A GENERIC CALCULATION SCHEME TO ESTIMATE SEASONAL PERFORMANCE OF COMBINED SYSTEMS AND EXPERIMENTAL RESULTS

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ABSTRACT

The energy requirement for space heating is decreasing significantly in modern highly-insulated dwellings. Hence, the share of domestic hot water reaches a substantial part of the total energy requirement. In addition, auxiliaries have a considerable impact on the performance, as well.

A new European directive on the energy performance of buildings requires sound methods to calculate the over-all seasonal performance factor of building equipment. Within the framework of IEA HPP Annex 28 a generic calculation scheme for combined heat pump systems, i.e. systems for space heating and domestic hot water generation, has been developed by the University of Applied Sciences Basel (FHBB). This calculation method, called the FHBB method, has already been implemented in the CEN draft standard prEN 14335 and submitted to public enquiry. Furthermore the calculation method is extended to cover multi-function heat pump systems providing heating (cooling), ventilation and domestic hot water. At the same time, extensive measurements in two pilot plants are being carried out and evaluated to optimize layout and control and to get adequate measurement data for validation purposes.

Keywords: ***heat pump, standardisation, test procedure, seasonal performance.***

1 INTRODUCTION

Objective of the project is the development of an as far as possible easy-to-use calculation method for the seasonal performance factor of heat pump compact units and its validation. The calculation is based on the product characteristic of the heat pump compact unit, which has to be delivered by an adequate test procedure being developed at the test centre for heating, ventilation and refrigeration at the University of Applied Sciences in Lucerne (HTA Lucerne). The calculation method is to be validated by field measurements of two systems, the LWZ 303 SOL of the manufacturer Stiebel Eltron [Stiebel Eltron 2002] and the Vitotres 343 of the manufacturer Viessmann [Viessmann 2003]. As the systems are in the market introduction, neither detailed experience with the real behavior in the field application nor extensive data of the systems in operation exist, so field measurements for the two systems are to be carried out in this project as input for the validation of the calculation method.

The seasonal performance calculation of the systems is needed on the one hand to compare the performance of compact units to other heating systems, which is enhancing the market competitiveness, as currently only limited statements can be given on the annual system performance in the field. On the other hand, the seasonal performance calculation is needed for labeling, which is required e.g. for building standards like the Swiss MINERGIE standard [MINERGIE 2005] or in the framework of the European Directive on the Performance of Buildings [EPBD 2002]. The calculation method and the test procedure shall be an input to the CEN Standardization Committees on the European level [EC 2002].

The project is together with the former projects "Seasonal performance calculation for residential heat pumps with combined space heating and hot water production (FHBB Method)" [Wemhöner, Afjei 2003] and „Test method for residential heat pumps with combined space heating and hot water production” [Montani 2003] the Swiss contribution to the IEA HPP Annex 28 carried out in the heat pump program of the international energy agency [Zogg et al. 2003].

2 WORK CARRIED OUT AND RESULTS

2.1 Field Measurements Pilot Plant Gelterkinden

Fig. 1. Low energy building according to MINERGIE standard in Gelterkinden (canton Basel-Land)

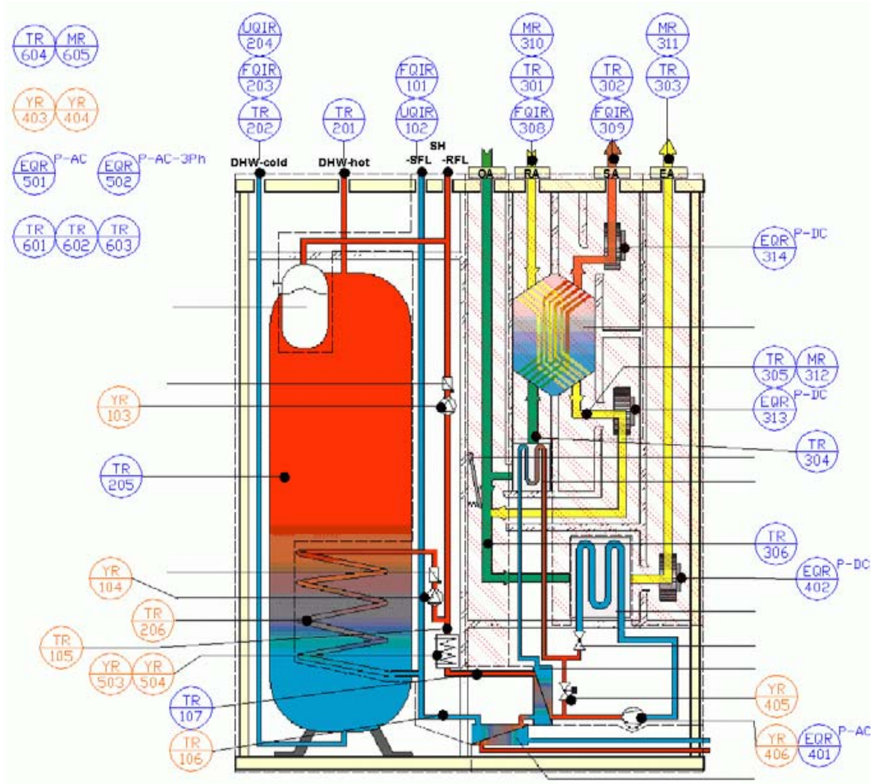

Fig. 2. Measurement sensors in Stiebel Eltron LWZ 303 SOL

The field measurements of the compact unit LWZ 303 SOL of manufacturer Stiebel-Eltron in Gelterkinden/BL started in the beginning of April 2004 and the unit is still operating successfully. The homeowners have been completely satisfied with the operation of the compact unit providing space heating, ventilation, and domestic hot water so far.

Characterization of the building and boundary conditions for the measurements are:

- One-family house according to MINERGIE requirements in Gelterkinden at south oriented hill-side location with solid construction walls and laterally placed basement outside insulation perimeter (s. Fig. 1)
- Energy reference area 153m^2 (net living space 125m^2, net volume 305m^3)
- Heating energy requirement according to Swiss standard SIA 380/1 = 157MJ/m^{2}a
- Heating power demand according to Swiss standard SIA 384/2 = 4.1kW (20°C/-8°C)
- Inhabitants are 2 adults, both employed, and 1 child in school
- Set domestic hot water temperature is 45°C (it has been adjusted to 55°C in the end of 11/2004)
- Volume flow of mechanical ventilation was set to 100m^3/h (air change 0.33 per hour). Measurements showed an actual volume flow of 60m^3/h (air change 0.2 per hour).

Figure 2 shows the position of the measurement sensors in the heat pump compact unit LWZ 303 SOL of the manufacturer Stiebel Eltron.

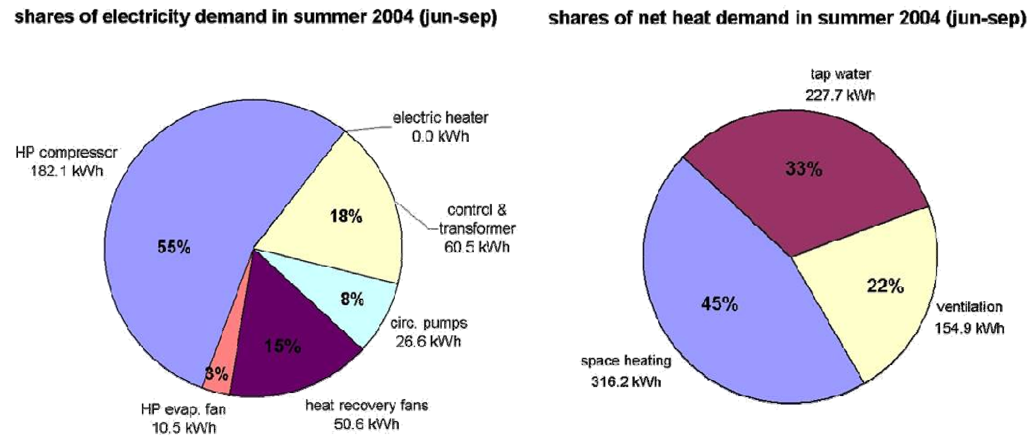

Fig. 3. Summer energy balance of Stiebel Eltron LWZ 303 SOL; left part: shares of electricity in summer 2004; right part: shares of net heat requirement in summer 2004

Fig. left part illustrates that the heat pump uses 55% of the electricity in summertime. Ventilation and heat recovery consume 15%, control and transformer 18% and circulation pumps 8%. Fig. right part shows a very low domestic hot water (DHW) energy consumption of 228 kWh for the summer period. According Swiss standard SIA 380/1 a consumption of 708 kWh for the corresponding period would be expected. Furthermore, an unexpected high space heating (SH) requirement of 316 kWh has been observed that is even higher than the DHW energy requirement.

At first sight the share of the heat pump seems rather low and the consumption for control, transformer, fans, and circulating pumps rather high, but the small total energy consumption for domestic hot water of 228 kWh in 18 weeks corresponds to the small energy consumption of the heat pump.

The control of the compact unit and the losses of the transformer used for control and ventilation fans consume 60.5 kWh in 18 weeks or 20 W permanently which is a common value. The fans for the heat recovery (HRV), which run also during summer, consume with 50.6 kWh less than the control and stand-by losses of the transformer. It has to be taken into consideration that the HRV was not active during 2 of 18 weeks. Thus, the average power consumption during operation is 18 W for the measured 60 m^3/h. The specific power consumption for the ventilation is in this case 0.3 W/(m^3/h) which shows efficient fans in a well-designed ventilation system. The electricity consumption of the two circulating pumps for SH and the DHW storage heating is quite small compared to their nominal power of 90 W for SH pump and 55 W for DHW pump due to the intermittent operation of both pumps yielding short running time.

The right part of Fig. 3 displays an unexpected result with regard to the net heat requirement during summer period. The net heat requirement for SH during summer was higher than for DHW. The explanation for the existence of SH during summer could be found in the measurement data that show always an energy flow into the building as soon as the space heating circulating pump starts even without heat pump operation. The temperature difference between flow and return pipe rises to about 2 K during the off-period of the circulation pump. After a circulation pump running time of about 10 minutes and without heat pump operation, the temperature difference falls to 0.1…0.2 K and remains with this offset. The remarkable fact is that a temperature difference up to 2 K exists without heat pump activity. The source of the heat flow could not be evaluated yet and is a matter of further investigation. Possible reasons could be a small, not desired mass flow through the DHW storage heat exchanger or a heat transfer from the DHW storage to the pipes in the compact unit.

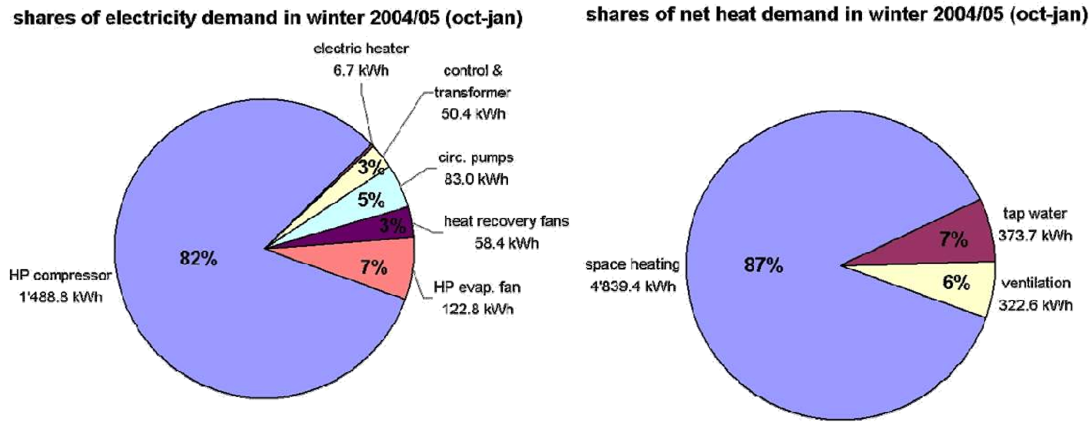

Fig. 4. Winter energy balance of Stiebel Eltron LWZ 303 SOL; left part: shares of electricity in winter '04/'05; right part: shares of net heat requirement in winter '04/'05

Figure 4 left part depicts that the heat pump with the evaporator fan uses 89% of the electricity consumption in wintertime, heat recovery fans consume 3%, control and transformer 3% and circulation pumps 5%. Figure 4 right part shows still a low domestic hot water (DHW) energy consumption of 373.7 kWh for the winter period, although it is a bit higher compared to summer period. The space heating (SH) energy requirement of 4'840 kWh is comparatively high. It accounts for 73% of the full winter heating requirement, which is estimated with a design value of 6'670 kWh and the period from February to April has not been covered yet.

For a further comparison the following characteristic values have been evaluated.

- Electro-thermal amplification factor ETV_{HRV} of the heat recovery,
  i.e. the ratio of recovered heat from outside to supply air and electricity consumption for fans.
- Heat pump weekly performance factor WPF-HP of compact unit,
  i.e. the produced heat from the heat pump in relation to the electricity input to heat pump (compressor, evaporator fan, control and transformer losses).
- Generator weekly performance factor WPF-G of compact unit,
  i.e. the produced heat for the heating, domestic hot water and ventilation system in relation to the electricity input to heat pump and back-up heater.
- System weekly performance factor WPF-SYS of compact unit,
  i.e. the net heat requirement of heating, domestic hot water and ventilation in relation to electricity input of the complete system (heat pump, fans of ventilation system, back-up heater, circulation pumps control and transformer losses).
- Temperature change coefficient Φ_{OA},
  i.e. the ratio of temperature increase from outside air to supply air and exhaust air - outside air temperature difference.

Remark: The COP-HP and the weekly energy performance factor of the heat pump WPF-HP do not include the pressure drop in the condenser.

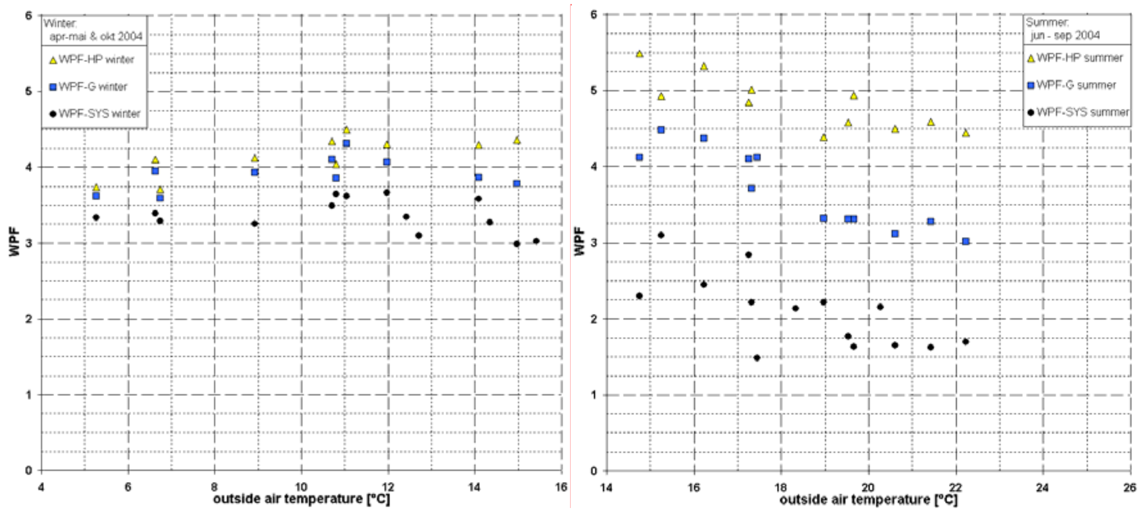

Fig. 5. Weekly Energy Performance Factors WPF for field measurement of LWZ 303 SOL (left: wintertime; right: summertime)

The values for the WPF-HP presented in Fig. 5 range between 3.7 and 4.5 during winter, i.e. for outside air temperatures of 5°C to 15°C. During summer, i.e. for outside air temperatures above 15°C, the measured values for the WPF-HP range between 5.5 and 4.3, decreasing with higher outside air temperatures. The WPF-SYS ranges between 3.0 and 3.7 for outside air temperatures in the range of 5°C to 15°C (winter period) and decreases from 3.1 to 1.6 above 21°C outside air temperature. The WPF-G ranges between 3.6 and 4.3 below 15°C and between 4.5 and 3.0 in summer.

The characteristic of WPF-HP in winter can be explained with an increasing performance factor of the heat pump at higher outside air temperatures. However, above 15°C the heat pump shifts to less efficient domestic hot water production. The raising heating capacity due to higher source temperatures combined with the limited heat flux of the DHW heat exchanger yield an increase of the temperature difference and hence an increasing heat pump supply temperature. As a result, all efficiency values in Fig. 5 deteriorate with the outside air temperature.

The characteristic of WPF-SYS is plausible, because system efficiency increases with lower outside air temperatures due to an increasing requirement of space heating and the ventilation heat recovery that is considered in WPF-SYS. The low system efficiency at high outside air temperatures results from relatively high standby losses in relation to the small energy requirement. But they are a small part of yearly energy requirement and thus of minor importance.

Table 1. Characteristic key values of the pilot plant Gelterkinden for summer period June-September '04

LWZ 303 SOL	ETV_{HRV}	*WPF-G*	*WPF-SYS*	Φ_{OA}
Summer	***3.1***	***3.4***	***2.1***	***0.78***
Winter	***-***	***3.8***	***3.1***	***0.72***

Table 1 contains the characteristic key values for the summer and winter period. The system performance factor WPF-SYS shows a big difference from summer to winter period, caused by a significant influence of the low domestic hot water consumption in summer period and the low ventilation volume flow that lead to a small net energy requirement and a relatively greater share of standby energy. The generator weekly performance factor WPF-G is higher in wintertime due to the high amount of produced energy and a lower average heat supply temperature. The electro-thermal amplification factor ETV_{HRV} is only depicted for summertime. In wintertime there are few undisturbed values available, where the heat recovery runs without heat pump. The ETV_{HRV} cannot be calculated with running heat pump, since the subcooler influences the temperature of the heat recovery (s. Fig. 2).

2.2 Field Measurements Pilot Plant Zeiningen

Fig. 6. Ultra-low energy building according Swiss MINERGIE-P standard in Zeiningen (canton Aargau)

Characterization of the building and boundary conditions for the measurements are:

- One-family house according to Swiss ultra-low energy standard MINERGIE-P in Zeiningen at south oriented location. Floor and ceiling are of concrete with embedded pipes for hydronic heat distribution and air channels for mechanical ventilation. Walls are made of a wood-frame construction with insulation (s. Fig.)
- Energy reference area 198 m^2 (net living space approx. 150 m^2)
- Heating energy requirement according to Swiss standard SIA 380/1 = 36 MJ/m^2a
- Heating power demand according to Swiss standard SIA 384/2 = 2.5 kW (20°C/-8°C)
- Inhabitants are 2 adults and 1 child
- Set domestic hot water temperature is 45°C
- The measured mean volume flow of the supply air is 140 m^3/h and 100 m^3/h for the exhaust air

For the field measurements of the compact unit Vitotres 343 of the manufacturer Viessmann an ultra-low energy building from the general contractor Genesis Home AG has been chosen. It is being certified according to the Swiss MINERGIE-P standard [MINERGIE 2005]. The measurement installation could be put into operation in the beginning of September 2004. Initially, problems with the data transfer from the data logger to the PC via telephone led to some data losses, but since October 2004, the monitoring works reliable. Moreover, in the initial phase some parameters of the control had to be optimized with regard to the building (e.g. heating characteristic curve). The new controller using an outside air temperature dependant supply temperature for the control of the hydronic distribution system was put into operation at December,1 2004.

Figure 7 shows the measurement sensors in the heat pump compact unit Vitotres 343 of the manufacturer Viessmann [Viessmann 2003]. In addition a separate wood stove is installed that is engaged rarely during cold days.

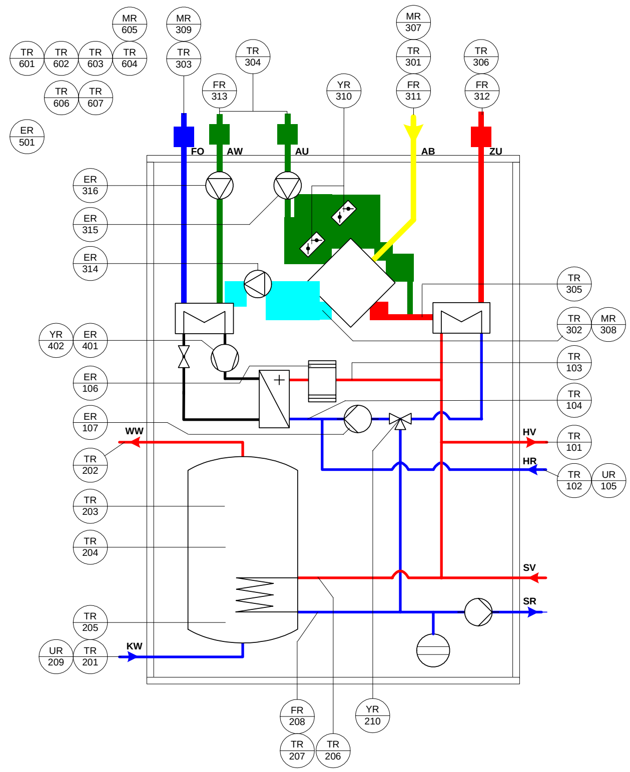

Fig. 7. Measurement sensors in Viessmann Vitotres 343

Figure 8 presents the energy balance for a two-month winter period. As indicated on the left side, the heat pump consumes 41%, the electric resistance heater 42%, heat recovery fans 6% and the evaporator fan 6%. The high share of energy delivered by the back-up heater indicates that the heat pump capacity is not sufficient. Reasons are a high heating power requirement of the building in comparison to the heat pump capacity and, presumably, a not optimally tuned control. The right side indicates the net heat requirement in wintertime. The main part is space heating with 62%. Minor parts are ventilation heat with 24% and domestic hot water with 12%. The ventilation heat is calculated with the enthalpy difference between supply air and outside air. 79% of the 554 kWh ventilation heat are provided by the heat recovery and 21% by the supply air heater (s. Fig. 7). The DHW consumption is for the two-month period in a normal range. The space heating energy requirement of 1’462 kWh is comparatively high. It accounts for 74% of the full winter heating requirement, that is estimated with a design value of 1’980 kWh. The remaining heating period from October to November and from February to April has not been covered yet in the measurements. However in ultra-low energy dwellings, the main part of heating requirement takes place during the coldest months, i.e. in January and February considering Swiss meteorological conditions.

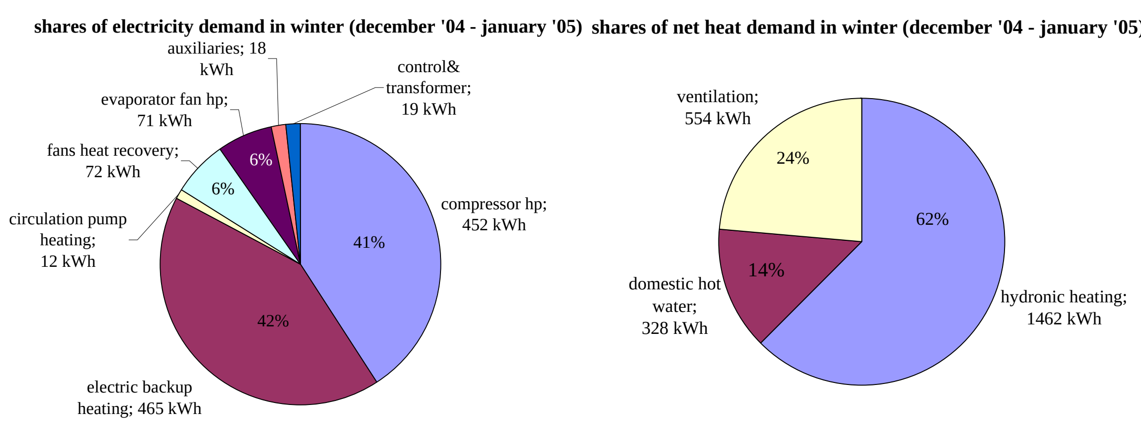

Fig. 8. Energy balance of Viessmann Vitotres 343; left part: shares of electricity use in winter ‘04/’05; right part: shares of net heat requirement in winter ‘04/’05

Subsequently the evaluation of the measurement results is described for the week 50/2004 (December, 6 to December, 12 2004). The defrosting cannot be recorded directly, but the electrical power input of the heat pump (see Fig. 9) indicates, that at outside temperatures near the freezing point, the heat pump changes sporadically to the defrosting mode. Obviously, the output capacity of the heat pump is not sufficient to cover the heat demand of the building, since the heat pump runs through and the electrical back-up heater is operated at the first capacity step (1.7 kW).

It has to be noted that the heating power demand of the building (2.5 kW) is 40% higher than the nominal capacity of the heat pump (1.5 kW). In addition an elevated measured indoor temperature of 22°C (instead of 20°C design value) has been applied and usually in the first year the energy requirement is increased by the drying process of the concrete building elements like ground floor and intermediate ceiling and floor.

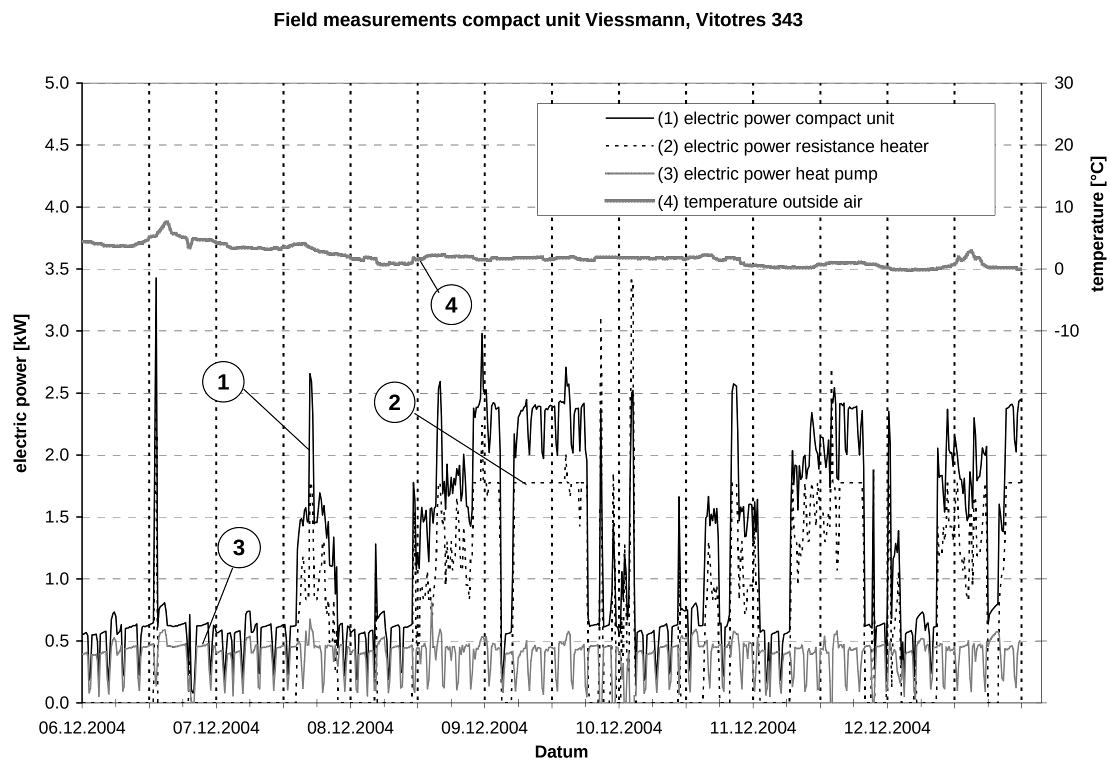

Fig. 9. Electric power consumption of HP compact unit Vitotres 343 in Zeiningen during week 50/2004

2.3 Calculation Method and Validation

The focus of the calculation method development was the integration of the heat recovery in the existing calculation method on the basis of testing points delivered by the test procedure.

In coordination with the HTA Lucerne, the following decisions were made for the calculation method:

- The calculation of the heat recovery will be accomplished on the basis of the temperature change coefficient, since this value is easy to measure and therefore the most reliable value to characterize the heat recovery.
- For the calculation of the heat recovery in connection with the heat pump, testing points in accordance with EN 14511 [CEN 2004] are used. The testing points delivered by the test procedure will comprise measurements of the single operation of the heat recovery and the combined operation of the heat recovery and heat pump. These two cases are sufficient, since the heat recovery is running through the entire heating period. Consequently, the heating period can be characterized by the two measured operation modes.

- For the summer operation, calculation will be based on testing results according to EN 255-3 [CEN 1997]. Since the method is time-consuming, the whole test procedure will only be performed for one point. For the other testing points, a reduced testing to determine the COP_t (phase 2 of EN 255-3) will be accomplished.

2.3.1 Calculation steps to consider the heat recovery

- Calculation of the energy delivery of the heat recovery
  The first step is the reduction of ventilation heat losses by the heat recovery. The energy reduction of the heating requirement of the bin is calculated by the enthalpy flow over the entire time of the bin (heat recovery is running through in wintertime). The temperature conditions of the heat recovery are given by the temperature change coefficient. The expense of this reduction of the heating requirement is calculated by the power consumption of the respective fans.
- Calculation of the heat pump operation
  As next step the diminished heating energy requirement has to be covered by the heat pump, or depending on the design of the heating system, by the heat pump and the electrical back-up heating. Thus, a power balance is evaluated to determine the fraction to be covered by the electrical back-up heating. Then, the electrical input for the heat pump operation is calculated by evaluating the heat pump characteristic measured in the test procedure.
- Evaluation of the bin performance factor
  To calculate the bin performance factor for the heating operation, the additional electrical energy for the back-up and the auxiliary energies not contained in the COP values have to be added.
- Seasonal performance for the heating mode
  To derive the seasonal performance for the heating mode, the electrical input is summed up over all bins. Depending on the systems configuration, installed storages have to be considered, too.
- Domestic hot water mode/summer operation
  The domestic hot water operation is evaluated in a similar way by using the test results of the COP_t and the output capacity according to EN 255-3.

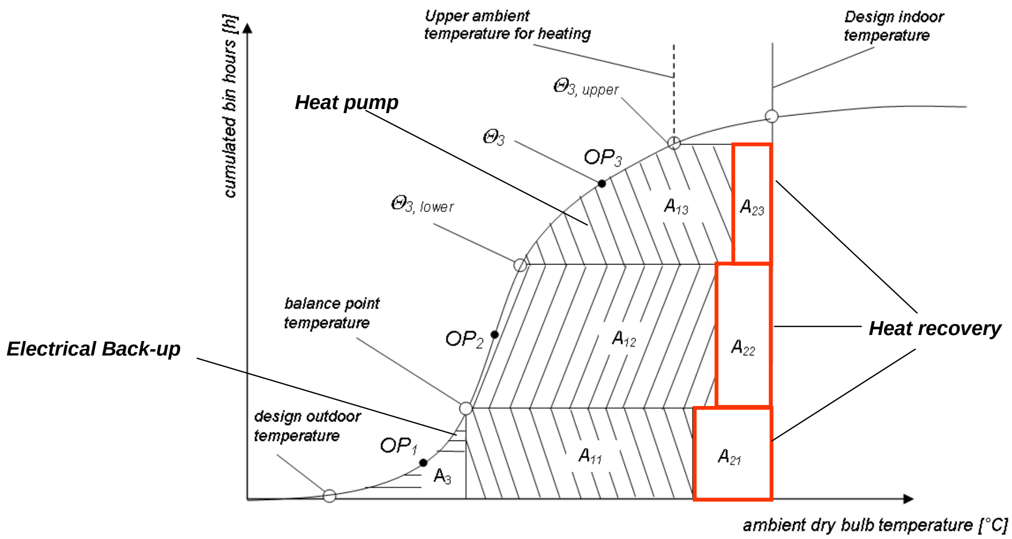

Fig. 10. Enhanced bin-method for heat pump compact units

Figure 10 illustrates how the various operation modes of the heat pump compact unit are accounted for. A large amount of ventilation losses are recovered by the heat recovery, the heat pump covers the remaining requirement up to the operation limit and the rest is covered by the electric auxiliary heater.

The above described approaches are currently implemented in an Excel spread sheet and compared to the measured values.

3 CONCLUSION

Newly erected ultra-low energy dwellings in Europe are more and more equipped with multi-function heat pump compact units, covering space heating, domestic hot water and mechanical ventilation with heat recovery. The energy requirement for space heating is decreasing significantly, hence the share of domestic hot water reaches a substantial part of the total energy requirement. In addition, auxiliaries have a considerable impact on the performance.

A new European directive on the energy performance of buildings requires sound methods to calculate the over-all seasonal performance factor of building equipment. Within the research project a generic calculation scheme for combined heat pump systems, i.e. systems for space heating and domestic hot water generation, has been developed by the University of Applied Sciences Basel (FHBB). This calculation method, called the FHBB method, has been implemented in the CEN draft standard prEN 14335 and will be submitted to public enquiry.

Furthermore extensive measurements in two pilot plants are being carried out and evaluated to optimize layout and control and to get adequate measurement data for validation purposes. The results are promising, however it has to be stressed that the heating capacity of the heat pump is sufficient high to cover the heating requirement of the building. The experimental work will continue up to the end of 2005.

The FHBB calculation method and the experimental analysis are submitted as Swiss contribution to IEA HPP Annex 28 [Wemhöner, Afjei 2004].

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