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Published in:
Sisäilmastoseminaari 2021. Verkkoseminaari 9.3.2021

Published: 01/01/2021

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Velashjerdi Farahani, A., Jokisalo, J., Korhonen, N., & Kosonen, R. (2021). Thermal comfort and energy demand of a Finnish detached house in a changing climate. In *Sisäilmastoseminaari 2021. Verkkoseminaari 9.3.2021* (pp. 201-206). (Sisäilmayhdistys raportti ; No. 39). SIY Sisäilmatieto Oy.

THERMAL COMFORT AND ENERGY DEMAND OF A FINNISH DETACHED HOUSE IN A CHANGING CLIMATE

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ABSTRACT

This study investigated the effects of passive strategies (orientation, thermal mass, window opening, and window properties) and the usage of an active cooling system on indoor temperature conditions and energy demand of a detached house in Finland in current and future climatic conditions (2050). So that nine different cases were defined and simulated. Regarding the results of passive strategies, in the current climate, using openable windows would be the best solution for keeping indoor air temperature of the spaces. While using an active cooling system in the hall of the upper floor is the only studied solution that can provide thermal comfort in the other spaces such as the warmest bedrooms, in the whole time of the cooling season in both current and future climate. In the future climate, the heating demand decreases way more than the amount of increase in the cooling demand but providing thermal comfort in the spaces will be challenging.

INTRODUCTION

Climate change is mostly about the gradual increase in ambient temperature. Northern areas will experience this warming up the most in addition to some frequent heatwaves [1]. Increasing temperatures cause adverse effects on health (e.g., increased infant mortality and lower life expectancy) both in the short and long run [2]. Providing comfort in indoor temperature conditions, global warming leads to a reduction in heating demands and a corresponding increase in cooling demands [3].

In this paper, we investigate the effects of passive strategies (orientation, thermal mass of the structure, window opening, and glass properties) and the usage of an active cooling system on energy demand and indoor temperature conditions of a detached house in Finland, in a changing climate using simulation.

METHODS

Case study

The example building of this study is a new 2-story detached house which locates in Helsinki. The heated net floor area of the house is 180 m², and the geometry and

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properties of the example building, and its orientation is described in Fig. 1. It is assumed that the example building is in a neighborhood where similar buildings surround it. The height of the surrounding buildings is as same as the example building.

The thermal insulation level of the building is high corresponding to the Finnish guidelines for Finnish Passive houses [4] and the type of building structure is massive. Space heating of the building is carried out with electric radiators which dimensioning heating power is 5 kW (28 W/m²) at dimensioning outdoor temperature (-26 °C) of Southern Finland. The temperature setpoint of space heating is 21°C. There is no mechanical cooling in the building in the base case.

The ventilation system is a balanced ventilation system with heat recovery and the setpoint temperature of supply air heating is constant 17 °C, and the air handling unit (AHU) doesn't have mechanical cooling. The AHU is equipped with an electric reheat coil, which is used for heating the supply air. Also, the airflow rates in different rooms are shown in Fig. 1. Positive values are the supply airflow rates and the negative ones the exhaust airflow rates. The total air exchange rate of the building is 0.5 ACH, and q50 is 0.7 $m^3/h, m^2$. The internal door of the bathroom is always closed, but other internal doors are always open. There is a 2 cm high gap between the bathroom door and the floor.

There is an integrated shading for all the windows, blinds between panes are used when the intensity of solar radiation on the windows exceeds 100 W/m². Four occupants (two adults and children) are in house during evenings and nigh time. During the daytime, the occupants are not in house. The activity and clothing levels of the occupants are 1.2 Met and 0.96 Clo.

Total annual electricity consumption of home appliance is 22.8 kWh/m^2 [5]. The annual net heating demand for domestic hot water (DHW) is 35 kWh/m^2 [6]. It was assumed that 50% of the DHW losses end up with internal heat gains. Total annual electricity consumption of the lightings is 8.4 kWh/m^2 [5].

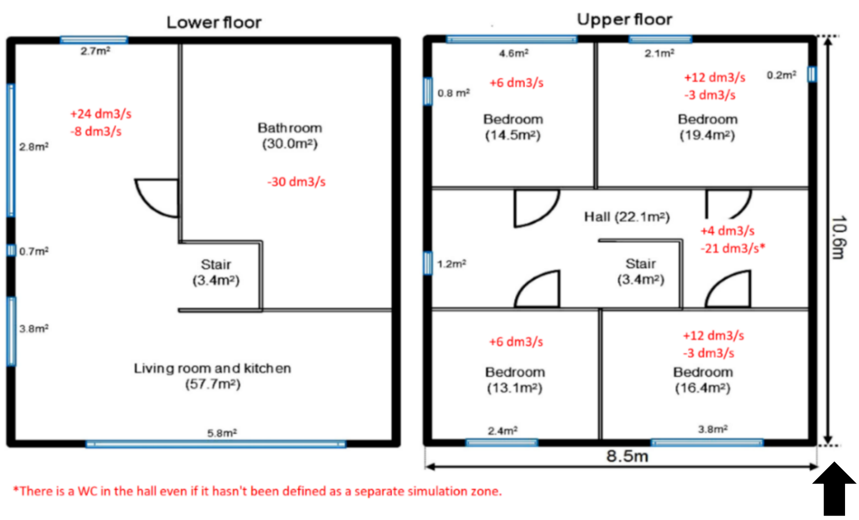

Figure 1. The geometry of the example building.

Climatic data and simulation tool

The simulation period of the cases is one year, and the weather data of the study is TRY (2012) of Helsinki-Vantaa, which describes the current climatic conditions of southern Finland [7]. Also, two of the cases are simulated using projected weather data of the year 2050 (TRY 2050) of Helsinki-Vantaa with A2 GHG emission scenario [8]. The time step of the simulation results is 1 hour. The simulation is done using the validated dynamic building simulation tool IDA ICE 4.8.

Simulation cases

The nine different cases are defined to investigate the effects of some passive cooling strategies and an active one on energy demand and indoor air temperature conditions. Except for Case 1, others can be categorized into three main groups. The first one investigates passive strategies; in the second one, an active cooling system is used. In the third one, the future weather file is used. The simulation cases are briefly described in Table 1.

Table 1. Brief description of simulation cases.

Groups	Cases	Description	Climatic data
Base Case	Case 1	Base Case which is the reference case for comparing electric heating (REF Heat).	TRY 2012
Passive strategies	Case 2	Similar to Case 1 but the Orientation is changed 180°.	TRY 2012
	Case 3	Similar to Case 1 but solar protection windows are used.	TRY 2012
	Case 4	Similar to Case 1 but 10% of the largest window of each room is openable.	TRY 2012
	Case 6	Similar to Case 1 but the structure is lightweight.	TRY 2012
Active cooling system	Case 5	Similar to Case 1 but a split cooling unit of 4.6 kW cooling capacity and SCOP of 3 is used in the hall of the upper floor. This case is the reference case for comparing electric cooling (REF Cool).	TRY 2012
	Case 7	Similar to Case 1 but the structure is lightweight and a split unit as in case 5 is used.	TRY 2012
Future climate	Case 8	Similar to Case 1 but the future climate is used for the simulation	TRY 2050
	Case 9	Similar to Case 5 but the future climate is used for the simulation.	TRY 2050

RESULTS AND DISCUSSION

The results are presented in two different parts, the first one, annual electricity consumption, which is compared in different cases. The second one is an assessment of the indoor air temperature in the warmest bedroom with 14.5 m^2 area (Fig.1), to find out the effects of the measures in each case on indoor conditions.

The breakdown of annual electricity consumption

Firstly, it is essential to compare the results of Case 1 to other cases. Thus, Table 2 is a summary of the breakdown of the annual electricity consumption of the nine cases. The heating demand in cases 8 and 9 which are simulated using the future weather data, is the lowest by 12.8 kWh/m^2,a, which has decreased by 5.4 kWh/m^2,a (30 %) compared to the base case, due to global warming.

In Case 2, because of the large windows facing south, the heating demand is less than in Case 1 by 0.9 kWh/m^2. The usage of solar protection windows causes an increase of 3 kWh/m²,a (16%) in heating demand in Case 3. Cases 6 and 7 have slightly higher heating demand by 0.7 kWh/m²,a (4%) due to the light structure and less thermal mass. Case 4 in energy demand is like case 1, but due to the openable windows, the indoor conditions may be different.

Comparing the cooling demand in cases 5, 7, and 9 reveals that Case 9 has the highest one, which is 0.2 kWh/m²,a (5%) higher than Case 5 which shows the effect of global warming. The next highest number is in Case 7 with 3 % increase, because of the lightweight structure. Since the share of annual cooling electricity in the total electricity consumption is quite low, it is not significantly influential on the current and future energy demand of the building.

Table 2. The breakdown of annual Electricity consumption (kWh/m², a).

Meter	Base case	Passive strategies				Active cooling system		Future Climate	
	1	**2**	**3**	**4**	**6**	**5**	**7**	**8**	**9**
	(REF Heat)	Orientation	Solar protection windows	Openable window	LW structure	Active cooling (REF Cool)	LW + Active cooling system	Base case 2050	Active cooling 2050
Electric heating (spaces + AHU)	18.2	17.3	21.2	18.2	18.9	18.2	18.9	12.8	12.8
DWH	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Electric Space cooling	0.0	0.0	0.0	0.0	0.0	3.7	3.8	0.0	3.9
HVAC aux	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Lighting	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4	8.4
Equipment	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8	22.8
Total	97.5	96.6	100.5	97.5	98.2	101.2	102.0	92.1	96.0
Difference (%) Electric heating in comparison to REF Heat		-5 %	16 %	0 %	4 %	0 %	4 %	-30 %	-30 %
Difference (%) Electric heating in comparison to REF Cool		-	-	-	-	-	3 %	-	5 %

The assessment of the indoor air temperature

Some of the strategies in different cases do not affect heating demand but can change the indoor temperature in the cooling season. Therefore, analyzing the hourly indoor temperature is necessary. The duration curves of different cases are shown in Fig. 2, 3, and 4.

Openable windows (Case 4) and solar protection windows (Case 3) are the most effective passive strategies on indoor air temperature during the year based on Fig. 2. South-front orientation and lightweight structure are the critical ones in terms of warm hours. Fig. 3 and 4 reveal that the split unit can significantly decrease the temperature in the bedroom even it is in the hall in both current and future climate, due to the open doors (Cases 5, 7 and 9).To understand the effects of each strategy, the degree hours above 25 °C in each case is shown in Table 3, and the percentage of difference in degree hours above 25 °C in comparison to Case 1, is calculated. Changing orientation and lightweight structure have negative effects on the indoor air temperature. In contrast, the openable windows and solar protection windows have been the most effective ones. Using a cooling system in the hall has improved the indoor condition of the bedroom by decreasing the degree hours above 25 °C, with more than 99% in both massive and lightweight structure cases.

In the future climate, maintaining acceptable indoor conditions without active cooling will be even more challenging due to global warming. As can be seen in the charts, Case 8 indoor condition is 28% worse than Case 1.

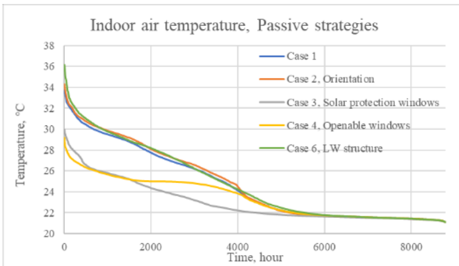

Figure 2. The indoor air temperature duration curves of the cases with the passive strategies in the warmest bedroom.

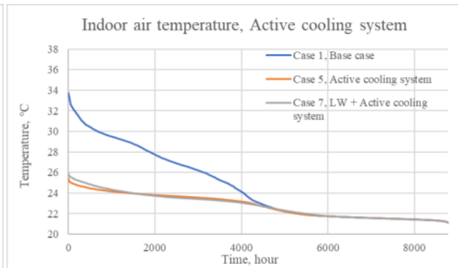

Figure 3. The indoor air temperature duration curves of the cases with the active cooling system in the warmest bedroom.

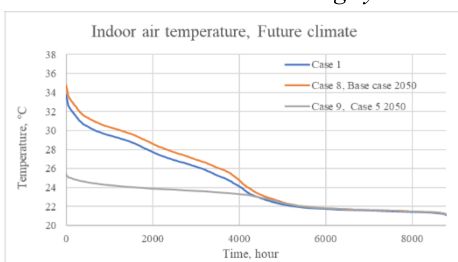

Figure 4. The indoor air temperature duration curves of the cases in the future climate in the warmest bedroom

	1	2	3	4	5	6	7	8	9
Degree hour above 25 °C	11752	13049	2257	1748	100	12893	150	15020	100
Difference in comparison to Case 1 (%)		11 %	-81 %	-85 %	-99 %	10 %	-99 %	28 %	-99 %

CONCLUSIONS

This study has investigated the effects of passive strategies, active cooling, and climate change on indoor temperature conditions and the energy demand of a Finnish detached house. Nine different cases were simulated in the cold climate of Finland.

Regarding the results of passive strategies, in the current climate, using openable windows would be the best solution for decreasing the cooling demand, and providing thermal comfort in all the spaces. It is important to note that depending on the location and surrounding of the building, window opening may decrease the indoor air quality and increase the indoor noise level, so the window opening cannot be recommended in such conditions. The lower level of the thermal mass of the building structure causes a slight increase in indoor temperature.

Because of the open door between the rooms, using an active cooling system in the hall of the upper floor is the only solution that can provide thermal comfort in all the spaces, the whole time of the cooling season in both current and future climate.

In the future climate, the space heating demand decreases about 30% which is way more than the amount of increase in the cooling demand by 5%. So that the total electricity demand in the future climate would be less than in the current climate and using the active cooling systems can provide acceptable indoor temperature. Also, the indoor conditions would be improved by utilizing passive strategies such as openable windows and solar protection windows.

Acknowledgements

This study is part of the following projects: HEATCLIM (Heat and health in the changing climate, Grant Numbers. 329306, 329307) funded by the Academy of Finland within the CLIHE (Climate change and health) programme, FINEST Twins funded by European Union (Horizon 2020 programme, Grant No. 856602) and the Estonian government, SUREFIT (Sustainable solutions for affordable retrofit of domestic buildings) funded by European Union (Horizon 2020 programme, Grant No. 894511).

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