Simulations of comfort cooling strategies in Passive Houses in a Swedish climate

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Abstract: Passive Houses have gained popularity the last ten years as a way of improving the energy efficiency in the housing stock. The challenge of avoiding external heating during the cold winter climate in Sweden has pushed the design of a Passive House in a direction where problems with excessive temperatures might occur summertime. The aim of this paper is to evaluate comfort cooling strategies for attaining good indoor climate summertime while maintaining good energy efficiency. Also, to add knowledge of comfort cooling strategies for Swedish conditions as the summer season is short and comfort cooling is normally not installed. The studied strategies include: airing, shading, increased ventilation, cooling machine and evaporative cooling. Additionally, combinations of these methods are studied. To evaluate the cooling strategies and their impact on the indoor temperature and the amount of electricity needed for their operation, computer simulations have been made using the simulation tool *IDA Indoor climate and energy*. The building model is based on an existing Passive House in the district Lambohov in Linköping, Sweden, where continuous logging of temperatures are available. Without comfort cooling the simulations show excessive temperatures summertime which is consistent with the field measurements from the real house. The overall judgement is that passive cooling strategies can provide sufficient cooling during the hottest part of the summer and that both shading and airing strategies should be used for a maximum cooling effect.

Keywords: *Building simulation, Comfort Cooling, Passive House*

1. Introduction

Passive Houses have gained popularity the last ten years as a way of improving the energy efficiency in the housing stock. A Passive House uses only the internal heat gains from lighting, equipment, humans and the incoming solar radiation to heat the building. This is possible through a combination of a highly insulated building envelope and a heat exchanger that heats the incoming air with the exhaust air. A Passive House has therefore no need for a traditional heating system, but occasionally, when the temperature drops fast during a cold period, there might still be a need for additional heating. The challenge of avoiding external heating during the cold winter climate in Sweden has pushed the design of a Passive House in a direction where problems with excessive temperatures might occur summertime.

The aim of this paper is to evaluate comfort cooling strategies in order to attain good indoor climate summertime while maintaining good energy efficiency. Can a clever use of shading, airing and ventilation provide enough cooling to avoid an installation of comfort cooling equipment. Moreover, the use of a cooling machine as well as evaporative cooling is also evaluated.

Socialstyrelsen (The Swedish National Board of Health and Welfare) recommends that the indoor temperature does not exceed 24 and 26 °C wintertime and summertime respectively (Socialstyrelsen 2005). Further, Boverket (The Swedish National Board of Housing Building and Planning) recommends an indoor temperature between 23 and 25 °C summertime (Boverket 2007) and FEBY(Forum for Energy Efficient Buildings) recommends that the indoor temperature does not exceed 26 °C more than 10 % of the time summertime in the hottest part of the building (FEBY 2009).

A study by SP (Technical Research Institute of Sweden) with temperature loggings from 20 terraced house apartments in 4 Passive Houses in Lindås, Sweden, show a mean indoor temperature of 25.2 °C summertime (Ruud and Lundin 2004). Some of these apartments have temperatures within good levels throughout the summer but others have periods with temperatures between 25 and 30 °C and there are occasions when the indoor temperature reaches 30 °C. Dwellers in Passive Houses in the districts of Oxtorget, Glumslöv and Frillesås responded to a questionnaire study about their indoor temperature summertime. The outcome of the questionnaire gave the result that in Oxtorget 31 %, in Glumslöv 56 % and in Frillesås 11 %, respectively, claimed it was too warm during this period (Samuelsson and Lüddeckens 2009). More reports of excessive temperatures summertime have been made from dwellers in a two-storey Passive House in Lidköping and from dwellers living on the top floor in a three-storey apartment building in Brogården, Alingsås (Janson 2010). In Lambohov, Linköping, temperature measurements from two Passive Houses also show excessive temperatures summertime. During the month of July 2010, the mean value of the exhaust air temperatures from these two apartments were 27.3 °C. Further, the exhaust air temperatures from these two apartments were 26 °C or higher during 60 % of this time (KTC 2010).

In contrast to warmer countries, comfort cooling equipment is normally not installed in Swedish dwellings. However, the combination of the isolating capacity of a Passive House and the large solar gains summertime could result in excessive temperatures even in this cold climate. Methods for comfort cooling in warmer countries are normally: shading, ventilation, cooling machines, evaporative cooling, solar chimneys, earth tubes, reflectors and night-time radiation cooling.

2. Methodology

With the use of computer simulations this paper investigates strategies for comfort cooling for a Passive House in a Swedish climate. The simulations have been carried out using the software *IDA Indoor climate and energy (ICE)*, a software that since its release in 1998 has grown to become one of the leading international tools (U.S. Department of Energy 2009). The input data representing the human presence, the use of electricity and domestic hot water are based on a collection of user related data from Boverket (2007). Applied to this household it results in the internal gains of 4.6 W/m^2. The building model in the IDA ICE-simulations is based on an existing Passive House apartment in Lambohov, Linköping, Sweden, where continuous logging of temperatures are available, see Fig. 1. It is one of two 4-room apartments in a Passive House building, both with two floors and an area of 105 m^2. The ground floor has a ceiling height of 2.5 meters and the second floor has a ceiling height of 2.4 meters. The apartment is equipped with an FTX-system that recovers the heat in the exhaust air to heat the incoming air and a constant air volume (CAV) ventilation system with two temperature meters controlling the ventilation. Further, a climate file from Meteonorm is used in IDA ICE to simulate the climate in Linköping. More details are presented in Appendix.

In order to evaluate the different comfort cooling strategies, the first ten days in the month of July, a period with excessive temperatures in the real Passive House are simulated. The reference case without different measures to cool the apartment is compared with implementations of different strategies for comfort cooling. Their individual cooling performances as well as the combinations of these are then evaluated.

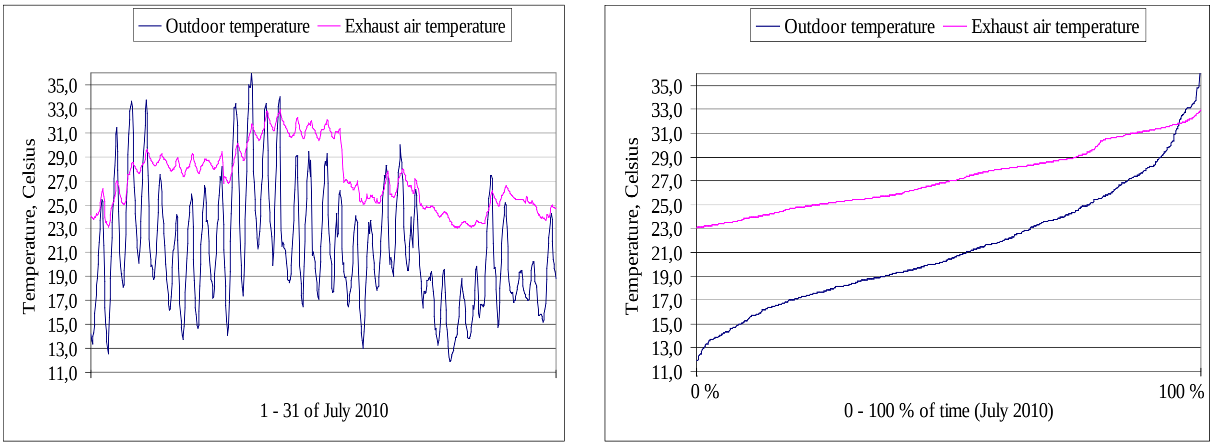

Fig. 1. Temperature loggings during July 2010 from the real Passive House in Lambohov, to the right presented in a duration diagram.

3. Comfort cooling strategies

The simulated comfort cooling strategies and their implementations in IDA ICE are here presented.

3.1. Integrated and external window shading

Integrated and external window shadings of separate types are used. In the simulations the integrated window shading is controlled by the solar radiation, the time of the day and the indoor temperature. It is activated if the direct normal radiation exceeds 100 W/m^2 and if the room temperature is higher than 22 °C. For the integrated shading the solar gains factor (g-value) equals 0.14, the short-wave shading coefficient (T-value) equals 0.09 and the U-value equals 1.0. Moreover, the integrated window shading is not used on the east façade since it could make the apartment too dark inside. This restriction is not made on the use of the external window shading, where an awning is implemented on every window at all times of the day.

3.2. Airing with windows

In contrast to shading, airing with windows is due to safety reasons only allowed certain hours of the day and only with the windows on the second floor. The hours for airing are set to 18:00-22:00 but only if the room temperature is higher than 22 °C and higher than the outdoor temperature. In that case the windows will be 25 % opened.

3.3. Increased ventilation

When the ventilation system is used as a mean to remove excess heat, the ground state of the CAV-ventilation and its airflow of 45 l/s is increased to 90 l/s.

3.4. Airing with a roof hatch

As an option for airing with windows which is only allowed daytime, a roof hatch is implemented in order to investigate how much night-time airing can lower the temperature. It is assumed that security measures are taken in order to keep it open night-time. The roof hatch has an area of 0.7 m^2 and is located in the upper hall. It is intended to be open between 18:00–08:00 but only if the indoor temperature in the room is higher than 22 °C and higher than the outdoor temperature.

3.5. Cooling machine

The cooling machine is connected to the FTX-system which distributes the cooling to the building. The set-point for the exhaust air temperature is 24 °C and the minimum allowed supply air temperature is set to 15 °C.

3.6. Evaporative cooling

Evaporative cooling is investigated as an alternative to the cooling machine. It is connected to the FTX-system and has an efficiency of 80 %. The set-point for the exhaust air temperature is 24 °C and the minimum allowed supply air temperature is set to 15 °C.

4. Results

The simulation results in Fig. 2 show that passive cooling can provide sufficient cooling during the hottest part of the summer. The best cooling result is obtained when both shading and airing strategies are used. Here, the most effective strategy is the combination of the external window shading and the roof hatch. The roof hatch proves to be the best single way to lower the temperature in the apartment. Fig. 3 shows that the combination of the increased ventilation with window shading also can provide a satisfactory cooling result. If the cooling machine or the evaporative cooling is used, the best combination are in both cases either with the external window shading or with the increased ventilation as can be seen in Fig. 4 and Fig. 5. The cooling machine has a better cooling performance than the evaporative cooling but with the standard ventilation airflow none of them can lower the temperature to a comfortable level. Higher ventilation or lower supply temperature than 15 °C is required.

The electricity use of the fans during the ten simulated days is 14.4 kWh/10 days with the standard flow of 45 l/s. The extra power demand for the doubled ventilation is 100 kWh/10 days. In comparison the power demand of the cooling machine for reducing the supply air temperature to 15 °C is about 30 kWh/10 days (cooling demand 100 kWh /10 days) but the temperature reduction is less.

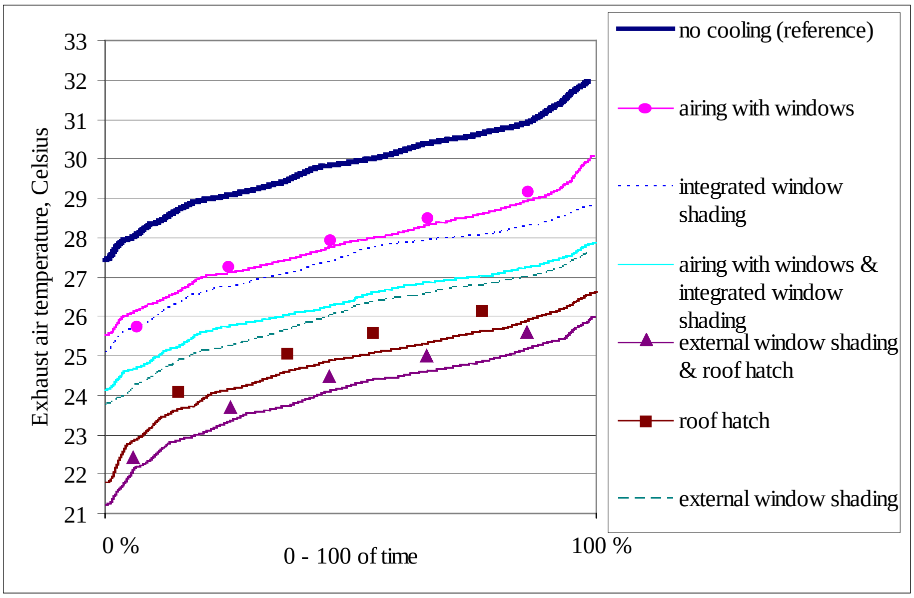

Fig. 2. Simulation results with passive cooling methods. The period is 1 – 10 of July.

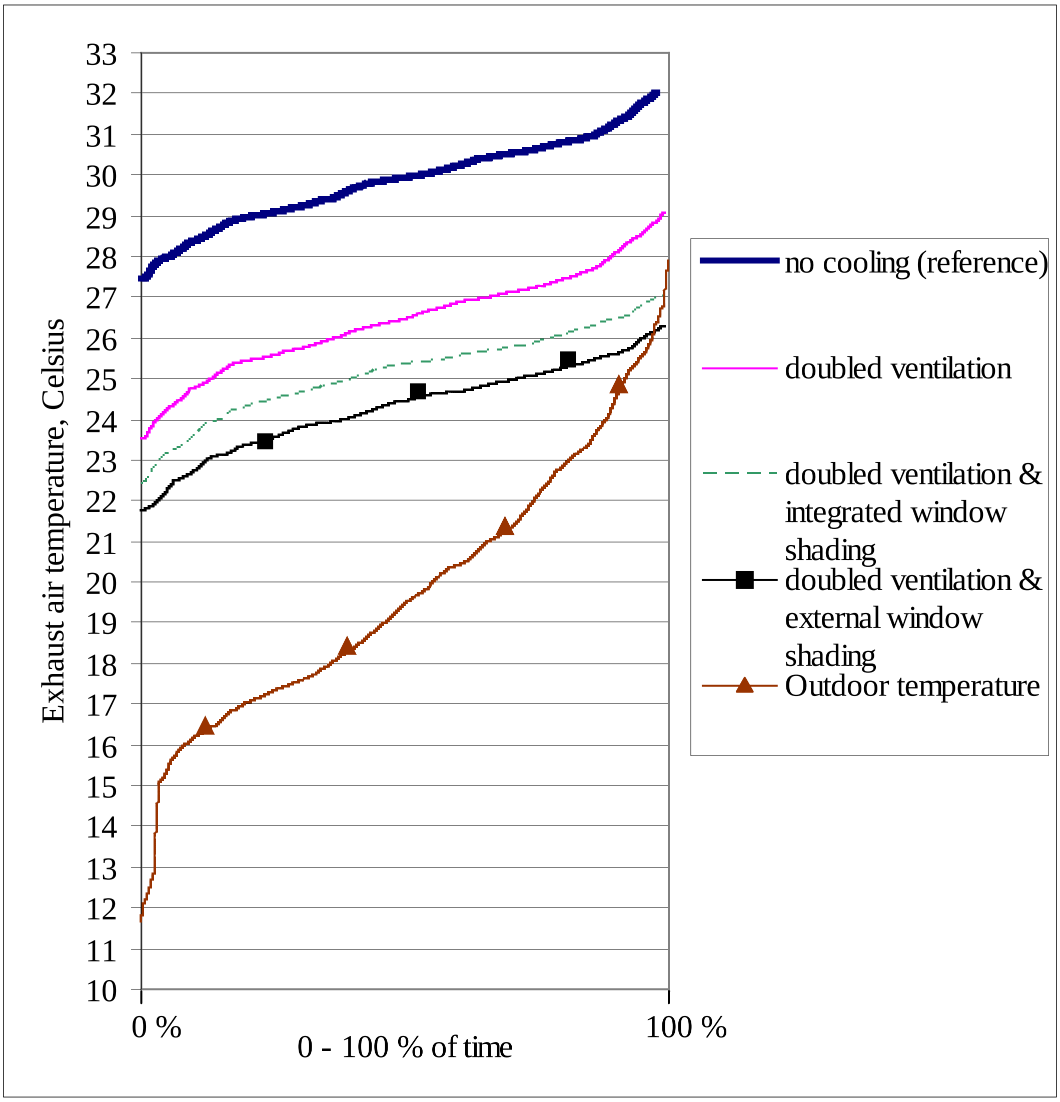

Fig. 3. Simulation results with an increased airflow in the ventilation system, with and without window shading. The period is 1 – 10 of July.

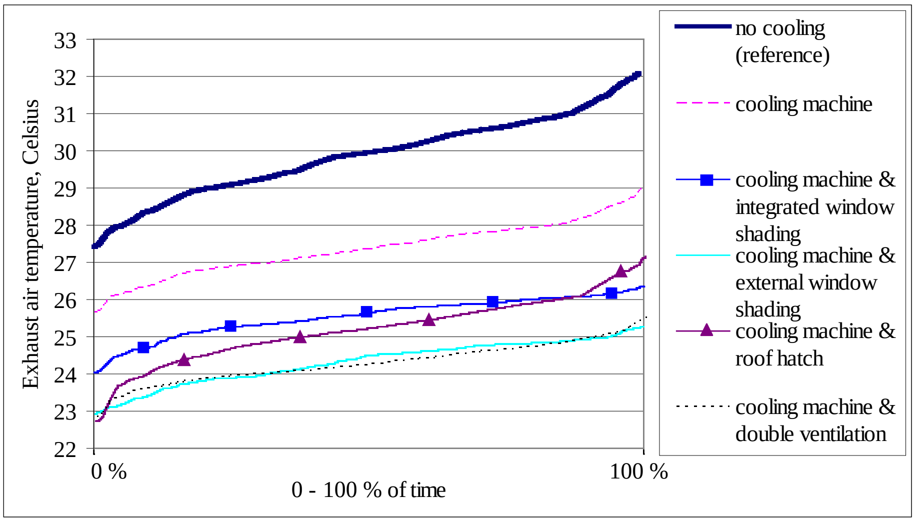

Fig. 4. Simulation results with the cooling machine, with and without passive cooling methods or an increased airflow in the ventilation system. The period is 1 – 10 of July.

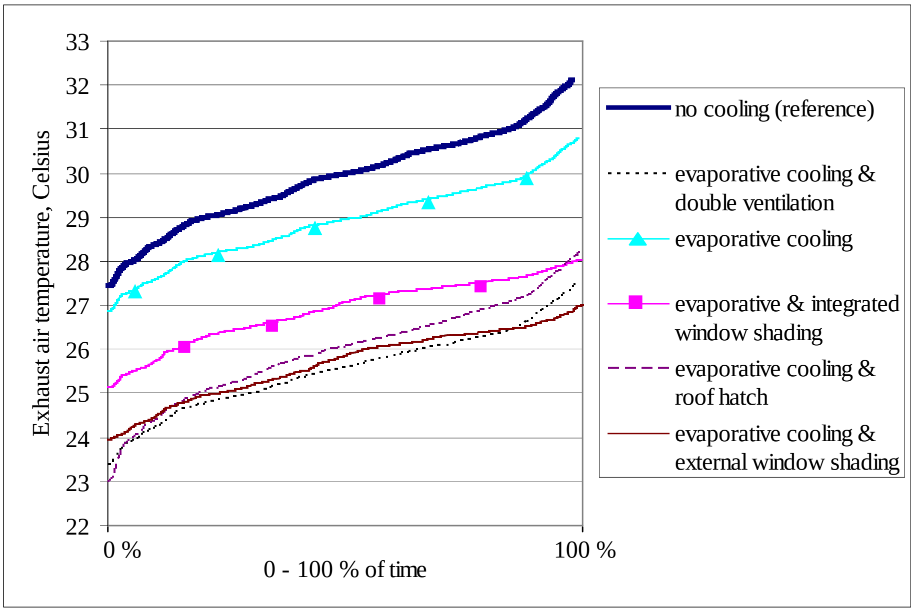

Fig. 5. Simulation results with evaporative cooling, with and without passive cooling methods or an increased airflow in the ventilation system. The period is 1 – 10 of July.

5. Conclusions

The simulation for the reference case agrees well with the practical experiences of excessive summer temperatures in Passive Houses. It seems likely that passive cooling strategies can provide sufficient cooling during the warmest part of the summer. A combination of shading and airing strategies should be used for the maximum cooling effect. However, in these simulations it is assumed that sophisticated devices are controlling the airing and shading based on the indoor and outdoor temperature and the solar radiation. Such devices are normally not yet installed in Passive Houses but nevertheless, the results demonstrate the potential with the use of passive cooling. On the other hand Fig. 2 illustrates that the best result of the passive cooling strategies is obtained with the roof hatch and the external window shading, two strategies that necessarily do not need any controlling devices. Instead of using a roof hatch, an already existing window could be kept open night-time, this would also require that security measures are taken but the installation of a roof hatch would not be needed. In addition, since an increased airflow in the ventilation system appears as an effective tool for lowering the indoor temperature, it should be made possible for the dwellers to control the airflow after their needs. Neither the cooling machine nor the evaporative cooling can by itself lower the temperature to a comfortable level, it has to be combined with higher ventilation or the supply temperature must be allowed to be lower than 15 °C.

The outcome of these results shows that options for passive cooling should be applied before any cooling machine or such equipment is installed. Since Passive Houses can contribute to increased energy efficiency in the housing stock, it is of great importance that they are well adapted to the summer climate, ensuring a comfortable living.

The outcome of simulations of this sort is highly depending on the implementation of the internal gains and the compilation of user related data used for this in this paper only offers an indication of these amounts. Furthermore, the amount of solar gains summertime is responsible for the excessive temperatures and different simulation software will differ in this result (Lundh and Wäckelgård 2009). Other sources of error come from the software's limitation in computational accuracy. Additionally, a more exact study of the ventilating capacity of a single roof hatch or window could be made using CFD-tools (Computational Fluid Dynamics). In our case the simulated reference case agrees very well with the actual temperature loggings in the house as can be seen by comparing Fig. 1 and 2.

Acknowledgements

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Appendix

Simulation input data

Building envelope	m^2	W/m^2K
Apartment area	105	
External wall		0.1073
Internal wall		0.6162
Internal floors		0.2259
Roof		0.08735
External floor		0.1289
Glazing		0.8800
Outer door, front		0.7500
Outer door, back		0.9000

Thermal bridges	m	W/mK
Edge beam	54	0.094
Wall corner	45	0.027
Windows & Doors	120	0.041
Wall/Joists	63	0.025

Ventilation		
Air leakage (at +/- 50 Pa)	0.24	$l/s,m^2$
Mechanical ventilation	45	l/s
Fan pressure	488	Pa
Fan power	60	W
Efficiency of ventilation fan	73	%
Efficiency of heat exchanger*	87	%

* During the cooling season the heat exchanger is only used if the outdoor temperature exceeds the indoor temperature

Ground reflection	20	%
Internal gains	4.6	W/m^2