LEP

The Low-Energy House Project
The Danish Ministry of Energy

SIMULTANEOUS TESTING OF HEATING SYSTEMS

128

Thermal Insulation Laboratory
Technical University of Denmark
November 1982

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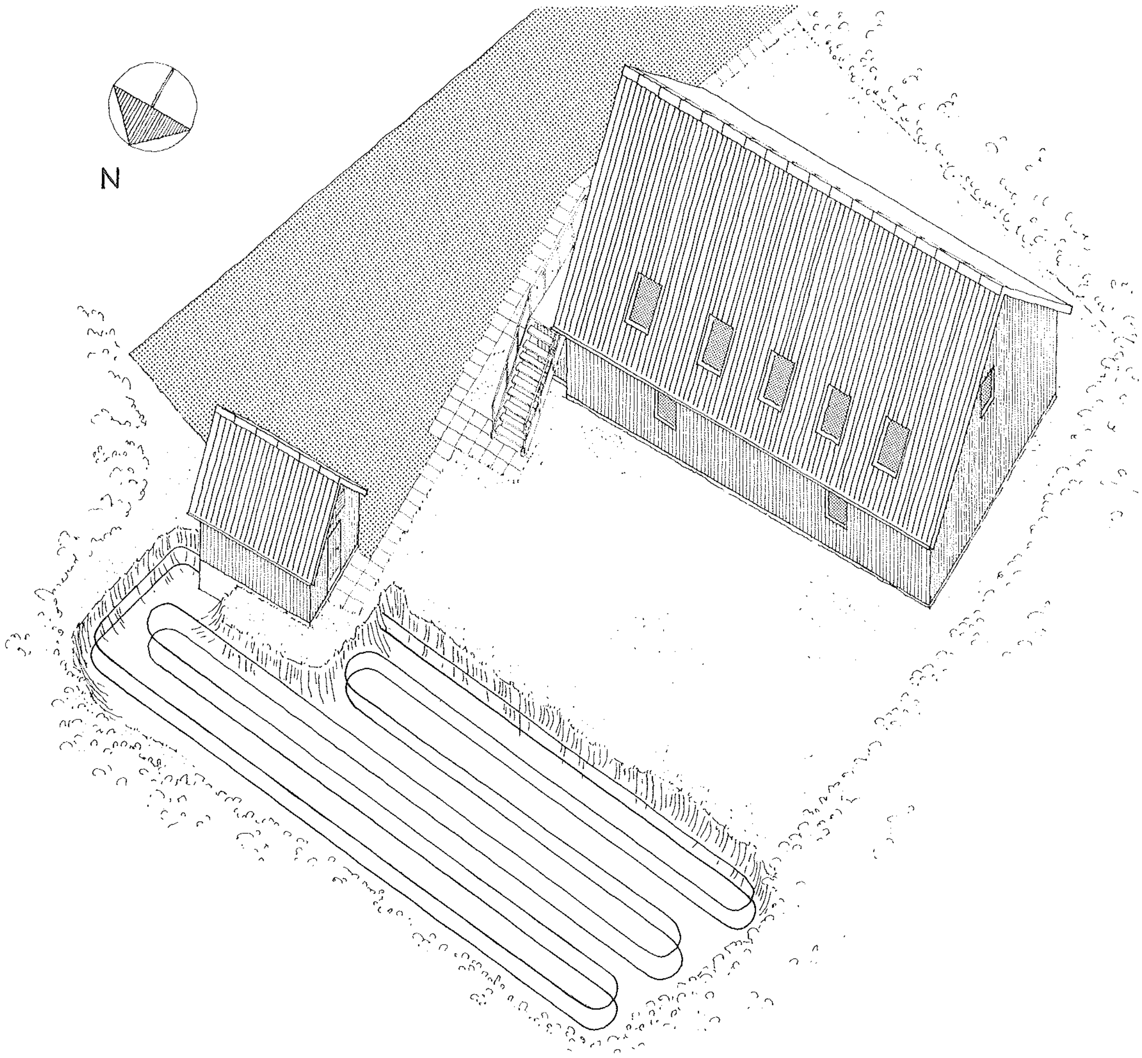

EXPERIMENTAL LOW-ENERGY HOUSE AT THE TECHNICAL UNIVERSITY OF DENMARK, description of a system for simultaneous testing of heating systems for conservation houses under actual climate conditions

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The Low-Energy House Project

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PREFACE

The main part of this report was presented at the ENERGEX'82 SESCI Energy Conference at Regina, Saskatchewan, Canada, August 23-29 1982. The content has been reedited and new material and illustrations have been added.

The Low-Energy House Project is carried out by the Thermal Insulation Laboratory at the Technical University of Denmark. The project is part of the National Energy Research Programme and is funded by the Danish Ministry of Energy.

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ABSTRACT

During the winter 1981-82 a test facility has been built in connection with a multiple-purpose experimental low-energy house. In this test facility different sources of heat, mainly for hydronic systems, can be tested simultaneously under actual climate conditions, each test unit at any time generating the quantity of heat demanded by the experimental house. The basic control unit of the simulation system is a sensitive differential controller operating a fast modulating magnetic three-way valve. A series of tests shows that these controls will adjust the distribution and return temperatures in the simulation system according to the system temperatures in the experimental house with a mean deviation of less than ±0.15 deg C.

The first heat sources to be tested in the simulation system are two heat pumps - an air-to-water heat pump drawing heat from the external air and a water-to-water heat pump drawing heat from the ground.

The air-to-water heat pump was installed in March 1982, and preliminary tests from the first period of operation (7 weeks) show efficiencies of the heat pump unit ranging from 2.2 to 2.6 - the power consumption including the electricity used by the compressor and the evaporator fan.

The water-to-water heat pump was installed in May 1982. The first measurements will be carried out at the beginning of the heating season 1982-83.

INTRODUCTION

Most energy conservation houses are characterized by a high degree of insulation and air tightness, thus having a low energy demand due to transmission and ventilation losses. Equally important is the fact that compared to standard houses a larger percentage of the heat loss is met by free heat (solar heat gain and internal load due to emission of heat from persons, lighting, electric appliances etc). In the Danish climate up to 40% of the demand may be met this way according to our experience.

Heating systems, however, are designed in total disregard of this, and furthermore the design external temperature is -12 deg C, a temperature that occurs only a few times in a normal heating season. Denmark has approx 70,000 heating degree hours (17 deg C base) in a year, and the average external temperature during the months October-April is 3.0 deg C.

In energy conservation houses the normal operating conditions for such heating systems will be less than half the heat production capacity. Especially for piped heating systems this causes a decrease of efficiency, eg of boilers, and also increased no-load losses.

It must be emphasized that whereas these undesirable losses may be neglected in normal houses that cannot be done in low-energy houses as they can play a significant part in the energy balance for the heating systems.

To investigate heating systems for conservation houses under natural weather conditions a special test facility was designed and built at the Technical University of Denmark. The main element of the test facility is a multiple-purpose experimental low-energy house built in 1980.

During the winter 1981-82 a smaller house has been built close to the experimental house, especially for the testing of heat sources. The general layout is outlined in Figure 1. In the smaller house the heat demand of the larger house is simulated so that different heat sources can be tested simultaneously.

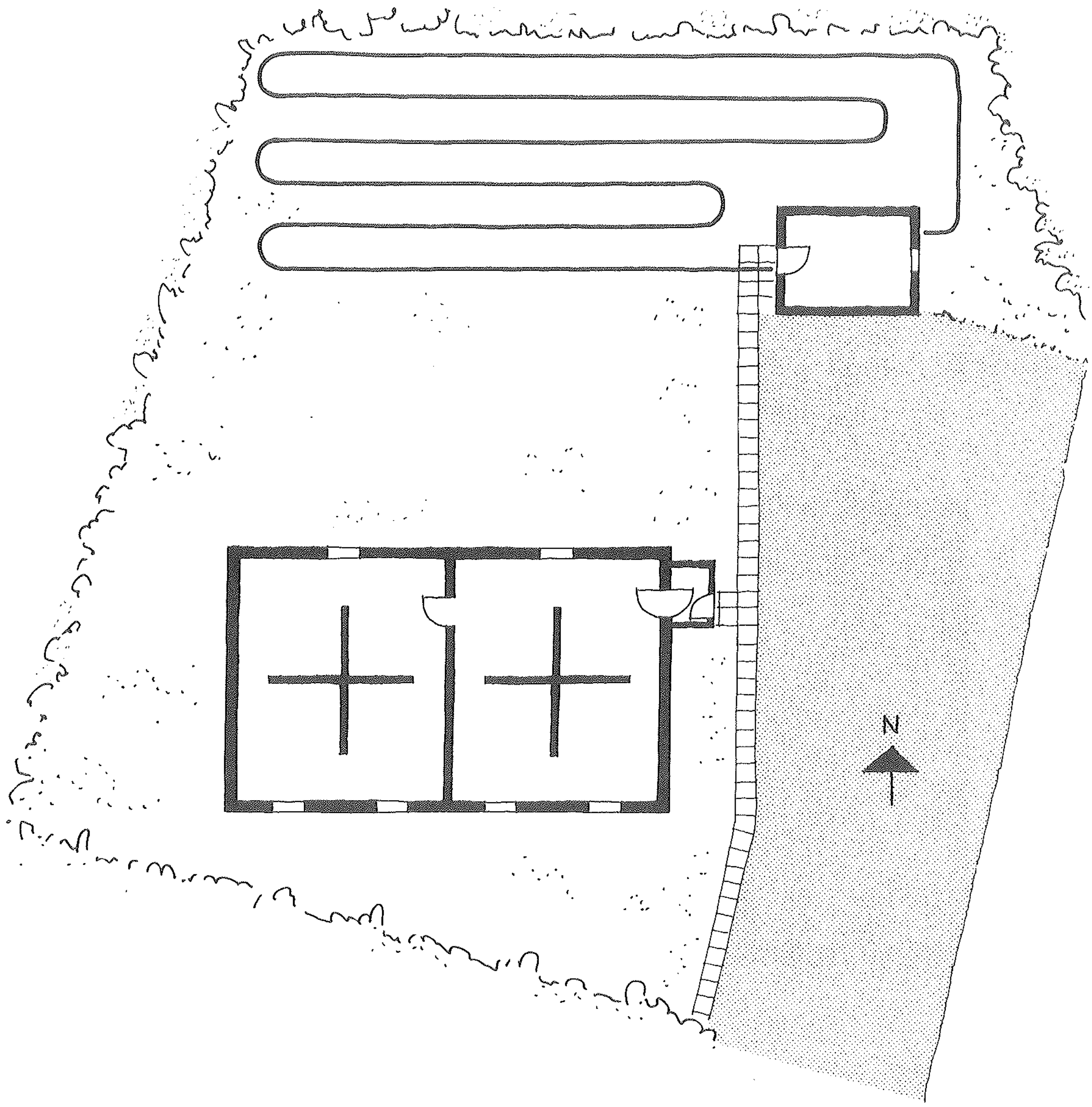


Figure 1. General layout. Window area equal to about 5% of the floor area.

THE EXPERIMENTAL LOW-ENERGY HOUSE

The experimental low-energy house is a one-storey house with a crawl space and a roof space, the latter being used as workshop and monitoring room. The house has a floor area of approx 120 m^2, divided by an insulated partition into an eastern and a western room of 60 m^2 each (A and B in Figure 2). The house is wood-built, the main storey being insulated with 300 mm mineral wool. Custom-built prefabricated building units have been used for the main storey, the wall elements being interchangeable. The joints between the elements are sealed with polyurethane foam, and the polyethylene vapour barrier has squeezed lap joints, cf Figure 3. Infiltration air change measurements indicate an air change rate of 0.008 per hour. Each room (A and B) has a ventilation system with a cross-flow plate type heat exchanger, normally giving a total air change of 0.5 a.c.h.

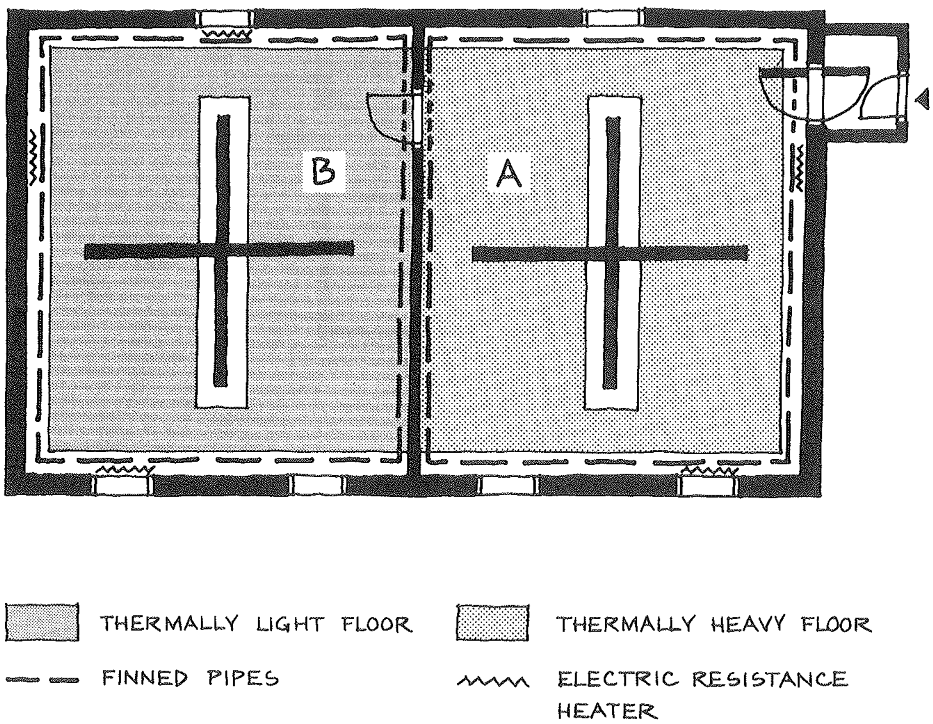


Figure 2. Experimental house - Floor plan showing the different heating systems. Window area equal to about 5% of the floor area.

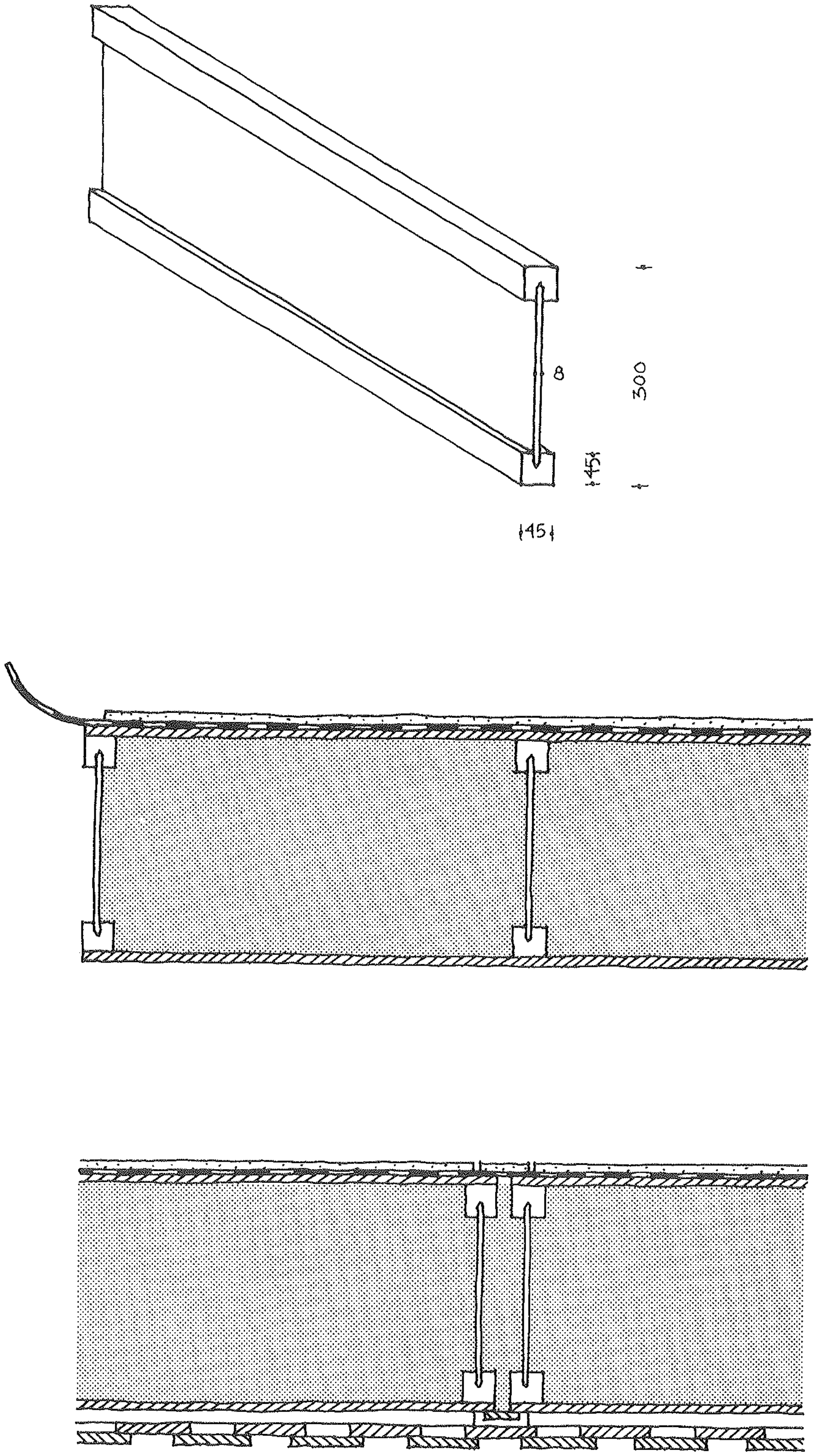


Figure 3. Experimental house - Building components. Masonite beam (top), wall (or floor) element (center) and joining of two elements (bottom).

During the first heating season (1980-81) the house had no windows at all. During the heating season 1981-82 the window area was approx 5% of the floor area - in the summer of 1982 the percentage was raised to 15. At 15% window area the design heat loss by transmission, infiltration and controlled ventilation (recovery performance coefficient 0.7) is 3.2 kW (design internal to external temperature difference 32 deg C). During the preliminary tests in the spring of 1982 the design heat loss was only 2.5 kW due to the smaller window area.

In both test rooms four alternative heating systems have been installed:

- floor heating (embedded tubes)
- perimeter heating (finned pipes)
- electric resistance heaters
- electric hot-air heating connected to the heat recovery unit.

The floor heating and the perimeter heating are low-temperature systems designed to have operating flow temperatures ranging from 25 deg C to 35 deg C. Both systems are connected to an electric boiler (each room has its own).

In room A a traditional floor heating construction (concreted plastic tubes) has been employed - in room B a thermally lighter construction has been used having a floor surface of 22 mm chip board on top of 50 mm expanded polystyrene, the plastic tubes being placed in premilled grooves in the polystyrene. Metal sheets between the chip boards and the tubes contribute to giving a uniform surface temperature. During the heating seasons 1980-81 and 1981-82 the heating systems have been tested with different control strategies, all controllers being based on room thermostats. The results of these tests will be published in the spring of 1983.

Detailed continuous measurements of energy consumption, internal temperatures, and weather data are carried out, thus creating a basis for thorough analyses and improved computer simulation programs, particularly regarding the solar heat gain.

THE TEST FACILITY FOR HEAT SOURCES

The heat source house (C in Figure 4) has a floor area of 17 m^2 and is located to the northeast of the experimental house.

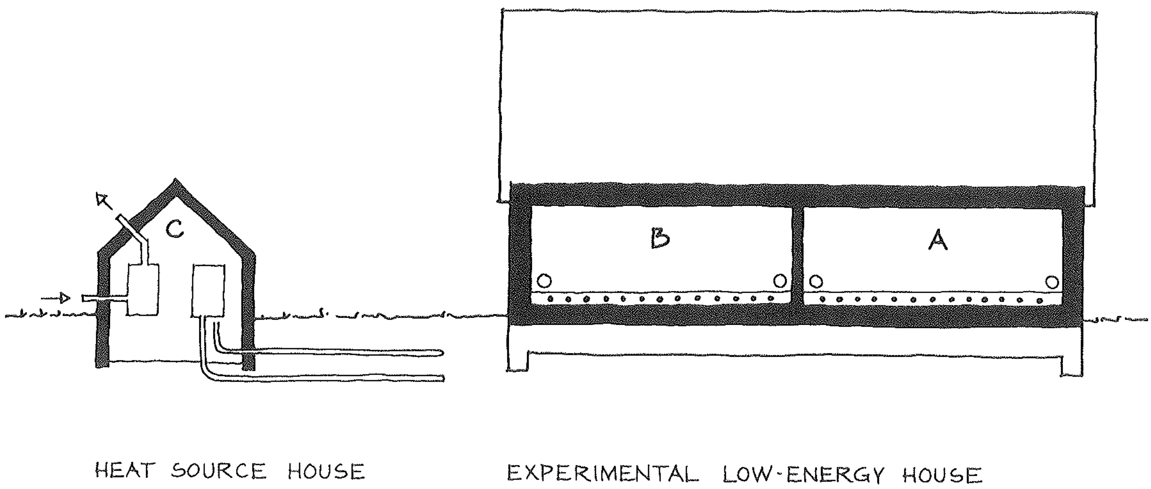
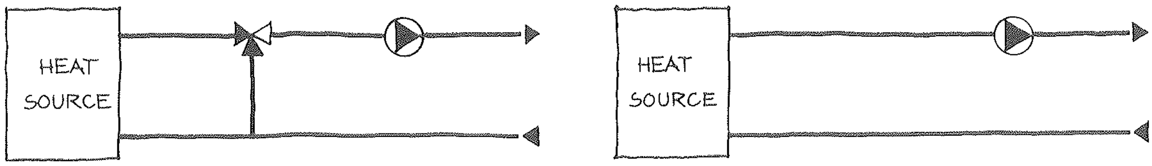


Figure 4. Schematic section of the two houses.

The physical separation of the heat sources and the heaters in combination with a very flexible simulation control system makes it possible to test a number of heat source systems simultaneously (the heating system temperatures being copied without interfering with the test programme for the experimental house) thus giving a good basis for a realistic comparison. At present two heat source systems can be operated from each room of the experimental house. For specific investigations of certain heat sources, especially heat pumps, the system can be operated the other way around. The distribution temperature in the experimental house can be adjusted according to the system temperature generated by the heat source.



Alternative 1
(with mixing)

Alternative 2
(without mixing)

Figure 5. The connection between the heat sources and the heat distribution system.

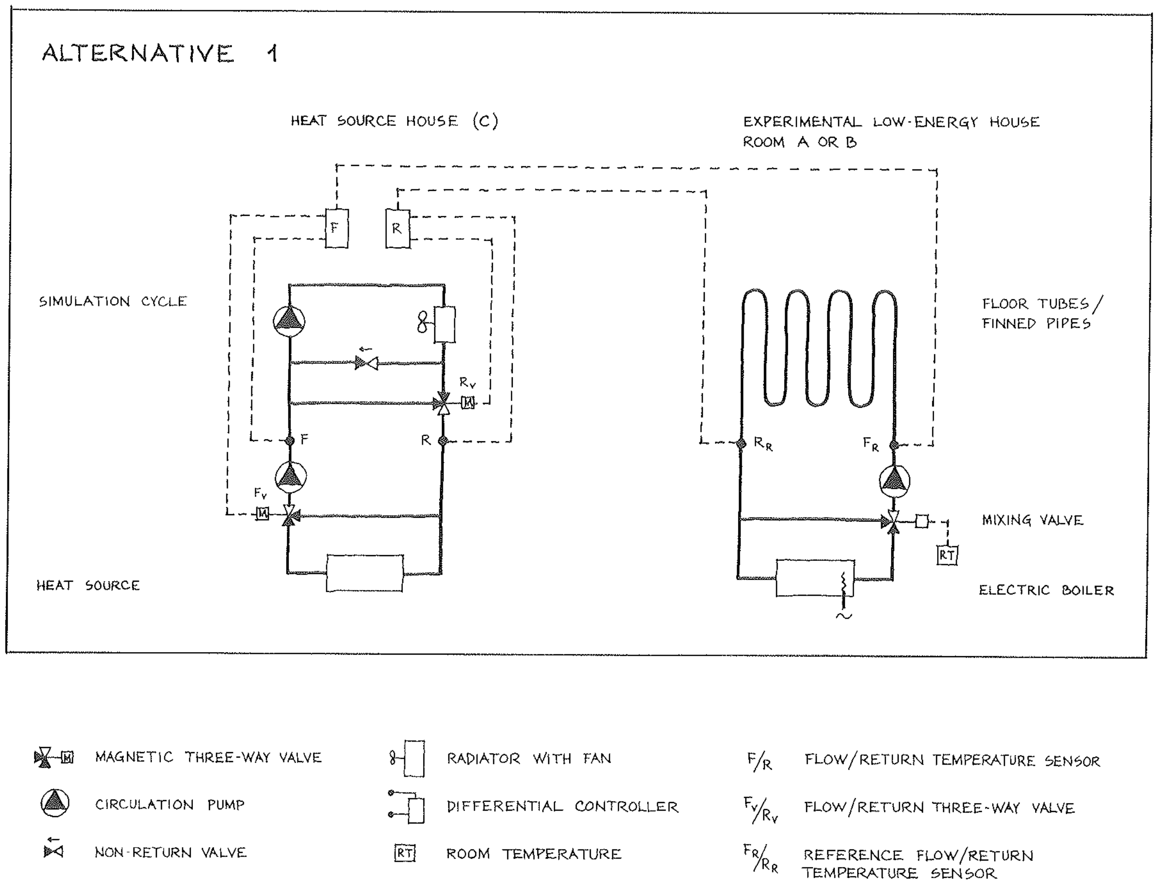
Figure 6 shows diagrams of the simulation system and one of the heating systems in the experimental house according to the two operation strategies.

Alternative 1:

The heat source is controlled according to the demanded flow temperature of the simulation cycle. The room thermostat in the test room (A or B) controls the flow temperature in the test room. This temperature dictates the flow temperature of the simulation cycle. Similarly, the return temperature in the test room dictates the return temperature of the simulation cycle. Thus the normal operation of the test room is not disturbed.

Alternative 2:

The room thermostat in the test room (A or B) controls the heat source directly. The simulation cycle flow temperature dictates the flow tempera-



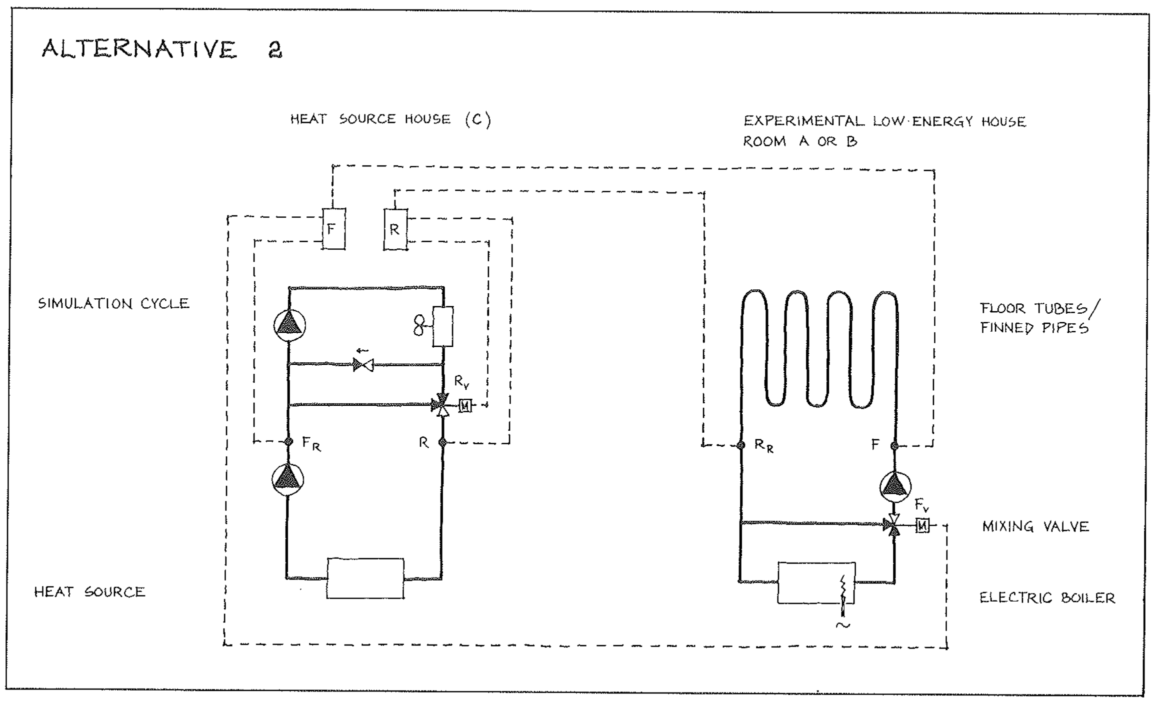


Figure 6. Diagrams of the simulation system and a heating system, according to the two strategies of operation.

ture in the test room. The heat output in the test room gives a certain return temperature. This temperature dictates the return temperature of the simulation cycle. This control strategy thus interferes with the operation of the test room.

The basic control unit in the simulation system is a sensitive differential controller RPR9 + RPR developed by Stäfa Control System. The controller is equipped with special high precision Pt-100 temperature sensors. The controller operates a fast magnetic type modulating three-way valve (SCS M3P15G), mixing to keep any set temperature difference between the two sensors - the set value mostly being 0.0 deg C.

The flow in the simulation cycle is mostly kept at twice the flow of the experimental house reference heating system to simulate the heat demand of a 120 m^2 conservation house. The flow is adjusted manually.

The heat delivered by the heat source is conducted away by ventilation as indicated in Figure 6.

Temperatures and flows in both the simulation system and the heating system are measured every ten minutes by the datalogger equipment installed on the top floor of the experimental house. These measurements show that the differential controllers and the magnetic three-way valves have functioned very satisfactorily. For a period of 10 days the mean deviation between the flow and return temperature difference of the perimeter heating system (test room A) and the corresponding difference of the simulation system was only 0.06 deg C. Figure 7 presents some of the measured and calculated data from this 10-day period, operated according to Alternative 1.

	t_F (flow temp.) [deg C]	t_R (return temp.) [deg C]	t_F-t_R [deg C]	Flow [m^3]	Heat output [kWh]
PERIMETER HEATING:					
Mean/total	26.66	25.86	0.80	218.34 *)	203.2 *)
Standard deviation	1.90	1.57	-	-	-
SIMULATION SYSTEM:					
Mean/total	26.77	25.92	0.85	237.43	236.7
Standard deviation	1.88	1.56	-	-	-
Mean deviation between the two systems [%]	0.4	0.2	6.3	8.7	16.2
*) Two times the true flow/output in test room A.					

Figure 7. Results from 10-day test period of simulation system (Alternative 1) and a perimeter heating system.

As indicated in Figure 7 the flow in the simulation cycle is a little higher than two times the flow in test room A. If it is considered important to have exactly twice the flow careful trimming may reduce the deviation almost to 0. It should be noticed that the flow/return temperature difference is as low as 0.8 deg C. Thus the small deviations in temperature result in a temperature difference deviation of 6.3%. Even at these extremely unfavourable operating conditions it will thus be possible to keep the difference of heat output in the two systems within ±10%.

Figure 8 illustrates how little the flow/return temperature difference of the simulation system deviates from the corresponding temperature difference in the test room during a 24-hour period. Attention is called to the scale of the ordinate axis.

DIFFERENCE BETWEEN :
THE FLOW - RETURN TEMPERATURE DIFFERENCE IN THE SIMULATION SYSTEM AND THE CORRESPONDING DIFFERENCE IN THE PERIMETER HEATING SYSTEM (TESTROOM A).

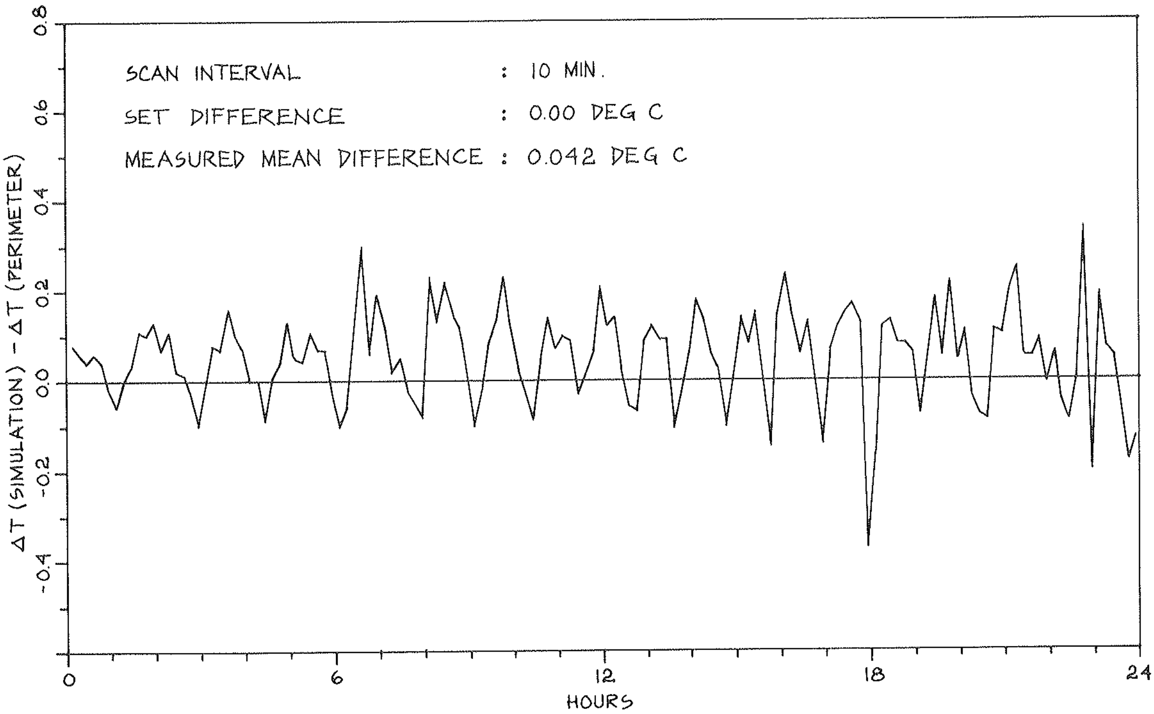


Figure 8. Precision of the simulation equipment.

THE HEAT SOURCES

The first heat sources to be tested in the simulation system are two heat pumps, each designed to meet approx 60% of the 3.2 kW design heat loss of the experimental low-energy house (15% window area). Complementary to each heat pump an electric heating element meets the peak load.

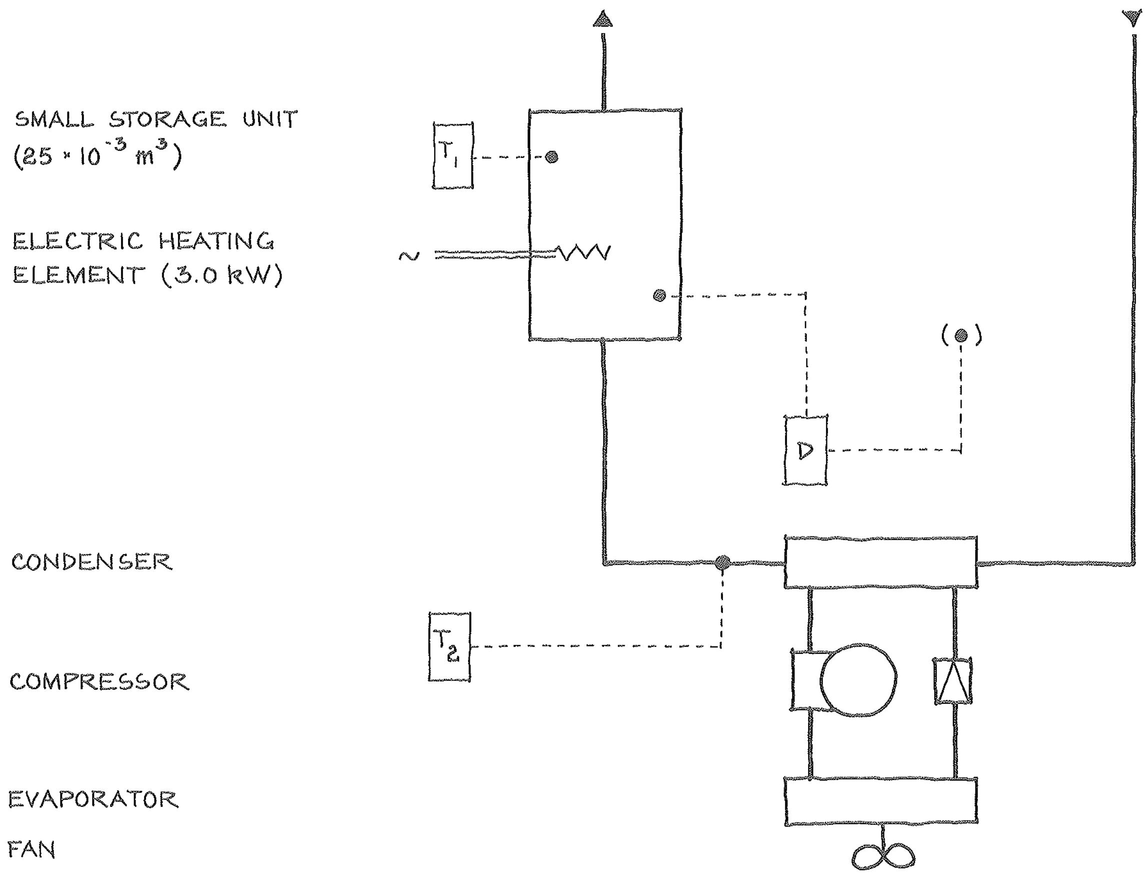
System 1 has a commercially produced Vesttherm air-to-water heat pump drawing heat from the external air. The system and its control equipment are shown in principle in Figure 9. The connections between the heat pump and the simulation system are drawn according to Figure 5 (Alternative 1). The mixing valve shown in Figure 5 is not physically removed when the system is operated according to Alternative 2 (without mixing), but the differential on-off controller is short-circuited to leave the left gate permanently open. In this situation the room thermostat located in the experimental house controls the operating periods of the compressor and the evaporator fan directly.

System 2 has a specially designed water-to-water heat pump drawing heat from the ground through 130 m plastic tubes (40 mm bore) buried at a depth of 1.5 m (spacing 1.5 m), alternatively through a set of tubes buried at a depth of 0.9 m, as shown on the title page. The two sets of tubes will be used in different heating seasons. Part of the experiment is to fill the tubes with plain water using no anti-freeze additives, eg ethylene glycol. Monitoring experience from a low-energy house at Hjortekær, north of Copenhagen, indicates that it should be possible. It is desirable to avoid anti-freeze solutions for environmental reasons. The system and its control equipment are shown in principle in Figure 10.

The connections between the heat pump and the simulation system are drawn according to Figure 5, Alternative 1. The mixing valve is operated as described for the air-to-water heat pump. A flow switch has been installed in the ground tube cycle. If the water temperature approaches the freezing point the flow decrease will switch off the compressor and the corresponding circulation pump. The heat source system 2 was installed in the spring and was ready for operation by the end of May 1982.

The detailed monitoring programme includes measuring of input and output (from the heat pump as well as the auxiliary heating element), operating temperatures and flow, working and defrosting periods, and no-load losses.

Figure 11 and 12 illustrate the measuring systems (showing electricity meters, flow meters, thermocouples, thermopiles etc). All data is collected and stored in the central datalogger located on the top floor of the experimental house.



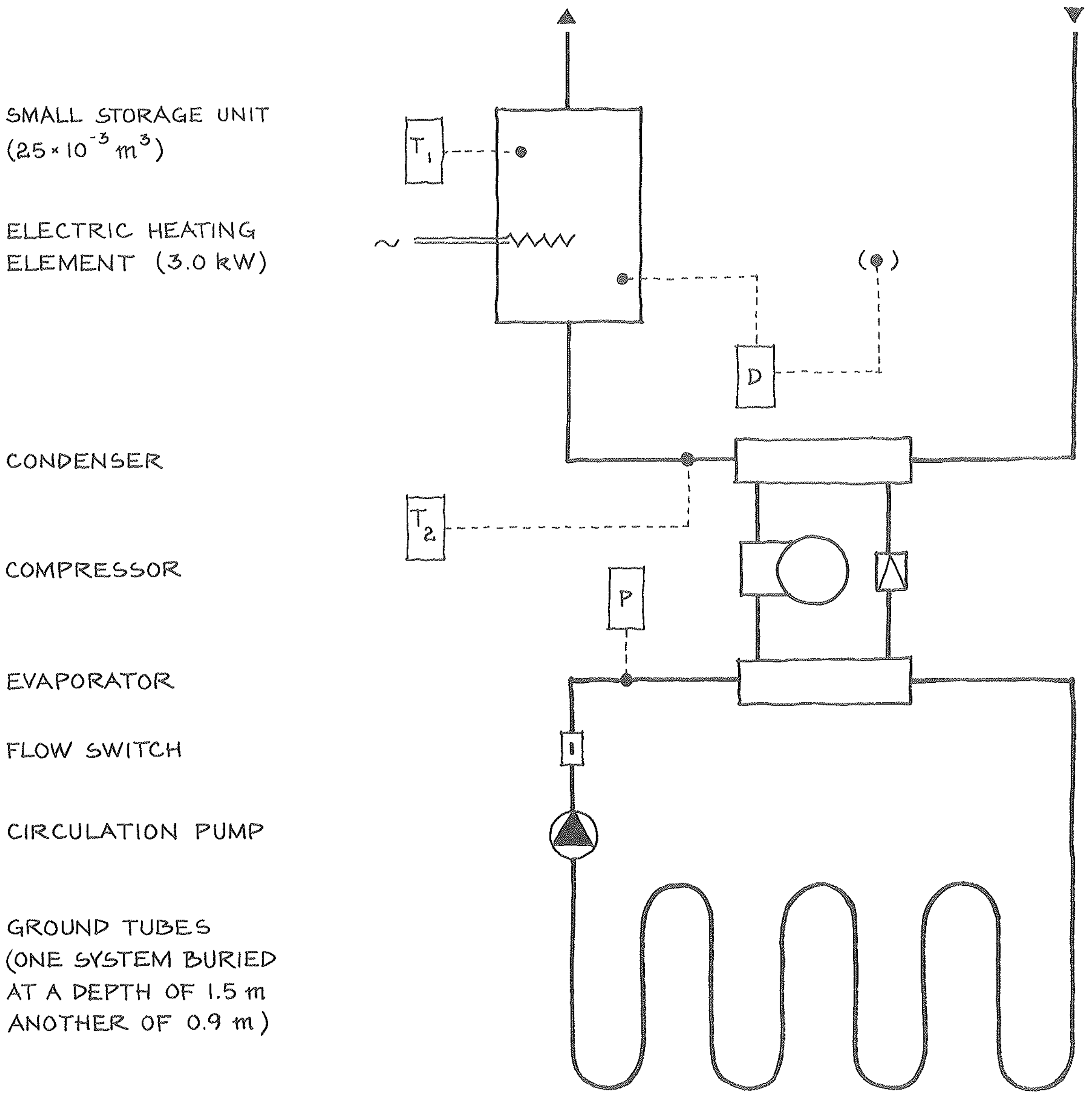
T_1 THERMOSTAT. ON-OFF CONTROL OF ELECTRIC HEATING ELEMENT.

T_2 THERMOSTAT INTEGRATED IN THE HEAT PUMP UNIT. ON-OFF CONTROL OF COMPRESSOR AND EVAPORATOR FAN.

D DIFFERENTIAL CONTROLLER. ON-OFF CONTROL OF COMPRESSOR AND EVAPORATOR FAN. REFERENCE SENSOR PLACED IN THE FLOW TUBE JUST AFTER THE CIRCULATION PUMP (SIMULATION CYCLE). OPERATION SENSOR PLACED IN STORAGE UNIT. (SET MIN/MAX TEMPERATURE DIFFERENCE EG 1.5 C / 4.0 C)

Figure 9. Heat source system 1. Air-to-water heat pump.

Figure 10. (opposite) Heat source system 2. Water-to-water heat pump.



T_1 THERMOSTAT. ON-OFF CONTROL OF ELECTRIC HEATING ELEMENT.

T_2 THERMOSTAT. ON-OFF CONTROL OF COMPRESSOR AND CIRCULATION PUMP IN GROUND TUBE CYCLE.

P PRESSURE SWITCH. MANDATORY (BY THE DANISH BUILDING CODE). STOPS THE COMPRESSOR IF THE PRESSURE DROPS IN THE GROUND TUBES.

D DIFFERENTIAL CONTROLLER. ON-OFF CONTROL OF THE COMPRESSOR AND THE CORRESPONDING CIRCULATION PUMP. REFERENCE SENSOR PLACED IN FLOW TUBE JUST AFTER THE CIRCULATION PUMP (SIMULATION CYCLE). OPERATION SENSOR PLACED IN STORAGE TANK. (SET MIN/MAX TEMPERATURE DIFFERENCE EG 1.5 C/4.0 C).

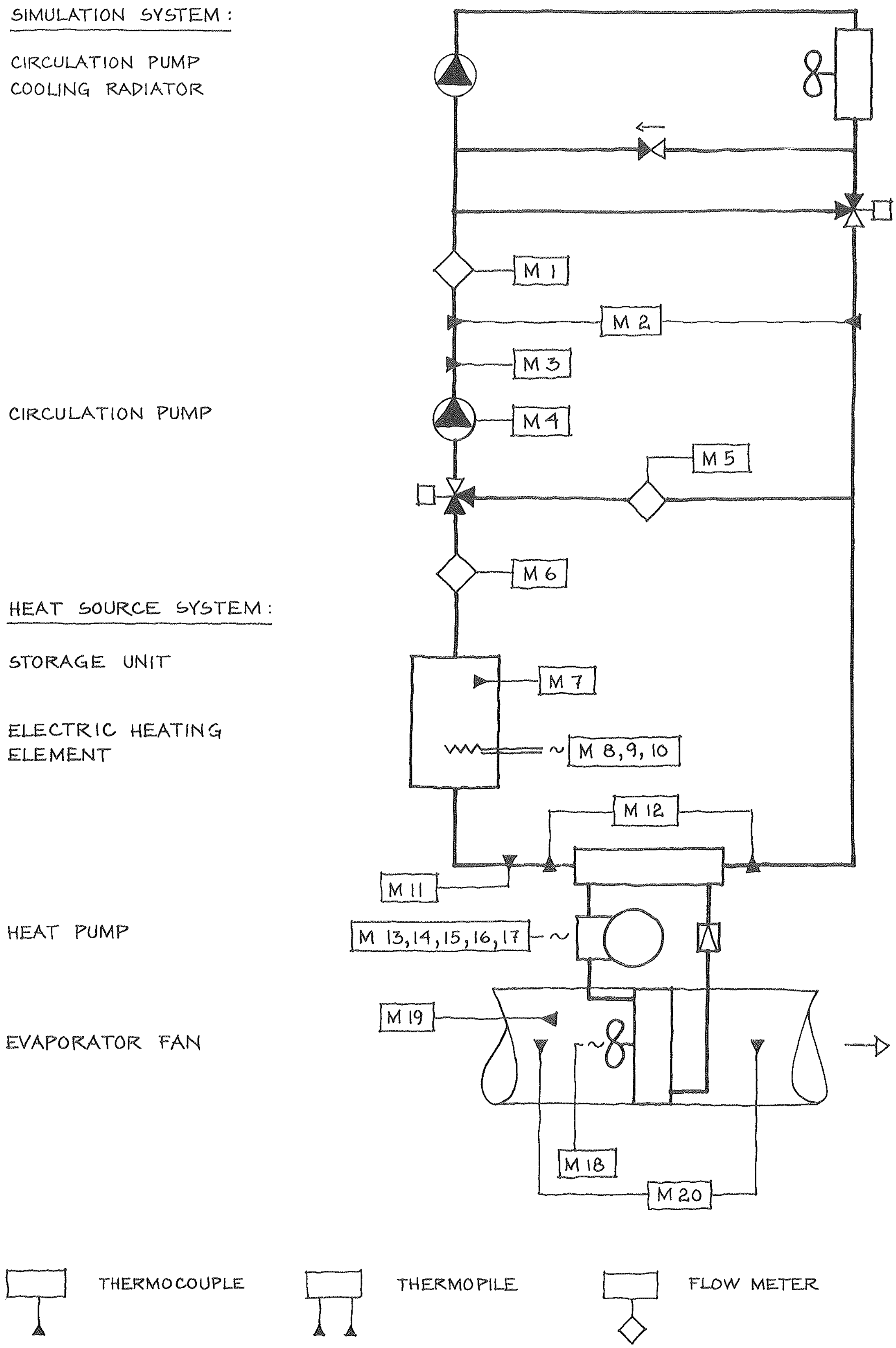


Figure 11. Heat source system 1. Diagram of monitoring system.

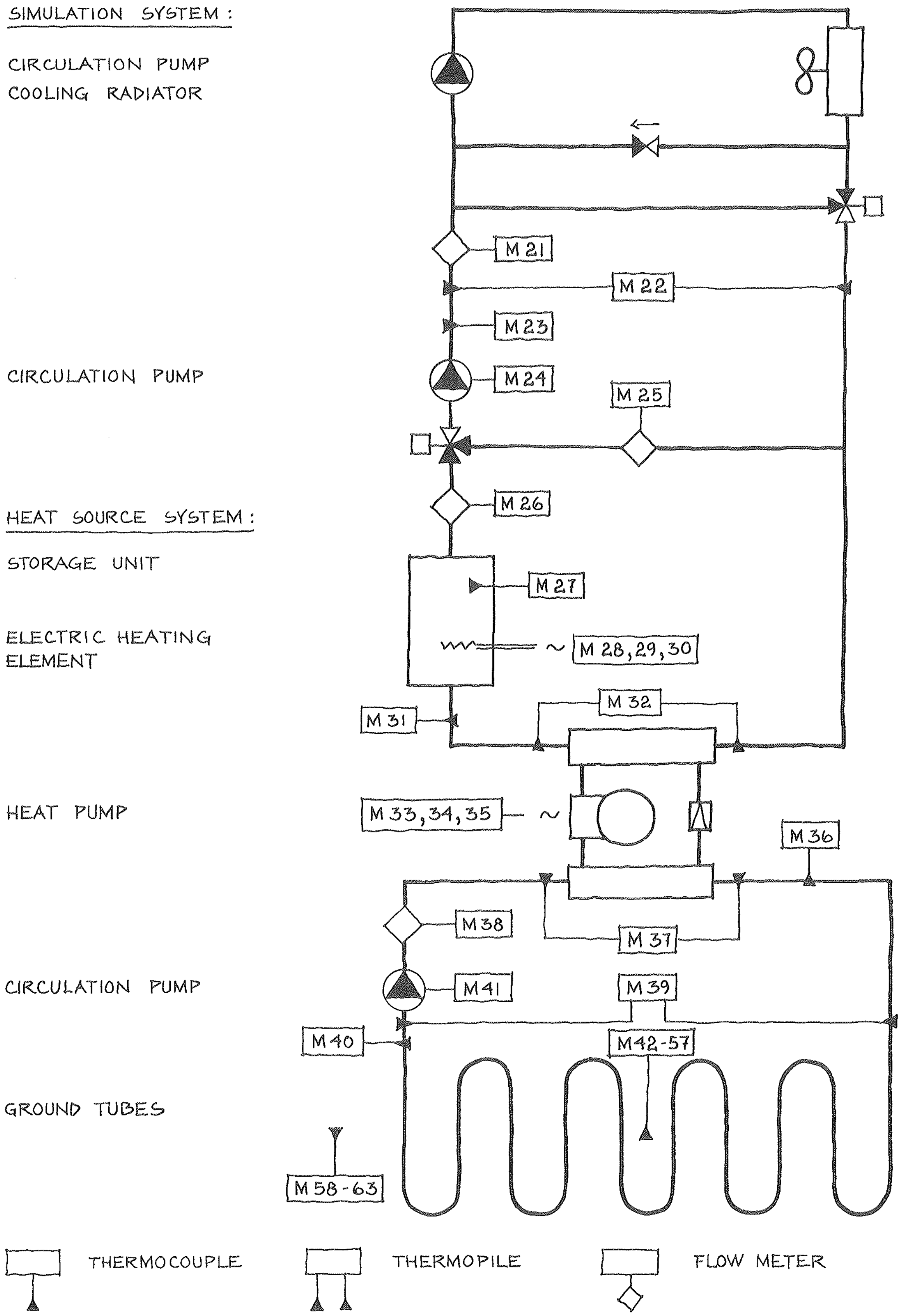


Figure 12. Heat source system 2. Diagram of monitoring system.

The detailed monitoring of system 1 was started on March 1st. It was planned to keep the water-to-water heat pump in system 2 working all summer to cool the ground to a reference temperature level measured at a low-energy house at Hjortekær. However, as shown in Figure 13 it was found that the temperature at the ground coil level regenerates during the summer, and therefore the system will be operated and monitored from the beginning of the heating season 1982-83.

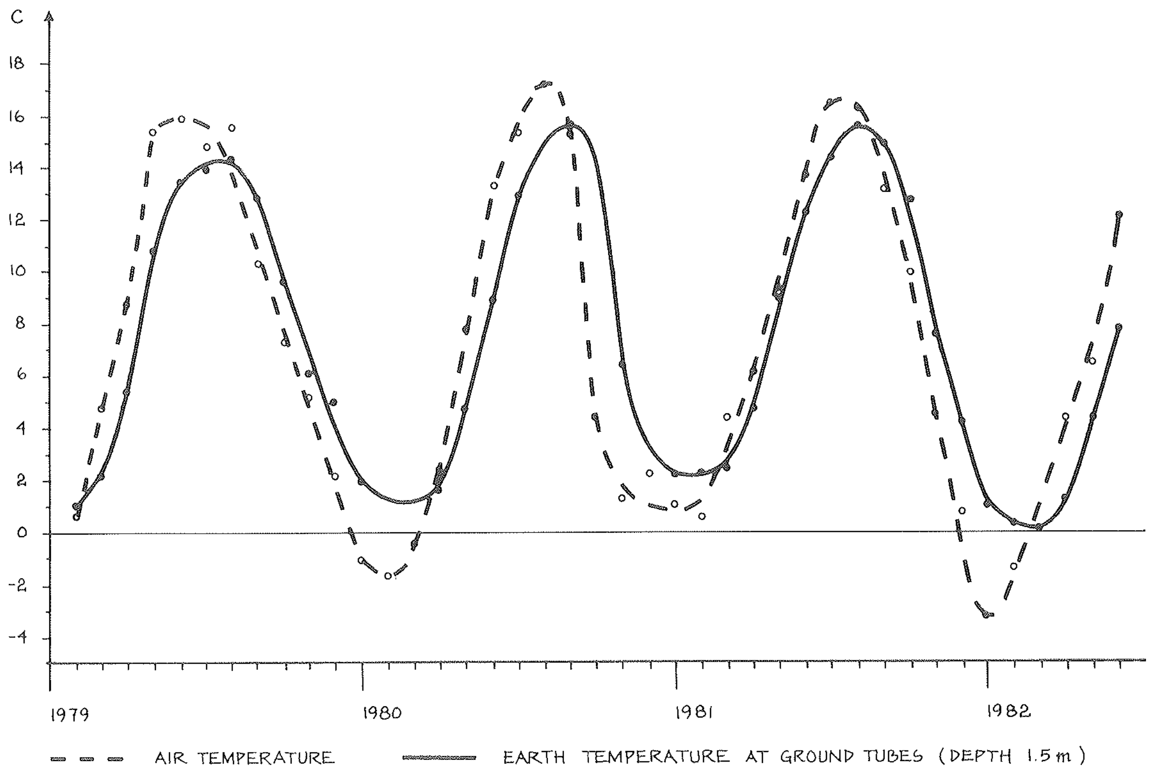


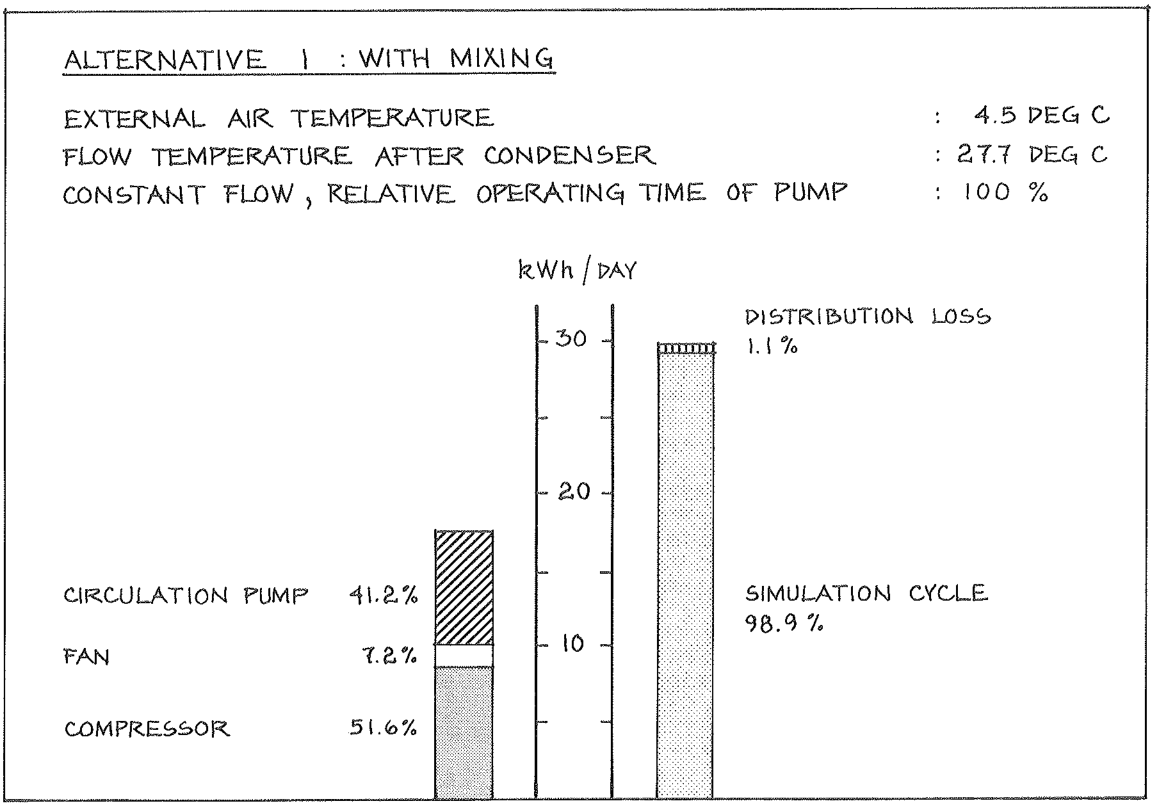
Figure 13. Temperatures at ground coil level at Hjortekær and the external air temperature.

Figure 14 shows results from two testing periods - corresponding to the two alternative test systems described in Figure 5 and 6. The overall efficiency of the simulation system is found as the ratio of the heat output to the total power consumption for compressor, evaporator fan and circulation pump. The efficiency of the heat pump unit, however, is found as the ratio of the condenser heat output to the electricity consumption for compressor and evaporator fan.

The considerable pressure drop in the simulation cycle due to the radiator, the three-way valves, the flow meters and the numerous immersed temperature sensors necessitates a powerful pump as is evident from the results in Figure 14. This makes it a little difficult to simulate very small outputs from the heat source.

The preliminary tests of the air-to-water heat pump yielded the overall system efficiencies 1.7/2.2 and the heat pump unit efficiencies 2.2/2.6 by Alternative 1/Alternative 2 respectively. As defrosting arrangement the fan is stopped and the hot fluid from the compressor is led directly to the evaporator. The efficiencies are not satisfactory but they can be improved through some modifications of the heat pump and the connections to the little storage tank. The partition separating the compressor space from the evaporator space was leaky and insufficiently lagged. As cold air (up to 1000 m^3/h) passes through the evaporator space air tightening and improved lagging will lessen the uncontrolled cooling of the compressor considerably, and as a special cooling circuit connects the condenser and the compressor the performance will improve. Secondly, by Alternative 1 the flow through the condenser is occasionally very low. The efficiency can be improved by installation of a secondary circuit connecting the condenser and the small storage unit (as illustrated in Figure 15) thus ensuring a permanent minimum circulation through the condenser. These improvements will be carried out in the near future. An even better solution (but hardly feasible in this case) would be to have the condenser immersed in the storage tank.

Generally speaking, higher heat pump efficiencies can be expected from Alternative 2 than from Alternative 1, because the flow through the condenser is larger in the first case (no part of the flow is diverted). However, that is not necessarily true of the overall system efficiencies, but that is one of the questions that will be answered after the forthcoming heating season.



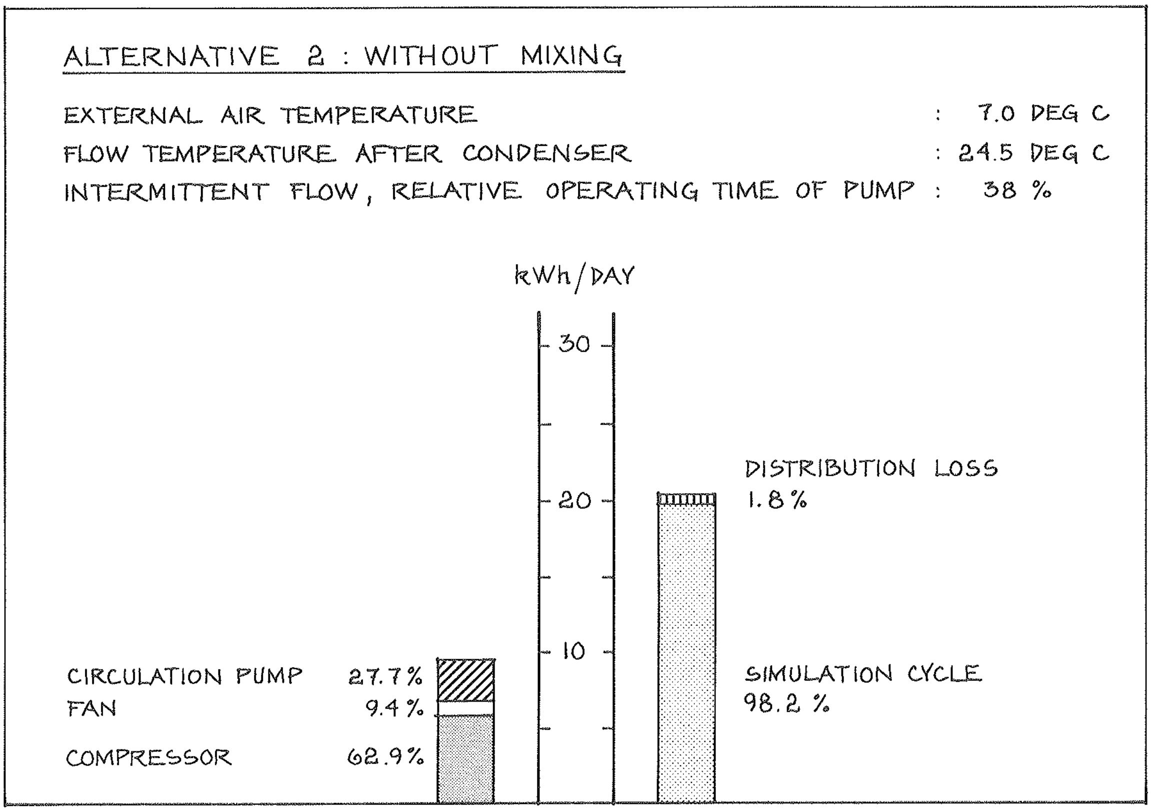


Figure 14. Power consumption and heat output from air-to-water heat pump (mean values from a monitoring period of about 14 days).

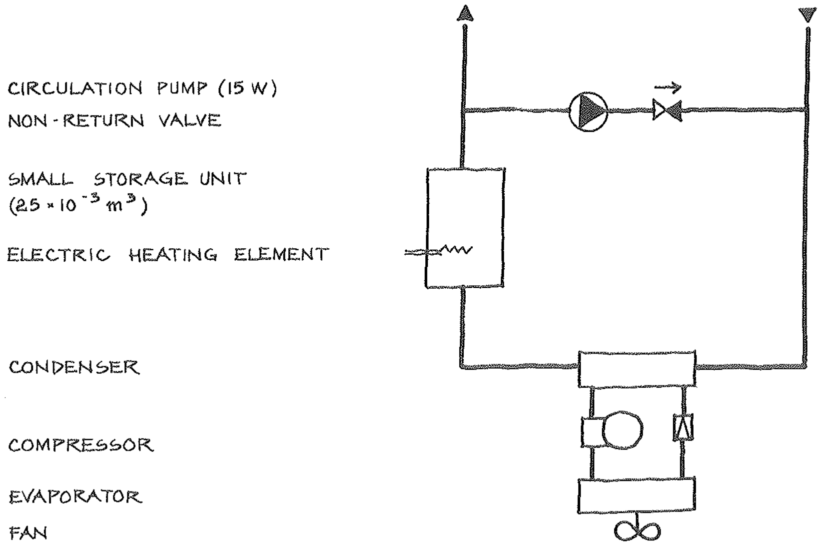


Figure 15. Heat source system 1. Installation of a secondary cycle.

CONCLUSION

A test facility comprising an experimental low-energy house with different heating systems and a separate house for heat sources has been described, the two houses being connected by underground cables only. Also a description has been given of a system in the heat source house performing simultaneous simulation of the actual heat output in the experimental house or any output directly proportional to this.

The monitoring of the simulation system has so far indicated that it is possible to simulate the actual heat demand and dynamics of the experimental low-energy house even at unfavourable operating conditions with a deviation of less than ±10%.

This opens up possibilities of testing several heat sources at the same time thus giving a good basis for comparisons.

The two heat pump systems described will be tested simultaneously during the forthcoming heating season after final trimming of the simulation systems during the summer of 1982.

No distinct and far-reaching conclusions about the air-to-water heat pump should be drawn from the preliminary test results reported here, but it must be stated that the commercial product has in some respects been found wanting - however, only minor efforts are required to repair the defects.

ACKNOWLEDGEMENT

We should like to thank our colleagues in the Low-Energy House Project research team, Mogens R. Byberg (project manager), Rolf G. Djurtoft and Johannes Poulsen, who have participated in either the planning or the construction of the simulation equipment.

APPENDIX

The measuring systems are illustrated in Figure 11 and 12.

Heat source system 1 with simulation system List of measuring points			
Item	Description	Unit	Data
M 1	SS: Flow through sim. cycle	m^3	L+R
M 2	SS: Temp.diff. flow/return	C	L
M 3	SS: Flow temperature	C	L
M 4	SS: Electricity for pump	kWh	R
M 5	SS: Flow diverted from HS	m^3	R
M 6	HS: Flow through condenser	m^3	L+R
M 7	HS: Temperature in tank	C	L
M 8	HS: Electricity for heater	kWh	L+R
M 9	HS: Operating time for heater	h	R
M 10	HS: Number of starts for heater	ND	R
M 11	HS: Condenser flow temperature	C	L
M 12	HS: Condenser flow temp.diff.	C	L
M 13	HS: Electricity for compressor	kWh	L+R
M 14	HS: Operating time for M 13	h	L+R
M 15	HS: Number of starts for M 13	ND	L+R
M 16	HS: Defrosting period	h	L+R
M 17	HS: Number of starts for M 16	ND	R
M 18	HS: Electricity for evap. fan	kWh	R
M 19	HS: Air temperature at evap.	C	L
M 20	HS: Air temp.diff. at evap.	C	L

HS = Heat source system (heat pump)

SS = Simulation system

L = Logged every 10 minutes (accumulated values for digital meters)

R = Daily (visual) meter readings

Heat source system 2 with simulation system List of measuring points			
Item	Description	Unit	Data
M 21	SS: Flow through sim. cycle	m^3	L+R
M 22	SS: Temp.diff. flow/return	C	L
M 23	SS: Flow temperature	C	L
M 24	SS: Electricity for pump	kWh	R
M 25	SS: Flow diverted from HS	m^3	R
M 26	HS: Flow through condenser	m^3	L+R
M 27	HS: Temperature in tank	C	L
M 28	HS: Electricity for heater	kWh	L+R
M 29	HS: Operating time for heater	h	R
M 30	HS: Number of starts for heater	ND	R
M 31	HS: Condenser flow temperature	C	L
M 32	HS: Condenser flow temp.diff.	C	L
M 33	HS: Electricity for compressor	kWh	L+R
M 34	HS: Operating time for M 33	h	L+R
M 35	HS: Number of starts for M 33	ND	L+R
M 36	HS: Flow temperature at evap.	C	L
M 37	HS: Water temp.diff. at evap.	C	L
M 38	HS: Flow through ground tubes	m^3	L+R
M 39	HS: Temp.diff. ground tubes	C	L
M 40	HS: Flow temperature at tubes	C	L
M 41	HS: Electricity for pump(M 38)	kWh	R
M 42 to M 57	HS: Ground temperatures, vertical section at ground tubes	C	(L)
M 58 to M 63	HS: Ground temperatures, vertical reference section away from ground tubes	C	(L)

HS = Heat source system (heat pump)

SS = Simulation system

L = Logged every 10 minutes (accumulated values for digital meters)

(L) = L, but discontinuously at regular intervals

R = Daily (visual) meter readings