ASPECTS OF AIR AND HEAT DISTRIBUTION IN LOW ENERGY RESIDENTIAL BUILDINGS

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ABSTRACT

In highly insulated residential buildings, complying with the Passive House Standard, the space heat demand can be covered by air heating at air flow rates given by air quality requirements, without the need for additional air re-circulation or for a water heating system. The air distribution system is kept compact. In a common concept the supply air terminal is located above the door to the corridor.
Such configurations were evaluated for typical air transfer devices and extreme supply temperatures. This paper gives results from measurements in the room air flow test chamber at EMPA, showing that room air distribution efficiencies and draught risk values remain within acceptable limits Also the risk for low indoor air humidity at low outdoor temperatures is discussed.
Wood stoves offer a chance to cover the remaining small space heat demand by renewable energies. The capabilities of the ventilation system to distribute the heat from the stove, placed in the living room, are investigated for a two storey apartment with an open staircase. Requirements in order to avoid overheating are specified for this type of stoves.

KEYWORDS

Low energy houses, air heating, ventilation, heat distribution, wood stove

INTRODUCTION

In many countries, global warming considerations have led to efforts to reduce fossil energy use by promoting low energy buildings and the use of renewable energies. Standards and building codes are issued in order to comply with the goals set in the Kyoto protocols. However, a really sustainable level of energy demand as defined by the 2000W society concept, Jochem et al (2002), requires still a much lower energy demand, which in addition has to be covered mainly by renewable energies (solar, biomass, wind, geothermal). The concept of the Passive House comes close to this envisaged energy level.

The term "Passive House" refers to a construction standard issued by the German Passivhaus Institute (1999). Very low U-values of walls (0.1 W/m^{2}K) and windows (overall 0.8W/m^{2}K), very low air leakage of the envelope (n_{50}-value < 0.6 h^{-1}), and passive use of solar and internal gains allow for a comfortable indoor climate in summer and in winter without the need for a conventional heat distribution system. The annual space heat demand per net floor area is required to be below 15 kWh/m².a. For Middle European climates, the maximum heat load typically is about 10 W/m². Thus, Passive House buildings need about 80 % less space heat than new buildings designed to the various national building codes valid in 1999. This allows to cover the small space heat demand by heating the supply air in the ventilation system, without any need for recirculation air. However, efficient heat recovery is required. No additional water circuit is necessary for space heating, thus compensating the cost penalties for the high insulation of walls and roof and the low U-value windows.

Efficient technologies are also used to generally minimize the energy consumption in the building, notably electricity for ventilation and household appliances. Therefore the total primary energy demand for space heating, domestic hot water *and household appliances* is required to be below 120 kWh/(m^2a). This is by a factor of 2 to 4 lower than the specific consumption levels of new buildings designed to present building codes in Europe.
The standard has triggered many new technological developments and Passive Houses are rapidly spreading across Germany, Austria and Switzerland. The technical, economic and social feasibility has been proven in the frame of the European CEPHEUS project, where more than 100 Passive House residential buildings have been evaluated, Schnieders (2003).

SUPPLY AIR TEMPERATURE WITH AIR HEATING

The ventilation system, including the air heating, provides (except for a few hours per year) sufficient heat and air, distributes the heat in the room and extracts pollutants from the room, meeting the thermal comfort (temperatures, draught risk) and IAQ requirements.

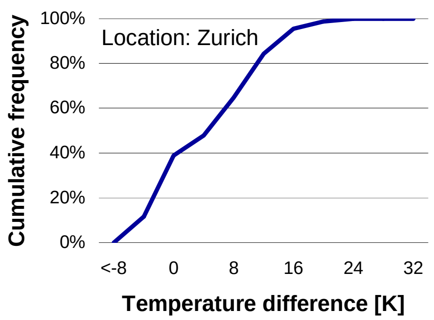


Figure 1: Cumulative frequency of the temperature difference between supply air and living room air temperature. Time period October to March for moderate climate (Zurich, Switzerland)

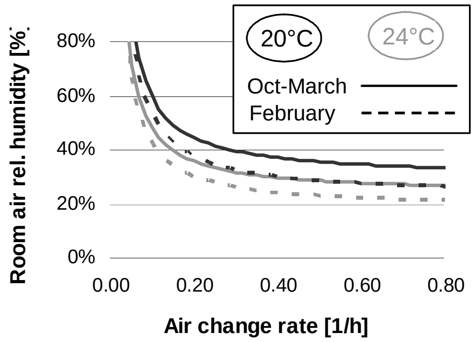


Figure 2: Room air relative humidity (steady state) as a function of outdoor air change rate, for two indoor temperatures and two typical winter periods. Living area 60 m^2/person

For the relevance of critical operational situations, not only the degree of discomfort has to be evaluated, but also the time of occurrence of such incidents. This has been determined by transient building simulation with TRNSYS, using a simplified model of a multifamily Passive House in Stans, Switzerland. Fig. 1 shows the cumulative histogram of the temperature difference between supply and room air temperature for a period between Oct. and March, for Zurich. Even when considering locations at higher elevations in the Alps of Switzerland, the temperature difference is relatively even distributed between –8 K und +20 K. There is no dominant supply air temperature value. Thus, an optimum position for the supply air transfer devices is not evident. Outdoor air flow rates are designed according to IAQ requirements. Higher air flow rates are to be avoided because the room air humidity would get too low in the winter period.
Fig. 2 shows that for typical winter conditions and for an air flow rate of 30 m^3/h.person (equivalent to 0.4 ach) the relative indoor air humidity can be below 30%, for cases with little moisture production and low occupant density.

ROOM AIR DISTRIBUTION

To further reduce costs and energy losses, the air distribution system is kept very compact. In a common concept the supply air terminal in the room is located above the internal door to the corridor (fig. 3). Such configurations were evaluated for typical air transfer devices and extreme supply temperatures by measurements in the room air flow test chamber at EMPA.

Investigations and measurements in real buildings indicate no critical situations in relation to thermal comfort conditions in the heating case, see Schwarz (1999), Schnieders (2001). These results were confirmed under reproducible conditions in the room air flow test chamber at EMPA and also by 3-D CFD calculations (using FLOVENT). Complementary, cases with minimum supply air temperature were investigated.

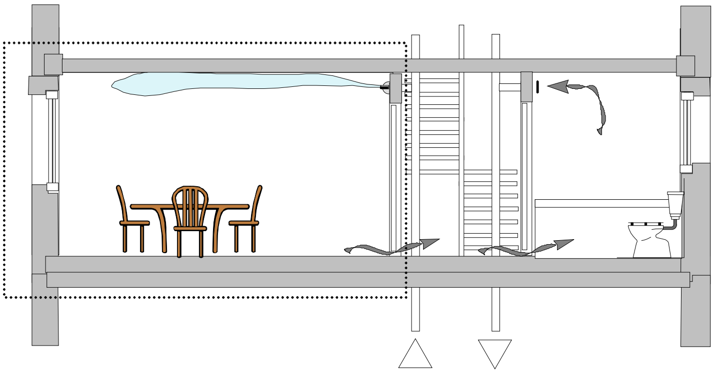
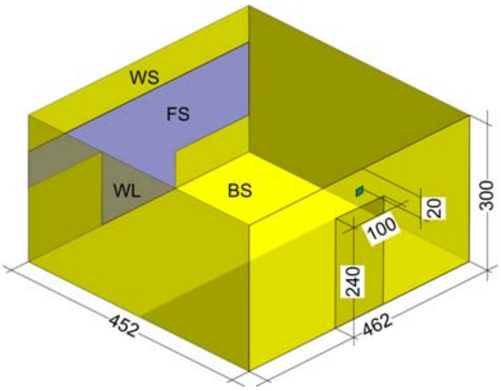


Figure 3: Typical Passive House ventilation configuration with far throw jet air inlet positioned at the internal wall to the corridor. The space covered by measurements is indicated by dotted lines

Measurement configuration (set-up)

The temperatures specified for the measurements reflect extreme conditions. These occur at cold, sunny winter days where no heating is necessary due to the solar gains. The supply air, heated in the heat exchanger only, enters a rather warm room. The other extreme is the case of maximum heat load, which occurs on moderate cold, but overcast days or at night. The boundary conditions for the measurements (surface, supply air and room air temperatures) are given in table 1.

TABLE 1: Geometry of test cabin (in cm) and boundary conditions for the measurements



		Maximum heating power	Heat recovery only
Supply air			
Temperature		40 °C	16 °C
Volume flow rate		30 m^3/h	30 m^3/h
Enclosing surfaces		Temperature difference surface – room air	
WS	External wall	-0.5 K	-0.5 K
FS	Window	-2.5 K	-1.3 K
WL	Wall left hand side	-0.5 K	-0.5 K
BS	Floor close to external wall	-0.5 K	+1.5 K
Room air		22.0 °C	25.0 °C

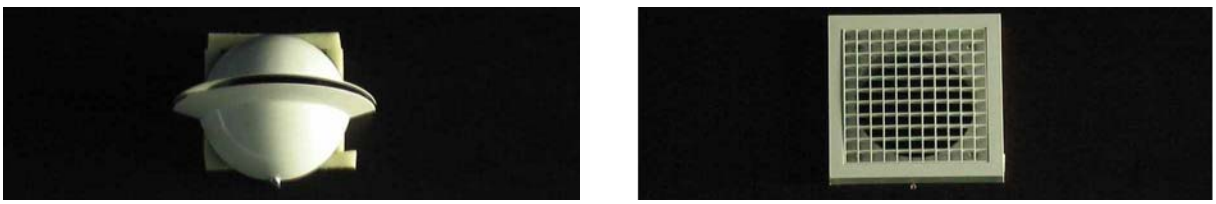


Figure 4: Supply air transfer devices: Adjustable far throw nozzle (left), supply grille (right)

The measurements were made for two types of supply air transfer devices (ATD): A far throw nozzle with adjustable slot width, and a simple supply grille without any features for adjustment (figure 4).

Room air flow patterns

At a supply air temperature of 40 °C for both ATD the supply air distributed evenly between ATD height and the ceiling. The supply air reached the external wall directly below the ceiling and then – slowly sinking – flowed back to the upper sill of the door. At a supply air temperature of 16 °C, with the throw nozzle, the supply air first reached the ceiling and but then soon fell down (at about 1.5 to 2 m distance from the ATD). With the grille, the supply air did not tend to attach to the ceiling. With both ATD the supply air spread along the floor and then slowly rose along the walls. Fig. 5 shows the visualisation of the different cases.

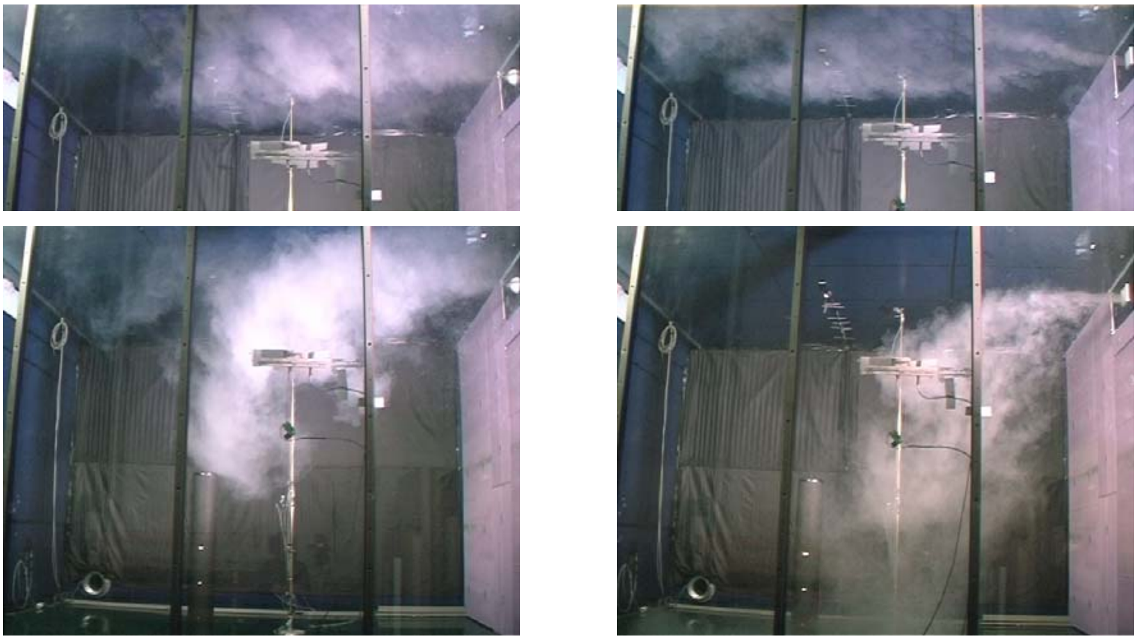


Figure 5: Visualisations of air flow patterns.
Pictures on the left hand side with far throw jet nozzle, on the right hand side with grille type ATD.
Case "Ventilation and maximum heating load", supply air temperature 40 °C (top).
Case "Ventilation only", supply air temperature 16 °C (bottom)

Draught risk

In respect to draught risk the most critical case is the one with low supply air temperature and the supply grille. But also here the draught risk (according to ISO EN 7730) was below 15% for all room lattice points below 2 m height.

Air exchange efficiencies

Air exchange efficiencies were measured using tracer gas decay techniques. Measured efficiencies were in the range from 0.45 to 0.54. This means that the air was mixed quite well in the cases with and without heating, and in the cases where the air transfer to the corridor was below the door as well as at the top of the door.

ROOM PLACED STOVES

Even for the very low energy demand of the Passive House building, there is still quite a potential to cover more of the demand with renewable energies. In central and Nordic European countries, wood biomass is abundantly available as renewable energy. Fireplaces

and wood stoves, a popular aesthetic accessory for a cheerful atmosphere, are rapidly gaining prominence also as an important supplemental heat source for low energy homes.
Besides safety issues, the problem is that only a few stove products are available which comply with the required low heating power level. With a room placed stove in a Passive House building the danger for overheating the living room is quite high. At the same time, all other rooms may cool down, as the control turns the air heating system down. With firewood stoves, the heat output of the stove cannot be reduced to very low levels, as a clean combustion of a small pile of firewood is difficult to realize. Stoves with higher heating power can only be used if a part of the heat output can be transferred to storage systems, such as domestic hot water storage. Stoves using wood chips or pellets are somewhat better for continuous operation at low power output.

The effect of a room placed wood stove was analysed by simulation for a multifamily Passive House in Stans, Switzerland. The individual apartments comprise rooms on two floor levels, connected internally by an open staircase (fig. 6).The distribution of heat and the required heat output limits for room placed stoves were investigated using a coupled air and heat transport model (TRNFLOW), and CFD (FLOVENT).

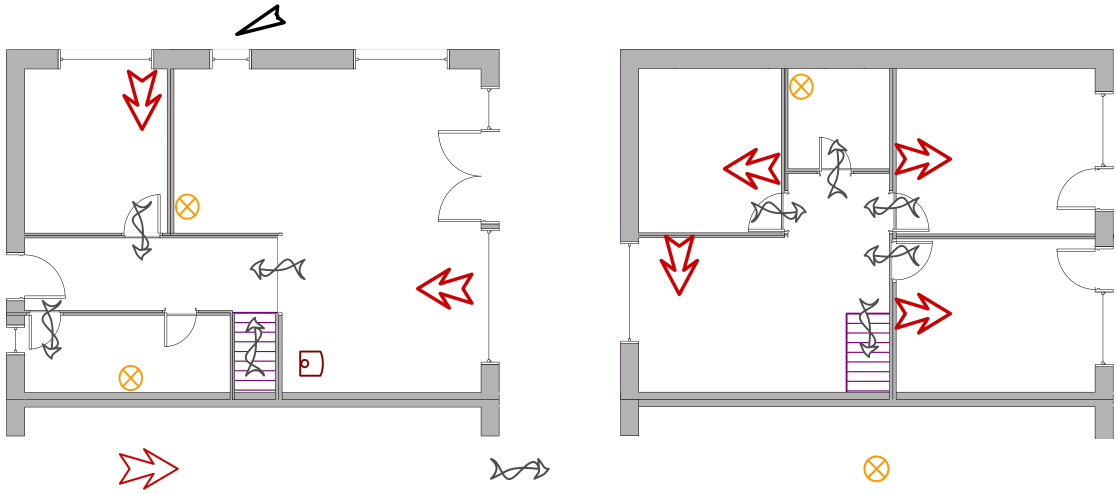


Figure 6: Floor plan with position of stove and air distribution of the simulated two-storey dwelling

In the simulations, the room air temperatures set point was 21°C. Supply air was heated as long as this set point was not reached. Design supply air flow rates were used. Such, a net design air flow of 30 m3/h resulted from the upper to the lower floor via the staircase. However, with internal doors open, CFD calculations showed that the naturally driven convective air exchange flow rates between the rooms are about a factor of 10 higher. The stove was placed in the living room. After firing up, the heat release of the stove was assumed to decrease linearly to zero within 12 h, and to be 50% convective, 50% radiative. In order to show the influence of the stove, outdoor conditions were assumed to be constant (temperature –2 °C, irradiation 1.3 kWh/(m^2.d) for 9 h, no wind.
It was assumed that the total heating capacity of the stove covers the heat demand for these outdoor conditions and for normal occupancy.

With internal doors always open, temperatures in the living room reached 27 °C. The northern room on the ground floor profited from the stove heat, while the upper storey tended to get too little heat. With internal doors are always closed, the temperature differences between the rooms increased (about 0.5 to 1.0 K).
If the maximum heating power of the stove was reduced to approx. 2 kW instead of 4 kW, and the heat release was split into two firing periods per day, the air temperatures in the living room remained within acceptable limits, as shown in fig. 7. Firing the stove several times per

day is equivalent to an increase of the thermal capacity of the stove, resulting in a prolonged period of heat release at reduced maximum heating power. However, if the dwelling was heated with the stove alone for a period of several days, significant temperature differences resulted between ground floor and upper storey (fig. 7 right).

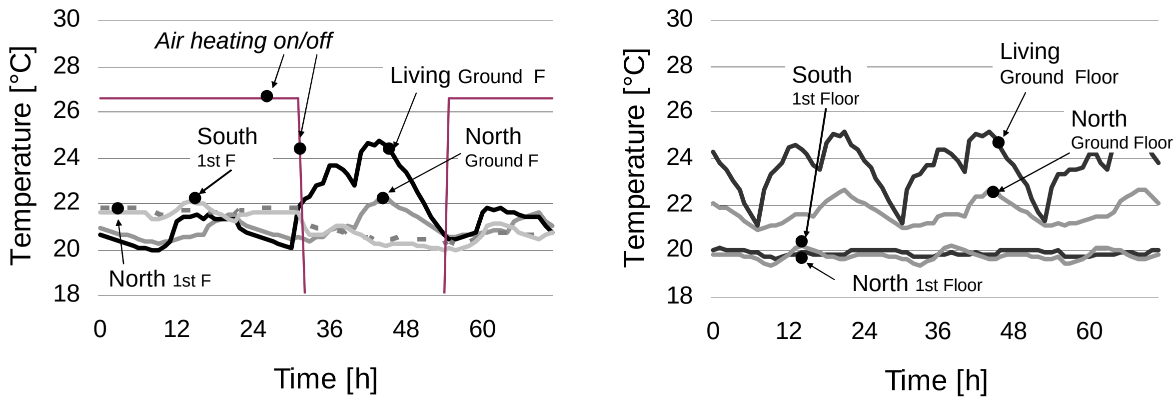


Figure 7: Room air temperatures with internal doors open. Stove fired twice a day (morning and evening) during one specific day; air heating the days before and afterward (left). Stove fired twice a day (morning and evening) during a series of days (right)

CONCLUSIONS

In Passive House buildings, the draft risk remains mostly acceptable even under unfavourable conditions in terms of supply temperature and in terms of position of air supply terminal and of air transfer terminal. Independent of the position of the air transfer device to the corridor, air is mixed quite well in the room and the air exchange efficiency does not vary much.
Room placed stoves with very little heating power and very large thermal mass can provide heating for the building within acceptable comfort conditions, if the stove firing is split into more than one charge per day. However if the building is heated by the stove alone for a period of several days, significantly lower temperatures result at the upper floor compared to the temperatures on the ground floor.

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