Testing of Ekoterm water heaters and hot water tanks

Jørn Stene
Reidar Tellebon
Rune Lillethun Hoggen

SINTEF Energy Research AS

June 2005

SINTEF

www.energy.sintef.no

SINTEF

TECHNNICAL REPORT

Case/assignment (title): **EKOTERM – testing of water heaters and hot water tanks**

SINTEF Energy Research AS
Reception: Sem Sælands vej 11
Fax: +47 73 59 7250

Postal address: 7465 Trondheim
Telephone: +47 7559 72 00
www.energy.sintef.no

Business number
NO 939 350 675 MVA

PRINCIPAL: Borup Gruppen Holding A/S, Denmark
DATE: 2005-05-14
PROJECT NO. 16X003.40
PROJECT MANAGER (NAME,SIGN): Jørn Stene
ISBN NO: 82-594-2849-0 REPORT TYPE:
Number of pages: 21
VISTING ADDRESS: Kolbjørn Hejes vej 1 D

TR No: TR F6141
REF FROM PRINCIPAL(S) Jack Agerskov
ELECTRONIC ID NO: 050511151513
Grade: Confidential
SUPERIOR: Inge R. Gran
DEPARTMENT: Energy Processes
FAX: +47 73 59 39 50

RESULT (summary)

The testing of the heat effect and thermal efficiency of two electric water heaters from Ekoterm have been carried out, i.e. the *Ekoterm 3F1* (15kW, 400 V, 3-phase) and the *Ekoterm 1F1* (7 kW, 230 V, 1-phase). The temperature drop (heat loss) has also been tested, and the average heat transfer coefficient (U-value) for the 200-litre hot water tank, *Ekoterm 3F1200V*, has been calculated.

The *Ekoterm 3F1* was tested at approximately 60/40 and 40/30° C inlet/outlet water temperatures for the plate heat exchanger and at approximately 5, 10 and 15 kW heat effect. Each test period lasted approx. 30 minutes. *Ekoterm 1F1* was tested at approximately 60/40 and 40/30°C inlet/outlet water temperature for the plate heat exchanger and at approximately 3.5 and 7 kW heat effect. Each test period lasted approx. 30 minutes.

The test of the hot water tank, *Ekoterm 3F1200V*, took place with a starting temperature of approximately 65°C and approx. 20°C ambient air temperature. The test period was 24 hours.

The accuracy of the test equipment followed the EN 14511, a European (CEN) test standard for heat pump systems./1/

- The thermal efficiency for *Ekoterm 3F1* (15 kW) was in the range of 96.7 to 98.7 percent, while calculated test uncertainties were in the order of 1.7 to 2.2 percent.
- The thermal efficiency for *Ekoterm 1F1* (7 kW) was in the range of 97.2 to 98.6 percent while the calculated test uncertainties were in the order of 1.7 to 2.2 percent.
- The temperature level at heat rejection, i.e. inlet and outlet temperatures for the plate heat exchanger had minimum impact on the Ekoterm unit's thermal efficiency (within the uncertainties of the test rig)
- The calibrated heat effect (3.5-7 kW and 5-15 kW) had minimum impact on the Ekoterm units' thermal efficiency (within the uncertainties of the test rig).
- The temperature level at heat rejection, i.e. the inlet and outlet temperatures for the plate heat exchanger had great impact on the calibrated heat effect.
- The temperature drop for the hot water tank, *Ekoterm 3F1200V* during the test period was approximately 0.35°C per hour. It corresponds with a average heat transfer coefficient (U-value) for the tank of approximately 0.45 W/(m²K).

CATCHWORDS:
Selective: Electric water heater, Testing, Hot water tank, heat loss

SINTEF

TABLE OF CONTENTS

1 SUMMARY 3
2 INTRODUCTION 4
3 TEST RIG – EXPERIMENTAL METHODS 5
3.1 TESTING OF EKOTERM WATER HEATERS 5
3.1.1 Test rig 5
3.1.2 Test procedure 5
3.1.3 Test conditions 5
3.1.4 Measuring equipment 6
3.1.5 Uncertainties in calculated values 7
3.2 TESTING OF EKOTERM HOT WATER TANK 8
3.2.1 Test rig 8
3.2.2 Test procedure 8
3.2.3 Test conditions 8
3.2.4 Measuring equipment 9
3.2.5 Uncertainties in calculated values 9
4 MEASURED VALUES 10
4.1 TESTING OF EKOTERM WATER HEATERS 10
4.1.1 Method of calculation 10
4.1.2 Measured heat effect and heat efficiency 10
4.1.3 Discussion – conclusion 11
4.2 TESTING OF EKOTERM HOT WATER TANK 11
4.2.1 Method of calculation 11
4.2.2 Measured temperature drop 12
4.2.3 Calculated U-value and heat loss for the tank 13
5 REFERENCES 14
6 APPENDIX A – DEGREE OF ACCURACY 15
6.1 INTRODUCTION 15
6.2 UNCERTAINTIES IN THE REJECTED HEAT EFFECT 15
6.3 UNCERTAINTIES IN THERMAL EFFICIENCY 16
7 APPENDIX B – EXAMPLE OF DATASHEET WITH TEST RESULTS 17

RESULT - s u m m a r y

The testing of the heat effect and thermal efficiency of two electric water heaters from *EKOTERM-2001* have been carried out, i.e. the *VULKAN- 3F* (15kW, 400 V, 3-phase) and the *EKONOMIK-03* (7 kW, 230 V, 1-phase). The temperature drop (heat loss) has also been tested, and the average heat transfer coefficient (U-value) for the 200-litre hot water tank, *VULKAN-3F 200 lit.*, has been calculated.

The *VULKAN- 3F* was tested at approximately 60/40 and 40/30° C inlet/outlet water temperatures for the plate heat exchanger and at approximately 5, 10 and 15 kW heat effect. Each test period lasted approx. 30 minutes. *EKONOMIK-03* was tested at approximately 60/40 and 40/30°C inlet/outlet water temperature for the plate heat exchanger and at approximately 3.5 and 7 kW heat effect. Each test period lasted approx. 30 minutes.

The test of the hot water tank, *VULKAN-3F 200 lit*, took place with a starting temperature of approximately 65°C and approx. 20°C ambient air temperature. The test period was 24 hours.

The accuracy of the test equipment followed the EN 14511, a European (CEN) test standard for heat pump systems./1/

- The thermal efficiency for *VULKAN- 3F* (15 kW) was in the range of 96.7 to 98.7 percent, while calculated test uncertainties were in the order of 1.7 to 2.2 percent.

- The thermal efficiency for *EKONOMIK-03* (7 kW) was in the range of 97.2 to 98.6 percent while the calculated test uncertainties were in the order of 1.7 to 2.2 percent.

- The temperature level at heat rejection, i.e. inlet and outlet temperatures for the plate heat exchanger had minimum impact on *EKOTERM-2001* unit's thermal efficiency (within the uncertainties of the test rig)

- The calibrated heat effect (3.5-7 kW and 5-15 kW) had minimum impact on the *EKOTERM-2001* units' thermal efficiency (within the uncertainties of the test rig).

- The temperature level at heat rejection, i.e. the inlet and outlet temperatures for the plate heat exchanger had great impact on the calibrated heat effect.

- The temperature drop for the hot water tank, *VULKAN-3F 200 lit* during the test period was approximately 0.35°C per hour. It corresponds with a average heat transfer coefficient (U-value) for the tank of approximately 0.45 W/(m²K).

CATCHWORDS:
Selective: Electric water heater, Testing, Hot water tank, heat loss

TABLE OF CONTENTS

1 SUMMARY 3

2 INTRODUCTION 4

3 TEST RIG – EXPERIMENTAL METHODS 5

3.1 TESTING OF *EKOTERM-2001* WATER HEATERS 5
3.1.1 Test rig 5
3.1.2 Test procedure 5
3.1.3 Test conditions 5
3.1.4 Measuring equipment 6
3.1.5 Uncertainties in calculated values 7

3.2 TESTING OF *EKOTERM-2001* HOT WATER TANK 8
3.2.1 Test rig 8
3.2.2 Test procedure 8
3.2.3 Test conditions 8
3.2.4 Measuring equipment 9
3.2.5 Uncertainties in calculated values 9

4 MEASURED VALUES 10

4.1 TESTING OF *EKOTERM-2001* WATER HEATERS 10
4.1.1 Method of calculation 10
4.1.2 Measured heat effect and heat efficiency 10
4.1.3 Discussion – conclusion 11

4.2 TESTING OF *EKOTERM-2001* HOT WATER TANK 11
4.2.1 Method of calculation 11
4.2.2 Measured temperature drop 12
4.2.3 Calculated U-value and heat loss for the tank 13

5 APPENDIX A – DEGREE OF ACCURACY 15
5.1 INTRODUCTION 15
5.2 UNCERTAINTIES IN THE REJECTED HEAT EFFECT 15
5.3 UNCERTAINTIES IN THERMAL EFFICIENCY 16

6 APPENDIX B – EXAMPLE OF DATASHEET WITH TEST RESULTS 17

1.–S U M M A R Y

The testing of the heat effect and thermal efficiency of two electric water heaters from *EKOTERM-2001* have been carried out, i.e. the *VULKAN-3F* (15kW, 400 V, 3-phase) and the *EKONOMIK-03* (7 kW, 230 V, 1-phase). The temperature drop (heat loss) has also been tested, and the average heat transfer coefficient (U-value) for the 200-litre hot water tank, *VULKAN-3F 200 lit.* , has been calculated.

The *VULKAN-3F* was tested at approximately 60/40 and 40/30° C inlet/outlet water temperatures for the plate heat exchanger and at approximately 5, 10 and 15 kW heat effect. Each test period lasted approx. 30 minutes. *EKONOMIK-03* was tested at approximately 60/40 and 40/30°C inlet/outlet water temperature for the plate heat exchanger and at approximately 3.5 and 7 kW heat effect. Each test period lasted approx. 30 minutes.

The test of the hot water tank, *VULKAN-3F 200 lit.* , took place with a starting temperature of approximately 65°C and approx. 20°C ambient air temperature. The test period was 24 hours.

The accuracy of the test equipment followed the EN 14511, a European (CEN) test standard for heat pump systems./1/

- The thermal efficiency for *VULKAN-3F (15 kW)* was in the range of 96.7 to 98.7 percent, while calculated test uncertainties were in the order of 1.7 to 2.2 percent.

- The thermal efficiency for *EKONOMIK-03 (7 kW)* was in the range of 97.2 to 98.6 percent while the calculated test uncertainties were in the order of 1.7 to 2.2 percent.

- The temperature level at heat rejection, i.e. inlet and outlet temperatures for the plate heat exchanger had minimum impact on the *EKOTERM-2001* unit's thermal efficiency (within the uncertainties of the test rig)

- The calibrated heat effect (3.5-7 kW and 5-15 kW) had minimum impact on the *EKOTERM-2001* units' thermal efficiency (within the uncertainties of the test rig).

- The temperature level at heat rejection, i.e. the inlet and outlet temperatures for the plate heat exchanger had great impact on the calibrated heat effect.

- The temperature drop for the hot water tank, *VULKAN-3F 200 lit.* during the test period was approximately 0.35°C per hour. It corresponds with a average heat transfer coefficient (U-value) for the tank of approximately 0.45 W/(m²K).

2.- *INTRODUCTION*

EKOTERM-2001 electric water heaters are used for both space heating and hot water heating in buildings and industries. The water heaters consist of a closed circuit (indirect system) in which a pump circulates water through a boiler and further to a plate heat exchanger where the heat is rejected to a heat distribution system in the building. The boiler uses the same heating principle as an electrode boiler where electric current is led from one electrode to another by the water in which they are soaked. Because of the electrical resistance, the water is heated. The conductivity of the water, and thus the thermal power of the boiler, is calibrated by adding salt to the water. The higher the salt resolution, the higher is its conductivity and the heat effect of the boiler.

The plate heat exchanger in the indirect circuit of the *EKOTERM-2001* unit is connected to a hydronic heat distribution system connected with a double shell hot water tank (alternatively a single shell hot water tank with an integrated tube heat exchanger) as well as heat elements for space heating (pipes for under-floor heating, radiators or convectors).

The competitors of *EKOTERM-2001* electric water heaters are, amongst others electric immersion heaters, electric boilers, oil boilers, gas boilers, bio boilers, heat pump systems or district heating.

In this report, the following *EKOTERM-2001* equipment has been tested.

VULKAN-3F – efficiency test
- 15 kW
- 400 V, 3 phase
- Without hot water tank

EKONOMIK-03 – efficiency test
- 7 kW
- 230 V, 1 phase
- Without hot water tank

VULKAN-3F 200 lit. – test of standstill loss in the tank
- 200-litres hot water tank with internal coil
- No testing of heat unit

VULKAN-3F was tested at approx. 60/40 and 40/30°C inlet/outlet water temperatures on the heat exchanger and by approx. 5, 10 and 15 kW heat effect; 6 tests in total. ***EKONOMIK-03*** was tested at approx. 60/40 and 40/30°C inlet/outlet water temperatures on the heat exchanger and at approx. 3.5 and 7 kW heat effect; a total of 4 tests. The hot water tank in the ***VULKAN-3F 200 lit.*** was tested at approx. 65°C starting temperature for the water in the tank, and the test took place during a period of approx. 24 hours.

3. *TEST RIG – EXPERIMENTAL METHODS*

3.1. TESTING OF *EKOTERM - 2001* WATER HEATERS

3.1.1. Test rig

A test rig was built for the purpose of measuring the heat effect and thermal efficiency for *VULKAN-3F* and *EKONOMIK-03* water heaters. The plate heat exchanger in the unit was connected to an open water circuit consisting of city water supply, mixing valve (BV1) for hot water feed (preheating), electric heater (preheating), control valve (RV1) as well as test equipment, i.e. temperature sensors (T), volume flow meter (V), and wattmeter (P). The sensors were connected to a computer logger of the Agilent 34970A type. Figure 3.1 illustrates the principle of the test rig.

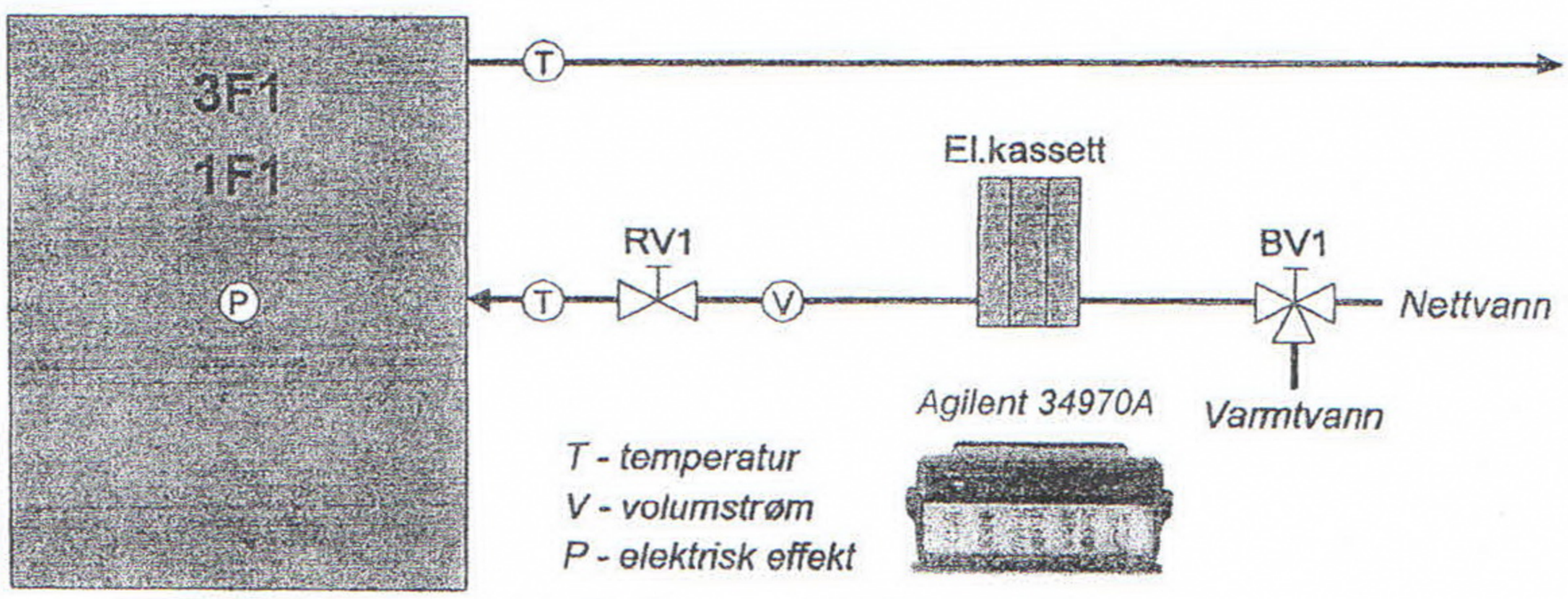


Figure 3.1 Principal sketch of test rig for *EKOTERM-2001* water heaters.
(Explanation to figure: T=temperature, V= Flow rate, P= Electric effect, electric heater, hot water, city water)

3.1.2. Test procedure

The test procedure was as follows:

- After the unit *(VULKAN-3F or EKONOMIK-03)* was calibrated to the required heat effect at a given temperature program, the control valve R1, the outlet water temperature from the mixing valve BV1 and the input power to the electric heater were regulated in order to give respectively the required supply water temperature (t_i) and the temperature difference (Δt) in the plate heat exchanger in the *EKOTERM-2001* unit.

- When the system had stabilized on the required inlet and outlet temperatures (60/40 or 40/30°C) the outlet water temperature (t_i), inlet temperature (t_r), volume flow and input electric power (P) was measured every 10th seconds within a period of minimum 30 minutes. Average values during the test period were used for the calculation of heat effect and thermal efficiency (see equations in chapter 4.1)

3.1.3. Test conditions

The thermal efficiencies for the *EKOTERM-2001* units were measured on different temperature levels on the water side (temperature program) and different heat effects. The test conditions with regards to inlet/outlet water temperatures for the plate heat exchanger on the unit, the rejected heat effect of the unit, as well as the volume flow rate through the heat exchanger were as shown in table 3.1.

Table 3.1 Test matrix – test effect as well as inlet/outlet temperatures and flow rate on the water side.

VULKAN-3F – max. approx 15 kW			*EKONOMIK-03* – max. approx. 7 kW	
5 kW	10 kW	15 kW	3.5 kW	7 kW
approx. 60/40°C *approx. 3.6 l/min*	*approx.* 60/40°C *Approx. 7.2 l/min*	*approx.* 60/40°C *approx. 10.8 l/min*	*approx.* 60/40°C *approx. 2.5 l/min*	*approx.* 60/40°C *approx. 5.0 l/min*
approx. 40/30°C *approx. 7.2 l/min*	*approx.* 40/30°C *approx. 14.4 l/min*	*approx.* 40/30°C *approx. 21.6 l/min*	*approx.* 40/30°C *approx. 5.0 l/min*	*approx.* 40/30°C *approx. 10.1 l/min*

The ambient air temperature varied between 20 to 21°C during the testing.

An inlet/outlet temperature of *60/40°C* for the plate heat exchanger in the *EKOTERM-2001* unit corresponds to an operating situation as if the units provide both space heating and heating of tap water. *40/30°C* corresponds to a operating situation with space heating (under-floor heating) only. Originally, the test situation was planned with inlet/outlet temperature of 40/35°C, but it was changed to 40/30°C in order to reach manageable water flow rates and to increase the degree of accuracy for the temperature measurements.

3.1.4. Test equipment

A test standard stating the requirements for the degree of accuracy does not exist for electric water heaters. Therefore, the requirements for the degree of accuracy in the test standard, EN14511 /1/ for heat pumps were used. Table 3.2 provides an overview of used test equipment and degree of accuracy for the measuring of inlet and outlet water temperatures from the plate heat exchanger in the *EKOTERM-2001* unit, water flow rate through the heat exchanger as well as the electrical input power to the unit. The sensors were connected to the computer logger of the *Agilent 34970A* type.

Table 3.2 Test equipment used for the test rig for EKOTERM-2001 water heaters.

Measured value	Type	Brand/model	Measuring area	Relative Degree of Accuracy	Absolute Degree of Accuracy
Temperature	Pt-100	Temp. Control	-260 to +100°C	*	±0.085°C [1]
Flow rate	Turbine	GPI turbine model S0501 KF2389	3.8 to 37.9 l/min	±1% of measured value [2]	±0.021 to 0.216 l/min
Electric power	Wattmeter	Hioki Clamp on Power Hitester model 3161 og 3166	3 to 900 kW (60 ranges)	±1.0% of measured value	15 to 75 W

1) The temperature sensors were calibrated for measuring temperature differences as this would increase the degree of accuracy. The pipe before and after the time sensor was insulated with 20mm cellular rubber to reduce heat leakage.

2) The measuring signal from the turbine flowmeter was calibrated and corrected by means of precise weight measurements of the water flow and stop watch, so the actual degree of accuracy is improved in comparison with the maximum value stated by the factory. The actual degree of accuracy is, thus, better than ±1 percent of the measured value.

3.1.5. Uncertainties in calculated values

The degree of accuracy in the calculated values and thermal efficiency for the *EKOTERM-2001* units are calculated according to the equation A.5 and A.7, See appendix A – Degree of Accuracy. Table 3.3 provides an overview of the absolute and relative uncertainties in the heat effect (Q) and thermal efficiency (□) at different heat effects (5 and 15 kW) and temperature programs (60/40 and 40/30°C).

Table 3.3 Calculated absolute uncertainty [W] and relative uncertainty [%] in emission of heat effect (Q) and thermal efficiency (□) for the EKOTERM-2001 units

Degree of Accuracy	5 kW – 60/40°C	5 kW – 40/30°C	15 kW – 60/40°C	15 kW – 40/30°C
Absolute δQ [W]	*66*	*99*	*197*	*296*
Relative δQ [%]	*±1.3*	*±2.0*	*±1.3*	*±2.0*
Absolute δ□[-]	*0.0173*	*0.0245*	*0.0173*	*0.0245*
Relative δ□[%]	±1.7	±2.2	±1.7	±2.2

Table 3.3 shows that the calculated degree of accuracy for the *EKOTERM-2001* units' heat effect and thermal efficiency are within the range of respectively ±1.3–2.0 percent and ±1.7–2.2 percent.

3.2. TESTING OF EKOTERM HOT WATER TANK

3.2.1. Test rig

A test rig was built for the measuring of the heat loss from the 200-litres hot water tank in the *VULKAN-3F 200* lit. . The hot water tank was connected to an open water circuit with city water supply, electric heater (preheating), control valve (RV1) as well as temperature sensors (T) by the inlet and outlet of the tank. A bar with 9 thermocouples (type T) with approx. 90mm separations was mounted at the centre of the tank for the measurements of the water temperatures, while two thermocouples were used for measuring the ambient air temperature at the top and bottom of the tank. The thermocouples were connected to a *Fluke Hydra 2625 Data logger*. Figure 3.2 illustrates the principle of the test rig.

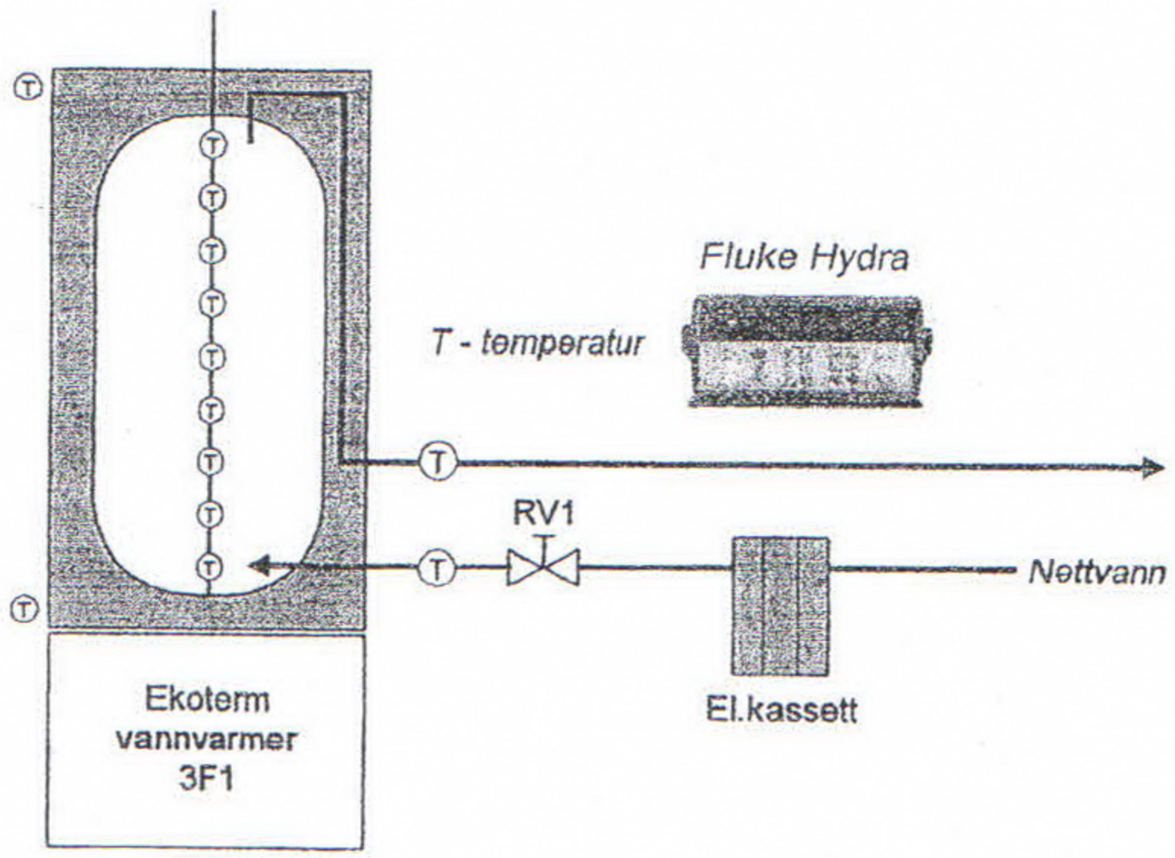


Figure 3.2 Principal sketch of the test rig for EKOTERM-2001 hot water tank VULKAN – 3F 200 lit.

Explanation for figure 3.2: EKOTERM-2001 water heater VULKAN - 3F, T-temperature, Fluke Hydra, RV1, electric heater and city water

3.2.2. Test procedure

The test procedure was as follows:

- The city water was preheated to the required temperature by means of the electric heater, and the water was circulated through the tank until the difference between the inlet and outlet water temperature from the tank was max. 0.1 K.

- The water flow was disconnected, and the water temperatures in the tank, as well as the air temperatures at top and bottom of the tank, were measured every 15 minute during a period of 24 hours. The temperature drop in the tank was used for calculating the average U-value of the tank [W/m²K].

3.2.3. Test conditions

Temperature measurements were carried through with an initial water temperature of approx. 65°C. This is a typical temperature level in hot water tanks which are heated with electrical immersion elements. The average air temperature was approx. 20°C during testing.

3.2.4. Test equipment

Pt-100 elements were used for measuring the temperatures in and out of the tank during the charging period. The elements have according to table 3.2 a degree of accuracy of ±0.085°C. The temperature measurements in the tank were carried out with Type T (Cu/K) thermocouples. First, the thermocouples were calibrated against an ice bath before they were connected to a *Fluke Hydra 2625 data logger*. This data logger has a very accurate internal nil point (Pt-100 element). In this set-up, the thermocouples had a degree of accuracy of ±0.2°C.

3.2.5. Uncertainties in calculated values

The temperature measurements were used to calculate the average heat transfer coefficient for the tank (U-value) [W/m²K] and heat loss [W/m²]. See also chapter 4.2.

4. *MEASURED VALUES*

4.1. TESTING OF *EKOTERM-2001* WATER HEATERS

4.1.1. Method of calculation

The average heat effect from the plate heat exchanger in the ***EKOTERM-2001*** units (W) during the measuring period (minimum 30 minutes – logging every 10 second) were calculated as follows:

$$\dot{Q} = \sum_{i=1}^{i=n} \left[\dot{V} \cdot \rho \cdot c_p \cdot (t_t - t_r) \right] \qquad (4.1)$$

where V is the measured flow rate through the plate heat exchanger [m³/s], t_t and t_r are respectively the measured inlet/outlet temperatures for the plate heat exchanger [°C] while □ and c_p are respectively the density [kg/m³] and the heat capacity [J/(kgK)] for water at current thermal level /3/.

The efficiency for the ***EKOTERM-2001*** units during the test period (approx. 30 minutes – logging every ten seconds) was calculated as follows:

$$\eta = \sum_{i=1}^{i=n} \left(\frac{\dot{Q}}{P} \right) \qquad (4.2)$$

where Q is the heat effect from the plate heat exchanger [W] at the given operational conditions and P is input electric power [W]. The difference between the input electric power and heat effect in the plate heat exchanger is due to losses in the boiler, necessary input power for operation of the circulation pump in the boiler as well as heat losses to the surrounding of the unit.

4.1.2. Measured heat effect and heat efficiency

Table 4.1 provides an overview of the measured heat effect and calculated thermal efficiency for the *EKOTERM-2001* units at varying temperature levels and heat effects. See also *Appendix B* for examples of test data from a test series (1F1, 40/30°C, approx. 3.5 kW).

Table 4.1 Average temperature level during the test period, average heat effects (Q), average electrical power input (P) and calculated thermal efficiency (η) for the EKOTERM-2001 units.

VULKAN-3F – max. 15 kW			**EKONOMIK-03 – max. 7 kW**	
607/40.6°C Q = 5.61 kW P = 5.76 kW ***η = 0.973***	60.1/39.8°C Q = 10.31 kW P = 10.47 kW ***η = 0.985***	60.8/40.4°C Q = 13.77 kW P =14.26 kW ***η = 0.966***	60.1/40.2°C Q = 3.57 kW P = 3.67 kW ***η = 0.973***	59.0/38.9°C Q = 6.90 kW P = 7.03 kW ***η = 0.982***
40.2/30.6°C Q = 4.25 kW P = 4.32 kW ***η = 0.985***	40.0/30.5°C Q = 9.91 kW P = 10.05 kW ***η = 0.986***	39.7/30.2°C Q = 12.55 kW*) P = 12.98 kW ***η = 0.967***	40.5/30.0°C Q = 3.07 kW P = 3.13 kW ***η = 0.981***	40.0/30.2°C Q = 6.13 kW P = 6.22 kW ***η = 0.986***

**) Heat effect was somewhat lower than stipulated in the test matrix, but this had no influence on the measured thermal efficiency.*

4.1.3. Discussion – conclusion

The calibrated heat effect for the *EKOTERM-2001* units depended on the temperature level during heat rejection. For example, the *VULKAN-3F* was calibrated to approx. 15kW at 60/40°C inlet/outlet temperatures for the plate heat exchanger. As the temperature levels were reduced to 40/30°C, the heat effect was reduced to approx. 10 kW. This fact made the calibration of units difficult and time consuming, and the heating power deviated somewhat from the original test matrix. This has, however, not influenced the validation of the test results as they clearly show that the efficiency is almost constant at different heat effects. With outset in table 4.1 and experiences from the testing, the following conclusions can be made:

- The thermal efficiency for *VULKAN-3F* (15kW) was in range of 96.7-98.7 percent while the calculated accuracy was in the range of 1.7 – 2.2 percent
- The thermal efficiency for *EKONOMIK-03* (7kW) was in the range of 97.2 – 98.6 percent while the calculated accuracy was in the range of 1.7 – 2.2 percent.
- The temperature level during heat rejection, i.e. the inlet/outlet temperature for the plate heat exchanger had a minimum impact on the *EKOTERM-2001* units' thermal efficiency (within the uncertainties of the test rig)
- The calibrated heat effect (3.5-7 kW and 5-15 kW) had minimum influence on the *EKOTERM-2001* units' thermal efficiency (within the uncertainties of the test rig)
- The temperature level at heat rejection, i.e. inlet/outlet temperatures for the plate heat exchanger had great influence on the calibrated heat effect.

4.2. TESTING OF *EKOTERM-2001* HOT WATER TANK

4.2.1. Method of calculation

The temperature drop in the tank during the test period was measured with 9 thermocouples with approx. 90 mm separation. Both the lower and the upper thermocouples were placed with approx. 5mm from respectively the bottom and top of the tank. In this way, it was possible to give a detailed picture of the temperature gradient (the stratification) in the tank over time. Earlier measurements have shown that the actual radial temperature gradient in a standard insulated hot water tank with 60 to 80°C hot water, is less than 0.2 K (insignificant) /3/.

As each of the nine temperature sensors measured the temperature in almost the same water volume, the average water temperature in the tank was measured as follows:

$$\bar{t} = \sum_{i=1}^{i=9} t_i \qquad (4.3)$$

With outset in the average water temperature, the average heat transfer coefficient for the tank (U-value) was calculated as follows:

$$U = \sum_{i=1}^{i=n} \left(\frac{V \cdot \rho \cdot c_p \cdot \left(\bar{t}_{i-1} - \bar{t}_i \right)}{A \cdot \left[\frac{t_{i-1} + t_i}{2} - t_R \right]} \right)$$

where U is the average heat transfer coefficient of the tank [W/(m²K)], V is the total water volume of the tank [m³], A is the outer surface area [m²], □ and c_p are respectively the density [kg/m³] and specific heat capacity [J/(kgK)] for water at the current temperature level, t_0 (i.e. t_{i-1}) is the average temperature in the tank at start-up [°C], t_R is the air temperature [°C] while n is the number of steps in the calculation (96 at the measurement every 15 minute during 24 hours)

With outset in the average U-value the average heat loss of tank could be calculated:

$$\dot{q} = U \cdot \left(\bar{t} - \bar{t}_R \right) \qquad (4.5)$$

4.2.2. Measured temperature drop

At the test of the heat loss for the hot water tank *(VULKAN-3F 200 lit.)*, the initial water temperature was 65.2°C (±0.1°C), and the average air temperature during the 24-hour test period was 20.3°C. Figure 4.1 shows the development of the average water temperatures in the tank during the test period.

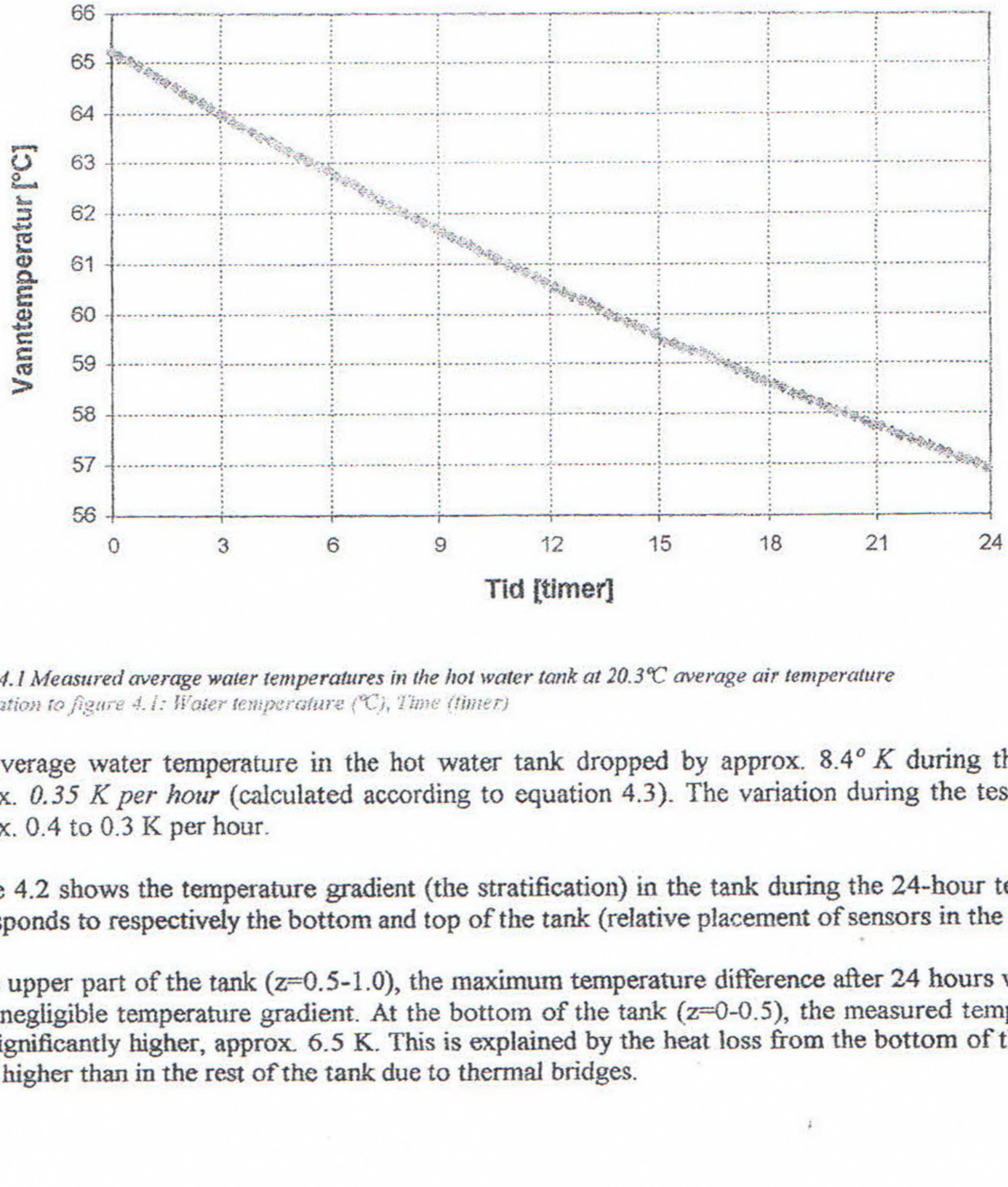
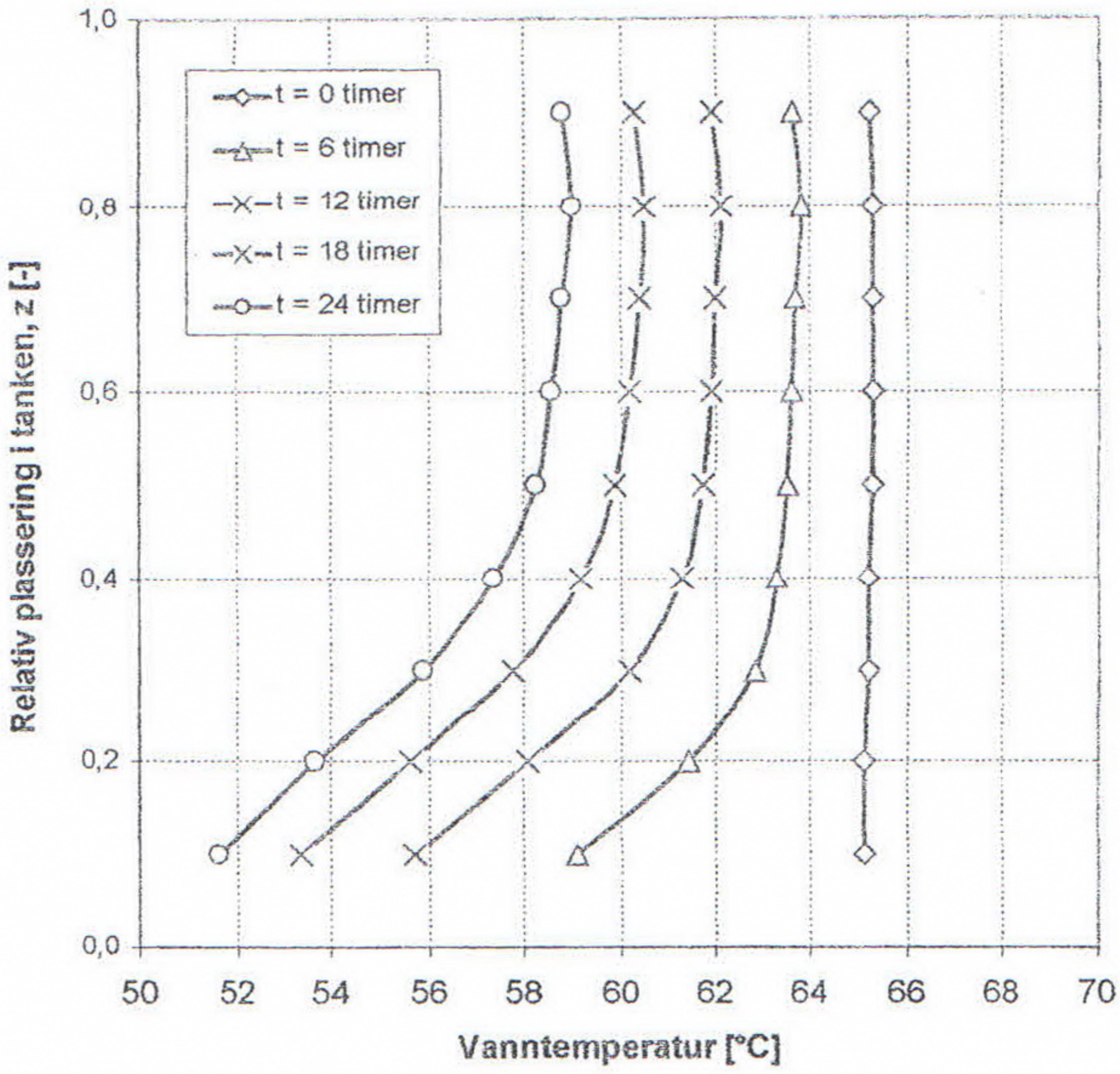


Figure 4.1 Measured average water temperatures in the hot water tank at 20.3℃ average air temperature
Explanation to figure 4.1: Water temperature (℃), Time (timer)

The average water temperature in the hot water tank dropped by approx. 8.4° *K* during the test period, i.e. approx. *0.35 K per hour* (calculated according to equation 4.3). The variation during the test period was from approx. 0.4 to 0.3 K per hour.

Figure 4.2 shows the temperature gradient (the stratification) in the tank during the 24-hour test period. 0 and 1 corresponds to respectively the bottom and top of the tank (relative placement of sensors in the tank).

In the upper part of the tank (z=0.5-1.0), the maximum temperature difference after 24 hours was approx. 0.7 K, i.e. a negligible temperature gradient. At the bottom of the tank (z=0-0.5), the measured temperature difference was significantly higher, approx. 6.5 K. This is explained by the heat loss from the bottom of the tank which was much higher than in the rest of the tank due to thermal bridges.



Explanation to figure: Relative placement in the tank, z, water temperature (°C)

Figure 4.2 Measured temperature development in the hot water tank (vertical temperature gradient) at 20.3°C average air temperatures in the test period, z shows the relative placement of the temperature sensors.

4.2.3. Calculated U-value and heat loss for the tank

With outset in the equation 4.4, the average heat transfer coefficient (the U-value) for the hot water tank (with a 200-litre water volume) was calculated to:

U = approx. 0.45 (W/m²K)

With outset in equation 4.5, the average heat loss for the hot water tank (the 200-litre water volume, 60°C hot-water temperature and 20.3°C average air temperature) was calculated to:

q = ca. 20 W/m²

The hot water tank had a total outer area of 3 m², i.e. a total heat loss at the given operational conditions were approx. 60 W.

5. *APPENDIX A – DEGREE OF ACCURANCY*

4.3. INTRODUCTION

R represents a value which at the given equation is calculated from a set of measurements where X_i to X_n represents the independent measurements/variables.

$$R = R(X_1, X_2, X_3, ..., X_n) \qquad \text{(A.1)}$$

The absolute degree of accuracy is δR for the calculated value R is found by using the following equation:

$$\delta R = \left[\sum_{i=1}^{n} \left(\frac{\partial R}{\partial X_i} \cdot \delta X_i \right)^2 \right]^{0.5} \qquad \text{(A.2)}$$

δX_i represents the uncertainty of the measurements/variable X_i, while the partially derived $\delta R/\delta X_i$ represents the sensitivity of the result R with respect to the measurement X_i. Each part of the equation (i=1 to n) represents the contribution from each singular measurement in the total degree of accuracy (R).

The relative uncertainty (R) in the calculated result is defined as

$$\alpha R = \left(\frac{\delta R}{R} \right) \cdot 100\% \qquad \text{(A.3)}$$

4.4. UNCERTAINTIES IN THE REJECTED HEAT EFFECT

The heat effect for the plate heat exchanger in the Ekoterm-2001 units [W] was calculated as follows:

$$\dot{Q} = \left[\dot{V} \cdot \rho \cdot c_p \cdot (t_t - t_r) \right] \qquad \text{(A.4)}$$

where V is the flow rate through the plate heat exchanger [m³/s], t_t and t_r are respectively inlet and outlet temperatures from the plate heat exchanger [°C] while □ and c_p are respectively the density [kg/m³] and specific heat capacity [J/(kgK)] for water at the actual temperature level.

According to the equation A.2, the absolute degree of accuracy in the heat effect is calculated as:

$$\delta \dot{Q} = \left[\left[\rho \cdot c_p \cdot (t_t - t_r) \cdot \delta \dot{V} \right]^2 + \left[2 \cdot \dot{V} \cdot \rho \cdot c_p \cdot \delta t \right]^2 \right]^{0.5} \qquad \text{(A.5)}$$

UNCERTAINTY IN THE THERMAL EFFCIENCY

The thermal efficiency for the Ekoterm-2001 units was calculated as follows:

$$\eta = \frac{\dot{Q}}{P} \qquad \text{(A.6)}$$

where Q is the heat effect for the heat exchanger in the *EKOTERM-2001* units [W] and *P* is the input electric power input for the unit, i.e. electric water heater and circulation pump [W]. According to equation A.2, the absolute uncertainty in the heat effect was calculated as:

$$\delta\eta = \left[\left(\frac{\delta \dot{Q}}{P}\right)^2 + \left(-\frac{\dot{Q}}{P^2}\cdot \delta P\right)^2\right]^{0.5} \qquad (A.7)$$

7. *APPENDIX B – EXAMPLE OF DATASHEET WITH TEST RESULTS*

(EKONOMIK-03, 40/30°C, approx. 3.5 KW)

101(Time stamp)	101(Seconds)	101(C)	102(C)	103(VDC)	104(VDC)
08.06.2005 08:45:33	4040.062	4.06E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:45:43	4050.023	4.06E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:45:53	4060.039	4.06E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:46:03	4070.055	4.06E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 08:46:13	4080.015	4.06E+01	3.02E+01	3.12E-01	4.71E+00
08.06.2005 08:46:23	4090.029	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:46:33	4100.043	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:46:43	4110.059	4.05E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:46:53	4120.014	4.05E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:47:03	4130.036	4.06E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:47:13	4140.054	4.05E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:47:23	4150.01	4.06E+01	3.00E+01	3.14E-01	4.69E+00
08.06.2005 08:47:33	4160.035	4.06E+01	3.00E+01	3.14E-01	4.69E+00
08.06.2005 08:47:43	4170.056	4.05E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:47:53	4180.011	4.06E+01	3.02E+01	3.13E-01	4.69E+00
08.06.2005 08:48:03	4190.029	4.06E+01	3.01E+01	3.14E-01	4.68E+00
08.06.2005 08:48:13	4200.047	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:48:23	4210.059	4.06E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:48:33	4220.02	4.05E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:48:43	4230.04	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:48:53	4240.056	4.05E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:49:03	4250.012	4.05E+01	3.01E+01	3.12E-01	4.68E+00
08.06.2005 08:49:13	4260.031	4.05E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:49:23	4270.046	4.05E+01	3.00E+01	3.14E-01	4.68E+00
08.06.2005 08:49:33	4280.057	4.05E+01	3.01E+01	3.11E-01	4.69E+00
08.06.2005 08:49:43	4290.015	4.05E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 08:49:53	4300.029	4.05E+01	3.01E+01	3.12E-01	4.69E+00
08.06.2005 08:50:03	4310.045	4.05E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 08:50:13	4320.061	4.05E+01	3.01E+01	3.13E-01	4.68E+00
08.06.2005 08:50:23	4330.017	4.05E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:50:33	4340.034	4.05E+01	3.00E+01	3.14E-01	4.70E+00
08.06.2005 08:50:43	4350.053	4.05E+01	3.00E+01	3.14E-01	4.69E+00
08.06.2005 08:50:53	4360.012	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:51:03	4370.027	4.04E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 08:51:13	4380.046	4.05E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 08:51:23	4390.062	4.05E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:51:33	4400.023	4.05E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:51:43	4410.04	4.04E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:51:53	4420.063	4.04E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 08:52:03	4430.023	4.04E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 08:52:13	4440.038	4.05E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:52:23	4450.057	4.04E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 08:52:33	4460.018	4.04E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 08:52:43	4470.03	4.04E+01	2.99E+01	3.13E-01	4.70E+00
08.06.2005 08:52:53	4480.05	4.05E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:53:03	4490.063	4.04E+01	3.00E+01	3.12E-01	4.68E+00
08.06.2005 08:53:13	4500.026	4.04E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:53:23	4510.049	4.04E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 08:53:33	4520.063	4.05E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 08:53:43	4530.02	4.04E+01	3.00E+01	3.12E-01	4.67E+00
08.06.2005 08:53:53	4540.039	4.04E+01	3.00E+01	3.12E-01	4.67E+00
08.06.2005 08:54:03	4550.055	4.04E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:54:13	4560.017	4.04E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:54:23	4570.036	4.04E+01	2.99E+01	3.13E-01	4.70E+00
08.06.2005 08:54:33	4580.054	4.04E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 08:54:43	4590.012	4.04E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 08:54:53	4600.032	4.04E+01	3.01E+01	3.12E-01	4.70E+00
08.06.2005 08:55:03	4610.049	4.04E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 08:55:13	4620.063	4.04E+01	2.99E+01	3.13E-01	4.69E+00
08.06.2005 08:55:23	4630.023	4.04E+01	2.99E+01	3.14E-01	4.68E+00
08.06.2005 08:55:33	4640.039	4.04E+01	2.99E+01	3.13E-01	4.69E+00
08.06.2005 08:55:43	4650.055	4.04E+01	2.99E+01	3.14E-01	4.67E+00
08.06.2005 08:55:53	4660.01	4.04E+01	2.99E+01	3.13E-01	4.67E+00
08.06.2005 08:56:03	4670.03	4.04E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 08:56:13	4680.052	4.04E+01	3.00E+01	3.12E-01	4.65E+00
08.06.2005 08:56:23	4690.014	4.04E+01	3.00E+01	3.13E-01	4.67E+00
08.06.2005 08:56:33	4700.03	4.04E+01	3.00E+01	3.12E-01	4.65E+00
08.06.2005 08:56:43	4710.043	4.04E+01	2.99E+01	3.13E-01	4.67E+00
08.06.2005 08:56:53	4720.06	4.04E+01	3.01E+01	3.13E-01	4.66E+00
08.06.2005 08:57:03	4730.019	4.04E+01	3.01E+01	3.13E-01	4.66E+00
08.06.2005 08:57:13	4740.043	4.04E+01	3.02E+01	3.13E-01	4.65E+00

08.06.2005 08:57:23	4750.06	4.05E+01	3.02E+01	3.14E-01	4.65E+00
08.06.2005 08:57:33	4760.02	4.06E+01	3.01E+01	3.14E-01	4.64E+00
08.06.2005 08:57:43	4770.032	4.06E+01	3.02E+01	3.13E-01	4.65E+00
08.06.2005 08:57:53	4780.048	4.06E+01	3.03E+01	3.14E-01	4.64E+00
08.06.2005 08:58:03	4790.01	4.07E+01	3.02E+01	3.14E-01	4.65E+00
08.06.2005 08:58:13	4800.037	4.07E+01	3.03E+01	3.13E-01	4.65E+00
08.06.2005 08:58:23	4810.053	4.07E+01	3.03E+01	3.12E-01	4.65E+00
08.06.2005 08:58:33	4820.013	4.08E+01	3.04E+01	3.15E-01	4.65E+00
08.06.2005 08:58:43	4830.029	4.08E+01	3.03E+01	3.14E-01	4.65E+00
08.06.2005 08:58:53	4840.049	4.09E+01	3.03E+01	3.13E-01	4.63E+00
08.06.2005 08:59:03	4850.012	4.09E+01	3.02E+01	3.15E-01	4.61E+00
08.06.2005 08:59:13	4860.026	4.09E+01	3.03E+01	3.15E-01	4.65E+00
08.06.2005 08:59:23	4870.039	4.09E+01	3.04E+01	3.16E-01	4.64E+00
08.06.2005 08:59:33	4880.056	4.09E+01	3.03E+01	3.15E-01	4.62E+00
08.06.2005 08:59:43	4890.02	4.09E+01	3.03E+01	3.15E-01	4.64E+00
08.06.2005 08:59:53	4900.035	4.09E+01	3.04E+01	3.15E-01	4.65E+00
08.06.2005 09:00:03	4910.052	4.09E+01	3.03E+01	3.13E-01	4.64E+00
08.06.2005 09:00:13	4920.013	4.09E+01	3.03E+01	3.14E-01	4.62E+00
08.06.2005 09:00:23	4930.033	4.09E+01	3.03E+01	3.15E-01	4.63E+00
08.06.2005 09:00:33	4940.057	4.09E+01	3.03E+01	3.13E-01	4.64E+00
08.06.2005 09:00:43	4950.012	4.09E+01	3.03E+01	3.13E-01	4.63E+00
08.06.2005 09:00:53	4960.03	4.09E+01	3.04E+01	3.13E-01	4.64E+00
08.06.2005 09:01:03	4970.048	4.09E+01	3.03E+01	3.12E-01	4.65E+00
08.06.2005 09:01:13	4980.062	4.09E+01	3.03E+01	3.13E-01	4.63E+00
08.06.2005 09:01:23	4990.017	4.09E+01	3.02E+01	3.13E-01	4.64E+00
08.06.2005 09:01:33	5000.032	4.09E+01	3.02E+01	3.13E-01	4.64E+00
08.06.2005 09:01:43	5010.049	4.08E+01	3.03E+01	3.14E-01	4.64E+00
08.06.2005 09:01:53	5020.066	4.08E+01	3.02E+01	3.13E-01	4.63E+00
08.06.2005 09:02:03	5030.023	4.08E+01	3.03E+01	3.12E-01	4.65E+00
08.06.2005 09:02:13	5040.037	4.08E+01	3.02E+01	3.15E-01	4.68E+00
08.06.2005 09:02:23	5050.059	4.08E+01	3.03E+01	3.13E-01	4.68E+00
08.06.2005 09:02:33	5060.021	4.07E+01	3.02E+01	3.15E-01	4.69E+00
08.06.2005 09:02:43	5070.042	4.07E+01	3.02E+01	3.15E-01	4.68E+00
08.06.2005 09:02:53	5080.058	4.07E+01	3.01E+01	3.13E-01	4.67E+00
08.06.2005 09:03:03	5090.016	4.07E+01	3.01E+01	3.15E-01	4.69E+00
08.06.2005 09:03:13	5100.034	4.07E+01	3.01E+01	3.14E-01	4.69E+00
08.06.2005 09:03:23	5110.053	4.06E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 09:03:33	5120.013	4.06E+01	3.02E+01	3.13E-01	4.69E+00
08.06.2005 09:03:43	5130.029	4.06E+01	3.01E+01	3.11E-01	4.69E+00
08.06.2005 09:03:53	5140.047	4.06E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 09:04:03	5150.061	4.06E+01	3.00E+01	3.14E-01	4.69E+00
08.06.2005 09:04:13	5160.018	4.06E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 09:04:23	5170.038	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 09:04:33	5180.049	4.05E+01	3.00E+01	3.14E-01	4.70E+00
08.06.2005 09:04:43	5190.01	4.05E+01	3.00E+01	3.12E-01	4.68E+00
08.06.2005 09:04:53	5200.026	4.05E+01	3.01E+01	3.13E-01	4.70E+00
08.06.2005 09:05:03	5210.047	4.05E+01	3.00E+01	3.13E-01	4.70E+00
08.06.2005 09:05:13	5220.056	4.05E+01	3.00E+01	3.13E-01	4.69E+00
08.06.2005 09:05:23	5230.018	4.05E+01	3.01E+01	3.13E-01	4.69E+00
08.06.2005 09:05:33	5240.029	4.05E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 09:05:43	5250.049	4.05E+01	3.01E+01	3.14E-01	4.70E+00
08.06.2005 09:05:53	5260.062	4.05E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 09:06:03	5270.021	4.05E+01	3.00E+01	3.13E-01	4.67E+00
08.06.2005 09:06:13	5280.041	4.05E+01	3.00E+01	3.14E-01	4.68E+00
08.06.2005 09:06:23	5290.055	4.04E+01	2.99E+01	3.13E-01	4.67E+00
08.06.2005 09:06:33	5300.02	4.05E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:06:43	5310.036	4.04E+01	3.00E+01	3.12E-01	4.68E+00
08.06.2005 09:06:53	5320.054	4.04E+01	3.00E+01	3.11E-01	4.68E+00
08.06.2005 09:07:03	5330.014	4.05E+01	3.00E+01	3.14E-01	4.67E+00
08.06.2005 09:07:13	5340.026	4.05E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 09:07:23	5350.036	4.04E+01	2.99E+01	3.13E-01	4.67E+00
08.06.2005 09:07:33	5360.052	4.04E+01	3.00E+01	3.13E-01	4.68E+00
08.06.2005 09:07:43	5370.015	4.05E+01	3.00E+01	3.12E-01	4.66E+00
08.06.2005 09:07:53	5380.027	4.04E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 09:08:03	5390.043	4.04E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 09:08:13	5400.053	4.04E+01	2.99E+01	3.12E-01	4.68E+00
08.06.2005 09:08:23	5410.016	4.04E+01	3.00E+01	3.12E-01	4.68E+00
08.06.2005 09:08:33	5420.031	4.03E+01	3.00E+01	3.12E-01	4.69E+00
08.06.2005 09:08:43	5430.045	4.03E+01	3.00E+01	3.11E-01	4.70E+00
08.06.2005 09:08:53	5440.01	4.03E+01	2.99E+01	3.12E-01	4.68E+00
08.06.2005 09:09:03	5450.024	4.03E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 09:09:13	5460.034	4.03E+01	2.99E+01	3.11E-01	4.69E+00
08.06.2005 09:09:23	5470.052	4.03E+01	3.00E+01	3.12E-01	4.70E+00
08.06.2005 09:09:33	5480.064	4.03E+01	2.99E+01	3.11E-01	4.69E+00
08.06.2005 09:09:43	5490.026	4.03E+01	2.98E+01	3.12E-01	4.69E+00
08.06.2005 09:09:53	5500.04	4.04E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:10:03	5510.058	4.03E+01	2.99E+01	3.12E-01	4.69E+00

08.06.2005 09:10:13	5520.023	4.03E+01	2.98E+01	3.12E-01	4.69E+00
08.06.2005 09:10:23	5530.035	4.03E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:10:33	5540.049	4.03E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 09:10:43	5550.009	4.03E+01	2.99E+01	3.12E-01	4.68E+00
08.06.2005 09:10:53	5560.026	4.03E+01	2.98E+01	3.13E-01	4.69E+00
08.06.2005 09:11:03	5570.045	4.03E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:11:13	5580.01	4.03E+01	2.98E+01	3.13E-01	4.69E+00
08.06.2005 09:11:23	5590.024	4.03E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 09:11:33	5600.044	4.03E+01	2.98E+01	3.11E-01	4.68E+00
08.06.2005 09:11:43	5610.06	4.03E+01	2.99E+01	3.13E-01	4.69E+00
08.06.2005 09:11:53	5620.021	4.03E+01	2.99E+01	3.11E-01	4.68E+00
08.06.2005 09:12:03	5630.039	4.03E+01	2.98E+01	3.12E-01	4.69E+00
08.06.2005 09:12:13	5640.053	4.03E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:12:23	5650.01	4.02E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:12:33	5660.029	4.03E+01	2.99E+01	3.12E-01	4.68E+00
08.06.2005 09:12:43	5670.046	4.03E+01	2.98E+01	3.13E-01	4.70E+00
08.06.2005 09:12:53	5680.063	4.03E+01	2.99E+01	3.13E-01	4.68E+00
08.06.2005 09:13:03	5690.028	4.03E+01	2.98E+01	3.12E-01	4.69E+00
08.06.2005 09:13:13	5700.04	4.03E+01	2.98E+01	3.12E-01	4.70E+00
08.06.2005 09:13:23	5710.058	4.03E+01	2.99E+01	3.12E-01	4.68E+00
08.06.2005 09:13:33	5720.016	4.02E+01	2.99E+01	3.12E-01	4.69E+00
08.06.2005 09:13:43	5730.031	4.02E+01	2.99E+01	3.12E-01	4.70E+00
08.06.2005 09:13:53	5740.048	4.03E+01	2.99E+01	3.13E-01	4.69E+00
08.06.2005 09:14:03	5750.009	4.02E+01	2.98E+01	3.13E-01	4.68E+00
08.06.2005 09:14:13	5760.023	4.02E+01	2.99E+01	3.12E-01	4.70E+00
08.06.2005 09:14:23	5770.037	4.02E+01	2.98E+01	3.14E-01	4.67E+00
08.06.2005 09:14:33	5780.051	4.03E+01	2.98E+01	3.12E-01	4.67E+00
08.06.2005 09:14:43	5790.008	4.02E+01	2.97E+01	3.13E-01	4.69E+00
08.06.2005 09:14:53	5800.021	4.02E+01	2.98E+01	3.13E-01	4.69E+00
08.06.2005 09:15:03	5810.042	4.02E+01	2.98E+01	3.11E-01	4.68E+00
08.06.2005 09:15:13	5820.057	4.02E+01	2.97E+01	3.12E-01	4.69E+00
08.06.2005 09:15:23	5830.014	4.02E+01	2.98E+01	3.10E-01	4.69E+00
08.06.2005 09:15:33	5840.035	4.01E+01	2.98E+01	3.10E-01	4.69E+00
08.06.2005 09:15:43	5850.054	4.02E+01	2.98E+01	3.10E-01	4.70E+00
	30.17	**4.05E+01**	**3.00E+01**	**3.13E-01**	**4.68E+00**

ΔT	**10.466**	Q	**3.068**
c_p	4.177	P	**3.129**
ρ	994.030	η	**0.981**
m	**4.210**		

Key to symbols

ΔT	Average temperature difference for water in the period [K]
c_p	Specific heat capacity for water in the actual temperature level [kJ/(kgK)]
ρ	Density for water in the actual temperature level [m^3/kg]
m	Average mass flow rate for water in the test period [kg/s] – from calibration curve to water weight
Q	Heat effect from the plate heat exchanger [kW]
P	Input electric power to the Ekoterm unit [kW]
η	Calculated thermal efficiency for the Ekoterm unit [-]