# The risk of overheating and energy demand of new and old Finnish apartment buildings in the cooling season

Azin VELASHJERDI FARAHANI [1*], Juha JOKISALO [12], Natalia KORHONEN[3], Risto KOSONEN[124]

[1] Department of Mechanical Engineering, Aalto University, Espoo, Finland
[2] Smart City Center of Excellence, TalTech, Tallinn, Estonia
[3] Weather and Climate Change Impact Research, Finnish Meteorological Institute, Helsinki, Finland
[4] College of Urban Construction, Nanjing Tech University, Nanjing, China
* *Corresponding author: azin.velashjerdifarahani@aalto.fi*

**ABSTRACT**

This study has compared the risk of overheating of a new and old apartment building in Finland and aimed to improve the indoor temperature conditions of the new apartment building using the passive strategies (sun shading, window opening, and window properties) and an active cooling system. So that seven different cases were defined and simulated. Regarding the results, the risk of overheating in the old building is significantly less than in the new building, and using new well-insulated windows with the same old wall construction in the old building, decreases the heating demand but has no significant effect on indoor air temperature. So that the windows are more important for energy usage but not for the indoor air temperature in the old Finnish apartment building during the summer period. Using openable windows would be the best passive solution for keeping the indoor air temperature of the spaces of the new building within the comfort limits with less than 10% of the time above the recommended temperature limits based on EN 16789-1 standard without any significant increase in heating demand. While Using an active cooling system in the living room of each apartment is the only solution that can provide thermal comfort for 100% of the cooling season in all the spaces including bedrooms.

## INTRODUCTION

In Nordic countries overheating problems have not been an issue to date. However, new apartment buildings, with large windows and well-insulated construction have changed the situation “Maivel et al. (2015)” . On the other hand, studies showed that renovations on existing buildings may increase the risk of overheating in cold climate. A study by Zukowska et al. indicated a high risk of overheating in Danish renovated apartment buildings “Zukowska et al. (2019)”. Another study by Psomas et al. investigated the effects of window control systems on overheating risk in Danish renovated houses “ Psomas et al. (2017)”. Thus, there is a need for some solutions to cope with this issue and reduce its effects. On the other hand, overheating mitigation would cause an increase in energy consumption. It seems to be necessary to see the effects of strategies on both overheating and energy demand of residential buildings.

This study has investigated the risk of overheating of a new and old apartment building in Finland and examined the passive strategies including sun shading, window opening, and window properties to improve the indoor temperature conditions of the new apartment as well as the effects of an active cooling system.

## MATERIAL AND METHODS

### Description of the building

The example buildings of this study are two similar 5-story apartment buildings which locate in Helsinki. The geometry and orientation of the example buildings are the same and described in Fig. 1. The buildings have four living floors and a basement floor which is located underground containing storage and technical spaces. The heated net floor area of the buildings is 1943.5 m². It is assumed that the example buildings are located in a neighborhood where they are surrounded by similar buildings. This is shown in Fig. 2.

The new building is assumed to be built after 2012 while the old building belongs to the 1960s. Thus, ventilation systems, envelop properties, window to wall ratio, and window properties are different according to their construction year. The new and old buildings envelop properties including the U values and window properties are reported in Table 1 and 2.

The ventilation system in the old apartment building is a mechanical exhaust CAV ventilation system. The specific fan power (SFP) of the ventilation system is 0.7 kW/m³/s. The floor plan, room types, and exhaust airflow rates (negative values) in different rooms of the old apartment building are shown in Fig. 3. The air leakage rate of building envelope $q_{50}$

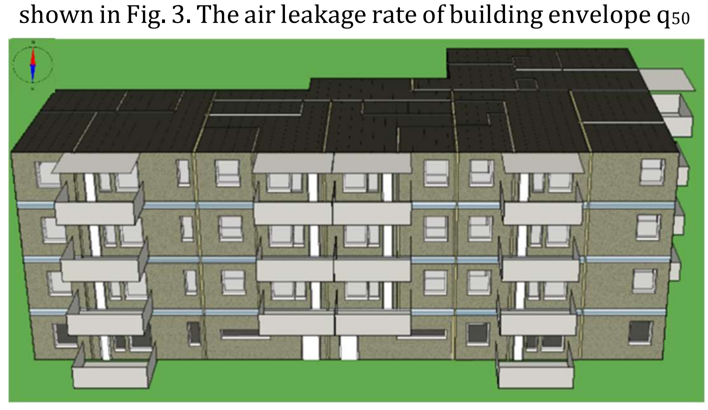

*Figure 1. The geometry of the building.*

at 50 Pa pressure difference is 4 m³/hm². The total air exchange rate of the building is 0.52 ACH in both old and new buildings.

The ventilation system of the new apartment building is a constant air volume (CAV) mechanical supply and exhaust ventilation system. The setpoint temperature of supply air heating is 17 °C and it is assumed that supply and exhaust air temperature increase by 1 °C due to fans and ducting. The air handling unit (AHU) doesn't have mechanical cooling. The AHU is equipped with a district heated reheat coil which is used for heating supply air. The specific fan power (SFP) of the ventilation system is 1.8 kW/m³/s. The room types and the airflow rates in different rooms are shown in Fig. 3 in which positive values are the supply airflow rates and the negative ones the exhaust airflow rates. The air leakage rate of building envelope $q_{50}$ at 50 Pa pressure difference is 2 m³/hm².

Table 3 shows the number of occupants in each apartment type in both buildings. The occupancy density is 1 occupant per 28 m². The activity level of 1.2 MET and adjustable clothing level (0.85 ± 0.25 CLO) are used. It is assumed that there are no heat gains from occupants in the staircase and base floor. The presence of the occupants corresponds with the lifestyle of working townspeople.

In both buildings, all the windows of the apartments are equipped with blinds between the outer windowpanes. The blinds between panes are used when There are no blinds in the windows of the staircase.

The heating system of both old and new buildings is district heating (DH) and the efficiency of the heat exchanger in the DH substation in the building is 97%. Space heating is carried out by 70/40°C water radiators and the heat distribution efficiency is 80%. The temperature setpoint of space heating is 21 °C in the apartments, except 22 °C in the bathrooms. The setpoint of space heating is 17 °C on the staircase and basement floor. There is no mechanical cooling in the base case.

The annual net heating demand of domestic hot water (DHW) in both old and new buildings is 35 kWh/m², per total heated net floor area of the building. It is that DHW consumption is constant with time. Heat losses of the DHW circuit are 0.56 W/m² and 50% of the heat losses can be assumed to end up with internal heat gains in the zones. The total annual electricity consumption of household equipment is 21.0 kWh/m², per heated net floor area. The electric power of the appliances (W/m²) is assumed to be evenly distributed by the floor area of all the simulated

*Table 1. The envelope properties of the new building.*

| Elements of construction | U value (W/m²K) | g-value | $q_{50}$ (m³/h,m²) |
|---|---|---|---|
| External wall | 0.17 | _ | _ |
| Roof | 0.09 | _ | _ |
| Base floor | 0.17 | _ | _ |
| Air leakage | _ | _ | 2 |
| window | 1.0 | 0.35 | _ |

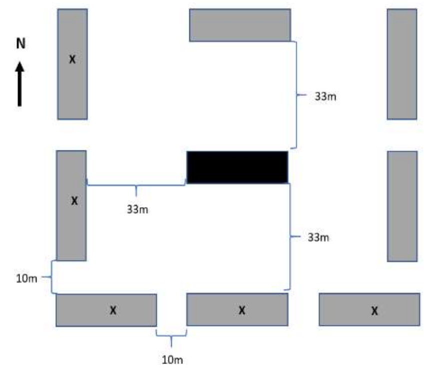


Figure 2. The location of the simulated example building (black box) and the surrounding buildings (grey boxes).

zones in the apartments and the appliances are used every day between 7:00-23:00. There are no appliances on the staircase or base floor.

The total annual electricity consumption of indoor lighting is 7.9 kWh/m², per total heated net floor area of the building. The electric lighting power (W/m²) is assumed to be evenly distributed by the floor area of all the simulated zones in the apartments and by the floor area of the staircase. There are no heat gains from lighting on the base floor. The usage time of the lights are:

May to August: between 21:00-23:00

Sep to Apr: between 6:30 - 9:00 and 15:00 – 23:00

The internal door of the bathrooms or WCs is always closed but the other internal doors inside the apartments are always open. The air airtightness of the closed doors is considered in the simulation and the equivalent leakage areas at 4 pa pressure difference are 0.02, 0.1, and 0.08 m² for the bathroom door, doors between the apartments, the outdoor of the staircase, and the staircase, respectively.

## Climatic data and simulation tool

The simulation period of the cases is one year, and the weather data of the study are TRY (2012) of Helsinki-Vantaa, which describes the current average climatic conditions of southern Finland "Kalamees et al. (2012)". The average outdoor temperature of three summer months (June, July, and August) is 15.9 °C and the annual average outdoor temperature is 5.6 °C.

The time resolution of the simulation results is 1 hour. The simulation is done using the validated dynamic building simulation tool IDA ICE 4.8.

*Table 2. The envelope properties of the old building.*

| Elements of construction | U value (W/m²K) | g-value | $q_{50}$ (m³/h,m²) |
|---|---|---|---|
| External wall | 0.6 | _ | _ |
| Roof | 0.34 | _ | _ |
| Base floor | 0.6 | _ | _ |
| Air leakage | _ | _ | 4 |
| window | 2.5 | 0.76 | _ |

*Table 3. The total number of occupants in each apartment type.*

| Apartment | No of rooms | No of occupants |
|---|---|---|
| A | 3 | 3 |
| B | 1 | 1 |
| C | 2 | 2 |
| D | 3 | 3 |
| E | 4 | 4 |

**Simulation Cases**

There are 5 different cases defined to investigate the effects of sun shading, building age, window opening, and window properties, and an active cooling system on energy demand and indoor air temperature conditions of the new building which is the main focus of this study. Furthermore, the indoor conditions of the existing old building, as well as the effects of replacing its windows with the new well-insulated windows, are investigated in two cases.

*Case 1* is a reference case without mechanical cooling and openable windows. Properties of the building and HVAC system are as described previously. It simulates the new building.

*Case 2* is similar to Case 1, but there are no blinds in the windows.

*Case 3* is the old building with the properties that are described previously.

*Case 4* is similar to Case 3, but the old windows have been replaced by new windows similar to the new building as in table 1.

*Case 5* is similar to Case 1, but the building is equipped with solar protection windows whose U-value is 1 W/m2K, but the total solar heat transmittance (g-value) of the windows is 0.19 and the direct solar transmittance (ST-value) is 0.16.

*Case 6* is similar to Case 1, but 10% of the area the largest windows of each room is open during the occupied hours when the indoor temperature of a room exceeds 25 °C which is the target value of the maximum indoor air temperature in Finnish classification of indoor climate "Ahola et al. (2019)".

*Case 7* is similar to Case 1, but the living room of each apartment is equipped with a split cooling unit. Dimensioning cooling capacity of the units is 45 W/m$^2$ and the area used in the dimensioning is the total floor area of the apartment. SCOP of the cooling unit is 3. The temperature setpoint of space cooling is 23°C.

These cases are briefly described in Table 4.

*Table 4. Brief description of the simulation cases.*

| Cases | | Description |
|---|---|---|
| Case 1 | New building, Ref Case | Base Case which is the reference case. |
| Case 2 | New building with no blinds | There are no blinds in the windows |
| Case 3 | Old building | The building properties correspond to old apartment buildings built in the 1950s and 1960s. |
| Case 4 | Old building with new windows | The building properties correspond to old apartment buildings built in the 1950s and 1960s, but the old windows have been replaced by new windows similar to Case 1. |
| Case 5 | New building with solar protection windows | The building is equipped with solar protection windows whose U-value is like Case 1, but the total solar heat transmittance (g-value) of the windows is 0.19 and the direct solar transmittance (ST-value) is 0.16. |
| Case 6 | New building with openable windows | 10 % of the area of the largest window of each room is opened during the occupied hours when the indoor temperature of a room exceeds 25 °C. |
| Case 7 | New building with an active cooling system | The living room of each apartment is equipped with a split cooling unit. The cooling capacity of the units is 45 W/m$^2$. SCOP of the cooling unit is 3. The temperature setpoint of space cooling is 23°C. |

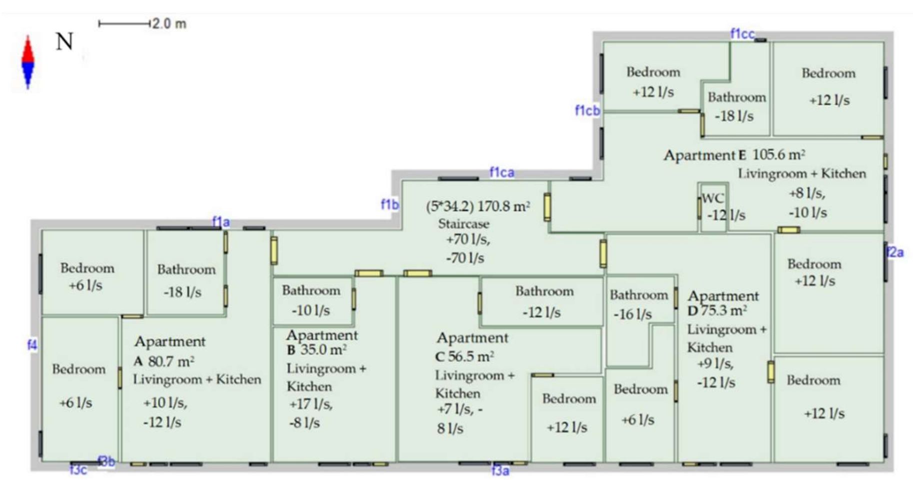


*Figure 3. Floor plan and room types in the studied building.*

### Target values of indoor air temperature

Different categories of thermal environments, which are used for analyzing the indoor air temperature, are based on EN 16798-1; the European standard specifies the indoor environmental parameters, which have an impact on the energy performance of the buildings. Table 5 shows the recommended range of indoor temperatures for the cooling season for the categories “Finnish Standards Association SFS.(2019)”. For comparing the cases’ results, the hourly indoor temperature of the warmest room of the building is reported and compared to Case 1 as the reference case. The indoor temperature in the warmest bedroom of each case is compared to the maximum acceptable indoor temperature of each category shown in Table 5. Moreover, the degree hours above 25 °C are calculated in the warmest bedroom of each case. 25 °C is the target value of maximum air temperature in Finnish classification of indoor climate “Ahola et al. (2019)”.

## RESULTS

The results are presented in two different parts, in the first one, the annual district heating and space cooling electricity consumption of each case are compared. The second one is an assessment of the indoor air temperature in the warmest bedroom of the building to find out the effects of each strategy on indoor conditions.

### Energy consumption

Table 6 is a summary of the breakdown of district heating and space cooling electricity consumption in all 7 cases. The effects of each strategy on district heating demand for space heating and the reheat coil of ventilation and cooling electricity will be discussed.

Omitting the blinds in Case 2 decreases the district heating demand by 1.6% due to the increase of solar heat gain in the heating season.

*Table 5. Different categories of thermal environments based on EN 16798-1.*

| Type of building or space | Categories | Explanation | Temperature range for cooling °C |
|---|---|---|---|
| Residential buildings, living spaces (bedrooms and living rooms, etc.) Activity 1.2 MET | I | High level of expectation only used for spaces occupied by very sensitive and fragile persons | 23.5-25.5 |
| | II | Normal expectation for new buildings and renovations | 23-26 |
| | III | A moderate expectation (used for existing buildings) | 22-27 |

*Table 6. Breakdown of annual energy consumption (kWh/m²)*

| | 1<br>Ref case | 2<br>No blinds | 3<br>Old construction | 4<br>Old construction and new windows | 5<br>Solar protection windows | 6<br>Openable windows | 7<br>Active cooling system |
|---|---|---|---|---|---|---|---|
| district heating (spaces + AHU) | 36.7 | 36.1 | 145.5 | 127.4 | 37.3 | 36.8 | 37.2 |
| Electric space cooling | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.5 |
| Difference (%) of District heating in comparison to Ref case | | -1.6 % | 296.5 % | 247.1 % | 1.6 % | 0.3 % | 1.4 % |

Old construction and old windows with Poor thermal insulation level and ventilation without heat recovery in Case 4, caused a significant increase with 296.5% in the district heating demand. While using the new windows with a higher U value with the old construction increases the district heating demand by 247% which is about 50% less (Case 4). As can be predicted, solar protection windows in Case 5 cause a slight increase in the district heat demand because of the lower solar heat gain in the heating season, and the openable windows don’t have a significant effect on district heating consumption.

In Case 7, an active cooling system is used in the living room of each apartment. The space cooling electricity consumption is 2.5 kWh/m$^2$ which is significantly lower than the energy consumption for space heating.

### The assessment of the indoor air temperature

Some of the changes in different cases do not affect heating demand but can change the indoor temperature in the cooling season. Therefore, analyzing the hourly indoor temperature seems to be necessary.

The annual hourly indoor air temperature and the overheating risk are investigated in the warmest bedroom of both building types which is shown in Fig. 4 with a red star. It is located in Apartment D and faces to the south.


*Figure 4. The location of the warmest bedroom in the buildings*

The duration curves of the indoor air temperature of each case in the warmest bedroom of the building are shown in Fig.5. The degree hours above 25 °C in the warmest bedroom of the building in each case are calculated and reported in Table 7.

As can be seen in Fig.5 omitting the blinds causes a slight increase in indoor air temperature with less than 1 °C. Old construction in cases 3 and 4, decreases the temperature significantly in both the cooling and heating season. The solar protection window in Case 5, has a small effect on indoor air temperature, while the openable window decreases the indoor air temperature in a way that the maximum temperature goes down to around 27°C. The active cooling system in the living room decreases the indoor air temperature of the warmest bedroom to below 25 °C.

The degree hours above 25 °C in the warmest bedroom in the case with no blinds increase by 32 % in comparison to the base case. Old construction reduces the degree hours above 25 °C. However, the combination of old construction and new windows reduces it more.

The least effective passive solution on degree hours above 25 °C is the solar protection windows by a decrease of 22%. The most effective one is the openable window by a 95% decrease.

The active cooling system in the living room is the only studied solution that can reduce the degree hours above 25 °C in the bedroom by 100%.

On the other hand, it is necessary to compare the results to the standards. The percentage of time in which the indoor air temperature of the warmest bedroom is higher than the maximum recommended temperature in each thermal environment category is calculated based on EN 16798-1 standard in each case. It is shown in Fig.6.

The case with the active cooling system is the only studied solution in which the indoor air temperature of the warmest bedroom is below the recommended temperature in all three categories.

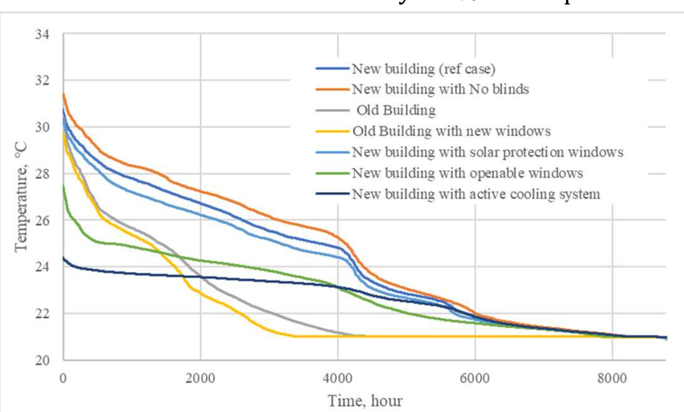


*Figure 5. The duration curves of indoor air temperature of the warmest bedroom in the buildings.*

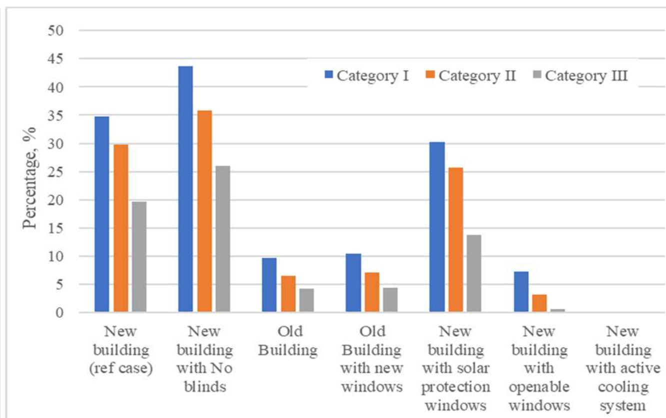


*Figure 6. The percentage of hours above the thermal comfort cooling temperature range in the warmest bedroom of each case (EN 16798-1).*

*Table 7. The degree hours above 25 °C in the warmest bedroom of each case.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| | New building, Ref case | New building with no blinds | Old building | Old building with new windows | New building with solar protection windows | New building with openable windows | New building with active cooling system |
| Degree hours above 25°C | 7291 | 9604 | 2244 | 1848 | 5694 | 389 | 0 |
| Difference (%) in comparison to Ref case | | 32 % | -69 % | -75 % | -22 % | -95 % | -100 % |

The next effective solution is the openable window that can keep the indoor air temperature below the recommended value in more than 92%, 95%, and 98% in categories I, II, and III, respectively.

In the case with old construction, the indoor air temperature is above the recommended temperature range in category I about 10% of the time and about 5% of the time in categories II and III. The new window combined with the old construction is not that effective on indoor air temperature. The solar protection window reduces the percentage of time above the recommended temperature range by 5 % in comparison to the Ref case. Omitting the blinds can increase the percentage of the time above the recommended temperature range around 10 % in comparison to the Ref case.

## CONCLUSIONS

This study has investigated the effect of passive strategies (orientation, building age, window opening, and glazing properties), and active cooling on indoor temperature conditions and the energy demand of a Finnish apartment building. 7 different cases were simulated in the cold climate of Finland. The goal was to improve the indoor temperature conditions in cooling months and see the effect of global warming on energy demand.

Regarding the results of passive strategies, using openable windows would be the best solution for keeping the indoor air temperature of the spaces within the comfort limits with less than 10% of the time above the recommended temperature range without any significant increase in heating demand. Using solar protection windows can decrease the degree hours above 25 °C by 20-30% but increases the heating demand by just 1.6%. The usage of poor thermal insulation level and mechanical exhaust ventilation without heat recovery with old windows can decrease the overheating in cooling months but increases the heating demand by more than 290%. While using new well-insulated windows in the same old building increases the heating demand by about 247% but has no significant effect on indoor air temperature. So that the windows are more important for energy usage but not for the indoor air temperature in the old Finnish apartment building during the summer period. Omitting the blinds can decrease the heating demand by 1.6% but increases the discomfort hours.

Using an active cooling system in the living room of each apartment is the only solution that can provide thermal comfort in the bedrooms. The space cooling electricity is not significant in comparison to the energy consumption for heating and utilizing the active cooling system for providing better indoor temperature conditions seems reasonable. However, considering passive strategies such as openable windows would be helpful.

## ACKNOWLEDGMENT

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