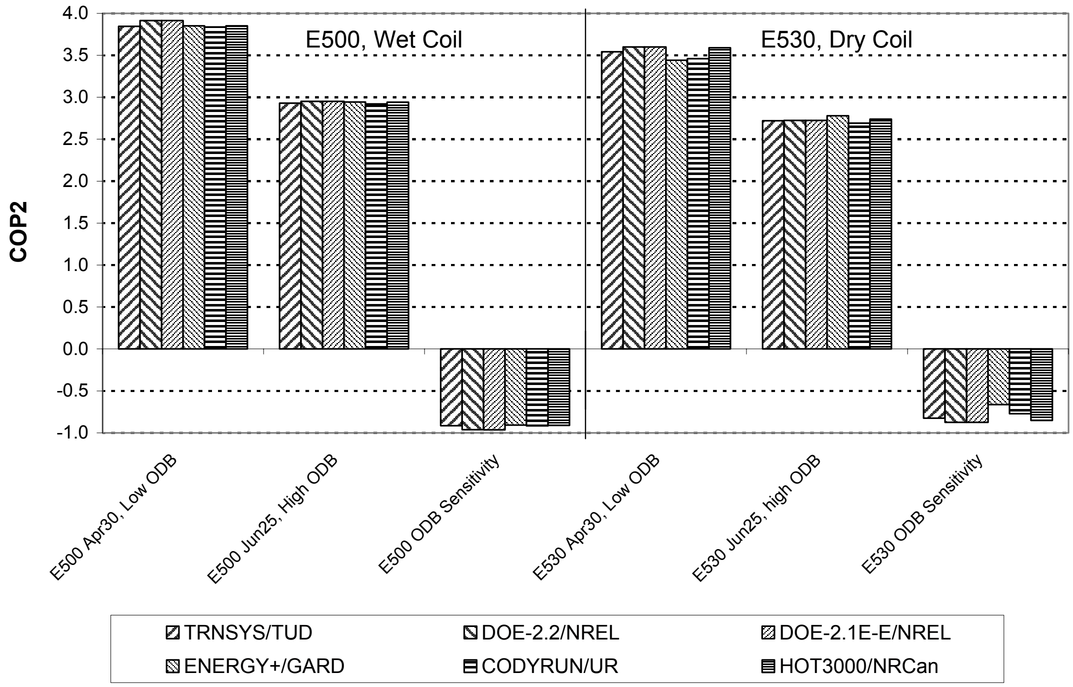


HVAC BESTEST: E300 - E545
Minimum Zone Relative Humidity
Relative Humidity (%)
100
90
80
70
60
50
40
30
20
10
0
E300 Base, 15% OA
E310, High Latent
E320, High Infiltration
E330, 100% OA
E340, 50% OA, 50% Infl
E350, Tstat Set Up
E360, Undersized System
E400, Ec. Temp. Ctrl.
E410, Ec. Comp. Lockout
E420, Ec. ODB Limit
E430, Ec. Enthalpy Ctrl.
E440, Ec. Enthalpy Limit
E500, Base w/ 0%OA
E510 High PLR
E520, EDB = 15°C
E522, EDB = 20°C
E525, EDB = 35°C
E530, Dry Coil
E540, Dry, EDB = 15°C
E545, Dry, EDB = 35°C
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

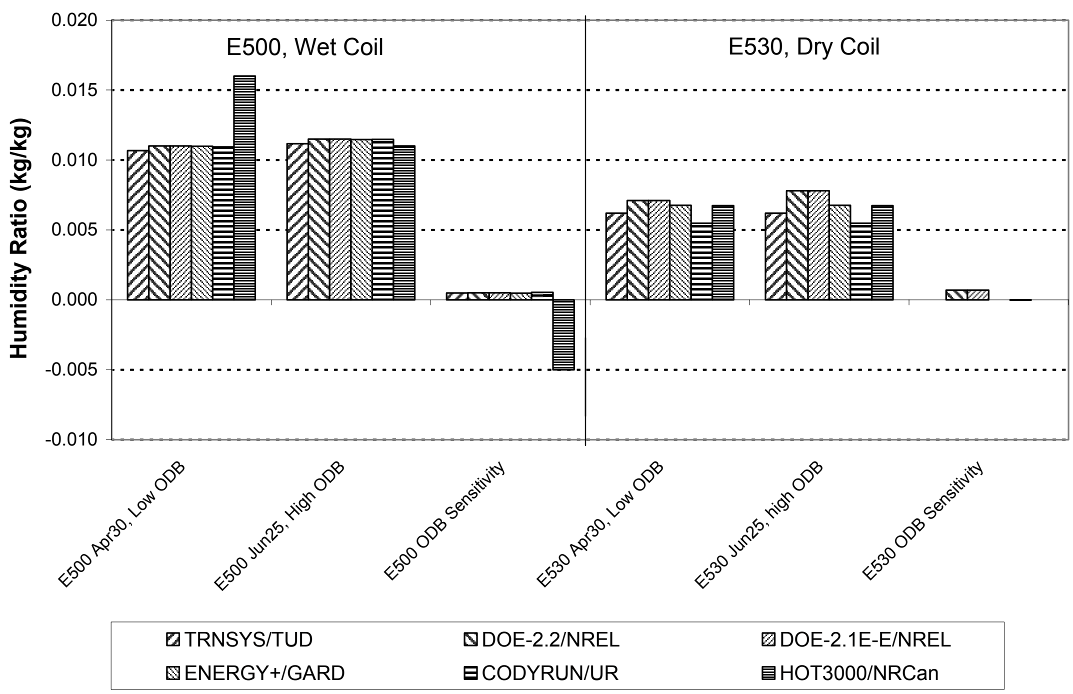

HVAC BESTEST: f(ODB) for E500, E530
Specific Day Electricity Consumptions
Consumption (Wh)
Total (compr + both fans)
Outdoor Fan
Indoor Fan
E500
E530, Dry Coil
E500, Wet Coil
E530, Dry Coil
E500, Wet Coil
E530, Dry Coil
E500 Apr30, Low ODB
E500 Jun25, High ODB
E500 ODB Sensitivity
E530 Apr30, Low ODB
E530 Jun25, high ODB
E530 ODB Sensitivity
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

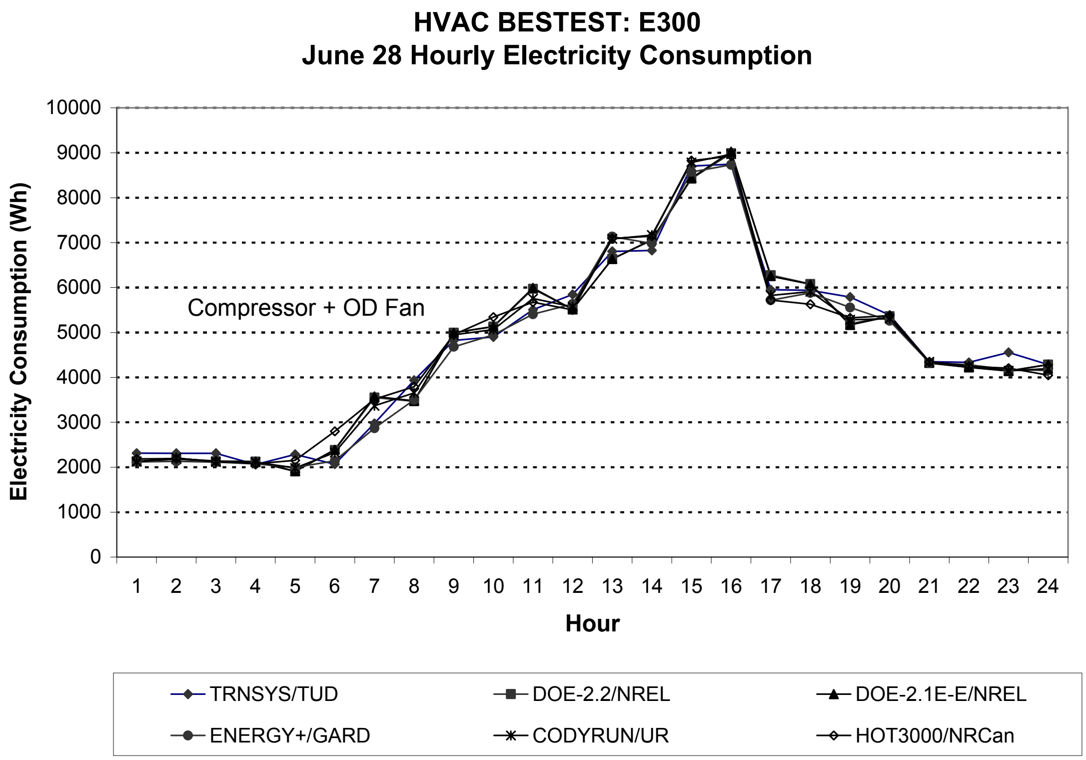

HVAC BESTEST: f(ODB) for E500, E530
Specific Day Coil Loads
Daily Load (Wh thermal)
Total
Sensible
Latent Loads
E500
E530, Dry
E500, Wet
E530, Dry
E500, Wet
E530, Dry
E500 Apr30, Low ODB
E500 Jun25, High ODB
E500 ODB Sensitivity
E530 Apr30, Low ODB
E530 Jun25, high ODB
E530 ODB Sensitivity
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

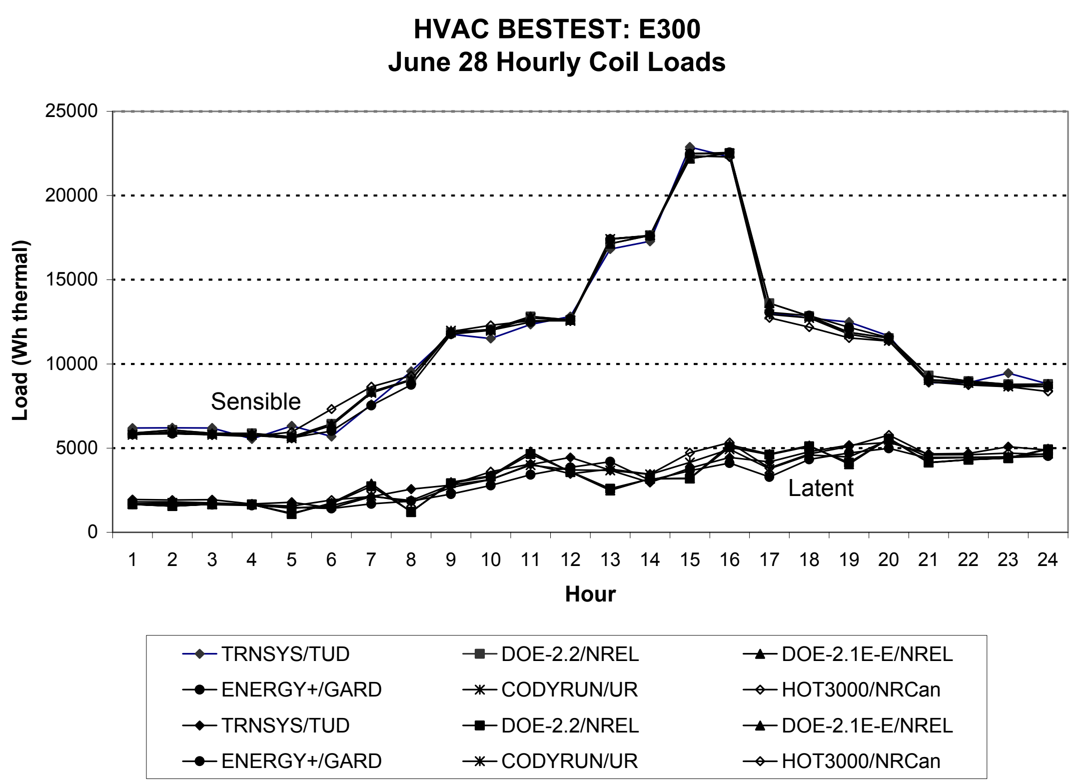
HVAC BESTEST: f(ODB) for E500, E530
Specific Day COP2

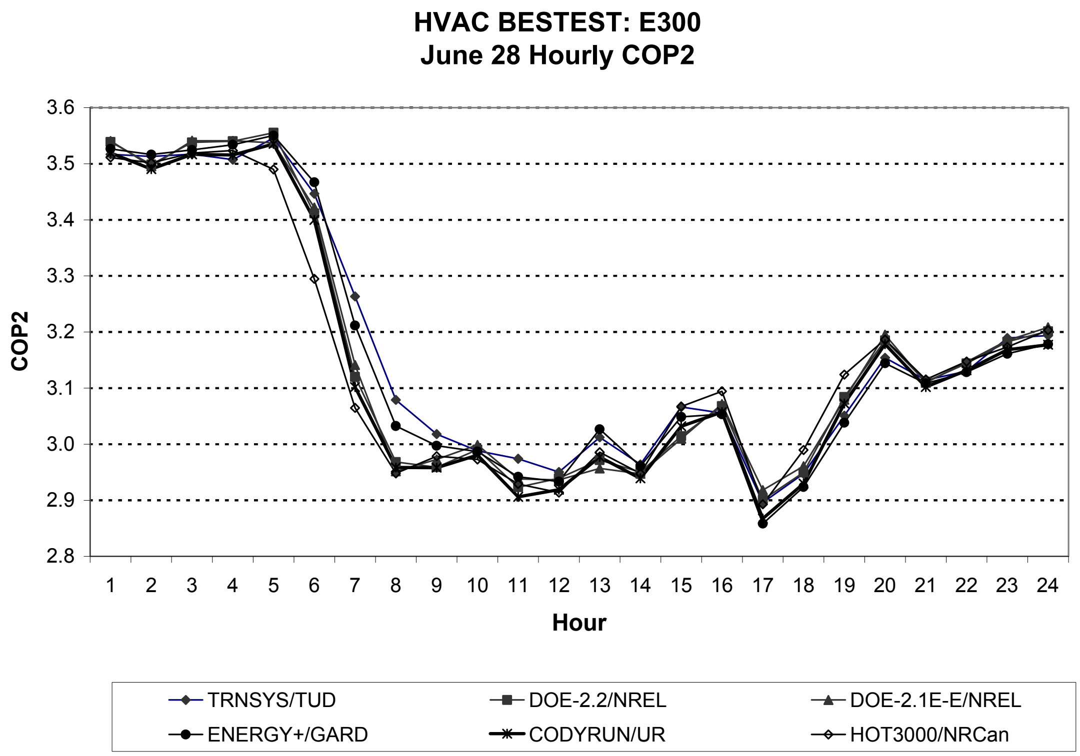


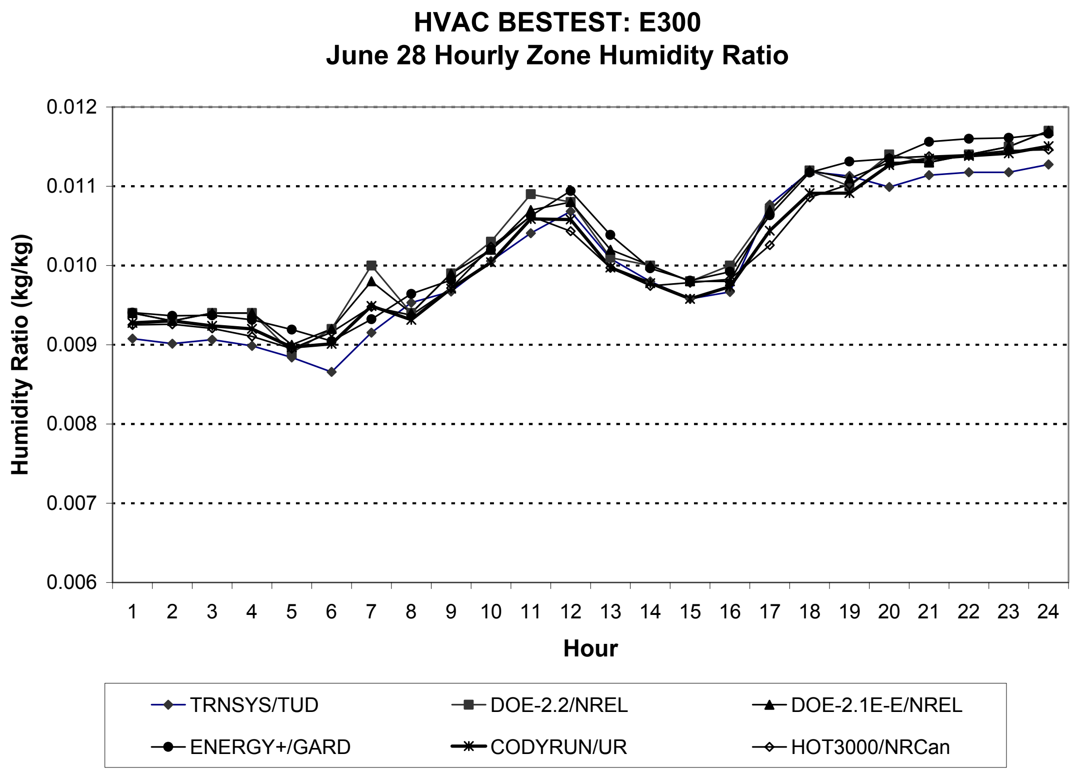
HVAC BESTEST: f(ODB) for E500, E530
Specific Day Humidity Ratio

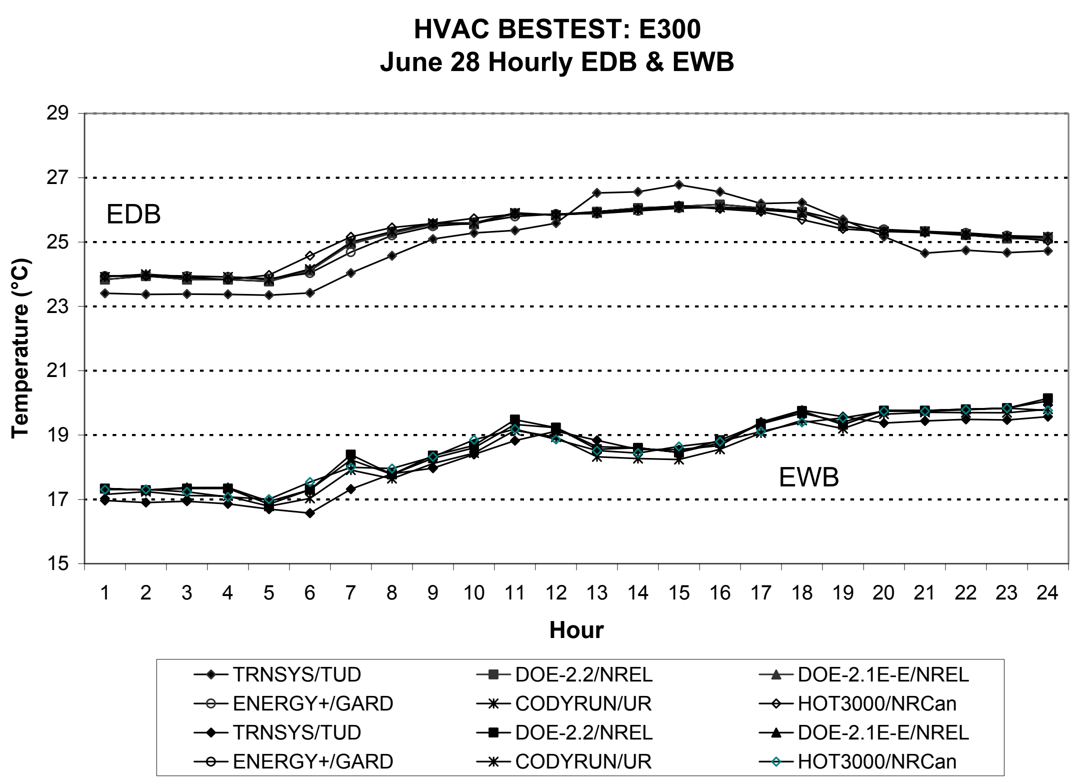


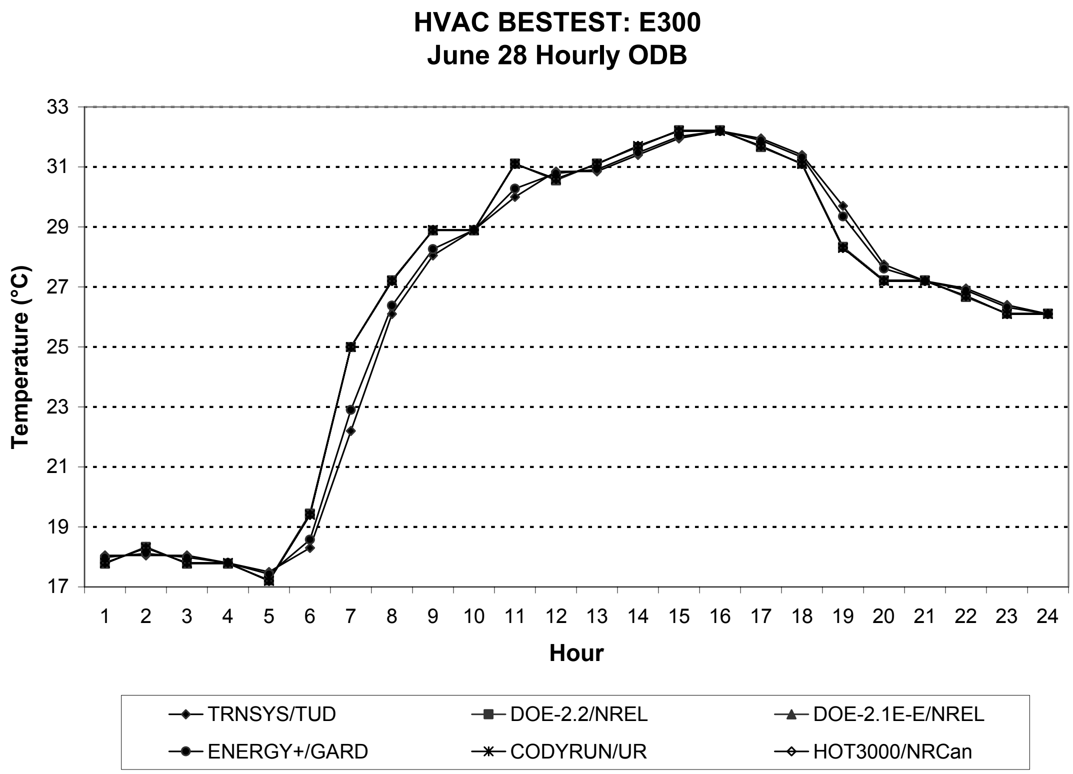

HVAC BESTEST: E300
June 28 Hourly Electricity Consumption
Electricity Consumption (Wh)
Compressor + OD Fan
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

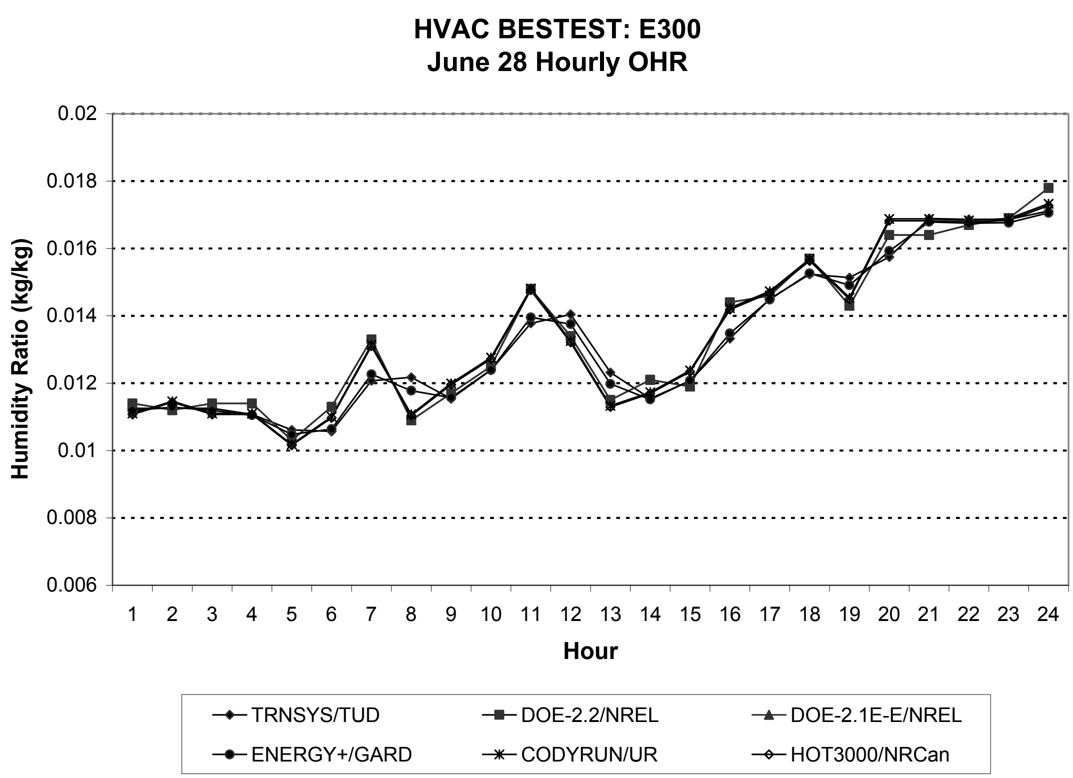

HVAC BESTEST: E300
June 28 Hourly Coil Loads
Load (Wh thermal)
Sensible
Latent
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300
June 28 Hourly COP2
COP2
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300
June 28 Hourly Zone Humidity Ratio
Humidity Ratio (kg/kg)
0.012
0.011
0.010
0.009
0.008
0.007
0.006
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300
June 28 Hourly EDB & EWB
Temperature (°C)
29
27
25
23
21
19
17
15
EDB
EWB
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300
June 28 Hourly ODB
Temperature (°C)
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan


HVAC BESTEST: E300
June 28 Hourly OHR
Humidity Ratio (kg/kg)
Hour
TRNSYS/TUD
DOE-2.2/NREL
DOE-2.1E-E/NREL
ENERGY+/GARD
CODYRUN/UR
HOT3000/NRCan

Space Cooling Electricity Consumption

Energy Consumption, Total (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	35634	34750	34755	34746	34976	35070	34746	35634	2.5%
E310	39973	39379	39384	39290	39520	39608	39290	39973	1.7%
E320	40060	38745	38792	39079	39401	39457	38745	40060	3.3%
E330	40963	39708	39438	40143	40535	40330	39438	40963	3.8%
E340	40619	39358	39265	39783	40065	39947	39265	40619	3.4%
E350	32237	30547	30548	31145	31587	31742	30547	32237	5.4%
E360	55299	54064	54016	54705	54843	55068	54016	55299	2.3%
E400	32045	30846	30876	31013		31413	30846	32045	3.8%
E410	32078	31668	31699			31503	31503	32078	1.8%
E420	33387	32530	32910	32736		33208	32530	33387	2.6%
E430	32538	31932	31811	31772		31818	31772	32538	2.4%
E440	33691	33032	32973	33032		33248	32973	33691	2.2%
E500	22338	22817	22822	23035	22323	23138	22323	23138	3.6%
E500 May-Sep	17391	17872	17870	17996	17435	18051	17391	18051	3.7%
E510 May-Sep	34609	35971	35970	35732	34849	35845	34609	35971	3.8%
E520	24987	25389	25390	25017	25131	25781	24987	25781	3.1%
E522	23544	24293	24307	24078	23620	24360	23544	24360	3.4%
E525	20321	20408	20421	20702	20242	21323	20242	21323	5.3%
E530	17281	17540	17537	17742	17442	17875	17281	17875	3.4%
E540	19430	19878	19874	19061	19537	20164	19061	20164	5.6%
E545	15687	15802	15791	16636	15791	16339	15687	16636	5.9%

Energy Consumption, Compressor (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	22354	21569	21573		21770	21876	21569	22354	3.6%
E310	26340	25813	25817		25937	26053	25813	26340	2.0%
E320	26433	25250	25294		25846	25912	25250	26433	4.6%
E330	27300	26172	25925		26928	26775	25925	27300	5.2%
E340	26963	25829	25745		26473	26400	25745	26963	4.6%
E350	19317	17802	17801		18738	18891	17801	19317	8.2%
E360	40106	38999	38955		39697	39941	38955	40106	2.9%
E400	19179	18106	18131			18629	18106	19179	5.8%
E410	19204	18823	18850			18685	18685	19204	2.8%
E420	20359	19596	19934			20214	19596	20359	3.8%
E430	19599	19059	18951			18966	18951	19599	3.4%
E440	20629	20042	19989			20249	19989	20629	3.2%
E500	17854	18473	18478		17858	18522	17854	18522	3.7%
E500 May-Sep	13942	14508	14506		13989	14491	13942	14508	4.0%
E510 May-Sep	27748	28811	28810		27902	28721	27748	28811	3.7%
E520	19521	20121	20126		19655	20185	19521	20185	3.3%
E522	18620	19407	19418		18690	19281	18620	19418	4.2%
E525	16558	16880	16893		16507	17443	16507	17443	5.6%
E530	13657	14127	14124		13856	14172	13657	14172	3.7%
E540	15021	15680	15677		15164	15664	15021	15680	4.3%
E545	12622	12967	12957		12751	13215	12622	13215	4.6%

e300results.xls q:a06..m55; 07/19/04

Space Cooling Electricity Consumption

Energy Consumption, Supply Fan (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E310	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E320	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E330	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E340	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E350	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E360	10880	10880	10880	10862	10880	10880	10862	10880	0.2%
E400	10880	10880	10880	10862		10880	10862	10880	0.2%
E410	10880	10880	10880			10880	10880	10880	0.0%
E420	10880	10880	10880	10862		10880	10862	10880	0.2%
E430	10880	10880	10880	10862		10880	10862	10880	0.2%
E440	10880	10880	10880	10862		10880	10862	10880	0.2%
E500	2564	2369	2369	2628	2553	2639	2369	2639	10.7%
E500 May-Sep	1972	1837	1837	2029	1970	2035	1837	2035	10.2%
E510 May-Sep	3923	4099	4099	4063	3972	4073	3923	4099	4.4%
E520	3125	2874	2871	3019	3131	3200	2871	3200	10.8%
E522	2816	2704	2707	2843	2819	2904	2704	2904	7.1%
E525	2152	1886	1885	2180	2136	2221	1885	2221	16.2%
E530	2072	1833	1833	2090	2051	2117	1833	2117	14.2%
E540	2522	2258	2258	2309	2500	2573	2258	2573	13.1%
E545	1753	1501	1501	1871	1739	1786	1501	1871	21.9%

Energy Consumption, Condenser Fan (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	2400	2301	2302		2326	2323	2301	2400	4.3%
E310	2754	2686	2687		2703	2691	2686	2754	2.5%
E320	2747	2615	2618		2675	2681	2615	2747	4.9%
E330	2784	2656	2633		2727	2693	2633	2784	5.6%
E340	2776	2649	2640		2713	2684	2640	2776	5.1%
E350	2040	1865	1867		1969	1970	1865	2040	9.0%
E360	4313	4185	4181		4266	4272	4181	4313	3.1%
E400	1986	1860	1865			1902	1860	1986	6.6%
E410	1994	1965	1969			1936	1936	1994	3.0%
E420	2149	2054	2096			2115	2054	2149	4.5%
E430	2059	1993	1980			1970	1970	2059	4.5%
E440	2182	2110	2104			2120	2104	2182	3.7%
E500	1920	1975	1975		1912	1976	1912	1976	3.3%
E500 May-Sep	1477	1527	1527		1476	1524	1476	1527	3.4%
E510 May-Sep	2938	3061	3061		2974	3050	2938	3061	4.1%
E520	2340	2394	2393		2345	2396	2340	2396	2.4%
E522	2108	2182	2182		2111	2174	2108	2182	3.4%
E525	1611	1642	1643		1599	1663	1599	1663	3.9%
E530	1552	1580	1580		1536	1585	1536	1585	3.1%
E540	1888	1940	1939		1872	1926	1872	1940	3.5%
E545	1312	1334	1333		1302	1337	1302	1337	2.7%

e300results.xls q:a56..m105; 07/19/04

Weather Data Checks, E300 Only

	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
Annual Mean Output									
ODB	19.91	19.89	19.89	19.91	19.91	19.91	20	20	0.1%
OHR	0.01164	0.01160	0.01160	0.01159	0.01165	0.01160	0.01159	0.01165	0.5%
Annual Hourly Integrated Maxima									
ODB	34.70	35.00	35.00	34.78	35.00	35.00	35	35	0.9%
OHR	0.02188	0.02250	0.02250	0.02184	0.02241	0.02230	0.02184	0.02250	3.0%

e300results.xls q:a109..m119; 07/19/04

Space Cooling Coil Loads

Total Sensible + Latent (kWh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	80427	77283	77292	77318	77745	78257	77283	80427	4.0%
E310	99342	97395	97412	96448	97296	97261	96448	99342	3.0%
E320	99792	96356	96493	96084	97141	96957	96084	99792	3.8%
E330	105013	100730	100993	102211	103713	102008	100730	105013	4.2%
E340	102728	99028	99223	99709	100676	99753	99028	102728	3.7%
E350	69388	63736	63635	65790	66860	67389	63635	69388	8.7%
E360	162974	159807	159854	161248	161200	162168	159807	162974	2.0%
E400	68793	64918	65025	65414		66898	64918	68793	5.9%
E410	68673	66780	66844			66175	66175	68673	3.7%
E420	72609	69611	70882	70349		71803	69611	72609	4.2%
E430	69756	67641	67219	67141		67200	67141	69756	3.9%
E440	73711	71380	71181	71417		72029	71181	73711	3.5%
E500	63357	65996	65992	65571	63105	65614	63105	65996	4.5%
E500 May-Sep	48443	50693	50690	50354	48440	50357	48440	50693	4.5%
E510 May-Sep	108974	114018	114015	112793	108979	112781	108974	114018	4.5%
E520	63422	66571	66565	66088	63212	66146	63212	66571	5.1%
E522	63389	66373	66372	65851	63157	65900	63157	66373	4.9%
E525	63293	65399	65395	64973	63002	65155	63002	65399	3.7%
E530	45046	46634	46631	46944	44875	47002	44875	47002	4.6%
E540	45113	47130	47126	47297	44980	47462	44980	47462	5.3%
E545	44981	46240	46236	46612	44775	46668	44775	46668	4.1%

Sensible Coil Load (kWh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	56662	55797	55805	55252	55209	55191	55191	56662	2.6%
E310	56256	56301	56313	55225	55185	55083	55083	56313	2.2%
E320	62859	62697	62747	62043	62009	62734	62009	62859	1.4%
E330	63083	63311	63328	63779	62649	61822	61822	63779	3.1%
E340	63033	63053	63111	62886	62381	61406	61406	63111	2.7%
E350	50371	47684	47677	48545	48589	48768	47677	50371	5.5%
E360	134977	134920	134940	135287	134206	134697	134206	135287	0.8%
E400	41952	41419	41437	40688		41181	40688	41952	3.1%
E410	45677	47659	47660			45585	45585	47660	4.4%
E420	50390	49666	50612	49524		49984	49524	50612	2.2%
E430	47863	47731	47454	46739		46143	46143	47863	3.6%
E440	50876	50593	50492	50060		49785	49785	50876	2.2%
E500	45044	47650	47646	47491	44874	47530	44874	47650	5.9%
E500 May-Sep	34443	36596	36593	36476	34448	36480	34443	36596	6.0%
E510 May-Sep	77489	82306	82303	81566	77499	81563	77489	82306	6.0%
E520	45110	48102	48096	47986	44977	48059	44977	48102	6.6%
E522	45076	47962	47961	47758	44924	47795	44924	47962	6.5%
E525	44979	47218	47213	46930	44775	47110	44775	47218	5.3%
E530	45046	46574	46570	46944	44874	47002	44874	47002	4.6%
E540	45112	47023	47019	47288	44977	47460	44977	47460	5.3%
E545	44981	46214	46210	46612	44775	46668	44775	46668	4.1%

Latent Coil Load(kWh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	23765	21487	21487	22066	22535	23067	21487	23765	10.2%
E310	43086	41094	41099	41222	42111	42178	41094	43086	4.8%
E320	36932	33659	33746	34040	35133	34224	33659	36932	9.5%
E330	41929	37419	37666	38433	41063	40186	37419	41929	11.4%
E340	39695	35974	36113	36823	38296	38346	35974	39695	9.9%
E350	19017	16052	15958	17245	18271	18621	15958	19017	17.5%
E360	27997	24887	24914	25961	26994	27470	24887	27997	11.8%
E400	26840	23498	23588	24726		25717	23498	26840	13.4%
E410	22996	19121	19184			20590	19121	22996	18.9%
E420	22219	19945	20270	20826		21855	19945	22219	10.8%
E430	21893	19909	19765	20403		21057	19765	21893	10.3%
E440	22835	20788	20689	21357		22244	20689	22835	9.9%
E500	18313	18346	18346	18080	18231	18084	18080	18346	1.5%
E500 May-Sep	14000	14097	14097	13879	13991	13877	13877	14097	1.6%
E510 May-Sep	31485	31712	31712	31226	31480	31217	31217	31712	1.6%
E520	18312	18470	18470	18101	18235	18087	18087	18470	2.1%
E522	18313	18411	18410	18093	18233	18104	18093	18411	1.7%
E525	18314	18182	18182	18044	18227	18045	18044	18314	1.5%
E530	0	61	61	0	1	0	0	61	297.1%
E540	1	107	107	9	3	2	1	107	278.2%
E545	0	25	25	0	0	0	0	25	300.0%

e300results.xls q:a125..m198; 07/19/04

Various Annual Means (COP2, IDB)

COP2	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	3.249	3.238	3.237	3.237	3.226	3.230	3.226	3.249	0.7%
E310	3.415	3.417	3.417	3.393	3.397	3.380	3.380	3.417	1.1%
E320	3.420	3.458	3.457	3.405	3.406	3.390	3.390	3.458	2.0%
E330	3.491	3.494	3.536	3.491	3.497	3.460	3.460	3.536	2.2%
E340	3.454	3.477	3.496	3.448	3.450	3.420	3.420	3.496	2.2%
E350	3.249	3.241	3.235	3.244	3.229	3.230	3.229	3.249	0.6%
E360	3.669	3.701	3.706	3.678	3.667	3.660	3.660	3.706	1.2%
E400	3.250	3.251	3.252	3.246		3.260	3.246	3.260	0.4%
E410	3.240	3.212	3.211			3.210	3.210	3.240	0.9%
E420	3.226	3.215	3.218	3.216		3.210	3.210	3.226	0.5%
E430	3.221	3.213	3.211	3.211		3.210	3.210	3.221	0.3%
E440	3.231	3.222	3.222	3.221		3.220	3.220	3.231	0.4%
E500	3.204	3.227	3.227	3.213	3.192	3.200	3.192	3.227	1.1%
E500 May-Sep	3.142	3.161	3.162	3.154	3.132	3.140	3.132	3.162	0.9%
E510 May-Sep	3.551	3.577	3.577	3.562	3.530	3.550	3.530	3.577	1.3%
E520	2.901	2.957	2.956	3.004	2.873	2.920	2.873	3.004	4.5%
E522	3.058	3.074	3.073	3.101	3.036	3.070	3.036	3.101	2.1%
E525	3.484	3.531	3.528	3.508	3.480	3.410	3.410	3.531	3.5%
E530	2.962	2.969	2.969	2.999	2.916	2.980	2.916	2.999	2.8%
E540	2.668	2.675	2.675	2.823	2.640	2.690	2.640	2.823	6.8%
E545	3.228	3.233	3.236	3.157	3.186	3.200	3.157	3.236	2.5%

IDB (°C)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	23.62	24.06	24.06	24.09	24.08	23.99	23.62	24.09	1.9%
E310	23.76	24.11	24.06	24.09	24.09	24.01	23.76	24.11	1.5%
E320	23.90	24.39	24.39	24.25	24.33	24.53	23.90	24.53	2.6%
E330	23.88	24.28	24.28	24.27	24.30	24.18	23.88	24.30	1.7%
E340	23.88	24.28	24.28	24.30	24.31	24.21	23.88	24.31	1.8%
E350	25.66	26.17	26.17	26.24	26.27	26.15	25.66	26.27	2.3%
E360	25.36	25.61	25.56	25.32	25.48	25.37	25.32	25.61	1.1%
E400	24.13	24.06	24.06	24.09		23.99	23.99	24.13	0.6%
E410	24.12	24.06	24.06			23.99	23.99	24.12	0.5%
E420	23.93	24.06	24.06	24.09		23.99	23.93	24.09	0.7%
E430	23.99	24.06	24.06	24.09		23.99	23.99	24.09	0.4%
E440	23.91	24.06	24.06	24.09		23.99	23.91	24.09	0.7%
E500	20.23	20.67	20.56	20.38	21.10	22.86	20.23	22.86	12.5%
E500 May-Sep	24.57	25.00	25.00	24.98	25.00	25.00	24.57	25.00	1.7%
E510 May-Sep	25.82	25.11	25.11	24.96	25.00	25.00	24.96	25.82	3.4%
E520	13.52	13.78	13.72	13.58	14.14	14.89	13.52	14.89	9.9%
E522	16.95	17.28	17.22	17.00	17.73	18.70	16.95	18.70	10.0%
E525	26.84	27.39	27.28	27.10	27.77	30.69	26.84	30.69	13.8%
E530	20.03	20.61	20.56	20.59	21.10	22.86	20.03	22.86	13.5%
E540	13.29	13.78	13.72	13.79	14.14	14.98	13.29	14.98	12.1%
E545	26.61	27.33	27.28	27.31	27.72	30.69	26.61	30.69	14.7%

e300results.xls q:a205..m254; 07/19/04

Various Annual Means (Humidity Ratio, Zone Relative Humidity)

Humidity Ratio (kg/kg)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	0.0091	0.0092	0.0092	0.0093	0.0092	0.0092	0.0091	0.0093	2.4%
E310	0.0111	0.0113	0.0113	0.0113	0.0112	0.0111	0.0111	0.0113	2.0%
E320	0.0100	0.0101	0.0101	0.0101	0.0100	0.0099	0.0099	0.0101	2.1%
E330	0.0097	0.0099	0.0099	0.0100	0.0098	0.0099	0.0097	0.0100	2.3%
E340	0.0098	0.0099	0.0099	0.0100	0.0099	0.0099	0.0098	0.0100	1.9%
E350	0.0097	0.0100	0.0100	0.0099	0.0098	0.0098	0.0097	0.0100	3.0%
E360	0.0085	0.0087	0.0087	0.0088	0.0086	0.0086	0.0085	0.0088	3.1%
E400	0.0098	0.0100	0.0100	0.0101		0.0100	0.0098	0.0101	2.9%
E410	0.0097	0.0095	0.0095			0.0095	0.0095	0.0097	2.5%
E420	0.0093	0.0094	0.0094	0.0094		0.0093	0.0093	0.0094	2.0%
E430	0.0093	0.0094	0.0094	0.0095		0.0094	0.0093	0.0095	1.9%
E440	0.0092	0.0093	0.0093	0.0093		0.0092	0.0092	0.0093	1.9%
E500	0.0098			0.0094	0.0102	0.0107	0.0094	0.0107	13.2%
E500 May-Sep	0.0110	0.0114	0.0114	0.0113	0.0113	0.0109	0.0109	0.0114	4.5%
E510 May-Sep	0.0114	0.0114	0.0114	0.0113	0.0113	0.0109	0.0109	0.0114	4.4%
E520	0.0067			0.0060	0.0070	0.0076	0.0060	0.0076	23.1%
E522	0.0082			0.0076	0.0086	0.0090	0.0076	0.0090	16.8%
E525	0.0137			0.0138	0.0140	0.0151	0.0137	0.0151	9.8%
E530	0.0062			0.0067	0.0058	0.0067	0.0058	0.0067	14.4%
E540	0.0045			0.0043	0.0039	0.0046	0.0039	0.0046	17.9%
E545	0.0062			0.0067	0.0067	0.0072	0.0062	0.0072	14.8%

Relative Humidity (%)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	48.61	48.26	48.28	48.59	47.83	47.93	47.83	48.61	1.6%
E310	58.33	58.51	58.53	58.55	57.84	57.80	57.80	58.55	1.3%
E320	52.01	51.21	51.25	51.84	51.10	49.94	49.94	52.01	4.0%
E330	50.84	50.58	50.65	51.18	50.08	50.70	50.08	51.18	2.2%
E340	51.09	50.69	50.73	51.15	50.30	50.78	50.30	51.15	1.7%
E350	45.48	45.45	45.55	45.17	44.32	44.56	44.32	45.55	2.7%
E360	41.03	41.49	41.49	42.37	40.87	41.21	40.87	42.37	3.6%
E400	50.77	52.21	52.25	52.55		52.01	50.77	52.55	3.4%
E410	50.50	49.65	49.63			49.75	49.63	50.50	1.7%
E420	48.78	49.14	48.97	49.40		48.76	48.76	49.40	1.3%
E430	48.82	49.17	49.30	49.60		49.17	48.82	49.60	1.6%
E440	48.33	48.46	48.57	48.83		48.23	48.23	48.83	1.2%
E500	66.53			59.20	65.94	63.73	59.20	66.53	11.5%
E500 May-Sep	57.05	57.47	57.47	57.32	57.07	55.13	55.13	57.47	4.1%
E510 May-Sep	54.70	57.36	57.36	57.44	57.06	55.24	54.70	57.44	4.8%
E520	69.87			61.40	70.23	72.17	61.40	72.17	15.7%
E522	68.68			60.75	68.23	68.11	60.75	68.68	11.9%
E525	61.47			54.99	60.14	57.37	54.99	61.47	11.1%
E530	46.73			48.97	41.45	39.60	39.60	48.97	21.2%
E540	48.52			46.31	40.05	43.82	40.05	48.52	19.0%
E545	36.62			38.63	36.87	29.20	29.20	38.63	26.7%

e300results.xls q:a255..m304; 07/19/04

f(ODB) Sensitivity E500 and E530, April 30 and June 25

	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
Energy Consumption, Compr. + Both Fans (Wh,e)									
E500Apr30	3893	3975	3975	4029	3901	4073	3893	4073	4.5%
E500Jun25	5045	5204	5204	5229	5067	5230	5045	5230	3.6%
Del E500	1152	1229	1229	1200	1165	1157	1152	1229	6.5%
E530Apr30	3023	3062	3062	3101	3092	3144	3023	3144	3.9%
E530Jun25	3894	3978	3978	4029	3935	4043	3894	4043	3.7%
Del E530	871	916	916	927	843	899	843	927	9.4%
Energy Consumption, Compressor (Wh,e)									
E500Apr30	3015	3120	3120		3020	3159	3015	3159	4.7%
E500Jun25	4084	4264	4263		4106	4239	4084	4264	4.3%
Del E500	1069	1144	1144		1086	1080	1069	1144	6.7%
E530Apr30	2311	2390	2390		2378	2411	2311	2411	4.2%
E530Jun25	3118	3243	3243		3166	3248	3118	3248	4.1%
Del E530	807	853	853		787	837	787	853	8.0%
Energy Consumption, Condenser Fan (Wh,e)									
E500Apr30	376	389	389		377	391	376	391	3.9%
E500Jun25	411	426	426		411	424	411	426	3.6%
Del E500	35	37	37		34	33	33	37	12.0%
E530Apr30	305	311	311		305	314	305	314	3.1%
E530Jun25	332	340	340		329	340	329	340	3.2%
Del E530	28	28	29		24	26	24	29	17.0%
Energy Consumption, Supply Fan (Wh,e)									
E500Apr30	502	467	466	519	504	522	466	522	11.2%
E500Jun25	550	514	514	566	549	566	514	566	9.5%
Del E500	47	48	48	47	45	44	44	48	8.5%
E530Apr30	407	361	361	412	408	419	361	419	14.8%
E530Jun25	444	396	396	450	440	454	396	454	13.6%
Del E530	37	35	35	38	32	35	32	38	16.0%
Sensible + Latent Coil Load (Wh,th)									
E500Apr30	13186	13733	13733	13655	13170	13673	13170	13733	4.2%
E500Jun25	13188	13838	13837	13733	13198	13727	13188	13838	4.8%
Del E500	2	105	104	78	29	54	2	105	165.3%
E530Apr30	9353	9721	9721	9775	9365	9798	9353	9798	4.6%
E530Jun25	9376	9761	9761	9835	9388	9834	9376	9835	4.8%
Del E530	23	40	39	60	22	36	22	60	102.8%
Sensible Coil Load (Wh,th)									
E500Apr30	9375	9925	9925	9884	9365	9902	9365	9925	5.8%
E500Jun25	9378	9981	9981	9953	9388	9946	9378	9981	6.2%
Del E500	3	56	56	69	22	44	3	69	158.2%
E530Apr30	9353	9721	9721	9775	9365	9798	9353	9798	4.6%
E530Jun25	9376	9761	9761	9835	9388	9834	9376	9835	4.8%
Del E530	23	40	39	60	22	36	22	60	102.9%
Latent Coil Load (Wh,th)									
E500Apr30	3811	3808	3808	3772	3804	3770	3770	3811	1.1%
E500Jun25	3810	3856	3856	3781	3810	3780	3780	3856	2.0%
Del E500	-1	48	48	9	6	10	-1	48	242.3%
E530Apr30	0	0	0	0	0	0	0	0	28464.8%
E530Jun25	0	0	0	0	0	0	0	0	300.0%
Del E530	0	0	0	0	0	0	0	0	300.0%

e300results.xls q:a316..m69; 07/19/04

f(ODB) Sensitivity E500 and E530, April 30 and June 25

	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
Humidity Ratio (kg/kg)									
E500Apr30	0.0107	0.0110	0.0110	0.0110	0.0109	0.0160	0.011	0.016	45.3%
E500Jun25	0.0112	0.0115	0.0115	0.0115	0.0115	0.0110	0.011	0.012	4.4%
Del E500	0.0005	0.0005	0.0005	0.0005	0.0005	-0.0050	-0.005	0.001	-1334.8%
E530Apr30	0.0062	0.0071	0.0071	0.0068	0.0055	0.0067	0.005	0.007	24.6%
E530Jun25	0.0062	0.0078	0.0078	0.0068	0.0055	0.0067	0.005	0.008	34.2%
Del E530	0.0000	0.0007	0.0007	0.0000	0.0000	0.0000	0.000	0.001	304.5%
COP2									
E500Apr30	3.845	3.914	3.914	3.850	3.837	3.850	3.837	3.914	2.0%
E500Jun25	2.931	2.951	2.951	2.943	2.921	2.940	2.921	2.951	1.0%
Del E500	-0.914	-0.963	-0.963	-0.907	-0.916	-0.910	-0.963	-0.907	-6.1%
E530Apr30	3.543	3.599	3.599	3.441	3.460	3.590	3.441	3.599	4.5%
E530Jun25	2.720	2.724	2.724	2.780	2.690	2.740	2.690	2.780	3.3%
Del E530	-0.823	-0.874	-0.875	-0.662	-0.770	-0.850	-0.875	-0.662	-26.3%
ODB (°C)									
E500Apr30	16.79	16.83	16.83	16.81	16.88	16.96	16.79	16.96	1.0%
E500Jun25	29.52	29.50	29.50	29.52	29.52	29.50	29.50	29.52	0.1%
Del E500	12.73	12.67	12.67	12.70	12.63	12.54	12.54	12.73	1.5%
E530Apr30	16.79	16.83	16.83	16.81	16.88	16.96	16.79	16.96	1.0%
E530Jun25	29.52	29.50	29.50	29.52	29.52	29.50	29.50	29.52	0.1%
Del E530	12.73	12.67	12.67	12.70	12.63	12.54	12.54	12.73	1.5%
EDB (°C)									
E500Apr30	24.64	24.94	24.94	24.98	25.00	25.00	24.64	25.00	1.4%
E500Jun25	24.55	25.00	25.00	24.98	25.00	25.00	24.55	25.00	1.8%
Del E500	-0.09	0.06	0.06	0.00	0.00	0.00	-0.09	0.06	4740.8%
E530Apr30	24.37	24.94	24.67	25.00	25.00	25.00	24.37	25.00	2.6%
E530Jun25	24.35	24.94	24.94	25.00	25.00	25.00	24.35	25.00	2.6%
Del E530	-0.01	0.00	0.28	0.00	0.00	0.00	-0.01	0.28	651.2%

e300results.xls q:a370..m402; 07/19/04

Hourly Integrated Maxima (Total Cooling System Energy Consumption and Total Coil Load)

Energy Consumption, Compressor + Both Fans (Wh,e)

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	11626	20-Jul	15	11564	20-Jul	15	11602	20-Jul	15	11900	07/20	15:00	11932	20-Jul	15	11548	20-Jul	15	11548	11932	3.3%
E310	12594	20-Jul	15	12583	20-Jul	15	12595	20-Jul	15	12541	07/20	15:00	12653	20-Jul	15	12162	16-Aug	16	12162	12653	3.9%
E320	13028	20-Jul	15	12916	20-Jul	15	12981	20-Jul	15	12954	07/20	15:00	13104	20-Jul	15	12875	20-Jul	14	12875	13104	1.8%
E330	13347	20-Jul	15	13212	20-Jul	15	13407	20-Jul	15	13314	07/20	15:00	13467	20-Jul	15	13335	20-Jul	15	13212	13467	1.9%
E340	13181	20-Jul	15	13158	20-Jul	15	13190	20-Jul	15	13134	07/20	15:00	13277	20-Jul	15	13101	20-Jul	14	13101	13277	1.3%
E350	11627	20-Jul	15	11654	20-Jul	15	11602	20-Jul	15	11900	07/20	15:00	11932	20-Jul	15	11546	20-Jul	15	11546	11932	3.3%
E360	12770	20-Jul	15	12736	20-Jul	15	12726	20-Jul	15	12744	07/20	15:00	12863	20-Jul	15	12762	20-Jul	14	12726	12863	1.1%
E400	11628	20-Jul	15	11564	20-Jul	15	11677	18-Sep	15	11900	07/20	15:00				11519	20-Jul	15	11519	11900	3.3%
E410	11628	20-Jul	15	11564	20-Jul	15	11602	20-Jul	15							11549	20-Jul	15	11549	11628	0.7%
E420	11626	20-Jul	15	11564	20-Jul	15	11602	20-Jul	15	11900	07/20	15:00				11548	20-Jul	15	11548	11900	3.0%
E430	11626	20-Jul	15	11564	20-Jul	15	11602	20-Jul	15	11900	07/20	15:00				11548	20-Jul	15	11548	11900	3.0%
E440	11626	20-Jul	15	11564	20-Jul	15	11602	20-Jul	15	11900	07/20	15:00				11461	16-Aug	16	11461	11900	3.8%
E500	10166	20-Jul	15	10431	20-Jul	15	10425	20-Jul	15	10399	07/20	15:00	10177	20-Jul	15	10274	4-Jun	15	10166	10431	2.6%
E510	11205	20-Jul	15	11590	20-Jul	15	11587	20-Jul	15	11410	07/20	15:00	11186	20-Jul	15	11344	20-Jul	14	11186	11590	3.5%
E520	11035	20-Jul	15	10989	20-Jul	15	11014	20-Jul	15	11101	07/20	15:00	11044	20-Jul	15	10684	4-Jun	15	10684	11101	3.8%
E522	10431	20-Jul	15	10972	20-Jul	15	10966	20-Jul	15	10762	07/20	15:00	10639	20-Jul	15	10747	16-Aug	15	10431	10972	5.0%
E525	9367	20-Jul	15	9538	20-Jul	15	9531	20-Jul	15	9570	07/20	15:00	9419	20-Jul	15	9585	16-Aug	15	9367	9585	2.3%
E530	8028	20-Jul	15	8059	20-Jul	15	8055	20-Jul	15	8171	07/20	15:00	7992	20-Jul	15	8089	16-Aug	15	7992	8171	2.2%
E540	8699	20-Jul	15	8943	20-Jul	15	8939	20-Jul	15	8677	07/20	15:00	8846	20-Jul	15	8985	16-Aug	15	8677	8985	3.5%
E545	7205	20-Jul	15	7350	20-Jul	15	7346	20-Jul	15	7763	07/20	15:00	7351	20-Jul	15	7471	4-Jun	15	7205	7763	7.5%

Sensible + Latent Coil Load (Wh,th)

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	32174	08-Jul	15	31401	20-Jul	15	31455	20-Jul	15	32733	07/20	15:00	32502	20-Jul	15	32072	20-Jul	15	31401	32733	4.2%
E310	37328	03-Sep	15	36750	3-Sep	16	37033	3-Sep	16	37126	09/17	15:00	37261	3-Sep	15	36991	3-Sep	16	36750	37328	1.6%
E320	40318	03-Sep	16	53813	2-Oct	9	53823	2-Oct	9	39765	09/03	16:00	39904	3-Sep	16	39920	3-Sep	16	39765	53823	31.5%
E330	43492	02-Oct	9	43628	2-Oct	9	64572	2-Oct	9	43445	10/02	09:00	43978	2-Oct	9	42415	10-Jul	11	42415	64572	47.2%
E340	41652	02-Oct	10	50819	2-Oct	9	59549	2-Oct	9	41328	10/02	10:00	41366	3-Sep	15	41132	3-Sep	16	41132	59549	40.1%
E350	32092	08-Jul	15	31401	20-Jul	15	31454	20-Jul	15	32733	07/20	15:00	32502	20-Jul	15	32077	20-Jul	15	31401	32733	4.2%
E360	38857	02-Oct	10	40613	2-Oct	9	41019	2-Oct	9	38460	10/02	11:00	38322	2-Oct	10	38451	2-Oct	10	38322	41019	6.9%
E400	41179	16-Sep	15	40543	18-Sep	14	49838	18-Sep	15	40728	09/16	15:00				40774	16-Sep	14	40543	49838	21.8%
E410	32092	08-Jul	15	31401	20-Jul	15	31455	20-Jul	15							32073	20-Jul	15	31401	32092	2.2%
E420	32174	08-Jul	15	31401	20-Jul	15	31455	20-Jul	15	32733	07/20	15:00				32072	20-Jul	15	31401	32733	4.2%
E430	32174	08-Jul	15	31401	20-Jul	15	31455	20-Jul	15	32733	07/20	15:00				32072	20-Jul	15	31401	32733	4.2%
E440	32174	08-Jul	15	31401	20-Jul	15	31455	20-Jul	15	32733	07/20	15:00				31777	8-Jul	16	31401	32733	4.2%
E500	27486	28-Oct	15	27707	16-Aug	16	27706	16-Aug	16	27646	06/29	16:00	26567	29-Jun	16	27555	29-Jun	15	26567	27707	4.2%
E510	30593	29-Apr	19	31188	20-Jul	15	31188	20-Jul	15	31178	06/17	14:00	29948	17-Jun	14	31097	17-Jun	13	29948	31188	4.0%
E520	27330	28-Sep	15	27878	14-Aug	16	27878	23-Jul	16	27653	06/29	16:00	26675	20-Jul	16	28343	23-May	15	26675	28343	6.0%
E522	27384	12-Mai	15	27868	16-Aug	16	27866	16-Aug	16	27659	06/29	16:00	26514	29-Jun	16	27636	29-Jun	15	26514	27868	4.9%
E525	27740	26-Jul	16	27466	8-Jul	16	27466	8-Jul	16	27577	06/29	16:00	26683	29-Jun	16	27462	29-Jun	15	26683	27740	3.9%
E530	19834	29-Mai	15	19576	24-Apr	16	19575	24-Apr	16	19639	07/20	15:00	18776	4-Jun	15	19626	8-Jul	15	18776	19834	5.4%
E540	19575	30-Aug	16	19766	24-Apr	16	19766	24-Apr	16	19726	07/20	15:00	18794	4-Jun	15	19799	16-Aug	15	18794	19799	5.1%
E545	20075	17-Jun	16	19475	24-Apr	16	19474	24-Apr	16	19540	07/20	15:00	18764	20-Jul	15	19497	4-Jun	15	18764	20075	6.7%

Hourly Integrated Maxima (Sensible Coil Load and Latent Coil Load)

Sensible Coil Load (Wh,th)	TRNSYS			DOE-2.2			DOE21E-E			Energy+			CODYRUN			HOT3000			Statistics, All Results		(Max-Min)
	TUD	Date	Hour	NREL	Date	Hour	NREL	Date	Hour	GARD	Date	Hour	UR	Date	Hour	NRCan	Date	Hour	Min	Max	/Mean
E300	23277	20-Jul	16	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00	23457	20-Jul	15	22908	4-Jun	15	22908	23531	2.7%
E310	23094	10-Sep	15	23080	10-Sep	16	23119	4-Jun	16	23276	07/11	16:00	23078	10-Sep	15	22649	13-Jun	16	22649	23276	2.7%
E320	31316	24-Apr	16	31119	24-Apr	16	31072	24-Apr	16	31972	04/24	15:00	31134	3-Jun	16	30967	24-Apr	15	30967	31972	3.2%
E330	33226	14-Jun	14	33410	14-Jun	14	34490	14-Jun	15	34765	06/14	15:00	33997	24-Apr	16	33421	9-Sep	14	33226	34765	4.5%
E340	32829	24-Apr	15	32086	16-May	16	32086	16-May	16	32888	04/24	15:00	32940	24-Apr	16	32180	24-Apr	15	32086	32940	2.6%
E350	23278	29-Jul	15	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00	23457	20-Jul	15	22876	10-Jul	15	22876	23531	2.8%
E360	32061	24-Apr	16	32111	24-Apr	16	32065	24-Apr	16	32621	04/24	16:00	31981	24-Apr	16	32179	24-Apr	15	31981	32621	2.0%
E400	23278	29-Jul	15	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00				22877	8-Jul	16	22877	23531	2.8%
E410	23266	10-Sep	16	23203	20-Jul	15	23205	20-Jul	15							22893	29-Jul	15	22893	23266	1.6%
E420	23277	20-Jul	16	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00				22893	29-Jul	15	22893	23531	2.7%
E430	23277	20-Jul	16	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00				22893	29-Jul	15	22893	23531	2.7%
E440	23277	20-Jul	16	23203	20-Jul	15	23205	20-Jul	15	23531	07/20	15:00				22875	16-Aug	16	22875	23531	2.8%
E500	19549	28-Oct	15	20009	4-Jun	16	20008	10-Sep	16	19849	07/20	15:00	18776	4-Jun	15	19818	29-Jul	15	18776	20009	6.3%
E510	21729	29-Apr	19	22513	11-Jul	15	22513	11-Jul	15	22290	07/20	15:00	21121	4-Jun	13	22269	20-Jul	14	21121	22513	6.3%
E520	19416	28-Sep	15	20159	26-May	16	20154	26-May	16	19999	07/20	15:00	18969	20-Jul	16	20378	23-May	15	18969	20378	7.1%
E522	19489	12-Mai	15	20137	11-Jul	16	20135	11-Jul	16	19934	07/20	15:00	18785	4-Jun	15	19920	16-Aug	15	18785	20137	6.9%
E525	19703	26-Jul	16	19850	24-Apr	16	19850	24-Apr	16	19664	07/20	15:00	18759	4-Jun	15	19661	4-Jun	15	18759	19850	5.6%
E530	19834	29-Mai	15	19576	24-Apr	16	19575	24-Apr	16	19639	07/20	15:00	18776	4-Jun	15	19626	8-Jul	15	18776	19834	5.4%
E540	19575	30-Aug	16	19766	24-Apr	16	19766	24-Apr	16	19726	07/20	15:00	18794	4-Jun	15	19799	16-Aug	15	18794	19799	5.1%
E545	20075	17-Jun	16	19475	24-Apr	16	19474	24-Apr	16	19540	07/20	15:00	18759	4-Jun	15	19497	4-Jun	15	18759	20075	6.8%

Latent Coil Load (Wh,th)	TRNSYS			DOE-2.2			DOE21E-E			Energy+			CODYRUN			HOT3000			Statistics, All Results		(Max-Min)
	TUD	Date	Hour	NREL	Date	Hour	NREL	Date	Hour	GARD	Date	Hour	UR	Date	Hour	NRCan	Date	Hour	Min	Max	/Mean
E300	9636	03-Sep	16	9304	3-Sep	15	9394	3-Sep	15	10235	07/10	13:00	10375	3-Sep	15	10392	3-Sep	15	9304	10392	11.0%
E310	15907	03-Sep	15	15139	3-Sep	15	15270	3-Sep	15	16275	08/04	15:00	16112	4-Aug	15	16077	3-Sep	16	15139	16275	7.2%
E320	23147	02-Oct	10	31497	2-Oct	9	31503	2-Oct	9	22195	10/02	10:00	21697	17-Sep	12	21929	1-Oct	20	21697	31503	38.7%
E330	27825	18-Sep	16	26941	18-Sep	15	40809	2-Oct	9	27134	09/18	16:00	28184	18-Sep	15	27488	18-Sep	15	26941	40809	46.6%
E340	24848	02-Oct	9	30451	2-Oct	9	36011	2-Oct	9	23911	10/02	10:00	24225	3-Sep	17	23794	1-Oct	20	23794	36011	44.9%
E350	9751	01-Oct	13	9303	3-Sep	15	9393	3-Sep	15	10235	07/10	13:00	10755	2-Oct	8	11603	3-Aug	7	9303	11603	22.6%
E360	9275	02-Oct	10	10026	2-Oct	9	10336	2-Oct	9	8520	10/02	11:00	8859	3-Sep	17	8934	3-Sep	17	8520	10336	19.5%
E400	27075	16-Sep	15	25578	18-Sep	14	32396	18-Sep	15	26317	09/16	14:00				26645	16-Sep	14	25578	32396	24.7%
E410	11139	16-Sep	15	9304	3-Sep	15	9391	3-Sep	15							10377	9-Sep	15	9304	11139	18.3%
E420	9751	01-Oct	13	9304	3-Sep	15	9394	3-Sep	15	10235	07/10	13:00				10394	3-Sep	15	9304	10394	11.1%
E430	9636	03-Sep	16	11105	24-Oct	14	11101	21-May	15	11074	10/24	13:00				10394	3-Sep	15	9636	11105	13.8%
E440	9636	03-Sep	16	9304	3-Sep	15	9391	3-Sep	15	10235	07/10	13:00				10139	3-Sep	15	9304	10235	9.6%
E500	7965	06-Oct	15	7733	3-Sep	15	7733	3-Sep	15	7839	06/29	16:00	7805	29-Jun	16	7762	29-Jun	15	7733	7965	3.0%
E510	8893	15-Sep	11	8723	2-Oct	9	8723	2-Oct	9	8955	06/17	14:00	8850	17-Jun	14	8874	17-Jun	13	8723	8955	2.6%
E520	7914	28-Sep	15	7785	3-Sep	15	7785	3-Sep	15	7699	06/29	16:00	7726	30-Jun	16	7964	23-May	15	7699	7964	3.4%
E522	7907	02-Mai	15	7760	3-Sep	15	7760	3-Sep	15	7770	06/29	16:00	7743	29-Jun	16	7745	29-Jun	15	7743	7907	2.1%
E525	8037	26-Jul	16	7663	3-Sep	15	7663	3-Sep	15	7947	06/29	16:00	7938	29-Jun	16	7820	29-Jun	15	7663	8037	4.8%
E530	0	18-Jun	16	0	0-Jan	0	0	0-Jan	0	1	03/16	10:00	179	11-Mar	11	36	1-Nov	20	0	179	497.3%
E540	627	11-Mar	10	0	0-Jan	0	0	0-Jan	0	1655	03/11	10:00	845	11-Mar	10	1181	11-Mar	10	0	1655	230.5%
E545	0	01-Jul	16	0	0-Jan	0	0	0-Jan	0	0	05/23	15:00	4	20-Jul	15	0	1-Jan	1	0	4	600.0%

e300results.xls r:a07..w102; 08/19/04

Hourly Integrated Maxima and Minima (COP2)

Maximum COP2

	TRNSYS			DOE-2.2			DOE21E-E			Energy+			CODYRUN			HOT3000			Statistics, All Results		
	TUD	Date	Hour	NREL	Date	Hour	NREL	Date	Hour	GARD	Date	Hour	UR	Date	Hour	NRCan	Date	Hour	Min	Max	(Max-Min) /Mean
E300	4.168	16-Apr	3	3.869	30-Apr	16	3.857	30-Apr	16	3.925	04/30	15:00	3.871	30-Apr	16	3.880	30-Apr	16	3.857	4.168	7.9%
E310	4.143	30-Apr	15	4.141	30-Apr	16	4.128	30-Apr	16	4.173	04/30	15:00	4.128	30-Apr	15	4.120	30-Apr	15	4.120	4.173	1.3%
E320	4.168	16-Apr	3	5.143	2-Oct	9	4.967	2-Oct	9	3.940	09/16	15:00	3.943	16-Sep	15	4.380	18-Dec	3	3.940	5.143	27.2%
E330	4.168	16-Apr	3	4.109	17-Jun	16	5.595	2-Oct	9	4.071	09/16	14:00	4.122	17-Jun	16	4.050	17-Jun	16	4.050	5.595	35.5%
E340	4.168	16-Apr	3	4.621	2-Oct	9	5.339	2-Oct	9	3.987	09/16	15:00	4.017	16-Sep	16	3.950	16-Sep	16	3.950	5.339	32.0%
E350	4.168	16-Apr	3	3.889	27-Apr	5	3.863	5-Oct	3	4.555	10/13	01:00	3.932	4-Oct	24	3.880	30-Apr	16	3.863	4.555	17.1%
E360	4.401	05-Oct	1	4.428	4-Oct	24	4.427	4-Oct	24	4.455	10/04	24:00	4.432	4-Oct	24	4.440	4-Oct	24	4.401	4.455	1.2%
E400	4.077	16-Sep	15	4.088	17-Jun	16	4.776	18-Sep	15	4.071	09/16	14:00				4.050	17-Jun	16	4.050	4.776	17.2%
E410	3.888	30-Apr	15	3.903	30-Apr	15	3.855	30-Apr	16							3.840	21-May	15	3.840	3.903	1.6%
E420	3.781	27-Sep	16	3.807	21-May	15	3.759	27-Sep	15	3.821	05/21	15:00				3.940	21-May	13	3.759	3.940	4.7%
E430	3.781	27-Sep	16	3.805	24-Oct	15	3.759	27-Sep	15	3.793	05/21	16:00				3.930	30-Apr	13	3.759	3.930	4.5%
E440	3.883	12-Dez	7	3.774	27-Sep	15	3.759	27-Sep	15	3.802	05/21	15:00				3.810	30-Apr	15	3.759	3.883	3.3%
E500	4.275	13-Oct	1	7.367	11-Mar	10	5.301	13-Oct	9	4.198	03/16	10:00	4.185	16-Mar	10	4.140	30-Apr	16	4.140	7.367	65.7%
E510	4.693	05-Oct	1	7.367	11-Mar	10	5.301	13-Oct	9	4.685	10/05	01:00	4.690	4-Oct	24	4.530	4-May	3	4.530	7.367	54.4%
E520	3.814	30-Apr	15	4.896	16-Mar	10	4.652	16-Mar	10	3.938	04/30	15:00	3.802	30-Apr	16	3.840	30-Apr	16	3.802	4.896	26.3%
E522	3.986	16-Mar	10	6.233	11-Mar	10	5.678	11-Mar	10	4.042	04/30	15:00	3.986	30-Apr	16	4.000	30-Apr	16	3.986	6.233	48.3%
E525	4.718	13-Oct	1	6.325	12-Apr	9	6.031	16-Mar	10	4.704	03/16	10:00	4.638	16-Mar	10	4.400	16-Mar	10	4.400	6.325	37.5%
E530	4.006	02-Nov	1	3.981	11-Mar	10	3.850	13-Oct	9	3.925	03/16	10:00	3.840	16-Mar	10	3.880	16-Mar	10	3.840	4.006	4.2%
E540	3.456	30-Apr	15	3.456	30-Apr	16	3.455	30-Apr	16	3.696	03/16	10:00	3.667	11-Mar	22	3.690	17-Oct	5	3.455	3.696	6.7%
E545	4.250	16-Mar	10	4.275	16-Mar	10	4.428	16-Mar	10	4.166	03/16	10:00	4.156	16-Mar	10	4.170	16-Mar	10	4.156	4.428	6.4%

Minimum COP2

	TRNSYS			DOE-2.2			DOE21E-E			Energy+			CODYRUN			HOT3000			Statistics, All Results		
	TUD	Date	Hour	NREL	Date	Hour	NREL	Date	Hour	GARD	Date	Hour	UR	Date	Hour	NRCan	Date	Hour	Min	Max	(Max-Min) /Mean
E300	2.793	24-Apr	17	2.798	1-Dec	14	2.801	1-Dec	12	2.782	06/13	17:00	2.786	13-Jun	17	2.810	14-Jun	12	2.782	2.810	1.0%
E310	2.865	01-Dec	15	2.850	1-Dec	14	2.851	1-Dec	12	2.893	12/01	15:00	2.873	1-Dec	15	2.870	1-Dec	14	2.850	2.893	1.5%
E320	2.825	31-Mar	14	2.801	1-Dec	14	2.805	1-Dec	15	2.842	03/31	15:00	2.815	31-Mar	15	2.830	31-Mar	14	2.801	2.842	1.4%
E330	2.825	31-Mar	14	2.798	1-Dec	14	2.801	1-Dec	12	2.844	03/31	15:00	2.823	31-Mar	15	2.840	31-Mar	14	2.798	2.844	1.6%
E340	2.825	31-Mar	14	2.798	1-Dec	14	2.801	1-Dec	12	2.844	03/31	15:00	2.823	31-Mar	15	2.840	31-Mar	14	2.798	2.844	1.6%
E350	2.790	24-Apr	17	2.798	1-Dec	14	2.801	1-Dec	12	2.782	06/13	17:00	2.786	13-Jun	17	2.810	14-Jun	12	2.782	2.810	1.0%
E360	2.825	31-Mar	14	2.799	1-Dec	14	2.801	1-Dec	12	2.844	03/31	15:00	2.823	31-Mar	15	2.840	31-Mar	14	2.799	2.844	1.6%
E400	2.782	31-Mar	19	2.734	3-Dec	15	2.735	3-Dec	13	2.782	06/13	17:00				2.810	14-Jun	12	2.734	2.810	2.7%
E410	2.786	24-Apr	17	2.798	1-Dec	14	2.801	1-Dec	12							2.810	14-Jun	12	2.786	2.810	0.9%
E420	2.793	24-Apr	17	2.798	1-Dec	14	2.801	1-Dec	12	2.782	06/13	17:00				2.810	14-Jun	12	2.782	2.810	1.0%
E430	2.771	30-Mar	19	2.734	3-Dec	13	2.735	3-Dec	13	2.782	06/13	17:00				2.810	14-Jun	12	2.734	2.810	2.7%
E440	2.782	31-Mar	19	2.734	3-Dec	13	2.735	3-Dec	13	2.782	06/13	17:00				2.810	8-Apr	13	2.734	2.810	2.7%
E500	2.685	30-Jul	12	2.693	29-Jul	12	2.652	30-Mar	17	2.705	07/30	12:00	2.666	30-Jul	12	2.710	29-Jul	12	2.652	2.710	2.2%
E510	2.888	31-Mar	15	2.817	5-Apr	17	2.652	30-Mar	17	2.865	03/31	18:00	2.882	31-Mar	15	2.900	31-Mar	14	2.652	2.900	8.8%
E520	2.442	30-Jul	12	2.463	5-Apr	17	2.394	5-Apr	17	2.532	07/30	12:00	2.333	29-Jan	10	2.470	30-Jul	12	2.333	2.532	8.1%
E522	2.569	08-Jul	17	2.572	29-Jul	12	2.562	31-Mar	17	2.613	07/30	12:00	2.429	30-Mar	17	2.590	29-Jul	12	2.429	2.613	7.2%
E525	2.911	14-Jul	17	2.939	30-Jul	12	2.814	31-Mar	17	2.940	07/30	12:00	2.894	29-Jul	12	2.900	29-Jul	12	2.814	2.940	4.3%
E530	2.501	30-Jul	12	2.495	29-Jul	12	2.498	29-Jul	12	2.532	07/30	12:00	2.473	29-Jul	12	2.520	29-Jul	12	2.473	2.532	2.3%
E540	2.253	30-Jul	12	2.261	29-Jul	12	2.262	30-Jul	12	2.383	07/30	12:00	2.143	5-Apr	20	2.280	29-Jul	12	2.143	2.383	10.6%
E545	2.733	14-Jul	17	2.720	29-Jul	12	2.722	30-Jul	12	2.660	07/30	12:00	2.692	29-Jul	12	2.720	29-Jul	12	2.660	2.733	2.7%

Hourly Integrated Maxima and Minima (IDB)

Maximum IDB (°C)

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	26.20	07-Jul	15	25.11	22-Apr	15	25.11	22-Apr	15	25.00	09/23	08:00	25.05	21-Feb	17	26.19	3-Nov	15	25.00	26.20	4.7%
E310	27.08	20-Jul	15	26.89	20-Jul	16	26.72	20-Jul	16	26.47	07/20	16:00	26.62	20-Jul	15	27.19	8-Jul	15	26.47	27.19	2.7%
E320	32.36	20-Jul	15	31.61	8-Jul	16	31.50	8-Jul	16	31.71	07/20	15:00	32.32	20-Jul	15	31.65	8-Jul	15	31.50	32.36	2.7%
E330	32.23	20-Jul	15	31.72	8-Jul	16	32.00	20-Jul	16	31.07	07/08	16:00	31.90	20-Jul	15	31.30	8-Jul	15	31.07	32.23	3.7%
E340	32.31	20-Jul	15	31.61	8-Jul	16	31.56	8-Jul	16	31.50	07/20	15:00	32.15	20-Jul	15	31.58	8-Jul	15	31.50	32.31	2.5%
E350	34.58	01-Oct	24	34.94	23-Jun	24	34.94	24-Jun	24	35.00	10/01	02:00	35.00	21-Apr	1	35.00	21-Apr	2	34.58	35.00	1.2%
E360	33.76	10-Jul	13	32.78	20-Jul	15	32.56	20-Jul	16	32.51	07/10	13:00	33.00	20-Jul	15	33.13	10-Jul	12	32.51	33.76	3.8%
E400	27.11	16-Sep	15	27.56	16-Sep	16	28.83	18-Sep	16	26.91	09/16	16:00				26.04	15-Aug	15	26.04	28.83	10.2%
E410	26.83	23-Oct	15	25.11	22-Apr	15	25.11	22-Apr	15							26.19	3-Nov	15	25.11	26.83	6.6%
E420	26.20	07-Jul	15	25.11	22-Apr	15	25.11	22-Apr	15	25.00	09/23	08:00				26.23	20-Oct	15	25.00	26.23	4.8%
E430	27.20	01-Nov	16	25.11	22-Apr	15	25.11	22-Apr	15	25.00	05/18	19:00				26.45	23-Oct	15	25.00	27.20	8.5%
E440	27.05	28-Apr	15	25.11	22-Apr	15	25.11	22-Apr	15	25.00	04/24	19:00				26.26	23-Oct	15	25.00	27.05	7.9%
E500	25.81	30-Apr	15	25.11	21-Apr	16	25.11	21-Apr	16	25.00	03/31	18:00	25.02	30-Mar	17	25.00	11-Mar	11	25.00	25.81	3.2%
E510	26.10	09-Jul	15	25.11	21-Apr	3	25.11	21-Apr	3	25.00	03/31	18:00	25.02	30-Mar	17	25.00	24-Apr	12	25.00	26.10	4.4%
E520	16.12	15-Aug	15	16.11	16-Aug	16	15.94	10-Jul	16	15.00	04/16	01:00	15.98	20-Jul	15	18.62	4-Jun	16	15.00	18.62	22.2%
E522	21.01	16-Jul	15	20.11	21-Apr	15	20.11	21-Apr	15	20.00	04/16	20:00	20.05	13-Mar	22	20.93	21-Apr	15	20.00	21.01	5.0%
E525	36.08	10-Mai	16	35.06	21-Apr	16	35.06	21-Apr	16	35.00	03/11	12:00	35.00	11-Mar	10	35.00	11-Mar	11	35.00	36.08	3.1%
E530	26.12	04-Jun	15	25.06	21-Apr	16	25.06	21-Apr	16	25.00	03/30	17:00	25.02	30-Mar	17	25.00	11-Mar	11	25.00	26.12	4.4%
E540	16.15	21-Sep	16	15.11	31-May	16	15.11	31-May	16	15.00	03/25	08:00	15.05	28-Jan	20	15.00	11-Mar	10	15.00	16.15	7.5%
E545	35.67	20-Jul	15	35.00	21-Apr	15	35.00	21-Apr	15	35.00	07/09	22:00	35.00	11-Mar	10	35.00	11-Mar	11	35.00	35.67	1.9%

Minimum IDB (°C)

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E310	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E320	7.93	06-Jan	6	10.83	6-Jan	7	10.78	6-Jan	7	7.75	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	10.83	44.1%
E330	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E340	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E350	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E360	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00	8.00	6-Jan	5	6.99	6-Jan	5	6.99	8.89	23.1%
E400	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00				6.99	6-Jan	5	6.99	8.89	23.0%
E410	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6							6.99	6-Jan	5	6.99	8.89	23.3%
E420	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00				6.99	6-Jan	5	6.99	8.89	23.0%
E430	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00				6.99	6-Jan	5	6.99	8.89	23.0%
E440	7.93	06-Jan	6	8.89	6-Jan	6	8.83	6-Jan	6	8.72	01/06	06:00				7.00	6-Jan	5	7.00	8.89	22.8%
E500	8.43	20-Dec	22	8.17	20-Dec	12	7.94	20-Dec	11	8.94	12/21	02:00	8.54	20-Dec	20	24.04	15-Apr	5	7.94	24.04	146.2%
E510	8.43	20-Dec	22	8.17	20-Dec	12	7.94	20-Dec	11	8.94	12/21	02:00	8.54	20-Dec	20	24.04	15-Apr	5	7.94	24.04	146.2%
E520	8.31	20-Dec	22	8.11	20-Dec	12	7.89	20-Dec	12	8.83	12/21	01:00	8.51	20-Dec	20	13.57	1-Nov	7	7.89	13.57	61.7%
E522	8.41	20-Dec	22	8.17	20-Dec	12	7.94	20-Dec	11	8.90	12/21	01:00	8.54	20-Dec	20	15.98	12-Apr	19	7.94	15.98	83.3%
E525	8.44	20-Dec	22	8.17	20-Dec	13	7.94	20-Dec	12	9.01	12/21	02:00	8.54	20-Dec	20	33.01	1-Apr	8	7.94	33.01	200.2%
E530	8.42	20-Dec	22	8.17	20-Dec	12	7.94	20-Dec	11	8.94	12/21	02:00	8.54	20-Dec	20	24.04	15-Apr	5	7.94	24.04	146.3%
E540	8.23	20-Dec	22	8.11	20-Dec	12	7.89	20-Dec	12	8.83	12/21	01:00	8.51	20-Dec	20	14.95	19-Dec	1	7.89	14.95	74.9%
E545	8.45	20-Dec	22	8.17	20-Dec	13	7.94	20-Dec	12	9.01	12/21	02:00	8.54	20-Dec	20	33.01	1-Apr	8	7.94	33.01	200.2%

e300results.xls r:a111..aa204; 07/19/04

Hourly Integrated Maxima and Minima (Zone Humidity Ratio)

Maximum Humidity Ratio

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	0.0133	16-Nov	17	0.0138	16-Nov	16	0.0137	16-Nov	16	0.0136	11/16	17:00	0.0135	16-Nov	16	0.0134	16-Nov	16	0.0133	0.0138	3.8%
E310	0.0158	01-Oct	23	0.0188	15-Oct	9	0.0189	15-Oct	9	0.0156	10/01	08:00	0.0154	2-Oct	8	0.0157	2-Oct	8	0.0154	0.0189	20.8%
E320	0.0180	10-Jul	13	0.0177	10-Jul	12	0.0176	10-Jul	12	0.0178	07/10	13:00	0.0175	10-Jul	12	0.0177	10-Jul	12	0.0175	0.0180	2.7%
E330	0.0177	10-Jul	12	0.0178	2-Oct	9	0.0177	10-Jul	13	0.0179	07/10	12:00	0.0170	10-Jul	13	0.0177	10-Jul	12	0.0170	0.0179	5.0%
E340	0.0179	10-Jul	13	0.0177	10-Jul	12	0.0174	10-Jul	12	0.0178	07/10	12:00	0.0173	10-Jul	13	0.0177	10-Jul	12	0.0173	0.0179	3.4%
E350	0.0168	01-Oct	24	0.0199	2-Aug	22	0.0199	2-Aug	22	0.0172	10/02	01:00	0.0165	2-Oct	2	0.0166	2-Oct	1	0.0165	0.0199	19.2%
E360	0.0134	10-Jul	13	0.0138	16-Nov	16	0.0137	16-Nov	16	0.0139	07/10	13:00	0.0135	16-Nov	16	0.0134	16-Nov	16	0.0134	0.0139	3.4%
E400	0.0169	05-Apr	22	0.0170	5-Apr	21	0.0170	5-Apr	21	0.0169	04/05	22:00				0.0173	22-Apr	6	0.0169	0.0173	2.5%
E410	0.0168	05-Apr	22	0.0169	2-Apr	5	0.0169	2-Apr	5							0.0173	22-Apr	6	0.0168	0.0173	2.7%
E420	0.0143	02-Apr	10	0.0147	1-Apr	21	0.0141	17-Apr	3	0.0146	04/02	18:00				0.0147	2-Apr	18	0.0141	0.0147	4.1%
E430	0.0162	02-Apr	5	0.0156	2-Apr	4	0.0156	2-Apr	4	0.0161	04/02	05:00				0.0158	2-Apr	5	0.0156	0.0162	4.0%
E440	0.0133	16-Nov	17	0.0138	16-Nov	16	0.0137	16-Nov	16	0.0136	11/16	17:00				0.0134	16-Nov	16	0.0133	0.0138	3.6%
E500	0.0117	11-Jul	15	0.0119	20-Jul	15	0.0118	6-Apr	10	0.0117	07/20	15:00	0.0117	20-Jul	15	0.0115	11-Mar	10	0.0115	0.0119	3.4%
E510	0.0119	07-Sep	15	0.0119	20-Jul	15	0.0119	20-Jul	15	0.0117	07/20	15:00	0.0117	20-Jul	15	0.0115	11-Mar	10	0.0115	0.0119	3.4%
E520	0.0075	07-Sep	15	0.0077	10-Jul	16	0.0078	29-Mar	10	0.0070	07/20	15:00	0.0076	20-Jul	15	0.0106	5-Jan	16	0.0070	0.0106	44.5%
E522	0.0094	20-Jul	16	0.0095	4-Jun	15	0.0138	6-Apr	10	0.0091	07/20	15:00	0.0094	20-Jul	15	0.0107	1-Jan	2	0.0091	0.0138	45.4%
E525	0.0179	10-Mai	16	0.0180	20-Jul	15	0.0180	20-Jul	15	0.0185	07/20	15:00	0.0176	20-Jul	15	0.0173	20-Jul	15	0.0173	0.0185	6.6%
E530	0.0070	01-Jan	1	0.0081	20-Jul	15	0.0081	20-Jul	15	0.0068	03/11	01:00	0.0055	1-Apr	1	0.0068	26-Oct	9	0.0055	0.0081	37.1%
E540	0.0061	01-Jan	1	0.0050	4-Jun	13	0.0063	8-Apr	8	0.0068	03/11	01:00	0.0033	1-Apr	1	0.0063	11-Mar	9	0.0033	0.0068	62.6%
E545	0.0070	01-Jan	1	0.0122	20-Jul	15	0.0122	20-Jul	15	0.0068	12/31	07:00	0.0067	1-Apr	1	0.0076	5-Nov	9	0.0067	0.0122	63.0%

Minimum Humidity Ratio

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E310	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/05	07:00	0.0020	5-Jan	7	0.0020	5-Jan	7	0.0017	0.0020	17.1%
E320	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E330	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E340	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E350	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E360	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00	0.0020	11-Jan	3	0.0020	5-Jan	6	0.0017	0.0020	14.5%
E400	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00				0.0020	5-Jan	6	0.0017	0.0020	14.7%
E410	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24							0.0020	5-Jan	6	0.0017	0.0020	14.9%
E420	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00				0.0020	5-Jan	6	0.0017	0.0020	14.7%
E430	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00				0.0020	5-Jan	6	0.0017	0.0020	14.7%
E440	0.0019	11-Jan	3	0.0017	4-Jan	24	0.0017	4-Jan	24	0.0019	01/11	03:00				0.0020	5-Jan	7	0.0017	0.0020	14.7%
E500	0.0068	20-Dec	22							0.0070	12/20	12:00	0.0069	20-Dec	20	0.0103	2-Nov	2	0.0068	0.0103	44.7%
E510	0.0068	20-Dec	22							0.0070	12/20	12:00	0.0069	20-Dec	20	0.0105	2-Apr	22	0.0068	0.0105	47.0%
E520	0.0061	26-Nov	2							0.0065	11/10	09:00	0.0065	27-Nov	23	0.0066	1-Nov	7	0.0061	0.0066	7.3%
E522	0.0068	20-Dec	22							0.0070	12/20	12:00	0.0069	20-Dec	20	0.0078	2-Apr	21	0.0068	0.0078	14.1%
E525	0.0068	20-Dec	22							0.0070	12/20	12:00	0.0069	20-Dec	20	0.0154	2-Nov	2	0.0068	0.0154	94.7%
E530	0.0062	01-Apr	1							0.0067	10/18	12:00	0.0055	1-Nov	21	0.0066	1-Apr	5	0.0055	0.0067	20.5%
E540	0.0041	05-Oct	3							0.0038	10/18	09:00	0.0033	29-Apr	23	0.0042	15-Oct	5	0.0033	0.0042	24.6%
E545	0.0062	01-Apr	1							0.0068	04/01	02:00	0.0067	20-Jul	15	0.0070	1-Apr	8	0.0062	0.0070	11.9%

Hourly Integrated Maxima and Minima (Relative Humidity)

Maximum Relative Humidity

	TRNSYS TUD	Date	Hour	DOE-2.2 NREL	Date	Hour	DOE21E-E NREL	Date	Hour	Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	68.79	16-Nov	17	69.35	16-Nov	16	68.85	16-Nov	16	68.37	11/16	17:00	68.00	16-Nov	16	67.44	16-Nov	16	67.44	69.3500	2.8%
E310	77.70	02-Oct	4	100.18	15-Oct	9	100.70	15-Oct	9	78.64	10/02	08:00	77.00	12-Jun	8	78.19	2-Oct	8	77.00	100.7000	27.8%
E320	81.84	18-Sep	10	83.41	2-Oct	9	83.67	22-Apr	18	82.97	09/18	10:00	83.00	3-Sep	17	81.88	16-Sep	20	81.84	83.6700	2.2%
E330	76.66	22-Sep	20	78.46	2-Oct	9	77.94	18-Sep	9	76.88	09/03	10:00	76.00	10-Jun	18	78.70	2-Sep	12	76.00	78.7000	3.5%
E340	79.93	18-Sep	10	81.37	18-Sep	9	81.26	22-Apr	18	80.80	09/18	10:00	80.00	3-Sep	17	80.25	16-Sep	20	79.93	81.3700	1.8%
E350	68.79	16-Nov	17	81.12	7-Aug	21	81.12	7-Aug	21	68.37	11/16	17:00	70.00	2-Oct	8	72.65	3-Aug	7	68.37	81.1200	17.3%
E360	68.79	16-Nov	17	69.35	16-Nov	16	68.85	16-Nov	16	68.37	11/16	17:00	68.00	16-Nov	16	67.44	16-Nov	16	67.44	69.3500	2.8%
E400	83.75	05-Apr	22	85.57	5-Apr	21	85.57	5-Apr	21	84.64	04/05	22:00				86.31	22-Apr	6	83.75	86.3100	3.0%
E410	83.22	05-Apr	22	84.79	2-Apr	5	84.79	2-Apr	5							86.18	22-Apr	6	83.22	86.1800	3.5%
E420	70.84	02-Apr	10	74.51	17-Apr	7	71.53	17-Apr	3	73.28	04/02	18:00				73.85	2-Apr	18	70.84	74.5100	5.0%
E430	80.71	02-Apr	5	78.43	2-Apr	4	78.43	2-Apr	4	80.74	04/02	05:00				78.94	2-Apr	5	78.43	80.7427	2.9%
E440	68.72	16-Nov	17	69.35	16-Nov	16	68.85	16-Nov	16	68.37	11/16	17:00				67.51	16-Nov	16	67.51	69.3500	2.7%
E500	100.00	21-Nov	24							100.00	11/21	09:00	100.00	14-Nov	5	60.08	1-Apr	5	60.08	100.0000	44.3%
E510	100.00	21-Nov	24							100.00	11/21	09:00	100.00	14-Nov	5	57.51	1-Apr	5	57.51	100.0000	47.5%
E520	90.23	20-Dec	22							93.81	12/20	11:00	95.00	20-Dec	17	71.77	16-Aug	17	71.77	95.0000	26.5%
E522	100.00	18-Dec	8							100.00	12/15	22:00	100.00	15-Dec	1	71.32	5-Apr	17	71.32	100.0000	30.9%
E525	100.00	12-Nov	20							100.00	11/12	19:00	100.00	11-Nov	23	51.12	1-Apr	8	51.12	100.0000	55.7%
E530	91.04	20-Dec	22							96.16	12/20	11:00	79.00	20-Dec	8	36.01	20-Apr	21	36.01	96.1602	79.6%
E540	61.28	20-Dec	22							55.18	12/20	11:00	47.00	20-Dec	6	39.96	18-Apr	18	39.96	61.2750	41.9%
E545	90.88	20-Dec	22							96.23	12/20	11:00	97.00	20-Dec	4	24.14	24-Dec	1	24.14	97.0000	94.5%

Minimum Relative Humidity

	TRNSYS TUD	Date	Hour	DOE-2.2			DOE21E-E			Energy+ GARD	Date	Hour	CODYRUN UR	Date	Hour	HOT3000 NRCan	Date	Hour	Statistics, All Results Min	Max	(Max-Min) /Mean
E300	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.40	11/06	06:00	15.00	6-Nov	5	14.94	6-Nov	8	11.97	15.0000	22.3%
E310	13.39	06-Nov	6	11.97	6-Nov	4	11.97	6-Nov	4	15.50	11/06	08:00	16.00	6-Nov	8	15.93	6-Nov	8	11.97	16.0000	28.5%
E320	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.64	11/06	06:00	15.00	6-Nov	5	12.92	20-Dec	5	11.97	15.0000	22.8%
E330	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.40	11/06	06:00	15.00	6-Nov	5	14.94	6-Nov	8	11.97	15.0000	22.3%
E340	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.40	11/06	06:00	15.00	6-Nov	5	14.94	6-Nov	8	11.97	15.0000	22.3%
E350	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.40	11/06	06:00	15.00	6-Nov	5	14.94	6-Nov	8	11.97	15.0000	22.3%
E360	13.33	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	14.40	11/06	06:00	15.00	6-Nov	5	14.94	6-Nov	8	11.97	15.0000	22.3%
E400	13.21	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	13.93	11/06	06:00				14.57	6-Nov	5	11.97	14.5700	19.8%
E410	13.21	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4							14.58	6-Nov	5	11.97	14.5800	20.2%
E420	13.21	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	13.93	11/06	06:00				14.59	6-Nov	5	11.97	14.5900	19.9%
E430	13.21	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	13.93	11/06	06:00				14.58	6-Nov	5	11.97	14.5800	19.9%
E440	13.21	06-Nov	5	11.97	6-Nov	4	11.97	6-Nov	4	13.93	11/06	06:00				14.54	6-Nov	5	11.97	14.5400	19.6%
E500	53.41	30-Apr	15							55.17	04/30	04:00	54.00	4-Oct	24	52.83	5-Oct	1	52.83	55.1668	4.3%
E510	52.09	04-Oct	23							55.29	05/04	03:00	54.00	4-Oct	23	53.15	4-May	4	52.09	55.2884	6.0%
E520	61.27	25-Nov	24							61.73	11/27	24:00	61.00	27-Nov	22	61.90	20-Jul	15	61.00	61.9000	1.5%
E522	58.51	30-Apr	15							59.18	04/30	04:00	60.00	4-Oct	23	57.97	5-Oct	1	57.97	60.0000	3.4%
E525	45.53	30-Apr	15							47.85	10/05	02:00	44.00	4-May	4	44.40	5-Oct	1	44.00	47.8518	8.5%
E530	29.59	04-Jun	15							34.03	04/18	18:00	28.00	1-Apr	10	33.68	1-Apr	13	28.00	34.0277	19.2%
E540	36.47	21-Sep	16							36.00	09/28	16:00	31.00	1-Apr	1	39.74	5-Oct	1	31.00	39.7400	24.4%
E545	17.12	20-Jul	15							19.23	04/18	17:00	19.00	1-Apr	10	20.14	1-Apr	12	17.12	20.1400	16.0%

e300results.xls r:a215..aa308; 07/19/04

June 28 Hourly Output - Case E300

TRNSYS-TUD	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	2056	257	8132	6189	1942	0.0091	3.517	18.05	23.41	16.96	0.0113
2	2054	257	8116	6202	1914	0.0090	3.513	18.05	23.37	16.90	0.0113
3	2054	257	8128	6194	1934	0.0091	3.517	18.05	23.38	16.94	0.0113
4	1830	230	7224	5549	1676	0.0090	3.507	17.80	23.37	16.86	0.0111
5	2029	256	8105	6319	1786	0.0088	3.546	17.50	23.35	16.70	0.0106
6	1839	230	7131	5686	1445	0.0087	3.447	18.30	23.42	16.57	0.0106
7	2667	309	9711	7597	2115	0.0092	3.263	22.20	24.04	17.32	0.0121
8	3553	384	12121	9558	2563	0.0095	3.079	26.10	24.57	17.79	0.0122
9	4365	458	14556	11758	2798	0.0097	3.018	28.05	25.09	17.97	0.0115
10	4441	458	14639	11506	3133	0.0101	2.988	28.90	25.28	18.40	0.0124
11	5000	506	16374	12342	4032	0.0104	2.974	30.00	25.36	18.82	0.0138
12	5317	529	17248	12810	4438	0.0107	2.950	30.85	25.59	19.12	0.0140
13	6189	617	20498	16816	3682	0.0101	3.012	30.85	26.53	18.84	0.0123
14	6211	616	20234	17284	2951	0.0098	2.964	31.40	26.56	18.55	0.0115
15	7922	781	26687	22882	3805	0.0096	3.066	31.95	26.78	18.55	0.0121
16	7965	781	26723	22285	4438	0.0097	3.055	32.20	26.56	18.67	0.0133
17	5421	529	17231	13048	4183	0.0108	2.896	31.95	26.20	19.40	0.0145
18	5410	529	17506	12721	4785	0.0112	2.947	31.40	26.23	19.77	0.0152
19	5260	529	17662	12491	5171	0.0111	3.051	29.70	25.70	19.58	0.0151
20	4880	506	16990	11655	5335	0.0110	3.154	27.75	25.17	19.37	0.0157
21	3939	409	13540	8882	4658	0.0111	3.114	27.20	24.65	19.44	0.0169
22	3924	410	13565	8880	4684	0.0112	3.130	26.95	24.74	19.48	0.0169
23	4123	434	14531	9449	5082	0.0112	3.189	26.40	24.67	19.47	0.0169
24	3877	410	13692	8807	4885	0.0113	3.194	26.10	24.73	19.57	0.0171

DOE-2.2	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	1897	237	7552	5889	1663	0.0094	3.539	17.78	23.83	17.34	0.0114
2	1941	240	7630	6070	1560	0.0093	3.499	18.33	23.94	17.29	0.0112
3	1897	237	7550	5881	1669	0.0094	3.538	17.78	23.83	17.34	0.0114
4	1891	237	7534	5878	1656	0.0094	3.540	17.78	23.83	17.34	0.0114
5	1697	215	6798	5675	1123	0.0089	3.555	17.22	23.78	16.85	0.0103
6	2126	259	8136	6439	1698	0.0092	3.411	19.44	24.11	17.30	0.0113
7	3198	352	11076	8342	2734	0.0100	3.120	25.00	24.94	18.39	0.0133
8	3135	332	10291	9070	1221	0.0094	2.968	27.22	25.28	17.78	0.0109
9	4528	469	14786	11873	2913	0.0099	2.959	28.89	25.56	18.36	0.0117
10	4651	479	15340	12039	3301	0.0103	2.990	28.89	25.56	18.68	0.0125
11	5434	537	17455	12812	4643	0.0109	2.923	31.11	25.89	19.48	0.0148
12	5019	498	16215	12612	3603	0.0108	2.939	30.56	25.83	19.23	0.0134
13	6040	597	19723	17139	2584	0.0101	2.972	31.11	25.94	18.56	0.0115
14	6420	633	20808	17638	3170	0.0100	2.950	31.67	26.06	18.60	0.0121
15	7671	751	25387	22196	3191	0.0098	3.014	32.22	26.11	18.46	0.0119
16	8190	800	27581	22528	5053	0.0100	3.068	32.22	26.17	18.84	0.0144
17	5715	561	18205	13599	4605	0.0107	2.901	31.67	26.06	19.35	0.0146
18	5536	544	17933	12830	5103	0.0112	2.950	31.11	25.94	19.75	0.0157
19	4711	481	16012	11876	4137	0.0110	3.084	28.33	25.50	19.32	0.0143
20	4859	504	17082	11532	5550	0.0114	3.185	27.22	25.33	19.76	0.0164
21	3913	405	13435	9302	4133	0.0113	3.111	27.22	25.33	19.76	0.0164
22	3825	399	13280	8974	4307	0.0114	3.144	26.67	25.22	19.80	0.0167
23	3750	395	13192	8787	4404	0.0115	3.183	26.11	25.11	19.84	0.0169
24	3880	407	13724	8799	4925	0.0117	3.201	26.11	25.11	20.14	0.0178

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June 28 Hourly Output (Ctd.) - Case E300

DOE-2.1E-E	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	1894	237	7545	5887	1658	0.0094	3.541	17.78	23.83	17.34	0.0114
2	1941	241	7627	6067	1560	0.0093	3.495	18.33	23.94	17.29	0.0112
3	1894	237	7546	5878	1668	0.0094	3.541	17.78	23.83	17.37	0.0114
4	1890	236	7528	5873	1655	0.0094	3.541	17.78	23.83	17.37	0.0114
5	1694	215	6753	5672	1081	0.0090	3.537	17.22	23.78	16.94	0.0103
6	2133	259	8185	6439	1747	0.0092	3.422	19.44	24.11	17.30	0.0113
7	3223	353	11233	8348	2885	0.0098	3.141	25.00	24.94	18.23	0.0133
8	3145	335	10272	9069	1203	0.0094	2.952	27.22	25.28	17.78	0.0109
9	4526	467	14844	11875	2969	0.0099	2.973	28.89	25.56	18.28	0.0117
10	4655	478	15393	12041	3352	0.0102	2.999	28.89	25.56	18.60	0.0125
11	5456	536	17605	12818	4787	0.0107	2.938	31.11	25.89	19.33	0.0148
12	5015	498	16188	12611	3577	0.0108	2.936	30.56	25.83	19.23	0.0134
13	6036	600	19621	17135	2486	0.0102	2.957	31.11	25.94	18.64	0.0115
14	6429	635	20819	17639	3180	0.0100	2.947	31.67	26.06	18.60	0.0121
15	7683	754	25393	22197	3196	0.0098	3.010	32.22	26.11	18.46	0.0119
16	8222	803	27721	22533	5188	0.0098	3.072	32.22	26.17	18.76	0.0144
17	5696	556	18245	13600	4644	0.0107	2.918	31.67	26.06	19.35	0.0146
18	5531	541	17978	12832	5146	0.0112	2.961	31.11	25.94	19.68	0.0157
19	4689	479	15914	11871	4043	0.0111	3.079	28.33	25.50	19.40	0.0143
20	4855	503	17120	11534	5586	0.0113	3.195	27.22	25.33	19.76	0.0164
21	3918	406	13445	9303	4142	0.0113	3.109	27.22	25.33	19.76	0.0164
22	3823	399	13285	8974	4311	0.0114	3.147	26.67	25.22	19.80	0.0167
23	3748	394	13192	8787	4405	0.0115	3.185	26.11	25.11	19.84	0.0169
24	3880	407	13754	8800	4955	0.0117	3.208	26.11	25.11	20.06	0.0178

EnergyPlus	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	2119	Note 1	7472	5811	1661	0.0094	3.527	17.99	23.95	0.00	0.0112
2	2131	Note 1	7494	5853	1641	0.0094	3.516	18.11	23.96	0.00	0.0113
3	2113	Note 1	7447	5809	1637	0.0094	3.525	17.99	23.95	0.00	0.0112
4	2075	Note 1	7332	5744	1588	0.0093	3.534	17.80	23.92	0.00	0.0111
5	1997	Note 1	7091	5614	1477	0.0092	3.550	17.43	23.86	0.00	0.0105
6	2142	Note 1	7425	6015	1410	0.0090	3.467	18.58	24.03	0.00	0.0106
7	2870	Note 1	9216	7532	1684	0.0093	3.212	22.90	24.68	0.00	0.0123
8	3499	Note 1	10609	8757	1853	0.0096	3.033	26.38	25.21	0.00	0.0118
9	4682	Note 1	14032	11767	2265	0.0098	2.997	28.26	25.49	0.00	0.0116
10	4948	Note 1	14778	11996	2781	0.0102	2.987	28.90	25.59	0.00	0.0124
11	5407	Note 1	15905	12488	3417	0.0106	2.942	30.28	25.79	0.00	0.0140
12	5632	Note 1	16522	12671	3851	0.0109	2.933	30.79	25.87	0.00	0.0138
13	7133	Note 1	21588	17401	4187	0.0104	3.027	30.91	25.88	0.00	0.0120
14	6983	Note 1	20678	17592	3086	0.0100	2.961	31.48	25.97	0.00	0.0115
15	8572	Note 1	26133	22481	3652	0.0098	3.049	32.01	26.05	0.00	0.0121
16	8733	Note 1	26665	22557	4107	0.0099	3.053	32.20	26.08	0.00	0.0135
17	5718	Note 1	16345	13061	3283	0.0106	2.858	31.89	26.04	0.00	0.0145
18	5881	Note 1	17193	12870	4324	0.0112	2.924	31.33	25.95	0.00	0.0153
19	5555	Note 1	16878	12170	4708	0.0113	3.038	29.35	25.65	0.00	0.0149
20	5259	Note 1	16536	11556	4981	0.0113	3.144	27.61	25.39	0.00	0.0159
21	4326	Note 1	13445	9063	4383	0.0116	3.108	27.20	25.33	0.00	0.0168
22	4279	Note 1	13387	8953	4434	0.0116	3.129	26.89	25.29	0.00	0.0168
23	4173	Note 1	13191	8753	4437	0.0116	3.161	26.33	25.20	0.00	0.0168
24	4152	Note 1	13196	8674	4522	0.0117	3.178	26.10	25.17	0.00	0.0171

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June 28 Hourly Output (Ctd.) - Case E300

CODYRUN	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	1886	237	7472	5788	1684	0.0093	3.520	17.80	23.92	17.16	0.0111
2	1964	244	7707	5961	1747	0.0093	3.490	18.30	24.00	17.24	0.0115
3	1881	236	7445	5788	1657	0.0092	3.517	17.80	23.92	17.12	0.0111
4	1878	236	7432	5788	1644	0.0092	3.516	17.80	23.92	17.10	0.0111
5	1756	224	7000	5580	1420	0.0090	3.535	17.20	23.83	16.79	0.0102
6	2075	253	7915	6341	1574	0.0090	3.400	19.40	24.16	17.03	0.0110
7	3035	334	10450	8277	2173	0.0095	3.102	25.00	25.00	17.91	0.0131
8	3303	352	10813	9038	1775	0.0093	2.958	27.20	25.33	17.65	0.0111
9	4483	463	14631	11971	2660	0.0097	2.958	28.90	25.59	18.12	0.0120
10	4594	472	15099	11971	3128	0.0100	2.980	28.90	25.59	18.44	0.0128
11	5238	516	16722	12731	3991	0.0106	2.906	31.10	25.91	19.14	0.0148
12	5066	504	16258	12559	3699	0.0106	2.919	30.60	25.84	18.94	0.0133
13	6442	642	21090	17422	3669	0.0100	2.977	31.10	25.91	18.33	0.0113
14	6523	645	21067	17629	3438	0.0098	2.939	31.70	26.00	18.27	0.0117
15	8000	785	26636	22491	4145	0.0096	3.032	32.20	26.08	18.24	0.0124
16	8169	799	27416	22491	4925	0.0097	3.057	32.20	26.08	18.56	0.0142
17	5306	519	16702	12939	3763	0.0104	2.867	31.70	26.00	19.06	0.0147
18	5381	528	17312	12729	4582	0.0109	2.930	31.10	25.91	19.46	0.0157
19	4791	492	16232	11761	4470	0.0109	3.072	28.30	25.50	19.20	0.0145
20	4809	498	16867	11381	5486	0.0113	3.178	27.20	25.33	19.65	0.0169
21	3939	408	13484	9036	4447	0.0113	3.102	27.20	25.33	19.71	0.0169
22	3852	402	13322	8864	4459	0.0114	3.132	26.70	25.25	19.70	0.0168
23	3752	395	13139	8656	4482	0.0114	3.168	26.10	25.16	19.69	0.0169
24	3794	399	13323	8656	4666	0.0115	3.177	26.10	25.16	19.81	0.0173

HOT3000	Energy Consumption		Evaporator Coil Load			Zone Hum.					
	Compressor	Cond Fan	Total	Sensible	Latent	Ratio	COP2	ODB	EDB	EWB	OHR
Hour	(Wh)	(Wh)	(Wh)	(Wh)	(Wh)	(kg/kg)		(°C)	(°C)	(°C)	(kg/kg)
1	1943	241	7668	5870	1798	0.0093	3.511	17.80	23.94	17.30	0.0111
2	1951	241	7674	5872	1803	0.0093	3.502	18.30	23.94	17.31	0.0114
3	1902	237	7528	5783	1745	0.0092	3.519	17.80	23.90	17.24	0.0111
4	1845	231	7317	5683	1634	0.0091	3.524	17.80	23.84	17.08	0.0111
5	1914	239	7514	5955	1559	0.0090	3.490	17.20	23.98	17.01	0.0102
6	2507	293	9223	7312	1911	0.0092	3.295	19.40	24.58	17.54	0.0110
7	3171	343	10770	8647	2123	0.0095	3.065	25.00	25.16	17.99	0.0131
8	3434	361	11186	9299	1888	0.0094	2.948	27.20	25.45	17.96	0.0110
9	4489	461	14744	11923	2821	0.0097	2.979	28.90	25.58	18.33	0.0120
10	4853	489	15882	12287	3595	0.0102	2.973	28.90	25.74	18.85	0.0127
11	5164	508	16615	12562	4053	0.0106	2.929	31.10	25.86	19.19	0.0148
12	5005	497	16030	12561	3468	0.0104	2.914	30.60	25.86	18.87	0.0132
13	6455	639	21180	17431	3749	0.0100	2.986	31.10	25.94	18.52	0.0113
14	6503	640	21055	17609	3447	0.0097	2.948	31.70	26.02	18.44	0.0117
15	8041	785	27070	22350	4719	0.0098	3.067	32.20	26.13	18.65	0.0123
16	8134	794	27623	22292	5331	0.0098	3.094	32.20	26.03	18.80	0.0142
17	5212	510	16551	12739	3812	0.0103	2.893	31.70	25.94	19.11	0.0147
18	5122	507	16830	12181	4649	0.0109	2.990	31.10	25.70	19.39	0.0156
19	4832	493	16635	11541	5095	0.0110	3.124	28.30	25.41	19.53	0.0145
20	4875	501	17131	11359	5772	0.0114	3.187	27.20	25.33	19.74	0.0168
21	3936	406	13525	8931	4593	0.0114	3.115	27.20	25.29	19.74	0.0168
22	3844	399	13356	8747	4609	0.0114	3.148	26.70	25.21	19.79	0.0168
23	3807	397	13343	8647	4697	0.0114	3.173	26.10	25.16	19.84	0.0168
24	3664	386	12973	8360	4613	0.0115	3.203	26.10	25.04	19.77	0.0173

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Delta Annual Space Cooling Electricity Consumptions

Total (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	4340	4629	4629	4545	4543	4538	4340	4629	6.4%
E320-E300	4426	3995	4037	4333	4424	4387	3995	4426	10.1%
E330-E300	5330	4958	4683	5398	5559	5260	4683	5559	16.8%
E330-E320	904	963	646	1064	1134	873	646	1134	52.5%
E340-E300	4986	4608	4510	5037	5089	4877	4510	5089	11.9%
E330-E340	344	350	173	360	470	383	173	470	85.6%
E350-E300	-3397	-4203	-4207	-3601	-3390	-3328	-4207	-3328	-23.8%
E360-E300	19665	19314	19261	19959	19867	19998	19261	19998	3.7%
E400-E300	-3589	-3904	-3879	-3733		-3657	-3904	-3589	-8.4%
E410-E300	-3555	-3082	-3056			-3567	-3567	-3056	-15.4%
E420-E300	-2247	-2220	-1845	-2010		-1862	-2247	-1845	-19.7%
E430-E300	-3096	-2818	-2944	-2973		-3252	-3252	-2818	-14.4%
E440-E300	-1942	-1718	-1782	-1714		-1822	-1942	-1714	-12.7%
E500-E300	-13296	-11933	-11933	-11711	-12653	-11932	-13296	-11711	-12.9%
E510-E500	17218	18099	18100	17736	17414	17794	17218	18100	5.0%
E525-E520	-4666	-4981	-4969	-4316	-4889	-4458	-4981	-4316	-14.1%
E530-E500	-5057	-5277	-5285	-5293	-4880	-5263	-5293	-4880	-8.0%
E545-E540	-3743	-4076	-4083	-2425	-3745	-3825	-4083	-2425	-45.4%

Compressor (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	3986	4244	4244		4167	4177	3986	4244	6.2%
E320-E300	4080	3681	3721		4076	4036	3681	4080	10.2%
E330-E300	4946	4603	4352		5158	4899	4352	5158	16.8%
E330-E320	867	922	631		1082	863	631	1082	51.6%
E340-E300	4609	4260	4172		4703	4524	4172	4703	11.9%
E330-E340	337	343	180		455	375	180	455	81.4%
E350-E300	-3037	-3767	-3772		-3032	-2985	-3772	-2985	-23.7%
E360-E300	17752	17430	17382		17927	18065	17382	18065	3.9%
E400-E300	-3175	-3463	-3442			-3247	-3463	-3175	-8.7%
E410-E300	-3149	-2746	-2723			-3191	-3191	-2723	-15.9%
E420-E300	-1995	-1973	-1639			-1662	-1995	-1639	-19.6%
E430-E300	-2755	-2510	-2622			-2910	-2910	-2510	-14.8%
E440-E300	-1724	-1527	-1584			-1627	-1724	-1527	-12.2%
E500-E300	-4499	-3096	-3095		-3912	-3354	-4499	-3095	-39.1%
E510-E500	13806	14303	14304		13913	14230	13806	14304	3.5%
E525-E520	-2963	-3241	-3233		-3148	-2742	-3241	-2742	-16.3%
E530-E500	-4197	-4346	-4354		-4002	-4350	-4354	-4002	-8.3%
E545-E540	-2399	-2713	-2720		-2413	-2449	-2720	-2399	-12.6%

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Delta Annual Space Cooling Electricity Consumptions (ctd.)

Supply Fan (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0	0	0	0	0	0	0	0	#DIV/0!
E320-E300	0	0	0	0	0	0	0	0	#DIV/0!
E330-E300	0	0	0	0	0	0	0	0	#DIV/0!
E330-E320	0	0	0	0	0	0	0	0	#DIV/0!
E340-E300	0	0	0	0	0	0	0	0	#DIV/0!
E330-E340	0	0	0	0	0	0	0	0	#DIV/0!
E350-E300	0	0	0	0	0	0	0	0	#DIV/0!
E360-E300	0	0	0	0	0	0	0	0	#DIV/0!
E400-E300	0	0	0	0		0	0	0	#DIV/0!
E410-E300	0	0	0			0	0	0	#DIV/0!
E420-E300	0	0	0	0		0	0	0	#DIV/0!
E430-E300	0	0	0	0		0	0	0	#DIV/0!
E440-E300	0	0	0	0		0	0	0	#DIV/0!
E500-E300	-8316	-8511	-8511	-8234	-8327	-8241	-8511	-8234	-3.3%
E510-E500	1951	2262	2262	2034	2002	2038	1951	2262	14.9%
E525-E520	-973	-988	-986	-839	-996	-979	-996	-839	-16.3%
E530-E500	-491	-536	-536	-538	-502	-522	-538	-491	-9.0%
E545-E540	-769	-757	-757	-438	-762	-787	-787	-438	-49.0%

Condenser Fan (kWh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	354	385	385		376	368	354	385	8.4%
E320-E300	346	314	316		348	358	314	358	13.1%
E330-E300	383	355	331		401	370	331	401	19.0%
E330-E320	37	41	15		53	12	12	53	128.8%
E340-E300	376	348	338		386	361	338	386	13.3%
E330-E340	7	7	-7		15	9	-7	15	352.1%
E350-E300	-360	-436	-435		-358	-353	-436	-353	-21.4%
E360-E300	1913	1884	1879		1940	1949	1879	1949	3.7%
E400-E300	-414	-441	-437			-421	-441	-414	-6.3%
E410-E300	-406	-336	-333			-387	-406	-333	-20.1%
E420-E300	-252	-247	-206			-208	-252	-206	-20.1%
E430-E300	-341	-308	-322			-353	-353	-308	-13.6%
E440-E300	-218	-191	-198			-203	-218	-191	-13.4%
E500-E300	-481	-326	-327		-415	-347	-481	-326	-40.8%
E510-E500	1461	1534	1534		1499	1526	1461	1534	4.8%
E525-E520	-729	-752	-750		-746	-733	-752	-729	-3.1%
E530-E500	-368	-395	-395		-376	-391	-395	-368	-7.0%
E545-E540	-576	-606	-606		-571	-589	-606	-571	-6.0%

e300results.xls t:a51..m94; 07/19/04

Delta Cooling Coil Loads

Sensible Coil Load (kWh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	-405	504	508	-27	-24	-108	-405	508	1224.5%
E320-E300	6197	6900	6942	6791	6799	7543	6197	7543	19.6%
E330-E300	6422	7514	7523	8527	7440	6631	6422	8527	28.7%
E330-E320	224	614	581	1735	641	-912	-912	1735	550.9%
E340-E300	6371	7257	7306	7634	7171	6215	6215	7634	20.3%
E330-E340	51	258	217	893	269	416	51	893	240.2%
E350-E300	-6291	-8112	-8128	-6707	-6621	-6423	-8128	-6291	-26.1%
E360-E300	78315	79123	79135	80035	78996	79506	78315	80035	2.2%
E400-E300	-14709	-14378	-14368	-14564		-14010	-14709	-14010	-4.9%
E410-E300	-10985	-8138	-8145			-9606	-10985	-8138	-30.9%
E420-E300	-6272	-6131	-5193	-5728		-5207	-6272	-5193	-18.9%
E430-E300	-8798	-8066	-8351	-8513		-9048	-9048	-8066	-11.5%
E440-E300	-5786	-5204	-5313	-5192		-5406	-5786	-5192	-11.0%
E500-E300	-11618	-8147	-8159	-7761	-10335	-7661	-11618	-7661	-44.2%
E510-E500	43046	45710	45710	45091	43051	45083	43046	45710	6.0%
E525-E520	-131	-884	-882	-1057	-202	-949	-1057	-131	-135.4%
E530-E500	2	-1076	-1076	-547	0	-528	-1076	2	-200.6%
E545-E540	-130	-809	-809	-676	-202	-792	-809	-130	-119.1%

Latent Coil Load(kWh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	19321	19607	19612	19156	19576	19111	19111	19612	2.6%
E320-E300	13167	12173	12259	11974	12597	11157	11157	13167	16.4%
E330-E300	18164	15932	16179	16367	18528	17119	15932	18528	15.2%
E330-E320	4997	3760	3919	4393	5931	5962	3760	5962	45.6%
E340-E300	15930	14488	14625	14757	15760	15279	14488	15930	9.5%
E330-E340	2234	1445	1553	1610	2768	1840	1445	2768	69.3%
E350-E300	-4748	-5435	-5529	-4821	-4264	-4446	-5529	-4264	-26.0%
E360-E300	4232	3401	3427	3895	4459	4403	3401	4459	26.7%
E400-E300	3075	2012	2101	2660		2650	2012	3075	42.5%
E410-E300	-769	-2366	-2303			-2477	-2477	-769	-86.3%
E420-E300	-1546	-1542	-1217	-1240		-1212	-1546	-1212	-24.7%
E430-E300	-1872	-1577	-1722	-1663		-2010	-2010	-1577	-24.5%
E440-E300	-930	-699	-798	-709		-823	-930	-699	-29.1%
E500-E300	-5452	-3141	-3141	-3986	-4304	-4983	-5452	-3141	-55.5%
E510-E500	17485	17615	17615	17348	17488	17340	17340	17615	1.6%
E525-E520	2	-288	-288	-58	-9	-42	-288	2	-255.0%
E530-E500	-18313	-18285	-18286	-18080	-18230	-18084	-18313	-18080	-1.3%
E545-E540	-1	-81	-81	-9	-3	-2	-81	-1	-272.0%

e300results.xls t:a99..m142; 07/19/04

Delta Various Annual Means (COP2, IDB)

COP2	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.166	0.180	0.180	0.155	0.171	0.150	0.150	0.180	18.0%
E320-E300	0.171	0.220	0.220	0.168	0.180	0.160	0.160	0.220	32.3%
E330-E300	0.242	0.256	0.299	0.253	0.271	0.230	0.230	0.299	26.7%
E330-E320	0.071	0.036	0.079	0.086	0.091	0.070	0.036	0.091	76.3%
E340-E300	0.205	0.240	0.258	0.210	0.223	0.190	0.190	0.258	30.9%
E330-E340	0.036	0.017	0.041	0.043	0.048	0.040	0.017	0.048	82.5%
E350-E300	0.000	0.003	-0.002	0.006	0.003	0.000	-0.002	0.006	498.6%
E360-E300	0.420	0.463	0.468	0.441	0.440	0.430	0.420	0.468	10.9%
E400-E300	0.001	0.014	0.015	0.009		0.030	0.001	0.030	210.3%
E410-E300	-0.010	-0.025	-0.027			-0.020	-0.027	-0.010	-84.0%
E420-E300	-0.023	-0.022	-0.020	-0.021		-0.020	-0.023	-0.020	-14.9%
E430-E300	-0.028	-0.025	-0.026	-0.026		-0.020	-0.028	-0.020	-33.0%
E440-E300	-0.018	-0.015	-0.015	-0.016		-0.010	-0.018	-0.010	-51.9%
E500-E300	-0.045	-0.010	-0.011	-0.024	-0.034	-0.030	-0.045	-0.010	-135.4%
E510-E500	0.409	0.416	0.416	0.408	0.397	0.410	0.397	0.416	4.6%
E525-E520	0.582	0.574	0.572	0.504	0.606	0.490	0.490	0.606	21.0%
E530-E500	-0.242	-0.258	-0.257	-0.214	-0.276	-0.220	-0.276	-0.214	-25.5%
E545-E540	0.560	0.559	0.560	0.334	0.546	0.510	0.334	0.560	44.3%

IDB (°C)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.13	0.06	0.00	0.00	0.01	0.02	0.00	0.13	364.3%
E320-E300	0.28	0.33	0.33	0.16	0.25	0.54	0.16	0.54	119.3%
E330-E300	0.26	0.22	0.22	0.18	0.21	0.19	0.18	0.26	34.0%
E330-E320	-0.02	-0.11	-0.11	0.02	-0.03	-0.35	-0.35	0.02	-365.4%
E340-E300	0.25	0.22	0.22	0.21	0.23	0.22	0.21	0.25	19.5%
E330-E340	0.00	0.00	0.00	-0.02	-0.01	-0.03	-0.03	0.00	-319.0%
E350-E300	2.04	2.11	2.11	2.15	2.19	2.16	2.04	2.19	7.1%
E360-E300	1.74	1.56	1.50	1.23	1.40	1.38	1.23	1.74	34.6%
E400-E300	0.50	0.00	0.00	0.00		0.00	0.00	0.50	498.8%
E410-E300	0.50	0.00	0.00			0.00	0.00	0.50	400.0%
E420-E300	0.30	0.00	0.00	0.00		0.00	0.00	0.30	500.3%
E430-E300	0.37	0.00	0.00	0.00		0.00	0.00	0.37	500.3%
E440-E300	0.29	0.00	0.00	0.00		0.00	0.00	0.29	500.2%
E500-E300	-3.39	-3.39	-3.50	-3.71	-2.98	-1.13	-3.71	-1.13	-85.5%
E510-E500	1.24	0.11	0.11	-0.02	0.00	0.00	-0.02	1.24	526.6%
E525-E520	13.33	13.61	13.56	13.53	13.63	15.80	13.33	15.80	17.8%
E530-E500	-0.21	-0.06	0.00	0.21	0.00	0.00	-0.21	0.21	-4302.5%
E545-E540	13.32	13.56	13.56	13.52	13.58	15.71	13.32	15.71	17.3%

e300results.xls t:a145..m188; 07/19/04

Delta Various Annual Means (Zone Humidity)

Humidity Ratio (kg/kg)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.0020	0.0021	0.0021	0.0020	0.0020	0.0019	0.0019	0.0021	9.9%
E320-E300	0.0009	0.0009	0.0009	0.0008	0.0009	0.0007	0.0007	0.0009	25.7%
E330-E300	0.0007	0.0007	0.0007	0.0007	0.0006	0.0007	0.0006	0.0007	9.3%
E330-E320	-0.0002	-0.0002	-0.0002	-0.0001	-0.0002	0.0000	-0.0002	0.0000	-143.9%
E340-E300	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	4.1%
E330-E340	-0.0001	0.0000	0.0000	0.0000	-0.0001	0.0000	-0.0001	0.0000	-277.9%
E350-E300	0.0006	0.0008	0.0008	0.0006	0.0006	0.0006	0.0006	0.0008	34.2%
E360-E300	-0.0006	-0.0005	-0.0005	-0.0005	-0.0006	-0.0006	-0.0006	-0.0005	-22.0%
E400-E300	0.0007	0.0008	0.0008	0.0008		0.0008	0.0007	0.0008	8.7%
E410-E300	0.0007	0.0003	0.0003			0.0003	0.0003	0.0007	94.5%
E420-E300	0.0002	0.0002	0.0002	0.0002		0.0001	0.0001	0.0002	58.3%
E430-E300	0.0002	0.0002	0.0002	0.0002		0.0002	0.0002	0.0002	19.7%
E440-E300	0.0001	0.0001	0.0001	0.0000		0.0000	0.0000	0.0001	148.5%
E500-E300	0.0007			0.0001	0.0010	0.0015	0.0001	0.0015	169.4%
E510-E500	0.0004			0.0000	0.0000	0.0000	0.0000	0.0004	394.2%
E525-E520	0.0070			0.0078	0.0070	0.0075	0.0070	0.0078	10.9%
E530-E500	-0.0035			-0.0027	-0.0044	-0.0040	-0.0044	-0.0027	-48.0%
E545-E540	0.0018			0.0024	0.0029	0.0026	0.0018	0.0029	46.8%

Relative Humidity (%)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	9.72	10.25	10.25	9.96	10.01	9.87	9.72	10.25	5.3%
E320-E300	3.39	2.95	2.97	3.25	3.28	2.01	2.01	3.39	46.4%
E330-E300	2.23	2.32	2.37	2.59	2.26	2.77	2.23	2.77	22.3%
E330-E320	-1.16	-0.63	-0.60	-0.66	-1.02	0.76	-1.16	0.76	-347.8%
E340-E300	2.47	2.43	2.45	2.56	2.47	2.85	2.43	2.85	16.5%
E330-E340	-0.24	-0.11	-0.08	0.03	-0.21	-0.08	-0.24	0.03	-232.7%
E350-E300	-3.13	-2.81	-2.73	-3.42	-3.51	-3.37	-3.51	-2.73	-24.7%
E360-E300	-7.58	-6.77	-6.79	-6.22	-6.96	-6.72	-7.58	-6.22	-19.9%
E400-E300	2.16	3.95	3.97	3.96		4.08	2.16	4.08	53.1%
E410-E300	1.88	1.39	1.35			1.82	1.35	1.88	33.0%
E420-E300	0.16	0.88	0.69	0.81		0.83	0.16	0.88	106.1%
E430-E300	0.21	0.91	1.02	1.01		1.24	0.21	1.24	117.8%
E440-E300	-0.29	0.20	0.29	0.24		0.30	-0.29	0.30	394.1%
E500-E300	17.91			10.61	18.12	15.80	10.61	18.12	48.1%
E510-E500	-2.35			0.11	-0.01	0.11	-2.35	0.11	-461.4%
E525-E520	-8.41			-6.41	-10.09	-14.80	-14.80	-6.41	-84.5%
E530-E500	-19.80			-10.22	-24.49	-24.13	-24.49	-10.22	-72.6%
E545-E540	-11.90			-7.68	-3.18	-14.62	-14.62	-3.18	-122.5%

e300results.xls t:a191..m234; 07/19/04

Delta Hourly Integrated Maximum Total Consumptions

Total Consumption (Wh,e)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	968	1019	993	641	721	614	614	1019	49.0%
E320-E300	1402	1352	1379	1055	1172	1327	1055	1402	27.1%
E330-E300	1721	1648	1805	1414	1535	1787	1414	1805	23.7%
E330-E320	319	296	426	360	363	460	296	460	44.3%
E340-E300	1555	1594	1588	1234	1345	1553	1234	1594	24.3%
E330-E340	166	54	217	180	190	234	54	234	103.8%
E350-E300	1	90	0	0	0	-2	-2	90	621.2%
E360-E300	1143	1172	1124	844	931	1214	844	1214	34.5%
E400-E300	2	0	75	0		-29	-29	75	1087.2%
E410-E300	2	0	0			1	0	2	258.7%
E420-E300	0	0	0	0		0	0	0	#DIV/0!
E430-E300	0	0	0	0		0	0	0	-500.0%
E440-E300	0	0	0	0		-87	-87	0	-500.0%
E500-E300	-1460	-1133	-1177	-1501	-1755	-1274	-1755	-1133	-45.0%
E510-E500	1038	1159	1162	1011	1009	1070	1009	1162	14.2%
E525-E520	-1669	-1451	-1483	-1531	-1625	-1099	-1669	-1099	-38.6%
E530-E500	-2138	-2372	-2370	-2228	-2185	-2185	-2372	-2138	-10.4%
E545-E540	-1494	-1593	-1593	-915	-1495	-1514	-1593	-915	-47.3%

e300results.xls t:a242..m264; 07/19/04

Delta Hourly Integrated Maximum Coil Loads

Sensible + Latent Coil Load (Wh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	5154	5349	5578	4393	4759	4919	4393	5578	23.6%
E320-E300	8144	22412	22368	7032	7402	7848	7032	22412	122.7%
E330-E300	11318	12227	33117	10712	11476	10343	10343	33117	153.2%
E330-E320	3174	-10185	10749	3680	4074	2495	-10185	10749	898.0%
E340-E300	9478	19418	28094	8595	8864	9060	8595	28094	140.1%
E330-E340	1840	-7191	5023	2117	2612	1283	-7191	5023	1289.3%
E350-E300	-82	0	-1	0	0	5	-82	5	-669.0%
E360-E300	6683	9212	9564	5726	5820	6379	5726	9564	53.1%
E400-E300	9005	9142	18383	7995		8702	7995	18383	97.6%
E410-E300	-82	0	0			1	-82	1	-409.8%
E420-E300	0	0	0	0		0	0	0	#DIV/0!
E430-E300	0	0	0	0		0	0	0	-500.0%
E440-E300	0	0	0	0		-295	-295	0	-500.0%
E500-E300	-4689	-3694	-3749	-5087	-5935	-4517	-5935	-3694	-48.6%
E510-E500	3108	3481	3482	3531	3381	3542	3108	3542	12.7%
E525-E520	410	-412	-412	-76	8	-881	-881	410	-568.4%
E530-E500	-7651	-8131	-8131	-8008	-7791	-7929	-8131	-7651	-6.0%
E545-E540	500	-291	-292	-187	-30	-302	-302	500	-800.3%

Sensible Coil Load (Wh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	-183	-123	-86	-254	-379	-259	-379	-86	-136.9%
E320-E300	8038	7916	7867	8441	7677	8059	7677	8441	9.6%
E330-E300	9949	10207	11285	11234	10540	10513	9949	11285	12.6%
E330-E320	1911	2291	3418	2793	2863	2454	1911	3418	57.5%
E340-E300	9552	8883	8881	9357	9483	9272	8881	9552	7.3%
E330-E340	397	1324	2404	1877	1057	1241	397	2404	145.1%
E350-E300	0	0	0	0	0	-32	-32	0	-603.8%
E360-E300	8783	8908	8860	9090	8524	9271	8524	9271	8.4%
E400-E300	0	0	0	0		-31	-31	0	-503.2%
E410-E300	-12	0	0			-15	-15	0	-224.7%
E420-E300	0	0	0	0		-15	-15	0	-500.0%
E430-E300	0	0	0	0		-15	-15	0	-500.0%
E440-E300	0	0	0	0		-33	-33	0	-500.0%
E500-E300	-3728	-3194	-3197	-3682	-4681	-3090	-4681	-3090	-44.3%
E510-E500	2180	2504	2505	2441	2345	2451	2180	2505	13.5%
E525-E520	287	-309	-304	-336	-210	-717	-717	287	-379.1%
E530-E500	285	-433	-433	-211	0	-192	-433	285	-437.9%
E545-E540	500	-291	-292	-187	-35	-302	-302	500	-793.7%

Latent Coil Load (Wh,th)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	6271	5835	5876	6040	5737	5685	5685	6271	9.9%
E320-E300	13512	22193	22109	11961	11322	11537	11322	22193	70.4%
E330-E300	18190	17637	31415	16899	17809	17096	16899	31415	73.2%
E330-E320	4678	-4556	9306	4939	6487	5559	-4556	9306	314.9%
E340-E300	15213	21147	26617	13676	13850	13402	13402	26617	76.3%
E330-E340	2977	-3510	4798	3223	3959	3694	-3510	4798	329.2%
E350-E300	116	-1	-1	1	380	1211	-1	1211	426.5%
E360-E300	-361	722	942	-1715	-1516	-1458	-1715	942	-470.9%
E400-E300	17440	16274	23002	16082		16253	16082	23002	38.9%
E410-E300	1503	0	-3			-15	-15	1503	408.9%
E420-E300	115	0	0	0		2	0	115	491.5%
E430-E300	0	1801	1707	839		2	0	1801	207.1%
E440-E300	0	0	-3	0		-253	-253	0	-494.1%
E500-E300	-1670	-1571	-1661	-2396	-2570	-2630	-2630	-1571	-50.8%
E510-E500	927	990	990	1116	1045	1112	927	1116	18.3%
E525-E520	123	-122	-122	249	212	-144	-144	249	1201.2%
E530-E500	-7965	-7733	-7733	-7838	-7626	-7726	-7965	-7626	-4.4%
E545-E540	-627	0	0	-1655	-841	-1181	-1655	0	-230.7%

e300results.xls t:a266..m330; 07/19/04

Delta Hourly Integrated Maximum and Minimum COP2

Maximum COP2	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	-0.025	0.272	0.271	0.248	0.257	0.240	-0.025	0.272	141.1%
E320-E300	0.000	1.274	1.110	0.014	0.073	0.500	0.000	1.274	257.3%
E330-E300	0.000	0.240	1.738	0.146	0.251	0.170	0.000	1.738	409.6%
E330-E320	0.000	-1.034	0.628	0.132	0.179	-0.330	-1.034	0.628	-2344.2%
E340-E300	0.000	0.752	1.482	0.061	0.147	0.070	0.000	1.482	354.0%
E330-E340	0.000	-0.512	0.256	0.085	0.105	0.100	-0.512	0.256	13685.7%
E350-E300	0.000	0.020	0.006	0.630	0.061	0.000	0.000	0.630	526.8%
E360-E300	0.233	0.559	0.570	0.530	0.561	0.560	0.233	0.570	67.2%
E400-E300	-0.091	0.219	0.919	0.146		0.170	-0.091	0.919	370.7%
E410-E300	-0.280	0.034	-0.002			-0.040	-0.280	0.034	-436.1%
E420-E300	-0.387	-0.062	-0.098	-0.104		0.060	-0.387	0.060	-378.3%
E430-E300	-0.387	-0.064	-0.098	-0.133		0.050	-0.387	0.050	-346.0%
E440-E300	-0.285	-0.095	-0.098	-0.123		-0.070	-0.285	-0.070	-160.0%
E500-E300	0.107	3.498	1.444	0.273	0.314	0.260	0.107	3.498	345.1%
E510-E500	0.417	0.000	0.000	0.487	0.505	0.390	0.000	0.505	168.4%
E525-E520	0.904	1.429	1.379	0.766	0.836	0.560	0.560	1.429	88.8%
E530-E500	-0.269	-3.386	-1.451	-0.273	-0.345	-0.260	-3.386	-0.260	-313.5%
E545-E540	0.794	0.819	0.973	0.470	0.490	0.480	0.470	0.973	74.9%
Minimum COP2	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.072	0.052	0.050	0.111	0.087	0.060	0.050	0.111	84.8%
E320-E300	0.032	0.003	0.004	0.060	0.029	0.020	0.003	0.060	231.0%
E330-E300	0.032	0.000	0.000	0.063	0.038	0.030	0.000	0.063	231.1%
E330-E320	0.000	-0.003	-0.004	0.003	0.009	0.010	-0.004	0.010	584.2%
E340-E300	0.032	0.000	0.000	0.063	0.038	0.030	0.000	0.063	231.1%
E330-E340	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	#DIV/0!
E350-E300	-0.003	0.000	0.000	0.000	0.000	0.000	-0.003	0.000	-742.2%
E360-E300	0.032	0.001	0.000	0.063	0.038	0.030	0.000	0.063	229.7%
E400-E300	-0.011	-0.064	-0.066	0.000		0.000	-0.066	0.000	-233.8%
E410-E300	-0.007	0.000	0.000			0.000	-0.007	0.000	-400.0%
E420-E300	0.000	0.000	0.000	0.000		0.000	0.000	0.000	#DIV/0!
E430-E300	-0.022	-0.064	-0.066	0.000		0.000	-0.066	0.000	-217.2%
E440-E300	-0.011	-0.064	-0.066	0.000		0.000	-0.066	0.000	-234.7%
E500-E300	-0.108	-0.105	-0.149	-0.076	-0.119	-0.100	-0.149	-0.076	-66.6%
E510-E500	0.203	0.124	0.000	0.160	0.215	0.190	0.000	0.215	144.8%
E525-E520	0.469	0.476	0.420	0.408	0.561	0.430	0.408	0.561	33.2%
E530-E500	-0.184	-0.198	-0.154	-0.173	-0.193	-0.190	-0.198	-0.154	-24.2%
E545-E540	0.479	0.459	0.460	0.277	0.549	0.440	0.277	0.549	61.2%

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Delta Hourly Integrated Maximum and Minimum IDB

Maximum IDB (°C)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.88	1.78	1.61	1.47	1.57	1.00	0.88	1.78	65.1%
E320-E300	6.16	6.50	6.39	6.71	7.27	5.46	5.46	7.27	28.2%
E330-E300	6.03	6.61	6.89	6.07	6.85	5.11	5.11	6.89	28.4%
E330-E320	-0.13	0.11	0.50	-0.64	-0.42	-0.35	-0.64	0.50	-736.8%
E340-E300	6.11	6.50	6.45	6.50	7.10	5.39	5.39	7.10	27.0%
E330-E340	-0.07	0.11	0.44	-0.43	-0.25	-0.28	-0.43	0.44	-1078.3%
E350-E300	8.38	9.83	9.83	10.00	9.95	8.81	8.38	10.00	17.1%
E360-E300	7.56	7.67	7.45	7.51	7.95	6.94	6.94	7.95	13.4%
E400-E300	0.91	2.45	3.72	1.91		-0.15	-0.15	3.72	218.8%
E410-E300	0.63	0.00	0.00			0.00	0.00	0.63	400.0%
E420-E300	0.00	0.00	0.00	0.00		0.04	0.00	0.04	500.0%
E430-E300	1.00	0.00	0.00	0.00		0.26	0.00	1.00	396.6%
E440-E300	0.85	0.00	0.00	0.00		0.07	0.00	0.85	461.5%
E500-E300	-0.39	0.00	0.00	0.00	-0.03	-1.19	-1.19	0.00	-441.5%
E510-E500	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.29	600.0%
E525-E520	19.96	18.95	19.12	20.00	19.02	16.38	16.38	20.00	19.1%
E530-E500	0.31	-0.05	-0.05	0.00	0.00	0.00	-0.05	0.31	1025.2%
E545-E540	19.53	19.89	19.89	20.00	19.95	20.00	19.53	20.00	2.4%

Minimum IDB (°C)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-600.0%
E320-E300	0.00	1.94	1.95	-0.96	0.00	0.00	-0.96	1.95	597.5%
E330-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-600.0%
E330-E320	0.00	-1.94	-1.95	0.96	0.00	0.00	-1.95	0.96	-596.8%
E340-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-600.0%
E330-E340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!
E350-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!
E360-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	600.0%
E400-E300	0.00	0.00	0.00	0.00		0.00	0.00	0.00	-500.0%
E410-E300	0.00	0.00	0.00			0.00	0.00	0.00	#DIV/0!
E420-E300	0.00	0.00	0.00	0.00		0.00	0.00	0.00	-500.0%
E430-E300	0.00	0.00	0.00	0.00		0.00	0.00	0.00	-500.0%
E440-E300	0.00	0.00	0.00	0.00		0.01	0.00	0.01	500.0%
E500-E300	0.50	-0.72	-0.89	0.22	0.54	17.05	-0.89	17.05	644.6%
E510-E500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	600.0%
E525-E520	0.14	0.06	0.05	0.18	0.03	19.44	0.03	19.44	585.3%
E530-E500	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-533.6%
E545-E540	0.22	0.06	0.05	0.18	0.03	18.06	0.03	18.06	581.6%

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Delta Hourly Integrated Maximum and Minimum Zone Humidity Ratio

Maximum Humidity Ratio (kg/kg)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.0025	0.0050	0.0052	0.0020	0.0020	0.0023	0.0020	0.0052	102.1%
E320-E300	0.0047	0.0039	0.0039	0.0042	0.0041	0.0043	0.0039	0.0047	19.9%
E330-E300	0.0044	0.0040	0.0040	0.0043	0.0036	0.0043	0.0036	0.0044	19.0%
E330-E320	-0.0004	0.0001	0.0001	0.0001	-0.0005	0.0000	-0.0005	0.0001	-696.5%
E340-E300	0.0046	0.0039	0.0037	0.0042	0.0038	0.0043	0.0037	0.0046	21.8%
E330-E340	-0.0002	0.0001	0.0003	0.0001	-0.0002	0.0000	-0.0002	0.0003	3174.2%
E350-E300	0.0035	0.0061	0.0062	0.0036	0.0030	0.0032	0.0030	0.0062	74.6%
E360-E300	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0002	366.5%
E400-E300	0.0037	0.0032	0.0033	0.0033		0.0039	0.0032	0.0039	20.2%
E410-E300	0.0036	0.0031	0.0032			0.0039	0.0031	0.0039	23.3%
E420-E300	0.0010	0.0009	0.0004	0.0010		0.0013	0.0004	0.0013	98.3%
E430-E300	0.0029	0.0018	0.0019	0.0025		0.0024	0.0018	0.0029	49.6%
E440-E300	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	500.0%
E500-E300	-0.0016	-0.0019	-0.0019	-0.0019	-0.0017	-0.0019	-0.0019	-0.0016	-20.6%
E510-E500	0.0002	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002	352.6%
E525-E520	0.0104	0.0103	0.0102	0.0115	0.0101	0.0067	0.0067	0.0115	48.3%
E530-E500	-0.0047	-0.0038	-0.0037	-0.0049	-0.0062	-0.0047	-0.0062	-0.0037	-53.9%
E545-E540	0.0009	0.0072	0.0059	0.0000	0.0034	0.0013	0.0000	0.0072	230.7%

Minimum Humidity Ratio (kg/kg)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0001	646.4%
E320-E300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	600.0%
E330-E300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-600.0%
E330-E320	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-600.0%
E340-E300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-600.0%
E330-E340	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	#DIV/0!
E350-E300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	#DIV/0!
E360-E300	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-600.0%
E400-E300	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	500.0%
E410-E300	0.0000	0.0000	0.0000			0.0000	0.0000	0.0000	#DIV/0!
E420-E300	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	-500.0%
E430-E300	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	500.0%
E440-E300	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	-500.0%
E500-E300	0.0050			0.0051	0.0049	0.0083	0.0049	0.0083	58.2%
E510-E500	0.0000			0.0000	0.0000	0.0002	0.0000	0.0002	400.0%
E525-E520	0.0007			0.0005	0.0004	0.0088	0.0004	0.0088	322.8%
E530-E500	-0.0006			-0.0003	-0.0015	-0.0037	-0.0037	-0.0003	-226.1%
E545-E540	0.0021			0.0030	0.0034	0.0028	0.0021	0.0034	47.3%

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Delta Hourly Integrated Maximum and Minimum Zone Relative Humidity

Maximum Relative Humidity (%)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	8.91	30.83	31.85	10.28	9.00	10.75	8.91	31.85	135.4%
E320-E300	13.05	14.06	14.82	14.60	15.00	14.44	13.05	15.00	13.6%
E330-E300	7.87	9.11	9.09	8.51	8.00	11.26	7.87	11.26	37.8%
E330-E320	-5.18	-4.95	-5.73	-6.09	-7.00	-3.18	-7	-3	-71.3%
E340-E300	11.14	12.02	12.41	12.43	12.00	12.81	11	13	13.8%
E330-E340	-3.27	-2.91	-3.32	-3.92	-4.00	-1.55	-4	-2	-77.5%
E350-E300	0.00	11.77	12.27	0.00	2.00	5.21	0.00	12.27	235.6%
E360-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-600.0%
E400-E300	14.96	16.22	16.72	16.27		18.87	14.96	18.87	23.5%
E410-E300	14.44	15.44	15.94			18.74	14.44	18.74	26.7%
E420-E300	2.05	5.16	2.68	4.92		6.41	2.05	6.41	102.7%
E430-E300	11.92	9.08	9.58	12.38		11.50	9.08	12.38	30.3%
E440-E300	-0.06	0.00	0.00	0.00		0.07	-0.06	0.07	13500.0%
E500-E300	31.21			31.63	32.00	-7.36	-7.36	32.00	180.0%
E510-E500	0.00			0.00	0.00	-2.57	-2.57	0.00	-400.0%
E525-E520	9.77			6.19	5.00	-20.65	-20.65	9.77	39706.5%
E530-E500	-8.96			-3.84	-21.00	-24.07	-24.07	-3.84	-139.8%
E545-E540	29.60			41.06	50.00	-15.82	-15.82	50.00	251.1%

Minimum Relative Humidity (%)	TRNSYS TUD	DOE-2.2 NREL	DOE21E-E NREL	Energy+ GARD	CODYRUN UR	HOT3000 NRCan	Statistics, All Results Min	Max	(Max-Min) /Mean
E310-E300	0.06	0.00	0.00	1.10	1.00	0.99	0.00	1.10	209.6%
E320-E300	0.00	0.00	0.00	0.24	0.00	-2.02	-2.02	0.24	-761.2%
E330-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	600.0%
E330-E320	0.00	0.00	0.00	-0.24	0.00	2.02	-0.24	2.02	761.1%
E340-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	600.0%
E330-E340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!
E350-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!
E360-E300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-600.0%
E400-E300	-0.12	0.00	0.00	-0.48		-0.37	-0.48	0.00	-246.0%
E410-E300	-0.12	0.00	0.00			-0.36	-0.36	0.00	-298.7%
E420-E300	-0.12	0.00	0.00	-0.48		-0.35	-0.48	0.00	-251.4%
E430-E300	-0.12	0.00	0.00	-0.48		-0.36	-0.48	0.00	-248.3%
E440-E300	-0.12	0.00	0.00	-0.48		-0.40	-0.48	0.00	-238.1%
E500-E300	40.07			40.76	39.00	37.89	37.89	40.76	7.3%
E510-E500	-1.32			0.12	0.00	0.32	-1.32	0.32	-747.8%
E525-E520	-15.74			-13.87	-17.00	-17.50	-17.50	-13.87	-22.6%
E530-E500	-23.81			-21.14	-26.00	-19.15	-26.00	-19.15	-30.4%
E545-E540	-19.35			-16.77	-12.00	-19.60	-19.60	-12.00	-44.9%

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
December 2004

2. REPORT TYPE
Technical report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
International Energy Agency Building Energy Simulation Test and Diagnostic Method for Heating, Ventilating, and Air-Conditioning Equipment Models (HVAC BESTEST). Volume 2. Cases E300-E545.

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER
NREL/TP-550-36754

5e. TASK NUMBER
5500.5000

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Joel Neymark and Ron Judkoff

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-550-36754

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
This report documents an additional set of mechanical system test cases that are planned for inclusion in ANSI/ASHRAE STANDARD 140. The cases test a program's modeling capabilities on the working-fluid side of the coil, but in an hourly dynamic context over an expanded range of performance conditions. These cases help to scale the significance of disagreements that are less obvious in the steady-state cases. The report is Vol. 2 of HVAC BESTEST Volume 1. Volume 1 was limited to steady-state test cases that could be solved with analytical solutions. Volume 2 includes hourly dynamic effects, and other cases that cannot be solved analytically. NREL conducted this work in collaboration with the Tool Evaluation and Improvement Experts Group under the International Energy Agency (IEA) Solar Heating and Cooling Programme Task 22.

15. SUBJECT TERMS
Heating, Ventilating, and Air-Conditioning equipment models; HVAC; BESTEST; IEA; Building Energy Simulation; testing and diagnostics.

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
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