Performance and Experiences with Austrian Demonstration Projects for Lowest-Energy Houses (Passive Houses) in Social Housing

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ABSTRACT

The paper describes the experiences with passive houses that have been built and operated in Vienna during the last years. The first part of the paper is the description of the projects; the second part presents measurement results during the first years of operation regarding indoor climate and energy consumption. The third and main part describes the lessons learnt regarding the necessary accuracy of calculations in the design phase with special focus on solar shading, internal loads, thermal bridges, and the distribution losses of hot water and the heating systems.

INTRODUCTION

During the last years, more and more passive-house projects have been realized in Vienna. Especially multifamily buildings are of great interest. The use of energy efficient ventilation systems could increase indoor air quality and could help to decrease the risk of mold growth on surfaces. In Table 1, three projects are described where detailed post-occupancy evaluations (POE) have been done. All are in Vienna; the first project (UTE) is situated in the west, the second (DRE) is in the east, and the third (KAM) is in the north. Part of the POE included detailed modeling of the buildings to calculate heating load, summertime overheating and energy performance, and the comparison with measurements.

DESCRIPTION OF PROJECTS AND DESIGN CRITERIA

Projects UTE and DRE were designed with special focus on the heating load of each flat and the total heating energy demand (multizone model), as the flats are only heated with one heating coil per flat in the supply air. The design strategy and methods have been published in Bednar et al. (2008a, 2008b). Monitoring of indoor climate, system behavior, and energy consumption started after occupation because of a POE research project (Keul 2009).

Project KAM was designed considering the total heating load and heating energy consumption of all flats (single-zone model). The tool that has been used was the passive house planning package (PHPP) (Feist 2007). Monitoring of energy consumption started after occupation. Detailed monitoring of indoor climate and system behavior started after flat owners complained. The optimization of the system was completed in Summer 2009. Due to the monitoring, several failures in the system could be identified and corrected.

MEASUREMENT RESULTS

Unconditioned Spaces

Unconditioned spaces, such as an atrium or a staircase, can reduce transmission heat losses through the constructions facing the unconditioned space. Figure 1 presents the results of air temperature measurements in the atrium at different heights. To calculate the temperature inside the atrium, the following equation can be used.

$$T_u = \frac{L_{iu} \cdot T_i + L_{ue} \cdot T_e}{L_{iu} + L_{ue}} + \frac{1}{L_{iu} + L_{ue}} \dot{Q}_{sol} \qquad (1)$$

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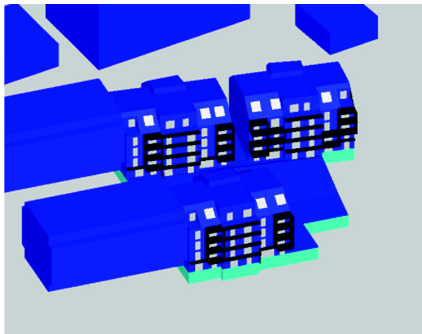
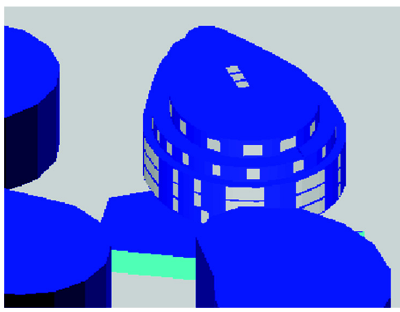
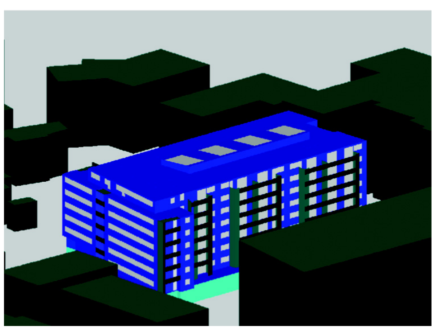
Table 1. Description of Building Projects

<table>
<tr><th></th><th>Model</th><th>Photo</th></tr>
<tr><td>UTE</td><td></td><td></td></tr>
<tr><td colspan="3">Start of occupation: 2007; Number of flats: 3 × 13; Gross floor area = 1330 m^2, Area inside flats = 901 m^2; Heating and hot water: central gas-fired condensing boiler, hot-water storage tank; distribution system with circulation pipe; heating of flat through supply air.</td></tr>
<tr><td>DRE</td><td></td><td></td></tr>
<tr><td colspan="3">Start of occupation: 2007; Number of flats: 27; Gross floor area = 3216 m^2, Net area inside flats = 2178 m^2; Heating and hot water: district heating, hot-water storage tank; distribution system with circulation pipe; heating of flat through supply air.</td></tr>
<tr><td>KAM</td><td></td><td></td></tr>
<tr><td colspan="3">Start of occupation: 2008; Number of flats: 80; Gross floor area = 8100 m^2, Net area inside flats = 6808 m^2; Heating and hot water: district heating, hot-water storage tank; distribution system with electric trace heating; heating of flat through minimized radiators.</td></tr>
</table>

The calculated temperature according to Equation 1 for the atrium of KAM is shown in Figure 1, as well. The temperature and solar load have been monthly averages.

Unheated Flats

For calculating heating energy demand, especially heating load, the temperature in unheated flats is very important.

$$T_u = \frac{1}{\sum_n L_{iu,n} + L_{inf} + L_v} \times \left(\sum_n L_{iu,n} \cdot T_{i,n} + L_{inf} \cdot T_e + L_v \cdot T_{sup} + \dot{Q}_{sol} \right) \quad (2)$$

Figure 2 shows the measured temperatures in three neighboring flats. The central flat is heated by the occupants on a set point around 23°C, the flat below on a set point around 22°C, and the flat above is not heated. The connecting area between two flats is 90 m^2. The U-factor of the floor is 0.9 W/(m^2·K), and 0.1 W/(m^2·K) for the exterior walls. The windows have an average U-factor of 0.85 W/(m^2·K). The conductances and the resulting temperature are listed in Table 2.

As can be seen in Figure 2, the calculated temperatures of the unheated and unused flat are around 17°C if the outdoor temperature is around 0°C, and the indoor temperature is around 16°C if the outdoor temperature is around –5°C. After a steep decrease of the outdoor temperature, it takes more than

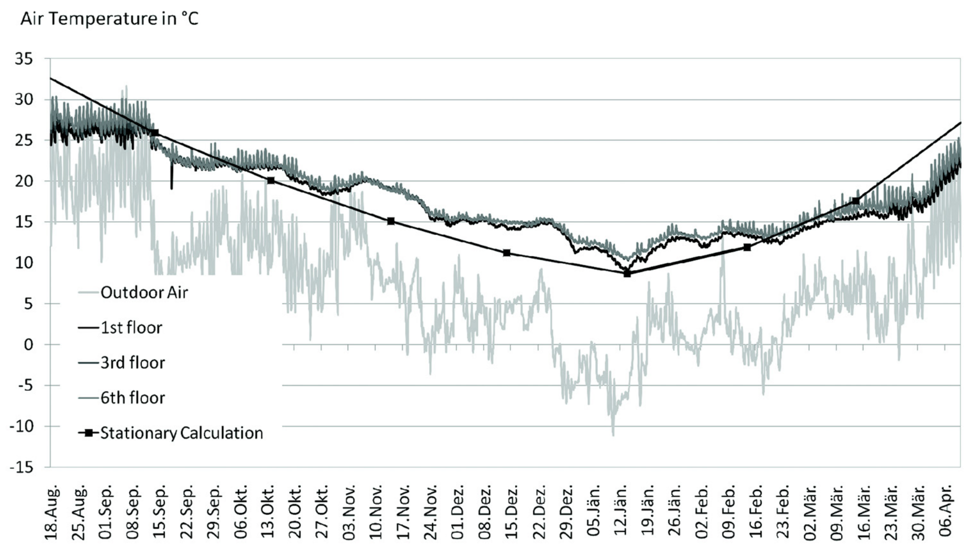


Figure 1 *Temperature inside atrium of KAM measured at different heights during winter 2008/09 compared with the calculated temperature using Equation 1.*

Table 2. Resulting Temperature for Unheated Flat under Cold and Cloudy Conditions

Connection	Conductance, W/K	Temperature, °C	Temperature, °C
Lower flat	81	23	23
Exterior ceiling	9	0	–5
Exterior walls	4.4	0	–5
Exterior windows	11.5	0	–5
Infiltration	13.5	0	–5
Ventilation (off)	2	0	0
Resulting temperature		**14.9**	**13.2**
Heat from appliances	91 W		
Solar radiation	28 W		
Resulting temperature		**16.1**	**14.4**

14 days until the indoor temperature reaches the new steady state. Comparing with the calculated temperature from Table 2, one can conclude that Equation 2 can be used to calculate the indoor temperature of unheated spaces if the temperatures used in the equation are more than two-week averages.

Heating Load

The calculation of the heating load of rooms/flats for lowest energy houses can be done with quasi-stationary methods (Feist 2007). In Figure 2, on the left side, the temperatures inside one critical flat are presented during winter 2008/2009 where the radiators emitted around 200 W less than necessary when the outdoor temperatures were less than 0°C. This mismatch leads to the decrease of the indoor temperatures before January 8th. During summer 2009, one radiator was changed to a larger one; the right side of Figure 2 presents the indoor temperatures during winter 2009/2010. One can conclude that the calculation of the heating load of rooms/flats has to be done with the assumption of unheated flats, with temperatures calculated according to Equation 2.

Heating Energy Demand

The heating energy demand according to *EN Standard 15603, Energy Performance of Buildings—Overall Energy Use and Definition of Energy Ratings*, *EN/ISO Standard 13790, Energy Performance of Buildings—Calculation of Energy Use for Space Heating and Cooling*, and *EN Standard 15316, Heating Systems in Buildings—Method for Calculation of System Energy Requirements and System Efficiencies* is calculated from transmission and ventilation losses, internal

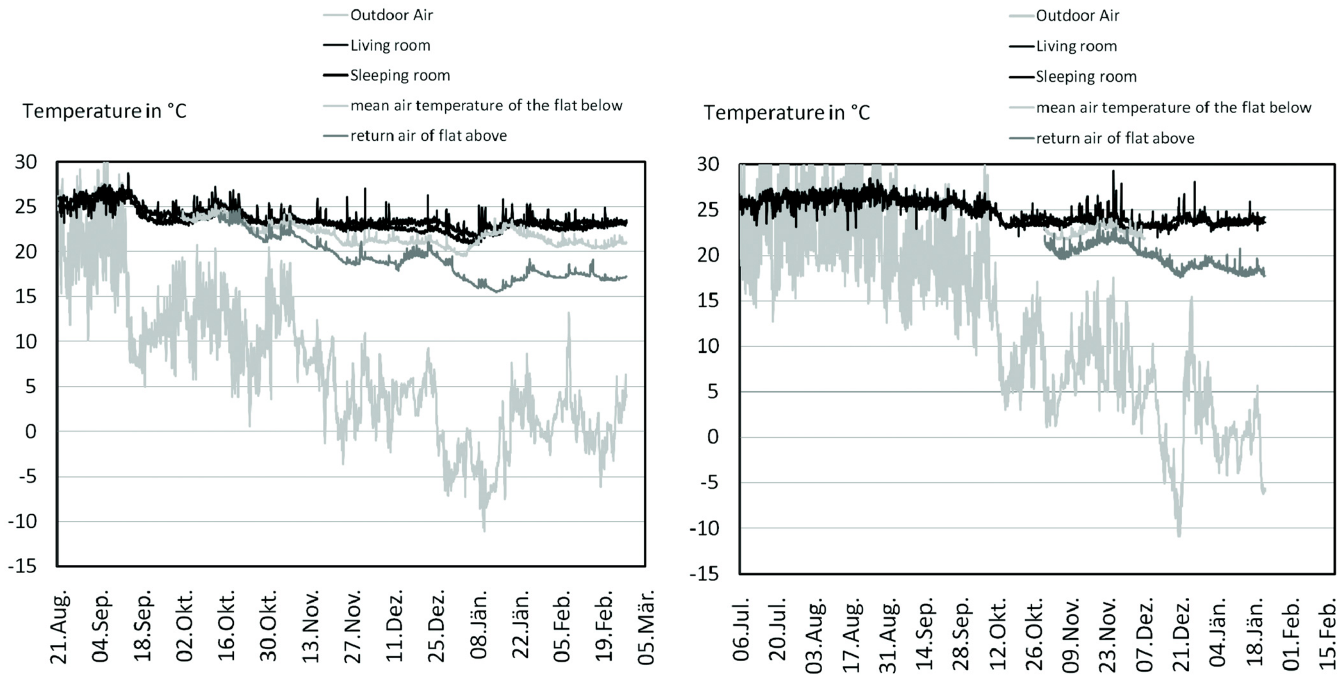


Figure 2 *Temperature inside the critical flat together with temperatures inside the flats above and below from KAM during winter 2008/09 (left) and 2009/2010 (right). Enhancement of heating system (radiators and temperature level) took place in summer 2009.*

and solar gains, and system losses. The comparison of the calculated monthly gas consumption and measurements for project UTE has already been presented in Bednar et al. (2008a 2008b). Figure 3 compares the calculated and measured heating energy use for project KAM in winter 2008/2009. The energy balance has been calculated for each flat with the help of the detailed 3D model in Buildopt_VIE (model presented in Table 1). Buildopt_VIE was developed at the research centre to simulate and calculate the performance of lowest-energy houses. The model consists of 670 zones. They are combined to 80 flats, one atrium, two staircases, and a cellar. To calculate the internal loads, the real occupancy of the house was used. As not all flats of the 80 flats were occupied, it was assumed that the occupied flats had an average internal load for people, lighting, and equipment, and an internal temperature of 22°C. The unoccupied flats had no internal loads, but it was assumed that they are also heated. The distribution losses of the heating system and the hot-water system have been counted as recoverable, as the pipes are situated in a funnel connected to the atrium. Solar shading by neighboring buildings and overhangs was calculated for each window in detail.

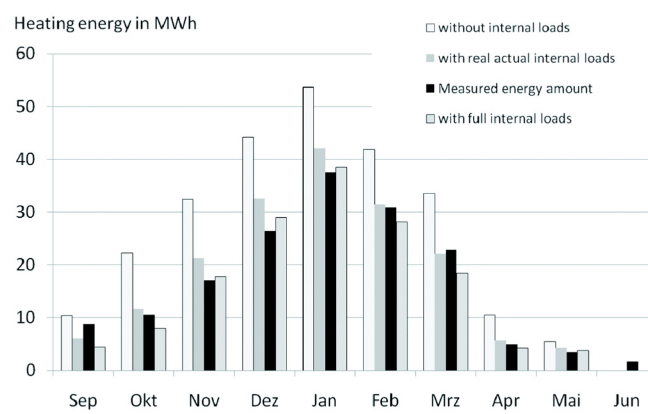


Figure 3 *Measured and calculated heating energy demand (with different scenarios for the internal loads and with distribution losses) for the winter 2008/2009.*

TOTAL ENERGY USE

To compare the total energy use for the projects, the electricity use by household equipment and the ventilation system, and the auxiliary electricity demand for staircase lighting and distribution pumps, was measured using electricity meters. The heating energy use was recorded with a meter for gas consumption in UTE and a heat flow meter in DRE and KAM. The heat exchanger between the district heating system and the building system was part of the measured energy use. As a reference area, the net area inside the flats has been used in Figures 4, 5, 6, and 7. The net areas inside the flats are 901 m^2

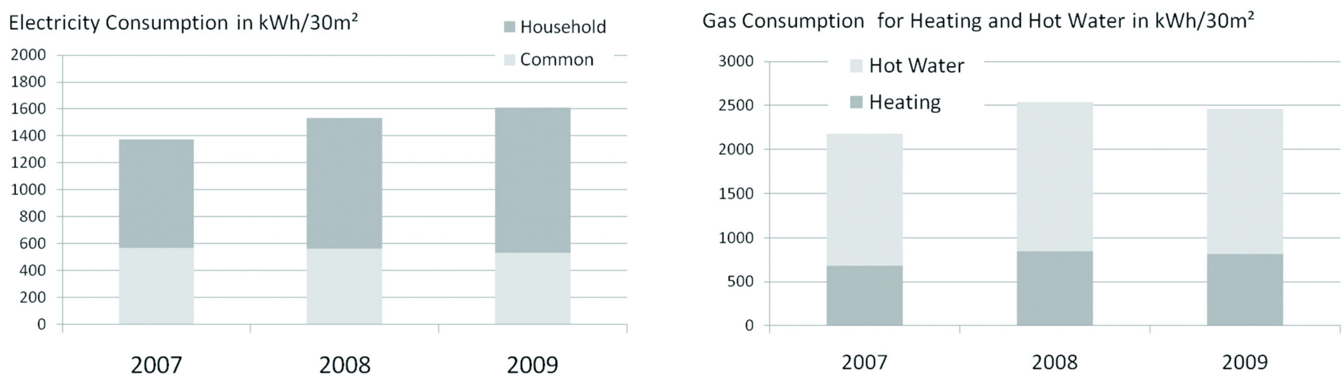


Figure 4 *Measured energy consumption for UTE during the first three years of occupation*

Table 3. Influence of Different Parameters on Total Primary Energy Demand

	Change of Total Primary Energy	
Parameter	**Change of Parameter –20%**	**Change of Parameter +20%**
Infiltration rate	–0.3%	0.3%
Ventilation rate	–3.3%	3.3%
Total conductance	–4.3%	5.2%
Solar shading	0.8%	–0.8%
Internal loads	3.0%	–2.1%
Distribution losses	–3.7%	3.7%
Pressure loss of ventilation system	–1.9%	1.9%
Best/worst combination	–15%	19%

(UTE), 2178 m^2 (DRE), and 6808 m^2 (KAM). In Figures 4 and 5, the energy consumption for 30 m^2 is presented, because 30 m^2 is close to the average living area per person in Austria.

In Figure 4, the total energy use for UTE is split into household electricity and common (ventilation, staircase lighting, pumps, central laundry, lift). The gas consumption (conversion factor: 11 kWh/m^3 gas) is split into hot water and heating. The division had been done with the help of two heat flow meters between the boiler and hot-water system, and the boiler and heating system. As one can see in Figure 4, the energy demand for household equipment and hot water increased during the last three years.

Figure 5 presents the results for DRE and KAM. The total electricity use during the first year of occupancy in DRE is lower than in UTE or KAM. In KAM, the distribution losses of the hot-water system are covered by a electrical trace heating system. Therefore, the heat demand is very low, but the electricity demand is increased by the trace heating system.

To compare the total energy use the energy demand in the form of gas, district heating and electricity is converted to the total primary energy (Figure 6). For the conversion factor for electricity, the Austrian energy mix was used: 1.8 kWh primary energy/kWh electricity. For gas, 1.3 kWh primary energy/kWh gas was used, and for district heating, 0.7 kWh primary energy/kWh heat.

In Schnieders et al. (2001), a similar multifamily house was examined. The measured results as documented in the report are as follows: end energy for heating, 18 kWh/m^2 (district heating); for hot water, 25 kWh/m^2 (district heating); and for household and auxiliary energy, 42 kWh/m^2 (electricity). Using the same conversions factors, a total primary energy demand of 106 kWh/m^2 gives a comparable result.

To analyze the necessary accuracy of the input parameters to ensure accuracy of the calculated total primary energy demand, a sensitivity analysis is presented in Table 3. The sensitivity analysis was done using the DRE project model with a total primary energy demand of 140 kWh/m^2. For this deterministic sensitivity, analysis parameters have been changed by 20%, as the variation in practice should be less.

As one can see, the conductance of the envelope, distribution losses of the systems, and ventilation rate are the most important parameters if the parameters are varied by 20%.

CONCLUSION

Out of the experiences during the last years, one can conclude that the calculated energy use for heating is very

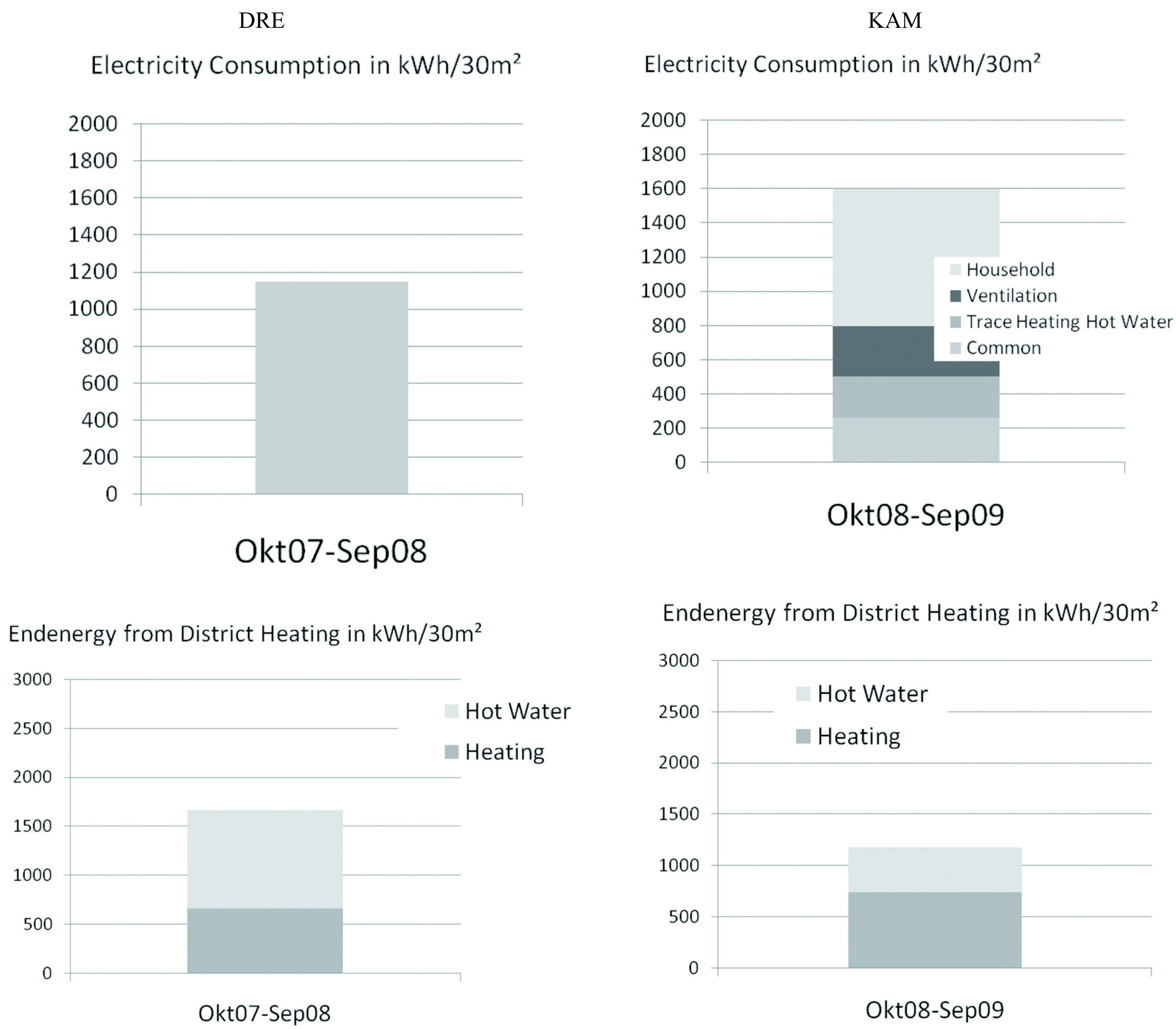


Figure 5 *Measured energy consumption for DRE (left) and KAM (right)*

close to the measured one. The monthly balance method is accurate enough for residential buildings of the investigated type. An accurate calculation and quality assurance of the thermal performance of the envelope and the duct system for heating and hot water is very important. Because the ventilation rate influence the heating energy demand and the electricity demand for ventilation, the best-performing systems are those with a central fan and a decentralized volume flow control. They can be practically noiseless, and occupants can minimize the airflow to achieve not-too-low relative humidity in winter. The primary energy demand for heating and hot water for those types of houses is already so low that the electricity demand for household and auxiliary systems dominate. In future developments, therefore, the electricity demand should be of great concern.

NOMENCLATURE

L = conductance, W/K

T = temperature, °C

$\dot{Q}$ = heat flow, W

Subscripts

i = internal

e = external

u = unheated

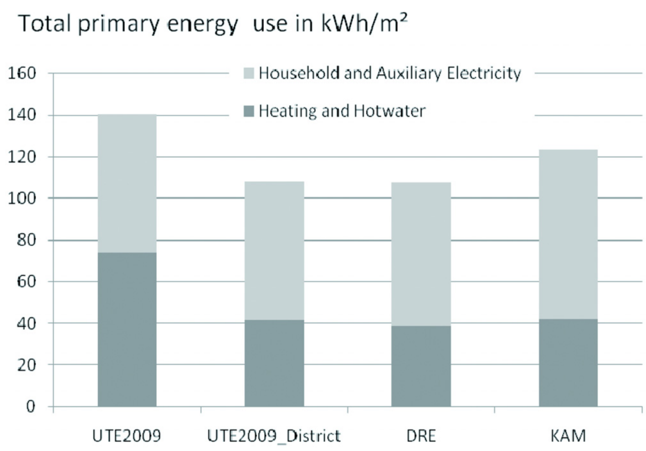


Figure 6 *Total primary energy consumption for heating, hot water, household and auxiliary electricity for the three projects. As in the projects DRE and KAM, district heating is used. UTE has been calculated with the actual gas boiler and with a connection to district heating (UTE_District).*

sol = solar
sup = supply
inf = infiltration
V = ventilation

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