IEA

SOLAR R&D

INTERNATIONAL ENERGY AGENCY

solar heating and
cooling programme
task VII

central solar heating plants with seasonal storage

heat storage systems: concepts, engineering data and compilation of projects

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INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the organization for Economic Cooperation and Development (OECD) to administer that agreement. Twenty countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat, coordinates the energy research, development, and demonstration program.

Solar heating and cooling program

Solar Heating and Cooling was one of the technologies selected by the IEA for a collaborative effort. The objective was to undertake cooperative research, development, demonstrations and exchanges of information in order to advance the activities of all Participants in the field of solar heating and cooling systems. Several tasks were developed in key areas of solar heating and cooling. A formal Implementing Agreement for this Program, covering the contributions, obligations and rights of the Participants, as well as the scope of each task, was prepared and signed by 15 (now 20) countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the tasks is the responsibility of Operating Agents who act on behalf of the other Participants.

The tasks of the IEA Solar Heating and Cooling Programs and their respective Operating Agents are:

I Investigation of the Performance of Solar Heating and Cooling Systems - Technical University of Denmark

II Coordination of R & D on Solar Heating and Cooling Components - Agency of Industrial Science and Technology, Japan

III Performance Testing of Solar Collectors - Kernforschungsanlage Jülich, Federal Republic of Germany

IV Development of an Insolation Handbook and Instrumentation Package - United States Department of Energy

V Use of Existing Meteorological Information for Solar Energy Application * Swedish Meteorological and Hydrological Institute

VI Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors - United States Department of Energy

VII Central Solar Heating Plants with Seasonal Storage - Swedish Council for Building Research

VIII Passive and Hybrid Solar Low Energy Buildings - United States Department of Energy

IX Solar Radiation and Pyranometry Studies - National Research Council, Canada

Collaboration in additional areas in likely to be considered as projects are completed or fruitful topics for cooperation identified.

Task VII - Central Solar Heating Plants with Seasonal Stc
Feasibility Study and Design

In colder climates solar energy for heating of buildings is least abundant when it is needed most - during the wir A seasonal storage is needed for making solar heat gainec during warmer months available for later use. From inves igations of various storage methods two observations can be made: The choice of storage method will greatly inflt the working conditions for and the optimal choice of the solar collectors and the heat distribution system; and based on the technique that is available today the most economic solutions will be found in large applications. The objective of Task VII is to determine the technical feasibility and cost-effectiveness of such seasonal solar energy storage for large-scale district heating systems. The Participants will evaluate the merits of various comp and system configurations for collecting, storing and dis buting the energy, and prepare site-specific designs for specific systems.

The work is divided in two phases, preliminary design anc parametric study of design alternatives. The work during the first phase is undertaken in five Subtasks:

Subtask 1a: System Studies and Optimization
(Lead Country: Canada)

Subtask 1b: Solar Collector Subsystems
(Lead Country: USA)

Subtask 1c: Heat Storage
(Lead Country: Switzerland)

Subtask 1d: Heat Distribution System
(Lead Country: Sweden)

Subtask 1e: Inventory and Preliminary Site Specific Syst Design
(Lead Country: Sweden)

The participants in this Task are Austria, Canada, the Commission of European Communities, Denmark, Germany, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States.

This report documents work carried out under Subtask 1c of this Task. The co-operative work and resulting rep is described in the following section.

central solar heating plants with seasonal storage

heat storage systems: concepts, engineering data and compilation of projects

Pierre Chuard, **Jean-Christophe Hadorn**
Sorane SA, Switzerland
and the participants in Subtask 1c of the IEA Task VII

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This report is part of the work within the IEA Solar Heating and Cooling Programme,

Task VII: Central Solar Heating Plants with Seasonal Storage
Subtask 1c: Heat Storage

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Three different versions of the reports were prepared by Pierre Chuard and Jean-Christophe Hadorn, of Sorane SA, Lausanne, Switzerland, under contract with the Swiss Federal Office of Energy. The work has been sponsored by the Swiss National Energy Research Foundation.

These versions have been improved by the joint effort of the Subtask 1c participants.

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LIST OF THE PARTICIPANTS IN SUBTASK 1c OF THE IEA TASK VII

Austria

G. SCHAFFAR
TU-Wien
Institut für Allgemeines Physik
Karlsplatz 13
A - 1040 WIEN

Canada

E. MOROFSKY
Public Works Canada
Energy Technology
Sir Charles Tupper Bldg. C 456
OTTAWA, Ontario K1A 0M2

Denmark

K.K. HANSEN
Thermal Insulation Lab.
Building 18
Technical University of Denmark
DK - 2800 LYNGBY

EC

D. VAN HATTEM
Commission of the European Communities
Joint Research Center
ISPRA Establishment
I - 21020 ISPRA

Federal Republic of Germany

H. RIEMER & F. SCHOLZ
Kernforschungsanlage Jülich GmbH
Postfach 1913 STE
D - 5170 JÜLICH

The Netherlands

C. DEN OUDEN & A. WIJSMAN
Institute of Applied Physics
TNO/TH
P.O. Box 155
NL - 2600 AD DELFT

Sweden

P.O. KARLSSON
Statens Vattenfallsverk
Konstruktion och byggarde
S - 162 87 VALLINGBY

G. HELLSTRÖM
University of Lund
Dept. of Mathematical Physics
Box 725
S - 220 07 LUND

Switzerland

P. CHUARD & J.C. HADORN
Sorane SA
Route du Châtelard 52
CH - 1018 LAUSANNE

The United Kingdom

B. ROGERS
Dept. of Mechanical Engineering
and Energy Studies
University College
Newport Road
GB - CARDIFF CF2 1TA - Wales

The United States of America

A.I. MICHAELS
Solar Thermal Storage Program
Argonne National Lab.
9700 South Cass Ave.
Building 362
ARGONNE, Illinois 60439

L. KANNBERG
Underground Energy Storage Program
Batelle Pacific Northwest Labs.
P.O. Box 999
RICHLAND, WA 99352

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EXECUTIVE SUMMARY OF THE WORK UNDERTAKEN IN SUBTASK 1c

A. INTRODUCTION

Within the IEA Task VII, the Subtask 1c called "Heat Storage" has the specific goal to collect and co-ordinate research and engineering information on heat storage systems to be considered in the design, analysis, and optimization of Central Solar Heating Plants with Seasonal Storage (CSHPSS).

In Subtask 1c three main fields were covered:

1. Seasonal heat storage simulation models
2. Cost data and cost equations for heat storage concepts
3. Basic engineering information for seasonal heat stores

The basic information collected in the Subtask among the ten participating countries has been analysed and presented in three reports dealing with each identified field. The Subtask work concurrently allowed the participants to select heat storage models suitable to the needs of Subtask 1a: "System Studies and Optimization", as well as adequate cost equations and cost parameters describing the various types of storage systems considered in the Task.

The purpose of this Executive Summary is to give an overview of the work accomplished in Subtask 1c, and of the three detailed reports which resulted from the cooperation and discussions among participants.

B. HEAT STORAGE CONCEPTS CONSIDERED IN TASK VII

Dealing with large-scale seasonal heat storage for solar heating plants, and considering the past and present developments in this field, the participants in Task VII decided, in 1980, to consider storage systems in which:

- the sensible heat of materials only is used
- the transfer medium is a liquid
- the annual variations of temperature are between 10°C and 100°C approximately

Seven storage types were identified as concepts to be investigated. They are the following:

1.	Tank	insulated	and/or	uninsulated
2.	Pit	insulated	and/or	uninsulated
3.	Cavern	insulated	and/or	uninsulated
4.	Aquifer	confined	or	unconfined
5.	Earth	disturbed	or	undisturbed
6.	Rock		undisturbed	

7. Solar controlled gradient pond

As the interest in solar ponds was not widespread among participants it was later decided not to consider these.

Hence, six concepts, mainly underground storage, have been considered in Subtask 1c.

C. HEAT STORAGE MODELS AND THEIR SELECTION

The aim of this part of the Subtask work was to gather information concerning seasonal heat storage simulation models, their capabilities and availabilities, to present in some detail several models suitable to the needs of Task VII, and, finally, to select models compatible with the optimization tool (the MINSUN program) and the analytical tool (the TRNSYS program) chosen in Subtask la.

In the resulting report, a general overview of about 50 existing heat storage models in the ten participating countries in 1981 is presented.

The information was processed by Lead Country lc, based on questionnaires which were distributed to the participants at the beginning of the Task.

Considering this basic information, a more precise analysis was performed for about 20 models, which were identified as being available.

A detailed analysis was then executed for 15 models classified in 3 categories:

- models for water tank, pit, and cavern storage systems
- models for earth and rock storage systems
- models for aquifer storage systems,

and typical test cases were submitted to the authors of the models.

Considering the capabilities, size, and results of each evaluated model, and keeping in mind the specialities and constraints of Task VII, the participants decided to choose a set of programs developed in Sweden by Lund University. These are the following:

SST: Stratified Storage Temperature Model (for tanks, pit, and cavern)

DST: Duct Storage Model (for earth and rock storage)

AST: Aquifer Storage Model (for aquifer storage)

These models are based on 2-D explicit finite differences, and they basically solve the heat conduction equation in soils.

For water storage in tanks, pits, and caverns, vertical stratification is accounted for.

For earth and rock storage, the local processes around pipes or ducts, and the global processes (storage losses) are treated with a superposition method.

For aquifer storage, a special technique is used to take into account the convective terms in a one-well or doublet system with prescribed horizontal water flow.

The models have the basic advantage to be complete (with few restrictions), while not consuming too much computer time. Furthermore, they are at least partly validated.

The integration of the models into TRNSYS and MINSUN, by their authors directly, started in Sweden in 1982 with a lower priority for AST, due to time constraints.

D. COST INFORMATION AND COST MODELS FOR HEAT STORAGE CONCEPTS

The optimization program for Central Solar Heating Plants with Seasonal Storage needs storage models used as subroutines, as well as cost equations describing the various storage components to be optimized.

For this main purpose and also for storage cost comparisons, the Subtask participants were asked to provide cost information concerning the storage types they were mostly interested in, as well as the distribution of investment costs between the storage main components.

After a general cost comparison among participating countries, cost equations were developed describing in terms of the MINSUN independent variables the total investment cost for each identified type of storage.

Typical values of the parameters involved in the equations (mainly specific costs) were then given - using the basic cost information provided by the participants - to the Subtask group responsible for optimization studies.

This work should be considered as a first attempt to give future cost projections since few large-scale storage systems have been built in the participating countries in 1981/1982.

Furthermore, as a result of the IEA cooperation, the Task participants are able to investigate, with some restrictions due to national conditions, the economic competitiveness of storage types with which they do not have much experience.

E. HEAT STORAGE CONCEPTS AND ENGINEERING DATA

The purpose of this part of the Subtask work was to gather information among the participating countries about engineering aspects of some major concepts of seasonal heat storage considered in the Task.

The aim was not to produce a "heat storage handbook", but rather an overview of the applicability, the existing experiences, and the future of the storage concepts.

To reach these objectives, the final report is organized into three main parts:

- the general design, applicability, and past experience of each storage type is outlined in a brief description written by some participants

- an overview of the national activities and specific interest in seasonal storage of each participating country is presented

- and, finally, based on questionnaires that were distributed to the participants during the Subtask work, a compilation of some interesting heat storage projects in participating countries was made, using a summary sheet for storage projects developed in the framework of similar EC work

More than 25 actually constructed projects or design studies in the field of large-scale seasonal storage are briefly presented, together with references and contact persons.

1. INTRODUCTION

The main purpose of Task VII of the IEA Solar Heating and Cooling Program, " Central Solar Heating Plants with Seasonal Storage", is to determine the technical feasibility and cost effectiveness of seasonal storage combined with large scale solar district systems.

During the past ten years, a great deal of studies and experiments has been achieved over the world in the field of seasonal heat storage.

Seasonal storage can be considered, in colder climates, as the only way to reach high solar fraction of domestic heating loads in an active solar system, and even in a hybrid system.

Moreover, seasonal heat storage can allow important savings (30-50%) on the total amount of solar collectors needed to meet a given part of a heating load.

Within Task VII, the Subtask 1c called "Heat Storage" has the specific goal to collect and co-ordinate research and engineering information on heat storage systems to be considered in the design, analysis, and optimization of Central Solar Heating Plants with Seasonal Storage (CSHPSS).

In Subtask 1c three main field are covered:

1. Heat storage simulation models
2. Cost data and cost equation for heat storage concepts
3. Engineering data for heat storage concepts

The purpose of this report, covering the third item of Subtask 1c, i.e. "Engineering information", is to gather information among the ten participating countries about the engineering aspects of some major concepts of heat storage considered in Task VII.

The report is organized into three parts:

1) the design, application, and major problems of each of the heat storage systems considered (Chapter 3)

2) a short description of the activities concerning seasonal heat storage in each participating country (Chapter 4)

3) a compilation of some basic data on heat storage projects of interest in participating countries (Chapter 5)

The aim of the report was not to produce some kind of handbook answering questions such as "How can I build a seasonal storage ?". It was rather to gather the information that had circulated among the Task participants, in order to give an overview of the applicability, the existing experiences, and the future of the storage concepts considered, and their technologies.

This basic approach can be seen as complementary to the work concerning heat storage, done in Annex 1 of the IEA program "Energy Conservation Through Energy Storage", dealing with large scale thermal storage systems, and especially focusing on the technical and economical evaluation of some large scale interesting projects (Report dated October 1981, classified IEA restricted).

2. HEAT STORAGE CONCEPTS CONSIDERED IN TASK VII

Dealing with large scale seasonal heat storage for solar heating plants, and considering the past and present developments in this field, the participants in Task VII decided to consider storage systems in which:

- the sensible heat of materials only is used
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Seven storage types were identified as concepts to be investigated:

1.	Tank	insulated	and/or	uninsulated
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7. Solar controlled gradient pond

As the interest in solar ponds was not widespread among participants it was decided not to consider these.

Hence, six concepts, mainly underground storage, have been considered in Subtask lc.

3. DESIGN, APPLICABILITY, AND PROBLEMS OF EACH STORAGE CONCEPT

This chapter is devoted to a brief description of the concepts and their applications, limits and interests.

Each section has been prepared by a participant in Subtask lc.

The chapter focuses essentially on the major aspects of each storage type considered in order to present the concept and to give a short overview of the state-of-the-art in the particular field.

3.1. Water tank storage (by F. Scholz, Federal Republic of Germany)

3.2. Pit storage (by B. Rogers, United Kingdom)

3.3. Cavern storage (By P.O. Karlsson, Sweden)

3.4. Aquifer storage (by J.C. Hadorn, Switzerland)

3.5. Earth storage (by A.J. Wijsman, the Netherlands)

3.6. Rock storage (by P.O. Karlsson, Sweden)

3.1. Water tank storage concepts (by F. Scholz, Federal Republic of Germany)

3.1.1. Technical description

Hot water storage in steel tanks (usually by elevated pressures) is a tried and tested technique in the construction of power stations and in district heating systems. The requirements for larger storage volumes also increase with increasing plant size. Moreover, the heat extracted from steam power stations can be provided more cheaply the lower the temperature is. Since, on the other hand, a flow temperature of just below 100°C is quite sufficient in many district heating systems during most of the year, and pressureless tanks can be specifically built much more cheaply, the construction of large tank reservoirs - such as are also common in the mineral oil industry - became possible.

As a rule, tank reservoirs are operated as stratified reservoirs, i.e. during loading, for example, hot water is fed in at the top of the tank and the same volume is withdrawn at the bottom. A stable transitional layer is formed between the hot and colder water, whose thickness mainly increases by thermal conduction, approximately with the square root of time. In special cases, particularly if several tanks are available, it can be appropriate to do without the stratification principle and, first of all, to additionally transfer the contents cyclically into an empty tank while changing the load. This, however, requires an additional storage tank.

Steel has gained widespread acceptance as a tank material. It has considerable advantages in comparison with concrete:

- the wall thicknesses are slight (there are hardly any problems with thermal stresses, even during rapid temperature changes)
- steel walls are water and steamtight
- steel is only slightly corrosive with hot water in the absence of O_2
- wall penetrations (possibly even subsequently) can be produced without difficulty
- the tightness and integrity of the tanks can easily and repeatedly be checked
- the thermal insulation can be conventionally and economically mounted externally

Figure 1 shows a steel tank heat reservoir of 30'000 m3 (T.J. Hedbäck system), such as is in operation in Uppsala (Sweden) and Flensburg (Federal Republic of Germany). The upper load changing device, in the form of a radial diffuser, is mounted in such a way that it floats, so that changes of several meters in water level can be tolerated. A cushion of steam prevents O_2 from entering. The production and maintenance of this steam cushion causes difficulties particularly if steam is not available, as is the case of solar plants.

Although there is ambient pressure at the water surface, overpressures build up with increasing water depth and lead to circumferential stresses and, thus, to wall thicknesses which increase towards the bottom. Since above a certain wall thickness (e.g. 40 mm) it is not permissible to weld the plates without subsequent annealing treatment (which can hardly be carried out at the construction site), restrictions result, regarding constructable volumes and influences on the structural shape. The constructable storage height decreases with increasing volumes. Due to the above-mentioned transitional temperature layer, slight heights are unfavourable for utilizing the volume. A storage size of approx. 10^5 m3 (100 m diameter, 13 m in height) /1/ must therefore be regarded as a meaningful upper limit. Investigations show, however, that even at this size it can be appropriate to divide the total volume between several tanks /2/. This way - with practically the same total costs - advantages result with respect to safety, availability, flexibility of operation, volume utilization, and possible unloading temperature. The latter particularly in the case of long loading and unloading times, such as occur in central solar heating stations.

A feasibility study (see Section 4.5.2.) is being carried out in Germany at present for a steel-membrane reservoir /1/, for which there is in principle no restriction in size.

The main advantages of large steel tank reservoirs as described above are:

- the technology is tested and available
- erection is possible almost everywhere
- great flexibility in operation (equalization of power fluctuations)
- no additional heat exchangers necessary (water quality)
- low heat losses
- high volume utilization at unloading temperatures which are only slightly below the loading temperatures (heat pumps are not necessary even in the case of long storage times).

3.1.2. Applicability

Up to now tank reservoirs have been exclusively used as short-time reservoirs for the temporal uncoupling of supply and demand in heating power stations or district heating systems. Since the expenditure for very effective thermal insulation is not all that great, this concept is also suitable (with slight modifications) for the long-time storage of solar heat in central heating stations, in order to supply small to medium-sized housing estates (a few hundred houses or approx. 1'000 residents) completely with solar heat.

As is frequently the case with technologies that are already more or less fully developed or tried and tested, the production costs are admittedly higher than those expected for systems still being developed (for example aquifer reservoirs), so that their application as seasonal reservoirs is only economically satisfying in certain exceptional cases.

3.1.3. Structural and other problems

We have already pointed out restrictions with respect to constructable volumes. In the same way we have mentioned the difficulties of reliably maintaining the necessary cushion of steam. In the case of large fixed-roof tanks, only quite small overpressures (approx. 0.01 bar) and even smaller underpressures (0.05 bar) are permissible for reasons of strength and stability, in spite of finned reinforcements in the roof zone. It has therefore been suggested that in the case of very large tanks one should change over to floating roofs, which are also used in the mineral oil industry. A further weak point is the joining of the very thin plane bottom plate to the thickest lower ring of the side-wall. Intolerable thermal stresses can result here in the case of great load changing velocities (rapid and different temperature changes in the bottom and sidewall).

Since these tanks can only be (economically) built above ground, safety measures against leakages are required in various cases (e.g. ring-shaped embankments and/or a slight lowering into the ground), which usually means additional space requirements and higher costs. However, in this connection we can fall back upon the worldwide positive experience with oil tanks.

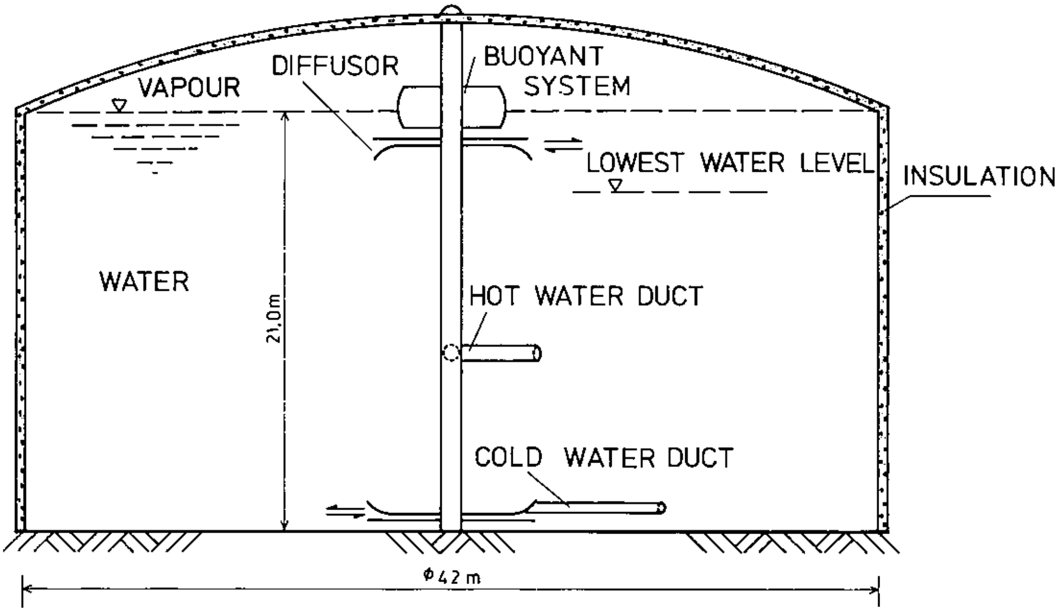


Fig. 1 Steel Tank Heat Reservoir (System: Th. J. Hedbäck)
Water Volume 30 000 m^3

3.2. Pit storage concepts (by B. Rogers, United Kingdom)

3.2.1. Technical description

Pit stores are also called insulated or covered ponds, lakes or reservoirs. A pit store is essentially a hollow in the ground which is insulated and lined, filled with water - the thermal storage medium - and covered. The thickness of insulation is constrained by economics, and may be zero if the ground has sufficient thermal resistance, especially in large stores. In the usual design the pit is semiexcavated with the sides of the store banked above the normal ground level using the excavated spoil.

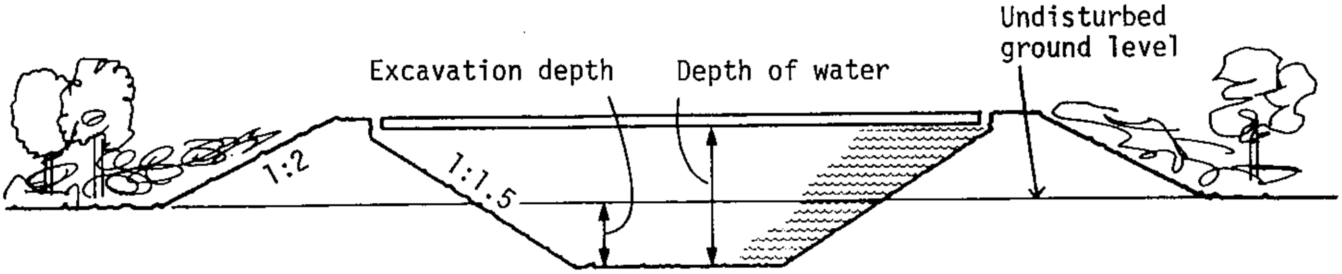


Figure 2: Semi-excavated pit storage partly insulated /77/

The optimum shape of the store depends on the price and availability of land as well as on the costs of construction. Excavation costs are least for shallow pits, while the costs of liners and thermal insulation favour aspect ratios close to one.

A durable watertight liner is necessary to prevent water leakages from the store, which would otherwise result in a direct loss of heat and could also cause thermal or mechanical damage to the thermal insulation. To protect the insulation from ground moisture an extra layer of proofing may be necessary, with a flexible underlay to prevent puncture during laying or subsequent earth movement. In some cases drainage may also be advisable.

The overall level of thermal insulation necessary depends on the size of the store, which determines the surface area to volume ratio, as well as on the desired operating temperatures. If the ground is sufficiently dry it may be possible to do without thermal insulation at the base of the store. Because of convective losses, however, insulation along the sides can only be dispensed with in very large pit stores. Whether the ground contributes usefully to the thermal capacity of the store in these cases depends on the heat transfer between the store and the ground.

The cover may be made simply by floating the top insulation, or may have a rigid construction. As a platform for a solar collector array, a floating cover can be designed to rotate to track the sun in azimuth, while a fixed rigid cover would allow a variety of uses to be made of the land area occupied by the store.

3.2.2. Applicability

Pit stores are at present best limited to a maximum temperature of about 70-80°C because of the impaired durability of lining and thermal insulation materials at higher temperatures. Liner and insulation materials allowing the use of higher temperatures ($>$ 80°C) have been tested in laboratories but not yet in demonstration plants. Pit stores are best used where the economic advantages of scale can be exploited. Pit storage is therefore best suited to large-scale space and water heating schemes.

Some land area is required for building a pit store, but with a suitable cover design this area can be given a second use.

The optimum geological conditions for building a pit store are easily excavated stable soil free of ground water. But rock may also be acceptable, since the ability to build stable stores with a less shallow aspect ratio can more than compensate for the additional unit excavation costs.

3.2.3. Design and problems

For pit stores the waterproof liner is of paramount importance. It must be both watertight and strong, and must retain these properties for many years at elevated temperatures. These technical qualities, which in themselves are attainable to the degree necessary, must also be combined with cheapness.

Among presently available liner materials are butyl, butyl and ethylene-propelene-diene-monomer mixtures and high density polyethylene, all of which are recommended to have an underliner of a material such as polyester for added strength.

Insulation must be sufficiently rigid to support both hydrostatic and soil loadings, and should be resistant to heat and moisture over a lifetime of many years. Cost is also critical.

Expanded polystyrene is a relatively rigid cheap thermal insulation material, but restricts the temperature of the store to a maximum of 80°C. Rigid polyurethane foam has a higher temperature limit but is less cost effective. Fibre glass is the only material which can withstand the pressures of 20 m or more of water at temperatures up to 100°C, but is brittle and susceptible to hydration, which destroys its material structure and substantially reduces its thermal resistance.

The essential elements of the cover are an effective vapour barrier to prevent evaporative heat loss and to protect the insulation, a layer of insulation to prevent heat loss by conduction, and a weatherproof outer skin to prevent precipitation from leaking into the store. For large stores a floating cover is more likely to be economic than one supported on pillars, but considerations of ease of assembly, safety and the efficiency of drainage all suggest a rigid pontoon type of structure. Economics may also dictate that the cover be sufficiently strong to permit a secondary use.

When the store is heated the moisture in the surrounding ground will be driven away as water vapour or by convection. If the process is maintained by a return flow of liquid water, then it is likely to be a significant mechanism of heat loss from the store. This is avoided by siting the store well above the ground water table and by preventing rainwater from seeping into the ground around the store. A layer of course sand or gravel between the store and the ground has been suggested as a barrier against capillarity, although its effectiveness has yet to be demonstrated at high temperatures.

The operation of a pit store can be seriously impaired by the presence of inorganic impurities in the water. Inorganic deposits are particularly likely when materials such as sintered clays are used in the construction. Biological growth is encouraged both by the presence of dissolved salts in the water and by high levels of oxygen. The control of the amount of air dissolved in the water is also important because of the danger of corrosion. The result of fouling is the blocking of filters and pumps and possible malfunction of monitoring and control instrumentation. Precautions which are necessary in the design of the system include isolating the elements of the system using heat exchangers, installing filters, and preventing contact between the water and free air. A special study of the chemistry of the store may be justified.

The effectiveness of the store depends largely on good design and careful matching with the other elements of the heating plant. To increase the effective range of temperatures of the store a heat pump may be incorporated in the design. When the store temperature fell below the demand temperature the heat pumps would be activated with the store as heat source for the evaporators. The inlet to the condensers could either be taken from the store or returned directly from the heat distribution system. But since heat pumps are expensive it may be economically preferable to either not include them or use them with an ambient source and no storage.

3.2.4. Experience

A 95 m3 pit store was built in 1975 at Machynlleth in Wales (National Centre for Alternative Technology) to provide space heating for an exhibition hall. The pit was semi-excavated from compacted slate waste, and has a butyl liner and polystyrene insulation. It has been operating since 1976.

The 640 m3 pit store at Studsvik (Studsvik Energiteknik AB)/3,4/ provides space heating for a two-storey (500 m2 floor area) office block. It is semi-excavated and has a woven polyester fabric liner with a butyl rubber coating. The insulation is partly mineral wool and partly expanded polyurethane. The lid is floating, and supports the solar collector array which supplies heat to the store. The installation has been in use since 1979, and larger versions have been designed /54/.

In the Lambohov project in Linköping (Swedish Council for Building Research) a 10'000 m3 store designed to provide the heating requirements of a group of 56 houses has been operating since 1980. the store is a rock excavated pit, but with a light concrete inner wall. Insulation is provided by concrete-bound sintered clay granules outside the concrete wall, and fibre reinforced plastic covered with polyester sheet inside supports the reinforced butyl liner. The cover is formed from floating expanded polyurethane /5,28,

A 500 m3 uninsulated pit store is tested at Lyngby (Technical University of Denmark) to operate experimentally with a simulated load and heat supply. A plastic liner is used, and a floating cover of mineral wool or polystyrene /52,53/.

At Wolfsburg (Forschungsgesellschaft Wolfsburg mbH) two 10'000 m3 pit stores are being studied to supply a district heating scheme of 45 houses. The first is being lined with concrete slabs and high density polyethylene foil and the second with an optimal composition asphalt concrete. Both are to have foam glass insulation in the cover, but only the first will have insulation on the sides and bottom. The cover of the first will be supported on floating bodies made of steel plate, while that of the second will be supported by concrete pillars and beams and will be given a hard wearing surface for use as a car park of sports ground /16,17,18,19/.

A 30'000 m3 pit store was to be built at Mannheim (Stadtwerke Mannheim Aktiengesellschaft) to meet the peak load of a large district heating scheme. The project was planned as a pilot study for schemes of up to 1'000'000 m3, but problems of ground water drainage, the need for massive supporting earth banks, and the difficulties of finding sufficiently robust insulation and waterproofing materials all suggested that pit stores where impracticable on the larger scale, and the plans for the Mannheim project were cancelled in favour of a tank construction /20,21,22/.

3.3. Cavern storage concepts (by P.O. Karlsson, Sweden)

3.3.1. Technical description

Rock caverns can be used for heat storage according to two main concepts:

- unlined, open rock cavern
- blockfilled rock cavern

Both systems can be constructed in hard rock and can be used for heat storage at high temperatures. A rock cavern can be pressurized comparatively easily which makes possible storage at temperatures over 100°C. This increases the "energy density" of the storage and the storage principles allow rapid inputs and outputs, increasing the versatility of the system.

In an unlined cavern water is the only storage material which means that a higher heat capacity per volume will be reached than in a blockfilled cavern. However, in both cases the surrounding rock will contribute to the heat storage capacity.

Lined caverns cannot normally be considered due to high construction costs.

Unlined open rock cavern

The construction of an unlined rock cavern is in principle similar to the construction of a rock cavern for oil storage. The technology is already well-known and the optimal volumes will also be of the same size, about 100'000 m3 for seasonal storage. The steady state heat losses will then be about 10-15%.

The concept can be exemplified by the storage plants in Avesta (completed in 1982) /25,26/, and Lyckebo (completed in 1983) /27/.

The Avesta storage (Figure 3) is connected to the municipal district heating system and will be loaded and unloaded in weekly cycles with surplus heat from a refuse disposal plant. The cavern has a volume of about 15'000 m3 and its roof is situated 25 m below the rock surface. The cavern will be top-filled with water and put under pressure (115°C). The maximum thermal output will be 11 MW, limited only by pumps, heat exchangers, etc. Operation temperature: 115/70°C.

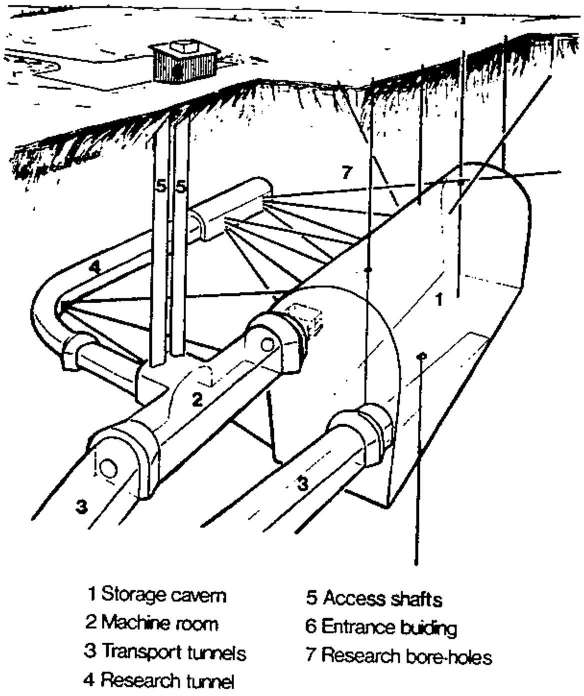


Figure 3: Three-dimensional sketch of the Avesta demonstration plant

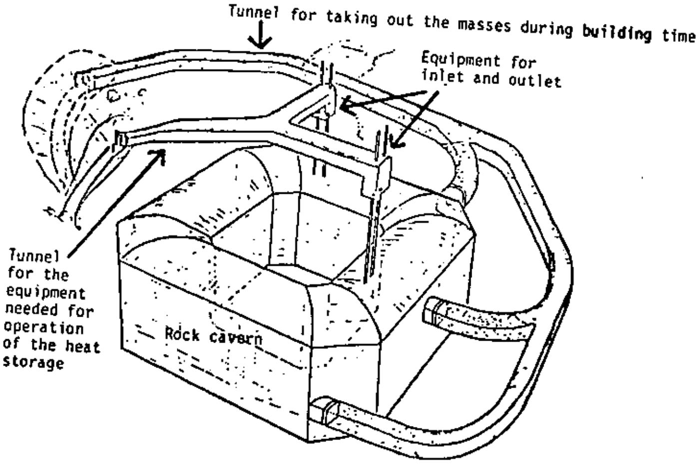


Figure 4: Three-dimensional sketch of the Lyckebo heat storage plant

Model tests have been carried out for the design of the equipments for input and output of water in the cavern. An unsymmetrical placing in one end of the cavern has been chosen for this equipment in order to minimize the length of pipes inside the caverns.

The Avesta storage plant is a research project. The volume of the cavern may be of a suitable size for short-time storage but is far too small to be optimal for seasonal storage. However, during the first part of the research period seasonal storage will be simulated.

The Lyckebo storage (Figure 4) is constructed for seasonal storage with a cavern volume of 100'000 m3.

An underground machine room in the upper transport tunnel contains heat exchangers, circulation pumps, control equipment, etc.

During injection the cavern will be top-filled with heated water by pumping cold water from the bottom through the heat exchanger. The heat front will then be moved downwards. Extraction will be done in the opposite way.

Movable inlet and outlet arrangements permit injection in and extraction from water layers with optimal temperatures.

Blockfilled rock cavern

The construction of a blockfilled rock cavern (Figure 5) can be done as follows: Holes are drilled from three parallel tunnels which will define the location of the storage roof (see Figure 6) /55/. Blasted rock is loaded from below and hauled in a transportation tunnel. From this tunnel an advance front is driven by blasting in holes, which are drilled upwards from the tunnel roof (fan drilling). After each round of blasting of the high bench rock is excavated only to keep the bench free from rock fill for the next stoping. Thus, unmucked rock will finally fill most of the cavity.

By injecting hot water at the blockfilled cavern roof and simultaneously pumping cold water at the bottom, a thermal storage is created. A thermal front will then move downwards in the cavern. Compared to the case without rockfill, the thermal front will be wider due to the presence of rock blocks. The arrival of the thermal front to the bottom of the cavern determines the effective thermal storage volume.

When discharging heat, the pumping is reversed. The pipes for hot and cold water are located in special pipe tunnels and connected to a heat exchanger at the surface by a shaft. All distribution pipes inside the cavern are constructed to avoid damages from falling rock.

The mechanical support of the rock walls from the remaining rock fill makes it possible to construct very large storage rooms. Typical spans would be of the order of 20-30 m and height 90-100 m. The construction costs as compared to conventional rock cavern design may be kept low for large storage volumes (a few million cubic meters corresponding to tens of thousands of dwellings).

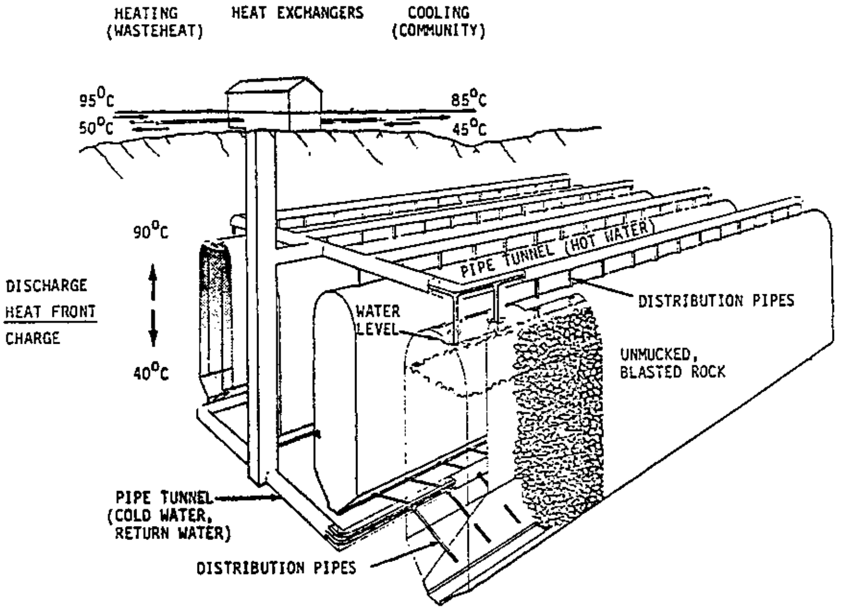


Figure 5: Layout of blockfilled rock caverns for seasonal storage of hot water

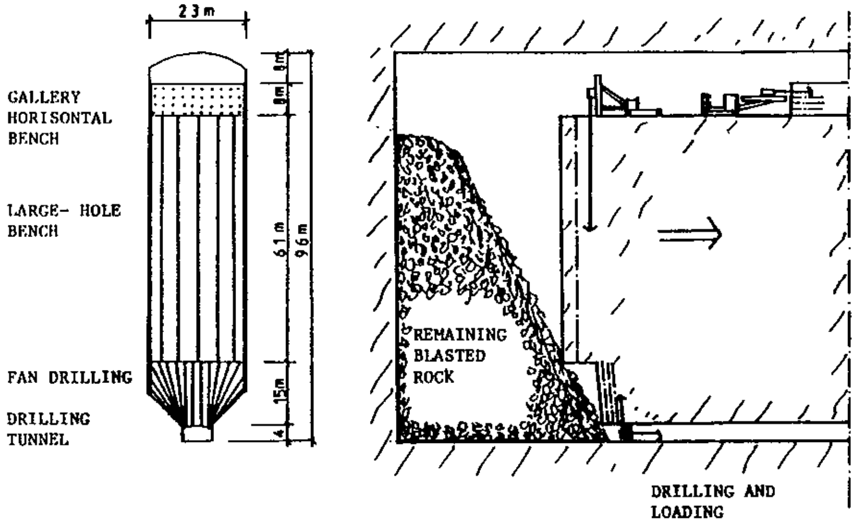


Figure 6: Principle for mining of a blockfilled rock cavern

3.3.2. Applicability

Storage in caverns is possible in crystalline rock and probably in many other types of rock. A blockfilled cavern has lower demands on the stability of the rock mass in comparison with an unlined open cavern.

Since it is possible to construct large volumes at low costs, cavern storage would be predominantly applicable for seasonal storage. However, short-time storage is also possible because of easy extraction and injection.

Heat can be stored at higher temperatures than 100°C. Hence, most heat sources can be effectively used and the storage can be directly connected to heat distribution systems.

3.3.3. Design and problems

When designing a cavern storage the geological and hydrogeological conditions must be well known. The cavern must be located below the natural ground water table, so that the hydrostatic pressure will prevent leakage of hot water out into the bedrock. The construction problems are similar as for other underground constructions. From a rock-mechanical point of view most types of rock in Scandinavia are suitable for the construction of caverns. However, temperature stresses and chemical precipitations have to be carefully considered.

High water temperatures can cause the dissolving of a significant amount of mineral substances in the rock. These substances can be deposited in the system and could accelerate corrosion /57/.

The stability of the thermal layer in the storage water must be considered especially in the blockfilled cavern where the thermal dispersion according to the blocks will mix warm and cold water. Another problem is the transfer of heat between the cavern walls and the hot or cold water.

Environmental disturbances are likely to be of no or minor significance, provided the ground water flow is small.

3.3.4. Experience

Unlined rock caverns have been used in many countries for the storage of heated oil. The operations experience indicates good possibilities of using caverns for heat storage. Volumes range from 50'000 m3 up to 2-3 millions m3.

An experimental storage plant with a water storage volume of 15'000 m3 has been constructed at Avesta, Sweden. A comprehensive test and evaluation programme has recently been started and will continue up to 1985.

The Lyckebo storage (100'000 m3) will also provide much useful experien
This means that by 1985 it will be possible to evaluate the unlined rock cavern concept satisfactorily.

No blockfilled cavern for heat storage has been constructed yet. However, the special working technique is well established in undergrou
mining.

3.4. Aquifer storage concepts (by J.C. Hadorn, Switzerland)

3.4.1. Technical description

Saturated porous media have thermal conductivities in the range of 1 to 3 W/mK, and heat capacities approximately half that of water.

The basic philosophy of aquifer storage is to store energy, using the sensible heat of both the water filling the porous medium and the porous medium itself, in rather quiet and deep aquifers, in order to minimize heat losses.

One of the great advantages of the aquifer storage is that the water is also the transfer medium. Thus, the thermal disturbance can be more simply controlled and large peak loads can be injected or withdrawn compared with other underground systems.

Different concepts are possible for using an aquifer (free or confined) for heat storage (Figures 7 and 8). They mostly differ from the geometries chosen for the wells.

The choice of a system depends on numerous parameters, among which can be mentioned:

- the temperature level in the accumulator
- the horizontal and vertical permeability of the porous media
- the ground water level and natural outflow rate
- the peak loads rate
- the aquifer dimensions and shape
- the control strategy and the storage duration
- the chemical effects and ecological risks
- the drilling costs

At present, the "good" choice in a given case cannot precisely be done, a number of indeterminations - especially concerning the real thermal behavior and the chemical effects - still having to be removed.

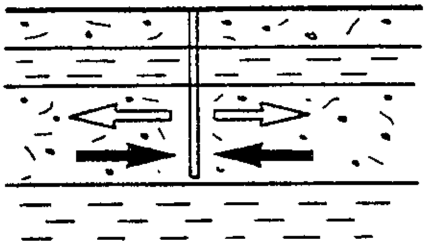
As an alternative, one can "re-build" an aquifer (the man-made aquifer concept), in which most of the parameters become known /31/.

For the moment, it is difficult to envisage the control of a thermal disturbance in media having heterogenous permeabilities such as fissured rock.

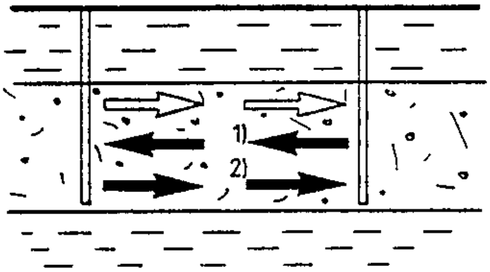
FIGURE 7 THERMAL ENERGY STORAGE IN CONFINED AQUIFERS

PROPOSED GEOMETRIES FOR INJECTION AND PUMPING WELLS

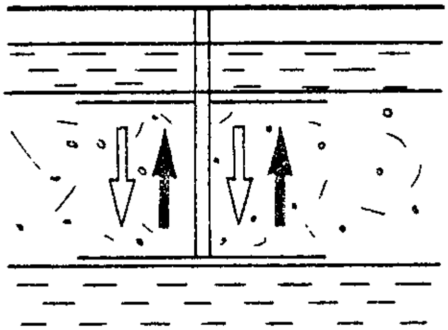
SINGLE WELL



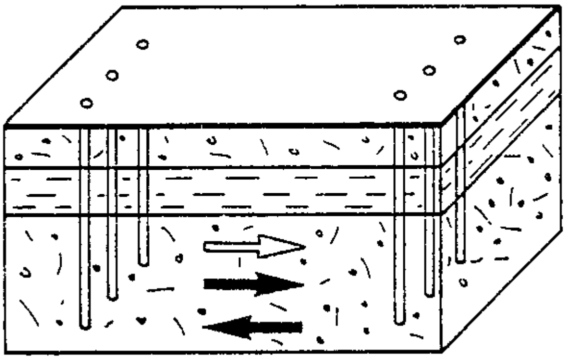
1) DOUBLET 2) DOUBLET WITH DOWN GRADIENT STORAGE SYSTEM



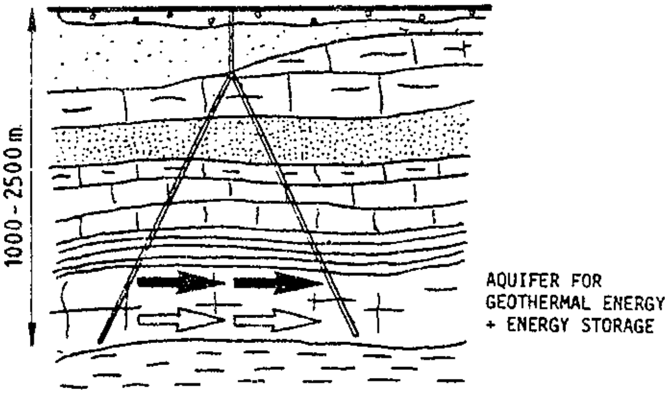
SINGLE WELL + HORIZONTAL RADIAL DRAINS



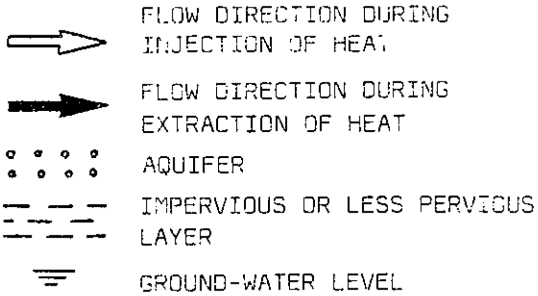
MULTI-WELLS DOUBLET



DEEP DOUBLET FOR RECHARGING AN EXHAUSTED GEOTHERMAL FIELD



EXPLANATION

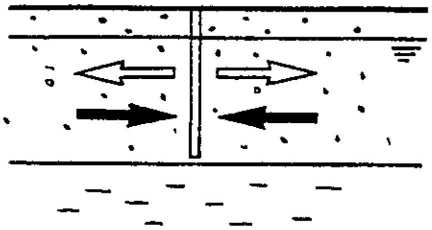


Taken from: IEA
Energy Conservation Through Energy Storage
Annex 1: Large Scale Thermal Storage System
Final report - October 1981

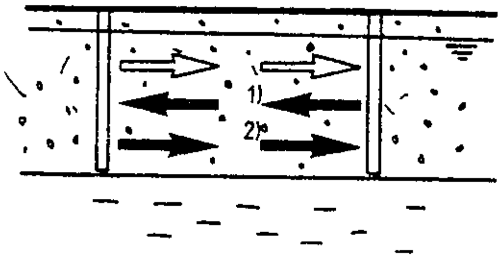
FIGURE 8 THERMAL ENERGY STORAGE IN FREE AQUIFERS

PROPOSED GEOMETRIES FOR INJECTION AND PUMPING WELLS

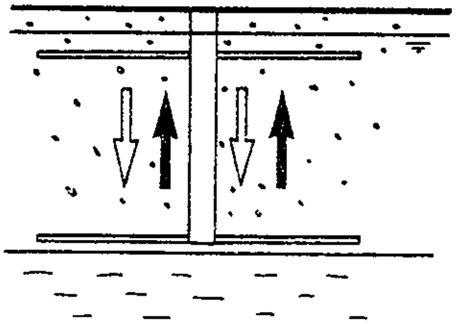
SINGLE WELL



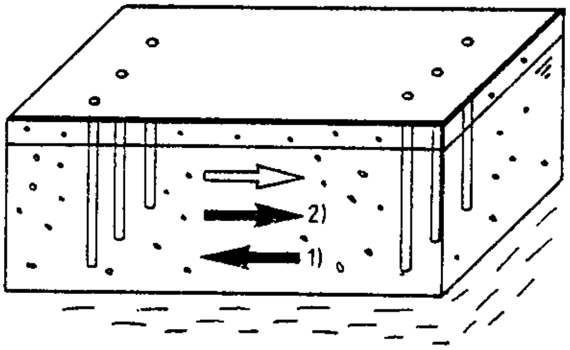
1) DOUBLET 2) DOWN GRADIENT THERMAL STORAGE SYSTEM



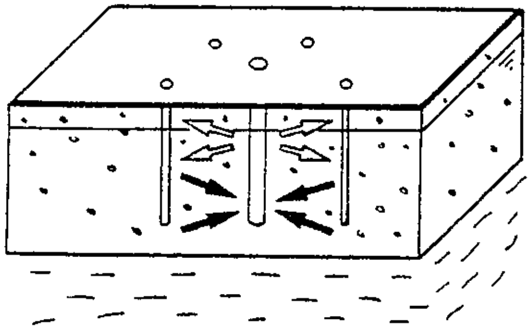
SINGLE WELL + HORIZONTAL RADIAL DRAINS



MULTI-WELLS DOUBLET



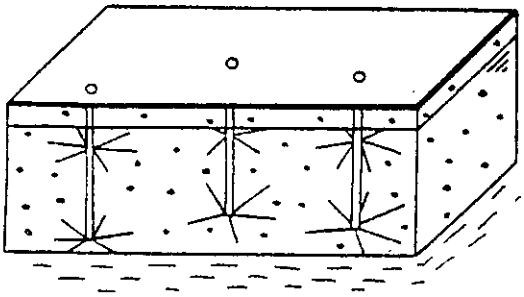
CENTRAL WELL+ SURROUDING CONTROL WELLS ALSO APPLICABLE FOR CONFINED AQUIFERS



EXPLANATION

⇨	FLOW DIRECTION DURING INJECTION OF HEAT
➡	FLOW DIRECTION DURING EXTRACTION OF HEAT
∴	AQUIFER
— — —	IMPERVIOUS OR LESS PERVIOUS LAYER
≡	GROUND-WATER LEVEL

MULTI-WELLS + HORIZONTAL RADIAL DRAINS



Taken from:

IEA
Energy Conservation Through Energy Storage
Annex 1: Large Scale Thermal Storage Systems
Final report - October 1981

3.4.2. Applicability

Aquifer storage is obviously possible in areas where suitable aquifers can be found and where aquifers are not used for drinking water supply.

The concept of aquifer storage is predominantly applicable in seasonal storage (cogeneration, waste and solar heat) in regions in which the winter heating demand exceeds the available heat source. In regions where air-conditioning is also necessary, the combination of hot and cold storage seems interesting and will be experimented, for instance in Scarborough /58/.

Three different working temperature ranges can be distinguished for aquifer storage systems:

a) very low temperature storage (5 to 20°C): energy is extracted from the aquifer by heat pumps during winter. The aquifer is thus colder than its natural temperature by about 5°C. In summer cheap solar collectors or ambiant air heat exchange contribute to recharge the aquifer up to its natural temperatu or somewhat higher (about 5°C higher). This type of aquifer managing permits to maintain constant the temperature at the producing wells, even when the distance between injection and production wells in a doublet system is small (suitable for dense urban areas). It also reduces the local temperature drop in the aquifer and avoids chemical problems /69/. The economic competitiveness of this system seems to be proved in some cases /59/

b) medium temperature storage (40 to 90°C): the use of performan solar collectors or waste heat at about 100°C is necessary in this case. The need for heat pumps can be avoided provided that a low temperature district heating network can be designe and that the extraction temperature at the end of the heating season is still higher than the feed temperature required by the network /35,66/

c) high temperature storage (150 - 200°C): in general, confined aquifers can reach such temperatures but certainly with a lot of chemical problems. Furthermore, the heat source would not be solar in the present state-of-art, but rather incinerat plants or cogeneration plants /64/.

3.4.3. Design and problems

Before any design, the prevaling local geological conditions must be very well known.

Systems with horizontal water movement (single well, doublet...) can be considered in case of horizontal intrinsec permeability between about 10^{-10} m2, and 10^{-13} m2; above 10^{-10} m2, the tilting of the thermal front, due to buoyancy effects will be too important /60/. Below 10^{-13} m2, the necessary hydraulic pressure will be too high, inducing high pumping costs.

For systems with vertical water movement (central well with radiant drains), it is difficult to give a range of suitable vertical permeabilities. It depends more on the whole system in which the storage will be incorporated, on the thickness of the aquifer, and on the duration of storage.

The basic problem in aquifer storage is the control of the thermal front, in order to avoid mixing of cold and hot water in the production well and high heat losses through the caprock.

Horizontal water movement systems with high charging temperature are obviously much more dependent on these buoyancy effects.

Another difficulty is linked to the maximum allowable velocity of water entering the wells during the production periods: in case of a single production well with limited inlet area, this can reduce the peak power rate and involve the use of a buffer storage between the storage and the distribution.

Clogging effects can also occur in the wells and in the heat exchangers and appear to be one of the technical issues not yet solved /35/.

3.4.4. Experience

One of the first known field experiments was carried out in 1974 in Switzerland (Neuchâtel) in a phreatic aquifer. Other experiments have been carried out in Germany (Experimental Area, Hülser Bruch), in France (Campuget, by Ecole des Mines, and Bonnaud, by the BRGM), in the United States (Auburn, by Auburn University), and in Japan (Yamagata Basin), and aquifers for cooling are used in Canada.

Chilled water storages in aquifers seem to be operational in the Republic of China since 1965.

None of the experiments done at present concern seasonal storage. They were all used to develop, test and validate mathematical models.

Several large scale experiments are in a design phase or in operation since 1982, and are to be considered as demonstration plants (SPEOS in Switzerland /35/, Horsholm in Denmark /66/, St Paul in the USA /63/, Paris in France /68/).

3.5. Earth storage concepts (by A.J. Wijsman, the Netherlands)

3.5.1. Technical description

In principle, an earth storage consists of a layer of subsoil with a heat exchanger in it. At the top and in some cases all around there is an insulation layer.

The storage of heat takes place in sensible form.

The heat capacity of the soil depends on the type of soil: dry soil has a heat capacity of 0.3 × water, whereas water saturated soil reaches 0.7 × water.

Different concepts for earth storage are possible. Various heat exchanger types can be used (see Figure 9) and the degree of insulation might be different depending on site specific situations and/or applications.

For large storage concepts, only insulation at the top is necessary. Around, the soil itself acts as insulation. For smaller storage concepts, insulation of the sidewalls or all around is necessary. In the latter case it becomes necessary to excavate the soil to place the insulation material.

In most cases, the heat exchanger is formed by tubes: both vertically and horizontally placed. The advantage of vertical tubes is that they can be inserted from the top, which means without excavation of the soil. For placing horizontal tubes excavation is necessary.

Containment: in water saturated soil with a high permeability, ground water movement and free convection of ground water (because of heating of the soil) can cause large extra heat losses. A vertical screen at the edge of the reservoir can limit these losses.

The choice of a system depends on various parameters:

- the soil properties: thermal and mechanical
- the ground water level and ground water movement
- the size of the storage reservoir
- the temperature level in the storage reservoir
- the temperature swing in the storage reservoir during a year
- the peak loads during charging and discharging
- the costs of a storage concept
- the chemical effect and ecological risks
- etc.

If the above-mentioned parameters are known, a first choice of storage can be made.

3.5.2. Applicability

Earth storage is possible in areas where suitable soil can be found because of heat capacity, which means preferably in areas with wet soil, that is in areas with a high ground water level.

Furthermore, the earth storage should be near the heat supplier (solar collectors, waste heat) and near the heat consumer (houses, buldings, greenhouses).

The applicability can be limited by the temperature level: at present there is no experience with the behaviour of soil at temperatures higher than 40°C.

In systems with heat pumps, the maximum temperature level is often no constraint.

3.5.3. Design and problems

Before any design is made, the prevailing local geological conditions must be very well known.

At a required total heat capacity the volume of the heat storage reservoir depends on the specific heat capacity.

For a required heat exchange rate the size of the heat exchanger (in m2 or tube length) depends on the thermal conductivity of the soil. The method of insertion of the heat exchanger tubes depends on the type of soil: by vibration, by water injection and vibration, etc. A soil with stones in it can cause big problems. Strong layers at a certain depth can have influence on the final shape of the reservoir.

In non-saturated soil drying out of the soil around the heat exchanger can take place, which causes a decrease in heat exchange rate.

The interconnection of the heat exchanger tubes at the top can be problematic. The total flow resistance must be reasonable and de-airing of the system must be possible.

With plastic tubes oxygen penetration from the ground water through the tube wall into the transfer fluid can occur, which can lead to corrosion problems. A separation of the soil circuit and the distribu network by a stainless steel heat exchanger can solve this problem.

At the design of the heat exchanger it can be important to improve and to use temperature stratification in the heat storage reservoir.

The degradation of materials used in the soil can be a problem.

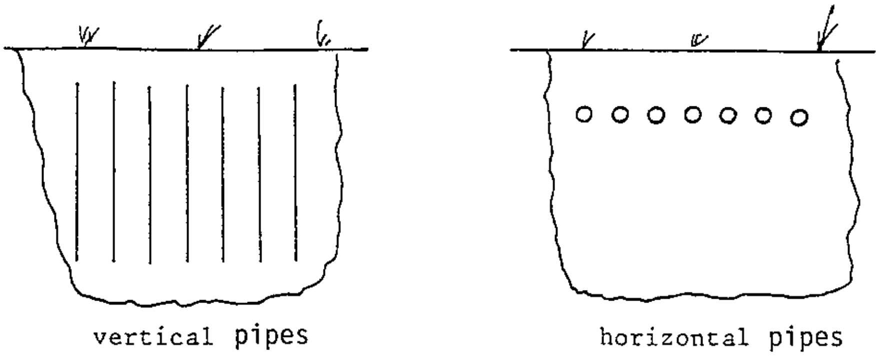
3.5.4. Experience

Since 1979 field experiments on scale (several hundred m3) have been done in Lausanne, Switzerland (Sorane SA) /42/ in Grenoble. France (Institut de Mécanique), and in Eindhoven, The Netherlands (Philips).

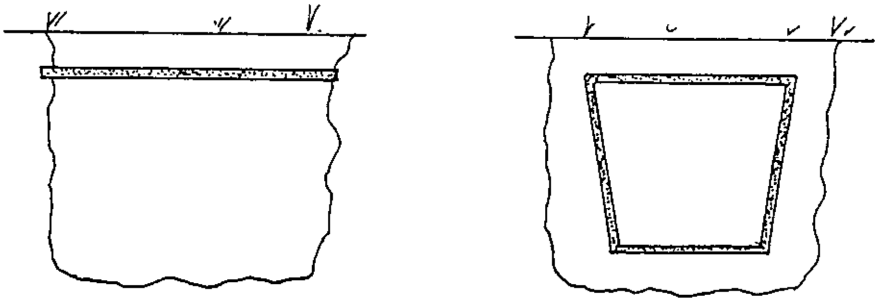
The Sunclay project at Kungsbacka near Göteborg, Sweden, is the first experiment on real scale. The reservoir contains 80'000 m3 of clay and operates between 12 and 20°C. The reservoir is coupled to a heat pump system. The project was built during the summer of 1980 and tested during 1981 and 1982 /45/.

At present (1983), in the Netherlands, two large scale experiments are carried out. Both projects (Groningen, 23'000 m3, and Almere, 2'500 m3) have been constructed. The experiments on the Groningen reservoir started in February 1983 /38,39,40,41/.

In Switzerland (Vaulruz), an earth storage of 3'500 m3 is in operation since March 1983 /43,44/.



A. Type of heat exchanger



B. Degree of insulation

Figure 9: Different concepts of earth heat storage

3.6. Rock storage concepts (by P.O. Karlsson, Sweden)

3.6.1. Technical description

A multiple well system in rock may be used for seasonal storage of thermal energy. The system function is based on the heat conductivity and storage capacity properties of the rock.

The heat is transferred to or from the rock by means of water circulated through a large number of boreholes or wells. The boreholes normally do not need casing.

The heat storage capacity of rock material such as gneiss and granite is about half the heat capacity of water. Hence, a multiple well heat storage system must have a volume twice as large as a water cavern with similar storage capacity /51/.

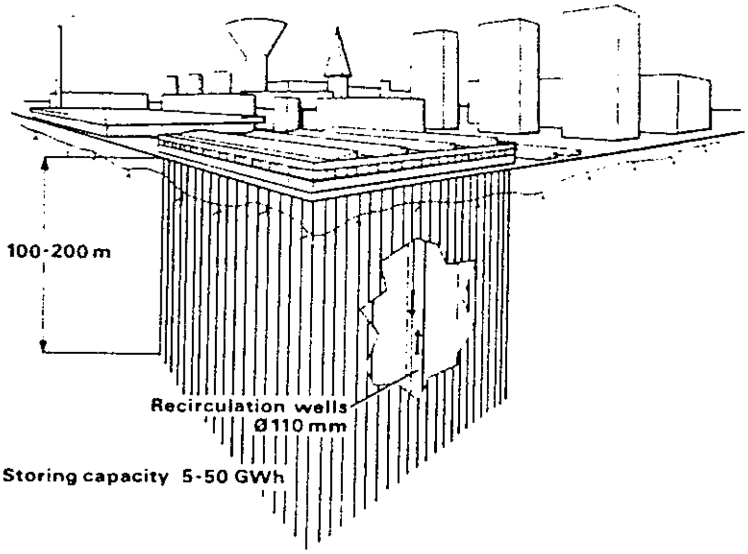


Figure 10: Multiple-well heat storage - Principal sketch

The heat carrying fluid, normally water, can be circulated through the wells in open or closed circulation systems (see Figure 11).

In a closed circuit system, the fluid is circulated through U-shaped tubes inserted into the wells. Ground water transfers the heat to and from the tube and the rock. The circulation fluid has no direct contact with the rock. Therefore, even if the storage system is constructed in a fissured rock, no loss of water will occur, nor will there be any problem of chemical precipitation in tubes or heat exchangers.

In an open circuit system, the fluid is conducted through a tube to the bottom of the well where it is released in direct contact with the rock. To limit heat and water losses, a multiple well heat storage system utilizing an open circulating system requires rock with a relatively low permeability.

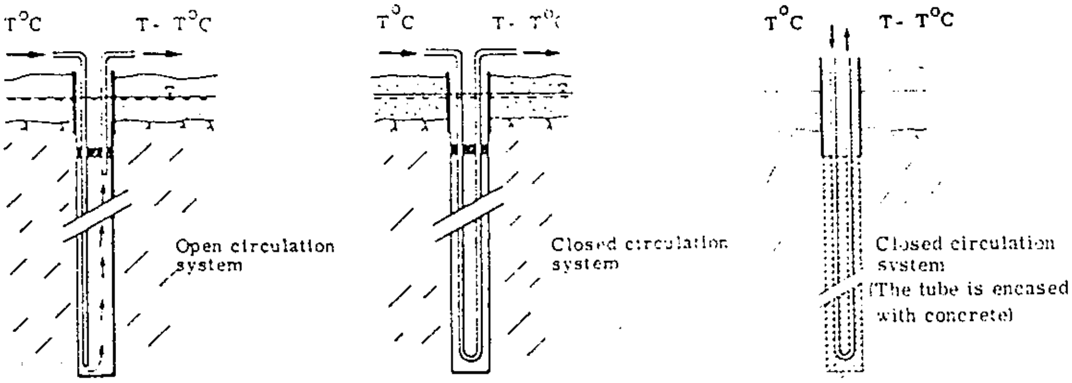


Figure 11: Multiple-well system - Circulation systems

Storage temperatures above +100°C can be used, provided the active part of the storage is at a sufficient depth under the ground surface (Figure 12).

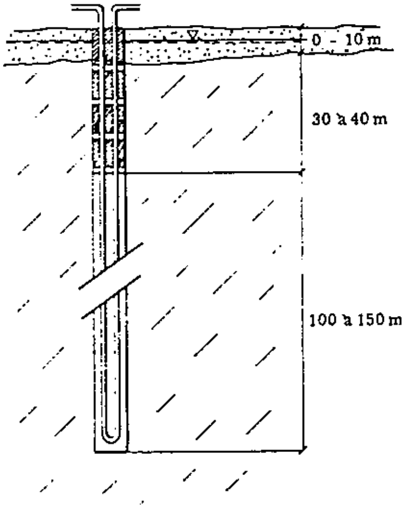


Figure 12: Closed circulation system
Storage temperature: 120-140°C

3.6.2. Applicability

The multiple well heat storage is applicable in many kinds of hard rock as granite and gneiss and can be easily located in places with a relatively thin covering soil layer. It can be constructed at comparatively low costs and with well-known technology /49/.

The storage system can be used for temperatures from 10°C up to above 100°C in some cases. This allows storage from different kinds of heat sources as waste heat and solar heat. The storage concept is primarily applicable for seasonal storage.

In some areas with a very thick soil layer above the bedrock, or in dense utilized areas, it would be possible to construct a tunnel system in the bedrock and drill the boreholes downwards, and create a multiple well heat storage system under the tunnels.

3.6.3. Design and problems

Before any design, the hydrogeological conditions must be determined clearfully. The natural or superimposed ground water flow may have a significant influence on the thermal behaviour and efficiency of a multiple well heat storage system. The ground water flow depends on the permeability of the rock and the hydraulic gradient.

A closed circulation system can be used even in fissured rock provided the hydraulic gradient is sufficiently low.

An open circulation system implies a superimposed hydraulic gradient because of the operation pressure. Hence, an open circulation system must always - if grouting, etc. are to be avoided - be placed in non or less fissured rock.

Different strategies can be applied for the charging and discharging operations. all parts of the storage volume can be charged or discharged at the same time, i.e. all the wells are throughflowed by similar flow at the same temperature level. A more efficient strategy implies that the storage is charged beginning in the centre and then outwards in a radial direction. Discharging will then be done by a reversed operation.

Different temperature zones can be formed within the storage by connecting the boreholes by groups (Figure 13).

To allow multiple-well designs to provide higher power outputs, the rock storage can be combined with a "buffer-tank", for instance water-filled tunnels used for daily storage /50/.

3.6.4. Experience

A pilot test involving storage at low temperature (35°C) has been carried out at Sigtuna, Sweden. The system is a closed circulation system. The experiences during the years of operation have shown a good coincidence with theoretical calculations. Initially, some practical and technical problems occurred, which, however, were rapidly solved. The tests will continue.

A multiple well storage downscaled 1:4 has been constructed in Luleå in the north of Sweden. The storage has 19 wells 19 m deep, with an open circulation system. Five years of seasonal heat injection and extraction have been simulated. The evaluation of continuous temperature measurements, within as well as outside the storage, shows that the storage operates in good accordance to the mathematical models worked out by Johan Claesson et al., University of Lund.

Another larger multiple well system comprising 120 wells, 65 m deep, has been built in Luleå. Operations will start during the summer 1983, and will be evaluated by the University of Luleå during a period of three years /47,48/.

Full-scale field tests, mainly concerning heat transfer from fluid to the surrounding rock, are currently carried out at Älvkarleby Hydraulica Laboratory and at Studsvik.

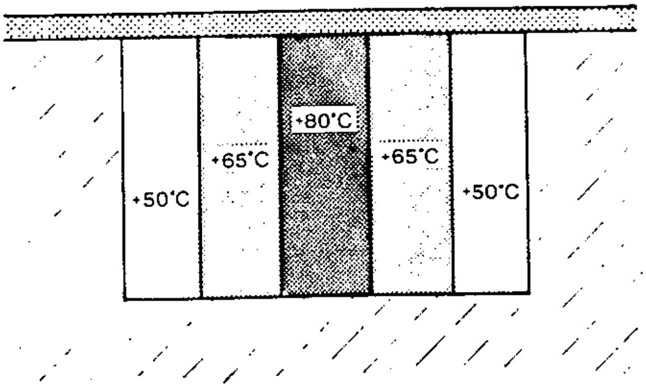


Figure 13: Temperature zones in a cylindrical multiple-well storage - Principal sketch

4. SURVEY OF THE SEASONAL HEAT STORAGE WORK IN THE PARTICIPATING COUNTRIES

This chapter is devoted to a general overview of the activities concerning seasonal heat storage in the Task VII participating countries.

Each section has been prepared by the Subtask 1c participants, and reflects the status in each country at the beginning of 1983.

The information given in this chapter does not represent an official position in any case but only the personnal views of the Subtask 1c participants.

The authors were asked to restrict themselves as much as possible by discussing only the activities related to seasonal storage.

4.1. Austria (by M. Bruck and A. Sigmund)

4.1.1. Pilot projects in ground-coupled systems

Within the framework of the "Austrian Measurement Network for the Utilization of Solar Energy", which is financed by the Austrian Federal Ministry for Science and Research, and co-ordinated by the Austrian Solar and Space Agency, several ground-coupled heat pump systems have been investigated /70/.

- Obdach

  Within the framework of the "Solar House Obdach" project, a system consisting of a ground heat exchanger, a low-temperature collector, a water-glycol/water heat pump, and a low-temperature heating system, was examined with regard to its suitability as only heat source of a house. With the design chosen (1 m2 ground collector area and 0.3 m2 low-temperature collector area per 80 W load), a seasonal performance factor of 2.83 could be obtained. About 40 percent of the low-temperature heat supplied to the heat pump were delivered directly or indirectly (by means of short-term storage in the ground) by the low-temperature collector, whereas about 60 percent came from the "natural" sources of energy of the ground (air heat, radiation, precipitation, ground water and slope water). The results obtained are used to verify and improve a computer model design program for ground collectors and ground-coupled storage systems which should help to optimize the design of solar plants, particularly under difficult conditions /71/.

- Bludenz

  The Solar House Bludenz was constructed from 1977 to 1978. One large and one small appartment were built on 200 m2 living area. The heating system is composed of:

  - an absorber
  - a ground-coupled storage on two planes
  - a heat pump

  The heat load of the building is 9 kW, the annual heat demand was calculated to be 72'000 MJ (20'000 kWh).

  The heat pump removes heat from the non-insulated ground-coupled storage by means of a circulating medium (water-glycol). As soon as the temperature in the asphalt absorber becomes higher than that in the ground-coupled storage, the motor valve switches to the water-glycol cycle of the asphalt absorber.

- Rankweil

Based on experience gained at the Solar House Bludenz, Vorarlberg, a ground-coupled heat pump system was designed for a housing estate at Rankweil and finished by the end of 1982. A ground-coupled heat pump system supplies the load of 69 apartments in eight smaller and six larger houses. In addition, a Total Energy System (TOTEM) consisting of five units and with an electrical output of 15 kW each is used.

The heat demand of the larger (multi-storey) houses is covered by two heat pumps with a connected load value of 30 kW each, for the operation of which electricity is supplied by the block power plant, and who retrieve heat from the ground. Two planes of plastic pipe (about 20'000 m), each plane coverin an area of 6'000 m2, are buried in the ground at a depth of 1.5 and 2.5 m, respectively. In order to regenerate the deeper plane (below about 1.8 m), the domestic reject heat from bathroom, kitchen and toilet is led through PVC-pipes of suitable dimensions to the ground.

By recovering heat from the exhaust air from bathroom and toilet, additional heat is supplied to the heating system via an air-water heat pump.

4.1.2. Seasonal storage - Project Kranebitten

The planning of military barracks construction in Innsbruck-Kranebitten offered the useful opportunity to use an existing gravel pit for the erection of a seasonal storage.

Preliminary investigations and plannings are finished. The earth storage has been built, the building of the barracks is nearly finished The active storage volume of 70'000 m3 will have an energy turnover of about 1'000 MWh per year. Two thirds of the energy requirement of the plant will be covered by ambient energy.

The pilot plant in Innsbruck-Kranebitten is expected to be finished in October 1985. Measurings of the various states of the object will be evaluated by the Austrian Institute for Building Research and will be used in future plannings. Future activities most probably will depend upon the results of these evaluations /72/.

4.2. Canada (by E.L. Morofsky)

4.2.1. Introduction

Seasonal energy storage activity in Canada began in the 1970's in two areas - storage of winter ambient temperatures as latent energy of ice and tank storage of solar heated water. The tank storage work was stimulated by proposed solar designs providing a large proportion of building space heating needs. Analytical numerical models of sensible heat storage have been developed at the University of Toronto as well as simplified design methods based on them (University of Toronto, 1980 and 1982). A single family residence and a thirty-unit building have been constructed with solar energy stored for winter use in tanks. Long-term latent energy storage of winter ambient air temperature for use of summer building cooling was initiated by Public Works Canada (PWC). The first field experiment was conducted in 1979 and recent field trials performed under contract to PWC have perfected an automated ice formation and energy extraction method (Morofsky, 1982). A full-scale building cooling application is presently under design with implementation planned for the winter of 1983-1984. A specialized geothermal model originally developed for permafrost related construction problems has been used to simulate the performance of several latent energy storage schemes, including the use of stored street snow to supply cooling (Merrifield, 1981). The overall potential of applying natural cooling techniques in Canada has been assessed based on a cost comparison to conventional cooling practices. Latent energy storage in the form of ice and cold water storage in aquifers was judged to be competitive in a range of applications (Bahadori and Hollands, 1982). The evaluation of aquifer thermal energy storage was begun in 1979 (Energy, Mines and Resources, 1979). A study of the technical and economic feasibility of aquifer-based cooling led to the investigation of the Atmospheric Environment Service building in Toronto as a possible site for a field trial of direct cooling using stored winter chilled water. The building and land are owned by PWC. Pumping tests, water analysis, modelling, and heated water injection tests have been conducted. A final design involving three well doublets has resulted. The Scarborough Government of Canada Building was undergoing final design when the presence of a suitable aquifer was found at the site. Modifications to the cooling tower and controls for winter chilling were included, as well as the piping necessary to store building waste heat or excess solar energy /56, 58/. The aquifer will be used as a heat source/sink for the building heat pumps. Construction at the Scarborough site is scheduled to begin early in 1983, while funding for the AES demonstration is presently being sought. An earth in-situ storage experiment has been underway at the National Research Council since 1977. It involves laboratory, modelling and field work. Of the storage types under consideration - tanks, aquifer, earth, mined cavern, undisturbed rock, salt gradient ponds, and pits - only pits and undisturbed rock are not represented by any significant Canadian research or projects.

4.2.2. Insulated tank

Two in-ground seasonal energy tank storage demonstration projects are presently being monitored. The Provident House in King City, Ontario, involves seasonal hot water storage for a single house /9,10/. The Aylmer, Ontario Senior Citizen's Home is an annual storage solar system intended to supply 100 percent of space heating needs and 85 percent of domestic hot water heating (University of Toronto, 1980). The project involved 220 square metres of collector area, 886 cubic metres of storage volume, and tank insulation of polyurethane foam (R9 m2·°CW). The building to be supplied has a gross floor area of 1'800 square metres. The thermal storage tank is an insulated concrete shell with a structural steel roof designed to store water at temperatures as high as 90°C. Storage efficiency is expected to be about 70 percent. Installed price for the storage was about $ 110'000. A small leak due to improper application of the urethane waterproofing interrupted charging of the storage. It has since been repaired and is operational /6,7/.

4.2.3. Aquifer storage

Typical ground water temperatures in Canada are within several degrees Celsius of those required by building cooling systems. Direct cooling at the natural temperature is the most economical and this is widely practiced in Winnipeg, Manitoba. As the water is not reinjected, well interference has resulted and a gradual warming of the aquifer has been noted. A study of aquifer-based cooling in 1979 indicated that it might be cost competitive on new buildings, although certain technical questions would only be answered by an actual implementation. The AES building in Downsview, Ontario, was chosen as a site because of its large size (30'000 square metres), large land area available for field work, and high probability of finding a suitable aquifer. Extensive field work was undertaken during 1981-1982 including pumping tests, water quality analysis, geothechnical examination, heated water injection, and surveying. Evaluation of the data, including modelling alternative well configurations, has led to a final design of a three well doublet system to provide the cooling of the building (Public Works Canada, 1981 and 1982). A seasonal energy storage field trial facility will be associated with the Scarborough Town Centre Government of Canada Building scheduled for occupancy in 1985 /58/ (Morofsky, 1982). This major centre of federal general purpose accomodation will be provided heating and cooling primarily by electrically driven centrifugal refrigeration machines operating on a heat pump cycle. A confined, artesian aquifer will be able to store winter chill, reject heat from the chillers, or excess solar energy. The aquifer may also serve as a constant temperature heat sink for the heat pumps if stored energy has been exhausted.

Geotechnical sampling, pumping tests, water quality testing and aquifer modelling have been accomplished. Project objectives are 1) to assess the practicality of implementing cost effective aquifer energy storage within the constraints of modern building design and construction, and 2) to evaluate the effectiveness of various operational strategies in maximizing the energy saving.

4.2.4. In-ground heat storage

The National Research Council of Canada is conducting field tests at its in-ground heat storage test facility (Svec and Plamer, 1980 and 1981). The project began in 1977 and involved both laboratory and numerical modelling. Four storage types are being tested:

a) a fully-insulated, rigid plastic tank filled with water

b) type a) filled with gravel

c) a flexible PVC lined tank filled with gravel, and

d) a nested, circular array of smaller diameter gravel-filled PVC pipes.

Type a) provides bench mark data. Laboratory tests indicated that the gravel in types b), c), and d) enhances stratification and does not inhibit convection. Types c) and d) have only surface insulation. The test facility is located in a Leda clay subsoil which is very sensitive to disturbance. The holes were augered with a standard caisson drilling machine. Water storage temperature is less than 120°C. The experimental time between charge and discharge is not seasonal as yet.

4.2.5. Analytical design aids

Analytical numerical models for heat transfer analysis of in-ground and above-ground storage tanks have been developed at the University of Toronto and have led to simplified design methods to determine optimal tank insulation and other system parameters (University of Toronto, 1982).

The EBA Geothermal Model was developed to predict the thermal response of the soil to changes in the thermal environment resulting from pipeline operations, heated or refrigerated structures, and alteration of ground surface properties (EBA Engineering Consultants, 1979). Unique properties of the program include:

- a thermal conduction code with finite element formulation of the transient heat conduction mechanism during freezing and thawing in the ground, in which latent heat is considered as a heat source in the energy balance equation

- a convection code which considers the heat exchange mechanism at the ground surface with respect to meteorological data.

The model was used for the cooling system design for high temperature storage tanks (175°C) at the Syncrude Tarsands Plant. Public Works Canada routinely uses the program for simulating highway designs in permafrost areas.

4.2.6. Mined cavern storage

Mined cavern storage of residual oil at 60°- 82°C is to be used at the Wesleyville, Ontario generating station of Ontario Hydro. This was the first such construction in North America. It involves tunnels 10 metres wide and 16 metres high excavated in limestone bedrock about 60 metres below the surface. The tunnels will not be lined. The oil will be in direct contact with the limestone walls. The caverns will be below the water table, thus the natural hydrostatic pressure will prevent the oil from leaking into the bedrock. The original plans involved three caverns each of 1.6 million barrels capacity. The proposed number of cavers has now been reduced to two of one million barrels individual capacity. The facilities are presently 25 percent completed. The total estimated cost was $ 41 million in 1978. The project has now been delayed due to decreased demand for electricity.

4.3. Commission of the European Communities (EC) Joint Research Centre, Ispra Establishment (by D. Van Hattem)

4.3.1. Historical

The activities in the field of the long-term storage of sensible heat started in Ispra in 1977. A small building (160 m2) with a heat storage of 50 m3 of water, solar collectors, and a heat pump was operated and monitored for several years.

The system was used to study the interaction of solar collectors, a large storage and a heat pump. Different system configurations and operating strategies have been tested.

A modelling study for a group of 50 houses has been carried out. Both water filled vessels and undisturbed ground were considered as heat storage medium.

4.3.2. Current activities

Since 1981 two pilot projects are undertaken in Ispra. One consists of a 2'000 m3 storage of undisturbed earth, the other is a 375 m3 buried concrete vessel filled with water. Both systems are only insulated at the top and operate at low temperatures (5-55°C). The water storage is heated artificially and the ground storage is heated with 200 m2 flat plate collectors. The house load is simulated in both cases.

4.3.3. Other EC activities

In the framework of its Energy R & D program on costs-sharing-basis, the EC has cofunded many projects for the seasonal storage of heat, throughout Europe, since 1975. The current program includes projects with undisturbed earth storage, earth-pit, buried water tank, solar pond and confined aquifer storage.

4.4. Denmark (by K.K. Hansen)

4.4.1. Historical

In the Zero Energy House Project a solar-heated store of 30 m3 was constructed in 1973-1975 at the Technical University of Denmark. This first project has given a considerable experience in many ways and during the last ten years a lot of smaller projects like this have been studied.

4.4.2. Current activities

Two short-time reservoirs made of steel are connected in thermoelectric power plants. The sizes of the tanks are 12'000 m3 in Odense and 30'000 m3 in Herning with a maximum loading temperature of 90°C.

Work on aquifer storage has continued since 1978 and a large scale experiment is in operation in Hørsholm. The size is 75'000 m3 with a capacity of 8.5 Tera-Joule /66/.

4.4.3 Future investigation

In the summer of 1982 a small test-pit of 500 m3 was built at the Technical University of Denmark. The pit has a floating lid of insulation material and the store/soil interface is uninsulated. This low-priced construction favours storage for solar energy, waste heat and even for heat from power plants /52, 53/.

4.5. Federal Republic of Germany (by F. Scholz)

4.5.1. Review

Several comprehensive studies were carried out on the topic of energy storage in the Federal Republic of Germany after the first oil price shock. Parallelly to this, short-time reservoirs made of steel with low to medium overpressures (0.5-25 bar) were erected in thermo-electric power stations in order to use the energetically favourable generating plans for as long and as optimally as possible both for the generation of electricity and also heat. The sizes of the individual tanks ranged from several 100 m3 to several 1'00 m3, the maximum loading temperatures were between 110°C and 180°C.

The major aim of the studies mentioned was to indicate new structural paths which could lead to the construction of very large low-cost heat reservoirs. Two suggestions seemed to be promising for conditions in Germany:

- artificial storage lakes and
- near-surface aquifer reservoirs

In the course of the more detailed planning work, which was accompannied by thorough theoretical and experimental studies (e.g. long-time behaviour of materials under the application conditions envisaged or the thermodynamics of the development of transitional layers between the warm and cold reservoir contents), it became apparent that the initial hopes placed in these systems could not be realized, or only with considerable technological and thus financial expenditure. Within the framework of international agreements the developmental priority was finally placed upon the storage lake concept. An aquifer concept adapted to German conditions was indeed developed by Messerschmidt-Bölkow-Blohm with financial support from the Federal Government. This was conceived as a long-time reservoir. This concept mainly differs from most foreign concepts by three items:

1. The upper layer of soil is first removed from the planned area and a horizontal system of drainage pipes is laid. Various insulating and sealing layers are applied on top of this and the soil layer is replaced. (By this means heat loss upwards is considerably reduced and it is perhaps possible to use the area for horticultural or traffic purposes.)

2. Horizontal wells in the bottom layers of the aquifer form the lower water exchange system. (The flow through the aquifer thus takes place in a vertical direction; buoyancy effects stabilize the thermal stratification.)

3. Watertight slit-walls are driven around the storage area down to the impermeable underlying strata. (In this way ground water flows within the aquifer and the concomitant heat losses are largely avoided or reduced.)

In a later project with the financial participation of the European Economic Community, the concept of an artificial aquifer reservoir was developed. The underlying concept of this is based on the storage lake. The natural storage material (gravel) is dug out and both the fine grain and the extremely coarse grain fractions are separated out. The bottom and the side surfaces can then be sealed off by a bentonite layer before the sieved gravel and the horizontal drainage pipe systems are put in place. The surface is prepared in the same way as the natural aquifer reservoir. In the same way, slit-walls are once again driven down around the artificial storage area in order to avoid contamination of the ground water in the adjacent natural aquifer (as a result of possible leakages in the bentonite layer). Thermal insulation towards the ground can be in principle also positioned.

This type of artificial aquifer reservoir is admittedly more expensive than a natural one. However, it displays very great and homogenous permeability, so that it can also be used to cover peak loads and as a short-time reservoir. Its environmental compatibility in densely populated areas has been assessed very favourably.

In chronological order there have been and are various developmental projects in the field of storage lakes: at the Jülich Nuclear Research Centre, the Mannheim municipal utilities, and in Wolfsburg. An overall solution from which we could expect a satisfying result from both a technological and economical point of view (also taking into consideration the reduction in costs in the case of very large plants) has not been discovered up to now. For this reason, the suggested prototype installations (between 10'000 and 30'00 m3) have not yet been constructed. We have been able to gather a large number of very useful detailed results. In addition to insights into the behaviour of sealing and thermal insulation materials, it has been proved both by model calculations and in experiments that the stratification is stable even in very large reservoirs and lends itself to computation.

4.5.2. Current activities

While the planning work has been abandonned in Jülich and Mannheim, we are still waiting for its conclusion in Wolfsburg. In particular, there are at the moment still no reliable cost specifications for two differently constructed experimental basins of 10'000 m3 each. One of them is envisaged without thermal insulation towards the ground and with a fixed thermally insulated upper rood, whereas the other is to have a floating cover and thermal insulation towards the ground. Local conditions are more favourable in Wolfsburg than in

Jülich or Mannheim because the ground water first occurs there at very great depths. Heat losses to the ground - with or without insulation - would then be considerably easier to control. On the other hand, however, transferability to other sites is doubtful because of this.

Due to difficulties with the new storage systems described above, various district heating utilities have recently decided to construct advanced steel reservoirs. The largest reservoir constructed as a steel tank is at the municipal works in Flensburg. The experience gathered in Sweden was used in its construction. It has a volume of 30'000 m3 (42 m diameter, 21 m cylindrical height) and is employed as a daily reservoir in connection with the intermittent operation of two back-pressure blocks.

A feasibility study for a novel tank concept must finally be mentioned. The major disadvantage of large cylindrical tanks is that theycan only be constructed for single volumes up to approx. 10^5 m3. In the case of the suggested new concept, there is in principle no limitation of this type since there are no circumferential stresses in the dish-type container form but rather merely membrane stresses in the direction of the contour of the sidewalls - similar to the case of a rope suspended at two levels with continual vertical load. The sidewall has approximately the contour of a vertical quarter ellipse. At the bottom it is joined to the plane bottom plate and is suspended from supports at the top. This study is intended to show whether this type of tank can be realized in various load cases (water levels) and whether they can be expected to be specifically cheaper than cylindrical steel tanks.

4.5.3. Future activities

When the study in Wolfsburg related to the storage lake, and the study on the advanced steel-membrane reservoir are concluded, a decision is expected about whether a prototype plant should be built for one of the three novel concepts:

- storage lake
- steel-membrane reservoir
- artificial aquifer reservoir

It also seems possible that if all three concepts prove to be less economical in comparison with cylindrical steel reservoirs that a prototye of an improved very large cylindrical steel tank (80'000 - 100'000 m3) will be constructed.

4.6. The Netherlands (by A.J. Wijsman)

4.6.1. Historical

In the Netherlands work on seasonal storage of solar heat is done since 1975. In most cases it concerns earth storage. The first work on heat storage in the soil was carried out by Prof. Van Koppen at the Eindhoven University.

In 1976/1977 this led to the idea of designing an office building in Lelystad with seasonal heat storage in clay soil. This project has not been constructed.

In the Veldhoven project (Philips, Eindhoven) one of the houses was coupled by a heat pump to a 500 m3 earth storage reservoir. Data from a step-response experiment on this store was used for computer model validation.

In 1978 the Delft Soil Mechanics Laboratory, Philips Energy Systems, Eindhoven, and the Institute of Applied Physics, Delft, started a feasibility study to investigate seasonal storage of solar energy in the soil. For this study a computer model for a group of solar houses connected to a heat storage reservoir in the soil was developed. The study was completed in 1980.

In the same period work was started to design the project of Leek: a group of 50 solar houses with a 2'500 m3 insulated earth storage. Until now it did not come to a construction.

4.6.2. Current activities

The study of the Delft Soil Mechanics Laboratory et al. led to the realization of the project of Groningen: 100 solar houses coupled to a 23'000 m3 earth storage. The construction of the seasonal heat storage reservoir took place from June 1982 to December 1982; the experiments started in February 1983 and will last several years.

In Arnhem an office building with an aquifer store will be constructed. The aquifer is used as a heat and cold storage; it is a two-well system.

In Almere, a new town in the latest diked country (polder), an office building is under construction with a 2'500 m3 earth store.

Both Arnhem and Almere work with heat pumps.

Furthermore, there are several projects with ground coupled heat pumps for heating a single house.

4.6.3. Future investigation

In Rotterdam large water reservoirs (concrete tanks) which were used in earlier days for the storage of drinking water, are available. At the moment studies are carried out to make an investigation to use these reservoirs for seasonal storage of solar heat.

The use of earth under greenhouses for seasonal storage of excess of heat in summertime is under study. In the system, a heat pump will be used.

4.7. Sweden (by P.O. Karlsson)

4.7.1. Historical

One of the first Swedish concepts concerning seasonal heat storage was elaborated in the early 1970's. The concept "Storage of hot water in rock caverns" was adopted in 1972 as a research project under the direction of the Swedish Rock Mechanics Research Foundation (BeFo). Since then, strongly influenced by the oil crisis in 1973, the interest in energy conservation, substitutional energy sources as well as heat storage, has increased rapidly.

A great number of different heat storage concepts have been developed, many of them also tested in small or full scale plants. The general development has been accelerated by comprehensive research programs and financial support from some state organizations, primarily the Swedish Council for Building Research (BFR). Prior to 1980 BFR has initiated about 150 projects, mainly pre-studies, concerning heat storage in soil, peat, rock and water.

Heat storage research and development have been carried out by a number of consulting engineers, by the technical universities, and by a number of other organizations.

The research projects have covered a wide range of storage concepts such as:

- aquifers
- open caverns
- blockfilled caverns
- abandoned mines
- rock
- clay
- peat
- pit storage
- insulated lake storage
- water tanks.

4.7.2. Current activities

A great number of heat storage systems are now in operation or under construction in Sweden. The energy sources are mainly solar heat, waste or surplus heat. Some of the heat storage systems are directly connected to large district heating systems.

Current activities may be exemplified by the following projects (detailed information is given in the attached summary sheets):

- Ingelstad, concrete tank, in operation since	1979
- Lambohov, concrete tank, "	1980
- Uppsala, steel tank "	1978
- Södertuna, steel tank, pre-study	1982
- Studsvik, pit magasin "	1979
- Avesta, unlined open rock cavern "	1982
- Lyckebo, unlined open rock cavern "	1983
- Kopparberg, abandoned mine, pre-study	1982
- Tranås, aquifer, pre-study	1982
- Klippan, aquifer, pre-study	1982
- Kungsbacka (SUNCLAY), clay, in operation since	1980
- Huddinge, heat-pile in clay, "	1981
- Upplands Väsby, clay, pre-study	1982
- Luleå, multiple well system, construction compl.	1982
- Stora Skuggan, multiple well system, pre-study	1982
- Södertuna, multiple well system, pre-study	1982
- Heat storage in clay, peat and aquifers. Potential studies	1980-1983

Operating plants are now under evaluation and feed back is continuously received for the continuing research and development activities.

In a current project, at the University of Lund, analyses and modelling of ground heat storage systems are carried through. The analyses and models cover a wide range of storage concepts thus giving considerable contribution to the rapid development of many storage systems.

In addition to the projects mentioned above a great number of laboratory tests, field tests, etc., are going on.

4.7.3. Future investigation

A great number of storage concepts have now been tested in small or full scale plants. The Swedish Council for Building Research (BFR) has therefore initiated an evaluation procedure in order to make clear applicability and remaining need for research, experiment, etc. The evaluation procedure will concentrate for every storage concept on the following:

- price
- potential
- performance
- problems

The result of the evaluation which will be completed in 1983 will form the base for the future national research program.

4.8. Switzerland (by J.C. Hadorn)

4.8.1. Historical

During the past ten years the interest has been focused on aquifer storage, and more recently on earth storage systems. This was mainly due to the Swiss geological conditions and geographical constraints.

Field experiments have been carried out since 1974 in a phreatic aquifer by the Centre of Hydrogeology of Neuchâtel. The results are mainly used as validation basis for finite element models developed by the "Institut d'Economie et Aménagements Energétiques" (IENER) of the Swiss Federal Institute of Technology in Lausanne, in order to predict the interest of large storage facilities.

Several small scale experiments on earth storage system (disturbed) have started since 1979 (the Marly storage, for example). Funding is assumed mainly by National Funds (FN, NEFF), but also by private company and office, and coordination is principally achieved by the Federal Office of Energy (OFEN).

4.8.2. Current activities

The SPEOS project (shallow aquifer confined and unconfined, 60'000 m3 approximately) is being tested in Dorigny, near Lausanne, and will be a full scale experiment for the radiant drains and vertical piston concept.

The earth storage in Vaulruz has been built during 1982. The reference volume is 3500 m3 of earth, and it is thermally confined on sides by 30 cm of insulation, and on top by 60 cm of insulation as well (expanded polystyrene).

4.8.3. Future investigation

A project called ACUS from the IENER should begin this year. It is, in essence, a rock storage system (depth 200 to 250 m) linked to evacuated flat plate collectors, for about 1000 inhabitants, foreseen to reach about 150°C during the charging period. A laboratory test (downscaled with 1 m3 of rock under 10 bars) should be conducted in 1983, as well as the technical and economical studies.

4.9. United Kingdom (by B. Rogers)

4.9.1. Historical

A solar-heated seasonal store of 100 m3 was constructed in 1976-1977 at the Centre for Alternative Technology at Machynlleth in Wales to provide space heating for an exhibition hall.

An integrated solar building design study has been undertaken by IDC Consultants Ltd of Stratford-upon-Avon, partly funded by the UK Department of Energy. A small factory building of floor area 1600 m2 was modelled. The thermal storage was in water-filled, insulated concrete tanks, which also acted as foundations for the superstructure of the building.

4.9.2. Current activities

The Hydrogeology Unit of the Natural Environment Research Council's Institute of Geological Sciences is undertaking an experimental project on heat storage in aquifers. Boreholes have been drilled into a 12 m thick confined Lower Greensand geological formation overlain by clay and chalk, for injection and extraction of water at 50-60°C. The project began in March 1981, and is due to finish in 1984.

The University of Sussex has an experimental salt gradient solar pond project partly funded by the EC. The aim of the project is to develop laboratory instrumentation and techniques for filling and maintaining ponds, extracting heat, and monitoring conditions and performance. A pond of storage volume 150-200 m3 is to be built and operated at a local farm.

A numerical model for solar ponds is being developed with the support of the Science and Engineering Research Council at the Solar Energy Unit of University College, Cardiff, to explore the dependence of performance on factors such as load, site, pond depth and salt concentration gradient. The model incorporates a detailed treatment of surface heat loss mechanisms, solar radiation extinction coefficients, and heat exchange with the surrounding soil and ground-water flows. Experimental studies have been made to validate the extinction coefficients and charging performance. An analytical steady-state model has also been developed; together the two models permit design optimization.

4.9.3. Future investigation

There are unlikely to be large-scale projects on the seasonal storage of solar energy in the near future.

4.10. United States of America (by A.I.Michaels)

4.10.1. Historical

The USA program for the development of large-scale, long-term thermal energy storage (TES) subsystems, which could be utilized for central solar heating plants, has largely been concentrated on two technologies: hot water storage in confined aquifers; and salt gradient ponds, which function as a combined collection and storage system. However, there have been a number of analytical studies and small scale experiments on other seasonal heat storage methods, including: undisturbed or moisture controlled earth; various rock or pebble-bed formations; fresh water ponds, serving as storage only or as a combined solar collector-storage system; and large, in-earth water tanks. In addition, a substantial amount of analysis and experimentation is being conducted on ground coupled heat pump systems which may have relevance to this solar seasonal storage application.

4.10.2. Current activities

The aquifer program is presently the most advanced. A series of large-scale field experiments has been carried out by Auburn University in Alabama. Two charge-store-recovery cycles at 55°C were completed with 67% recovery. Two cycles at 82°C have been completed. Due to high buoyancy effects and a non-uniform horizontal permeability in the aquifer, recovery has been very poor, less than 50% with a maximum recovery temperature of 55°C at best, in spite of attempts to control mixing of cold and hot water during recovery by upper well pumping only, and by pumping lower well to wast while upper well recovery was underway. A large-scale field test project for the storage of water up to 150°C in a deep aquifer was constructed and preliminary check-out was completed at the University of Minnesota in St. Paul. A project for evaluating storage of winter cold for summer cooling use has just been successfully completed at Stony Brook, N.Y. A detailed three-dimensional computer code has been developed, and validated against University of Auburn experimental data, by the Lawrence Berkeley Laboratory. A linear one-dimensional code and a simple graphical methodology were also developed and validated against the more complex code. Additional performance and cost analysis aquifer TES codes (including distribution costs) have been developed by Battelle Pacific Northwest Laboratory.

In the salt gradient pond program, a variety of small ponds have been built and operated with a fairly high degree of success. Several one-dimensional computer codes have been developed and utilized for analytical studies with a fair degree of correlation with experimental observations. A more complex, multi-dimensional code has been develope at Argonne National Laboratory. A number of larger experimental and demonstration ponds are under construction or planned (by the TVA in Tennessee, at the Salton Sea and at Owens Lake in California, at Truscott Brine Lake in Texas, etc.). An analysis of the utilization of a solar pond in a district heating system is under way at SERI.

There have been several analytical and cost studies of large scale water tanks in seasonal storage applications, but no experimental installations. One preliminary analysis of seasonal storage in earth was conducted by George Washington University, and a small scale experiment was conducted at Colorado State University. Another analyti study conducted by the University of Minnesota addressed seasonal heat storage in various rock-earth configurations. This was oriented to high temperature storage (up to 500°C) for power generation applications, but does have some relevance to heating. Finally there have been a number of analytical and simulation studies of solar collection and/or heat storage in fresh water ponds utilizing various types of surface covers.

A preliminary study has been completed for a retrofit solar heating system at the Charlestown, Boston Navy Yard Redevelopment Project. This system design would utilize storage in existing underground concrete tanks. The distribution system also would use existing underground piping tunnels. Collectors would be placed on roofs of existing buildings. As a result of savings through the use of available facilities, system costs are reduced, and the analysis indicated a strong potential for cost competitiveness with conventiona heating systems. Negotiations aimed at initiating the detailed design phase of the project are under way but uncertain.

4.10.3. Future investigation

In the aquifer program, initial short injection-recovery cycles are commencing at the University of Minnesota Field Test Facility; full charging tests will begin next summer. An aquifer seasonal cool-stora system was installed to provide air conditioning for a large departmen store in Tuscaloosa, Alabama. This has been instrumented and its performance will be monitored over the coming year. A new project to evaluate non-aquifer chill storage is currently being intiated.

The TVA salt-gradient pond has been checked out and has begun operatio Performance data is being obtained and analytical methods will be evaluated.

5. COMPILATION OF SOME HEAT STORAGE PROJECTS IN THE PARTICIPATING COUNTRIES

This chapter is devoted to the presentation of basic data concerning heat storage projects of special interest.

A summary sheet proposed within the EC working group by the Netherlands has been found suitable for this purpose by the participants in Subtask 1c.

It describes the main characteristics of the project. Illustrations, references, and contact people are provided as well for most of the projects described.

The numbers listed under References refer to the List of references and Bibliography.

The compilation of projects is presented by storage types:

5.1. Tank storage

5.2. Pit storage

5.3. Rock cavern storage

5.4. Aquifer storage

5.5. Earth storage

5.6. Rock storage

Some of the projects or design studies schematically presented here are not directly related to solar heating plants of seasonal storage. However, the experiences they present can certainly be used with great benefit for seasonal heat storage applications.

The illustrations have been taken from some relevant papers describing the projects under consideration.

5.1. Tank storage

5.1.1. Aylmer Senior Citizens Residence (Canada)

5.1.2. Provident House (Canada)

5.1.3. Ingelstad - Växjö solar heating plant (Sweden)

5.1.4. Lambohov - Solar heating plant (Sweden)

5.1.5. Södertuna - Alternative A: Steel tank (Sweden)

5.1.6. Water tank Uppsala (Sweden)

5.1.7. Seasonal water storage vessel - CCR, Ispra (EC)

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK /1

RESEARCH WORK

TITLE: AYLMER SENIOR CITIZENS RESIDENCE

PERIOD: testing
since Sept. 1978
till 1983

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 986 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.648 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 29 - 75 °C
8. Price : - UA/m^3

Properties at temperature : 55 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 916 m^3
   shape : truncated cylinder
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 3780 MJ/K
3. Containment present : YES/~~NO~~
   material : reinforced concrete walls
4. Insulation present : YES/~~NO~~
   position insulation : all around (internal)
   material : polyurethane foam
   total volume insulation material: 83 m^3
5. Heat exchanger present : not in tank ~~YES~~/NO
   heat exchange rate (theor./exp.): - W/K
6. Annual performance (theor./exp.): 72/ (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	UA 102'000 CAN$ 1978

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 30 unit apartment building (1784 m2)

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 2.27 10^5 MJ
   hot water load* : 6.75 10^4 MJ
   total load* : MJ
   total system load* : 2.945 10^5 MJ

* ~~per heat consumer~~ per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 240 m^2 / x m^2
- type : liquid flat plate

Short term heat storage: central/distributed/not pres

- storage volume : m^3 / x m^3
- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m
- heat loss rate : W/K.m_{piping}

Total cost : UA

5. Auxiliary heating: central/~~distributed/not pres~~

- type : electric boiler
- power installed : 30 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : 224'600 ~~UA~~ CAN$ 1978
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: 42° 46' Longitude: 81° 00

Climatological data for location :

- global irradiation horizontal : 4898 MJ/m^2 (1360 kWh/m^2)
- number of degree days : 3840 ; temperature below 18 °C

1. Total system load : 2.945 10^5 MJ
2. Total solar contribution : 2.718 10^5 MJ (92 % of load)

   idem per m^2 collector : 1132 MJ (315 kWh/m^2)
3. Total auxiliary heating : 2.28 10^4 MJ
4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :
2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

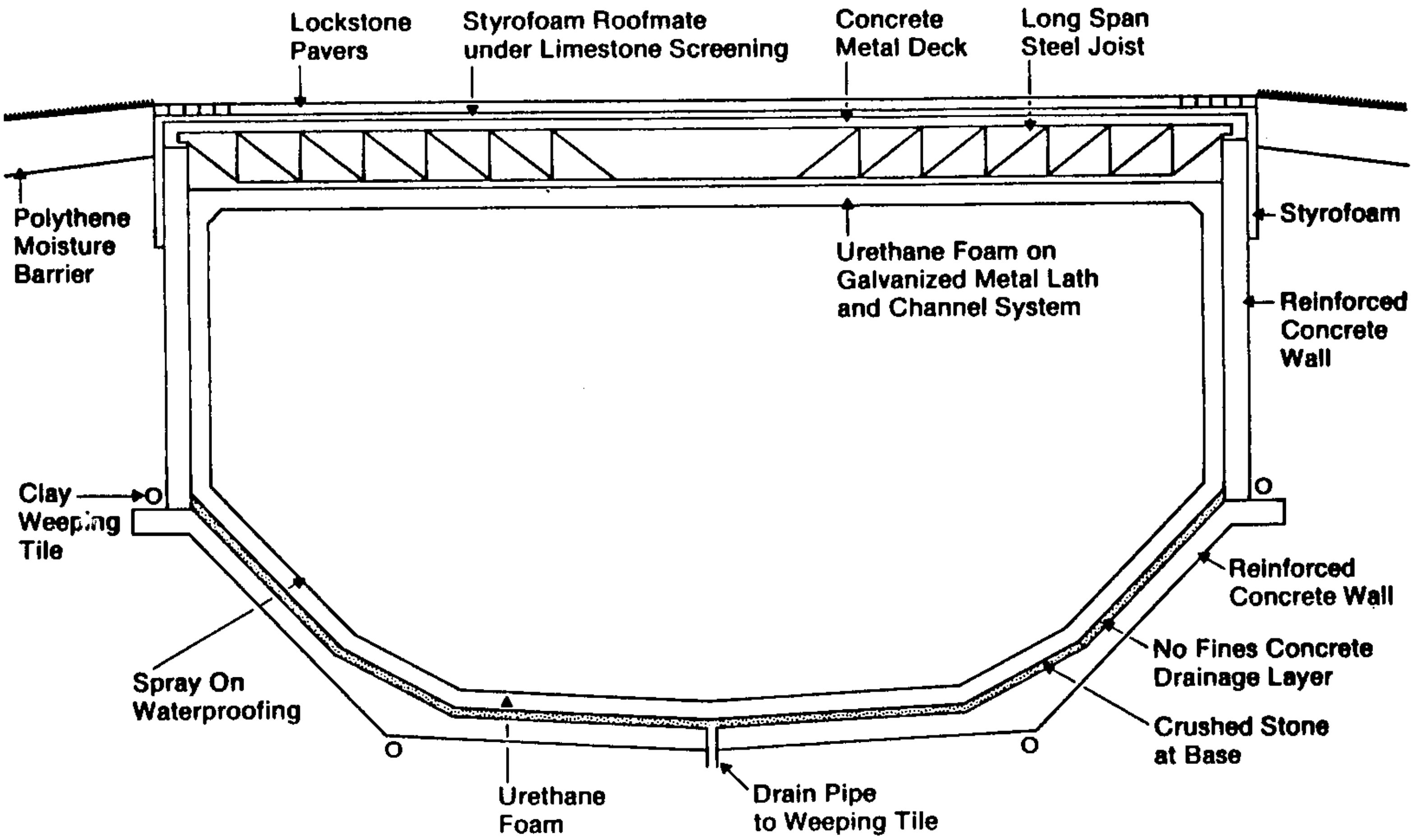


Figure 14: Aylmer tank details

REFERENCES

/6, 7, 8/

CONTACT

Otto SVEC
National Research Council
Division of Building Research
Geothechnical Selection,

for ground temperature sensors around the seasonal storage tank

Bruce SIFFITT
Solar Energy Program,
National Research Council,

for mounting of system

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/2

RESEARCH WORK

TITLE: PROVIDENT HOUSE

PERIOD: operating
since 1976
(end of test: April 1979)

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 986 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.648 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 32 - 80 °C
8. Price : UA/m^3

Properties at temperature : 55 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE	COST (incl. cost for labour)
1. Storage volume : 277 m^3	Storage UA
shape : rectangular with pyramidal bottom	
position: ~~above~~/below/~~partly below~~ ground level	
2. Total heat capacity : 1143 MJ/K	
3. Containment present : YES/~~NO~~	Containment UA
material : reinforced concrete	
4. Insulation present : YES/~~NO~~	Insulation UA
position insulation : all around (internal)	
material : polyurethane foam	
total volume insulation material: 30 m^3	
5. Heat exchanger present : ~~YES~~/NO	Heat exchanger UA
heat exchange rate (theor./exp.): - W/K	Miscellaneous UA+
6. Annual performance (theor./exp.): 60/ (%)	Total system UA 18000 CAN$ 1976

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1 family residence 259 m2

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : 6.5 10^5 MJ

hot water load* : MJ

total load* : MJ

total system load* : 6.5 10^5 MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 66.6 m^2 / x m^2

- type : liquid flat plate

Short term heat storage: central/distributed/not prese

- storage volume : m^3 / x m^3

- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m

- heat loss rate : W/K.m$_{piping}$

Total cost : UA

5. Auxiliary heating: central/~~distributed~~/~~not prese~~

- type : electric duct heater

- power installed : 15 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: 43° 54' Longitude: 79° 37'

Climatological data for location :

- global irradiation horizontal : 4850/ MJ/m^2 (1347 kWh/m^2)

- number of degree days : 4100/ ; temperature below 18 °C

1. Total system load : 65000/72122 MJ

2. Total solar contribution : 65000/41767 MJ (100 % of load) / 58%

idem per m^2 collector : 976/627 MJ (271 kWh/m^2) / 174 kWh/m2

3. Total auxiliary heating : 0/20922 MJ

4. Total electricity consumption : /2606 kWh (for pumps)

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

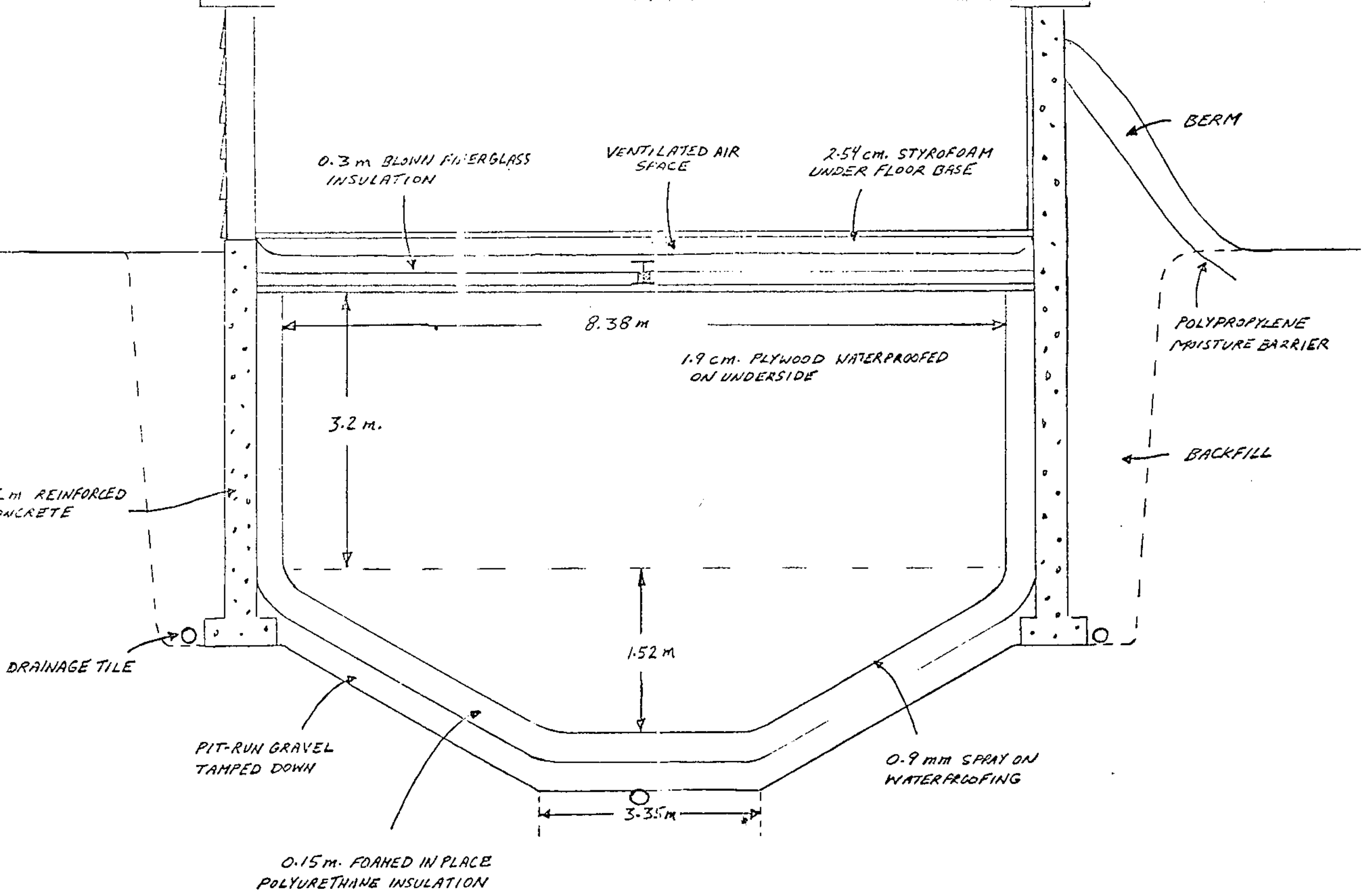


Figure 15: Provident House thermal storage tank

REFERENCES

/9, 10/

CONTACT

McClintock Homes, owner, Toronto 491-2701

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/3

RESEARCH WORK

TITLE: INGELSTAD – VÄXJÖ SOLAR HEATING PLANT

PERIOD: operating since 1979

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - ~~theoretical/experimental~~
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 40 - 95 °C
8. Price : UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 5'000 m^3
   shape : cylindrical Ø 28 m, h 8m
   position: above/~~below/partly below~~ ground level
2. Total heat capacity : 20 500 MJ/K
3. Containment present : YES/~~NO~~
   material : concrete
4. Insulation present : YES/~~NO~~
   position insulation : all around (external)
   material : glass fiber, min. wool
   total volume insulation material: 330 + 1200 m3 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage UA
Containment UA
Insulation UA
Heat exchanger UA
Miscellaneous UA+
Total system UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system:

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : 65'000 MJ / house
   total system load* : 4 10^6 MJ including distribution losses

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 1300 m^2 / x m^2
- type : concentrating - tracking /tilt 35°

Short term heat storage: central/distributed/not prese

- storage volume : m^3 / x m^3
- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network : 80°C/50°C

- total length : 3000 m
- heat loss rate : $W/K.m_{piping}$

Total cost : UA

5. Auxiliary heating: central/distributed/not prese

- type : boiler plant
- power installed : 700 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)
- number of degree days : ; temperature below °C

1. Total system load : MJ
2. Total solar contribution : MJ (% of load)

   idem per m^2 collector : MJ (kWh/m^2)
3. Total auxiliary heating : MJ
4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :
2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

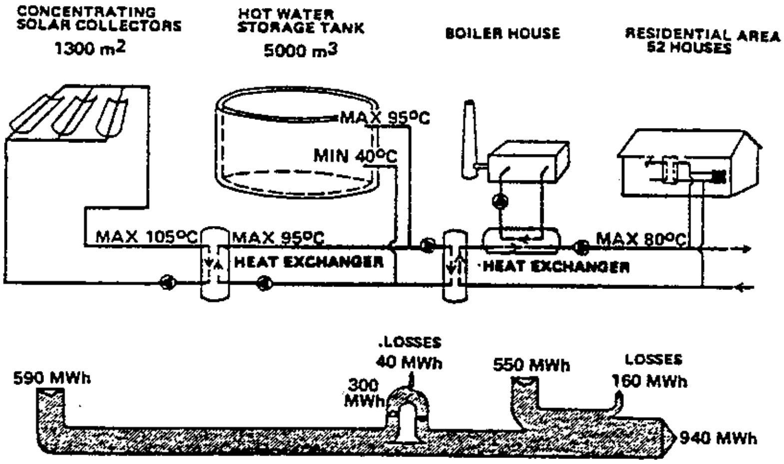


Figure 16: Ingelstad/Schematic diagram - Energy flows

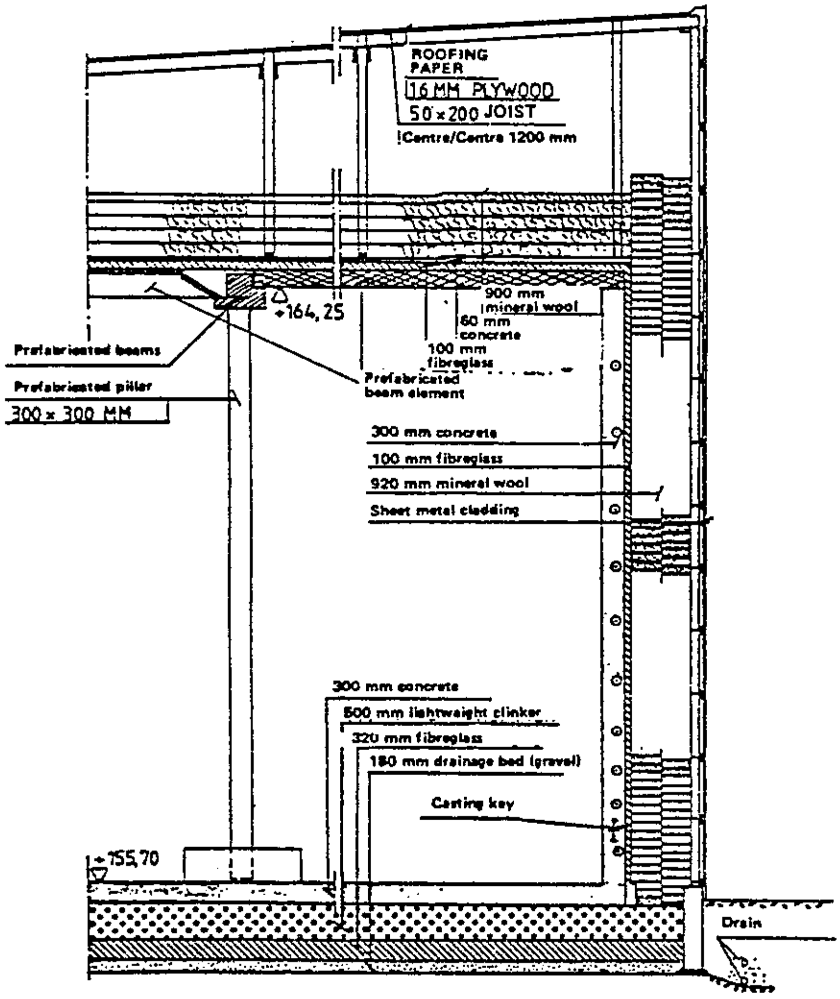


Figure 17: Ingelstad/Cross section through the tank

REFERENCES

/5, 11/

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/4

RESEARCH WORK

TITLE: LAMBOHOV SOLAR HEATING PLANT

PERIOD: operating since 1980

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - ~~theoretical/experimental~~
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 5 - 70 °C
8. Price : UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 10'000 m^3
   shape : cylindrical Ø 32 m, h 12m
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 40'500 MJ/K
3. Containment present : YES/~~NO~~
   material : concrete
4. Insulation present : YES/~~NO~~
   position insulation : all around
   material : light weight concrete polyurethane
   total volume insulation material: 1800 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage UA

Containment UA

Insulation UA

Heat exchanger UA

Miscellaneous UA+

Total system UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 55 terraced houses

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 3930 MJ
   hot water load* : 1440 MJ
   total load* : 5370 MJ
   total system load* : 3 10^6 MJ

* per heat consumer per year.

2. Solar heat collecting system :

Solar collectors : ~~central~~/distributed

- collector area : 2875 m^2 / 55 x92.3 m^2

- type : flat, single glazing, tilt 55°

Short term heat storage: ~~central/distributed~~/not prese

- storage volume : m^3 / x m^3

- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m

- heat loss rate : 80 MWh ~~W/K.m~~ piping

Total cost : UA

5. Auxiliary heating: central/distributed/not prese

- type : heat pumps

- power installed : 156 + 29 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)

- number of degree days : ; temperature below °C

1. Total system load : MJ

2. Total solar contribution : MJ (% of load)

idem per m^2 collector : MJ (kWh/m^2)

3. Total auxiliary heating : 324 10^3 MJ

4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

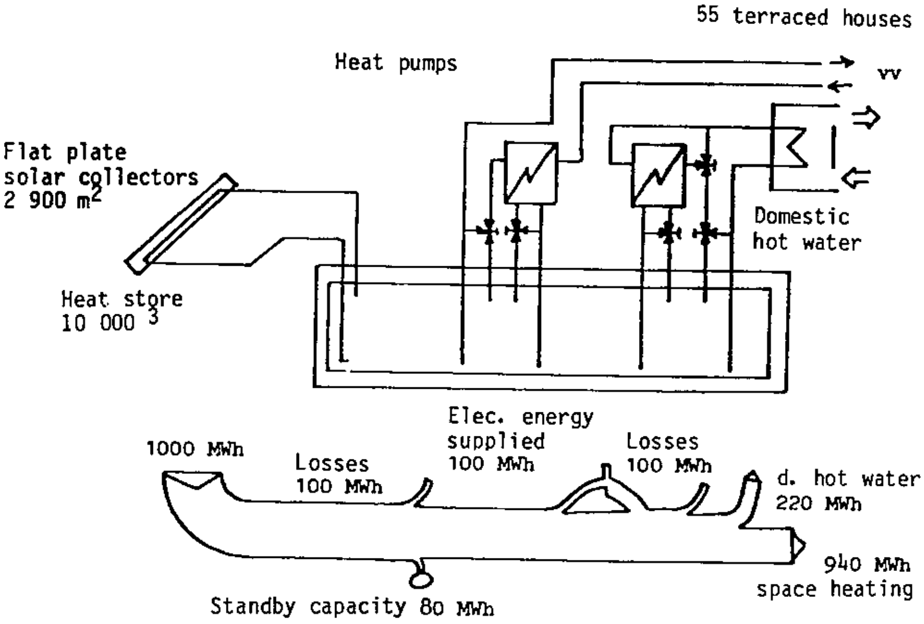


Figure 18: The Lambohov solar heating system and energy flows

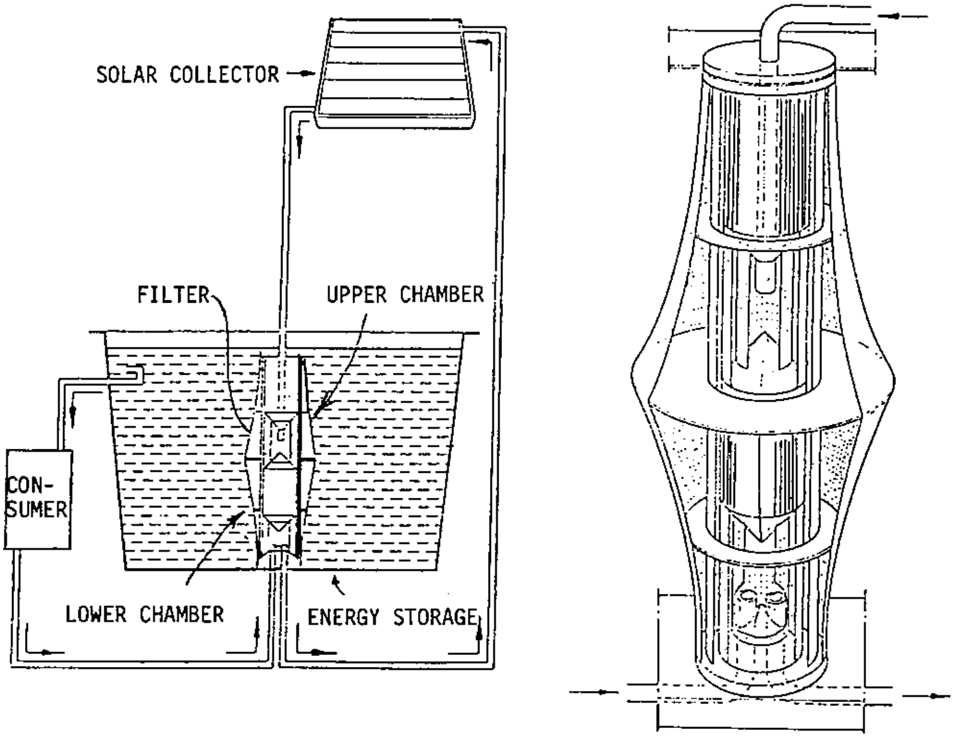


Figure 19: Lambohov/Stratifying infeed assembly

REFERENCES

/5, 12, 28, 29/

CONTACT

Solvärmecentral Lambohov
Allmogegatan 66
S - 583 30 LINKÖPING

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/5

RESEARCH WORK

TITLE: SÖDERTUNA ALTERNATIVE A: STEEL TANK **PERIOD:** 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/~~experimental~~
- storage system : YES/~~NO~~ - theoretical/~~experimental~~
- total system : YES/~~NO~~ - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material	:	water	
2. Density	:	998	kg/m^3
3. Specific heat	:	4190	J/kg K
4. Mean heat capacity	:	4.1	MJ/m^3 K (1 x water)
5. Thermal conductivity	:	0.6	W/m K
6. Permeability	:	_	m^2
7. Operating temperature interval:		15 - 65	°C
8. Price	:	290 SEK/m3	~~UA/m^3~~
Properties at temperature	:	20	°C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE			COST (incl. cost for labour)		
1. Storage volume :	55000	m^3	~~Storage~~		UA
shape :	cylindrical		Ground works	0.9 MSEK	
position: ~~above/below~~/partly below ground level					
2. Total heat capacity :	225 500	MJ/K			
3. Containment present :		~~YES~~/NO	Containment (tank)	5.2 MSEK	UA
material :					
4. Insulation present :		YES/~~NO~~	Insulation	2.0 MSEK	UA
position insulation :	roof and walls				
material :	mineral wool				
total volume insulation material:		m^3			
5. Heat exchanger present :		YES/~~NO~~	~~Heat exchanger~~		UA
heat exchange rate (theor./exp.):		W/K	Miscellaneous	4.9 MSEK	UA+
6. Annual performance (theor./~~exp.~~):	95/	(%)	Total system	13.0 MSEK	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 525 dwellings + 3500 m2 communal areas

1. Heat consumption system: space heating/domestic hot water/both

space heat load*	:	$19\ 10^3$	MJ	
hot water load*	:	$15\ 10^3$	MJ	
total load*	:	$34\ 10^3$	MJ	
total system load*	:	$39\ 10^3$	MJ	Incl. 13% losses

* ~~per heat consumer~~ per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : ~~central~~/distributed

- collector area : 13'000 m^2 / x m^2

- type : roof integrated

Short term heat storage: ~~central/distributed~~/not prese

- storage volume : m^3 / x m^3

- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network : primary system
secondary system
solar system (8%)

- total length : 12500 m

- heat loss rate : W/K.m piping

Total cost : 10.1 MSEK UA

5. Auxiliary heating: central/distributed/not prese

- type : heat pump 1 x 200

- power installed : 600 kW / 1 x 400 kW

Total cost : 1.8 MSEK UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW (130 MWh/year)

7. Total cost

- solar heating system : 34.6 MSEK UA

- conventional heating system : [illegible] MSEK UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: 59° 5' Longitude: 17° 36'

Climatological data for location :

- global irradiation : 3830 MJ/m^2 (1064 kWh/m^2)

- number of degree days : 3850 ; temperature below 17 °C

1. Total system load : 23 10^6 MJ

2. Total solar contribution : 4248 MWh ~~MJ~~ (65 % of load)

idem per m^2 collector : 1150 MJ (320 kWh/m^2)

3. Total auxiliary heating : 950 MWh ~~MJ~~

4. Total electricity consumption : 1080 MWh ~~kWh~~

PRIMARY ENERGY SAVED

Fuel: Electricity Fuel price: 0.20 SEK/kWh

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved: 80%

Extra system cost : 25.4 MSEK UA

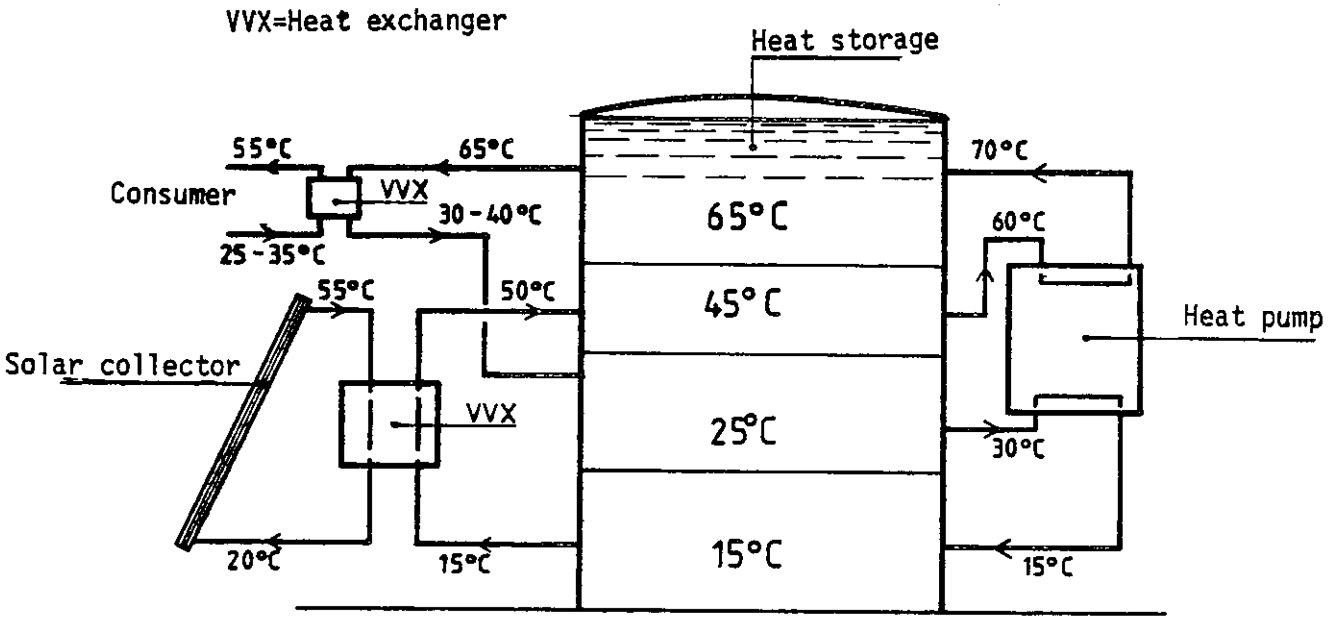


Figure 20: Södertuna alt. A/Schematic diagram of solar energy system

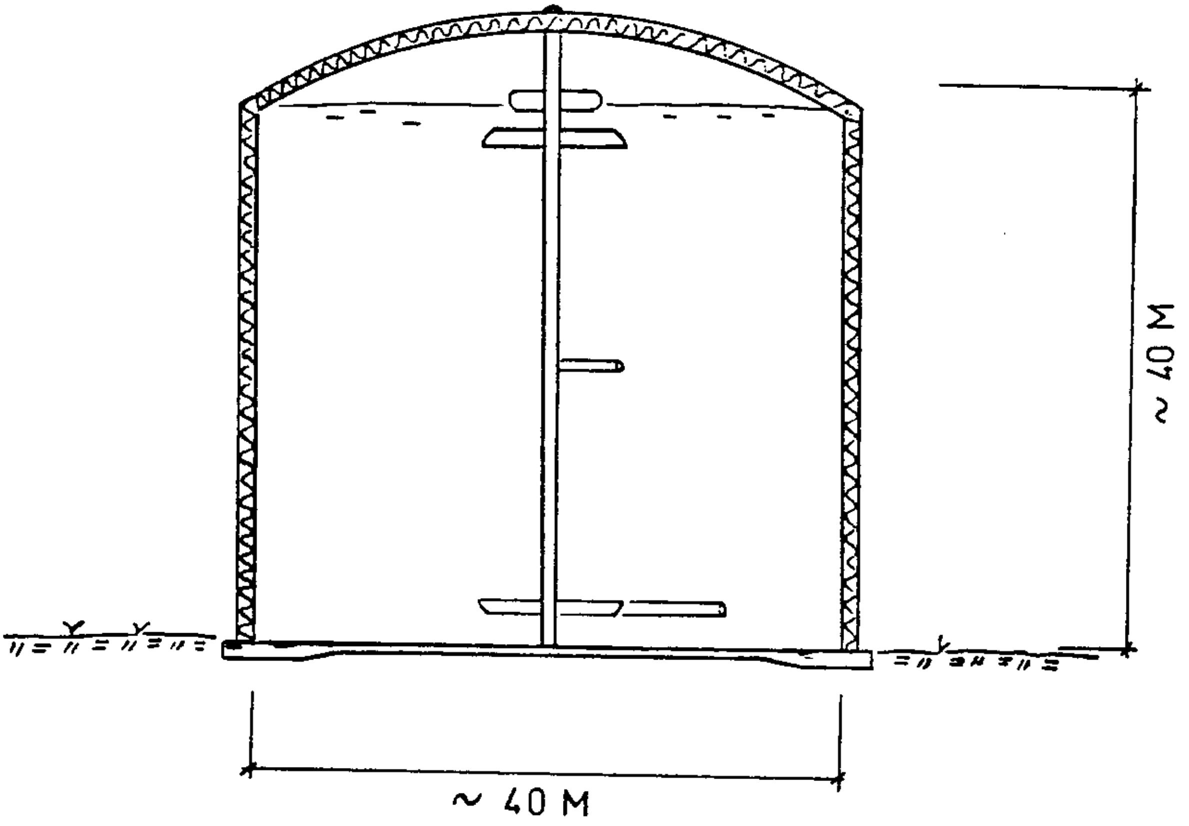


Figure 21: Södertuna alt. A/Basic design of steel tank of 50'000 m3

REFERENCE

/76/

CONTACT

T. BRUCE
Södertälje Energy Supply Authority
S - 151 89 SÖDERTÄLJE

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/6

RESEARCH WORK

TITLE: WATER TANK UPPSALA

PERIOD: operating since 1978

MAIN SUBJECTS OF RESEARCH: The tank is used as short term storage for a cogeneration plant

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 50 - 95 °C
8. Price : UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 30'000 m^3
   shape : cylindrical
   position: above/~~below/partly below~~ ground level
2. Total heat capacity : 120 10^3 MJ/K
3. Containment present : YES/NO
   material :
4. Insulation present : YES/~~NO~~
   position insulation : roof and walls
   material : 30 cm mineral wool
   total volume insulation material: 1300 m^3
5. Heat exchanger present : YES/NO
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage UA

Containment UA

Insulation UA

Heat exchanger UA

Miscellaneous UA+

Total system 10 MSEK ~~MUA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: District heating system

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.

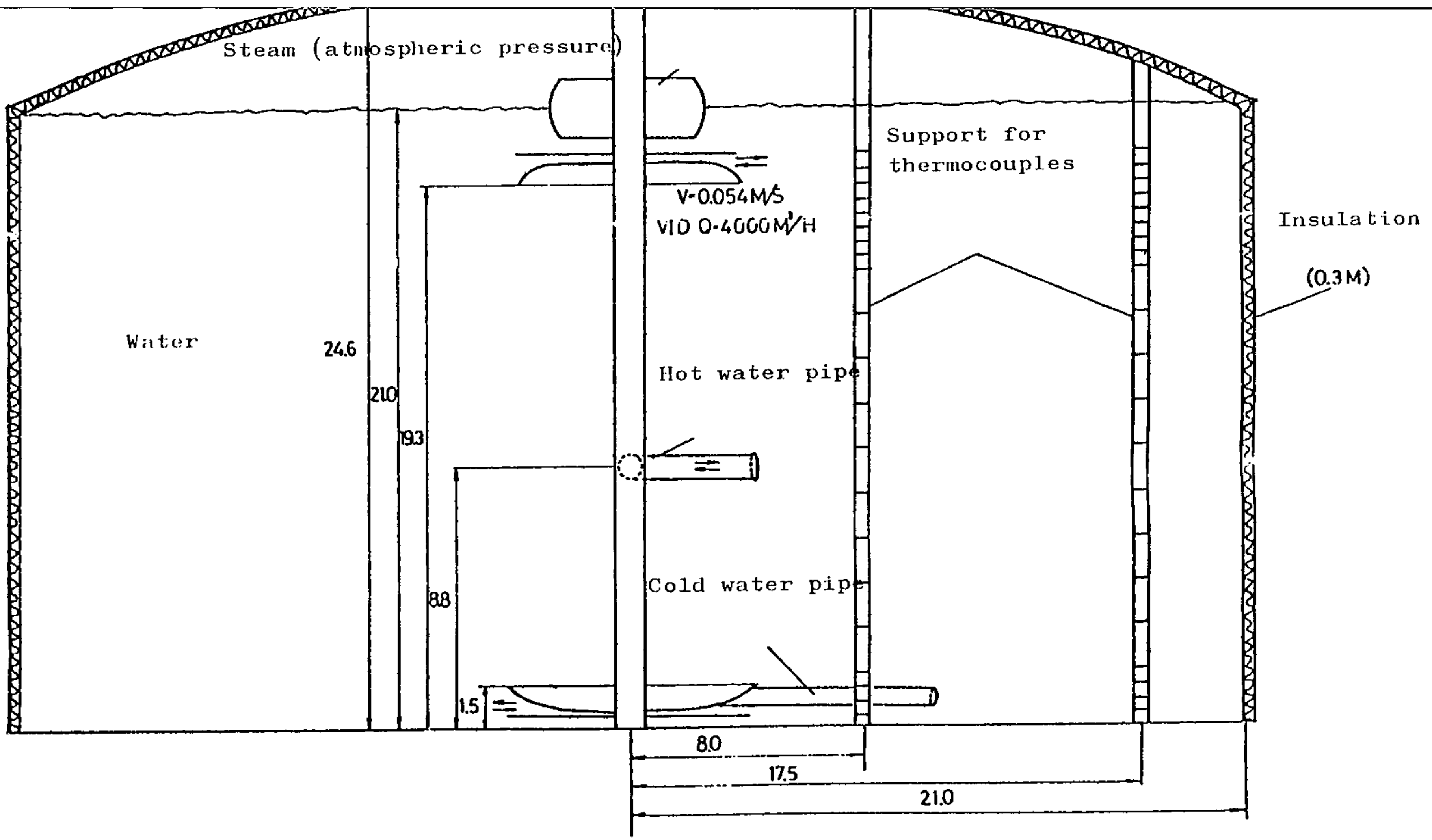


Figure 22: Uppsala/Water tank

CONTACT: E. KJELLSSON, Uppsala Kraftvärme AB, Box 125, S. 751 04 UPPSALA

SUMMARY SHEET: SEASONAL HEAT STORAGE TANK/7

RESEARCH WORK

TITLE: SEASONAL WATER STORAGE VESSEL – CCR-ISPRA **PERIOD:**

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO – theoretical/experimental
- storage system : YES/~~NO~~ – theoretical/experimental
- total system : ~~YES~~/NO – theoretical/experimental

STORAGE MATERIAL

1. Material : water + surounding ground ↴
2. Density : 1000 kg/m^3 $1.2 - 1.5\ 10^3$
3. Specific heat : 4180 J/kg K $1.2 - 2.9\ 10^3$
4. Mean heat capacity : 4.1 MJ/m^3 K (x water) 1.4 – 4.3
5. Thermal conductivity : 0.6 W/m K 0.6 – 1.5
6. Permeability : – m^2
7. Operating temperature interval: 25 – 80 °C
8. Price : UA/m^3

Properties at temperature : °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE	COST (incl. cost for labour)
1. Storage volume : 330 m^3	Storage UA
shape : rectangular vessel	
position: ~~above~~/below/~~partly below~~ ground level	
2. Total heat capacity : 1400 MJ/K	
3. Containment present : YES/~~NO~~	Containment UA
material : concrete	
4. Insulation present : YES/~~NO~~	Insulation UA
position insulation : roof	
material : expanded polystyrol	
total volume insulation material: 24 m^3	
5. Heat exchanger present : ~~YES~~/NO	Heat exchanger UA
heat exchange rate (theor./exp.): W/K	Miscellaneous UA+
6. Annual performance (theor./exp.): (%)	Total system UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: simulated load

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : MJ

hot water load* : MJ

total load* : MJ

total system load* : $280\ 10^3$ MJ

* per heat consumer per year.

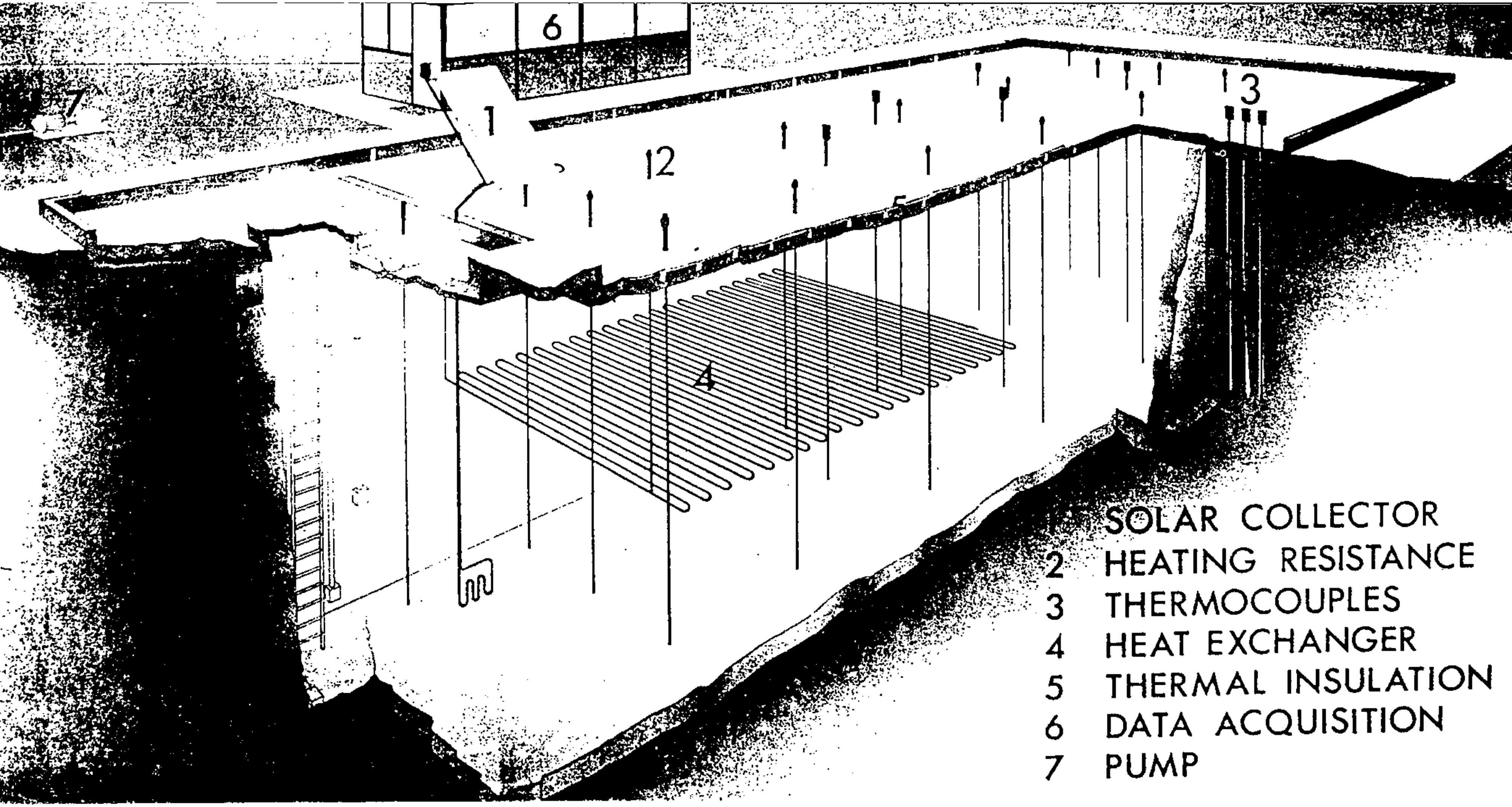


Figure 23: CCR Ispra/Seasonal water storage vessel

CONTACT: M. HARDY, Joint Research Center, I - 21020 ISPRA

5.2. Pit storage

5.2.1. Large warm water reservoir project (Germany)

5.2.2. Design of the Long Time Store in Wolfsburg (Germany)

5.2.3. Hot water storing project, Mannheim (Germany)

5.2.4. Interseasonal solar space heating (United Kingdom)

5.2.5. Solar heating plant at Studsvik (Sweden)

SUMMARY SHEET: SEASONAL HEAT STORAGE PIT/1

RESEARCH WORK

TITLE: LARGE WARM WATER RESERVOIR PROJECT **PERIOD:** 1975-1979

MAIN SUBJECTS OF RESEARCH: The reservoir was designed for a system with a cogeneration plant

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material : water
2. Density : 990 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 50 - 90 °C
8. Price : 0.70 DM ~~MJ~~/m^3
Properties at temperature : 70 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 5'000'000 m^3
shape : square pit
position: ~~above~~/~~below~~/partly below ground level
2. Total heat capacity : 20 10^6 MJ/K
3. Containment present : YES/~~NO~~
material : plastic sheets
4. Insulation present : YES/~~NO~~
position insulation : all around
material : polyurethane
total volume insulation material 2200 m^3
5. Heat exchanger present : ~~YES~~/NO
heat exchange rate (theor./exp.): _ W/K
6. Annual performance (theor./~~exp.~~) 80 (%)

COST (incl. cost for labour) *** (in DM 1975)

Storage 3.5 10^6 UA
Containment } 61 10^6 UA
Insulation } UA
Heat exchanger - UA
Miscellaneous 4 10^6 UA+
Total system 68.5 10^6 UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 140'000 inhabitants

1. Heat consumption system: space heating/domestic hot water/both
space heat load* : 20000 **MJ**
hot water load* : 5000 **MJ**
total load* : 25000 **MJ**
total system load* : 3.5 10^9 **MJ**

* **per heat consumer per year.**

*** not realistic according to 1982 state of knowledge

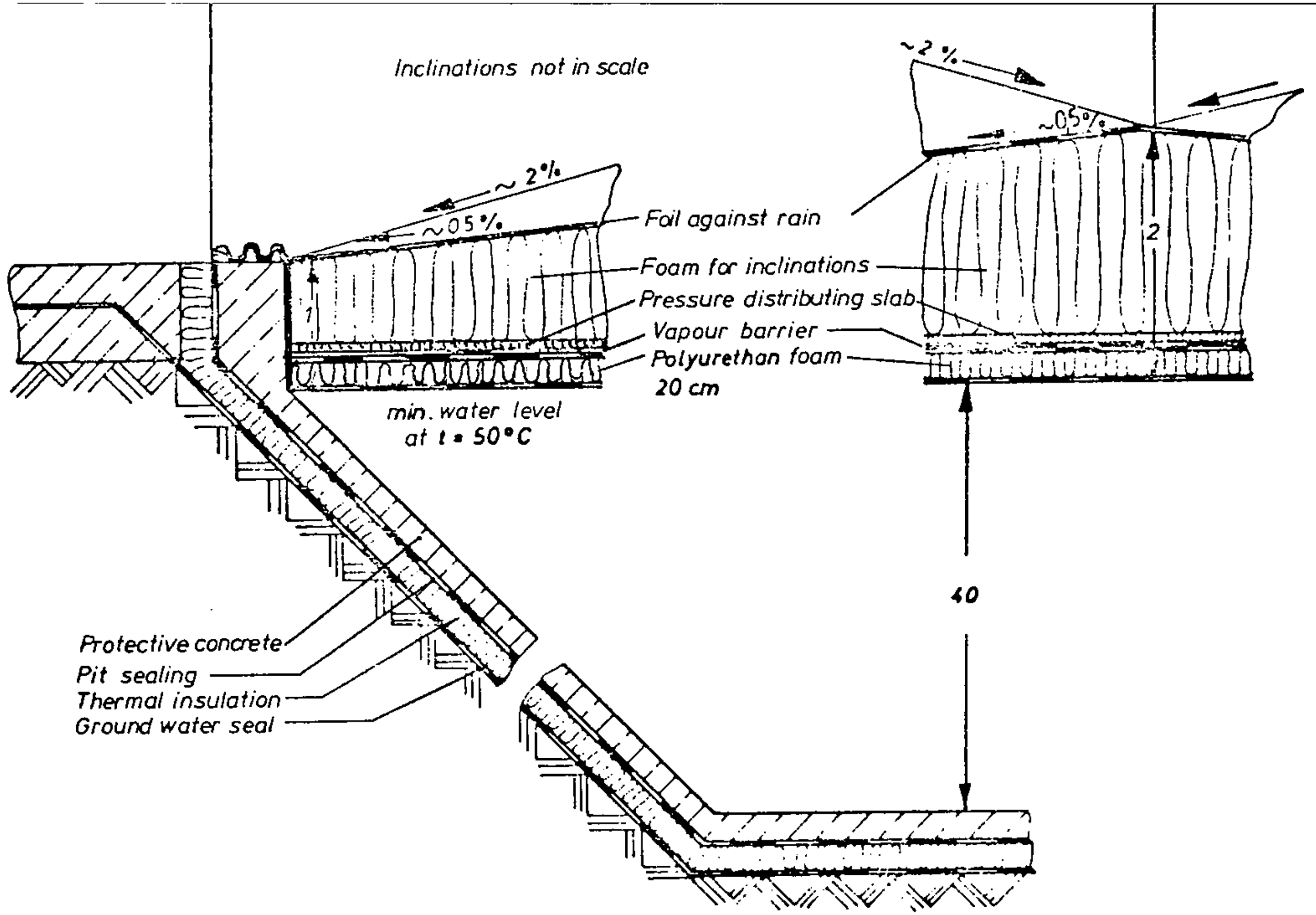


Figure 24: Warm water reservoir project/Version floating cover - Details

REFERENCES: /13, 14, 15/

CONTACT: F. SCHOLZ, Kernforschungsanlage Jülich GmbH, Postfach 1913 STE, D - 5170 JÜLICH

SUMMARY SHEET: SEASONAL HEAT STORAGE PIT/2

RESEARCH WORK

TITLE: DESIGN OF THE LONG TERM STORE IN WOLFSBURG **PERIOD:** 1979-1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 990 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 30 - 95 °C
8. Price : UA/m^3

Properties at temperature : 5 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 10000 m^3
   shape : truncated pyramid
   position: above/below/partly below ground level
2. Total heat capacity : 41800 MJ/K
3. Containment present : YES/~~NO~~
   material : asphalt concrete
4. Insulation present : YES/~~NO~~
   position insulation : roof
   material : foamglass
   total volume insulation material: 1458 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 23 family houses

1. Heat consumption system: space heating/domestic hot water/[✓ both]
   space heat load* : 65782 MJ
   hot water load* : 11609 MJ
   total load* : 77391 MJ
   total system load* : 1.78 10^6 MJ

* per heat consumer per year.

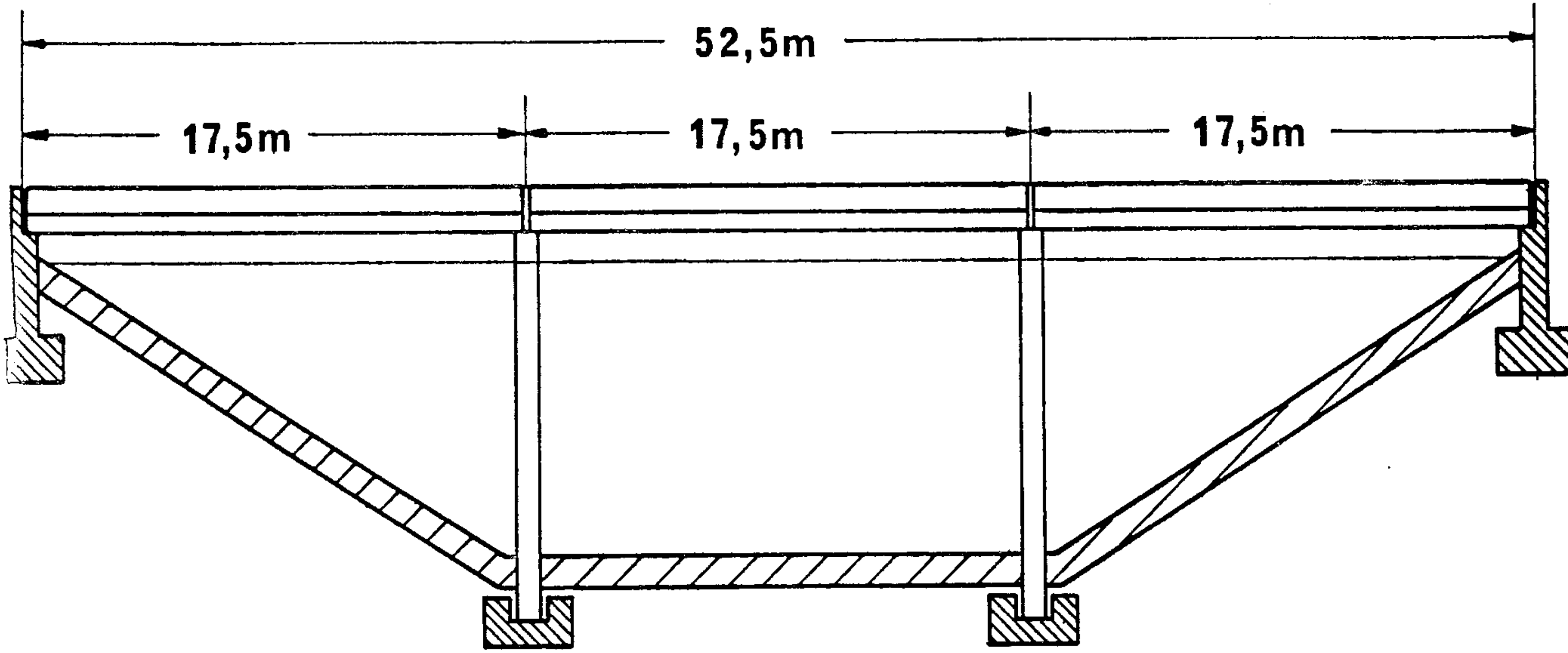


Figure 25: Wolfsburg/Cross section through the pit

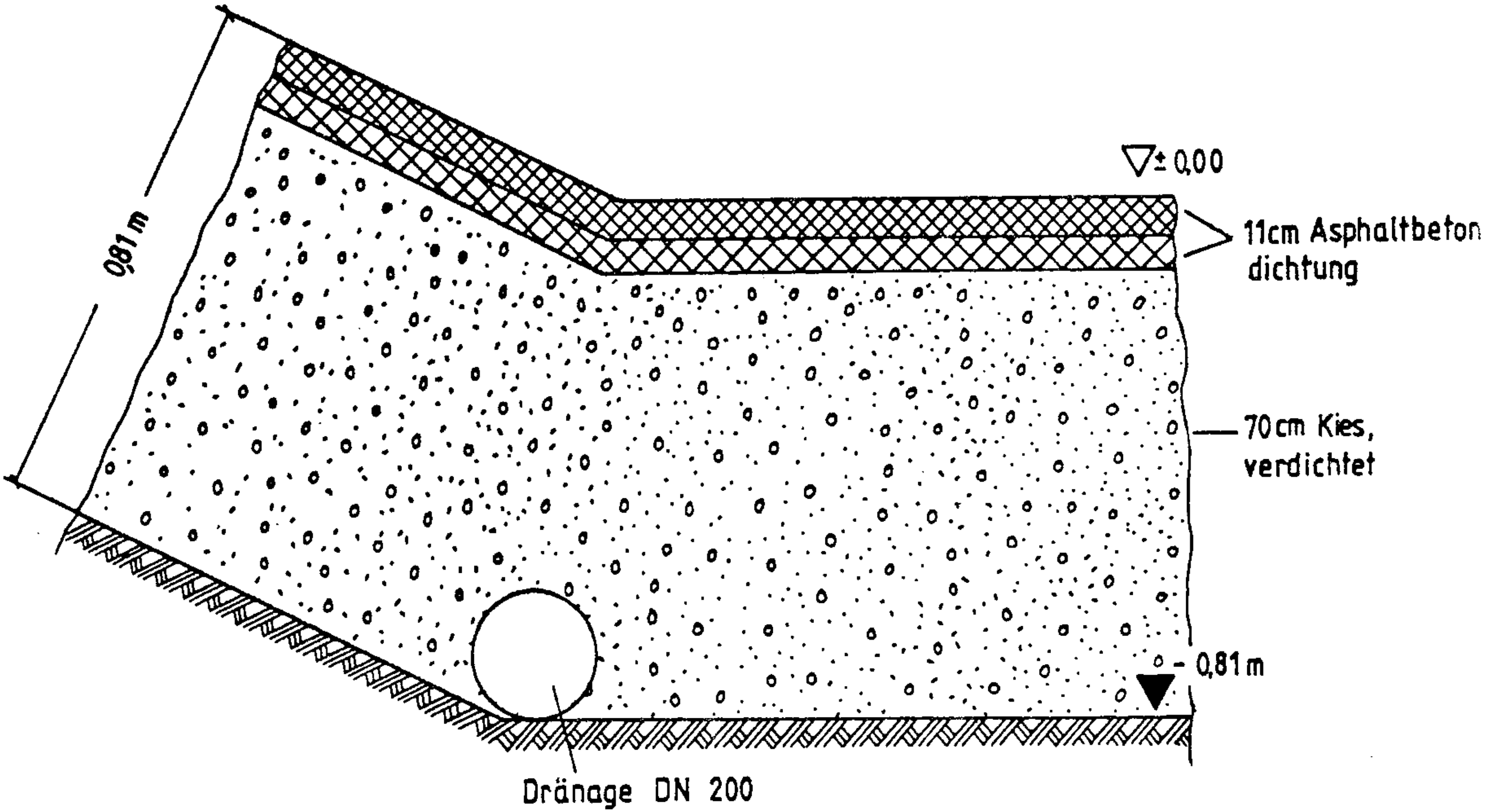


Figure 26: Wolfsburg/Detail of the side and bottom containment

REFERENCES

/16, 17, 18, 19/

CONTACT:

Dr. W. BREUER
Stadtwerke Wolfsburg AG
Postfach 100 954
D - 3180 WOLFSBURG 1

SUMMARY SHEET: SEASONAL HEAT STORAGE PIT/3

RESEARCH WORK

TITLE: HOT WATER STORING PROJECT MANNHEIM **PERIOD:** 1977-1979

MAIN SUBJECTS OF RESEARCH: The reservoir was designed for a system with a cogneration plant

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : ~~YES~~/NO - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 1000 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : _ m^2
7. Operating temperature interval: 50 - 90 °C
8. Price : 0.7 DM ~~UA~~/m^3

Properties at temperature : 70 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 30'000 m^3
   shape : rectangular or cylindrical
   position: ~~above~~/~~below~~/partly below ground level
2. Total heat capacity : 126'000 MJ/K
3. Containment present : YES/~~NO~~
   material : concrete + plastic sheets
4. Insulation present : YES/~~NO~~
   position insulation : all around
   material : faomglass
   total volume insulation material: 1500 m^3
5. Heat exchanger present : ~~YES~~/NO
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./~~exp~~.): ~ 65 (%)

COST (incl. cost * for labour)** (in DM 1978)

Storage	0.02 10^6	UA
Containment	5.8 10^6	UA
Insulation		UA
Heat exchanger		UA
Miscellaneous	1.65 10^6	UA+
Total system	7.47 10^6	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system:

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.

*** not realistic according to 1982 state of knowledge

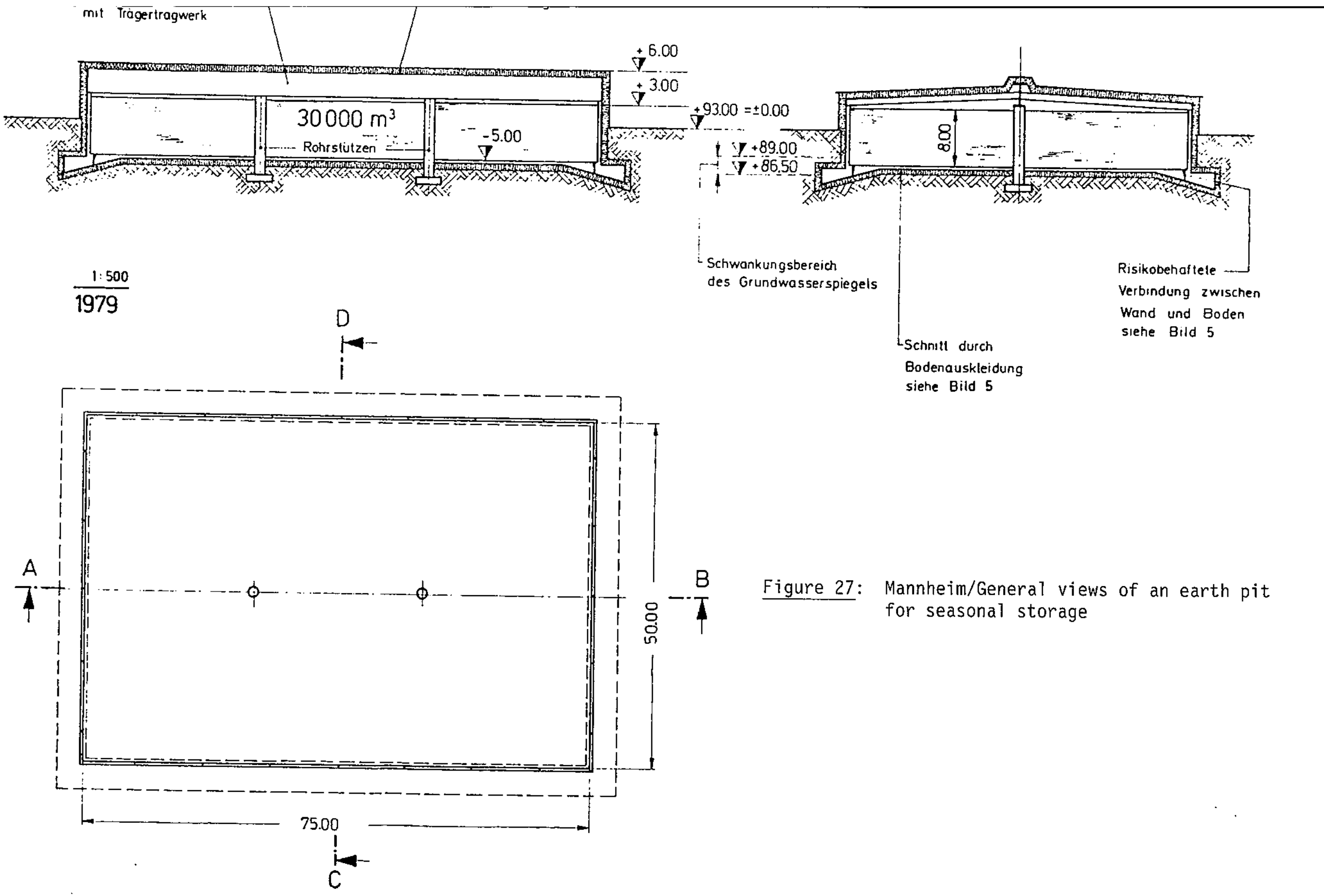


Figure 27: Mannheim/General views of an earth pit for seasonal storage

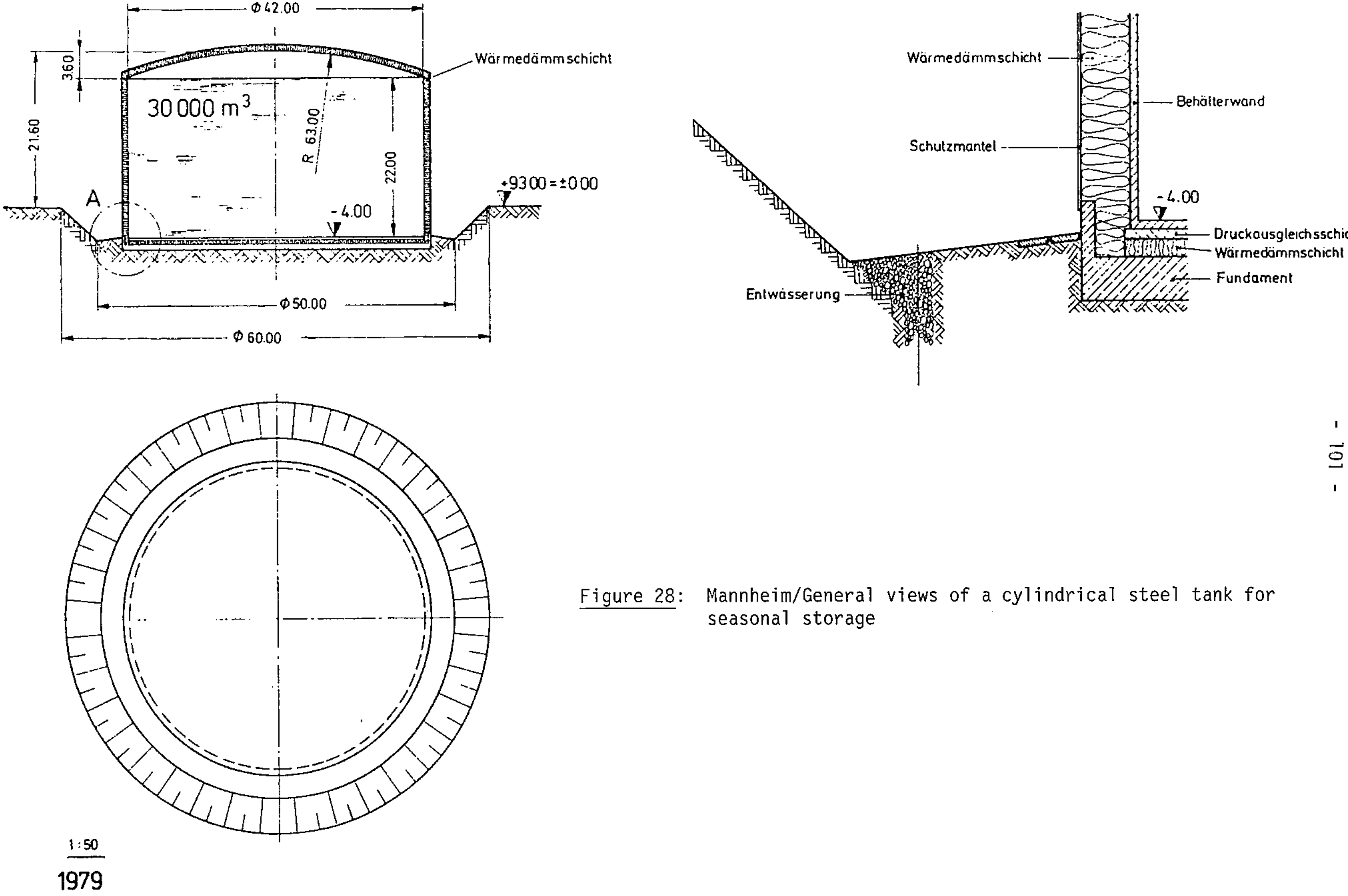


Figure 28: Mannheim/General views of a cylindrical steel tank for seasonal storage

REFERENCES

/20, 21, 22/

CONTACT

W. GEIPEL
c/o Stadtwerke Mannheim AG
Luisenring 49
D - 6800 MANNHEIM

SUMMARY SHEET: SEASONAL HEAT STORAGE PIT/4

RESEARCH WORK

TITLE: INTERSEASONAL SOLAR SPACE HEATING **PERIOD:** 1976-

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 1000 kg/m^3
3. Specific heat : 4180 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 25 - 65 °C (45°C in practice)
8. Price : 50 UA/m^3 (1976 excluding labour)

Properties at temperature : °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 95 m^3

   shape  : rectangular

   position: above/below/partly below ground level
2. Total heat capacity : 400 MJ/K
3. Containment present : YES/~~NO~~

   material : butyl rubber
4. Insulation present : YES/~~NO~~

   position insulation : all around

   material : polystyrene block with polyisocyanurate foam in gaps

   total volume insulation material: m^3
5. Heat exchanger present : ~~YES~~/NO

   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour) 1 UA = £ 0.50

Storage UA

Containment UA

Insulation UA

Heat exchanger UA

Miscellaneous UA+

Total system UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1 building (180 m2)

1. Heat consumption system: space heating/domestic hot water/both

   space heat load* : MJ

   hot water load* : MJ

   total load* : MJ

   total system load* : 49000 MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 100 m^2 / x m^2

- type : flat plate, double glazing, trickle type

Short term heat storage: central/~~distributed/not prese~~

- storage volume : 2 m^3 / x m^3

- storage material : water

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m

- heat loss rate : W/K.m$_{\text{piping}}$

Total cost : UA

5. Auxiliary heating: central/distributed/not prese

- type : wood burning stove

- power installed : 6 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : 0.1+0.1+0.25 kW

Total power installed : 0.45 kW

7. Total cost

- solar heating system : 10'000 UA

- conventional heating system : 500 UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)

- number of degree days : ; temperature below °C

1. Total system load : 49'000 MJ

2. Total solar contribution : 34'300 MJ (70 % of load) (estimated)

idem per m^2 collector : MJ (kWh/m^2)

3. Total auxiliary heating : MJ

4. Total electricity consumption : ~ 700 kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ____________ -

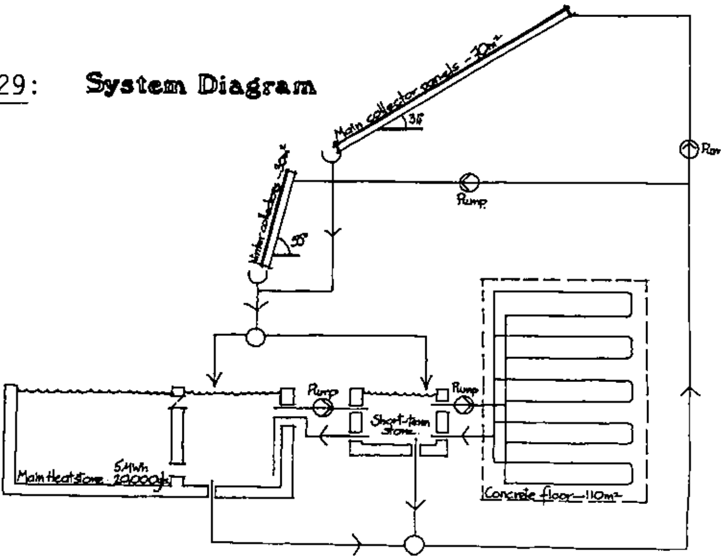
Primary energy saved :

<u>Resumé:</u>

Primary energy saved:

Extra system cost : UA

Figure 29: **System Diagram**



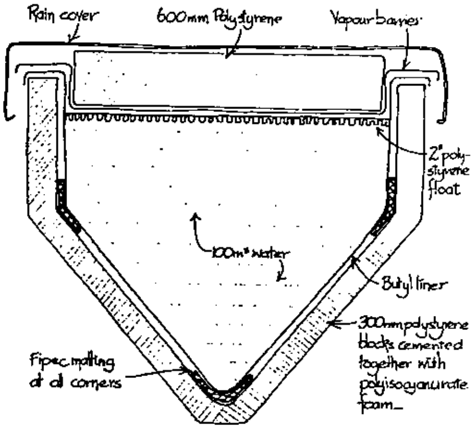


Figure 30: UK/**Cross-section through heat-store**

REFERENCES

/23, 24/

CONTACT

Dr. R.W. TODD
Centre for Alternative Technology
Llwyngwern Quarry
Machynlleth
Powys
Wales

SUMMARY SHEET: SEASONAL HEAT STORAGE

PIT/5

RESEARCH WORK

TITLE: SOLAR HEATING PLANT AT STUDSVIK

PERIOD: operating since 1979

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - ~~theoretical/experimental~~
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : _ m^2
7. Operating temperature interval: 30 - 70 °C
8. Price : UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 640 m^3
   shape : truncated cone
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 2670 MJ/K
3. Containment present : YES/~~NO~~
   material : earth + rubber liner
4. Insulation present : YES/~~NO~~
   position insulation : all around
   material : polyurethane + mineral wool
   total volume insulation material: 80 + 130 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (~~theor.~~/exp.): /50 (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1 office building (air system)

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : 81'000 MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~ on top of the store

- collector area : 120 m^2 / x m^2

- type : CPC rotating, tilt 25°

Short term heat storage: central/distributed/not prese

- storage volume : m^3 / x m^3

- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : 20 m

- heat loss rate : $W/K.m_{piping}$

Total cost : UA

5. Auxiliary heating: central/distributed/not prese

- type :

- power installed : kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)

- number of degree days : ; temperature below °C

1. Total system load : 81'000 MJ

2. Total solar contribution : MJ (% of load)

idem per m^2 collector : 1'100 MJ (300 kWh/m^2)

3. Total auxiliary heating : MJ

4. Total electricity consumption : 250 kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ____________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

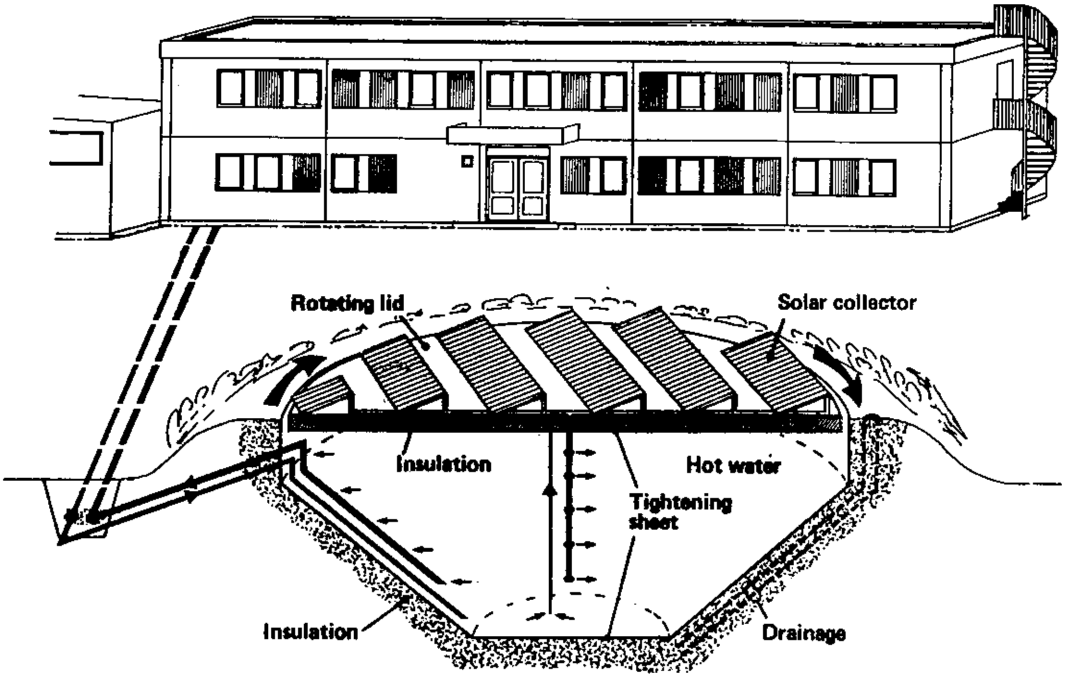


Figure 31: Studsvik pit/Sketch of the pilot plant and office building

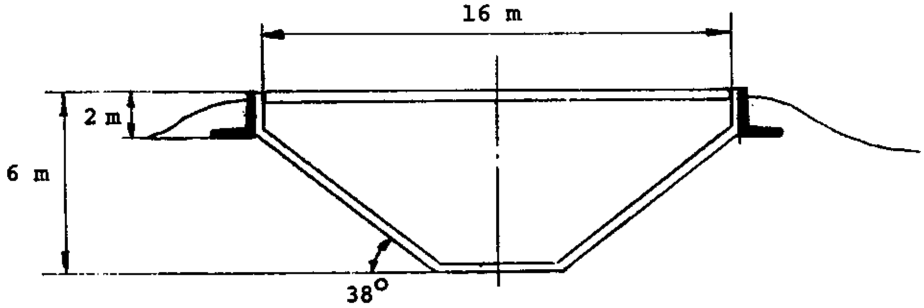


Figure 32: Studsvik pit/Heat store shape and dimensions

REFERENCES

/3, 4, 5, 77/

CONTACT

P. MARGEN
Studsvik Energiteknik AB
S - 611 82 NYKÖPING

5.3. Rock cavern storage

5.3.1. The Avesta project (Sweden)

5.3.2. The Lyckebo project (Sweden)

5.3.3. Seasonal storage of heat from lakes in an abandoned mine at Kopparberg (Sweden)

SUMMARY SHEET: SEASONAL HEAT STORAGE CAVERN/1

RESEARCH WORK

TITLE: THE AVESTA PROJECT

PERIOD: operating since 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - ~~theoretical/experimental~~
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 70 - 115 °C
8. Price : UA/m^3

Properties at temperature : °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 15'000 m^3
   shape : tunnel section
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 6.3 10^4 MJ/K
3. Containment present : YES/NO
   material :
4. Insulation present : YES/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	13 MSEK ~~UA~~

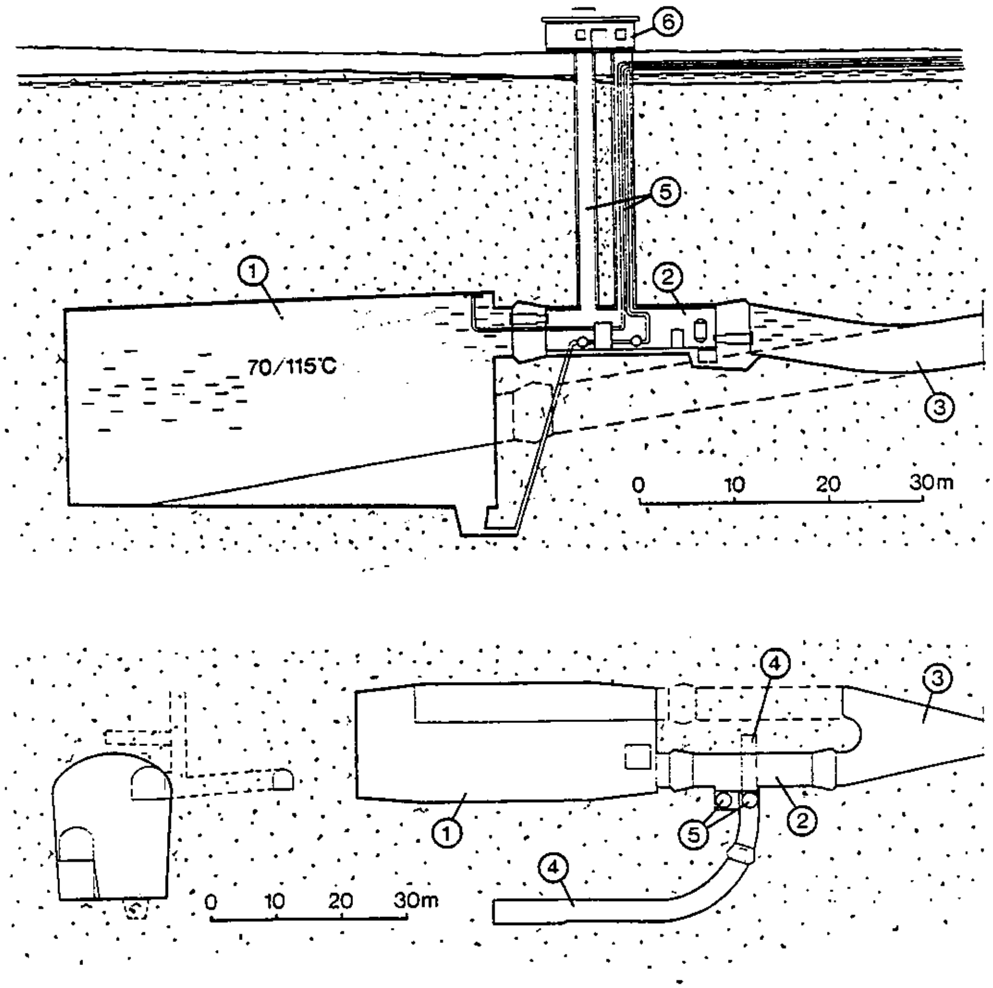
TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: District heating system

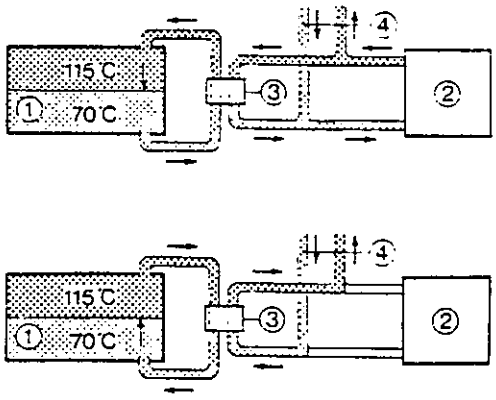
1. Heat consumption system: space heating/domestic hot water/[✓ both] 11 MW
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.



1 = Storage cavern; 2 = Machine room; 3 = Transport tunnel;
4 = Research tunnel; 5 = Access shaft; 6 = Entrance building

Figure 33: Avesta/Layout ofthe test plant



Surplus heat from the heating plant is used for loading the storage.

Heating plant out of operation. Unloading of the storage cavern.

1 = Storage cavern; 2 = Heating plant; 3 = Heat exchanger;
4 = District heating network.

Figure 34: Avesta/Principles for normal operation of the heat storage

REFERENCES: /25, 26/

CONTACT: P.O. KARLSSON
Swedish State Power Board
S - 162 87 VÄLLINGBY (Stoc

SUMMARY SHEET: SEASONAL HEAT STORAGE CAVERN/2

RESEARCH WORK

TITLE: THE LYCKEBO PROJECT

PERIOD: under constructio
1982-1983

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - ~~theoretical/experimental~~
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : ~~YES~~/NO - theoretical/experimental

STORAGE MATERIAL

1. Material : water
2. Density : 998 kg/m^3
3. Specific heat : 4190 J/kg K
4. Mean heat capacity : 4.1 MJ/m^3 K (1 x water)
5. Thermal conductivity : 0.6 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 40 - 90 °C
8. Price : 150 SEK ~~UA~~/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 100'000 m^3 + surrounding rock
   shape :
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : MJ/K
3. Containment present : ~~YES~~/NO
   material :
4. Insulation present : ~~YES~~/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./~~exp.~~): ∼ 80/ (%)
   (steady state)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	14.5 MSEK ~~UA~~

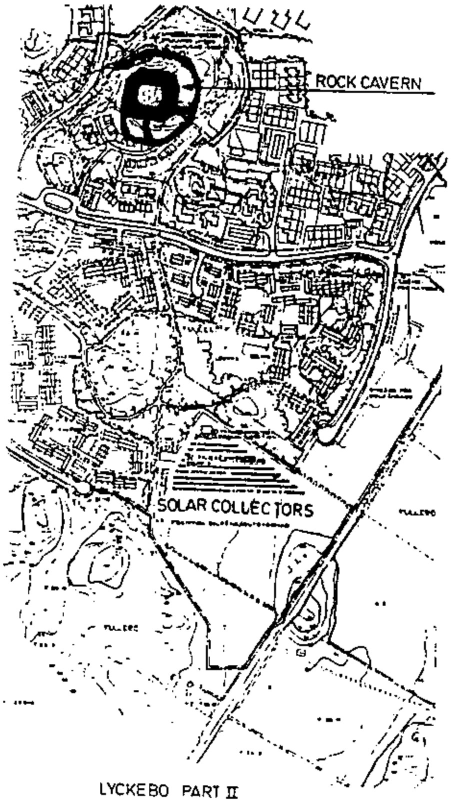
TOTAL SYSTEM

DATA OF TOTAL SYSTEM

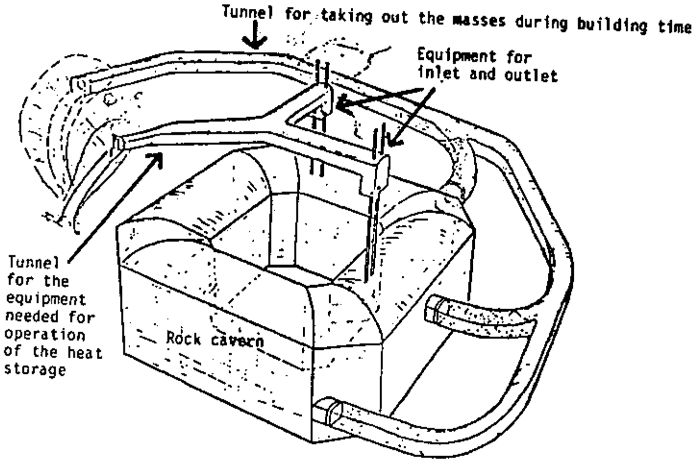
The number of heat consumers in the entire system: 550 dwellings

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 13.4 10^6 MJ
   hot water load* : 6.4 10^6 MJ
   total load* : MJ
   total system load* : 2.0 10^7 MJ (+ network losses)

* ~~per heat consumer~~ per year.



LYCKEBO PART II



Height: 30 m
Width : 18 m
Outer diameter: 75

Figure 35: Lyckebo/Three-dimensional sketch of the rock cavern

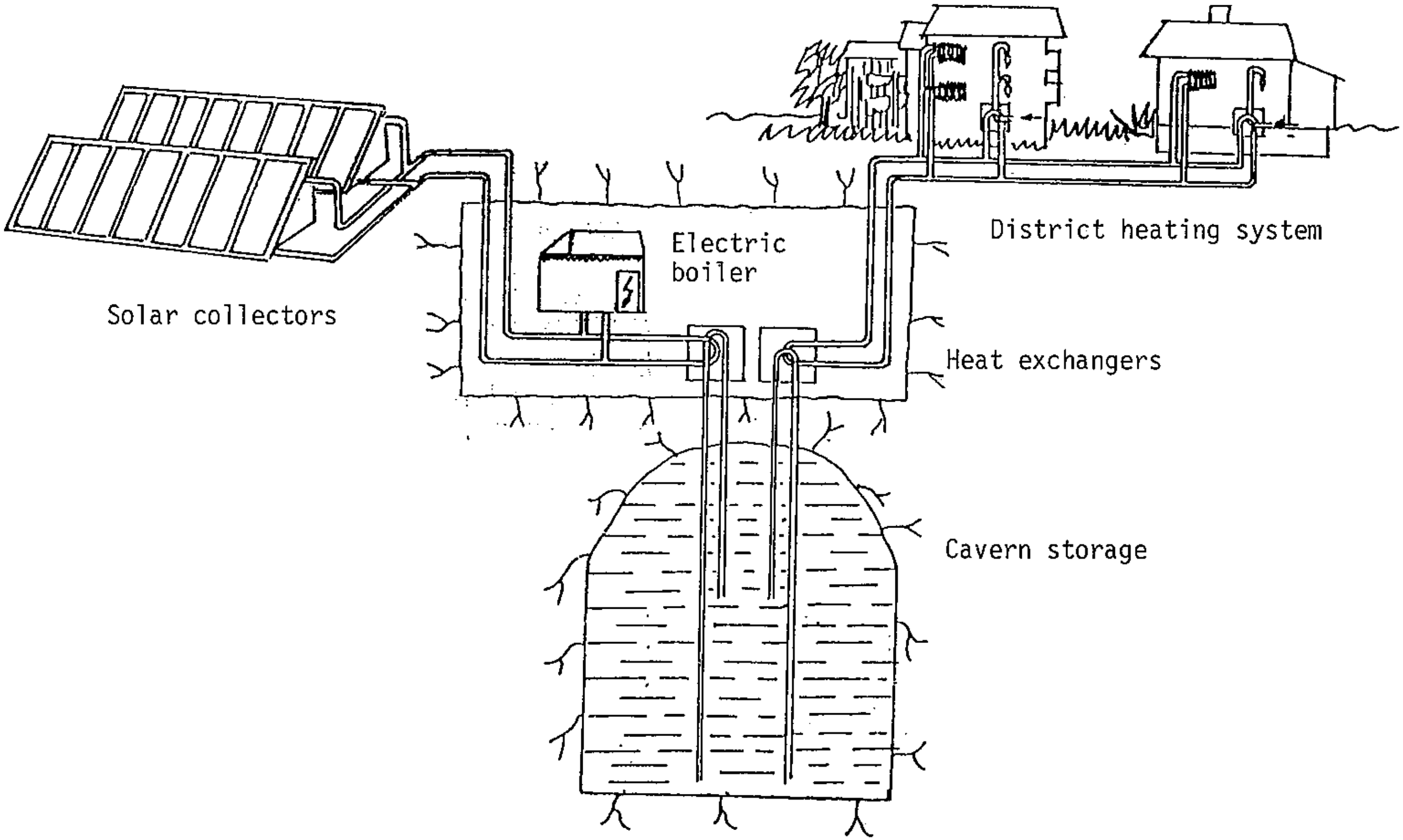


Figure 36: Lyckebo/System diagram

REFERENCE

/27/

CONTACT

1) I. WALLANDER
Uppsala Kraftvärme AB
Box 125
S - 751 04 UPPSALA

2) H. PILEBRO
Skanska (Turn-key projector)
S - 182 25 DANDERYD

SUMMARY SHEET: SEASONAL HEAT STORAGE CAVERN/3

RESEARCH WORK

TITLE: SEASONAL STORAGE OF HEAT FROM LAKES IN AN ABANDONED MINE AT KOPPARBERG **PERIOD:** 1982

MAIN SUBJECTS OF RESEARCH:

- **storage material:** YES/~~NO~~ - ~~theoretical~~/~~experimental~~
- **storage system :** YES/~~NO~~ - ~~theoretical~~/~~experimental~~
- **total system :** YES/~~NO~~ - ~~theoretical~~/~~experimental~~

STORAGE MATERIAL

1. Material : water
2. Density : 998 **kg/m³**
3. Specific heat : 4190 **J/kg K**
4. Mean heat capacity : 4.1 **MJ/m³ K (1 x water)**
5. Thermal conductivity : 0.6 **W/m K**
6. Permeability : – **m²**
7. Operating temperature interval: 5 - 50 **°C**
8. Price : **UA/m³**
Properties at temperature : 20 **°C**

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 150'000 **m³**
shape :
position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : **MJ/K**
3. Containment present : **YES/NO**
material :
4. Insulation present : **YES/NO**
position insulation :
material :
total volume insulation material: **m³**
5. Heat exchanger present : **YES/NO**
heat exchange rate (theor./exp.): **W/K**
6. Annual performance (theor./~~exp.~~): 50/ **(%)**

COST (incl. cost for labour)

Storage (existing mine) **UA**
Containment **UA**
Insulation **UA**
Heat exchanger **UA**
Miscellaneous **UA+**
Total system 0.5 MSEK ~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: District heating
1. Heat consumption system: space heating/domestic hot water/both
space heat load* : **MJ**
hot water load* : **MJ**
total load* : **MJ**
total system load* : **MJ**

*** per heat consumer per year.**

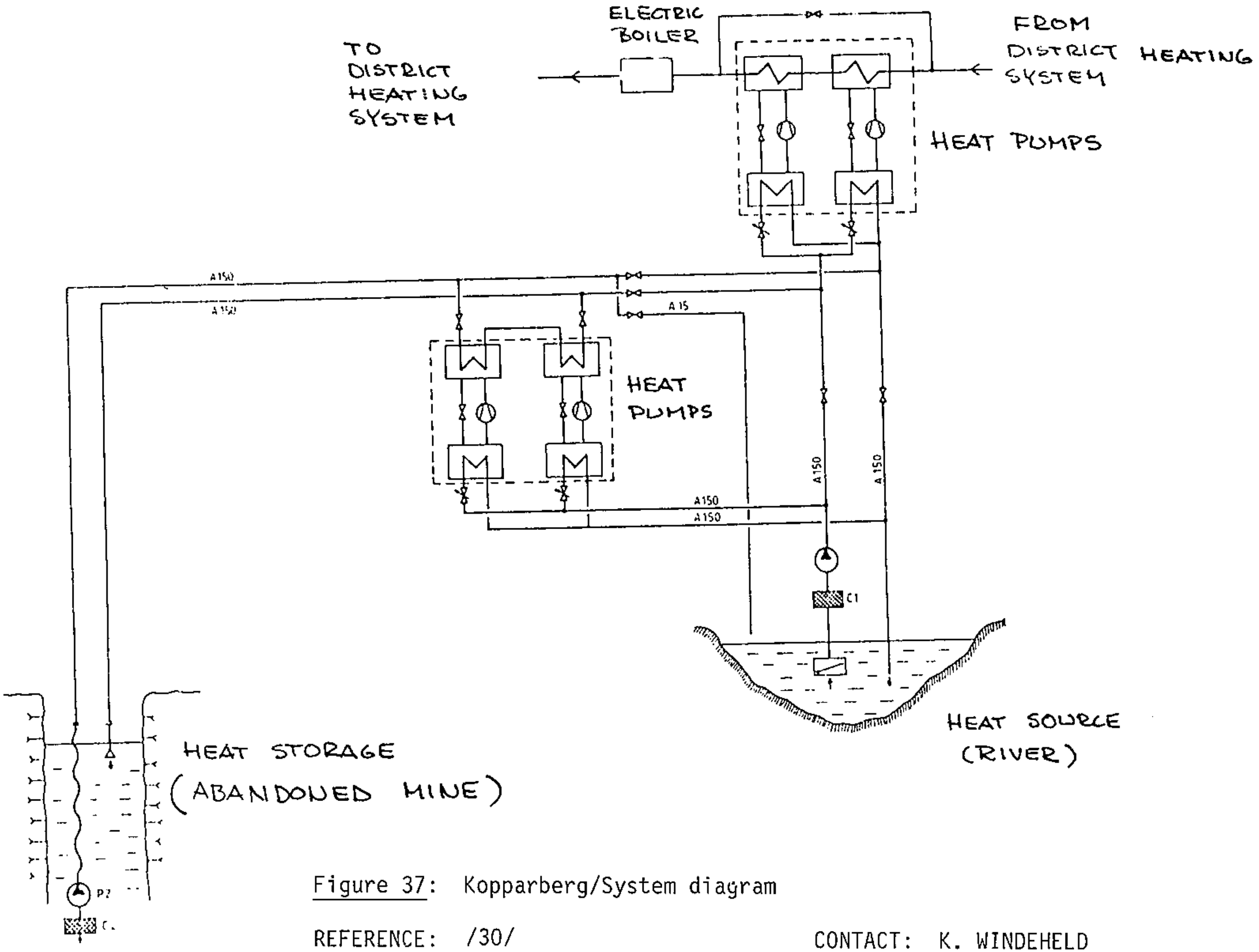


Figure 37: Kopparberg/System diagram

REFERENCE: /30/

CONTACT: K. WINDEHELD
Hagkonsult AG
Box 1214
S - 181 23 LIDINGÖ

5.4. Aquifer storage

5.4.1. Aquifer heat storage plant - Artificial aquifer (Germany)

5.4.2. SPEOS project (Switzerland)

5.4.3. St. Paul Minnesota, USA field test facility (USA)

5.4.4. Scarborough GOCB - Hot/cold aquifer thermal energy storage (Canada)

5.4.5. Tranås aquifer thermal energy storage (Sweden)

5.4.6. Klippan aquifer thermal energy storage (Sweden)

SUMMARY SHEET: SEASONAL HEAT STORAGE AQUIFER/1

RESEARCH WORK

TITLE: AQUIFER HEAT STORAGE PLANT - ARTIFICIAL AQUIFER **PERIOD:**

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : ~~YES~~/NO - ~~theoretical/experimental~~

STORAGE MATERIAL

1. Material : processed gravel (porosity ~ 30%)
2. Density : 2200 kg/m^3
3. Specific heat : 800 J/kg K
4. Mean heat capacity : 1.76 MJ/m^3 K (0.4 x water)
5. Thermal conductivity : 2.7 W/m K
6. Permeability : 10^{-2} m/s ~~m^2~~
7. Operating temperature interval: 5 - 80 °C
8. Price : UA/m^3

Properties at temperature : °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 15000 m^3
   shape : flat trough
   position: ~~above~~/below/~~partially below~~ ground level
2. Total heat capacity : 40'000 MJ/K
3. Containment present : YES/~~NO~~
   material : bentonite walls
4. Insulation present : YES/~~NO~~
   position insulation : top
   material : dry gravel + asphalt
   total volume insulation material: m^3
5. Heat exchanger present : radiant drains YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system:

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.

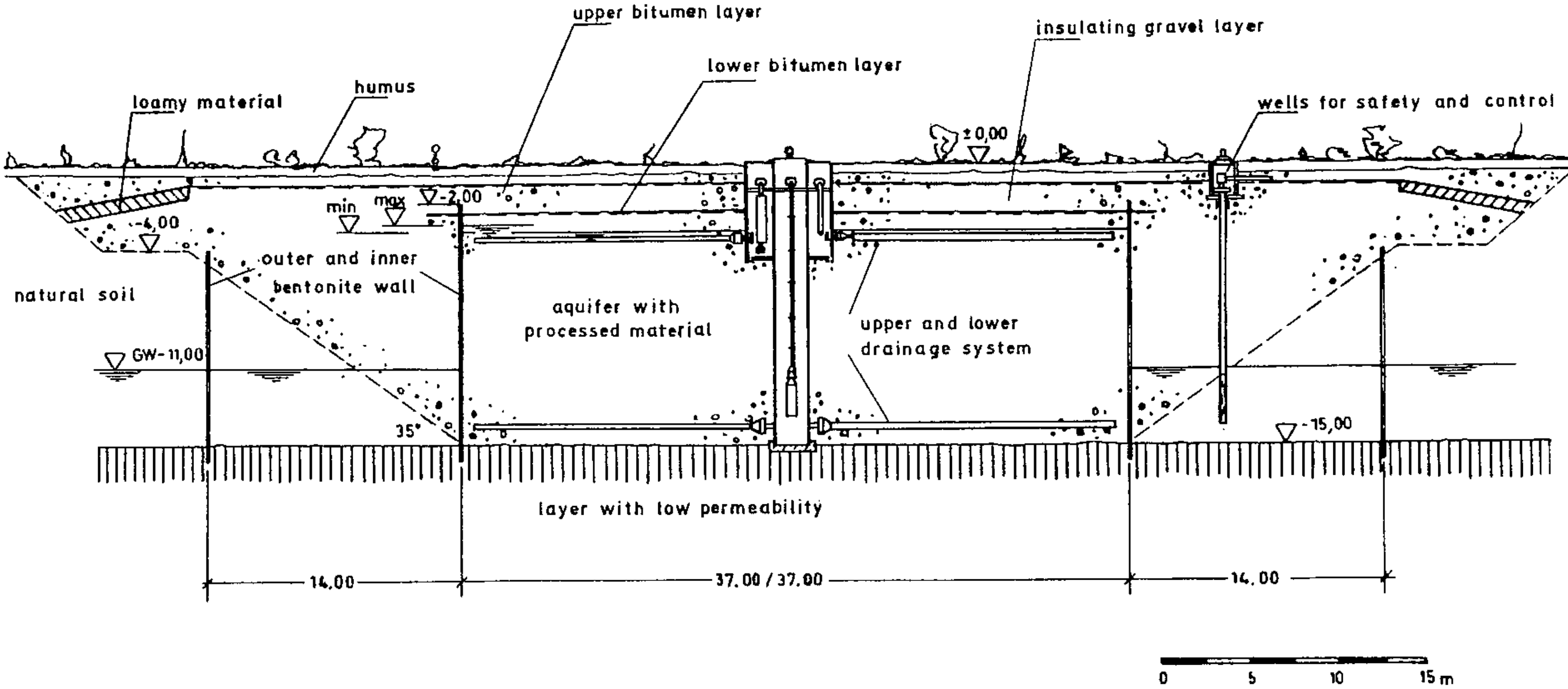


Figure 38: Artificial aquifer storage unit

REFERENCES: /31, 32/

CONTACT: Dr. B. WEISSENBACH
Messerschmidt-Bölkow-Blohm GmbH
Dpt. RT 321
Postfach 801169
D - 8000 MÜNCHEN 80

SUMMARY SHEET: SEASONAL HEAT STORAGE AQUIFER/2

RESEARCH WORK

TITLE: SPEOS PROJECT

PERIOD: operating since June 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : ~~YES~~/NO - ~~theoretical/experimental~~

STORAGE MATERIAL

1. Material	: saturated silt + sand	
2. Density	: ~ 1900	kg/m^3
3. Specific heat	: ~ 1300	J/kg K
4. Mean heat capacity	: ~ 2.5	MJ/m^3 K (0.5 x water)
5. Thermal conductivity	: 1 to 2.5	W/m K
6. Permeability	: 10^{-14} to 10^{-15}	m^2 (vertical)
7. Operating temperature interval	: 25 - 80	°C
8. Price	:	UA/m^3
Properties at temperature	: 20	°C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE			COST (incl. cost for labour) 1 UA = 1 US$ 1981	
1. Storage volume	: 60'000	m^3	Storage	UA
shape (delimited volume)	: cylindrical Ø 45 m h = 19 m		well and drains	250'000
position: ~~above~~/below/~~partially below~~ ground level				
2. Total heat capacity	: 150'000	MJ/K		
3. Containment present	:	~~YES~~/NO	Containment	UA
material	:			
4. Insulation present	:	~~YES~~/NO	Insulation	UA
position insulation	:			
material	: (6 m of earth on top)			
total volume insulation material:		m^3		
5. Heat exchanger present	: radiant drains	YES/~~NO~~	Heat exchanger	10'000 UA
heat exchange rate (theor./~~exp.~~):	17'000	W/K	Miscellaneous	240'000 UA+
6. Annual performance (theor./exp.): (first cycle)	35 / 40	(%)	Total system	500'000 UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: Pilot storage till 1984

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : MJ

hot water load* : MJ

total load* : MJ

total system load* : MJ

* per heat consumer per year.

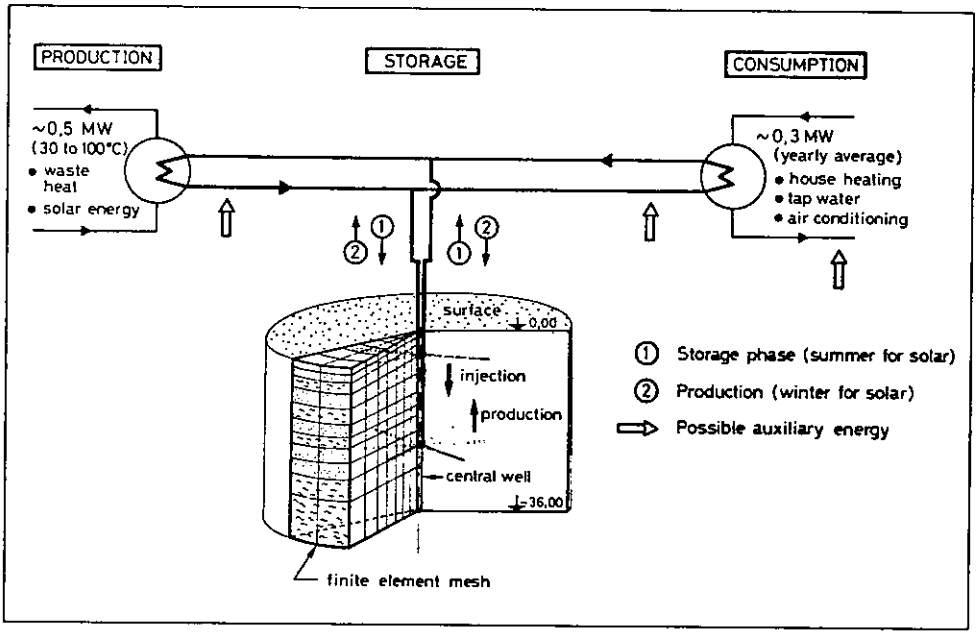


Figure 39: SPEOS/Storage concept

REFERENCES:

/33, 34, 35/

CONTACT:

Dr. G. SAUGY
Institut d'économie et aménagement énergétiques
Swiss Federal Institute of Technology
EPFL-Ecublens
CH - 1015 LAUSANNE

Prof. A. BURGER
Centre of Hydrogeology of the University of Neuchâtel
11, rue E. Argand
CH - 2000 NEUCHATEL 7

SUMMARY SHEET: SEASONAL HEAT STORAGE AQUIFER/3

RESEARCH WORK

TITLE: St. Paul, Minnesota, U.S.A. Field Test Facility PERIOD: 1980-Continuinc

MAIN SUBJECTS OF RESEARCH: Aquifer Thermal Energy Storage

- storage material: YES/~~NO~~ - ~~theoretical~~/experimental
- storage system : YES/~~NO~~ - ~~theoretical~~/experimental
- total system : YES/~~NO~~ - ~~theoretical~~/experimental

STORAGE MATERIAL

1. Material : Sandstone Aquifer
2. Density : 2162 kg/m^3
3. Specific heat : 837 J/kg K
4. Mean heat capacity : 1.81 MJ/m^3 K (x water)
5. Thermal conductivity : 2.52 W/m K
6. Permeability : 3.42×10^{-12} m^2
7. Operating temperature interval: 100 - 150 °C
8. Price : N/A UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 7.36×10^5 m^3
   shape : Cylindrical
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 1.33×10^6 MJ/K
3. Containment present : Confined aquifer YES/NO
   material :
4. Insulation present : ~~YES~~/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./~~exp.~~): > 5 MW XX/XX
6. Annual performance (theor./~~exp.~~): 50 - 80 (%)

COST (incl. cost for labour)

Storage UA

Containment UA

Insulation UA

Heat exchanger UA

Miscellaneous UA+

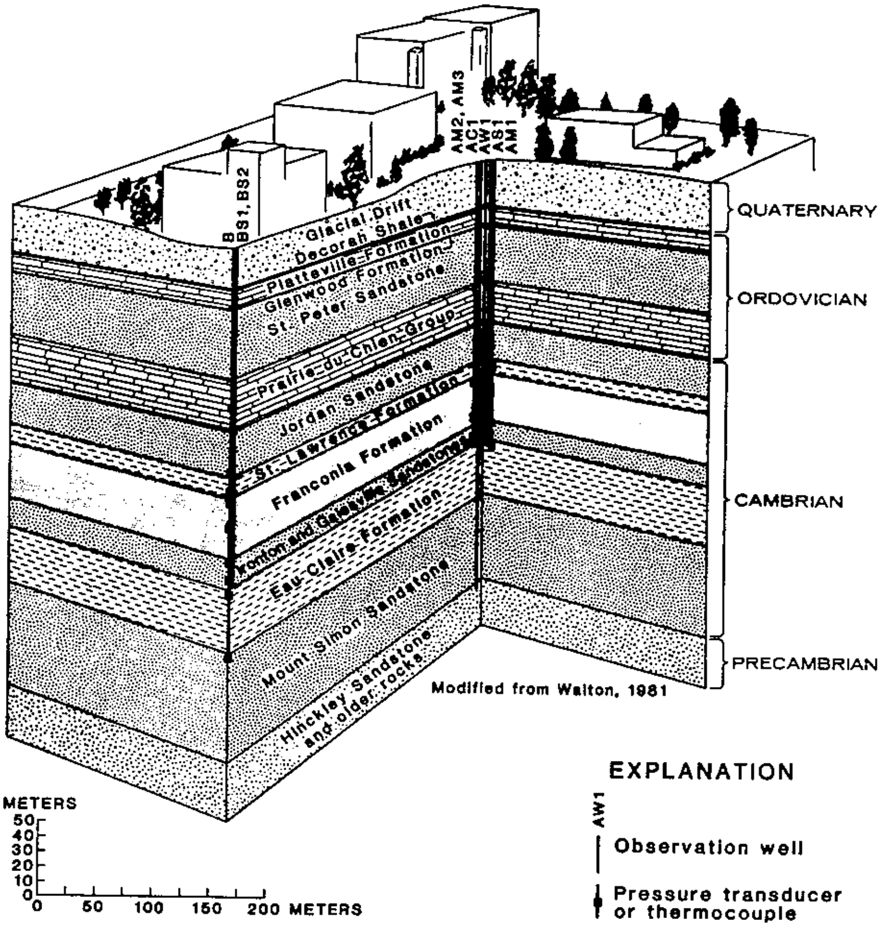
Total system ~$$1.5 \times 10^6$ UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: None - field test facility

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ



Modified from Walton, 1981

Figure 40: St Paul/Block diagram of the ATES site, University of Minnes

REFERENCE:

/63/

CONTACT:

J.R. RAYMOND
Underground Energy Storage Program
Battelle
Pacific Northwest Laboratory
P.O. Box 999
RICHLAND, Washington 99352
USA

SUMMARY SHEET: SEASONAL HEAT STORAGE AQUIFER/4

RESEARCH WORK

TITLE: SCARBOROUGH G.O.C.B.
Hot/Cold aquifer thermal energy storage

PERIOD: construction
start Feb. 1983

MAIN SUBJECTS OF RESEARCH:
Interaction of building energy requirement with aquifer energy storage and integration of aquifer thermal energy storage into modern building design

- **storage material:** ~~YES~~/NO - ~~theoretical/experimental~~
- **storage system :** YES/~~NO~~ - **theoretical/experimental**
- **total system :** YES/~~NO~~ - **theoretical/experimental**

STORAGE MATERIAL

1. Material : aquifer - sand, gravel, water (porosity 28%)
2. Density : 2670 **kg/m^3**
3. Specific heat : **J/kg K**
4. Mean heat capacity : 2.03 **MJ/m^3 K (x water)**
5. Thermal conductivity : 1.56 **W/m K**
6. Permeability : 2.72 10^4 **m/s** transmissivity 200 m2/day
7. Operating temperature interval: 4 - 50 **°C** storage coefficient 2.3 10^{-4}
8. Price : **UA/m^3** thickness ~ 10 m
Properties at temperature : **°C**

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume for one doublet : 530'000 **m^3**
~~**shape**~~ distances between wells : 130 m and 65 m
position: ~~**above**~~**/below/**~~**partly below**~~ **ground level**
2. Total heat capacity : **MJ/K**
3. Containment present : aquitard clay **YES/**~~**NO**~~
material : 1.71 W/mK
4. Insulation present : 10 m thickness **YES/NO**
position insulation : above and below aquifer
material : clay
total volume insulation material: **m^3**
5. Heat exchanger present : **YES/**~~**NO**~~
heat exchange rate (theor./exp.): **W/K**
6. Annual performance (theor./exp.): **(%)**

COST (incl. cost for labour)

Storage $ 200'000 **UA**
CDN$ 1983 (2 cold wells 60 m deep)
$ 20'000 (2 hot wells 40 m deep

Containment **UA**

Insulation no cost **UA**

150'000 $ cold
100'000 $ hot
Heat exchanger **UA**
Miscellaneous **UA+**
Total system **UA**

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1 building

1. Heat consumption system: space heating/domestic hot water/ + cooling

space heat load* : 1 TJ ~~**MJ**~~
cooling load : 10 TJ
hot water load* : 0.4 TJ ~~**MJ**~~
total load* : **MJ**
total system load* : 11.4 TJ ~~**MJ**~~

*** per heat consumer per year.**

2. Solar heat collecting system :

Solar collectors : 750 central/~~distributed~~

- collector area : m^2 / x m^2

- type : evacuated tube, roof

Short term heat storage: central/~~distributed/not pres~~

- storage volume : 600 m^3 / x m^3

- storage material : water hot in winter, cold in summer

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA $ 200'000

4. Heat transfer piping network :

- total length : m

- heat loss rate : $W/K.m_{piping}$

Total cost : UA

5. Auxiliary heating: central/~~distributed/not prese~~

- type : electric heat pump + resistance heating

- power installed : 514 kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : 216 kW lights 21 W/m2

Total power installed : kW fans 487 kW

7. Total cost CDN$ 1983 550/m3 ⟶ $ 385'000

- solar heating system : UA

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/~~EXPERIMENTAL~~

Results are given for this location TORONTO - Ontario

Latitude: 43°47'N Longitude: 79°15'W

Climatological data for location :

- global irradiation : 5019 MJ/m^2 (1390 kWh/m^2)

- number of degree days : 4000 ; temperature below 18 °C

1. Total system load : MJ

2. Total solar contribution : $2.2\ 10^6$ MJ (~~% of load~~)

idem per m^2 collector : 3000 MJ (833 kWh/m^2)

3. Total auxiliary heating : MJ

4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price: $ 0.05/kWh

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ____________ -

Primary energy saved : 3 GWh

Resumé:

Primary energy saved: 3 GWh ⟹ $ 150'000 CDN 1983 annual saving

Extra system cost : $ 350'000 UA

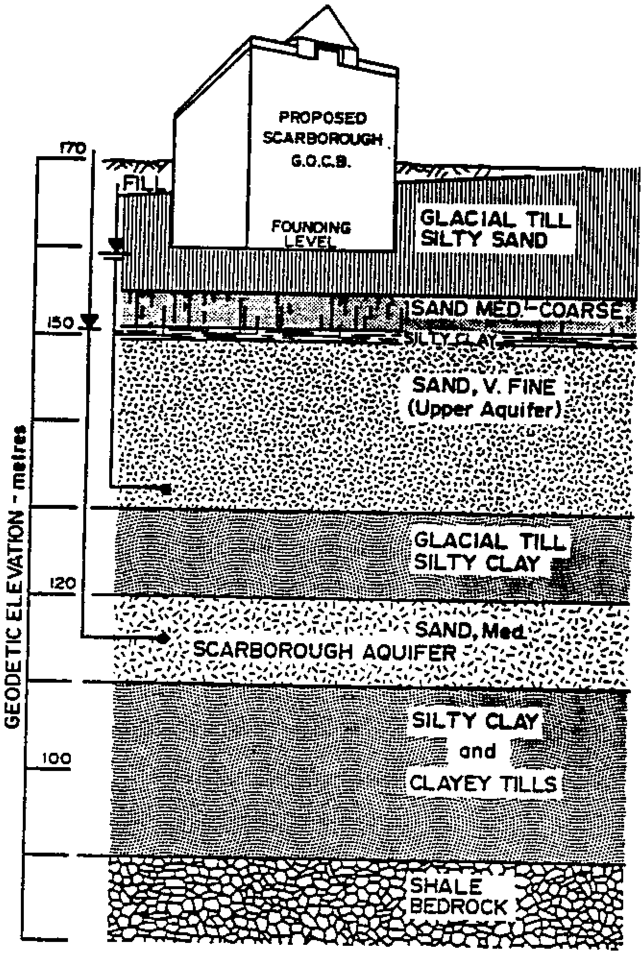


Figure 41: Scarborough/Site stratigraphy

REFERENCES

/56, 58/

CONTACT:

E.L. MOROFSKY
Public Works Canada
Energy Technology
Sir Charles Tupper Building C 456
OTTAWA, Ontario K1A 0M2
Canada

RESEARCH WORK

TITLE: TRANÅS AQUIFER THERMAL ENERGY STORAGE PERIOD: 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - ~~[illegible]~~
- storage system : YES/~~NO~~ - ~~[illegible]~~
- total system : YES/~~NO~~ - ~~[illegible]~~

STORAGE MATERIAL

1. Material : sandy gravel on bedrock
2. Density : 2200 kg/m^3 (saturated soil)
3. Specific heat : 1700 J/kg K
4. Mean heat capacity : 3.7 MJ/m^3 K (x water)
5. Thermal conductivity : 2.7 W/m K
6. Permeability : 10^{-10} m^2
7. Operating temperature interval: 5 - 18 °C
8. Price : 10 SEK UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE	COST (incl. cost for labour)
1. Storage volume : 1.6 10^6 m^3	Storage 4.4 MSEK UA
shape : about 250 x 650 x 10	
position: ~~above~~/below~~/partly below~~ ground level	
2. Total heat capacity : 6 10^6 MJ/K	
3. Containment present : ~~YES~~/NO	Containment UA
material :	
4. Insulation present : ~~YES~~/NO	Insulation UA
position insulation :	
material :	
total volume insulation material: m^3	
5. Heat exchanger present : YES/~~NO~~	Heat exchanger 1.2 MSEK~~UA~~
heat exchange rate (theor./exp.): W/K	Miscellaneous 4.0 MSEK~~UA~~
6. Annual performance (theor./~~exp.~~): ~ 60/- (%)	Total system 9.6 MSEK~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: The entire system is a part of a district heating system with 6000 dwellings

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : MJ

hot water load* : MJ

total load* : MJ

total system load* : MJ

* per heat consumer per year.

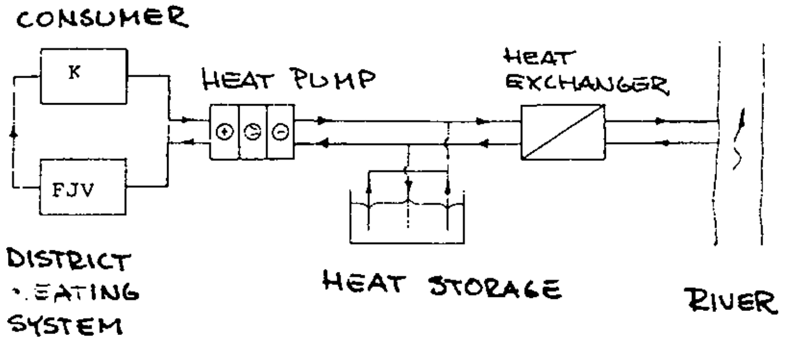


Figure 42: TRANÅS/Principal sketch of the system at injection phase (summer)

REFERENCE

/37/

CONTACT:

H. HYDEN
VBB AB
Box 5038
S - 102 41 STOCKHOLM

RESEARCH WORK

TITLE: KLIPPAN AQUIFER THERMAL ENERGY STORAGE PERIOD: 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/~~experimental~~
- storage system : YES/~~NO~~ - theoretical/~~experimental~~
- total system : YES/~~NO~~ - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material : sandy gravel on bedrock
2. Density : 2200 kg/m^3
3. Specific heat : 1700 J/kg K
4. Mean heat capacity : 3.74 MJ/m^3 K (x water)
5. Thermal conductivity : 2.7 W/m K
6. Permeability : 3.10^{-10} m^2
7. Operating temperature interval: 5 - - 18 °C
8. Price : 15 SEK ~~UA~~/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : ∿ 1 10^6 m^3

   shape : 350 x 800 x 4

   position: ~~above~~/below/~~partially below~~ ground level
2. Total heat capacity : 4 10^6 MJ/K
3. Containment present : ~~YES~~/NO

   material :
4. Insulation present : ~~YES~~/NO

   position insulation :

   material :

   total volume insulation material: m^3
5. Heat exchanger present : YES/~~NO~~

   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./~~exp~~.): 60/- (%)

COST (incl. cost for labour)

Storage 12.5 MSEK UA

Containment UA

Insulation UA

Heat exchanger 1.5 MSEK ~~UA~~

Miscellaneous 1.0 MSEK ~~UA~~

Total system 15.0 MSEK ~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: The system will be connected to a district heating system with 3000 dwellings

1. Heat consumption system: space heating/domestic hot water/both

   space heat load* : MJ

   hot water load* : MJ

   total load* : MJ

   total system load* : MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/distributed

- collector area : m^2 / x m^2

- type :

Short term heat storage: central/distributed/not pres

- storage volume : m^3 / x m^3

- storage material :

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : 6000 m

- heat loss rate : low $W/K.m_{piping}$

Total cost : 6.0 MSEK UA

5. Auxiliary heating: central/distributed/not pres

- type : heat/solid fuel/oil
pump/boiler/boiler

- power installed : 4000/6000/1400 kW / x kW

Total cost : 4 / 6 / 14 UA MSEK / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : 20 MSEK UA

- conventional heating system : 10 MSEK UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)

- number of degree days : ; temperature below °C

1. Total system load : MJ

2. Total solar contribution : MJ (% of load)

idem per m^2 collector : MJ (kWh/m^2)

3. Total auxiliary heating : MJ

4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system : 600 10^6

2. Idem for solar heating system with seasonal heat storage: 300 10^6 -

Primary energy saved : 300 10^6

<u>Resumé</u>:

Primary energy saved: 300 10^6 MJ

Extra system cost : 10 MSEK UA

REFERENCES

/36, 37/

CONTACT

L. LEMMEKE
VBB AB
Geijersgatan 8
S - 216 18 MALMÖ

5.5. Earth storage

5.5.1. The Groningen project (the Netherlands)

5.5.2. The Vaulruz project (Switzerland)

5.5.3. SUNCLAY - Project at Kungsbacka (Sweden)

5.5.4. Heat piles for foundation and heat storage, Huddinge (Sweden)

5.5.5. Energy storage in clay, Upplands Vasby (Sweden)

5.5.6. Alternativenergieprojekt, Innsbruck-Kranebitten (Austria)

5.5.7. Seasonal solar coupled ground storage, CCR - Ispra (EC)

SUMMARY SHEET: SEASONAL HEAT STORAGE - EARTH/1

RESEARCH WORK

TITLE: THE GRONINGEN PROJECT PERIOD: 1982 - 1985

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : Saturated sand with clay and peat layers
2. Density : 2060 kg/m^3
3. Specific heat : 1300 J/kg K
4. Mean heat capacity : 2.7 MJ/m^3 K (0.64x water)
5. Thermal conductivity : 1.5 - 2.2 W/m K
6. Permeability : $0.5 - 2 * 10^{-11} m^2$
7. Operating temperature interval: 25 - 60 °C
8. Price : - UA/m^3

Properties at temperature : 10 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 23 000 m^3
   shape :
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 62 000 MJ/K
3. Containment present : ~~YES~~/NO
   material :
4. Insulation present : YES/~~NO~~
   position insulation : top, overlapping
   material : foam glass
   total volume insulation material: 270 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./~~exp~~.): 40 000 W/K
6. Annual performance (theor./~~exp~~.): 62 (%)

COST (incl. cost for labour) in OFL 1983

Storage 35 000 UA

Containment -- UA

Insulation 100 000 UA

Heat exchanger 180000 UA

Miscellaneous 18000 UA

Total system 333000 UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 96 houses (low temperature radiator heating

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 36 000 MJ
   hot water load* : 7 200 MJ
   total load* : 43 200 MJ
   total system load : $4.1 * 10^{+6}$ MJ

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : ~~central~~/distributed

- collector area : m^2 / *96* x *25* m^2

- type : *High performance solar collector*

Short term heat storage: central/~~distributed/bot~~

- storage volume *(CST)* : *100* m^3 / *-* x *-* m^3

- storage material : *water*

Total cost : *1 100 000* UA *(CST of 80.000 UA inc*

3. Seasonal heat storage resevoir (see above)

Total cost : *333 000* UA

4. Heat transfer piping network :

- total length : *1 900* m

- heat loss rate : *0.2* W/K.m$_{\text{piping}}$

Total cost : *130 000* UA

5. Auxiliary heating: central/distributed/~~bot~~

- type : *gas boiler for space heating/gasboile*

- power installed : *850* kW / *96* x *1.5* kW

Total cost *(boiler house of 65000 UA included)* : *110 000* UA / *96* x *?* UA *(included in 2)*

6. Electrical power for pumps : *-* kW

Total power installed : *-* kW

7. Total cost

- solar heating system : *1 673 000* UA

- conventional heating system : *236 000* UA *(distributed)*

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location *De Bilt, The Netherlands*

Latitude: *52^0 6^1 North* Longitude: *5^0 11^1 East*

Climatological data for location :

- global irradiation : *3 300* MJ/m^2 (*910* kWh/m^2)

- number of degree days : *3 000* ; temperature below *18* °

1. Total system load : *4.10 10^{+6}* MJ

2. Total solar contribution : *2.75 10^{+6}* MJ (*67* % of load)

idem per m^2 collector : *1150* MJ (*320* kWh/m^2)

3. Total auxiliary heating : *1.35 10^{+6}* MJ

4. Total electricity consumption : *90 000* kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

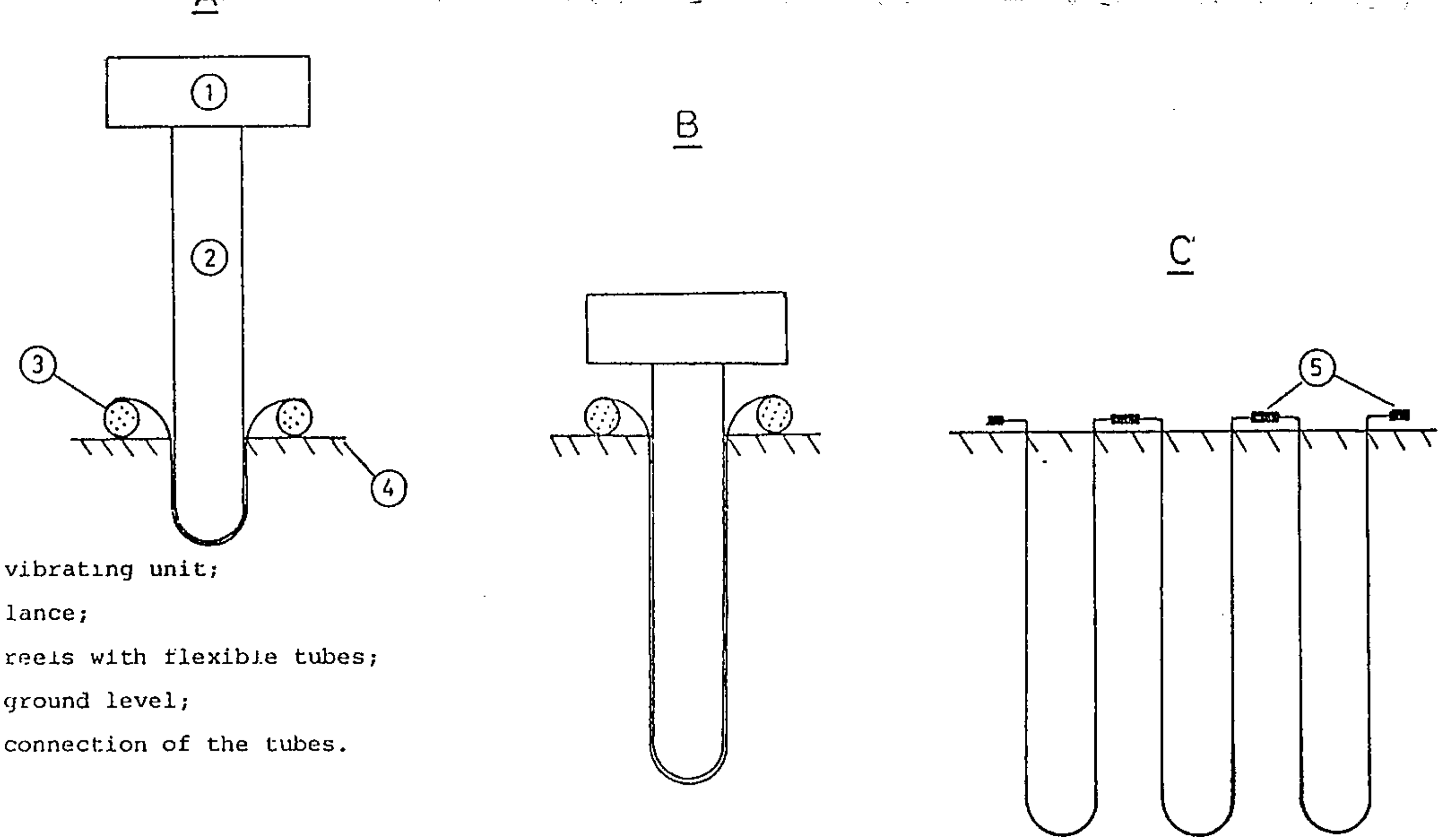
2. Idem for solar heating system with seasonal heat storage: ____________

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

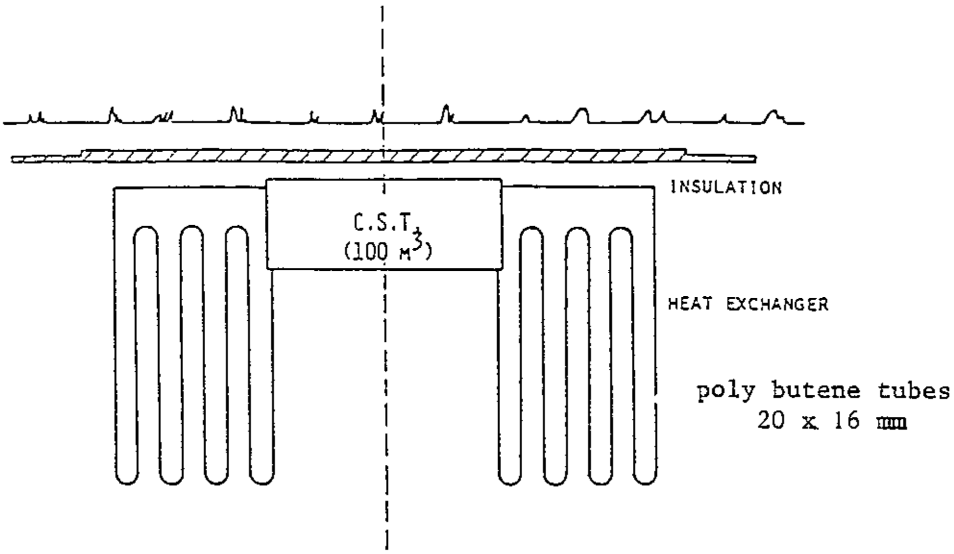


1) vibrating unit;
2) lance;
3) reels with flexible tubes;
4) ground level;
5) connection of the tubes.

Three phases are given, phases a) and b) show the lowering of the tube by means of a vibrating lance, while phase c) shows the final stage. It should be noted that on removal of the lance the hole created by the lance closes leaving the tube completely surrounded by the soil.

Figure 43: Groningen/Insertion of the tubes by a vibrating lance method

Figure 44: Groningen/The heat storage system



SCHEME OF THE SEASONAL HEAT STORAGE RESERVOIR WITH
A CENTRAL SHORT TERM STORAGE RESERVOIR (C.S.T.)

Characteristics

- shape : *cylindrical; vertical axis*
- dimensions : *diameter 38 m, depth 20 m*
- total volume : *23.000 m^3*
- total heat capacity : *62.000 MJ/K*

REFERENCES

/38, 39, 40, 41/

CONTACT

A.J.Th.M. WIJSMAN
C. DEN OUDEN
Institute of Applied Physics TNO-TH
P.O. Box 155
NL - 2600 AD DELFT

J.W. DE FEIJTER
Delft Soil Mechanics Laboratory
Stieltjesweg 2
NL - 2628 CK DELFT

SUMMARY SHEET: SEASONAL HEAT STORAGE EARTH/2

RESEARCH WORK

TITLE: THE VAULRUZ PROJECT

PERIOD: operating since 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : sandy gravel with clay
2. Density : 2200 kg/m^3
3. Specific heat : 900 J/kg K
4. Mean heat capacity : 2.0 MJ/m^3 K (0.5 x water)
5. Thermal conductivity : 1.5/2.0 W/m K
6. Permeability : _ m^2
7. Operating temperature interval: 5 - 50 °C
8. Price : 0 UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 3500 m^3
   shape : pyramidal
   position: ~~above~~/below/~~partially below~~ ground level
2. Total heat capacity : 7000 MJ/K
3. Containment present : YES/~~NO~~
   material : vapour barrier
4. Insulation present : YES/~~NO~~
   position insulation : roof and walls
   material : expanded polystyren
   total volume insulation material: 640 m^3
5. Heat exchanger present : polyethylen tubes YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./~~exp.~~): 65 (%)

COST (incl. cost for labour) 1 UA = 1 US$ 1980

Storage	60'000	UA
Containment	20'000	UA
Insulation	30'000	UA
Heat exchanger	20'000	UA
Miscellaneous	40'000	UA+
Total system	170'000	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1 maintenance center

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 1'111'500 MJ
   hot water load* : 116'500 MJ
   total load* : MJ
   total system load* : 1'228'000 MJ

* per ~~heat consumer per year.~~ design year and average utilization conditions

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/distributed

- collector area : 510 m^2 / x m^2

- type : flat plate, double glazing, tilt 38°

Short term heat storage: for heat pump central/

- storage volume : 2 m^3 / x m^3

- storage material : water + glycol

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : 170'000 US$ 1980 UA

4. Heat transfer piping network : in the storage

- total length : 8000 m of polyethylen tubes

- heat loss rate (max.) : ~ 4 $W/K.m_{piping}$

Total cost : 20'000 UA

5. Auxiliary heating: central/

- type : oil burner

- power installed : 340 kW / x kW

Total cost : UA / x UA

6. Electrical power for heat:pump: 44 kW

Total power installed : kW

7. Total cost

- solar heating system : 445'000 UA including back-up system

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location VAULRUZ

Latitude: 46°38'N Longitude: 6°58'E

Climatological data for location : Vaulruz

- global irradiation horizontal : 4238 MJ/m^2 (1180 kWh/m^2)

- number of degree days 18/10°C : 3886 ; temperature below 18 °C

1. Total system load : 1'288'000 MJ

2. Total solar + heat pump contribution: : 796'000 MJ (65 % of load)

idem per m^2 collector : MJ (390 kWh/m^2) collected per ye

3. Total auxiliary heating : 432'000 MJ by oil burner

4. Total electricity consumption : 66'000 kWh by heat pump

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

<u>Resumé</u>:

Primary energy saved:

Extra system cost : UA

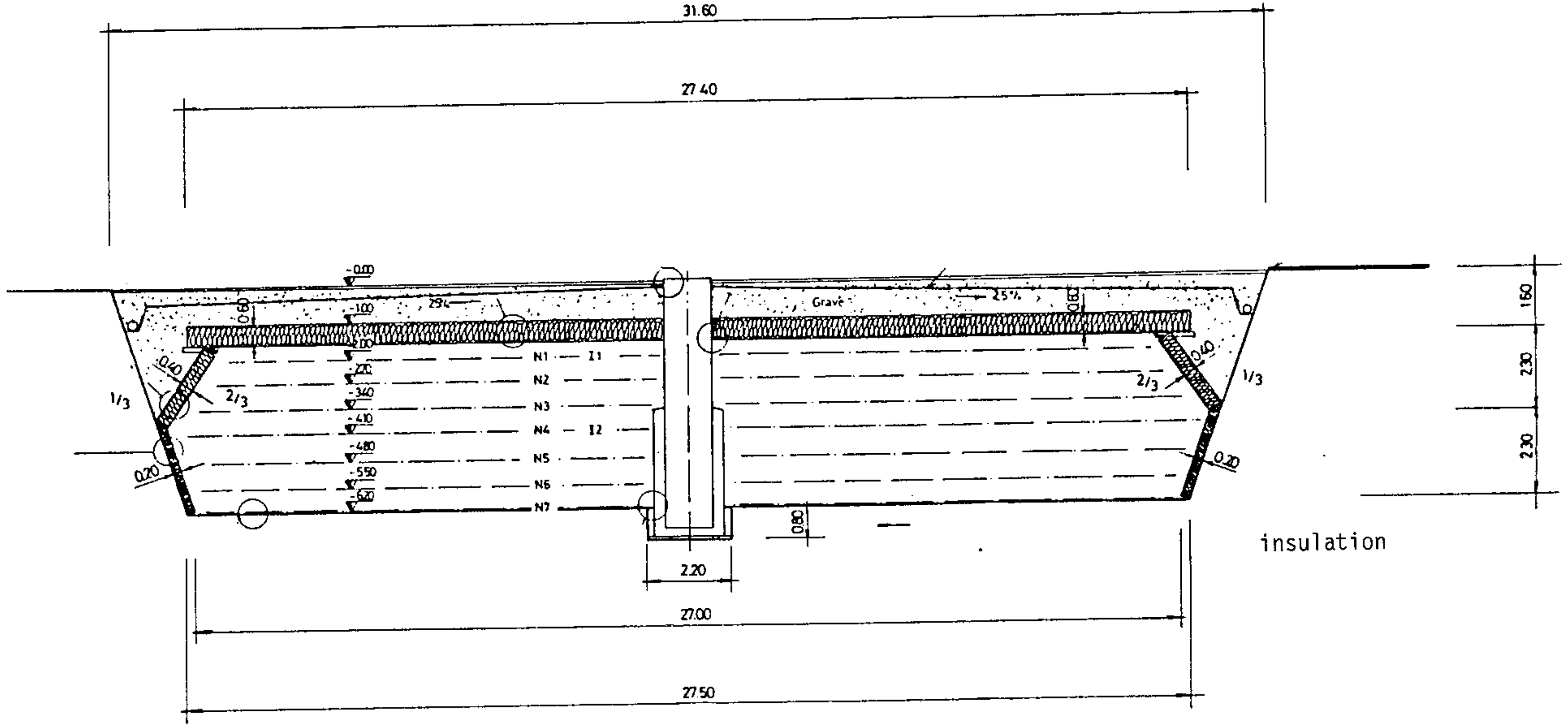


Figure 45: Vaulruz/Cross section through the excavated earth storage

N1 to N7: levels of plastic tubes

REFERENCES

/42, 43, 44/

CONTACT

SORANE SA
Route du Châtelard 52
CH - 1018 LAUSANNE

SUMMARY SHEET: SEASONAL HEAT STORAGE EARTH/3

RESEARCH WORK

TITLE: SUNCLAY PROJECT AT KUNGSBACKA

PERIOD: in operation since 1980

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : pipe system in natural clay
2. Density : 1.6 kg/m^3
3. Specific heat : 2300 J/kg K
4. Mean heat capacity : 3680 MJ/m^3 K (x water)
5. Thermal conductivity : 1.0 W/m K
6. Permeability : m^2
7. Operating temperature interval: 7 - 15 °C
8. Price : 12 SEK UA/m^3

Properties at temperature : °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 85'000 m^3
   shape : 36 x 68 x 35
   position: above/below/partly below ground level
2. Total heat capacity : 310.10^6 MJ/K
3. Containment present : ~~YES~~/NO
   material :
4. Insulation present : YES/~~NO~~
   position insulation : above
   material : expanded burned clay
   total volume insulation material: 100 m^3
5. Heat exchanger present : YES/NO
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage 0.5 MSEK UA

Containment UA

Insulation UA

Heat exchanger 0.5 MSEK ~~UA~~

Miscellaneous ______ UA+

Total system 1,0 MSEK ~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: a school building

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : 4.10^6 MJ

* per heat consumer per year.

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 1500 m^2 / x m^2
- type : plate, integrated in the roof

Short term heat storage: central/~~distributed/not pres~~

- storage volume : m^3 / x m^3
- storage material :

Total cost : 0.4 UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m
- heat loss rate : W/K.m$_{\text{piping}}$

Total cost : UA

5. Auxiliary heating: central/distributed/not pres

- type : heat pump, diesel engine
- power installed : kW / x kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : 3400 MJ/m^2 (940 kWh/m^2)
- number of degree days : ; temperature below °C

1. Total system load : MJ
2. Total solar contribution : MJ (% of load)

idem per m^2 collector : 1700 MJ (485 kWh/m^2)

3. Total auxiliary heating : MJ
4. Total electricity consumption : kWh

PRIMARY ENERGY SAVED

Fuel: oil Fuel price:

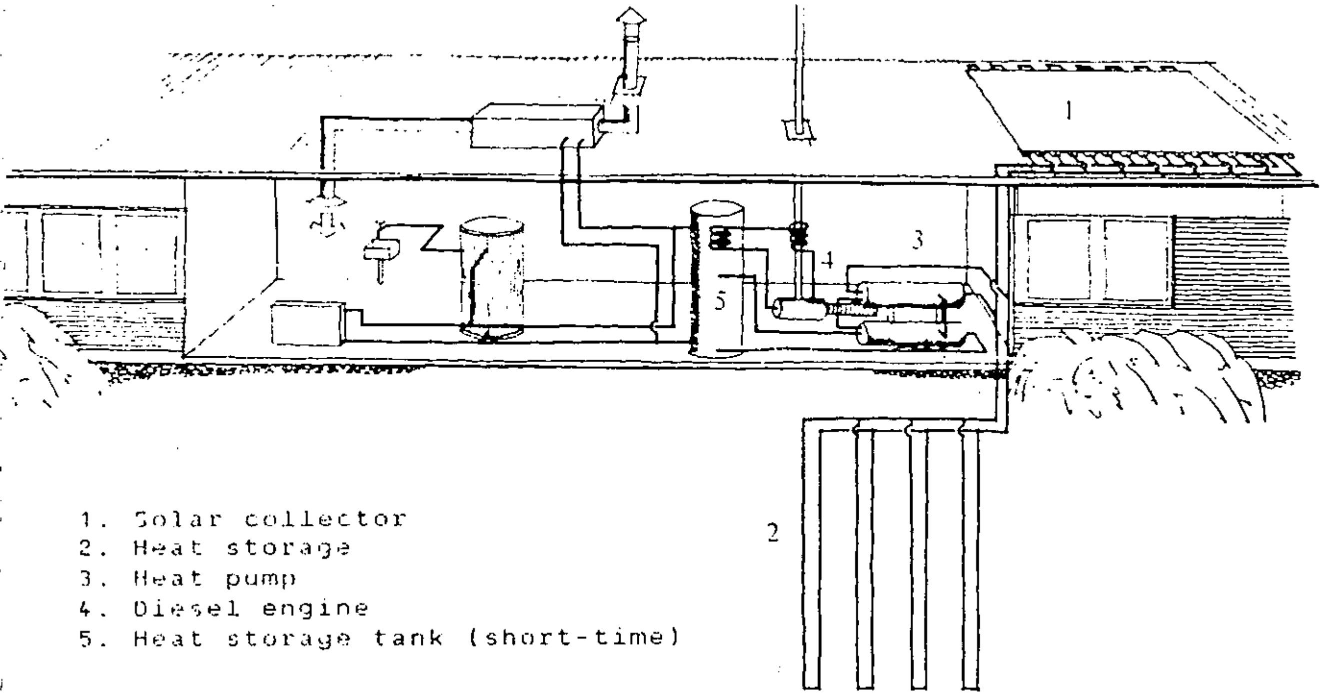
1. Primary energy consumption for conventional system : 155 m3 oil
2. Idem for solar heating system with seasonal heat storage: 110 m3 oil -

Primary energy saved : 45 m3 oil

Resumé:

Primary energy saved: 45 m3 oil

Extra system cost : UA



1. Solar collector
2. Heat storage
3. Heat pump
4. Diesel engine
5. Heat storage tank (short-time)

Figure 46: SUNCLAY/Energy system schematic

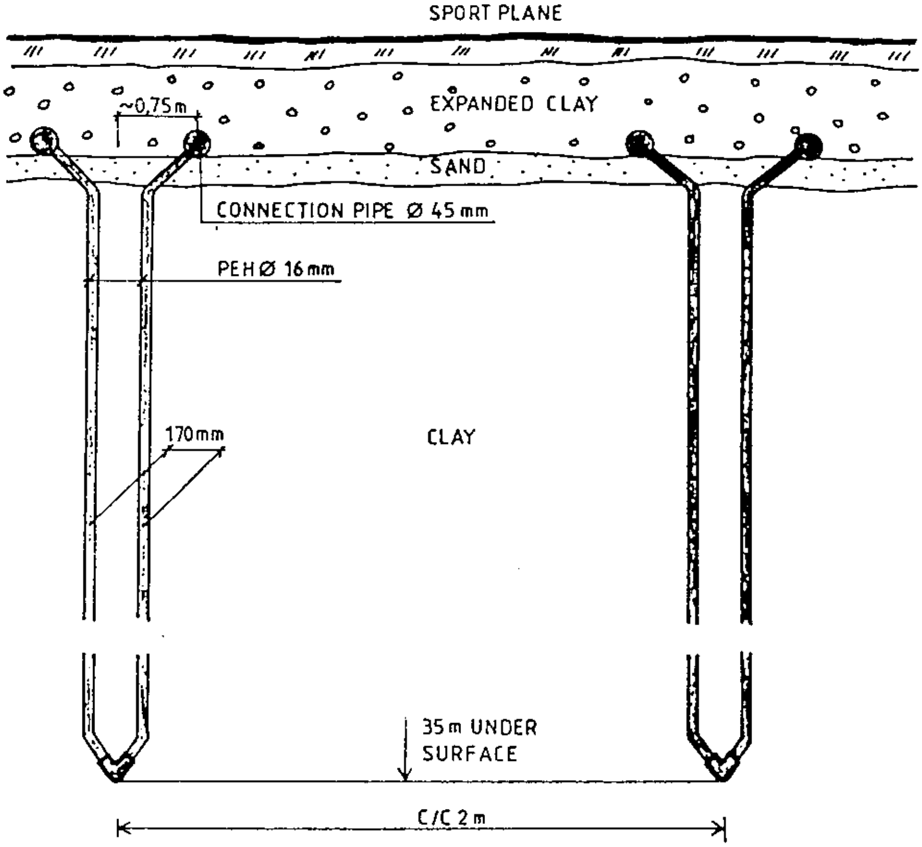


Figure 47: SUNCLAY/Principal section of the ground storage

REFERENCE

/45/

CONTACT

G. HULTMARK
Andersson & Hultmark
Box 24 135
S - 400 32 GOTHENBURG

SUMMARY SHEET: SEASONAL HEAT STORAGE EARTH/4

RESEARCH WORK

TITLE: HEAT PILES FOR FOUNDATION AND HEAT STORAGE, HUDDINGE

PERIOD: in operation since 1981

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : clay and silt
2. Density : 1800 kg/m^3
3. Specific heat : 350 J/kg K
4. Mean heat capacity : 0.63 MJ/m^3 K (x water)
5. Thermal conductivity : 1.3 W/m K
6. Permeability : 10^{-15} m^2
7. Operating temperature interval: 7 - 30 °C
8. Price : 7 SEK UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE		COST (incl. cost for labour)
1. Storage volume : 1500	m^3	Storage 10'000 SEK UA
shape :		
position: ~~above~~/below/~~partly below~~ ground level		
2. Total heat capacity :	MJ/K	
3. Containment present :	~~YES~~/NO	Containment UA
material :		
4. Insulation present :	YES/~~NO~~	Insulation 3'000 SEK UA
position insulation : above		
material : mineral wool		
total volume insulation material: 5	m^3	
5. Heat exchanger present :	~~YES~~/NO	Heat exchanger UA
heat exchange rate (theor./exp.):	W/K	Miscellaneous 2'000 SEK ~~UA~~
6. Annual performance (theor./exp.): 50/-	(%)	Total system 15'000 SEK ~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: one dwelling

1. Heat consumption system: space heating/domestic hot water/both
   - space heat load* : 54.10^3 MJ
   - hot water load* : 13.10^3 MJ
   - total load* : 67.10^3 MJ
   - total system load* : 54.10^3 MJ

* per heat consumer per year.

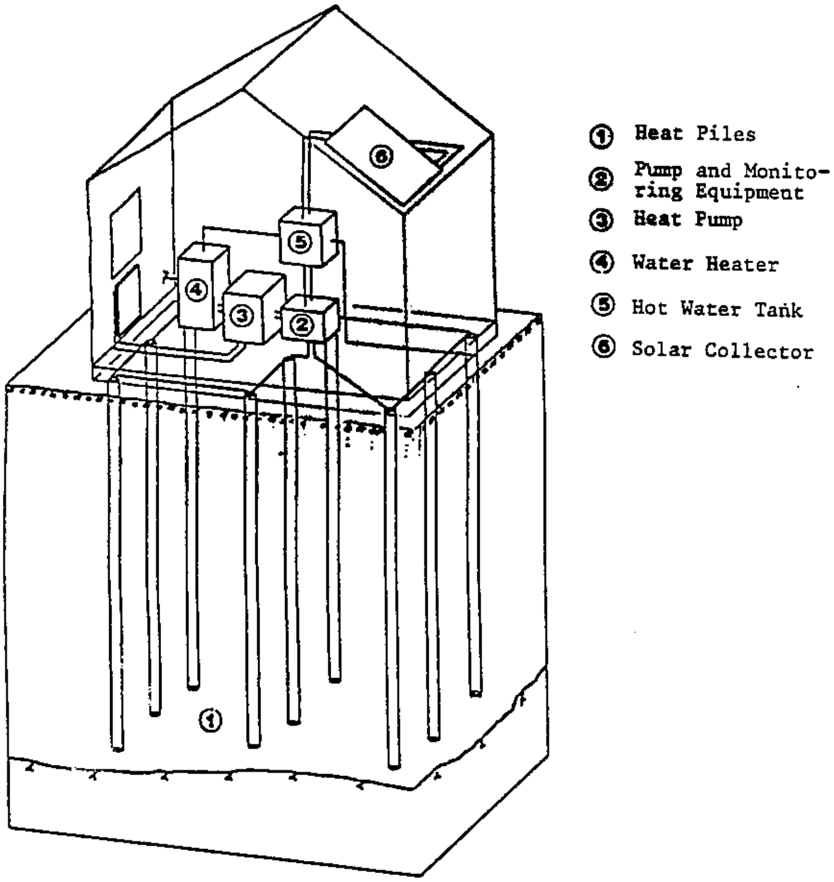


Figure 48: Huddinge/Seasonal storage of solar energy in clay with heat piles (system Hagkonsult)

REFERENCE

/46/

CONTACT

L. WAHLSTRÖM
Hagkonsult AB
Box 1214
S - 181 23 LIDINGÖ

SUMMARY SHEET: SEASONAL HEAT STORAGE

RESEARCH WORK

TITLE: ENERGY STORAGE IN CLAY, UPPLANDS VÄSBY

PERIOD: 1982/83

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/~~experimental~~
- storage system : YES/~~NO~~ - theoretical/~~experimental~~
- total system : ~~YES~~/NO - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material : pipe system in clay
2. Density : 1.6-1.8 kg/m^3
3. Specific heat : 1.9 10^3 J/kg K
4. Mean heat capacity : 3.24 MJ/m^3 K (x water)
5. Thermal conductivity : 1.29 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 4 - 25 °C
8. Price : 30 SEK UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 100'000 m^3
   shape : 300 x 25 x 13
   position: ~~above~~/below/~~partially below~~ ground level
2. Total heat capacity : 325 10^3 MJ/K
3. Containment present : YES/NO
   material :
4. Insulation present : YES/~~NO~~
   position insulation : on top
   material : burut expanded clay
   total volume insulation material: 1100 m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.): (%)

COST (incl. cost for labour)

Storage 3.1 MSEK ~~UA~~

Containment UA

Insulation 0.4 MSEK ~~UA~~

Heat exchanger 1.6 MSEK ~~UA~~

Miscellaneous 0.3 MSEK ~~UA~~+

Total system 5.4 MSEK ~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: one factory

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.

CONTACT

L. ENGVALL
Viak AB
Box 519
S - 162 15 VALLINGBY

SUMMARY SHEET: SEASONAL HEAT STORAGE EARTH/6

RESEARCH WORK

TITLE: ALTERNATIVENERGIEPROJEKT INNSBRUCK KRANEBITTEN

PERIOD:

MAIN SUBJECTS OF RESEARCH:

- storage material: ~~YES~~/NO - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : GRAVEL
2. Density : 2,3 kg/m^3
3. Specific heat : J/kg K
4. Mean heat capacity : 1.5 MJ/m^3 K (x water)
5. Thermal conductivity : 1.5 W/m K
6. Permeability : m^2
7. Operating temperature interval: -6 - 10 °C
8. Price : 25 AUS UA/m^3

Properties at temperature : 10 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 60'000 m^3
   shape : 110 x 55 x 10 m
   position: ~~above~~/below/~~partly below~~ ground level
2. Total heat capacity : 90'000 MJ/K
3. Containment present : ~~YES~~/NO
   material :
4. Insulation present : ~~YES~~/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/~~NO~~
   heat exchange rate (theor./~~exp.~~): 156'000 W/K
6. Annual performance (theor./~~exp.~~): 135 % (%)

COST (incl. cost for labour)

Storage	UA
Containment	UA
Insulation	UA
Heat exchanger	UA
Miscellaneous	UA+
Total system	UA

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 1

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 1.9 10^6 MJ
   hot water load* : 2.5 10^6 MJ
   total load* : 4.4 10^6 MJ
   total system load* : MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~XXX

- collector area : 400 m^2 / x m^2
- type : (EPDM) uncovered

Short term heat storage: central/distributed/not pres

- storage volume : 40 m^3 / x m^3
- storage material : WATER

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : 24'000 m (Ø 20 mm)
- heat loss rate : W/K.m piping

Total cost : UA

5. Auxiliary heating: central/~~distributed/not pres~~

- type : OIL + HEAT PUMP
- power installed : 231 + 350 kW / * kW

Total cost : UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : UA
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: 48° 15' N Longitude: 16° 22' E

Climatological data for location :

- global irradiation : 3'917 MJ/m^2 (kWh/m^2)
- number of degree days : 3'235 ; temperature below 12 °C

1. Total system load : $4.4\ 10^6$ MJ
2. Total solar contribution : $2.3\ 10^6$ MJ (% of load)

   idem per m^2 collector : $5.7\ 10^3$ MJ (kWh/m^2)
3. Total auxiliary heating : $10.8\ 10^3$ MJ
4. Total electricity consumption : 443'000 kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :
2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved: 63 %

Extra system cost : $5.5\ 10^6$ AUS UA

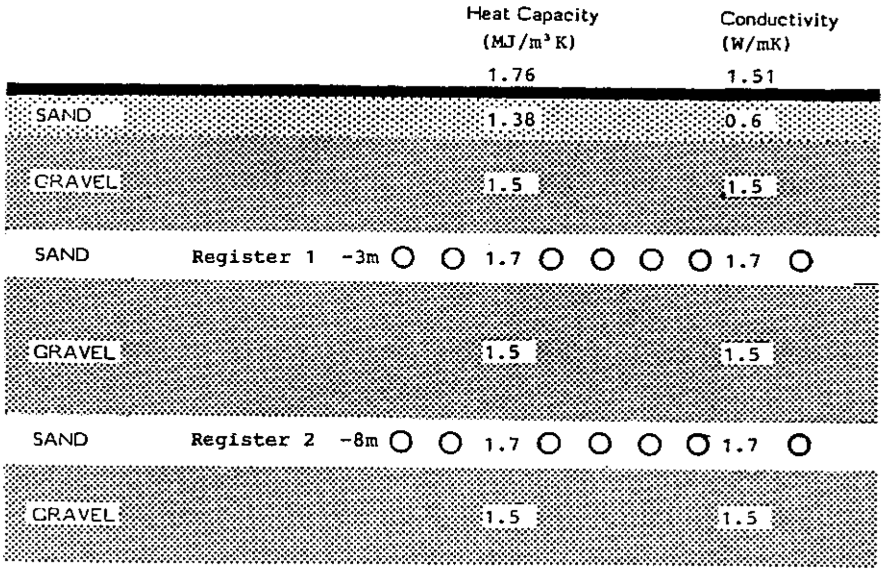


Figure 49: Kranebitten/Soil storage schematic (vertical cross section)

REFERENCE

/72/

CONTACT

G. SPIELMANN & A. SIGMUND
Austrian Institute for Building Research
An den langen Lüssen 1/6
A - 1190 WIEN

SUMMARY SHEET: SEASONAL HEAT STORAGE EARTH/7

TITLE: SEASONAL SOLAR COUPLED GROUND STORAGE
CCR – ISPRA

PERIOD:

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

1. Material : Clay soil
2. Density : $1.2\text{-}1.5 \cdot 10^3$ kg/m^3
3. Specific heat : $1.2\text{-}2.9 \cdot 10^3$ J/kg K
4. Mean heat capacity : 1.4-4.3 MJ/m^3 K (x water)
5. Thermal conductivity : 0.6-1.5 W/m K
6. Permeability : m^2
7. Operating temperature interval: 5 - 60 °C
8. Price : UA/m^3

Properties at temperature : °C

STORAGE CONTAINER AND COMPONENT PERFORMANCE	COST (incl. cost for labour)	
1. Storage volume : 2250 m^3	Storage	UA
shape : cubic		
position: ~~above/below/partly~~ below ground level		
2. Total heat capacity : MJ/K		
3. Containment present : ~~YES~~/NO	Containment	UA
material :		
4. Insulation present : YES/~~NO~~	Insulation	UA
position insulation : on top		
material : expanded clay		
total volume insulation material: 50 m^3		
5. Heat exchanger present : vertical tubes ~~YES~~/NO	Heat exchanger	UA
heat exchange rate (theor./exp.): W/K	Miscellaneous	UA+
6. Annual performance (theor./exp.): (%)	Total system	UA

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: simulated load

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : MJ

hot water load* : MJ

total load* : MJ

total system load* : 280.10^3 MJ

2. Solar heat collecting system :

Solar collectors : central/~~distributed~~

- collector area : 180 m^2 / ~~m^2~~
- type : flat plate, single glazing, incl.4

Short term heat storage: central/distributed/not pres

- storage volume : 8 m^3 / x m^3
- storage material : water

Total cost : UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : 75 m
- heat loss rate : W/K.m piping

Total cost : UA

5. Auxiliary heating: central/distributed/not pres

- type : heat pump
- power installed : 32 kW / ~~kW~~ heat

Total cost : UA / x UA

6. Electrical power for pumps : 3 kW

Total power installed : kW

7. Total cost

- solar heating system : UA
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: 45 °N Longitude: 8 °E

Climatological data for location :

- global irradiation horiz. : 4200 MJ/m^2 (~~kWh/m^2~~
- number of degree days : 2500 ; temperature below 15 °C

1. Total system load : 280.10^3 MJ
2. Total solar contribution : 80% MJ (% of load)

idem per m^2 collector : 350 ~~MJ~~ (kWh/m^2)

3. Total auxiliary heating : -- MJ
4. Total electricity consumption : 15.10^3 kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :
2. Idem for solar heating system with seasonal heat storage: ______________ -

Primary energy saved :

Resumé:

Primary energy saved:

Extra system cost : UA

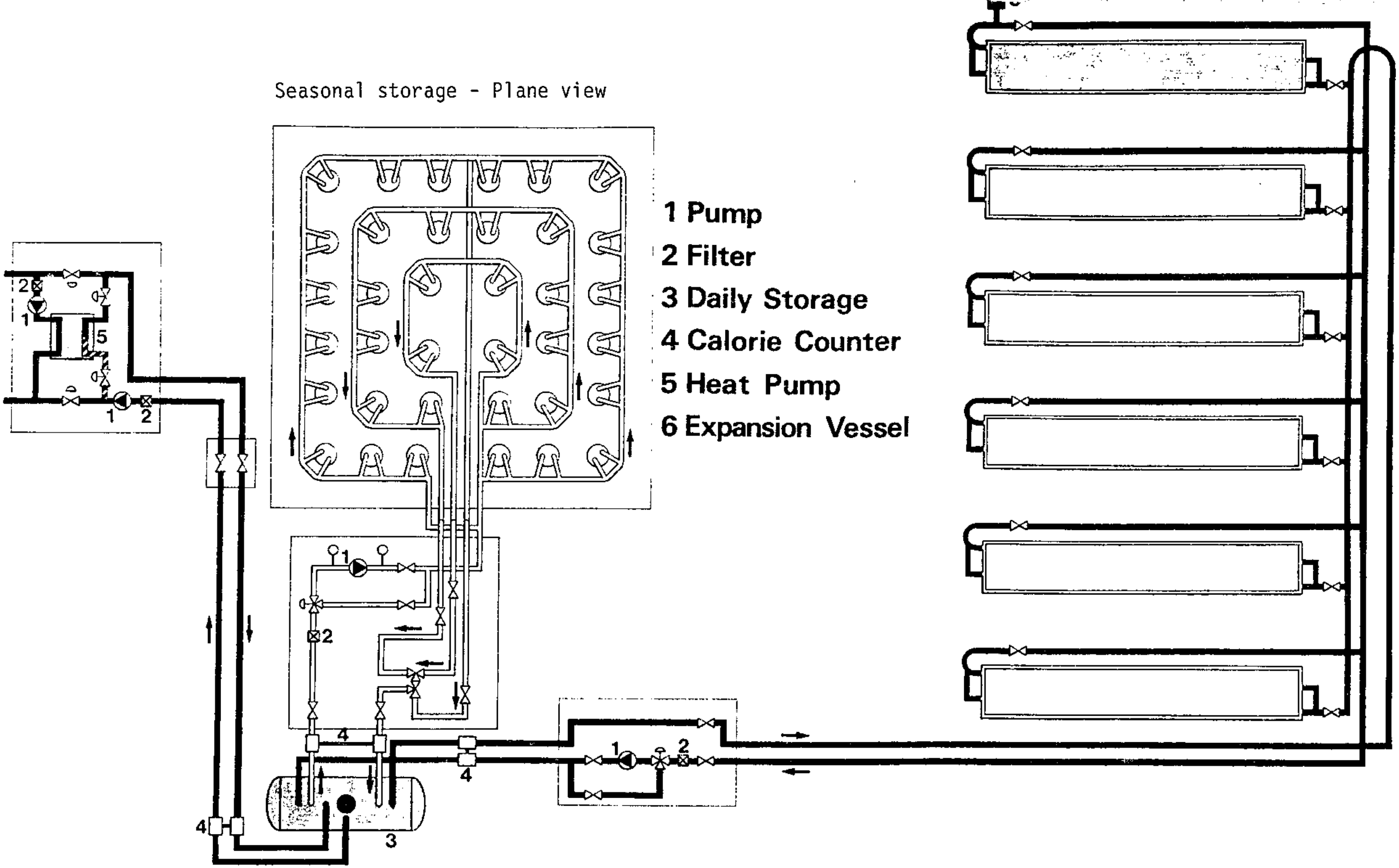


Figure 50: CCR Ispra/Schema seasonal solar coupled ground storage

CONTACT

M. HARDY
Joint Research Center
Ispra Establishment
I - 21020 ISPRA

5.6. Rock storage

5.6.1. Multiple well system at Luleå (Sweden)

5.6.2. SUNSTORE project, Stora Kuggan (Sweden)

5.6.3. Södertuna - Alternative C: Multiple well system (Sweden)

SUMMARY SHEET: SEASONAL HEAT STORAGE ROCK/1

TITLE: MULTIPLE WELL SYSTEM AT LULEÅ

PERIOD: under construction 1982/83

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/experimental
- storage system : YES/~~NO~~ - theoretical/experimental
- total system : YES/~~NO~~ - theoretical/experimental

STORAGE MATERIAL

1. Material : granite
2. Density : 2610 kg/m^3
3. Specific heat : 800 J/kg K
4. Mean heat capacity : 2.16 MJ/m^3 K (x water)
5. Thermal conductivity : 3.5 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 10 - 70 °C
8. Price : UA/m^3

Properties at temperature : 100 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 100'000 m^3
   shape : 44 x 36 x 60
   position: ~~above~~/below/~~partially below~~ ground level
2. Total heat capacity : 0.22 10^6 MJ/K
3. Containment present : YES/NO
   material :
4. Insulation present : YES/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/NO
   heat exchange rate (theor./exp.): 200 10^3 W/K
6. Annual performance (theor./exp.): 0.6-0.8/ (%)

COST (incl. cost for labour)

Storage 3.9 MSEK ~~UA~~

Containment UA

Insulation UA

Heat exchanger 0.15 MSEK~~UA~~

Miscellaneous 0.35 MSEK~~UA~~

Total system 4.4 MSEK~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: a school building

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : MJ
   hot water load* : MJ
   total load* : MJ
   total system load* : MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :
Solar collectors : central/distributed
- collector area : m^2 / x m^2
- type :
Short term heat storage: central/distributed/not prese
- storage volume : m^3 / x m^3
- storage material :
Total cost : UA
3. Seasonal heat storage resevoir (see above)
Total cost : 4.4 MSEK UA
4. Heat transfer piping network :
- total length : 250 m
- heat loss rate : low W/K.m_{piping}
Total cost : 0.2 MSEK UA
5. Auxiliary heating: central/distributed/not preser
- type : heat/district pump/heating
- power installed : 300 /2000 kW / x kW
Total cost : 0.4 / MSEK MUA / x UA
6. Electrical power for pumps : 5 kW
Total power installed : 100 kW
7. Total cost
- solar heating system : 5.0 MSEK UA
- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location
Latitude: Longitude:
Climatological data for location :
- global irradiation : MJ/m^2 (kWh/m^2)
- number of degree days : 6250 ; temperature below 20 °C
1. Total system load : MJ
2. Total solar contribution : MJ (% of load)
idem per m^2 collector : MJ (kWh/m^2)
3. Total auxiliary heating : $2.2\ 10^6$ MJ
4. Total electricity consumption : $250\ 10^3$ kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:
1. Primary energy consumption for conventional system :
2. Idem for solar heating system with seasonal heat storage: ____________ -
Primary energy saved :

Resumé:
Primary energy saved:
Extra system cost : UA

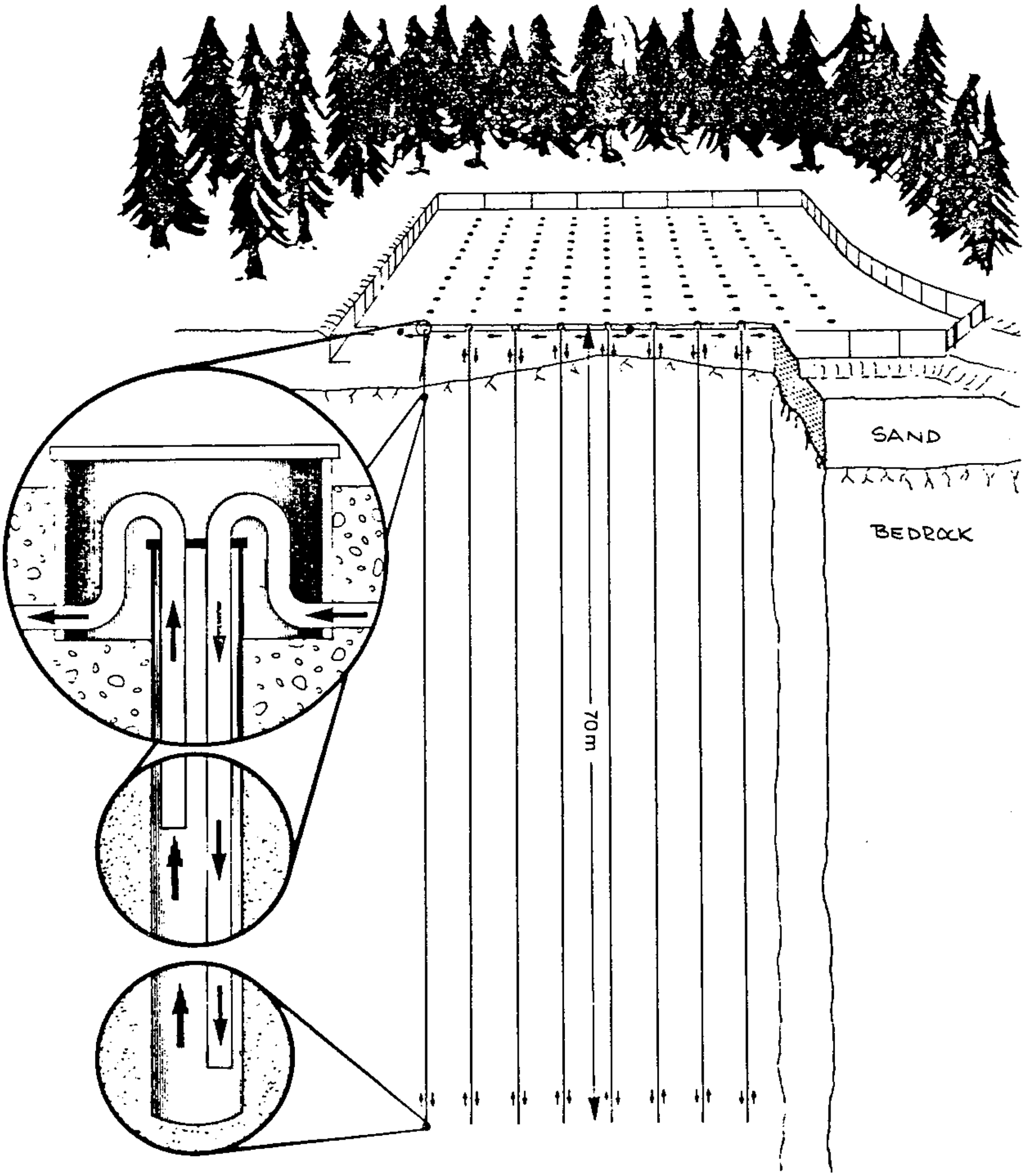


Figure 51: Luleå/Multiple-well storage system

REFERENCES

/47, 48/

CONTACT

S. ANDERSSON
AIB
Box 5511
S - 114 85 STOCKHOLM

SUMMARY SHEET: SEASONAL HEAT STORAGE ROCK/2

RESEARCH WORK

TITLE: SUNSTORE PROJECT, STORA SKUGGAN PERIOD: 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/~~experimental~~
- storage system : YES/~~NO~~ - theoretical/~~experimental~~
- total system : YES/~~NO~~ - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material : gneiss and granite
2. Density : 2640 kg/m^3
3. Specific heat : 800 J/kg K
4. Mean heat capacity : 2.1 MJ/m^3 K (x water)
5. Thermal conductivity : 3 - 3.5 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 24 - 31 °C
8. Price : 15 SEK UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE	COST (incl. cost for labour)
1. Storage volume : 180'000 m^3	Storage 2.0 MSEK UA
shape : 50 x 40 x 90	
position: ~~above~~/below/~~partly below~~ ground level	
2. Total heat capacity : 0.4 10^6 MJ/K	
3. Containment present : ~~YES~~/NO	Containment UA
material :	
4. Insulation present : ~~YES~~/NO	Insulation UA
position insulation :	
material :	
total volume insulation material: m^3	
5. Heat exchanger present : ~~YES~~/NO	Heat exchanger UA
heat exchange rate (theor./exp.): W/K	Miscellaneous 0.5 MSEK~~UA~~
6. Annual performance (theor./exp.): (%)	Total system 2.5 MSEK~~UA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system:

1. Heat consumption system: space heating/domestic hot water/both

space heat load* : MJ

hot water load* : MJ

total load* : 1.8 10^6 MJ

total system load* : 1.6 10^6 MJ

* per heat consumer per year.

2. Solar heat collecting system :

Solar collectors : central/distributed

- collector area : 2200 m^2 / x m^2

- type : plane covered low temperature

Short term heat storage: central/~~distributed/not prese~~

- storage volume : 1000 m^3 / x m^3

- storage material : water

Total cost : 2.0 MSEK UA

3. Seasonal heat storage resevoir (see above)

Total cost : 2.5 MSEK UA

4. Heat transfer piping network :

- total length : m

- heat loss rate : $W/K.m_{piping}$

Total cost : UA

5. Auxiliary heating: central/distributed/not prese

- type : heat/wood pump/boiler

- power installed : 65 /85 kW / x kW

Total cost : 0.13 MSEK UA / x UA

6. Electrical power for pumps : kW

Total power installed : kW

7. Total cost

- solar heating system : 6 MSEK UA

- conventional heating system : UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : MJ/m^2 (kWh/m^2)

- number of degree days : 5000 ; temperature below 20 °C

1. Total system load : 1800 10^3 MJ

2. Total solar contribution : 1550 10^3 MJ (85 % of load)

idem per m^2 collector : MJ (kWh/m^2)

3. Total auxiliary heating : 250 10^3 MJ

4. Total electricity consumption : 35'000 kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system : 500 MWh

2. Idem for solar heating system with seasonal heat storage: 65 MWh -

Primary energy saved : 435 MWh

(63 m3 oil/year)

Resumé:

Primary energy saved:

Extra system cost : UA

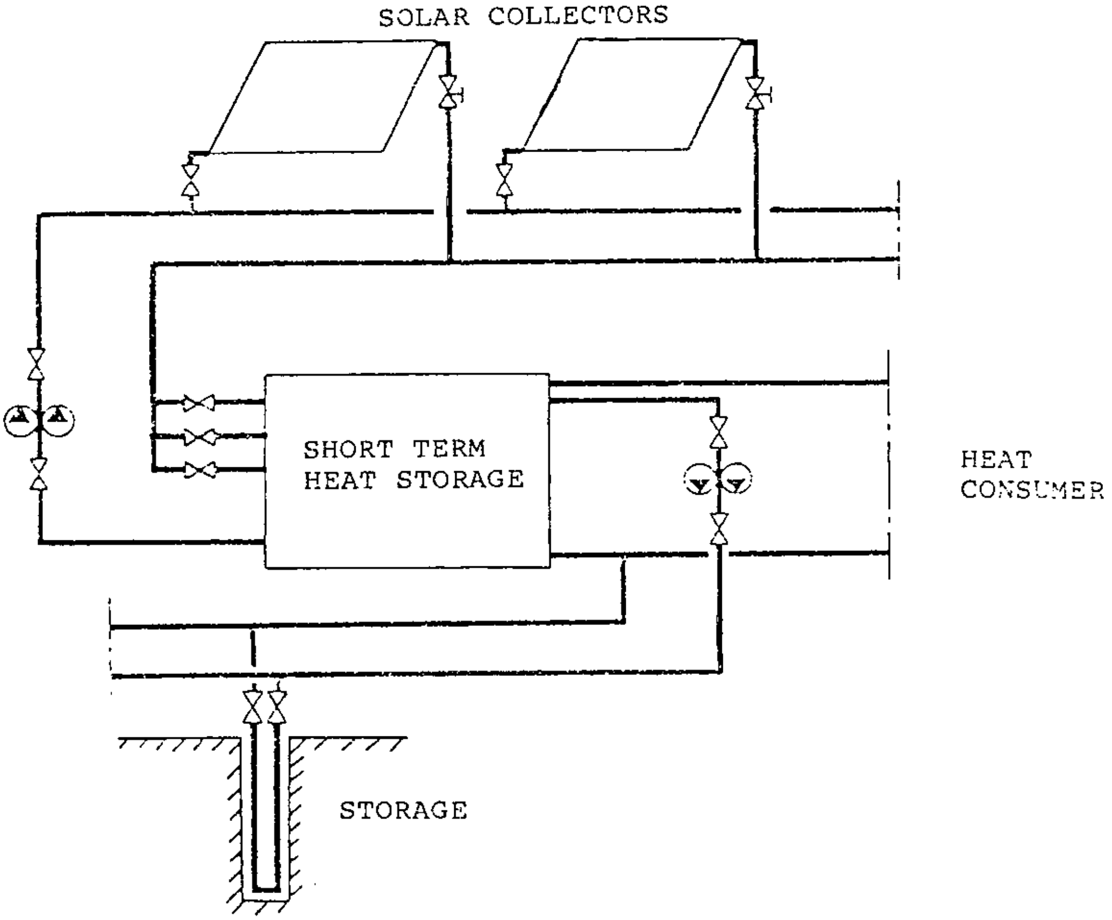


Figure 52: Stora Skuggan/Principal sketch

REFERENCES

/49, 50/

CONTACT

H. HYDEN
VBB AB
STOCKHOLM
Sweden

SUMMARY SHEET: SEASONAL HEAT STORAGE ROCK/3

RESEARCH WORK

TITLE: SÖDERTUNA ALTERNATIVE C MULTIPLE WELL SYSTEM PERIOD: 1982

MAIN SUBJECTS OF RESEARCH:

- storage material: YES/~~NO~~ - theoretical/~~experimental~~
- storage system : YES/~~NO~~ - theoretical/~~experimental~~
- total system : YES/~~NO~~ - theoretical/~~experimental~~

STORAGE MATERIAL

1. Material : granite
2. Density : 2700 kg/m^3
3. Specific heat : 800 J/kg K
4. Mean heat capacity : 2.1 MJ/m^3 K (x water)
5. Thermal conductivity : 3 - 3.5 W/m K
6. Permeability : - m^2
7. Operating temperature interval: 10 - 70 °C
8. Price : 100 SEK UA/m^3

Properties at temperature : 20 °C

STORAGE SYSTEM

STORAGE CONTAINER AND COMPONENT PERFORMANCE

1. Storage volume : 105'000 m^3
   shape : cylindrical r=h
   position: above/below/partly below ground level
2. Total heat capacity : 220 10^3 MJ/K
3. Containment present : YES/NO
   material :
4. Insulation present : YES/NO
   position insulation :
   material :
   total volume insulation material: m^3
5. Heat exchanger present : YES/NO
   heat exchange rate (theor./exp.): W/K
6. Annual performance (theor./exp.) 70/- (%)

COST (incl. cost for labour)

Storage UA

Containment UA

Insulation UA

Heat exchanger UA

Miscellaneous ______ UA+

Total system 10.2 MSEK~~MUA~~

TOTAL SYSTEM

DATA OF TOTAL SYSTEM

The number of heat consumers in the entire system: 525 dwellings

1. Heat consumption system: space heating/domestic hot water/both
   space heat load* : 30 10^3 MJ
   hot water load* : 20 10^3 MJ
   total load* : 50 10^3 MJ
   total system load* : 45 10^3 MJ

* per heat consumer per year.

TOTAL SYSTEM (CONTINUED)

2. Solar heat collecting system :

Solar collectors : central/distributed

- collector area : 30'000 m^2 / x m^2

- type : integrated in the roof

Short term heat storage: ~~central/distributed/~~not pres

- storage volume : m^3 / x m^3

- storage material :

Total cost : 10.2 MSEK UA

3. Seasonal heat storage resevoir (see above)

Total cost : UA

4. Heat transfer piping network :

- total length : m

- heat loss rate : W/K.m$_{\text{piping}}$

Total cost : UA

5. Auxiliary heating: central/distributed/not pres

- type : heat pump

- power installed : 600 kW / $\substack{1\\1}$ x $\substack{200\\400}$ kW

Total cost : 1.0 MSEK UA / x UA

6. Electrical power for pumps : 20 kW

Total power installed : kW

7. Total cost

- solar heating system : 16 MSEK UA

- conventional heating system : 6 MSEK UA

ANNUAL ENERGY FLOWS IN TOTAL SYSTEM: THEORETICAL/EXPERIMENTAL

Results are given for this location

Latitude: Longitude:

Climatological data for location :

- global irradiation : 1300 MJ/m^2 (370 kWh/m^2)

- number of degree days : ; temperature below °C

1. Total system load : $23\ 10^6$ MJ

2. Total solar contribution : $15\ 10^6$ MJ (65 % of load)

idem per m^2 collector : 1150 MJ (320 kWh/m^2)

3. Total auxiliary heating : $12\ 10^6$ MJ

4. Total electricity consumption : $32\ 10^6$ kWh

PRIMARY ENERGY SAVED

Fuel: Fuel price:

1. Primary energy consumption for conventional system :

2. Idem for solar heating system with seasonal heat storage: ____________ -

Primary energy saved :

Resumé:

Primary energy saved: 80%

Extra system cost : 10 MSEK UA

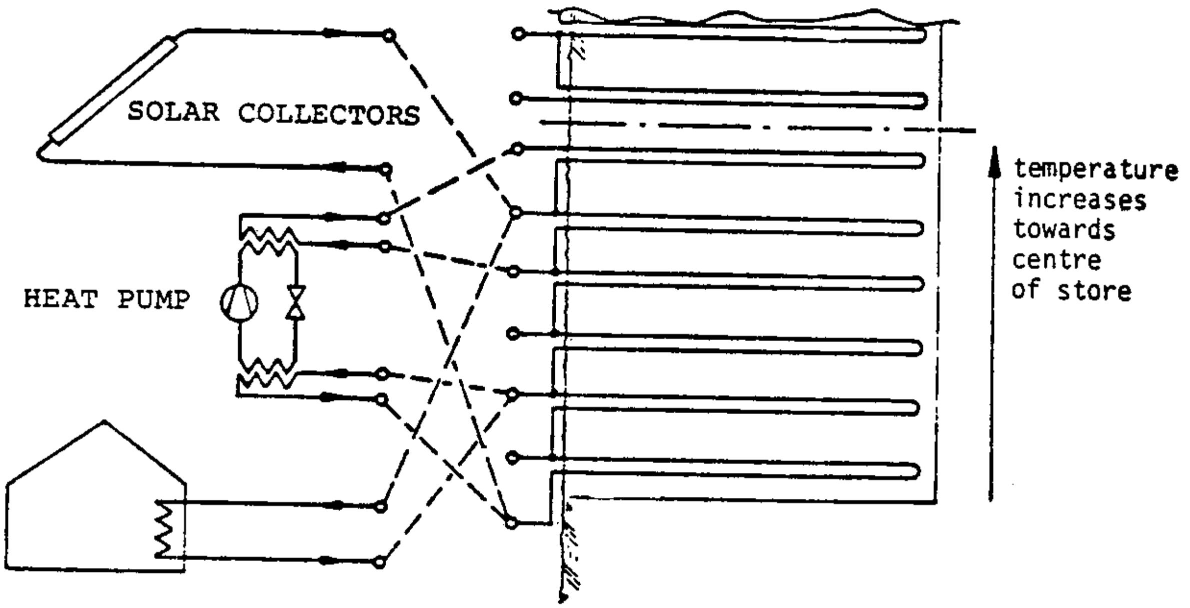


Figure 53: Södertuna alt. C/Multiple well store - Schematic drawing

REFERENCES

/51, 76/

CONTACT

L.L. JUNG
AIB
Box 5511
S - 114 85 STOCKHOLM

REFERENCES AND BIBLIOGRAPHY

The following abbreviations are used:

S.H.S.: International Conference on Subsurface Heat Storage in
Theory and Practice, Stockholm, June 6-8, 1983,
Swedish Council for Building Research, Department of
Energy, USA, National Research Council, Canada,
Proceedings available from Svensk Byggtjänst, Box 7853,
S - 10 399 Stockholm,
Document number D16:1983 and D17:1983/ISBN 91-540-3907-x

S.T.E.S.: International Conference on Seasonal Thermal Energy
Storage and Compressed Air Energy Storage, Seattle,
October 19-21, 1981,
Prepared for the Department of Energy, USA, by
the Pacific Northwest Laboratory,
Proceedings available from the National Technical Information
Service, United States Department of Commerce, 5285 Port
Royal Road, Springfield, Virginia 22151, USA,
Document number CONF-811066 (2 volumes)

1) W. GEIPEL, H.D. ZEITVOGEL:
"Auslegungsoptimierung für zylindrische Warmwasserspeicher aus Stahl", Energie 33 (1981), pp. 156-161

2) F. SCHOLZ, W. ADÄ:
"Advantages of Subdivided Seasonal Hot Water Reservoirs", in S.T.E.S., Proceedings, Vol. 1, pp. 320-328

3) R. ROSEEN, B. PERERS:
"A Solar Heating Plant in Studsvik - Design and First-Year Operational Performance", Swedish Council for Building Research, Stockholm, Document D21:1980

4) B. PERERS, R. ROSEEN:
"The Experiences from the Central Solar Heating Demonstration Plant at Studsvik", in S.H.S., Proceedings, Vol. 1, pp. 373-379

5) J.O. DALENBÄCK, E. GABRIELSSON, B. LUDVIGSSON:
"Three Swedish Group Solar Heating Plants with Seasonal Storage: A Summary of Experiences from the Studsvik, Lambohov and Ingelstad Plants up to the End of 1980", Swedish Council for Building Research, Stockholm, Document D5:1981

6) UNIVERSITY OF TORONTO SOLAR GROUP:
"Aylmer Annual Storage System Performance Evaluation", included in final report DOE-CS-32939-12,1980

7) HOOPER & ANGUS ASSOCIATES, Ltd:
"Aylmer Design Manual", Toronto, April 1979

8) F.C. HOOPER, J.D. McCLENAHAN:
"Design and Evaluation of Central Solar Heating Plants with Seasonal Storage (Storage Systems)", Final Report prepared for the Public Works Canada, April 1981, Dept. of Mechanical Engineering, University of Toronto, Toronto, Canada, M5S 1A4

9) ENVIROGETICS Ltd:
"Provident House Design History", NRC Contract N° OSUS-0032, Canadian Institute for Scientific and Technical Information

10) HOOPER & ANGUS ASSOCIATES, Ltd:
"Provident House Monitoring", Final Report, January 1979, DSS Contract N° 032-1091/1671

11) L. FINN:
"A Swedish Solar Heating Plant with Seasonal Storage - The Ingelstad Project: Design and Construction Stage", Swedish Council for Building Research, Stockholm, Document D14:1979

12) K. NORBÄCK, J. HALLENBERG:
"A Swedish Group Solar Heating Plant with Seasonal Storage - Technical-Economic Description of the Lambohov Project", Swedish Council for Building Research, Stockholm, Document D36:1980

13) F. SCHOLZ:
"Bau und Erprobung einer Versuchsausführung eines Grossraum-Warmwasserspeichers", Statusbericht Bundesministerium für Forschu und Technologie, Bonn, November 1976, Vortragsband Rationelle Energieverwendung BMFT, Statusbericht 1976, 2, Auflage 1977, S. 621-628

14) F. SCHOLZ:
"Warmwasserseen als Langzeitspeicher", VDI-Tagung Rationelle Energienutzung durch Wärmespeicherung, Oktober 1979, Stuttgart, VDI-Berichte 288, 1977, S. 15-26

15) H.J. LEYERS, F. SCHOLZ, A. THOLEN:
"Theoretische und experimentelle Ermittlung der Temperaturverteil in geschichteten Warmwasserspeichern", VDI-Tagung Rationelle Energienutzung durch Wärmespeicherung, Oktober 1977, Stuttgart, VDI-Berichte 288, 1977, S. 27-32

16) W. BREUER, R. DYHR, J. STRICKRODT:
"Langzeitwärmespeicher Prototyp in Wolfsburg", Fernwärme Internat 10 (1981), S. 19-24

17) J. STRICKRODT, W. BREUER, R. DYHR:
"Der Prototyp, Dichtung und Dämmung des Langzeitspeichers in Wolfsburg, Energie 34, April 1982, Heft 4

18) W. BREUER, R. REDECKE:
"Design of the Long Time Heat Store in Wolfsburg", IEA Conference on New Energy Conservation Technology, Berlin, 1981, Vol 1, Springer Verlag, pp. 709-714

19) W. BREUER, J. STRICKRODT:
"Sealing and Insulation of Long Time Heat Storages in Wolfsburg", in S.T.E.S., Proceedings, Vol. 1, pp. 245-252

20) W. GEIPEL:
"Bau des ersten Erdbechen-Wärmespeichers in Mannheim", Brennstoff Wärme-Kraft 31 (1979), S. 56-61

21) W. GEIPEL:
"Grosse Warmwasserspeicher in der Fernwärmeversorgung, Wunschdenken oder Realität ?", Fernwärme International, FWI (1980), S. 319-327

22) W. GEIPEL:
"Warum der Erdbechen-Warmwasserspeicher in Mannheim nicht gebaut wird", Fernwärme International II (1982), S. 52-29

23) R.W. TODD:
"A Solar Heating System with Interseasonal Storage", UK-ISES Conference, C15, UK-ISES, 19 Albermarle Street, London W1X 3Ha

24) W. PALZ, T.C. STEEMERS:
"Solar Houses in Europe - How They Have Worked", Pergamon Press , 1980, for the Commission of the European Communities

25) J. MARTNA:
"The Avesta Test Plant for Storage of Hot Water in an Unlined Rock Cavern", in S.T.E.S., Proceedings, Vol. 1, pp. 186-192

26) J. MARTNA:
"The Avesta Research Plant for Hot Water Storage - State of the Project", in S.H.S., Proceedings, Part I, pp. 367-372

27) E. KJELLSSON:
"The Lyckebo Project - Solar District Heating with Seasonal Storage in a Rock Cavern", in S.H.S., Proceedings, Part I, pp. 360-366

28) G. SÖDERLUND:
"The Lambohov Heat Store", in S.H.S., Proceedings, Part I, pp. 380-384

29) G. SÖDERLUND:
"Water Chemistry Problems in Heat Storage", in S.H.S., Proceedings, Part I, pp. 384-386

30) K. WINDELHED:
"Seasonal Storage of Heat from Lakes in a Mine at Kopparberg, Sweden", Report R68-1982, Hagkonsult AB, Stockholm, 1982

31) B. WEISSENBACH:
"The Man-Made Aquifer Concept", IEA Conference on New Energy Conservation Technologies, Berlin, 1981, Vol. 1, Springer Verlag, pp. 756-761

32) R. HORASIM, R. JANK, B. WEISSENBACH:
"Speicherung von Wärme in nassen Schatterbett", Brennstoff-Wärme-Kraft 32 (1980), N° 11

33) B. SAUGY, J.C. HADORN, G. BLOCH:
"Large Scale Underground Heat Storage", IEA Conference on New Energy Conservation Technology, Berlin, April 1981

34) IEA:
"Energy Conservation Through Energy Storage, Annex 1: Large Scale Thermal Storage Systems", Final Report, IEA restricted, October 1981, edited by the Center of Hydrogeology of the University of Neuchâtel, 2000 Neuchâtel 7, Switzerland

35) B. SAUGY, R. GAMPER, B. MATTHEY, J.J. MISEREZ, A. PARRIAUX, F. VUILLEUMIER:
"First Results of a Large Scale Underground Heat Storage Plant - Pilot Plant SPEOS", in S.H.S., Proceedings, Part I, pp. 253-266

36) C. VOSS:
"Klippan Aquifer Thermal Energy Storage and its Modelling", notes from an international seminar on heat storage in aquifer, Lund, April 15-16, 1980, Sweden

37) H. HYDEN, L. LEMMEKE:
"Värmelagring i grundvatten", 2 reports in Swedish, Stockholm, 1980-01-4

38) A.J.Th.M. WIJSMAN and C. DEN OUDEN:
"A Group of Solar Houses with Seasonal Heat Storage in the Soil" in S.T.E.S., Proceedings, Vol. 1, pp. 281-291

39) A.J.Th.M. WIJSMAN and J.W. DE FEIJTER:
"Field Test to Investigate the Performance of an Undeep Prototyp Seasonal Heat Storage System with a Heat Capacity for 100 Solar Houses Using the Soil as the Storage Medium", Proceedings of the EC contractors meetings held in Athens (November 1981), Meersbur (June 1982), and Brussels (June 1983)

40) A.J.Th.M. WIJSMAN and C. DEN OUDEN:
"Groningen - A Group of 100 Solar Houses with Seasonal Heat Stor in the Soil", Final Report for the IEA Task VII Subtask 1e, June 1983

41) A.J.Th.M. WIJSMAN:
"The Groningen Project - Seasonal Storage of Solar Heat in the Soil Using a Vertical Heat Exchanger", in S.H.S., Proceedings, Part II, pp. 589-590

42) P. CHUARD, D. CHUARD, C. MERCIER, J.C. HADORN:
"Experimental Results of an Earth Storage System of 350 m3", in S.T.E.S., Proceedings, Vol. 1, pp. 193-202

43) D. CHUARD, J.C. HADORN, J. VAN GILST:
"The Vaulruz Project", Final Report for the IEA Task VII Subtask 1e, June 1983

44) P. CHUARD, D. CHUARD, J. VAN GILST, J.C. HADORN, C. MERCIER:
"The IEA Task VII Swiss Project in Vaulruz - Design and First Experiences", in S.H.S., Proceedings, Part I, pp. 195-206

45) G. HULTMARK:
"Earth Storage with Vertical Pipes", in S.H.S., Proceedings, Part I, pp. 176-181

46) L. WAHLSTRÖM:
"Heat Piles for Foundation and Heat Storage", Report R79:1152-5, Hagkonsult AB, Stockholm, 1982

47) S. ANDERSSON, A. ERIKSSON:
"Heat Storage in Rock - Multiple Well System", in S.T.E.S., Proceedings, Vol. 1, pp. 253-262

48) S. ANDERSSON, T. ABYHAMMAR, B. NORDELL:
"Full-Scale Multiple Well Heat Storage System for Experiment and Demonstration", in S.H.S., Proceedings, Part II, pp. 610-615

49) O.B. PLATELL:
"Sunstore - The Complete Solar Energy System for Heating", in S.T.E.S., Proceedings, Vol. I, pp. 177-185

50) P. MARGEN, P. INGRE:
"Seasonal and Daily Storage of Heat by the Sunstore Deep Rock Storage Concept, and Possible Application to Industrial Waste Heat Storage in Gothenburg", in S.H.S., Proceedings, Part II, pp. 644-651

51) S. ANDERSSON, A. ERIKSSON, S. JOHANSSON, L. LJUNG:
"Multiple Well System in Rock - An Alternative for Heat Storage in the IEA Project at Södertuna", in S.H.S., Proceedings, Part II, pp. 604-609

52) K.K. HANSEN, P.N. HANSEN, V. USSING:
"Heat Storage in an Uninsulated Water Pit - Construction and Testing of a 500 m3 Store", in S.H.S., Proceedings, Part I, pp. 302-308

53) M. DYTCZAK, K.K. HANSEN, P.N. HANSEN, V. USSING:
"Hjørtekaer - A Central Solar Heating Plant with Seasonal Storage", in S.H.S., Proceedings, Part I, pp. 294-301

54) H. ZINKO, B. PERERS, R. ROSEEN:
"Earth Pits for Large Scale Central Solar Heating Applications", in S.H.S., Proceedings, Part I, pp. 401-408

55) I. BOGDANOFF, U. LINDBLOM:
"Block-filled Rock Caverns and Pits for Thermal Storage", in S.H.S., Proceedings, Part I, pp. 343-346

56) E.L. MOROFSKY:
"Overview of Canadian Aquifer Thermal Energy Storage Field Trials", in S.H.S., Proceedings, Part I, pp. 221-231

57) T. CLAESSON, B. RONGE:
"Water-Rock Interaction at Elevated Temperatures", in S.H.S., Proceedings, Patt I, pp. 347-351

58) V.G. CHANT, T. LEFEUVRE, E.L. MOROFSKY:
"Feasibility Analysis of Solar Energy Storage in an Aquifer, Scarborough, Ontario, Canada", Final Report for the IEA Task VII Subtask le, June 1983

59) L. LEMMEKE:
"Low-Temperature Heat Storage in Aquifers for Domestic Heating Purposes", in S.H.S., Proceedings, Part II, pp. 784-792

60) G. HELLSTRÖM, C.F. TSANG, J. CLAESSON:
"Heat Storage in Aquifers - Buoyancy Flow and Thermal Stratificat
Dept. of Math. Physics, Lund University, Lund, Sweden

61) B. ABERG:
"Thermal Front Stability in Very Permeable Aquifers", in S.H.S.,
Proceedings, Part II, pp. 793-799

62) L.D. KANNBERG, J.R. RAYMOND, R.D. ALLEN:
"Results of Recent Research on Aquifer Thermal Energy Storage
Technical Issues", in S.H.S., Proceedings, Part II, pp. 805-811

63) R.T. MILLER:
"Thermal Energy Storage in a Deep Sandstone Aquifer in Minnesota:
Field Observations and Preliminary Modelling", in S.H.S., Proceed
Part II, pp. 812-816

64) CEA-SNEA:
"Prototype of an Underground Heat Storage System at Thiverval-Grignon (France)", in S.H.S., Proceedings, Part II, pp. 744-749

65) G. GUSTAFSON:
"Aspects on Heat Storage in Aquifers", in S.H.S., Proceedings,
Part I, pp. 246-252

66) J. HAGELSKJAER, J.A. LETH, J. MORTENSEN:
"Underground Heat Storage in Hørsholm, Denmark", in S.H.S.,
Proceedings, Part I, pp. 232-241

67) R. BONFILS, J. ADNOT, P. IRIS:
"Solar Heating and Seasonal Heat Storage in Aquifer", in S.H.S.,
Proceedings, Part II, pp. 730-736

68) G.J. GROENEVELD, A.L. SNIJDERS:
"Aquifer Thermal Energy Storage as Part of the Dutch National
Solar Energy Research Programme", in S.H.S., Proceedings, Part II
pp. 757-761

69) P. IRIS, J.P. MARIE:
"Overview of the French Activity in the Field of Heat Storage
in Aquifer", in S.H.S., Proceedings, Part I, pp. 242-245

70) G. FANINGER, H. RÜNZLER:
"Experiences with Solar Coupled Storages with Heat Pumps for
Space Heating in Austria", International IEA Workshop on Solar
Ground Coupled Systems, Ispra, Italy, 1982

71) M. BRUCK, P. BLUM, E. HELD:
"The Solar House Obdach - Experiences with a Solar Ground-Coupled
Storage System", International IEA Workshop on Solar Ground
Couple Systems, Ispra, Italy, 1982

72) M. BRUCK, G. SCHAFFAR, A. SIGMUND, G. SPIELMANN:
"Alternative Energy Project Innsbruck-Kranebitten", Austrian Institute for Building Research, Vienna, Final Report for the IEA Task VII Subtask le, June 1983

73) F. BAYLIN, S. SILLMAN:
"The Value of Storage in Annual Cycle Solar Heating Systems", SERI/TR-721-1168, September 1981

74) C.J. SWET, F. BAYLIN:
"Central Unresolved Issues in Thermal Energy Storage for Building Heating and Cooling", SERI/RR-721.455, July 1980

75) D. VAN HATTEM:
"Solar Heated High School Center in Northern Italy", Final REport for the IEA Task VII Subtask le, June 1983

76) T. BRUCE et al.:
"Södertuna - The Solar Heated Community 525 Flats", Final Report for the IEA Task VII Subtask le, June 1983

77) P. MARGEN:
"Seasonal Thermal Storage - Swedish Practice, Developments and Cost Projections", Studsvik Energiteknik AB, Nyköping, Sweden, 1981

78) C.F. MEYER, W. HAUZ:
"Guidelines for Conceptual Design and Evaluation of Aquifer Thermal Energy Storage", Pacific Northwest Laboratory, PNL-3581, October 1980

LIST OF THE IEA TASK VII REPORTS

1. Tools for Analyzing Central Solar Heating Plants with Seasonal Storage,
Verne G. Chant, Ronald C. Biggs,
Subtask I(a) - June 1983 - Document CENSOL 1
Distribution: Technical Information Office
Solar Energy Program
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National Research Council
Ottawa, Ontario K1A OR6, Canada

2. The MINSUN Simulation and Optimization Program - Application and User's Guide,
prepared by Subtask I(a) participants from Canada and Sweden - Document CENSOL 2
Distribution: see Report N° 1

3. Basic Performance, Cost, and Operation of Solar Collectors for Heating Plants with Seasonal Storage,
Charles A. Bankston
Subtask I(b) - May 1983
Distribution: National Technical Information Service
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Springfield, Va. 22161, USA

4. Heat Storage Models/Evaluation and Selection,
Jean-Christophe Hadorn, Pierre Chuard,
Subtask I(c) - June 1983
Distribution: EDMZ
3000 Berne, Switzerland

5. Cost Data and Cost Equations for Heat Storage Concepts,
Jean-Christophe Hadorn, Pierre Chuard,
Subtask I(c) - June 1983
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6. Heat Storage Systems: Concepts, Engineering Data, and Compilation of Projects,
Pierre Chuard, Jean-Christophe Hadorn,
Subtask I(c) - June 1983
Distribution: EDMZ
3000 BERNE, Switzerland

7. Basic Design Data for the Heat Distribution System,
Thomas Bruce, Lennart Lindeberg,
Subtask I(d) - October 1982 - Document D22:1982, ISBN 91-540-3819-7
Distribution: Svensk Byggtjänst
Box 7853
S - 10399 Stockholm, Sweden

8. Central Solar Heating Plants with Seasonal Storage - Preliminary Designs for Ten Countries,
Subtask I(e) - 1983
Distribution: see Report N° 7

This report is part of the work within the IEA Solar Heating and Cooling Programme.
Task VII : Central Solar Heating Plants with Seasonal Storage
Subtask 1c: Heat Storage

This report deals with the seasonal storage of energy by means of sensible heat. The aim is to present basic engineering information for the different heat storage concepts considered in the IEA Task VII for Central Solar Heating Plants Seasonal Storage (CSHPSS).

The report describes briefly the heat storage concepts and their applicability, reviews the present situation of the heat storage technology in participating countries, and presents a short technical compilation of some interesting projects in participating countries.

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