SOLAR COMBISYSTEMS

Task 26

Industry Workshop

Espoo, Finland, October 9, 2000

Compiled by Werner Weiss

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

Industry Workshop

Task 26 - Solar Combisystems

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13:00 h	**Welcome Address** *Heikki Reijonen, Fortum* ***Prof. Peter Lund and Petri Konttinen, Helsinki University of Technology***
13:15 h	**The Solar thermal market in Finland and future plans** *Prof. Peter Lund, Helsinki University of Technology*
	SOLAR COMBISYSTEMS – GENERAL OVERVIEW
13:30 h	**Solar Combisystems – scope and goals of Task 26** *Werner Weiss, OA Task 26, Austria*
13:45 h	**Durability and reliability of solar combisystems** *Peter Kovács, Swedish National Testing and Research Institute, Sweden*
	SOLAR COMBISYSTEMS FOR MULTIPLE FAMILY HOUSES
14:10 h	**The Ekoviikki-Large Scale Solar Project: project overview and general system design** *Heidrun Faninger-Lund, SOLPROS AY, Finland*
14:25 h	**Multifamily houses with solar system and district heating connection** *Heikki Reijonen, Fortum Power and Heat, Finland*
14:40 h	**Multifamily houses with solar and geothermal heating system** *Risto Kilpi, Shield Ltd, Finland*
14:55 h	**Discussion + Questions**
15:10 h	***COFFEE BREAK***
15:35h	**Monitoring results of a Swiss 30 m² system with 11 m³ storage tank** *J.C. Hadorn*, Swiss Research Program, Switzerland
15:55 h	**Solar Combisystem for a multi-apartment building – the Klosterenga Project in Oslo** *Michaela Meir, University* of Oslo, Norway
16:15 h	**System design and monitoring results of Austrian large scale solar combisystems for multiple family houses and office buildings** *Werner Weiss,* AEE, Austria
16:35 h	**Wagner Office Building** *Klaus Vajen, University of Marburg, Germany*
16:55 h	**Performance of an Air-based solar thermal System after twenty Years of Operation** *William A. Beckman, University of Wisconsin, USA*
17:15 h	***COFFEE BREAK***

17:40 h	**Space heating and DHW system with standard tank** *Klaus Ellehauge, SolEnergiCenter Denmark*
	CONNECTING SOLAR COMBISYSTEMS TO A DISTRICT HEATING NETWORK
18:00 h 18:20 h	**Modular heat exchange module for solar heating systems** *Pertti Ruotsalainen, LPM OY Finland* **Discussion + Questions**
19:00 h	**End of workshop – Dinner and informal discussions**

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THE SOLAR THERMAL MARKET IN FINLAND AND FUTURE PLANS

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The share of renewables energy sources in the Finnish energy balance is 22% and about 80% of this is bioenergy. New renewables such as solar energy and wind power have a negligible share. As a part of the agreements on climate (Kyoto), the Finnish Government has increased its efforts both in energy efficiency and renewable energies.

In its recent programme for promotion of renewables energy sources, the Ministry of Trade and Industry has set as a goal to increase the use of renewables by 50% by year 2010 compared to year 1995. The increase corresponds to 3 Mtoe. As a long-term goal for year 2025 is the doubling of the renewable energy use. The budget for the Action Plan is about 100 million EUR/year. Most of the increase in renewable energy comes through biomass and especially forestry related biowastes but also new renewables have penetrated into the programme.

The Finnish Action plan on renewable energy sources includes goals for solar energy utilization. By year 2010, solar energy should contribute by 0.1 TWh/year which will be met with 100.000 m2 of solar thermal systems and 40 MWp photovoltaics. For comparison, in year 2000 there will be some 10.000 m2 of active solar systems and 2 MWp of PV systems in total in Finland. In addition there are some 100.000 m2 of simple solar air collectors for crop drying.

Based on the Government's goals for solar energy, a more concrete action plan for solar energy is under preparation for the National Technology Agency (TEKES). TEKES is the main government agency responsible for technology development in Finland. In addition to meeting the energy targets for solar, the solar action plan includes a comprehensive plan for technology projects financed both by the private and public sector. Solar energy for the built environment and remote applications are of high priority but also special areas such as combined use of solar and biomass are considered. New solar technology components and applications are foreseen outgoing from the national industrial strenghts and competitive advantages such as IT technology, low temperature heating systems, district heating, materials etc. The interest shown by the industry in the solar action plan is encouraging.

SOLAR COMBISYSTEMS – SCOPE AND GOALS OF TASK 26

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1. Introduction

Solar heating systems for combined domestic hot water preparation and space heating, so called solar combisystems or SDHW&H systems, are increasing their market share in several countries such as Austria, Germany, Denmark, the Netherlands, Switzerland. In some countries, such as Sweden, they have been the dominant solar system type over a long time period.

Much is already known about solar domestic hot water systems, but solar combisystems are more complex and have interaction with extra subsystems. These interactions profoundly affect the overall performance of the solar part of the system. The general complexity of solar combisystems has led to a large number of widely differing system designs, many only very recently introduced onto the market. After the first period of combisystems (1975-1985) where design of not standard and complex systems by engineers was the rule, a new period has been opened since 1990. Now the design is done essentially by solar companies trying to sell simpler and cheaper systems. But current designs result mainly from field experiences and they have not yet been carefully optimised. Experts believe that substantial potential for cost reduction, performance improvement and increase in reliability exist and that this needs to be scientifically addressed.

International co-operation is needed to analyse and review more designs and ideas than one country alone could cover. Collaborative work in analysing and optimising combisystems is therefore a proactive action that can favour good systems on a more global market than the national one.

2. Scope and main activities to be undertaken

System survey, simulation tools and a standardised test procedure are the necessary infrastructure for understanding and supporting the growing market of solar combisystems. A unique classification and definitions are the necessary basis for any discussion and comparison of different system designs. Simulation gives insight in the thermal behaviour of solar combisystems, which is needed for development, and also for designing and sizing such systems. A standardised test procedure will allow for rating solar combisystems under standardised conditions for testing and for performance prediction. This will lead to greater confidence of the end user in this technology.

Task 26 will review, analyse, test, compare, optimise and improve designs and solutions of solar combisystems for:

- detached one family houses
- groups of one family houses, and
- multifamily houses or equivalent in load

with their own heating installations. This Task does not refer to solar district heating systems or systems with seasonal storage or central solar heating plants with seasonal storage.

Companies from several participating countries will be taking part in the work. This will help to make the results of the Task more relevant to the solar heating industry in general.

3. Subtasks

A: System Survey and Dissemination of Task Results

The objective of this Subtask is to present to a wide audience various solar combisystems designs and their respective figures of merits, so as to increase the penetration of good solar combisystems on the market. The production of a yearly newsletter, targeted at solar industry, a colour brochure presenting existing and new solar combisystems and the preparation of a handbook on solar combisystems are the main results of this subtask.
Subtask Lead Country: Switzerland

B: Development of Performance Test Methods and Numerical Models for Combisystems and their Components

The objective of this Subtask is to provide reliable means of evaluation and comparison of different solar combisystems components and designs. The objectives will be achieved by selecting existing performance test methods for evaluating, rating and comparing elements of solar combisystems, or developing new procedures, and by providing component numerical models needed to assess performances during tests as well as models for systems needed to simulate and optimise system configurations.
Subtask Lead Country: The Netherlands

C: Optimisation of Combisystems for the Market

The objective is to enhance existing solar combisystems designs by optimisation based on simulation models of the systems and to help industry to propose new system designs being able to match demand with better thermal and economical performances and better durability than before. Aspects such as reliability will also be considered.
Subtask Lead Country: Austria

further information: ***www.iea-shc.org/***

DURABILITY AND RELIABILITY OF SOLAR COMBISYSTEMS

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Abstract

When designing a solar combisystem, or comparing different concepts for systems, durability and reliability has to be carefully considered. A set of European standards and pre-standards for solar energy components and systems is close to final approval. The focus has been set on thermal performance and short term reliability. This is a brief overview of how the durability issue is covered in the standards. Furthermore, a methodology for comparing the long term reliability of the combisystems using failure mode and effect analysis along with fault tree analysis is demonstrated.

1. Introduction

In order to assure the buyer of a Solar combisystem that the investment is sound he or she must be able to trust the system being able to deliver the announced quantity of renewable energy without major problems under a period of several years. This requires durable components which is achieved through the use of high quality materials, adequately chosen for the particular application. It also requires reliable systems and components i.e. with a low probability of failure. High quality components and appropriate maintenance schemes, preferably supported by highly developed systems for failure recognition- and handling as well as foolproof interfaces to the user will all contribute to this.

A basic Solar combisystem is comparatively reliable in operation as we know it. Still there are things that can be done to improve this. When comparing different concepts, durability and reliability has to be carefully considered in order to reach a true optimum.

2. The durability issue in the coming EN standards

A set of European standards and prestandards for solar energy components and systems is close to final approval. The focus has been set on thermal performance and an impressive set of test methods, software and reference conditions is presented to evaluate the components and systems from this point of view. The durability issue however, has not been as thoroughly handled in the process of preparing the standards. But a high performing system may soon be a low performing one if e.g.:

- Low quality- or improperly chosen materials for the specific application are used
- The installer is not provided with a good installation manual
- The user doesn’t understand the system function
- The system does not provide any simple means for checking it’s performance
- Improper heat transfer fluids are used in the system

This is a brief overview of how the durability issue is covered in those of the standards that are appropriate for solar combisystems. The purpose of this is to direct the attention of manufacturers and designers to the guidelines and recommendations concerning choice of materials and corrosion protection that is included in or appended to the standards. One final outcome of the work of Task 26 should be a compilation of these documents, adapted to practitioners.

In the standard **prEN 12975-1**, requirements on solar collectors are specified. Concerning reliability (short term), a number of tests are being performed e.g. high temp resistance, exposure test and rain penetration. “No major failure” which is the pass criteria means that none of the following occurs:

- Absorber leakage or deformation leading to permanent contact between cover and absorber
- Breaking or permanent deformation of cover or cover fixing
- Breaking or permanent deformation of collector fixing points or collector box
- Vacuum loss
- Accumulation of humidity inside the collector

No tests to ensure the long-term durability of the collectors are required.

Information about durable materials and designs and references to appropriate test methods are given in the *informative* annexes B and D.

In the standard **prENV 12977-1**, requirements on custom built systems (here: solar combisystems) are specified. Among these can be mentioned:

- Requirements on materials (paragraph 6.2) which shall be UV- and weather resistant over the maintenance interval if they are used in outdoor application. Materials in collector loop shall be in compliance with *ISO TR 10217 “Solar energy-water heating systems. Guide to materials selection with regard to internal corrosion”.*

- For the store of a solar heating system (paragraph 6.3.7) parts in contact with drinking water shall comply with requirements in *prEN 12897 “Water supply- specifications for indirectly heated unvented (closed) hot water storage systems”.*

- For the pipe work of a solar heating system (paragraph 6.3.8): Design of system and used materials shall be such that there is no possibility of clogging which could drastically reduce performance. Materials shall withstand stagnation conditions and thermal expansion.

- For the thermal insulation (paragraph 6.3.9): All thermal insulation shall comply with the requirements in *prEN 12828 “Heating systems in buildings-Design and installation of water heating systems”*. It shall be resistant to stagnation temperatures and outdoors protected against solar radiation, weather and animal impact.

3. Reliability assessment of solar combisystems

A great variety of system concepts are being presented in the collaborative effort of Task 26. In order to make these systems attractive to buyers on a mass market a number of properties are desirable. One of the properties is that the system function is *reliable over the lifetime of the system*. To be able to introduce this as a system specific parameter that can be compared to other system’s, a technique to analyse it is required. The results can also be used in the design process of a solar combisystem.

In the following, an outline of how such an analyse could be made is drawn. The analyse is applied to an HVAC- system which in many respects is similar to a solar combisystem. However, the combisystem represents a young and at least as complex technology which means that the analyse will be somehow different. Major differences and possible obstacles when applying a similar methodology to a solar combisystem are discussed below.

Here, a combination of Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) [1] and [2] is used to assess the reliability of a mechanical exhaust ventilation system for a single family house [3]. A schematic illustration of the procedure is shown in figure 1.

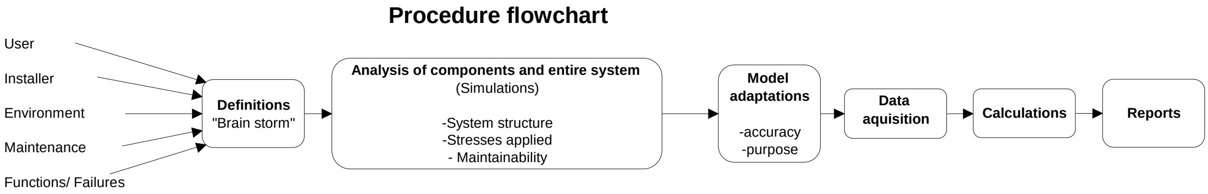

Fig. 1: Flowchart showing the procedure of the system reliability analysis.

The calculations of reliability on the component level is based on the following definition:

The reliability of a component means the probability that the component performs in such a way that the design flowrate of the system is maintained within a certain interval.

For each component, a mean lifetime and a standard deviation from this mean is derived. These are then used to calculate the reliability of the component, see figure 2. A normal distribution for the probability of failure is used. In this context “lifetime” means time elapsed until the particular component causes the system’s design flow rate to drop below the desired level. For a ball bearing this will be equal to it’s true lifetime, but for an air duct it will mean the time up to a certain degree of fouling. In addition to this, a simplified model for maintenance states that the component is “as good as new” after each maintenance interval. By connecting the component probabilities in a fault tree the reliability of the system can be calculated.

In the HVAC case, three different quality standards for the components and three different levels of maintenance intensity were defined. This lead to nine different predictions of the reliability of each given system configuration. In figure 3 the predictions for a system of average quality components and high and low maintenance intensity respectively are shown.

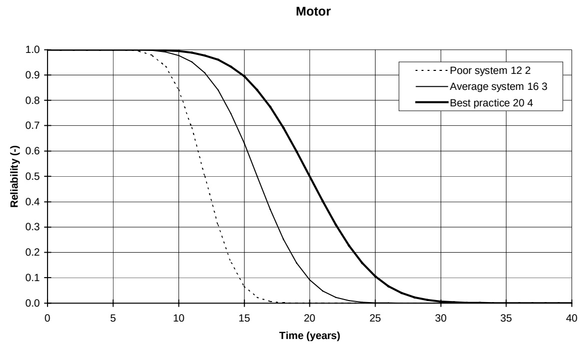

Fig. 2: Reliability of a component as a function of mean lifetime (m) and standard deviation (s).

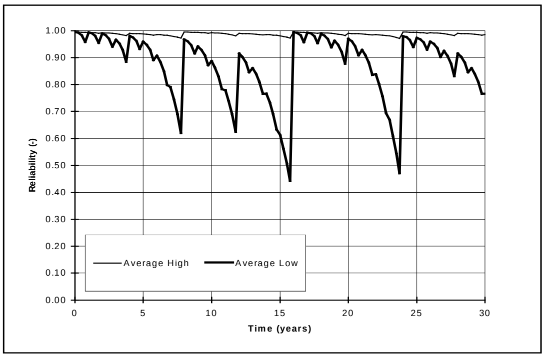

Fig. 3: Reliability on system level. Average quality and high and low level of maintenance intensity.

Resulting mean and minimum values over a time span of 30 years are finally summarised in a matrix, table 1. These values are the key numbers to be used when the system is compared to others.

Table 1: System reliability key values: Mean and minimum over 30 years

Type of system	Reliability	Maintenance intensity		
		High	Medium	Low
Poor system	Mean	0.97	0.88	0.64
	Minimum	0.90	0.48	0.04
Average system	Mean	0.99	0.97	0.87
	Minimum	0.97	0.86	0.44
Best practice	Mean	0.99	0.98	0.94
	Minimum	0.98	0.95	0.71

In a solar heating system, the target function for an analyse of the reliability should be the fractional energy savings.

Component data in general is difficult to get, and the fact that this is a young technology will not make this task easier. In the example mentioned, data was gathered from empirical experience of maintenance personnel and researchers. A similar approach will be tried within this project and here, the experts within Task 26 will be a big asset. Particularly when it comes to estimates of probabilities of the more “solar specific” events such as e.g. pressure loss due to overheating, clogging of filters due to degraded heat transfer fluid, different effects of failures due to sensor breakdown etc.

Furthermore, environmental factors such as the irradiance levels, ambient temperatures, humidity and the quality of the water will have a stronger and less predictable influence on the system than in the HVAC case. The same can be assumed for the influence of human action on the system. The installer’s know-how will definitely have an effect on the probability of a fault free system function. The user will most certainly be more engaged in the system function than in the case of an air handling device and thus he is to be considered as a potential threat or a possibility when it comes to estimates of failure probabilities.

The purpose of the predictions will govern the requirements on accuracy and depth in the analysis. In this case, the figures of reliability will be used to compare the different system concepts within the task. Other possible uses of this data could be as a design parameter, to identify weak points in a certain system or for the planning of maintenance intervals.

4. Conclusions

Demands on high performance at low cost, reduced environmental impact and ability for recycling of materials can be difficult to combine with the ones asking for durable and reliable systems. The European standards for solar technology are mainly focused on performance and reliability issues and the explicit requirements on durability are few. However, the documents contain a great deal of information on how to reach a durable system. Furthermore it has been shown how a combination of Failure Mode and Effect Analysis and Fault Tree Analysis can be used to assess the long term reliability of a solar combisystem.

References:

[1] International electrotechnical commission, IEC standard. Publication 812.Analysis techniques for system reliability- Procedure for failure mode and effects analysis (FMEA), 1985.

[2] International electrotechnical commission, IEC standard. Publication 863. Presentation of reliability, maintainability and availability predictions, 1986.

[3] Kronvall. J et al. IEA Annex 27, Volume 6 Reliability of domestic ventilation systems. 1998.

THE EKOVIIKKI-LARGE SCALE SOLAR PROJECT: PROJECT OVERVIEW AND GENERAL SYSTEM DESIGN

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Abstract

Ekoviikki solar project is the largest realized solar heating system in Finland. Consisting of 9 different subsystems and with a total areas of 1,246 m^2, Ekoviikki provides a very interesting case for comparison of slightly different solar combi system approaches. Different integration aspects have been given much thoughts in Ekoviikki. For example, for the collectors a large-module roof integrated approach was chosen. In addition to dhw, the solar systems may provide heat for space heating and also for low-temperature floor heating.

Ekoviikki solar project started in 1997 with an exploratory project initiated and coordinated by SOLPROS. This lead later to a E.C. Thermie A project in which 7 Finnish partners and 2 Austrian partners realizes the construction of the solar systems. The Thermie project started in early 1999 and by now 4 have been fully completed, 3 are in the finishing phase, and 2 are in the design phase. The first prelimenary measurements from the summer 2000 indicate that expected and measured performance match. The expected solar output for the Ekoviikki site is around 400 kWh/m^2, yr. The solar systems provide some 45-50% of the dwh and 10-15% of the total heat demand. The total project cost is about 0.8 MEUR.

The general solar design in Ekoviikki comprises a solar dhw system connected with district heating. The storage discharge has been given special attention to maximize solar output with dh backup. In some of the 9 solar systems, a floor heating connection has been done as the space heat for bathrooms and saunas may be considerable even in the summer. Health issues have been given consideration starting from the whole building planning ending to practical issues such as legionella prevention and mold protection.

MULTIFAMILY HOUSES WITH SOLAR SYSTEM AND DISTRICT HEATING CONNECTION

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Abstract

In order to obtain the highest possible solar fractions for domestic hot water and heating applications various Integrated Hybrid Renewable Energy Systems (IHRES) have been studied and implemented in Finland during the recent years.

Typically the best applications are those communities that are located in the rural environment and where the relable supply of biomass in the form of wood chips or dry burnable municipal waste can be organized in an economical way. The optimum way to use solar heat systems in these types of situations is to concentrate the collectors into fields of some 200 m^2 and couple them into the local building services systems or alternatively into the district heating network to minimize distribution losses in the system. This type of a system design could also help eliminating those situations where solid fuel based boilers would operate under very low loads and efficiencies.

As an example the district heating scheme for the City of Laihia is shown, illustrating also the connection of the solar system to a school building with a Thermonet system supplied by ABB. Operating experiences of the overall heating scheme will be shown.

MULTIFAMILY HOUSES WITH SOLAR AND GEOTHERMAL HEATING SYSTEM

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Abstract

Countries located at sub arctic areas can annually receive solar radiation energy having cumulative value 1000 kWh/m2 (southeast + south + southwest). Traditional solar systems can produce hot water and also room heating, but typically these systems work as independent part without any better, intelligent optimized level of system.

If noteworthy part of the received solar radiation can be transformed and reserved having high coefficient of efficiency the situation is better. And if this energy will become part of the whole building energy balance thus it will make this energy structure more beneficial in the long term run.

So simple, but also difficult the make it as a reality. We decided to combine geothermal heating and great number of solar collectors. The result is low exergy energy production system called Hot&Cold. And first installation was carried out 15 apartment housing development in Northern Western Finland.

1. State-of-the-Art solutions

Summer 1998 Shield Oy started to create design parameters which set limits for good coefficient of efficiency and for example the number of solar collectors. We make things opposite way so we did not try to find the best features and then produce optimal combination. We decided to challenge problematic aspects on existing field of technology.

Things that make the use of solar energy problematic in northern countries:

- big thermal losses during spring/autumn period
- huge solar radiation variation compared winter and summer time
- maximum load and low radiation culmination in same time of the year
- summertime gives ”too” much energy from collectors
- large thermal reserves are expensive

The use of geothermal energy is difficult in north because of:

- ground temperature (wells) is not so high (typically +6…+9 deg. Celcius)
- bed-rock gets easily too (near zero) cold and it effects low operation coefficient

- radiator heating requires high temperature and also it effects low operation coefficient

2. Conclusion

Process description was built, where aforementioned imposing reasons were added together and we indeed received the solution. But that process and it's functionality wasn't good enough thinking of a real system and it's construction. Most difficult phase was then done when the simplification of the process was carried through.

Some base principles are:

- thermal heat wells / pumps (units I, II, III,…) runs all the year round
- solar collectors starts working if intensity is enough
- collectors produce temperature:
  - ***T[out] or T[bed-rock] + Delta-T, where Delta-T is typically low***
- thermal heat is always reserved into the bed-rock (long term / short term)
- “old” and “new” geothermal heat is combined as low temperature energy reserve
- temperature cooling of a bed-rock is (over)compensated
- low temperature floor heating use instead radiators

Fig. 1: Test target, multifamily house in Kurikka

MONITORING RESULTS OF A SWISS 30 M² SYSTEM WITH 11 M³ STORAGE TANK

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Abstract

The RENOVA project is the retrofitting of a 1900 house so that the available floor area is doubled but with a strongly reduced energy demand and with a high solar both passive and active solar fraction. The project was completed by the owner of the house, M. J. Aeschbacher in three steps: thermal insulation of the envelope of the redesign construction, greenhouse extension of the south wall, solar combisystem with largely sized component in order to target a 100% solar installation. The owner has received financial support from the Geneva canton and the Swiss federal office of energy for this pilot project called RENOVA.

The combisystem is not of common type in Switzerland, since the primary goal of the project was to demonstrate the possibility of reaching high solar fractions with a reduced storage volume compared to previous projects such as the Jenni houses. The solar combisystem has been intensively monitored by CUEPE of Geneva University from June 1997 to December 1999 within the Swiss research program “Solar Heat” of the Federal Office of Energy. The goal was to assess the solar fraction of the combisystem and to evaluate the interest of the seasonal underground storage that was tested on this pilot project.

1. System description

The building is a villa built at the beginning of the century and renovated in 1994-1996 with an external insulation, double glazed with selective coating windows and a greenhouse. The living area is 97 m^2. The house is occupied most of the time by two persons. Technical data for the new heating system built in 1997 (fig.1) are:

- 31 m^2 of flat plate collector, roof integrated, with selective absorbers and low emissivity glass, tilt angle 33°, south oriented.
- 11 m^3 of water tank storage with a stainless DHW tank placed inside the main tank, without any auxiliary heater inside the tank,
- a heat storage in the clay soil beneath the house, with 7 boreholes of 7 m deep (∅ ¾ en PE,∅ 12 cm filled with bentonite) tilted at 45° and drilled from the cellar beneath the house, the storage was built by the owner and intended to be a test prototype of a cheap seasonal summer heat storage,
- a condensing gas burner of 15 kW, placed in serie after the storage in order to avoid to store heat from gas in the storage
- low temperature radiator for the heat distribution.

The monitoring equipment has 44 temperature sensors, with acquisition every 15 seconds and storage every 30 minutes. 24 months of data are available.

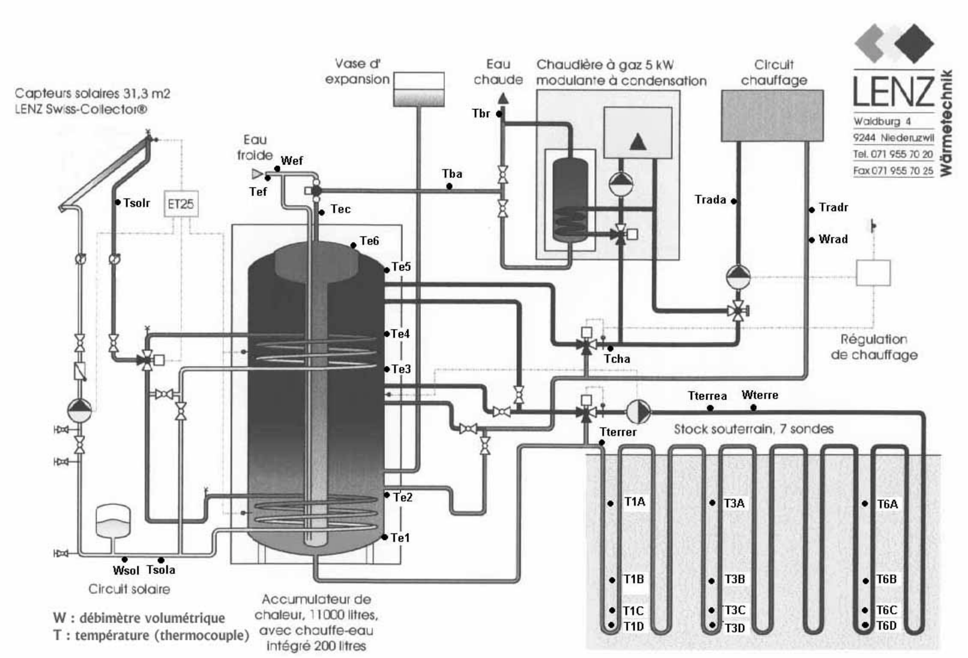

Fig. 1: Layout of the solar combisystem aimed at 100% solar

2. Main results of the two years monitoring program

2.1 The solar collectors

The solar roof has good performances for a reasonable cost. Under the following equation, the parameters of the collectors are:

$$Q / G\,t = \eta_0 - K_0 \Delta T / G - K_1 \Delta T^2 / G - C \Delta T_C / G\,t$$

t =30 minutes
ΔT =$T_{absorber} - T_{ambient}$[K]
ΔT_c =absorber temperature variation [K]
η_0 =optical efficiency
Q =useful solar energy [J/m^2]

G =incident solar power [W/m^2]
K_0 =thermal loss coefficient [W/m^{2}K]
K_1 =thermal loss 2èmeorder coefficient [W/m^{2}K^2]
C =heat capacity of the solar circuit [J/m^{2}K]

	Optical efficiency η_0	K_0 [W/m^{2}K]	K_1 [W/m^{2}K^2]	C [kJ/m^{2}K]
Average value	0.90 ± 0.03	5.11 ± 0.3 *	0.0095 ± 0.003 *	19.17 ± 3 *
As of Rapperswill	0.83	3.6	0.012	-
Night time value	-	4.95 for ΔT between 15 and 20°C		16.3

* including solar circuit plumbing

Fig. 2: Table of collector performances

The value obtained for the optical efficiency is higher than that of the standard test done by SPF in Rapperswill [2]. This is due to the different glass of the cover and also to the measuring conditions with lower deltaT than during a standard test. The heat loss coefficient K is also higher, but includes the loss of the solar circuit piping up to the solar heat exchanger. The night time value confirms however the field value. It should be noted that the collectors were roof integrated so that they might slightly differ from the collector given by the manufacturer to the SPF for the test.

The heat capacity of the solar loop was measured during a cooloing down test as C= 16.3 kJ/Km^2 which is close to the one calculated based on the materials or measured during operation at day time compatible (19±3 kJ/Km^2). The data monitored from June 1997 to May 1998 have been used to derive the input-output diagram of the solar roof (ill. 3).

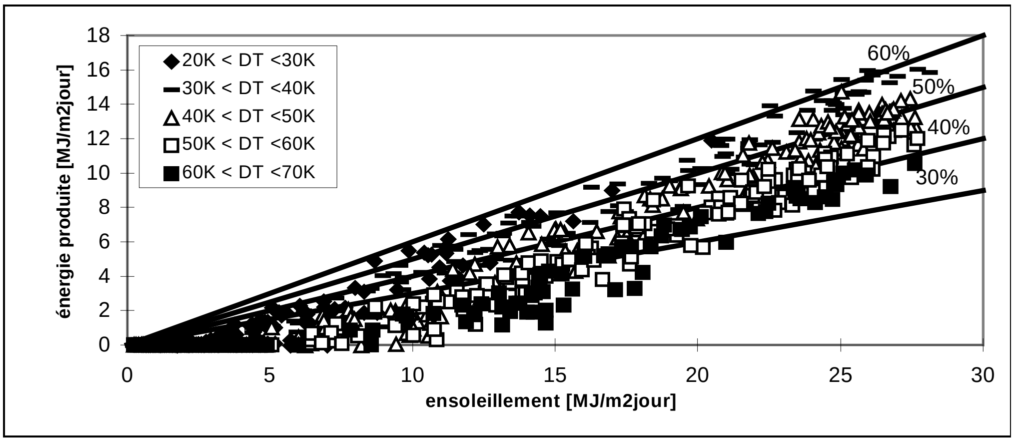

Fig. 3: Daily input-output diagram of the collectors

The daily efficiency of the solar roof is greater than 50% in summer time, when the tank temperature in kept below 60 C by injecting all excess heat in the earth storage. The efficiency is still 30 to 40% in Autumn when the tank temperature is above 60 C and the operating collector ΔT (Tabs-Tamb) exceeds 50K. These values are excellent and demonstrate the good quality of the solar roof integrated collectors.

2.2 The earth storage

The earth storage function was primarily to store excess heat from collectors in summer and to cool down the storage tank, keeping it at 60C during spring and 80C at the end of the summer hot period. The earth temperature close to the boreholes never exceeded 55C and decrease rapidly to 30C when the loading is stopped. Figure 4 shows that no withdrawal during winter time was possible since the seasonal heat losses of the earth volume (150 m3 approx.) are much too high. At the beginning of the summer season, 25 W/m of pipe could be injected, whereas at the end the value was closer to 15 W/m. Per borehole the injection capacity is 60 W/m.

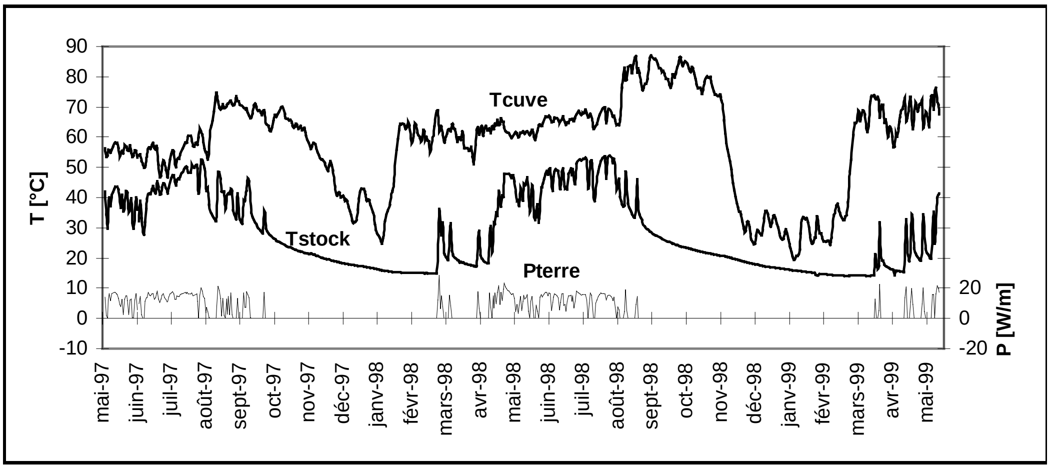

Fig. 4: Evolution of the earth storage temperature and the stored energy

Figure 5 shows that the heat flux from earth to cellar is positive until the month of Februar so that three is some passive heat recovery from summer to winter, but few.

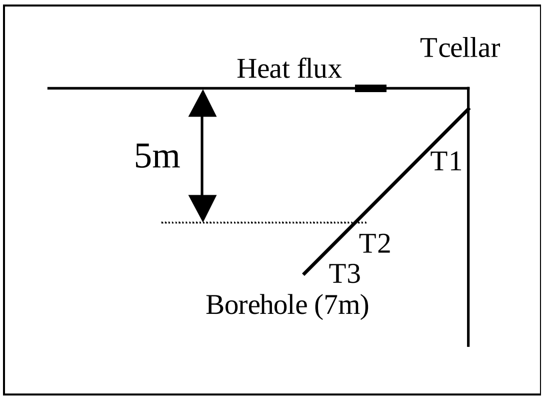

Fig. 5: Heat flux and temperature difference between earth and cellar.

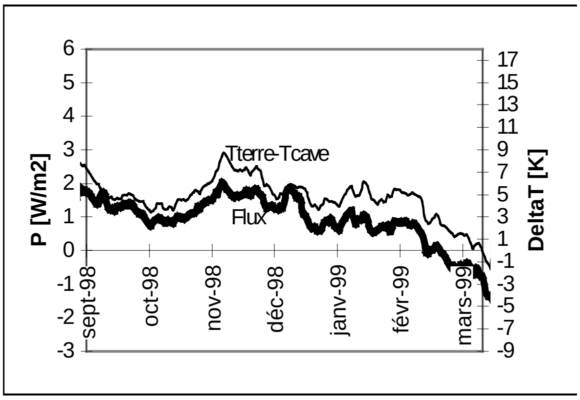

Fig. 6: location of sensors within a borehole..

An estimation based on the ratio P/ΔT_{CT} gives a thickness of active earth (λ = I .8 à 2.2 W/Km) between 5 and 10 m, which is what was expected (fig. 6). A more detailed study of the behaviour of the earth storage is planned [1].

2.3 The water tank storage

The energy balance of the tank storage from June 1997 to May 1998 is shown in Figure 7.

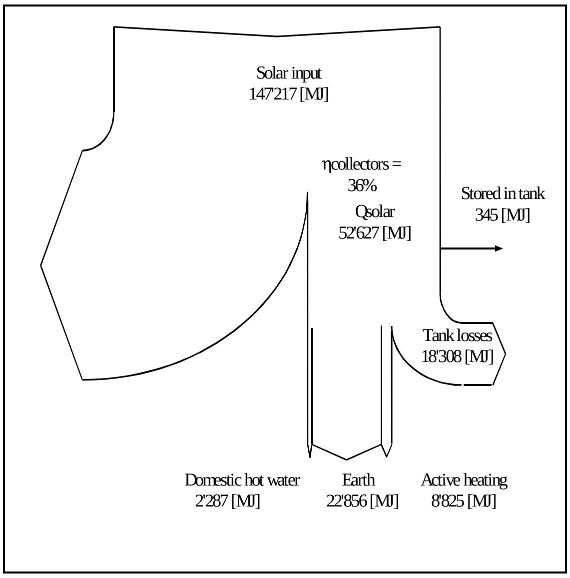

Fig.7: Energy balance of the tank

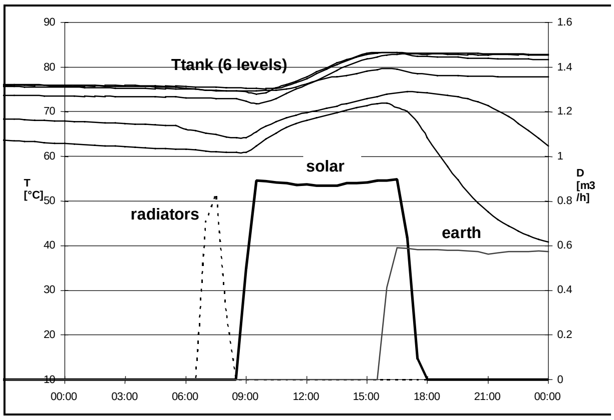

Fig. 8: Temperature stratification in the tank and flow rates on May 16th, 1999.

The main results of this project are:

- The average efficiency of the solar loop over one year is 36% and all the DHW demand has been met by solar energy. The yearly output from the solar loop has been a very good 470 kWh/m^{2}year
- Most of the collected solar energy (Qsolar) was injected into the earth storage. Only 21 kWh/m^{2}an have been used for DHW needs and 25 kWh/m^{2}year for the house heating. The contribution of the earth storage to the house heating is difficult to estimate but the heat losses through the basement of the house are not fully compensated during wintertime.
- The heat losses of the water amount to approx. 35% of the stored energy. The K value of the tank 21W/K (that is 0.2 W/K per 100 liters).

The temperature stratification in the storage is complex (fig. 8), three water fluxes cross the tank daily : the heating loop, the solar loop and the earth storage loop.

2.4 The energy balance of the house

The energy balance of the house from June 98 to June 99 is shown in figure 9. The balance error is 12% (29 MJ/m^2 compared to 255 MJ/m^2 total heat losses). The gas burner has not been used during the two years of monitoring. The external energy used was wood in the chimney : the energy index of this consumption is low 85 MJ/m^{2}year for winter 98-99 (520 kg of dry wood, 16 MJ/kg, efficiency around 70%).

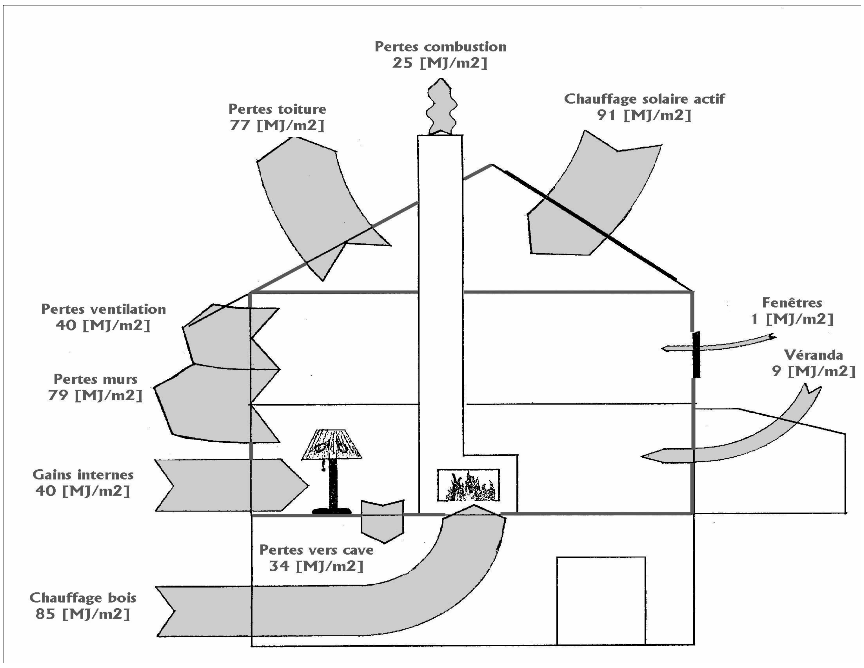

Fig. 9: Energy balance of the house

3. Conclusions

- The owner of the monitored house wanted to reach almost 100% solar for a total investment less than 70’000 CHF. He succeeded.
- In any renovation, building envelope insulation is the first point to focus on
- In a low energy house, a combisystem with 30 m2 of collectors and 11 m3 of storage under the swiss plateau conditions can meet the goal of being almost 100% solar.
- The storage volume of 11 m3 might not be the minimum for the same goal.
- A non insulated earth storage can cool down the storage and collectors in summertime for a limited investment (10'000 CHF) but cannot act as a real seasonal heat storage. Its function as a cooling device has however to be replaced by another solution for such sized combisystems.
- Solar combisystems with a solar fraction objective of 40% can offer better economics.

The owner is pleased to have contributed to the scientifical knowledge of the solar energy domain and is also proud of living in a 90% solar and 100% renewable energy house.

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SOLAR COMBISYSTEM FOR A MULTI-APARTMENT BUILDING - THE KLOSTERENGA PROJECT IN OSLO

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Abstract

The Klosterenga residence represents a pioneer project of ecological dwellings as a part of urban revitalisation in the centre of Oslo. The project aim was among others to reduce to total energy consumption related to the building by 40%. The combined solar system for domestic hot water pre-heating and floor heating is presented, further the experiences from the energy monitoring during the first months.

1. Introduction

The Klosterenga project represented Norway in the Green Building Challenge '98 (GBC) conference at Vancouver. The GBC is an on-going international process focusing on the development and testing of a new system of assessing the environmental performance. Among 34 projects, which include office buildings, multi-unit apartment buildings and schools, this project has been selected for its suitability to test the GBC '98 assessment system. The most advanced element in the Klosterenga project is the integrated ecological and energy design process. As a result of this process most of the energy-saving measures are building- or architectural integrated elements. The general ecological approach contains elements of water-saving and local purification devices, reduced amounts of both garbage and building waste, focus on building materials from an ecological and indoor climate point of view, and of course, energy saving design and installations and use of both passive and active solar energy.

The Klosterenga residence is a free standing 6-floors building complex with 35 apartments, 10 two-rooms apartments, 10 three-rooms and 15 four-rooms apartments. The typical building population is 70 persons. The predicted total energy demand is approximately 300 000 kWh/a excluding the contributions from the active and passive solar systems. This paper focuses on the description of the active solar thermal system at the Klosterenga residence and the results of the first energy monitoring carried out between end of May - beginning of September 2000.

Fig. 1: The Klosterenga residence in Oslo with a solar combisystem, 218 m^2 collector area.

2. System description

The solar system has been delivered and installed by SolarNor AS. The design of the solar heating system has been an interactive process between the owner[1], architects[2], the building administrator[3] and the system deliverer from an early planning phase.
The solar system consists of 80 collector modules with an active collector area of 218 m^2. The collector field is an 'almost' building integrated roof construction. It forms the tilted south facing roof of the technical room which is built on the top of the building. The SolarNor collectors are made of engineering thermoplastics; the collector and the basic design of the system has been described earlier, e.g. [1], [2]. The solar collectors are part of a drain-back system.

The solar system contributes to domestic hot water (DHW) pre-heating and to space heating (floor heating). The energy flow in the solar heating system is schematically shown in Fig. 2. The solar heated water is delivered to the un-pressurized buffer store 1 (6,0 m^3). This store includes 6 immersed DHW pre-heating tanks at 200 l. The pre-heated water is delivered to two 15 kW-DHW stores with electric heating. The DHW is mixed with cold water so that the end-user will receive DHW at a temperature of approximately 45°C.

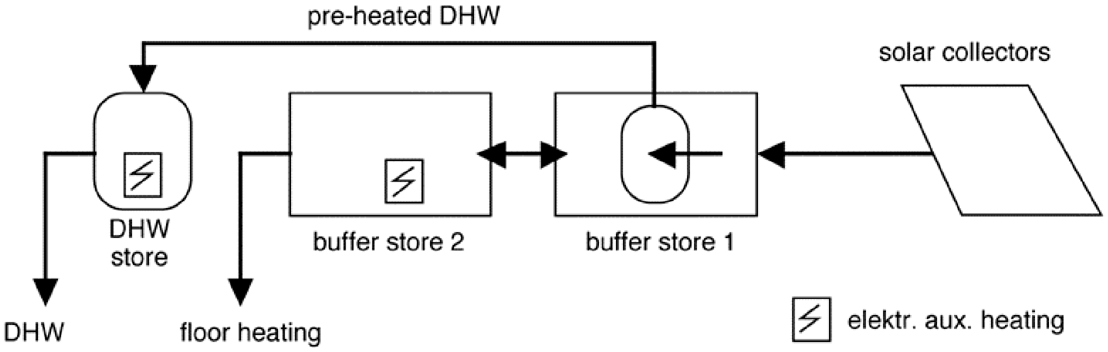

Fig. 2: Schematic energy flow in the solar system

A thermostat controlled circulation pump transfers heat from buffer store 1 to buffer store 2. Buffer store 2 is an un-pressurized tank of 6,5 m^3 which provides heat to the floor system. The auxiliary heating of buffer store 2 is governed by the ambient temperature through a dynamic thermostat function implemented in the solar controller. The space heating consists of a floor heating system in which 2901 m^2 heated floor area are directly coupled to the heat buffer store 2.

The design of the complete heating system is based on the principle that all demands are covered at lowest possible temperature. The system is constructed for direct transfer of energy without heat exchangers in order to keep the system temperature at a minimum level. The heat store and the controller are prepared for low cost night-tariff electricity which is expected to be introduced in the near future. The system details are specified in Table 1.

The temperature controller of the floor heating system in each dwelling is able to register the energy supplied. In this way the tenants will be charged according to individual consumption.

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[1] USBL, Storgt. 49, P.O. Box 4764 Sofienberg, 0506 Oslo

[2] Arkitektkontoret GASA AS, Nedre Slottsg. 11, 0157 Oslo, Akitektskap AS, Seilduksgt. 25, 0553 Oslo

[3] Veidekke ASA, Postboks 505 Skøyen, 0214 Oslo

Table 1. Specifications, solar combisystem at the Klosterenga residence

solar collectors	
type	SolarNor flat plate collector
heat carrier	water (drain-back-system)
collector modules	80 à 510 x 60 cm
gross collector area	240 m^2
active collector area	218 m^2
coupling	parallel, 2 fields à 40 modules
tilt angle	37°
DHW pre-heating, buffer store 1	
type, store	un-pressurized tank
material	stainless steel
volume	6,0 m^3
includes:	
6 DHW pre-heating tanks	1,2 m^3 (6 stk. à 200 l)
material	stainless steel
heat transfer capacity	approximately 700 W/K
auxiliary heating, DHW	
type	standard 15 kW DHW store, electric heating
volume	2 x 550 l
floor heating, buffer store 2	
type, store	un-pressurized tank
material	stainless steel
volume	6,5 m^3
electr. auxiliary heating	max. 150 kW (3 x 30 kW, 1 x 60 kW)

3. Energy monitoring

Figure 3 shows the schematic set-up of the solar combisystem at Klosterenga residence with the installed energy monitoring equipment. The energy monitoring and the analysis of the data is carried out by a calorimetric method, a technique for determining the solar system performance on the basis of in situ measurements [3].

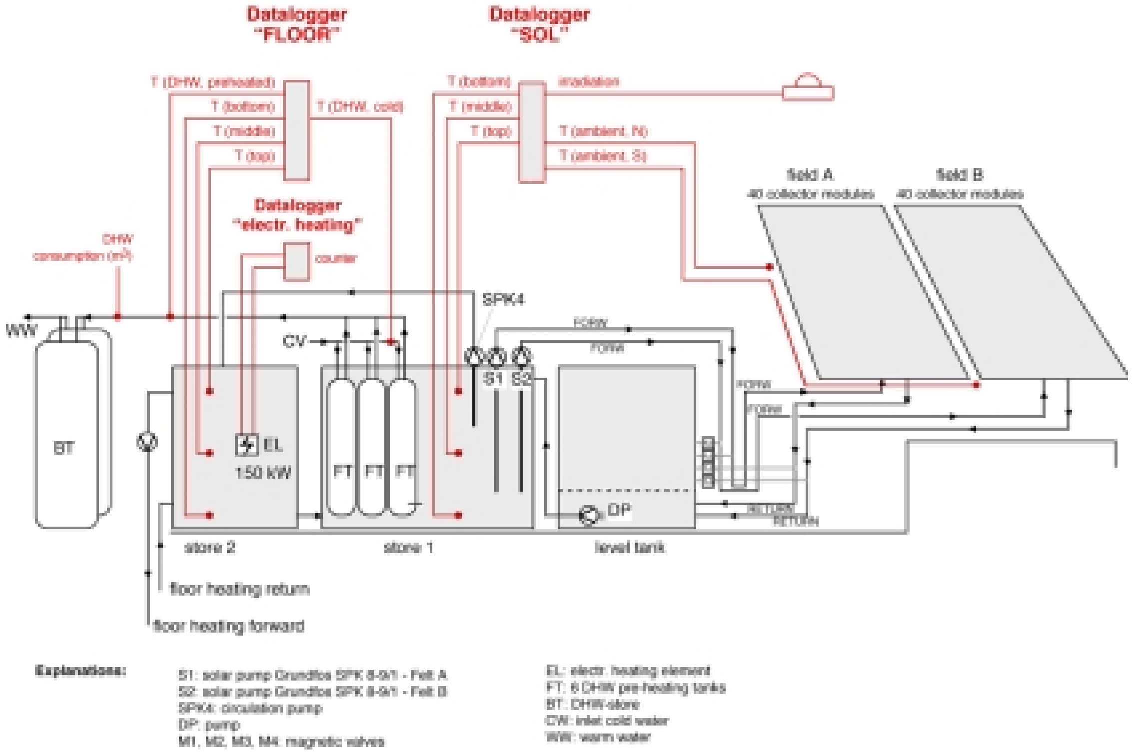

Fig. 3: Schematic set-up of the solar combisystem at Klosterenga residence with energy monitoring equipment

4. First Results

The start-up of the solar system was in May 2000. The energy monitoring is carried out since end of May. Fig. 4 shows the ambient temperature, the global solar irradiation and the profiles of the average temperature in buffer store 1 and 2.

The average temperature in buffer store 1 was from 23.5.-29.5. (no figure) between 20-65°C and for the period 1.8.-8.8. (Fig. 4) between 30-70°C. The average temperature in buffer store 2 was for the same periods between 34-44°C (May) and 30-44°C (August). The average ambient temperatures in the corresponding periods were

7-24°C (May) and 12-27°C (August). The total solar irradiation for August 2000 was approximately 120 kWh/m^2 or 3,7 kWh/(m^2d)][4].

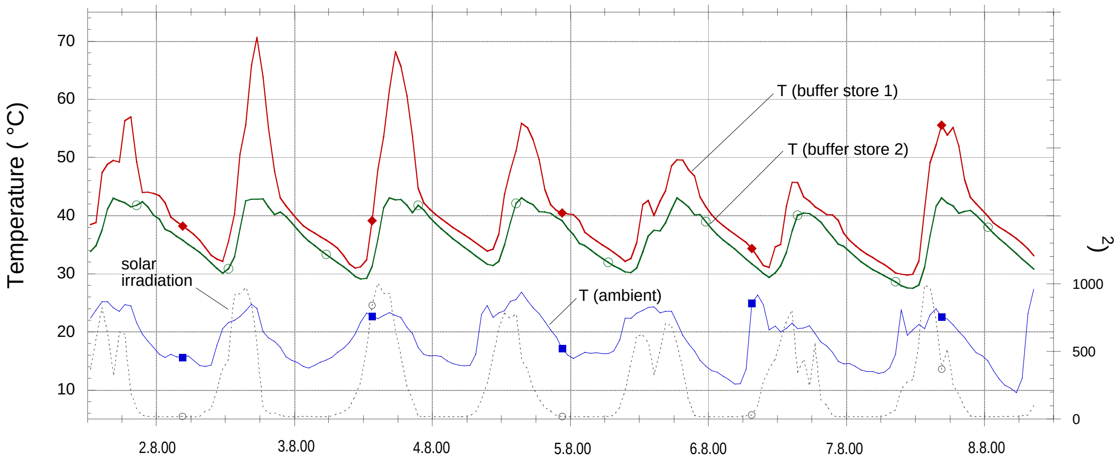

Fig. 4: Raw data of the energy monitoring period in the beginning of august.
The profiles of the ambient, the average temperature in buffer store 1 and 2 and the solar irradiation are shown.

The first results of the energy monitoring at the Klosterenga residence are shown in Table 2. The solar system has been operative in 101 of 109 days in the monitoring period from 24.5.-11.9. (no data were available for 2 days).

The total load for DHW preparation, space heating including the operation of all installations in the technical room (circulation pumps, etc.) was 59 400 kWh. The solar gain covered 29 300 kWh or 49%.

The total load for DHW preparation has been approximately 220-230 kWh/d.

The auxiliary heating load has been unexpectively high, 520 kWh/d in May falling to an average load in august of 143 kWh/d. The high demand during this period can be partly explained by the fact that the solar irradiation in 2000 has been significantly below the average irradiation for this location.

The reduced auxiliary space heating load for August and September is related to the introduction of the dynamic thermostat control after 28.7.2000. The consumption of electricity was reduced by approximately 190 kWh/d, basically related to that the solar gain increased. The relatively high space heating load is obviously related to the fact that the tenants want to keep a high comfort temperature in the bath room. In addition it has to be considered that the controllers of the floor systems in the single apartments are not optimally adjusted.

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[4] Here the solar irradiation has been integrated over periods when the solar system was operative.

Table 2: First results of the energy monitoring at the Klosterenga residence

period	avg. ambient temperature (°C)	aux. heating floor (kWh/d)	aux. DHW heating (kWh/d)	avg. solar gain (kWh/d)	avg. solar irradiation (kWh/(d)	solar fraction (%)
24.-31.5.	12,6	395	125	227	-	30
June	16,2	228	114	252	424	42
July	18,4	140	126	245	700	48
August	18,0	18	125	339	798	70
1.-11.9.	13,6	182	119	224	754	43

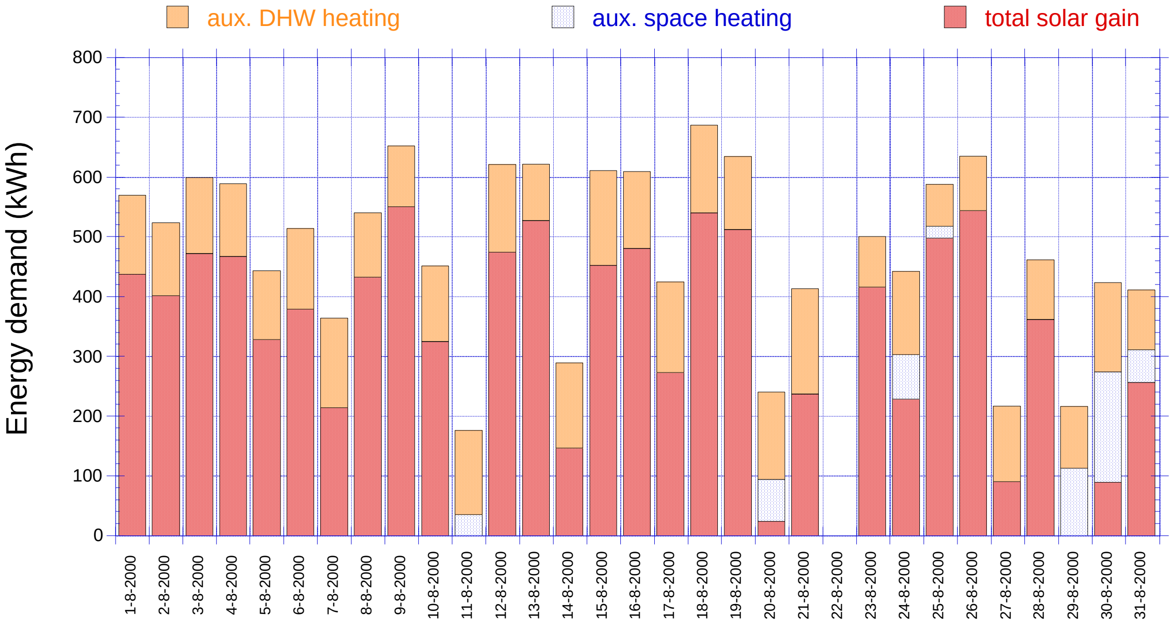

Fig. 5: Total demand during August 2000: solar gain to DHW and space heating (bathroom) and auxiliary heating to DHW preparation. The histogram shows the delivered energy to the buffer- and the DHW stores; the fluctuations are related to accumulation effects. No data were available for 22.8.

5. Resume

This report presents the first results of the solar heating system in the Klosterenga residence since the system was started up in spring 2000. The system has operated without technical problems. The energy demand has steadily decreased as expected for a new building which has to dry out and establish thermal equilibrium. Gained experience with the dynamics of the system contributed to optimise the adjustment of the solar controller and resulted in given sizeable results, in particular the introduction of a dynamic thermostat control of the auxiliary heat supply to the buffer store 2. This improvements are revealed by the amount of electricity supplied, which has decreased from 520 kWh/day in May to a minimum of 143 kWh/day in August. The weather conditions towards the end of the summer can only partly explain this improvement.

The solar system seems to be well adapted to the energy demand of the building. The maximum amount of solar energy delivered to the heat stores in one (sunny) day is close to 700 kWh, corresponding to a net solar energy gain per squaremeter collector area of 3.21 kWh/day.

Further reduction in the energy demand is expected as a result of better communication with and instructions of the tenants. Finally, a more dynamic method for the auxiliary DHW heating and the protection against legionella will be introduced, resulting in an overall reduction of the DHW temperature.

The Project was supported by the EU's Thermie program and the Norwegian Water and Energy Resources Directorate (NVE).

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SYSTEM DESIGN AND MONITORING RESULTS OF AUSTRIAN LARGE SCALE SOLAR COMBISYSTEMS FOR MULTIPLE FAMILY HOUSES AND OFFICE BUILDINGS

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1. Low-Energy Housing Estate “Sundays”

Within the framework of a project sponsored by the European Union (THERMIE), the Scientific Department of the Province of Styria and the Innovation and Technology Fund of the Research Promotion Fund (FFF) a low-energy terraced house was developed as a result of co-operation between the AEE (Arbeitsgemeinschaft ERNEUERBARE ENERGIE), the architectural office Reinberg in Vienna and the prefabricated-housing company HOLZ-BAU-WEIZ which supplies a basic concept which can be applied to other buildings as a result of the large-scale standardisation of individual components and the development of a systems technique devised for this type of building. A demonstration project with six terraced houses and an office unit was erected in Gleisdorf.

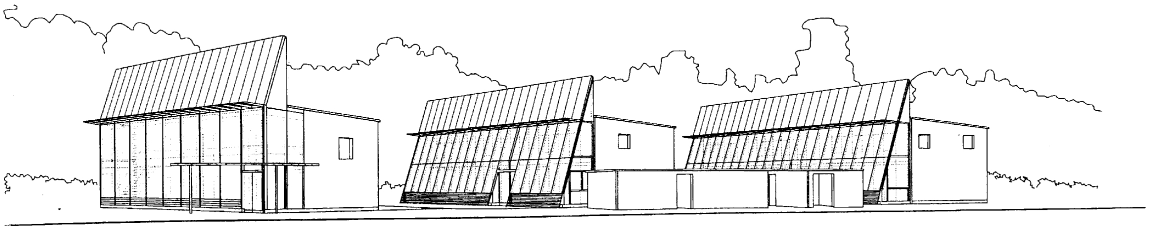

Fig. 1: View - solar low-energy housing estate in Gleisdorf

1.1 Thermal quality of the building cover

Apart from optimising energy and costs, the development of an innovative and ecological wood prefabricated part concept was one major focus of the project. A wall structure developed especially for this type of house made it possible to attain the heating insulation standard (u = 0.11 respectively 0.17 W/m²K) in a manner which saved both costs and space. Moreover, this wooden construction system permitted a high extent of prefabrication. The wall and ceiling structure, which contains absolutely no thermal bridge, offers another advantage. Both the outside walls and the ceiling and roof structures are made of laminated and bonded solid wood panels (KLH) with a thickness of 10 respectively 12 cm. These panels assume a load-bearing function as well as acting as a diagonal bracing and air and vapour barrier. The heat insulation, comprising wooden softboards of a thickness of 20 to 35 cm is applied to the outside and directly plastered. The middle wall and separation walls were designed as solid concrete walls plastered with clay. Thus corresponding energy storage masses are available for the solar energy gained passively which also have an evening out effect on the climate in the room.

At the development stage and when assembling the components, considerable attention was also given to the wind resistance. Without the use of air-resistant films the „Blower Door Test“ produced a value of n_{50} = 1,0 according to ISO 9972. The glazing of the conservatory was constructed of a three-fold heat protection glass filled with inert gas (U-value = 0,7 W/m²K). The window glazing has a U value of 0.9 W/m²K.

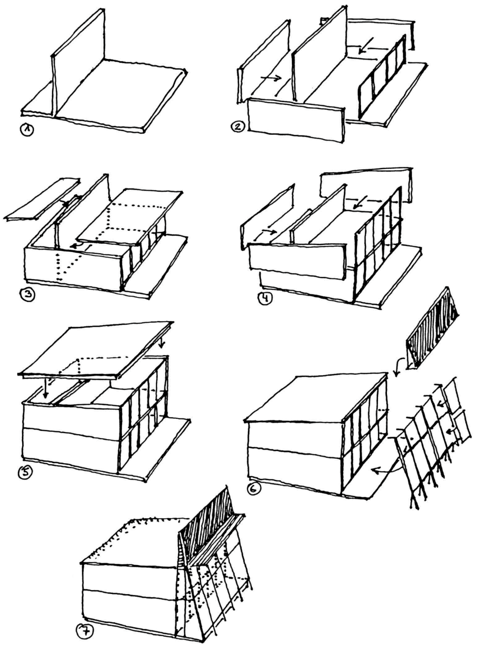

Fig.2: Systems sketch

1 Fixing dowel
2 10cm Wood fibre insulation (Pavatherm)
3 10 cm Wood fibre insulation (Diffutherm)
4 Dry filler
5 Mat reinforcement
6 Ceiling plaster
7 Base rail
8 Load bearing wood
9 Foundation insulation
10 Foundation plate
11 Joint tape
12 KLH – heavy wood board
13 Plaster board

Wall: sectional view

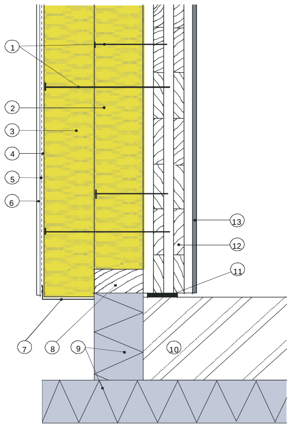

Fig. 3: Outside wall, corner connection

1.2. The energy concept

The development of the technical energy concept and the optimisation of the building was performed using non-stationary calculations and with the help of a simulation programme TRNSYS.

Use of passive solar energy

The heat gained in the conservatory can on the one hand be stored in the storage masses in the solid wall and in the screed topping and on the other hand it can be used for the subsequent warming of the supply air which enters the conservatory via the earth to air heat exchanger. During operation in the summer the inlet air flaps located at the foot of the conservatory and outlet air flaps at the highest point guarantee efficient subsequent ventilation. Moreover, there is a possibility of shading on the inside using folding blinds.

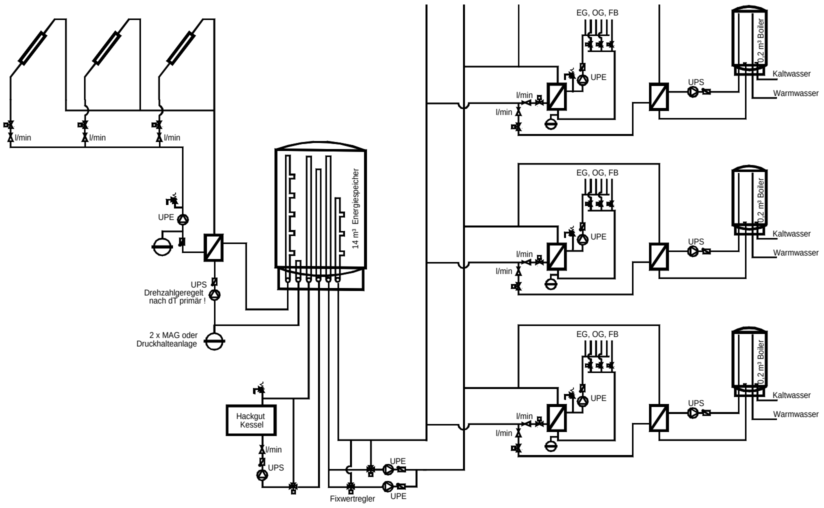

Fig. 4: Hydraulics concept for the district heating network:

Active use of solar energy

In the main, thermal collectors meet the hot water and space heating requirements. The collector areas, which cover a total of 213 m², were integrated in the roofs of the conservatory. The remaining heat requirement is met by a biomass pellet boiler. Thus, the supply of heat to the buildings is performed 100% with renewable forms of energy. The energy is stored in a water storage tank with a capacity of 14 m³. The individual houses are supplied from a central storage tank via a local heating network which is operated 22 hours a day at a low temperature level (35 - 40°C) (heating operation). To prepare warm water the same local heating network is operated during the night for two hours at a higher temperature level (65 - 70 °C). In this period the heating is switched off and only the decentralised domestic hot water storage tanks are loaded.

With due consideration to the higher heat insulation standard of the building cover, the passive use of solar energy and the internal gains, the heating energy requirement was ascertained on the basis of the simulations carried out with TRNSYS as 26 kWh/m² for the office building and 32 kWh/m²a for the terraced houses.

In the first heating season 1998/99 the actual consumption of heating energy in the office building equalled only 20 kWh/m². This means that in practice it was possible to clearly undercut the values ascertained in the simulation. To round off the overall solar concept a roof-integrated photovoltaic plant connected to the network with a performance of 1.44 kW_{peak} supplies part of the electrical energy requirement. The photovoltaic plant was designed so that all of the drive energy required to operate the solar, heating and ventilation plant, the pumps, control systems, ventilating fans etc., can be covered by the solar energy produced.

The low temperature wall heating system

The efficiency of solar heating systems is also determined by the temperature level of the thermal output. I.e. the lower the inlet and outlet temperatures of the space heating system, the more readily these can be made available in the winter by the solar plant. For this reason the buildings are equipped with low-temperature wall heating systems in combination with floor heating systems. The average inlet temperature with low-temperature wall heating systems equals less than 30°C during the heating period.

Controlled aeration and ventilation via earth heat exchangers

The fresh air is sucked up by earth to air heat exchangers and pre-warmed (winter operation) respectively pre-cooled (summer operation). In the office building this fresh air is supplied to the conservatory and is warmed further by the winter sun and forwarded into the rooms through the energy storage wall via corresponding ventilation flaps. From here the air consumed is drawn off via a central waste air ventilating fan.

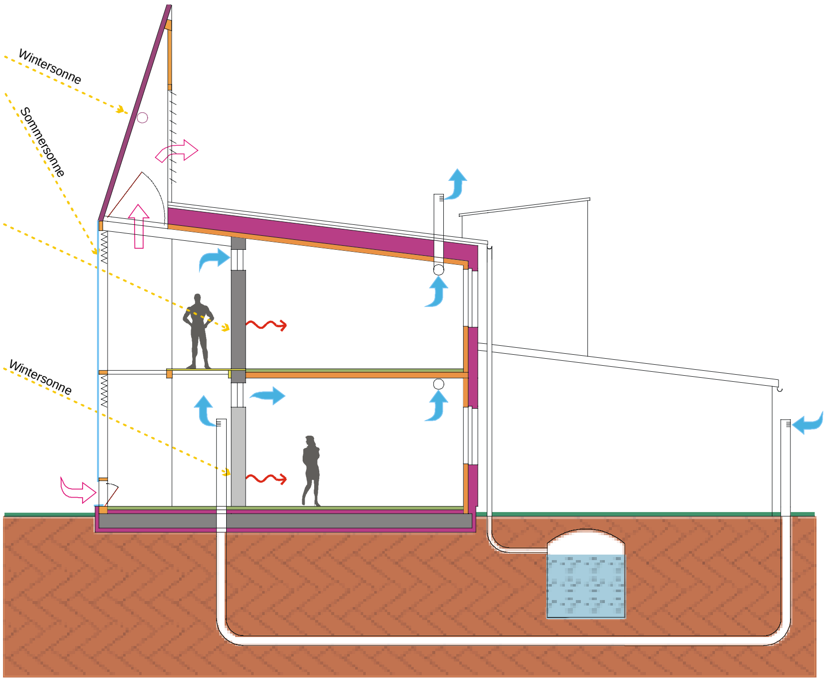

Fig. 5: section of office building

1.3 Measurement results

Total energy consumption in the office building

Since building part I (office building) was occupied in July of 1998 data is available from October 1998 to December 1999 for the overall consumption of energy. The overall energy requirement of the office building equalled 50.99 kWh in the period between October 1998 to September 1999 (a complete year) for each m² of heated net floor space. Of this 20.67 kWh was accounted for by space heating (instead of the 26 kWh simulated), 3.81 kWh was accounted for by domestic hot water, 2.70 kWh for auxiliary energy (drive energy for facility management facilities such as pumps, control systems etc.) and 23.81 kWh for office electricity (lights, computers...). The specific electricity yield from the photovoltaic plant equals 3.79 kWh. Of the 24,48 kWh for space heating and domestic hot water, 60% was met by solar energy, i.e. 14.68 kWh so that the remaining energy consumption which was covered by the pellet boiler, now only equalled 9.8 kWh/m².

After subtracting what is produced by the photovoltaic and thermal solar plant one is left with an **overall energy consumption of 34.8 kWh/m²** of heated net floor space which has to be met by pellets and electricity and imported beyond the boundaries of the building. A comparison with the limit value determined for the passive energy house of 43 kWh clarifies this low value.

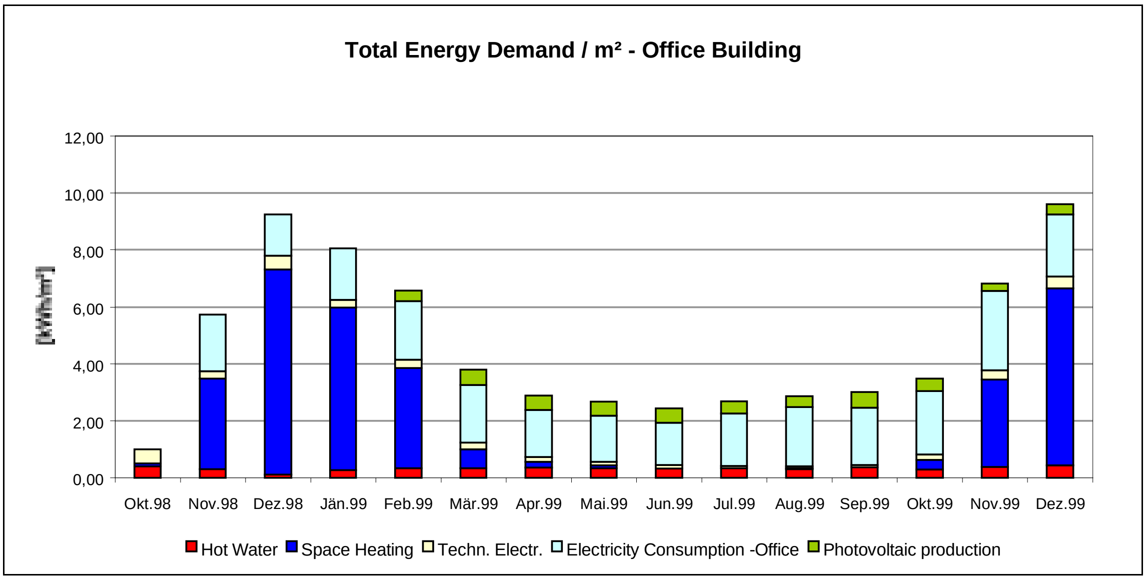

Fig. 6: Total energy consumption of office building between Oct. 1998 and Dec. 1999

Figure 7 shows the total heating energy balance for the project as a whole (6 terraced houses and an office building). From this we can recognise that heating energy from the pellet boiler is only required in the months of November to February.Regarding this overall balance it should, however, be pointed out that over the entire period of measurement only two terraced houses were occupied with one person each. I.e. the domestic hot water requirement was correspondingly low. The unoccupied terraced houses were kept at a temperature of 16°C.

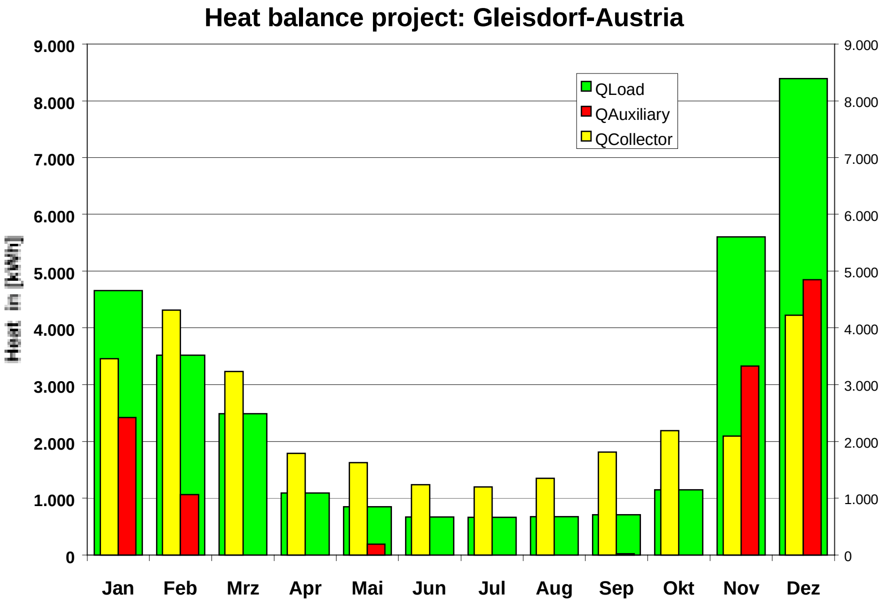

Fig.7: Heat balance for project as a whole from January to December 99:

2. Solar Combisystems for Hotels

Apart from residential buildings and office buildings hotels also have a high requirement for low-temperature heat. The specific requirement per person is normally higher than in residential buildings. Numerous hotels and places of accommodation were equipped with solar plants supported by grants from the „Österreichische Kommunal Kredit AG“ and the Federal Ministry for the Environment. The system concept and some results from Hotel

„Sylvretta-Haus“, which was measured in detail and evaluated within the framework of the EU project „Sunny Resorts“ by the AEE, will be presented in the following.

Fig. 8: Hotel Sylvretta Haus, altitude 2200 m

The hotel on the Bielerhöhe (2020 m above sea level) has 28 beds and a restaurant with 40 seats for day guests. It is open from December to April respectively from July to October. The average consumption of hot water per day equals about 1,250 litres (60°C). Due to the location of the hotel high up in the Alps there is a need for heat for space heating almost all year round. The annual heating requirement equals around 110 MWh.

The heat requirement for hot water and space heating is covered by almost 30% by a 60 m² collector plant. The heat produced by solar energy can be fed either into the space heating store or if necessary directly into the heating supply system. The storage tank (tank in tank system) comprises a 14,000 litre space heating store with 3 integrated domestic-hot water stores with a capacity of 310 litres each. The auxiliary heating of the space–heating store is performed via two electrical heaters which are arranged at different levels in the storage tank. As the efficiency of a solar space heating system is also determined by the temperature level of the heat supply and a low return temperature to the space heating store, the building is equipped with a special low-temperature wall heating system. The medium flow temperature of the low-temperature wall heating system is 30 C°.

To avoid a covering of snow in the winter as far as possible and to optimise the solar yields for the winter months, the collectors are erected at an angle of 78°.

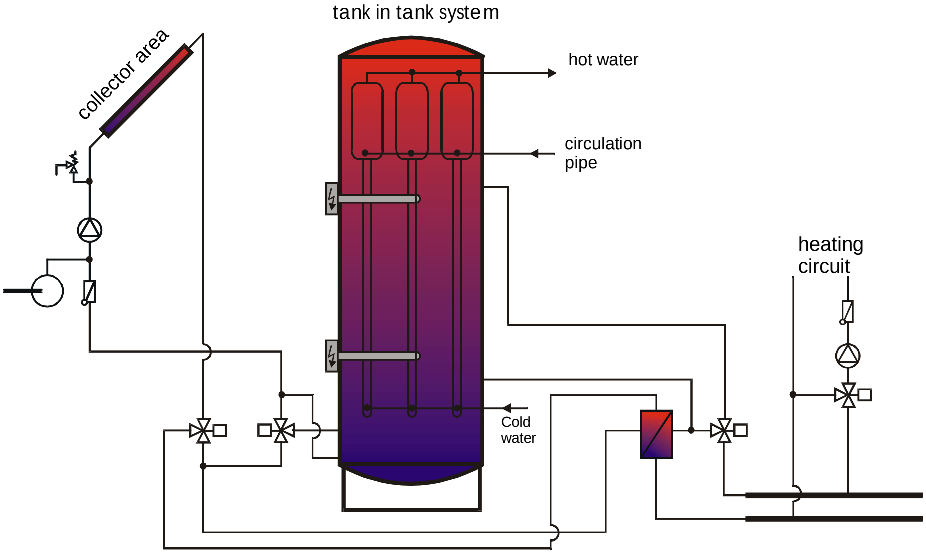

Fig. 9: Hydraulic scheme – solar system with tank in tank storage

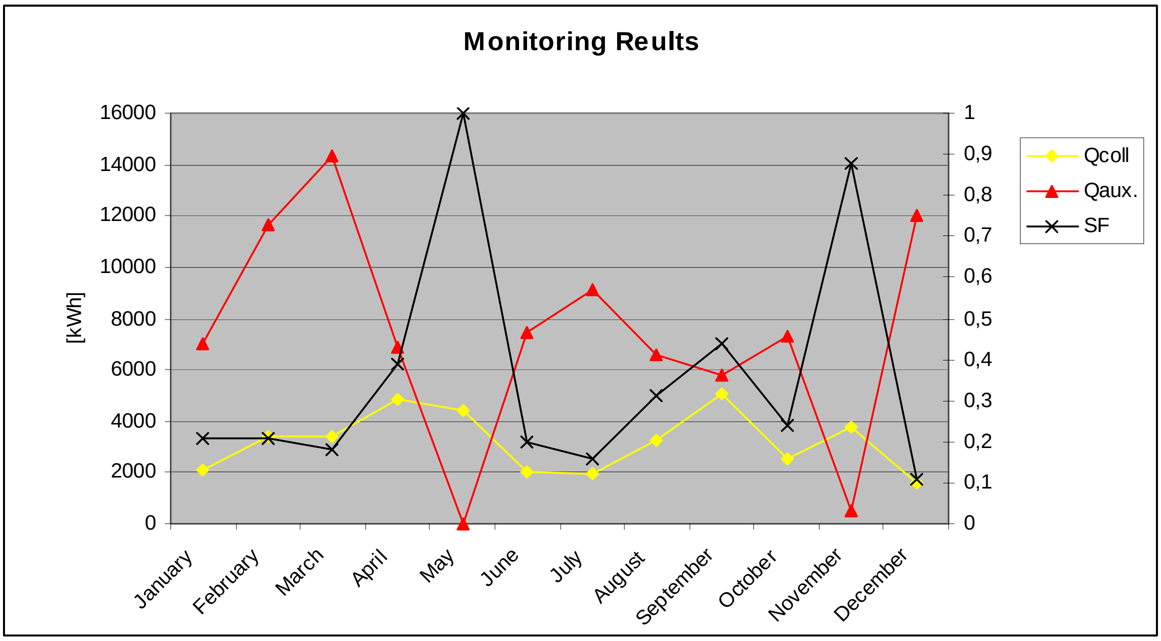

Fig. 10: Monitoring results – Hotel Sylvretta Haus

The plant has produced excellent operating results for several years. Figure 10 depicts the monitoring results from the year 1999. Due to the very good solar radiation conditions (1,330 kWh/m²a) and the optimum operating conditions the collector circuit produces between 650 kWh/m² and 750 kWh/m² per annum on average.

3. Conclusions

Several thousand solar combisystems for single family homes and several hundred plants for multiple family dwellings and hotels demonstrate the high performance of solar space heating systems in central European conditions. The demonstration plant phase has therefore been overcome. To achieve European wide market penetration in the years to come it will be necessary to optimise the systems and standardise tried and tested system concepts.

For the development of efficient storage technologies it will be particularly important to conduct more research work to open up the way to a solar future.

WAGNER OFFICE BUILDING: FIRST EXPERIENCES AND MEASUREMENTS

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Abstract

Since September 1998 the first european passive solar office building is in operation in Marburg (Germany). To draw conclusions for similar projects in future, the building is measured in detail. After the experience of one year with complete measurements, one can say that the building fulfills the passive house standard with a space heating demand less than 15 kWh/m²a and a total primary energy consumption of less than 120 kWh/m²a. Nevertheless, the measurement also leads to wrong-planned or unefficient-working examples as far as the built earth-to-air heat exchanger or the control strategy for space heating are concerned. Before the second heating period, a modified strategy was implemented. Statistical methods show, that this lead to a more comfortable indoor climate even when the the heat energy consumption has not changed significantly.

1. Introduction

The passive solar office building of the company Wagner & Co is in operation since september 1998. It is the first office building in Europe that was realized following the passive house standard.
The high insulation on the one hand in combination with the active ventilation system with the high efficient heat recovery unit on the other hand makes possible to reach the very low heat demand of less than 15 kWh/m²a (calculated by Feist, 1998).

2. The investigated system

2.1 Use and function of the building

Mainly, the building contains office working places. On the one hand there are open-plan offices on the first floor, on the other hand there are single offices on the ground floor. But the building also contains zones with special requirements. Firstly, on the ground floor are a big reception zone as well as a workshop. Furthermore, on the second floor there are a kitchen in combination with a canteen and two seminar rooms together with an open area for communication (cf. fig. 1).

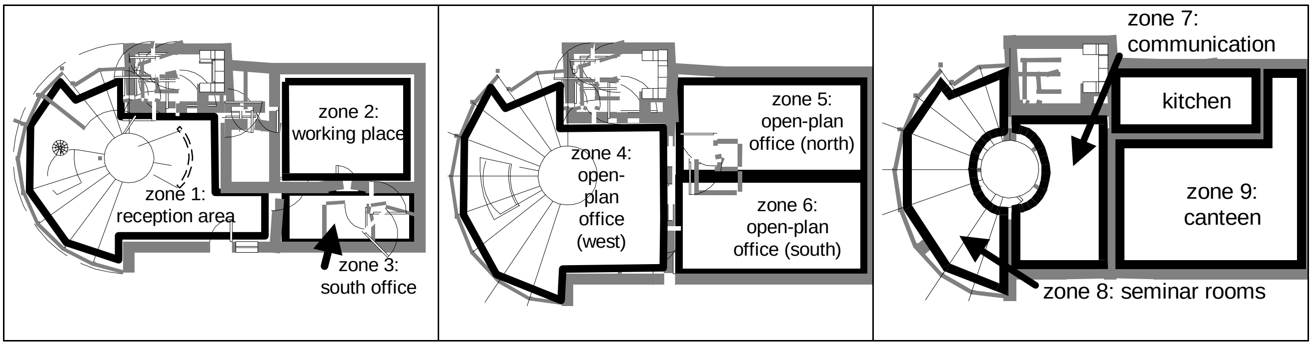


Fig. 1: Cross-section of the three floors in the passive solar office building

One can imagine, that the nine thermal zones of the building have a quite different thermal behaviour, depending on the different internal gains and their volume.

2.2 The concept of the house

In the following, the concept of the house will be described as far as the three main parts of the concept, the building design, the active ventilation system and the active solar heating system are concerned, (cf. fig. 2).

The building with a gross floor area of 2180 m² has a well-insulated building envelope, consisting of up to 40 cm of mineral wool. Even under the foundations there is a layer of 24 cm of foam glas to insulate the building against the ground. To make the envelope air tight, a PE-foil runs all around the building and is carefully adhered to the window frames. The windows themselves are realized as triple glazed windows with a filling of inert gas (krypton). All in all the walls achieve an average U-value of 0.15 W/m²K, whereas the floor and the ceiling have a U-value of 0.12 W/m²K.
Not least the tightness of the building requires an active ventilation system: The fresh air passes an earth-to-air heat exchanger ground heat exchanger (4x32 m pipes of concrete, Ø = 0.5 m, distance: 0.15 m, depth: 1.5 m), and a highly efficient heat recovery unit (4 cross flow heat exchanger with a dry efficiency of up to 90 %). During the heating period the air can be warmed up in the central pre-heater (water- air heat exchanger with a rated capacity of 42 kW). Then the air is distributed to the nine thermal zones in the building passing additional decentral re-heaters (water- air heat exchangers with rated capacities of 2-6 kW), to reach the zonal rated value for the temperature. The return air is exhausted in the sanitary rooms and passes the heat recovery unit before leaving the building.

The energy to heat up the air in the pre-heater as well as in the nine re-heaters is delivered by the active solar heating system. It consists of 64 m² of collectors (solar roof, 28 ° tilted, south-orientatated), charging a seasonal storage with a volume of 87 m³. A cogeneration system (12.5 kW_{therm}, 5.5 kW_{el}) acts as backup system.

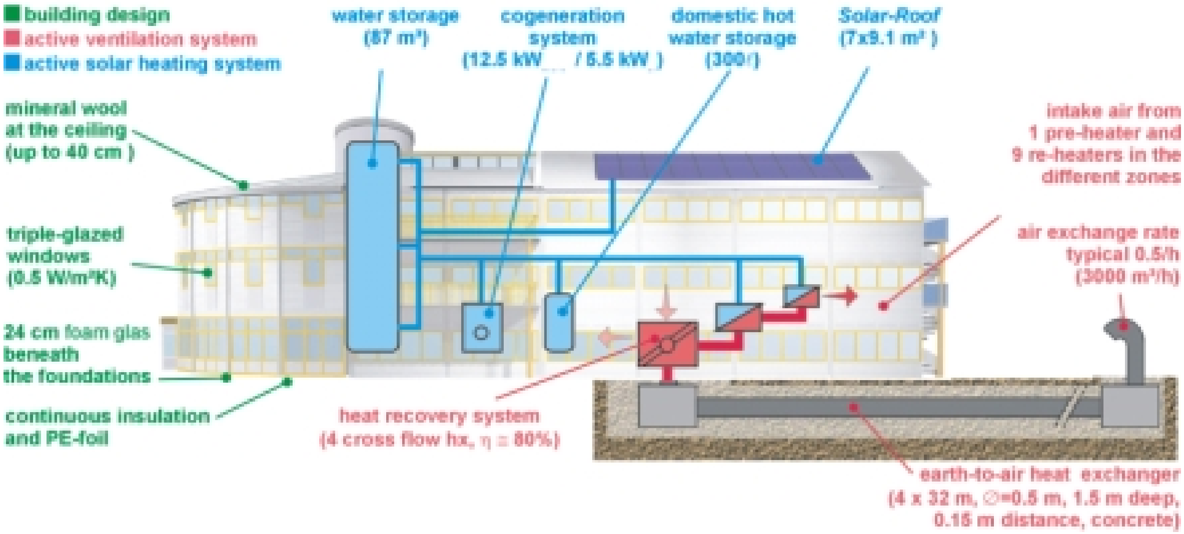


Fig. 2:The concept of the building, as far as the three main components are concerned: Building design, active ventilation system and active solar heating system.

2.3 Measurement system

The whole building and its technique are measured in detail. All in all, more than 240 signals are recorded. Even at the storage there are about 60 temperature sensors (PT 100) to examine the vertical and horizontal temperature profiles. The earth-to-air heat exchanger ground heat exchanger is also measured in detail: Depending on the distance from the pipes there are temperature sensors in different depths in the ground as well as in the pipes themselves. Moreover, the humidity of the air in front of and behind the earth-to-air heat exchanger ground heat exchanger is measured and the humidity of the return air, too.

The ventilation system and the active heating system is also examined in detail: Signals from all pumps, valves, etc. as well as temperatures and flow-rates of the active ventilation and solar heating system are measured. To summarize, all important energy fluxes can be specified.
To combine scientific demand and building control, all signals are collected by a DDC. On a connected PC, once the day all stored data are sent via e-mail to the university, where they are extracted to existing databases (Wagner, 2000a).

3. Measurements

3.1 First experiences

After one summer and two heating periods, one can summarize, that the concept of the house works well. During the summer, no overheating could be recognized, during the winter, it was all over the time comfortable warm in the building. The heating demand was as low as expected (measured 12 kWh/m²a), the indoor climate was comfortable in 58 % of all hourly mean values, quite comfortable in 42 % and never uncomfortable. This also means that the average relative humidity of the return air never fell below 30 %. Figure 4 shows the measured values. During the summer, the maximum indoor air temperature never exceeded 29 °C, even in case of ambient temperatures of 32 °C during hot periods. Moreover, these high temperatures have been measured in the canteen in the second floor and not in the offices. The average indoor temperature was always even below 27 °C, as one can see in figure 3.

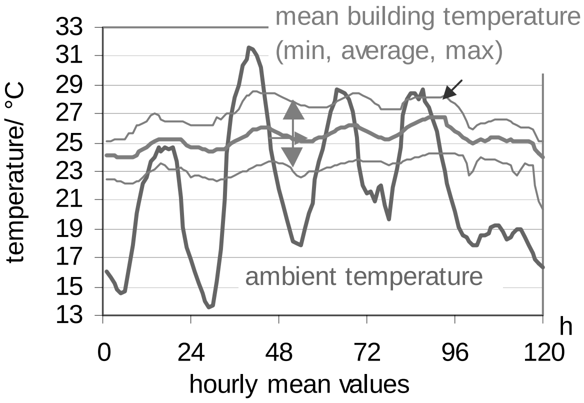


Fig. 3: Measured minimum, maximum and average temperature in the building during a hot period from 07/02 until 07/06/99.

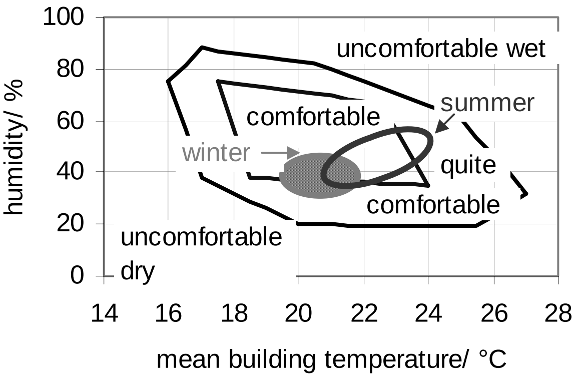


Fig. 4: Hourly mean values of the average building temperature and the relative humidity of the return air for winter and summer (05/99-04/00).

As far as the indoor climate in summer is concerned, it was never uncomfortable, in 84 % of all cases it was comfortable, in 16 % it was quite comfortable, based on the definition of (RWE, 1996), see fig. 4.

The comfortable indoor climate in summer is mainly due to the concept the night ventilation. In the central part of the building around the seasonal storage the ceilings are opened up to the top in the second floor. Furthermore, the ceilings (consisting of concrete) are not covered with any kind of linings. During hot periods in summer, the skylights in all three floors are opened automatically, thus, the air driven by thermal ascending forces flows through the building, compare fig. 5. This prevents an overheating during a period of hot days as both, room temperatures and wall temperatures are decreased during the night.

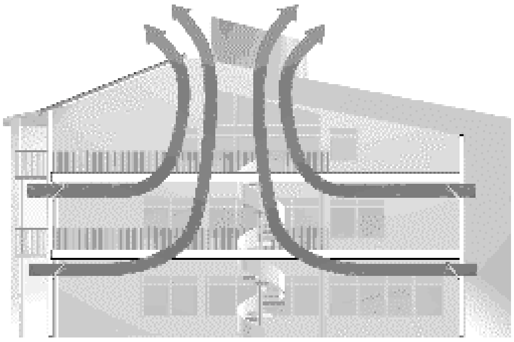


Fig. 5: Scetch of thermosiphonally driven air movement through the building to prevent overheating in summer.

3.2 Active ventilation system

During the summer, the heat recovery unit is bypassed, whereas the earth-to-air heat exchanger ground heat exchanger cannot be bypassed and is in operation all over the year as well as the ventilation system itself. Corresponding to the hygienic need, the average airchange rate is 0.4 h^{-}1 in winter. The electric power consumption of the ventilation system consisting of two fans (one to suck the fresh air in, one to exhaust the return air), filter bags to keep the air clean (in front of and behind the earth-to-air heat exchanger ground heat exchanger and also in front of the heat recovery unit on the return air side) and the heat recovery unit itself is about 0.54 W/(m^3/h). This is a bit more than the value of 0.4 W/(m^3/h) prescribed by (Feist, 1998) for passive houses.

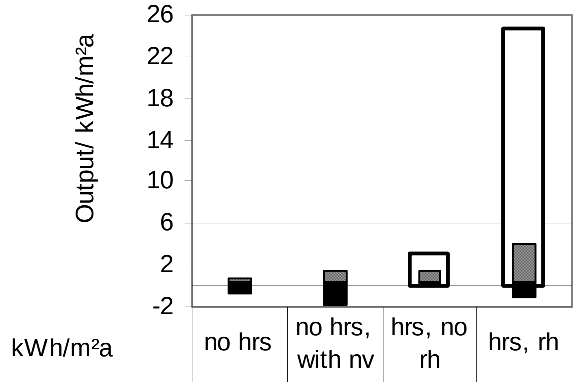
For the comparison of the gains from the heat recovery unit and the earth-to-air heat exchanger ground heat exchanger one has to regard four periods over the year, see also (Wagner, 2000b):

i. Heating period from November to March: The air is preconditioned by the earth-to-air heat exchanger ground heat exchanger and the heat recovery unit, but it has to be heated up further in the pre-heater and/or in the re-heater.
ii. Period from March to May: After passing the heat recovery no warming up is necessary anymore.
iii. From May to September (inclusive) the heat recovery unit is bypassed, during the subperiod from June to september the night ventilation is used.

In fig. 6, the period form 05/99-04/00 is divided up into these four periods, and the balances are shown.

One can see that the earth-to-air heat exchanger ground heat exchanger cools not only in summer but in winter, too, whereas heating occurs also all over the year even though the contributions are different during the four periods. Furthermore, it is important to point out, that the heat recovery unit delivers about 7 times more useful energy than the earth-to-air heat exchanger ground heat exchanger although it runs only during seven months a year.

Looking at the cumulated distribution function of the measured ambient temperature and the outlet temperature of the earth-to-air heat exchanger ground heat exchanger in winter in fig. 7, one can see that the earth-to-air heat exchanger ground heat exchanger always prevents a freezing of the heat recovery unit, as the inlet temperature never falls below –2 C, what is the minimum. But analyzing the ambient temperature one also has to take the fact into account, that this temperature was only in 6 % of all cases between –10 °C and –2 °C as shown in figure 7. This is equivalent to 154 hours and would lead to a necessary heating energy to prevent freezing of only 120 kWh. Additionally, one has to take a cooling output of 2.5 MWh into account. Especially as far as period i is concerned, this leads to an increased heating energy consumption. These facts show, that the realized concept of the earth-to-air heat exchanger does not work well: The useful energy output of this earth-to-air heat exchanger does not match with the investment costs. But these experiences must not be generalized, rather one should draw the conclusion, that generally speaking there are no suitable tools to dimension systems like this exactly.



kWh/m²a	no hrs	no hrs, with nv	hrs, no rh	hrs, rh
☐ hrs output	0	0	3.04	24.79
▨ etahe heating	0.41	1.01	0.96	3.17
■ etahe cooling	-0.85	-1.88	-0.14	-1.26

Fig. 6: Measured yields of the earth-to-air heat exchanger and the heat recovery system during the year, hrs: heat recovery system, etahe: earth-to-air heat exchanger, nv: night ventilation, rh: reheating.

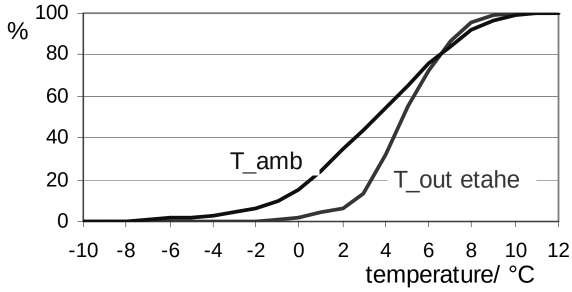


Fig. 7: Cumulated distribution function of the ambient temperature and the outlet temperature of the earth-to-air heat exchanger measured in the heating period 99/00.

As the finished earth-to-air heat exchanger cannot be modified any more, one should think about the possibility to bypass it in summer when heating appears and especially in winter, when the earth-to-air heat exchanger causes an additional heat demand. During the summer, nevertheless 84% of the heating hours occur between 19 and 7 h and 76 % of the cooling hours are during the day, when they are needed – even though the cooling effect is not very pronounced (see fig. 8).

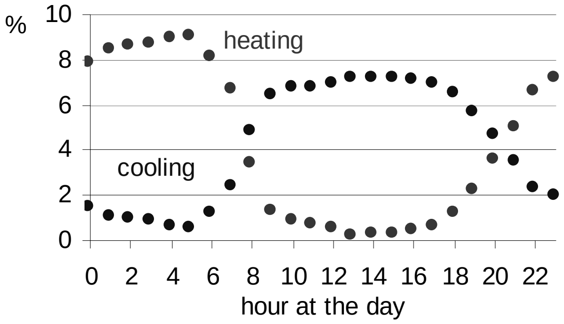


Fig. 8: Distribution of heating and cooling output of the earth-to-air heat exchanger over the day in summer.

To summarize, detailed simulations would be necessary, to judge whether a bypass for the earth-to-air heat exchanger is efficient. One should keep in mind that the coexistence of heating and cooling prevents an exhausting of the ground. Another important topic to analyze with simulations would be the question, whether the electric energy savings might be worth switching off the whole ventilation system in summer nights and just using the night ventilation to cool down the building.

3.3 Active solar heating system

During the summer, the seasonal storage could be charged completely up to 94 °C. From September to the beginning of the heating period in November, the useful energy has to be stored. During this time, discharging only takes place to warm up the domestic hot water. As far as the whole consumption for domestic hot water and the space heating demand is concerned, 16.7 MWh were supplied to the whole system by the solar cycle, 24.3 MWh by the cogeneration system during the last year (05/99-04/00).

As the collectors are installed on a surface with a tilt angle of only 28 °, the solar gains during the heating period are negligible. Therefore, during this time the heat supply of the building depends mostly on the cogeneration system. To extend the runtime, the neighbouring conventional building is also connected to the cogeneration system. During the last heating period, the cogeneration system worked about 2800 hours for the old building. This increases its runtime to 4700 hours altogether.

But nevertheless, energy from the cogeneration system is only supplied to the old building, if the passive building has no heat demand at all what includes, that a volume of 25 m³ in the upper part of the storage has a temperature of at least 65 °C.
The energy demand for domestic hot water strongly depends on the number of seminars in the office building. Figure 9 shows the measured values for the related energy consumption, to heat up the 300 l-storage up to 60 °C. Generally speaking, the average domestic hot water consumption is about 5.5 MWh/a.

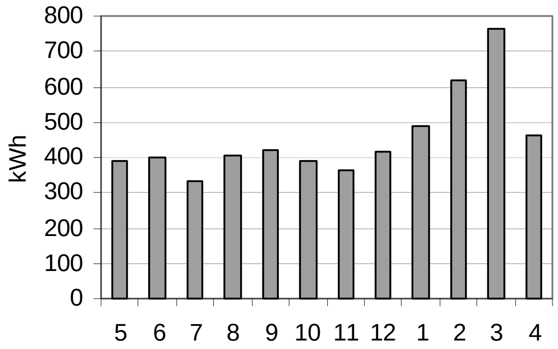


Fig. 9: Domestic hot water consumption in kWh from 05/99 to 04/00.

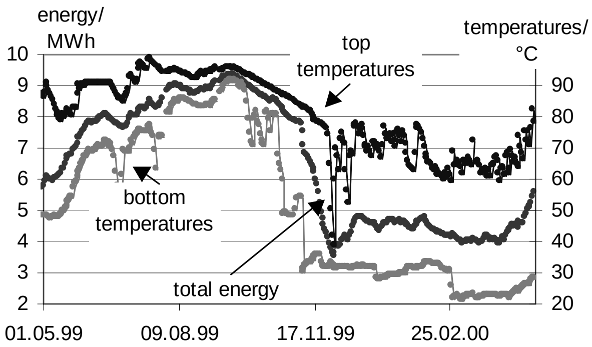


Fig. 10: Minimum, maximum temperature and total energy

Towards the end of the heating period in April, the return temperatures of the load (space heating and domestic hot water) decreases to less than 25 °C. This leads to the charging capacity of 6 MWh of the seasonal storage. The minimum and maximum temperature in the storage as well as the total energy content are shown in fig. 10.

In the following section the control strategy to fulfill the space heating demand will be presented as well as the measured consumptions.

3.4 Space heating demand and control strategy

As pointed out in chapter 2.1., a control strategy for space heating must take care of the different thermal behaviour of the nine zones.
Generally speaking there are two possibilities to control the energy input to a zone via the air side. Both, the air flow rate and the temperature can be varied or just the air temperature. As far as passive houses are concerned, the air flow rate should be constant and as low as the hygienic needs allow because an high air exchange rate yields to an unacceptably dry indoor climate. As far as the air flow temperature is concerned one should keep in mind that the temperature must not rise above 50 °C, otherwise dust smouldering could occur.

In the first heating period a control strategy for space heating from the DDC-company was implemented, varying the flow rates on the water and air side as well as the temperatures. So many problems occured during the first heating period: leading to high air exchange rates, high return temperatures on the water side and oscillations caused by the control strategy.

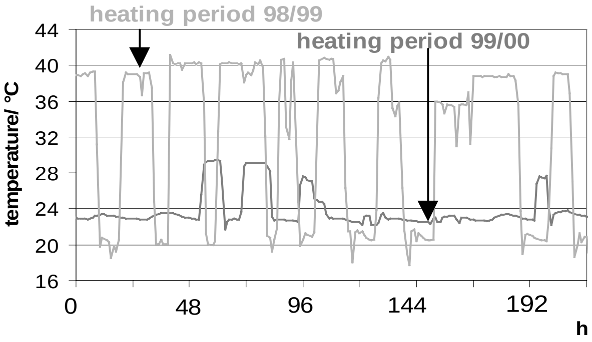


Fig. 11: Example for high return temperatures and oscillations due to unsufficient control concepts during the heating period 98/99.

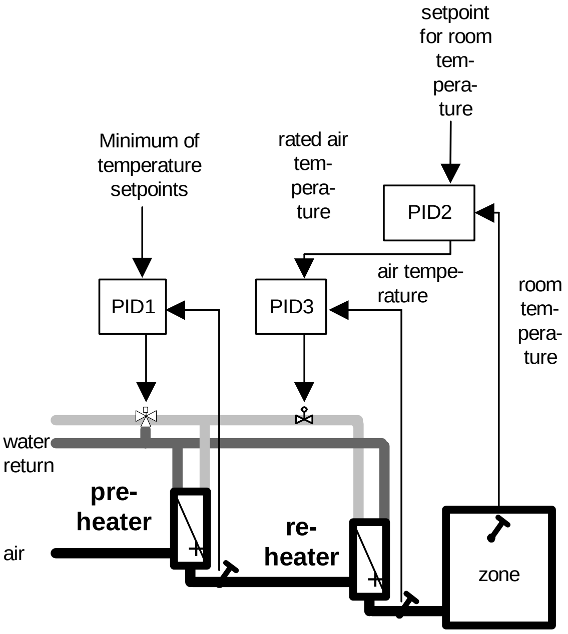


Fig. 12: Scheme of the control strategy for space heating.

Before the heating period 99/00, the old strategy was modified. One important modification was that the air volume flow rates are constant and depend only on the hygienic need. Points varied by the control strategy are the temperatures of the flow water, as well as its flow rate. On the air side, only the temperature of the air is varied.The modified control strategy for space heating can be explained as follows, (cf. figure 12). The incoming air is heated up in the central pre-heater to the minimum of the temperature setpoints of the nine zones. In the re-heaters, the measured room temperatures are compared with the rated room temperature, depending on this comparison, the preheated air is further warmed up by varying the flow rates in the water circuit. The temperature of the water is calculated from the related air temperature for the special zone.

Especially for optimizing the control strategy to minimize the energy consumption, variations of the described strategy have been implemented.After the heating period 99/00 one can say that the modification of the old strategy from the heating period 98/99 has been successful. To draw more detailed conclusions, statistical methods have been used to judge the energy consumption on the one hand and the indoor climate on the other hand.To compare the measured heat demand from the two winter periods, one first has to check, whether the relevant periods of time (heating period 98/99 and 99/00) are comparable as far the most important influential factor – the weather conditions - is concerned. Another fact, that is also very important – the user behaviour – is treated as constant.To compare the weather conditions, at first global radiation, the ambient temperature and the humidity were tested for gaussian distribution. As this prerequisite was fulfilled, the average values of the distribution functions were calculated and compared with the related value from the other heating period using the T-test. Therefore, the comparison bases on the Pearson-coefficient.

As the weather conditions from the two heating periods are not significantly different, the heating periods can be compared as far as the related energy consumption and the indoor climate are concerned.

The energy consumption for space heating in both periods is quite the same, whereas the comfort in the building differs in the two periods. One can see the differences in figure 13. In both periods, no values are in the uncomfortable region, but nevertheless in 98/99, only 14 % of all values are comfortable, whereas in 99/00 58 % of all values are in a comfortable indoor climate range (base on the definition of (RWE, 1996).

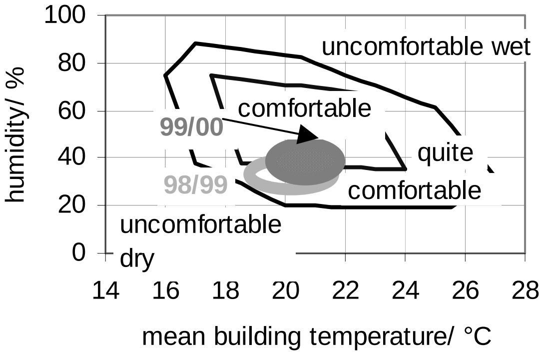


Fig. 13: Indoor climate during the heating period 98/99 and 99/00 after modifying the existing control strategy for space heating.

The main reason for this difference is the fact that the air flow rate was nearly constant in 99/00 on a low level (average value: 0.4 h^{-1}), therefore an increased humidity in the zones could be observed whereas the temperature is nearly the same.

4. Total Energy balances

4.1 Space heating demand

Generally speaking, the average power for space heating was 7 kW, the maximum was 20 kW, which is equal a specific value of 10 W/m². Moreover, this is exactly the value calculated by the PHPP (Feist, 1998). The PHPP is a well-proved calculation method to determine the heating demand, considering internal gains, passive solar gains as well as transmisson and ventilation losses. Figure 14 shows the measured value for the heating power as well as the calculated heating curve, fitting the measured points quite well.

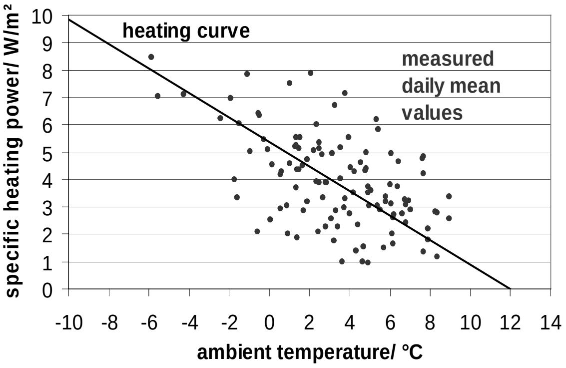


Fig. 14: Measured values for the heating powers (daily average) for the heating period 99/00 and calculated heating curve.

From the measured values one can calculate a space heating demand for the period 99/00 of 12 kWh/m²a, which corresponds to the value predicted by the PHPP (Feist, 1998) of about 9 kWh/m²a.

4.2 Electric power consumptions

Altogether, the whole building has a power consumption of 71.0 MWh/a, whereas 10 MWh/a are delivered by the cogeneration system. This leads to a specific electric power consumption for the whole building of 37 kWh/m²a.
In contrast to the space heating demand, the offices in the first floor (zone 5, 6) have the biggest demand, as in this part of the building there is the highest number of PC as well as the server.

4.3 Primary energy consumption

Taking all gains and losses into account, the energy balance of the whole building is obtained, shown in fig. 15.

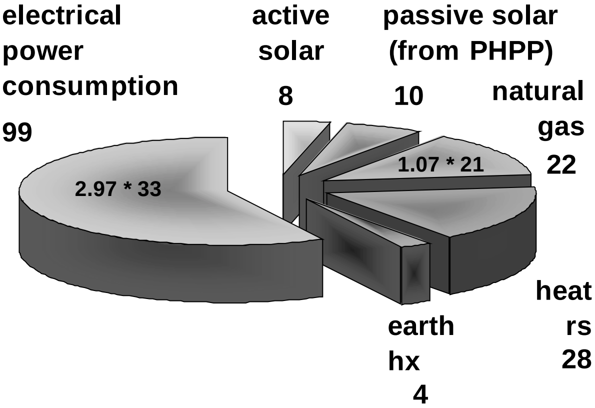


Fig. 15: Measured consumptions in kWh/m²a of the building from 04/99-05/00, (*) based on PHPP-calculations, (Feist, 1998), earth hx: earth-to-air-heat exchanger, heat rs: heat recovery system.

It is important to point out that the building fulfills the passive house standard, as far as the limits for the whole primary energy consumption of 120 kWh/m²a and for the space heating demand of 15 kWh/m²a are concerned: The total primary energy consumption was 121 kWh/m²a, consisting of an electric power consumption of 99 kWh/m²a and a natural gas consumption of 22 kWh/m²a. For the conversion of the measured energy consumption into the primary energy consumption, the conversion factors (for Germany) for electic energy of 2.97 and for natural gas of 1.07 were used (Gemis, 1997).

This is remarkable as the primary energy consumption includes the whole office demand what is not necessary to compare with the limits for passive houses.

5. Conclusions

The passive solar office building of the company Wagner & Co is measured in detail with more than 240 sensors connected to a DDC. As far as the active ventilation system is concerned the measured data show, that the earth-to-air heat exchanger was not as efficient as it would have been possible if it had been constructed in another way. A bypass to prevent undesirable heating and cooling should be considered. One also has to think about switching off the active ventilation system in summer nights when the night ventilation is used to cool room and wall temperatures to prevent overheating during the day.

During the first heating period, a control strategy varied the air flow rates to fulfill the space heating demand. But this strategy did not take care of the special demand of a passive building. This led to an uncomfortable indoor climate and unacceptable return temperatures in the water concerning the solar circuit. In the second heating period 99/00, the strategy was modified. E.g., the air flow rates were kept constant and only depending on the hygienic need. Statistical methods show, that this led to a more comfortable indoor climate in combination with better operation conditions for the active solar heating system, although the energy demand did not increase.

After the experience of one year of measurements, one can draw the conclusion that the concept of the building as passive solar house works very well. The measured total primary energy consumption was 121 kWh/m²a, consisting of 12 kWh/m²a for space heating and 99 kWh/m²a elctric power consumption.

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PERFORMANCE OF AN AIR-BASED SOLAR THERMAL SYSTEM AFTER TWENTY YEARS OF OPERATION

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Abstract

Investigations of a 20 year old air-based solar installation were made to quantify the degradation of system components as well as operation of the system as a whole. The current solar fraction of the system is extremely low at 13 percent. Experiments show a marked degradation in both the transmittance-absorbance product and the loss coefficient of the collector array. The pebble beds were also subject to high losses through the building foundation as well as non-uniform flows caused by an obstruction in the upper plenum. The effects of these degradations would lower the solar fraction from an optimum of 44 to 32 percent. The low value for the current performance is attributed to poor sensor placement and the control strategy.

1. Introduction

In the late 70's and early 80's, a wide range of solar thermal systems were installed in the United States. Along with the physical installations came the deployment of simulation tools that could predict the annual performance and fuel savings. Annual performance predictions gave designers the ability to optimize components and control strategies while estimates of fuel savings provided the economic justification for initially building the systems. We are now in a good position to ask how well these systems have held up and whether our models and predictions have come close to reality. If we have missed the mark, what was the cause, what was the effect, and what is the remedy?

The air-based system at the McKay Center in Madison Wisconsin provided an ideal installation for addressing these questions. The McKay center is a traditional air-based design with roof mounted collectors combined with pebble bed storage. The system was installed in 1978, and has been left to operate largely unmodified for the last 22 years. Far from being a dedicated and constantly maintained research installation, the center has been the daily workplace of approximately 25 administrative and outreach personnel. The McKay center offers us insights into how systems actually perform over their expected operating life as opposed to how they should perform in the case of well supervised research systems.

To determine the overall system performance at the McKay center, individual performance characteristics were experimentally determined for each of the major system components (i.e. collectors and pebble bed storage). The individual components were then coupled with the actual control strategy and weather at the site in a computer-modeling environment (TRNSYS) to predict annual building energy usage. A final calibration of the model was made by comparing the actual and predicted energy quantities over a 28 day period in late winter. Once the model was validated, the effects of degradation and control strategies were evaluated by adjusting the appropriate variables and logic within the model.

2. Description of Systems

The installation at the McKay center consists of two entirely separate systems servicing different zones within the building. Collectors are double glazed Solaron 2000 modules with non-selective absorbers. The array is arranged with a series connection of two collectors oriented due south at a slope of 55 degrees. The 30 collectors on the west side of the array are connected to the downstairs basement zone and the remaining 40 are connected to the upstairs office zone. A small lecture zone within the building is serviced by a conventional HVAC system with no solar component. Figure 1 is a layout of the heating systems, which are identical for both solar zones. Motorized dampers within each zone drive the different modes of operation:

Mode 1: Direct heating of building space with airflow from the solar array
Mode 2: Heating of building space with solar energy stored in the pebble bed
Mode 3: Charging of pebble bed with airflow from the solar array
Mode 4: Direct heating of building space with airflow from the furnace

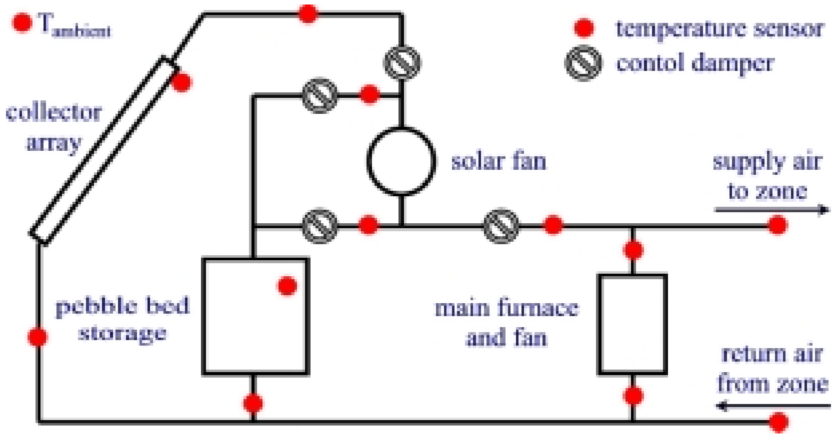

Fig. 1: layout of solar zone heating systems

Operation of the modes is determined by the control system based on temperature sensors located in the pebble bed and on the collector absorber plate. Data collection was made possible by a complete retrofit of the control system in 1995 to a direct digital control design that allowed all of the temperature sensors, fan operation, and damper positions, shown in Figure 1 to be monitored.

3. Solar Test in Interval

Calibration of the solar system components can be greatly simplified if the system is run in a quasi steady-state mode of operation. In non steady state, the effects of thermal capacitance must be accounted for in components such as the collector array and even the temperature sensing elements themselves. Also, under periodic charge and discharge cycles, the characterization of the pebble bed becomes unmanageable. To overcome these difficulties, the system was forced into continuous operation of mode 3 (charging of storage) for a one-week interval in late spring after the heating season was over. This “solar test interval” allowed for the quasi steady-state operation required for rock box characterization and collection of the necessary nighttime data for calibrating the collector.

4. Calibration of Collector Array

The collector array can experience temperature extremes from 280°F during stagnation in summer down to -20°F in winter. These temperatures coupled with moisture and UV exposure make the array one of the components most susceptible to degradation. Visual inspection of the array revealed that the seals on all of the collector cover systems were broken. Condensation was visible inside nearly all covers with most showing accumulated deposits or scale. However, the damage appeared to be restricted to the cover system with the absorber coating clean and fully intact.

While qualitative observations provide information of where the damage occurred, they are unable to tell us the degree to which cover opacity and possible leakage within the array has affected collector performance. To quantify these degradations, the collector parameters $F_r(\tau\alpha)$ and F_rU_l were determined under current conditions and compared to the original values as determined by the manufacturer in a manner nearly identical to that done today by the Solar Rating and Certification Corporation (SRCC). One method of obtaining these parameters is to re-run the SRCC test method on the existing array. By measuring the necessary variables while the system is running, operating points can be calculated based on the Hottel-Whillier model of flat-plate collectors [3]. Figure 2 shows operating points for the days of February 22nd and May 13th of 1999. For the February measurement there was a wide enough range of operating conditions to readily discern the intercept $F_r(\tau\alpha)$ and slope F_rU_l of the array. Conditions in May and throughout the next five months were not so favorable. During this time, a combination of high ambient temperatures and high solar incidence angles restricted the available data to too narrow a range for fitting the parameters through linear regression. While testing facilities can overcome this restriction by artificially preheating the collector inlet stream and physically orienting the collector directly at the sun, such methods are either impractical or impossible in actual installations. If collector characterization is needed during these times then another method must be sought.

The premise behind the standard SRCC method is to determine performance based upon a line fitted through a series of operating points. The slope and intercept of this line then determine collector parameters. This study employs a two point fitting method that calculates the slope of the performance curve independent of the daily operating points. If the collector array is driven at night when the irradiance is zero then the Hottel-Whillier model simplifies to:

$$Q_u = A_c F_r U_l \left(T_{in} - T_{ambient}\right) \qquad [1]$$

Where Q_u is the energy gain or loss of the array, A_c is array area, and T_{in} is the array inlet temperature. By eliminating the restriction on irradiance and operating under lower nighttime ambient temperatures with the air entering the collector coming from the high temperature storage, a wide temperature difference across the collector results and the slope can be determined with good accuracy and confidence. By then fitting this slope through the May operating points shown in Figure 2, the intercept can be determined. This method was applied to the last two days of the solar test interval. Operating points were calculated for a 3-hour period centered on solar noon when incidence angles were below 50° and the slope was fitted for the period from one hour after sunset to one hour before sunrise. Collector parameters determined during this 2-day period were then used to predict the collector outlet temperature over the entire interval shown in Figure 3.

To determine the amount of collector degradation, the current operating parameters were compared to the original parameters. With no test data available for the array in its originally installed condition, the array performance was derived from the manufacturer's measured parameters under the assumption that it was properly installed. Because the McKay array is constructed of two collectors in series, it runs at a flow rate of 82 CFM per collector for the basement system and 90 CFM per collector for the office, which are more than double the 38 CFM per collector of the original rating. This increase in flow rates changes the collector parameters considerably and must be accounted for. Methods of adjusting parameters based on the dimensionless capacitance rate have been proposed by Duffie and Beckman [2]. However, a significant limitation of this method is that the collector efficiency factor F' and therefore heat transfer coefficients are assumed constant. For large flow increases, the assumption of a static F' is not valid and the change in heat transfer coefficients must be calculated. Adjustments to heat transfer coefficients were made by analytically deconstructing the array based on SRCC parameters and conditions under which the tests were performed [6]. A comparison between the calculated original array parameters and the current measured results shows a decrease in $F_r(\tau\alpha)$ from 0.53 to 0.48 and an increase in F_rU_l from 2.9 to 4.1 W/m^2-C for the basement array. The results were similar for the office array, with a decrease in $F_r(\tau\alpha)$ from 0.56 to 0.48 and an increase in F_rU_l from 3.0 to 4.0 W/m^2-C.

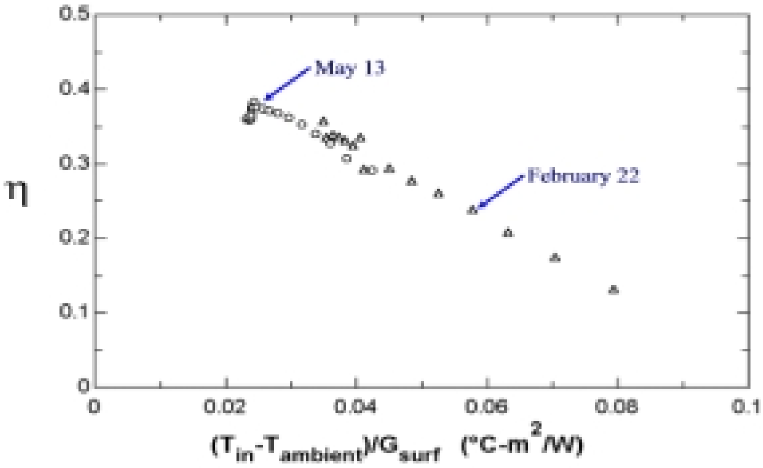

Fig. 2: Efficiency curves for office array.

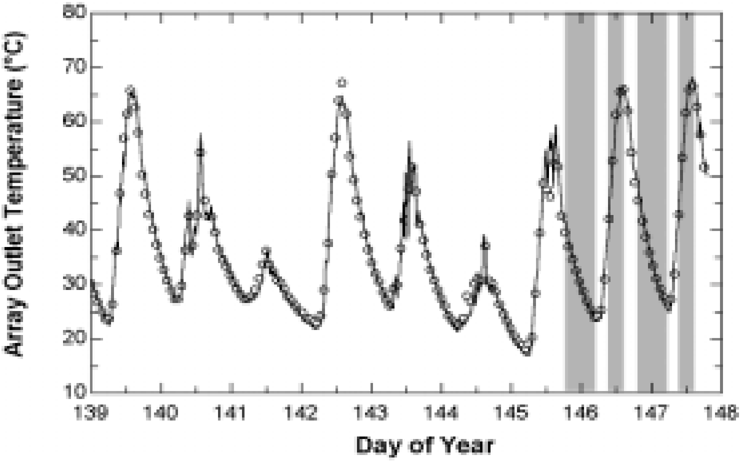

Fig. 3: Measured (points) vs. predicted (solid line) array outlet temperatures for office system during the solar test interval. Shaded bands indicate durations used for calibration of the array.

5. Calibration of Pebble Bed Storage

While some visual observations can be made of the collector array, the pebble bed storage is quite literally a black box. Without dismantling the ductwork, the only available data are temperature measurements of the entering and exiting airflows. These two measurements were coupled with thermodynamic and heat transfer relations to provide insights into operation of the pebble beds.

The established method of modeling pebble bed storage was originally proposed by Schumann [7] and is discussed with respect to solar systems in Duffie and Beckman [2]. In essence, the rock mass behaves as a combined heat exchanger and storage device.

Empirical relations from Lof and Hawley [5] were used to evaluate heat transfer coefficients and effectiveness of the bed. Losses to the environment were calculated through an energy balance applied to the entire bed during the constant charging of the solar test interval. Figure 4 is a plot of energy stored within the bed as defined by the integral of the difference between energy flowing into and out of the bed over the solar test interval. The periodic cycle represents the storage and release of energy within the bed as the thermal wave passes through. If the bed had no thermal losses then the amount of energy flowing into the bed would exactly equal the amount released over the course of a day and the curve would cycle around zero with a half-period roughly equal to the traversal time constant. The steady upward rise in the actual bed profile of Figure 4 represents energy that went into the bed and never came out through the ductwork. This discrepancy is due to energy lost through the bed walls and can be calculated by taking the difference between the measured profile and the ideal as predicted without losses. Loss coefficients were extremely high in both beds at 5.0 and 3.9 W/m^2-C for the office and basement systems respectively. By comparison, a commonly assumed loss coefficient is 0.4 W/m^2-C. The large discrepancies are explained from the construction of the boxes, which share a common wall with the high-density concrete of the building foundation. Additional measurements from sensors located within the bed walls also indicate high losses and suggest that the polystyrene insulation shown in the original construction drawings is either non existent or entirely ineffective.

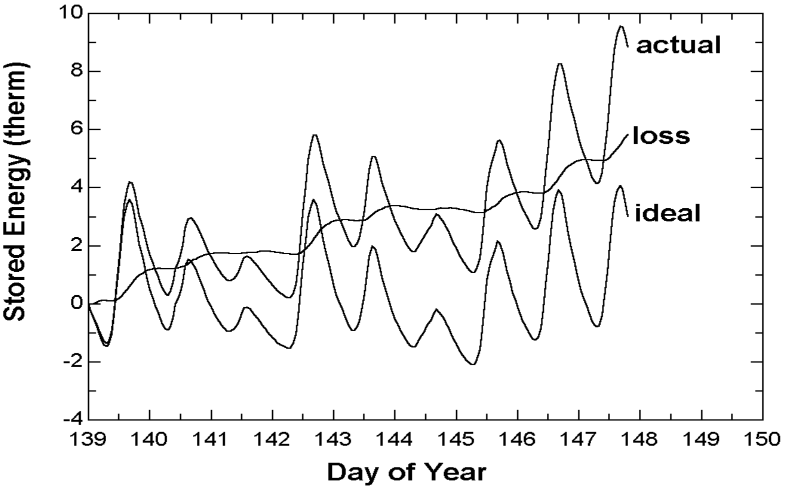

Fig. 4: Actual and ideal stored bed energies for office system integrated over the solar test interval.

Bed exit temperatures were originally predicted by correcting for the losses in the Schumann equation and assuming a uniform flow distribution through the bed. Figure 5 shows that the actual thermal wave within the bed breaks through before the uniform flow model predicts. Both the early arrival of the thermal wave at the bed exit and the wider profile can be explained by non-uniform flow within the bed, which creates separate thermal waves that break through at different times. To solve for the flow distributions, the actual bed was modeled as three separate beds with common inlets and outlets. The amount of flow into each bed was allowed to vary while the amount into all bed segments remained fixed. An optimization routine was then used to predict the flow distributions that yielded the closest match to the measured bed profiles.

The match shown in Figure 5 was produced by flow percentages of 0.50, 0.25, and 0.25 through the three assumed segments of the office bed. Flow percentages of 0.50, 0.32, and 0.18 were calculated for the three basement bed segments. The cause of the large variation in the basement system was immediately verified after visual inspection of the bed interior showed that the bottom lamination of the plywood cover had sheared off on three sides and was lying diagonally across the upper bed plenum. In this instance, the simulation had predicted a fault where visual inspections would not normally have been made.

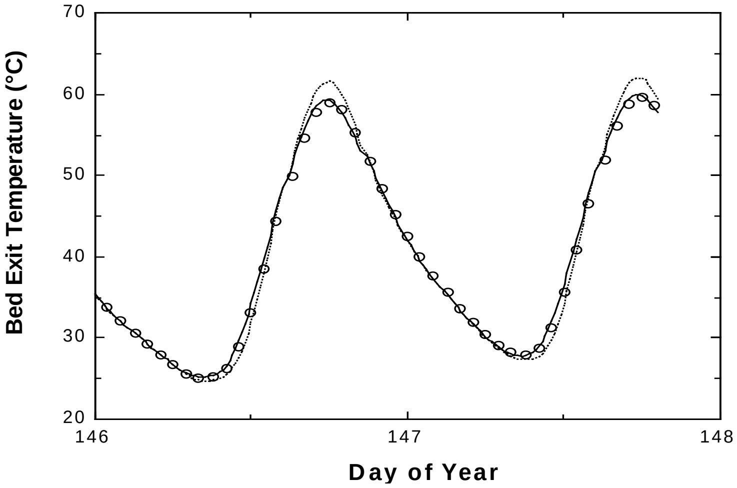

Fig. 5: Comparison of measured bed exit temperatures (points) with those predicted by uniform (dashed line) and non-uniform (solid line) flows.

6. Determinig the Building Load

The building load as defined by losses, internal gains, and thermal capacitance is central to system performance. Building construction and occupancy control the amount of energy needed and the times at which it is required. All building zones were modeled in a manner similar to that proposed by Borrenson [1] and consist of three separate capacitances representing the air, interior (i.e. furniture and partitions), and building shell. Thermal capacitance and loss products for the building shell were calculated from original construction drawings. The basement zone was modeled following the methods of Latta and Boileau [4], which accounts for conduction through the soil. Ventilation rates were based on the positions of outdoor air dampers and an infiltration rate of 0.3 air changes per hour typical of commercial spaces.

Internal gains were calculated based on winter electric loads after consumption from the air handler fans had been subtracted out. Sensible heat loads from the building occupants were also included. These gains were initially distributed to each of the building zone models based on equipment location and occupancy. Both solar gains through windows and the effective sol-air temperature were calculated within the model.

7. Final Model Calibration

To accurately estimate annual energy requirements, the entire building model was calibrated as an interconnected and dynamic system. As a first step in the process, the model was driven in the actual operating modes recorded from the building over a 28-day period in late winter. Energy quantities from all heating modes were then compared between the model and actual building. Figure 6 shows the close agreement provided by the model for the basement zone after small re-allocations of internal gains have been made between zones. All zones were within 3 percent for total integrated energies over the interval with average daily deviations of no more than 25 percent in any one zone.

Since total building performance is dependant on control of the building modes, the model was again run with imbedded control logic and only solar radiation and ambient temperatures as inputs. Figure 7 shows the final result of calibration where the model was free to decide how to operate in response to maintaining the building at the set point temperature. The control logic and load dynamic in the simulation closely parallel the real system in terms of the amount of energy delivered and retrieved from the various modes. An interesting result is that more energy is delivered to the load from storage (mode 2) than from direct solar (mode 1) indicating that there is very little coincidence of available solar radiation and the need for heating. Internal gains that are concentrated during the 9-5 workday are the main reason for the low coincidence in the basement zone. The effect is amplified in the office zone due to passive solar gains though the windows and heating of the building shell as driven by the sol-air temperature.

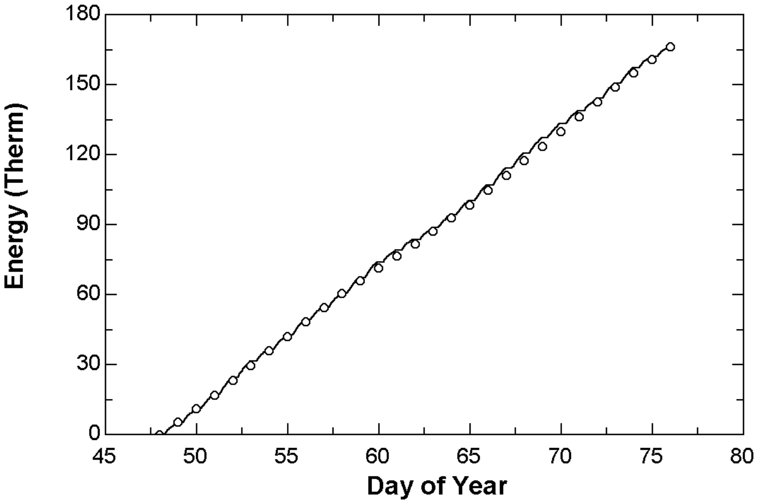

Fig. 6: Comparison of integrated energy required by basement zone to maintain set-point temperature (points) and energy supplied by simulation model (line) in forced mode calibration.

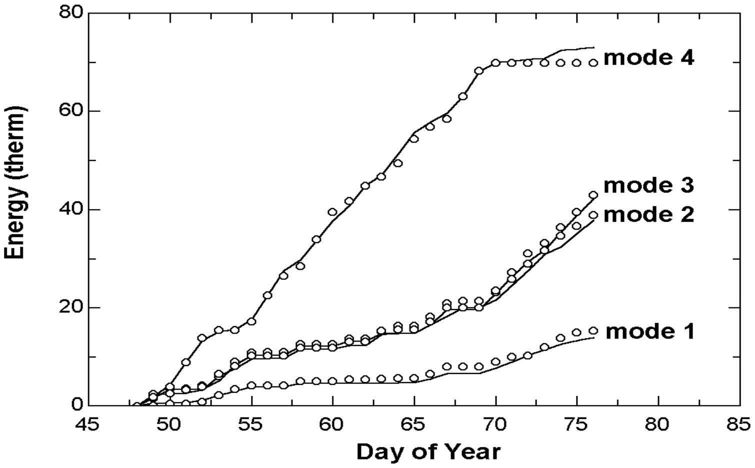

Fig. 7: Comparison of actual integrated mode energies (points) and model predictions (lines) for basement zone in free mode calibration

8. Modeling the Effects of Component Degradation and Controls

Once the model was matched to the calibration interval, actual weather data from the site was replaced with typical meteorological year (TMY) data representing Madison's average weather conditions. The simulation model was then run over an entire year to determine average annual performance, which can be characterized by the solar fraction:

$$SF = 1 - \frac{\sum Q_{auxilliary}}{\sum Q_{\sup plied}} \qquad [2]$$

Figure 8 shows the annual integrated energies from all modes that provide energy to the building for the existing system driven with TMY data. The low solar fraction of 13 percent is not attributable to component degradation for the most part. In the simulation of the existing system, the sensors for the pebble beds are modeled in their actual locations. They were found not to be inside the bed, but in the filled cores of the retaining walls 2" from the bed interior. This error was apparently recognized by the controls engineer and partially compensated for by adjusting the temperature differentials used for mode control. In addition, a fault in the control strategy left the damper that separates the solar and main air handlers open when the solar component was idle. A small fraction of the main air handler flow could then pass through the pebble beds effectively charging or discharging them depending on whether or not the furnace was firing (mode 4).

Table 1: Comparison of annual Performance under selected Conditions. All Energies are in Therms

Configuration	Q_{mode1}	Q_{mode2}	Q_{mode3}	Q_{mode4}	**Solar Fraction**
Existing system	146	294	480	1687	0.13
Existing system with optimal control	193	491	606	1351	0.32
Optimal system with optimal control	240	685	765	1124	0.44

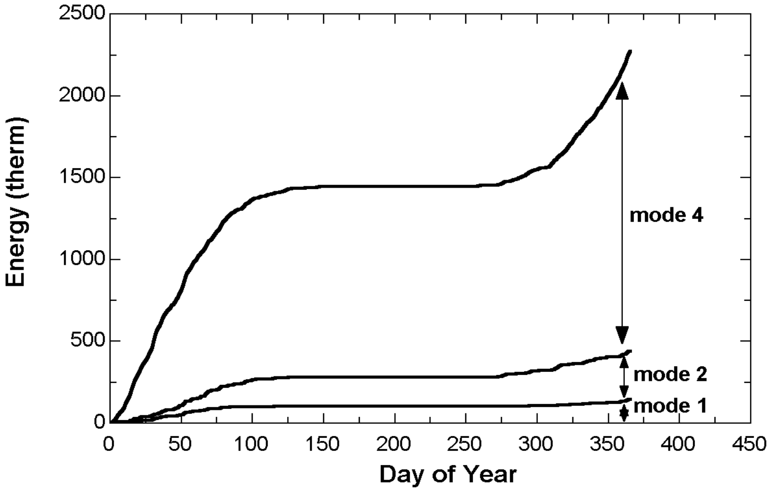

Fig. 8: Annual energy performance of existing system. Solar fraction is 13 percent

Figure 9 shows the annual performance for a physically identical system but with optimal control of the pebble beds and dampers. The large gain in solar fraction represents an annual fuel savings of $230. This benefit can be achieved solely through a minor re-write of the controller logic that allows it to sense bed energy through knowledge of mode operation and duct temperatures. Table 1 compares these two scenarios and illustrates the additional benefits of restoring all components to their original/optimal conditions.

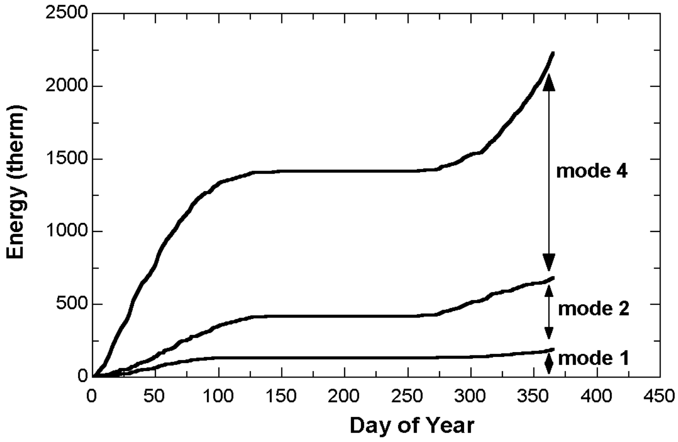

Fig. 9: Annual energy performance of existing system with optimal control. Solar fraction is 32 percent

9. Conclusions

The single largest issue affecting system performance was the inadvertent location of the pebble bed sensors and failure to properly control the damper separating the solar subsystem from the main air handler. Together, these two items lowered the solar fraction from 32 to 13 percent. Interestingly, restoring the pebble beds to uniform flow conditions provided no improvement in annual performance. Restoring the pebble bed insulation and the collectors to their original design parameters did raise the solar fraction from 32 to 44 percent with the majority of the increase provided by the increased output of the collector array and not by better insulation within the pebble beds.

While Figure 1 shows the installation of over a dozen sensors, all of the work presented in this paper was essentially based on only 4 of the 12 installed sensors. The entire system can be calibrated and diagnosed with the sensors located at the collector inlet, collector outlet, ambient temperature, and zone return air plenum. This makes it both practical and economical to install performance monitoring equipment and some form of fault detection on systems of this size in the future.

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SPACE HEATING AND DHW SYSTEM WITH STANDARD TANK

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Abstract

Experience shows that by integrating the room heating system it is possible to double the size of the solar system without changing the economic feasibility. The aim of the present project is to improve the use of combined systems and thereby increasing the share of solar energy in the heating sector. The idea is to make the solar systems more energy efficient and less complicated in a cost efficient way. The DHW tank is a standard tank with only one jacket heat exchanger making thermo syphon heating of the DHW possible with good stratification and low return temperatures. The DHW tank is always heated from the storage tank which again is heated by the solar collectors. Sometimes the top of the storage tank is heated by the boiler. Central heating water is when possible heated by passing through the storage tank. The innovation in this system is that a standard DHW is used. Another feature is that the DHW tank is heated by a low-flow (thermo syphon) system.The use of a standard tanks makes it easier later to extend a traditional heating installation with solar heating. The way the system works ensures that the DHW temperature in the tank never gets too high - this has different advantages compared to normal systems. Two systems have been running for 1 year and good results and a yield of approx. 400 kWh pr m² solar collector are obtained. This a good way to make a reliable, combined system with a high yield. The first intention was to make it more simple by always letting the central heating water pass through the lower part of the tank. This was not that easy and will take more experiments to do succesfully. Keywords: Standard DHW tank, easier to prepare for solar heating, energy not stored in overheated DHW, no use for automatic valves on the DHW side of the system, energy for heating only used when neccesary, reliable system with high performance, good interaction with condensing boilers.

1. Introduction

An increasing part of the Danish solar heating systems are made as Combined Space Heating & DHW (domestic hot water) Systems. Without extending the payback period the collector area can be doubled when some space heating is added. Furthermore, experience shows that a storage tank should be integrated in the system to gain the best results.

Based on experience from other combined systems a new design has been developed. The principles have been tested and afterwards 2 systems are installed. The most important new in the design is the use of a standard DHW tank with only one, but very efficient heat exchanger.

While the payback time remains more or less unchanged some operational benefits emerges in connection with the storage tank solution. Through the years there has been much talk about the quality of the DHW. In connection with this it is stated that a reduced size of the DHW tank, will reduce the period for the DHW to stay in the tank and by that help to solve the problems with the sometimes poor water quality. This speaks for a combined solution with a storage tank, where a bigger part of the energy storage takes place.

Another operational benefit to be achieved through a combined plant with a storage tank is that a reduced tank capacity makes it profitable to use materials or surface treatment with a long life span. As a consequence of the long payback time of the household solar heating system it is necessary to have very low maintenance cocts. In relation with this one must not forget temperature limiting regulation of the temperature of the DHW- cold and hot water are mixed to ensure that the temperature does not exceed 60°C. Time to time problems occur on these automatic valves built into the DW system. These problems increase in systems with circulating DHW. With energy stored in the storage tank the DHW temperature is controlled more reliable by regulating the supply of energy to the DHW tank. Lime deposits in the DHW tank are reduced much when the water temperature is kept below 55-60°C.

2. Solar based Renovation of existing Heating Systems

Preparation for Solar Heating

By the renovation of some natural gas fired heating systems in a dense build housing area in Humlebaek, North of Copenhagen, Denmark, the residents wanted to investigate, how this could be done in the best overall economic way. Some of the residents would furthermore look positively on the environmental impacts in their decision allowing a longer pay back period.

The selected solution was based on condensing boilers. Two of the systems were carried out as combined systems supplied with roof-integrated solar panels and storage tanks. All systems were installed by same principle, which in the future will make it possible to expand with solar heating without rebuilding installations already made. In principle it is just to add the solar panels and a storage tank.

3. The Design of the Systems

A new design was developed based on experiences from other combined systems. The keywords for the work were:

- standard DHW tank
- easier to prepare for solar heating
- energy not stored in overheated DHW
- no use for automatic valves on the DHW side of the system
- energy for heating only used when neccesary
- reliable system with high performance
- good interaction with condensing boilers.

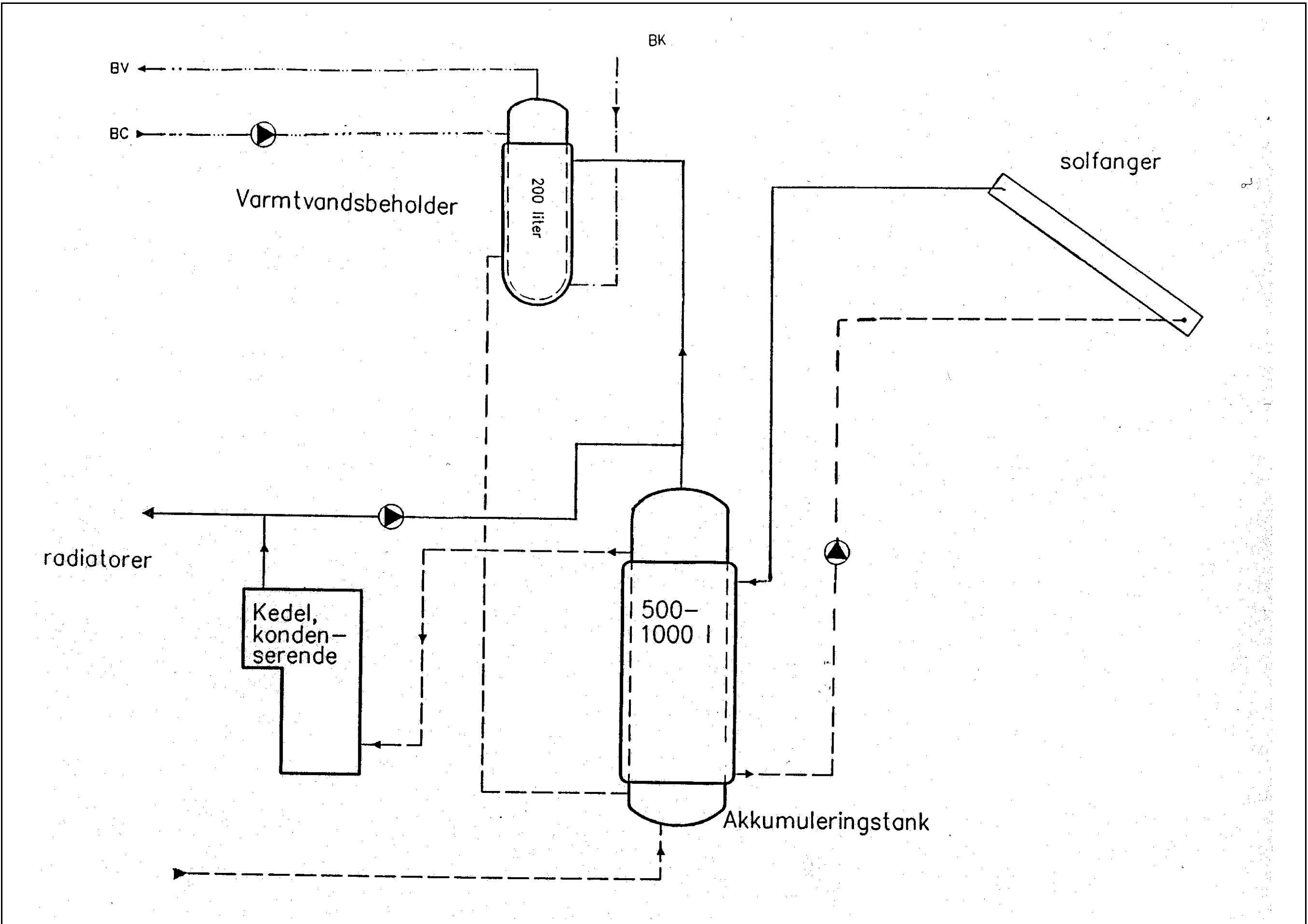

Fig. 1: Diagram for the combined solar system with a standard DHW tank

Ordinary DHW tanks

The DHW tanks installed are ordinary tanks (from Viessmann) with jacket heat exchanger. The heat-exchanging area in this type of tank is made extra large, through an extension of the jacket, down under the bottom part of the tank. Moreover the efficiency of the heating area is improved by a rib like surface - the surface looks like a washboard. The tanks are made of stainless steel.

The heat is transferred from the storage tank through a thermosyphon based circuit. A thermostatic valve limiting the temperature to approx. 60°C, when the storage tank is hot, controls the temperature of the DHW tank. In this way the DHW tank is not directly connected to the solar panel, but to the central heating water in the storage tank. Before installing the system the principles were tested at DTU (Danish Technical University). A few things were changed during the test to improve the performance of the system.

The storage tank

The storage tank is a standard tank with a jacket heat exchanger. The solar system is connected to the heat exchanger and it is run by the principles of low-flow.

As the DHW tank is only connected to the storage tank it is neccesary to add heat to loop between the tanks and hereby also to the top of the storage tank when the solar energy is not enough. The boiler supplies this heating when the temperature of the DHW tank is below approx. 47°C. The heat from the top of the storage tank is hereafter supplied to the hot water tank. Good operating conditions are obtained on the condensing boiler, which will get some longer, and thereby fewer, operation periods while heating DHW.

The central heating water runs through the storage tank when the temperature level is OK for that before it runs to the boiler. To keep some high temperature water left for the DHW heating the outlet for the central heating system is mounted at the top of the heat exchanger.

4. Realisation of the Project

After the tests were finished in the summer 1998, the 10 old boiler systems for the 29 houses were replaced with new systems. Two of them were made with solar heating and the rest were prepared as previously mentioned. Each of the systems with solar energy supplies 3 houses and has 18 m² roof integrated solar collectors, an 800 l storage tank and a 200 l DHW tank with DHW circuit.

Performance the first year

The systems were monitored during the first year. The results display a good performance:

Table 1: Key figures from the measurements 1999-2000

Parameters	**Houses 9-11**	**Houses 18-20**
Floor area, m²	391	409
Heated with floor heating, m^2	39	115
Tenants	10	9
Solar system yield, MWh/year	7,05	7,26
kWh pr m²/year	392	404
DHW, m^3 /year	119 a 50°C	92 a 47°C
Consumption of gas - before the renovation, m^3 NG/år	5966	5513
- after the renovation	4211	3674
Savings obtained due to solar energy and condensing boilers	29 %	33 %

The solar systems were subsided by the Danish Ministry of Energy as a development project.

5. System for 19 Row Houses

In the summer 1999 a bigger system was inaugurated 40 km south of Copenhagen. The system produces DHW and space heating for 19 row houses for elderly people. It consists of 104 m² roof integrated solar collectors, one 5500 l storage tank and one 700 l DHW tank with DHW circuit. The 60 kW oil fired boiler is a low temperature type allowing water temperatures down to 20°C. The houses are heated by floor heating systems. At the moment no results from this system are available.

6. Advantages and Disadvantages

The 2 most important differences of this system compared to other systems are discussed here.

Extra heat exchanger for the DHW
The solar energy is not transferred directly to the DHW tank but always through the heat exchanger in the storage tank. This means a small loss in the temperature level of the energy.

On the other hand the solar heat is allways loaded into the system through the biggest heat exchanger, whereas energy to the DHW tank with the smaller heat exchanger is transferred almost 24 hours a day. This connection also prevents the boiler from running on-off while loading the DHW tank.

Heating of the top of the storage tank
The top of the storage tank is during day time kept on 50-58°C to keep up the temperature of the DHW. During night time the temperature falls down to 40°C. When the storage tank is heated by the sun the temperatures will be higher.
Energy loss due to this amounts to approx. 60 kWh/month during wintertime. The performance of the solar system is at least 100 kWh at the same time, thereby exceeding the losses.

7. Conclusion

Experience shows a well working, reliable system with a yield of approx. 400 kWh/m² solar collector. Some things could be improved making the performance a little higher. Problems with the pump regulator reduced the running hours by 15 % on one of the systems.

The first intention was to make it more simple by always letting the central heating water pass through the lower part of the tank. With more development of the system we believe that it will be possible to make the design more economic and even more reliable.

The system makes it possible with less demands for the DHW tanks to prepare for a later installed solar system.

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MODULAR HEAT EXCHANGE MODULE FOR SOLAR HEATING SYSTEMS

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Founded in 1970, Oy LPM-GROUP Ltd is Finland's largest manufacturer, marketer and developer of Heat Exchangers and Substations for district heating systems.

Oy LPM-GROUP Ltd exports to all the Scandinavian and Baltic countries and also to Poland, Italy, Great Britain, Russia, Germany, China, Hungary, Yugoslavia and the Czech Republic. New operations are underway in Slovakia, Bosnia-Herzegovina, Croatia, Switzerland, Austria and Mongolia.

Oy LPM-GROUP Ltd has its own subsidiaries that undertake assembly of Substations in Estonia and Poland, and sales offices in Sweden, Russia, Latvia and Lithuania.

LPM Heat Exchangers are specially designed for district heating, with models suitable for any special conditions; thermal capacity, water quality, temperature program etc. The product range includes:

- Brazed Plate Heat Exchangers (7 plate sizes from about 10 kW- 3 MW)
- Plate Heat Exchangers with EPDM gaskets (4 plate sizes from 10 kW- 5 MW)

When connected in parallel over 20 MW of heating capacity can be reached. Plate material stainless steel AISI 304 or AISI 316.

The quality system of LPM has been found to conform to the Quality System Standard SFS-EN ISO 9001 and heat exchangers have been tested and approved in Finland (RS), Sweden (SA), Germany (TÛV), Poland (UDT), Russia (GOST), Mech. Fach. Uni. Of Belgrade, Yugoslavia and the Czech Republic (ITI/VUPS).

LPM Substations are made of heat exchangers, controlling system, pumps, and a pump control box, shut-off valves, thermometers, manometers, internal electrical wiring and all other essential equipment. LPM Substations can optionally be equipped with a heat measurement unit, a closed expansion tank, double pumps and remote control according to the customer's requirements. Oy LPM-GROUP Ltd produces also modules for solar heating systems.

A unique computer program developed by LPM ensures that each substation has the optimum capacity for its building. Units are individually assembled from the appropriate selection of alternative components and the substation always has right sized heat exchangers, efficient control systems and reliable pumps. Based on these facts can be said that LPM products save a great amount of energy while providing comfort and quality.

Oy LPM-GROUP Ltd has about 200 employees. The annual net sales during 1999 was about USD 25 million, of which the share of exports was about USD 11 million. In 1999 Oy LPM-GROUP Ltd supplied more than 15 000 plate heat exchangers and about 4000 substations in all. More than 50 000 LPM Substations have been installed.

As a long-experienced district heating professional LPM offers guaranteed quality.

SOLUS II STORAGE TANKS

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