CALCULATION OF THE PRIMARY ENERGY CONSUMPTION OF A SUPPLY AND EXHAUST VENTILATION SYSTEM WITH HEAT RECOVERY IN COM-PARISON TO A DEMAND-BASED (MOISTURE-CONTROLLED) EXHAUST VENTILATION

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ABSTRACT

A demand-based (moisture-controlled) exhaust ventilation system is assessed in comparison to a supply and exhaust ventilation system with heat recovery by means of computational investigations. By implementing the individual ventilation systems the energy demand, especially the primary energy consumption, as well as the effects on indoor climate and CO_2 content are calculated and compared. The calculations are based on a model apartment with a 3-person household for 3 different climates in Germany (cold, medium and hot climate). Despite the high heat recovery coefficient of the supply and exhaust ventilation system an only slightly higher energy use occurred for the demand-based exhaust ventilation system. If regenerative energy sources such as wood are used, primary energy consumption of the demand-based exhaust ventilation system is even lower in comparison to the supply and exhaust ventilation system with heat recovery. With demand-based exhaust ventilation system the CO_2 concentration remains permanently below 1200 ppm.

KEYWORDS

Ventilation systems, energy consumption; air quality, hygrothermal calculations, demand based ventilation

INVESTIGATIONS

To assess the different ventilation systems calculations are performed by means of the hygrothermal indoor climate model WUFI®-Plus. The software tool WUFI®-Plus allows the calculation of the hygrothermal conditions of the enclosure surfaces (walls and ceilings), the indoor air as well as the energy demand under transient boundary conditions (Holm et al 2004); (Lengsfeld and Holm 2007)). The calculations consider besides the materials used in the individual building components also boundary conditions such as air change rate, moisture generation as well as the performance of heating and cooling in the room to be analyzed. The hygrothermal indoor climate simulation model WUFI®-Plus is a 1-zone model, which differentiate individual rooms. The model was successfully validated by means of investigations in an appropriately equipped test building on the outdoor testing site of the Fraunhofer Institute for Building Physics in Holzkirchen (Rösler and Krus 2008).

MODEL APARTMENT

Comparative calculations of the ventilation systems are carried out on the basis of a model apartment with a ground floor of 75 m^2. The apartment is located in a multi-storey building in one of the middle storeys. The U-value of the external walls is 0.25 W/m^2K, the percentage of the windows in the facade amounts to 20 % with a U-value of the windows of 1.1 W/m^2K. Material data necessary for wall, ceiling and window constructions are taken from WUFI® material database.

The minimum indoor air temperature is 21°C. Internal heat sources are disregarded. The moisture and CO_2 input are oriented on a time and quantity basis of a 3-person household. The calculations are based on the typical internal moisture load of a 3-person household in such an apartment. According to Hartmann et al 2001 the moisture input amounts to 9 kg/d based on the assumption that laundry is dried in the apartment and 6.5 kg/d without drying of laundry. The moisture input (Fig. 1 left) as well as the CO_2 input is based on the typical course of the day. To assess the effectiveness of the different ventilation systems at various external climates calculations are performed with a cold (Hof), medium (Würzburg) and a hot (Freiburg) test reference year.

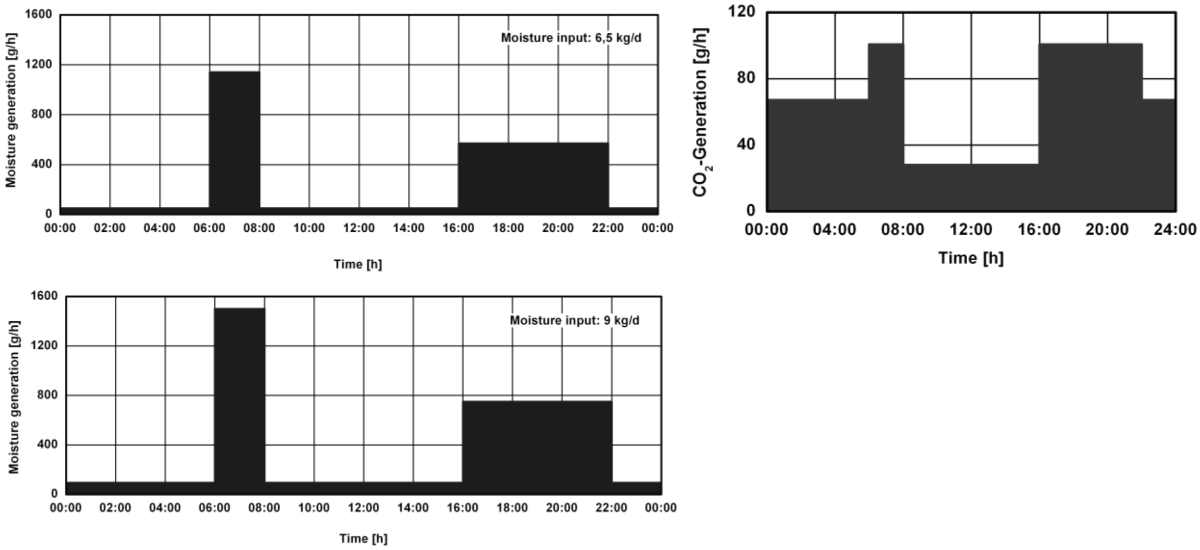

***Figure 1**. Daily course of moisture generation (left) in the model apartment without (above) and with drying of laundry (below), as well as the course of CO_2 production (right).*

VENTILATION SYSTEMS

A commercial supply and exhaust ventilation system with a constant air change rate of 0.4 h^{-1} and an integrated heat recovery with a energy efficiency of 80 % or 60 % respectively was used as ventilation system technology. Furthermore, the supply and exhaust ventilation system was also investigated without heat recovery for better comparison. To avoid problems due to condensation and the freezing of the heat exchanger in the system at low temperatures in winter especially with high heat recovery coefficients the ambient air has to be heated. When the exhaust air temperature falls below 1 °C the exhaust air temperature is heated up to at least 3 °C by means of a preheating unit. The typical power consumption of the ventilator amounts to 35 W. In addition to the constant air change rate of the ventilation system of 0.4 h^{-1} an air change by infiltration and user behavior, e.g. window ventilation, is to be fixed at a value of 0.2 h^{-1} for supply and exhaust ventilation systems with heat recovery according to DIN V 4701-10 (2003).

The demand-based exhaust ventilation system investigated consists of moisture-controlled supply and exhaust ventilation elements and a central ventilator, which is controlled in a way that it has an approximately constant pressure difference of 100 Pa independent of the flow rates. By moving the opening valves the exhaust ventilation elements vary the flow rate in dependence of the relative indoor humidity. By enlarging the opening of the valves, the difference pressure at the ventilator drops and the fan must be operated at a higher performance to regain the reference pressure difference. The moisture-controlled supply ventilation elements provide for a demand-based distribution of the air (zoning) in the apartment. Calculating the heat losses of the ventilation system the changing power consumption of the ventilator is considered. The additional air change rate due to infiltration and user behavior is to be fixed at 0.15 h^{-1} for demand-based exhaust ventilation systems according to DIN V 4701-10.

CALCULATIONS

Calculations are carried out in 1 h-steps over a period of three years, whereby the heating period of the third year is evaluated. According to DIN V 4108-6 (2003) the periods presented in Table 1 are used as heating period at a heating limit temperature of 10 °C for the three climates. The energy consumption for ventilation heat loss and the electrical energy for the operation of the ventilators and, if necessary, the preheating units are determined for both ventilation systems. The primary energy demand for ventilation heat is determined for three different energy sources for heating respectively (fuel oil and natural gas with a PE factor of 1.1; cogeneration of heat and electricity with fossil fuel with a PE factor of 0.7; heating by burning wood (pellets) with a PE factor of 0.2). The part of electricity is weighted by the PE factor of 2.7. The total primary energy demand results from adding the PE demand for ventilation heat and the PE demand for electricity.

Table 1: *Periods and duration of the heating periods for the three climates.*

Heating period	*Start*	*End*	*Duration [days]*
Hof	September 15	May 08	235
Würzburg	October 15	April 26	193
Freiburg	October 20	April 08	169

RESULTS

Calculated Energy Demand

Table 2 and Table 3 show the calculated energy demand for ventilation heat loss for both ventilation systems as well as the power demand for the ventilator and the preheating unit. The PE factors still remain unconsidered. It is obvious from Table 2 that with an increasing heat recovery coefficient the total energy demand for ventilation heat loss declines, but the part of energy necessary for the preheating unit increases. This effect is still enhanced the colder the outdoor climate is. It is also obvious that a heat recovery coefficient of 80 % for example does not at all mean a 80 % reduction of the total energy demand for ventilation heat loss but only energy savings of less than 40 %. The cause of this fact is on the one hand the ventilation heat losses by infiltration and user behavior, which do not pass the heat exchanger, and on the other hand the electrical power demands for ventilator and preheating unit.

As concerns the demand-based exhaust ventilation system (Table 3) the energy demand is clearly dependent on the moisture input (see without drying of laundry (WDL), Hof as an example) and on the assumed air change rate by infiltration and user behavior.

Table 2: *Energy demand for ventilation heat loss of the supply and exhaust ventilation system with various heat recovery coefficients (HRC) as well as electrical power demand for ventilator and preheating unit (PHU).*

climate	*HRC* [%]	*ventilation heat losses (without PHU)* [kWh]	*PHU* [kWh]	*Ventilator* [kWh]	*part of electrical power (ventilator+PHU)* [kWh]	*total energy demand* [kWh]
Hof	0	3837.2	0.0	197.4	197.4	4034.6
(235 days)	60	2300.1	9.8	197.4	207.2	2507.3
	80	1774.1	112.6	197.4	310.0	2084.1
	90	1517.8	227.4	197.4	424.8	1942.6
Würzburg	0	3029.9	0.0	162.1	162.1	3192.0
(193 days)	60	1816.6	4.1	162.1	166.2	1982.8
	80	1405.4	47.4	162.1	209.5	1614.9
Freiburg	0	2524.4	0.0	142.0	142.0	2666.4
(169 days)	60	1514.6	0.0	142.0	142.0	1656.6
	80	1173.7	24.2	142.0	166.2	1339.9

Table 3: *Energy demand for ventilation heat loss (VH) of demand-based exhaust ventilation system and electricity demand of ventilator.*

climate	*air change rate by infiltration and user behavior* [h^{-1}]	*ventilation heat losses* [kWh]	*electrical power demand ventilator* [kWh]	*total energy demand for ventilation heat loss* [kWh]
Hof	(WDL) 0.1	2561.3	74.3	2635.6
(235 days)	0.1	2883.4	77.7	2961.1
	0.15	3079.4	76.4	3155.8
Würzburg (193 days)	0.15	2496.1	63.1	2559.2
Freiburg (169 days)	0.15	2116.2	56.1	2172.3

Fig. 2 shows the total energy demand for ventilation by the example of Hof for both ventilation systems. In case of the supply and exhaust ventilation system with heat recovery the heat recovery coefficient is varied between 0 % and 80 %. The percentage shows the reduction of the total energy demand for ventilation heat in comparison to the supply and exhaust ventilation system without heat recovery. The „Part for Electricity“ and the „Part for Preheating Unit “ are evident. Both ventilation systems clearly reduce the total energy demand for ventilation heat loss in comparison to the supply and exhaust ventilation system without heat recovery.

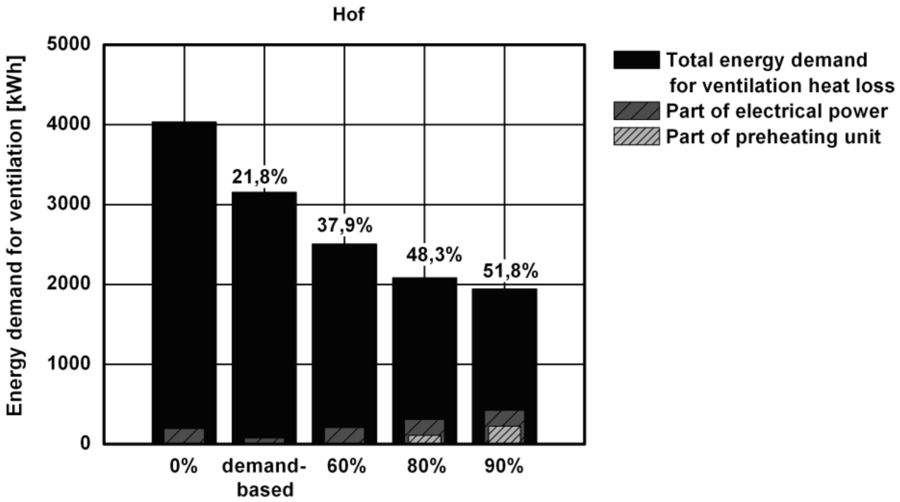

Figure 2. *Total energy demand for ventilation in case of a supply and exhaust ventilation system with a different heat recovery coefficient and in case of a demand-based exhaust ventilation system.*

If we consider primary energy factors, matters differ as is shown in Fig. 3. Compared to a supply and exhaust ventilation system with a heat recovery of 80 % there is only a slight difference with cogeneration of heat and electricity (PE factor 0.7). In case of heating by wood the demand-based ventilation is clearly superior to the supply and exhaust ventilation system with a heat recovery of 80 % with regard to the environment.

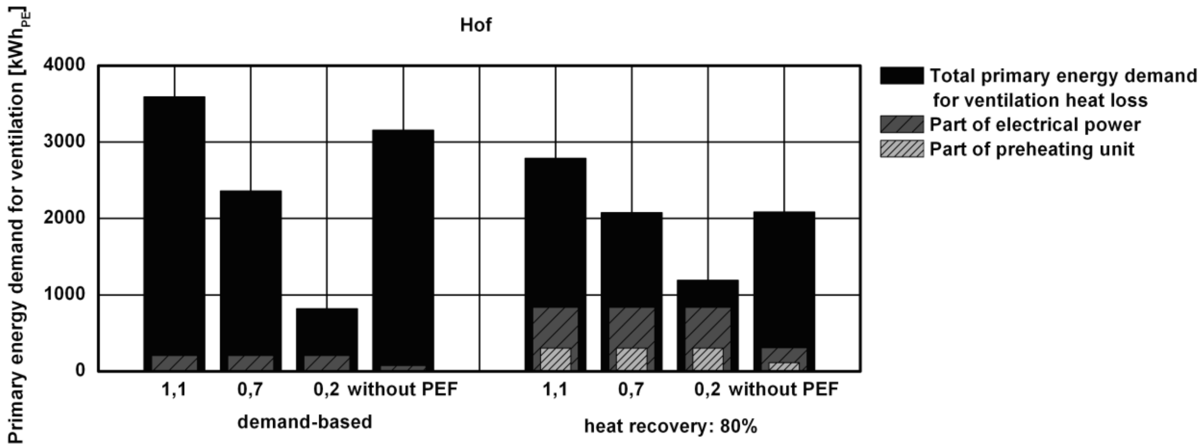

Figure 3*. Energy demand of supply and exhaust ventilation system with heat recovery of 80 % (right) compared to a demand-based exhaust ventilation system (left) by considering primary energy factors.*

Calculated course of CO_2 concentration

Whereas the air change rate is always constant in case of the supply and exhaust ventilation system, it decreases in case of the demand-based ventilation at a lower moisture load but also at a lower ambient air temperature. As desired, the result is lower heat losses but probably also higher concentrations of CO_2. Fig. 4 shows the annual course of calculated CO_2 concentrations using the demand-based ventilation system. To get conditions as unfavorable as possible, investigations were based on a moisture input without drying of laundry and an air change by infiltration and user behavior of only 0.1 h^{-1}. Anyway, the limit value of 1200 ppmV was never exceeded.

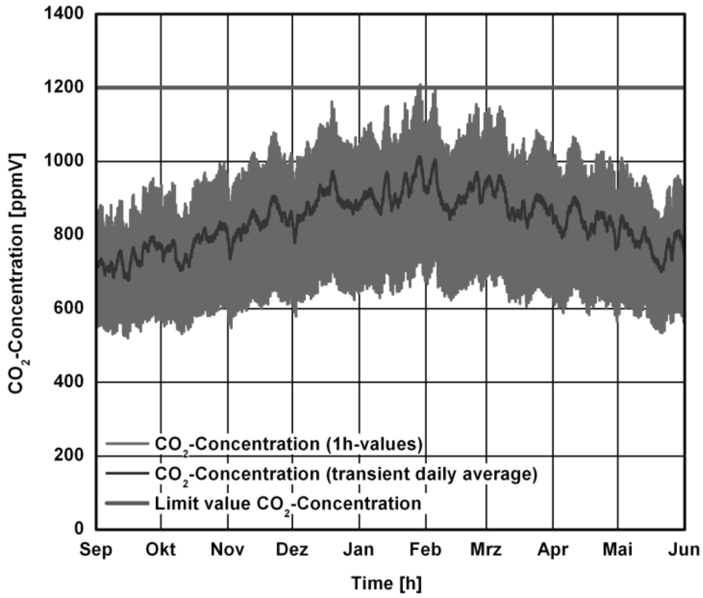

Figure 4. *Course of the CO_2 concentration in a 3-person household using the demand-based exhaust ventilation system as 1-h-values and transient daily average for Hof.*

SUMMARY

The differences in the energy demand between a demand-based exhaust ventilation system and a supply and exhaust ventilation system with heat recovery were determined by comparative calculations for a model apartment of a 3-person household. The moisture input to the model apartment is relatively high (with drying laundry) with unfavorable results for the demand-based exhaust ventilation system due to a higher air change rate. Nevertheless the total energy demand per heating period of the demand-based exhaust ventilation system amounts only to approx. 1000 kWh higher compared to the supply and exhaust ventilation system with 80 % heat recovery (dependent on the outdoor climate). Calculating the costs for electricity on the basis of 0.19 €/kWh and 0.07 €/kWh for heating energy (fuel oil or natural gas) the energy costs for the demand-based exhaust ventilation system are higher by approx. 47 €. These costs must be compared to the investment and maintenance costs of the ventilation systems in a life cycle assessment. Matters are quite different, if we compare the primary energy demand of the two ventilation systems by means of the respective energy source. Due to the high primary energy factor of 2.7, electricity consumption is decisive for the assessment of primary energy demand. With a cogeneration of heat and electricity the primary energy demand is almost equal. If regenerative energy sources are used, the demand-based exhaust ventilation system is clearly superior with regard to the primary energy demand. Calculations of the CO_2 concentration also show that despite a lower air change rate good indoor air quality can be guaranteed.

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