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THE IMPACT OF INCREASED AIRFLOW RATES ON INDOOR TEMPERATURES OF PASSIVE HOUSE IN THE NETHERLANDS

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SUMMARY

The increasing number of highly insulated and air tight buildings leads to the concern of indoor environment overheating and related comfort and health issues. This can already happen in a temperate climate as found in the Netherlands.

This work studies the ventilative cooling process as a possibility to avoid overheated dwellings. A monitored dutch passive house was modelled in Trnsys and the impact of increasing air flow rates on indoor temperatures was simulated.

The most overheated zone was chosen to be analysed. The ventilation rates were set in accordance with the ventilation system available in the house. Three possible ventilation rates were simulated and the results obtained for indoor temperatures were compared with measured data. The occupancy was estimated in accordance with registred CO_2 levels and the other heat gains were calibrated based on indoor temperature during winter time.

Results indicate that indoor temperatures can be considerably lowered by making use of constant outdoor flow rates during the warm season. However, alternative solutions such as shading devices and passive night cooling might be considered during very warm days, when outdoor temperatures rise above thirty degrees Celsius.

INTRODUCTION

The current development in building energy efficiency towards nearly-zero energy buildings represents a number of challenges to design and construction. Low-energy buildings and passive houses are highly insulated and air-tight, which leads to the immediate concern about overheating during summer and middle seasons caused even by low levels of internal gain. (Venticool, 2014)

In this context ventilative cooling may present an effective and low-energy solution to avoid, or at least reduce this problem. Ventilation has always been used with the purpose of improving air quality and thermal comfort indoors, however it is still necessary to address this phenomenon with a more systematic approach.

The Annex 62, currently in process by the International Energy Agency, states a series of challenges related to ventilative cooling, such as prediction of cooling needed in a building, integration of ventilative cooling in energy performance calculations, recommendations of performance indicators and its control strategies etc. (Annex 62, 2013)

This research investigates the effect of increased air flow rates on the indoor temperatures and the possibility of the indoor environment improvement by constant air exchange forced by ventilation system. One of the renovated passive houses located in the Netherlands was monitored and also simulated. The results should indicate if it is possible to avoid indoor overheating by making use of the ventilation system which is already incorporated in the house.

The outcomes of this research will be used for the development of a more detailed simulation model of the same case study, including an air flow network. The goal is to investigate the possibility of having indoor temperatures consistently lowered by passive ventilation and develop a model predictive control to optimize the comfort and quality of the indoor environment by simply opening or closing windows.

This work is a step towards the development of a data driven model in which simulation results combined with measured data obtained for this case study will be used in order to establish correlations between weather data, building properties, operations and indoor thermal comfort in the context of ventilative cooling.

METHODOLOGIES

The first stage of the research deals with the computational modelling of one of the renovated passive houses using multizonal simulation software Tnsys. The multizonal approach has been chosen due to its ability to perform long-term simulations within short time keeping low computational demands. Also the ability to describe each zone in detail with regards to construction materials and operational details is required, as well as the access to the weather databases.

The monitored and simulated passive house has three floors. The living room, kitchen and bathroom are located in the ground floor, see Fig. 1a. There is also an entrance hall and stair-case that leads to the upper floor. In the model developed in Trnsys the ground floor was divided into three zones.

The first floor includes 3 bedrooms, hall and a bathroom, see Fig. 1b. The hall and bathroom were represented by the same zone in the computational model, marked by number 3. The bedrooms are marked by numbers 4, 5 and 6.

The last zone is the attic, see Fig. 1c. It is located in the second floor of the house and it was represented by only one zone.

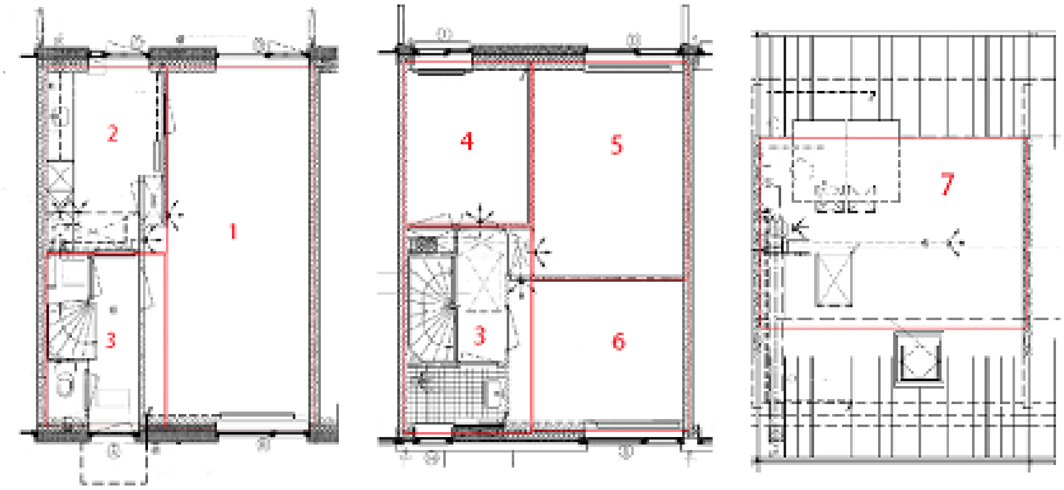

Figure 1. Plant of modelled passive house a) Ground floor: zone 1 – living room; zone 2 – kitchen; zone 3 – bathroom + hall; b) First floor: zone 3 – bathroom + hall; zones 4, 5 and 6 – bedrooms; c) Second floor: zone 7 – attic

The ventilation system of the passive house can be adjusted to three possible air flow rates: 132 kg/h, 162 kg/h and 214 kg/h. The heat recovery system pre-heats the air in average to 18 $^{\circ}$C and it is bypassed when the temperature reaches 23 $^{\circ}$C.

The number of people in the room was estimated from the measured levels of CO_2 in the room, see equation (1): (Novy et al., 2000)

$$\dot{M}_C + \dot{V}_{sup} \cdot c_{out} - \dot{V}_{ex} \cdot c = V \cdot \frac{dc}{dt} \qquad (1)$$

where $\dot{M}_C$ (kg/s) is the mass flow of CO_2 released per person, $\dot{V}_{sup}$ is the supply air flow (m^3/s), c_{out} (kg/m^3) is the concentration of CO_2 outdoors, $\dot{V}_{ex}$ is the exhaust air flow (m^3/s), *c* is the concentration of CO_2 indoors, *V* is the volume of the room and *t* (s) is time.

In average, the CO_2 concentration in the house was 1000 ppm. The ventilation supply flow rate was assumed to be the lowest possible, i.e. 132 kg/h, the exhaust flow rate was identical. The outdoor concentration of CO_2 was assumed to be 400 ppm and each occupant was assumed to release 0,02 m^3/h of CO_2. The measured CO_2 concentration indicates that the living room has, in average, three sitting occupants with low activity level.

The weather data were measured in a climate station at the vicinity of the passive house, during the period of monitoring. New weather database was created, using the measured dry bulb temperature, global horizontal radiation, wind speed and air humidity. It was incorporated in the Trnsys software.

RESULTS

First results show that living room is the zone which most overheats during summer, see Fig. 2. This is probably due to its largely glazed north and south walls. For this reason the living room was chosen to be further investigated in this study.

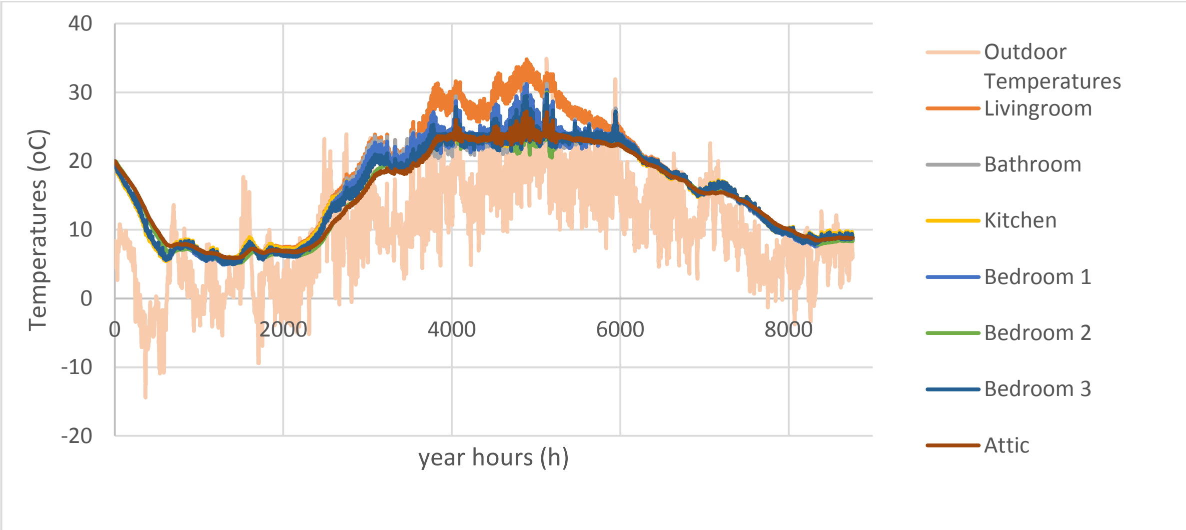

Figure 2. Simulated indoor temperatures for studied renovated passive house

Heat gains calibration: winter simulations

The simulations during winter season were used for the calibration of heat gains in the model and February was chosen as the representative month of the winter. Three different scenarios were simulated and compared with measured indoor temperatures, see Fig. 3.

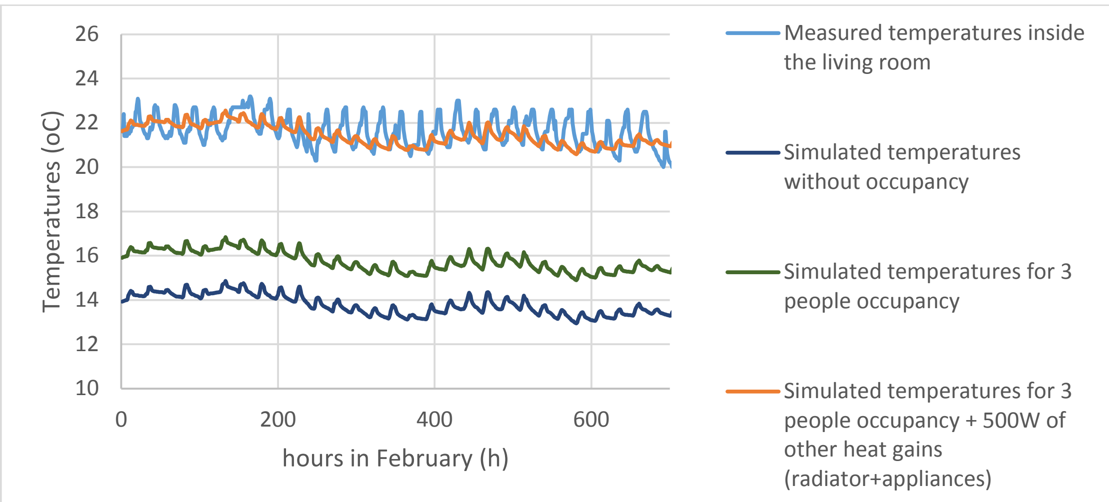

Figure 3. Measured and simulated temperatures inside the living room of the studied passive house during February for flow rate 132 kg/h of pre-heated outdoor air

The dark blue curve shows simulated temperature in living room during February. The ventilation flow rate in the house was considered 132 kg/h and the air was pre-heated to the temperature of 18 °C. This flow corresponds to the lowest setting of the ventilation system in the real premise, which should be used by the occupants during the winter.

The green curve indicates the temperature including the heat gains caused by the occupancy. According to the simulations, the heat gains caused by occupancy raise the temperature in the living room by 2 °C. The discrepancy between this curve and the measured temperatures may be caused by not considering the heat gains from the heating devices that operate during winter and other heat sources that operate all year long.

When considering heat sources with total heat output 500 W in the model, the simulated temperatures significantly raise and the curve corresponds better to the measured indoor temperatures with an error margin of 2 °C. In this work it is assumed that 10 % of this heat sources (i.e. heat output 50 W) represent year-round heat gains, such as lights and electrical devices. The other 90 % (i.e. heat output of 450 W) represent heating devices which are only used during the winter period.

Impact of air flows on indoor temperatures: summer simulations

During the summer months, the simulations are performed considering the heat gains from 3 occupants and from year-round heat sources with heat output 50 W. The three possible air flow rates from the ventilation system are simulated in order to evaluate the impact of increased air flow on the indoor temperature and the possibility to avoid overheating of the indoor environment by using ventilative cooling. The simulations were performed in August, which was chosen as the representative month of summer.

The results indicate that during 75 % of August the simulated temperatures indoors are lower than the measured temperatures in the same month when it is kept a constant flow of outdoor. This difference might vary from 1°C to 5°C and the simulated indoor temperature is kept below 24°C, especially when the highest flow rate is set, see Fig. 4.

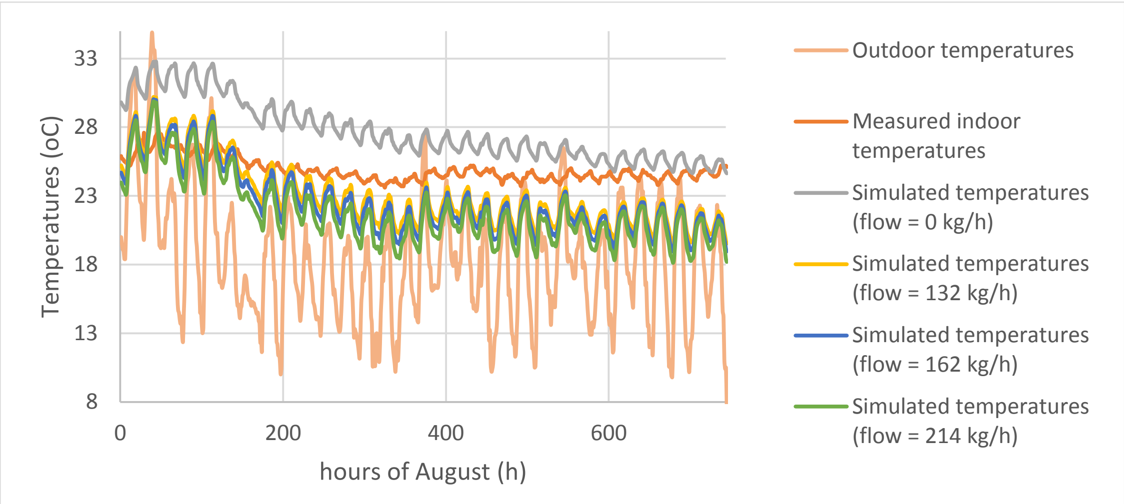

Fig. 4. Impact of increased air flows rates on the temperatures of the living room during August

DISCUSSION

From the comparison of the simulated cases it is clear that the highest indoor temperatures appear in the case without any ventilation. In such case, the indoor temperature is kept above 25 °C during the whole August and it gets higher than 30 °C in warmest days.

In order to avoid this overheated indoor scenario, the possible air flow settings in the ventilation system were simulated and even the lowest ventilation rate decreases the indoor temperatures by 4 °C. Further increase of the ventilation flow rate keeps decreasing the indoor temperature. The temperature difference when the flow rate is 132 kg/h or 162 kg/h is in average 0.5 °C. The same temperature difference is also when the flow rate is 162 kg/h or 214 kg/h.

During 25 % of August the simulated indoor temperatures are above the measured temperature values for all the considered ventilation flow rates, which happens due to outdoor temperature peaks above 30 °C. The constant flow of warm outdoor air raises the temperature indoors during very warm days.

The internal heat gains play a key role when it comes to the overheating in passive houses and this work focused on not under-estimating the impact of such gains. For this reason, the simulated model considered a constant occupancy of three people and constant year-round indoors heat source of 50 W, corresponding to 10 % of the calibrated heat gains in winter.

During the winter period it is noticeable that the amplitude of measured indoor temperature is higher than the amplitude of simulated ones. This can be explained by the fact that, in reality, the heat gains are not constantly distributed during the day. Especially during the winter, people tend to increase heating during the day-time and reduce it during the night-time.

During the summer season the amplitude of simulated temperatures are higher than the amplitudes during the winter season. This occurs due to the fact that the incident sun radiation is higher in the summer period, increasing the day-time indoor temperature. In the other hand, when comparing the simulated temperatures with the measured ones, it is noticeable that the amplitude of the simulated temperatures is higher than the measured amplitude (the opposite of summer). This can be explained by the fact that the computational model did not include the presence of any kind of shading device, which are likely to be used by occupants during the summer.

The ventilative cooling potential might be significantly higher when higher air flow rates are considered, such as the ones achieved through large openings. A study considering the impact of higher air flow rates is under development for the same case study.

CONCLUSIONS

This work analyses the real possibility of having the studied passive house cooled-down by making use of the ventilation system, which is already incorporated in the house.

The use of a constant ventilation air flow keeps indoor temperatures of the simulated passive house below measured temperatures during 75 % of August. When the highest ventilation rate is set, the temperatures are kept below 23 °C for the same period.

During 25 % of August, when outside temperatures reach values above 30 °C, the simulated temperatures are higher than measured temperatures. In such cases, alternative solutions such as day-time shading and night-time passive ventilation through windows might be considered in order to avoid overheating indoors.

Increasing outdoor air flow supply to the zone decreases the indoor temperature. The highest ventilation rate provides temperatures inside the living room about 1 °C lower than the lowest ventilation rate.

Although the ventilation system may be technically limited to further increase the amount of outdoor air mechanically taken inside the house, there is still option for increasing air flow rates through house openings. An additional study is under development, addressing how the airflow through openings affects the indoor temperature. The outcomes of the research will help with the development of a data driven model in which the simulation results and measured data acquired for the studied passive house will be used for obtaining correlations between weather data, building properties, operations and indoor thermal comfort in the context of ventilative cooling.

ACKNOWLEDGEMENT

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