Intelligent building envelope solutions in Finnish new and old apartment buildings

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Abstract. This study investigated the effects of intelligent building envelope solutions (automated blinds, openable windows, and awnings as well as electrochromic windows) in Finnish old and new apartment buildings. Moreover, the results are compared to the passive solutions (manual blinds and solar protection windows). The main goal was to compare the performance of each solution in improving the indoor temperature conditions in Finland's current climate. Thus, the solutions were simulated with the usage of a mechanical cooling system in the living room to see the effects on both the energy demand of the buildings and indoor temperature conditions in the warmest bedroom. Furthermore, indoor temperature conditions were analyzed in the warmest bedroom of the new building without an active cooling system, as well. According to the results, electrochromic and solar protection windows are the solutions with the lowest cooling electricity consumption in the old building. However, in the new building, the lowest cooling electricity consumption is for the case with the automated openable windows and the next effective solutions are solar protection and electrochromic windows. Considering the results of indoor temperature conditions, the combination of solar protection windows and manual blinds is the most effective solution in the old building. While automated openable windows have the best performance in the new building with or without the active cooling system. Overall, passive solutions are more effective in both the old and new apartment buildings except for automated openable windows in the new building.

Keywords: Intelligent building, residential building, Energy efficiency, automated solutions
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1 Introduction

One of the highest energy consumptions is for the building sector in Europe [1]. It is mentioned by the EU commission provisions that the level of energy consumption should be lower in future buildings [2].

On the other hand, climate change and increasing ambient temperature have been a growing concern and their effects on energy consumption are not questionable [3]. Based on the literature, climate change is likely to increase the cooling energy demand and decrease the heating energy demand in most of Europe [4]. Thus investigating the ways to reduce cooling energy seems to be necessary.

Intelligent control of building facilities has been an approach to making buildings more energy-efficient in recent decades [5]. However, there is still a need for evaluating their effects on energy efficiency as well as occupants' comfort in different buildings.

This study aims to determine the energy efficiency of intelligent building envelope solutions and their effects on indoor temperature conditions in Finnish old and new residential buildings. Furthermore, their performance will be compared to passive solutions.

2 Methods

2.1 Example building

The studied buildings are two 5-story (four living floors and a basement) apartment buildings with the same

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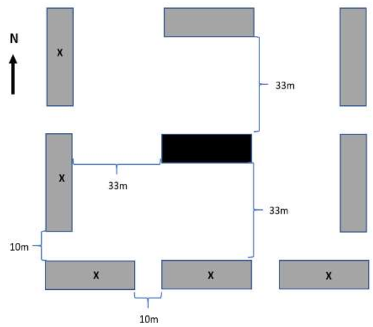

Figure 2. The simulated example building (black box) and the surrounding buildings (grey boxes).

geometry and orientation in Helsinki. Fig. 1 shows the geometry of these buildings. The heated net floor area of each building is 1943.5 m^2. Both buildings are surrounded by similar buildings as shown in Fig. 2.

These two buildings are different in their construction year. Thus, their ventilation systems, envelop properties, window to wall ratio, and window properties are different as well. The new building belongs to the period after 2012 and the old one to the 1960s. The new and old buildings' properties are reported in Table 1.

Table 1. The properties of the studied building.

	New building	**Old building**
Year of construction	after 2012	The 1960s, 1950s
Heated net floor area (m^2)	1943.5	
U-value of the external wall (W/m^{2}K)	0.17	0.6
U-value of external window (W/m^{2}K)	1	2.5
Airtightness of building envelope (q_{50}) (m^3/h,m^2)	4	6
Heating system	District heating, 70/40°C water radiators, 65 W/m²	District heating, 70/40°C water radiators, 100 W/m²
Ventilation system	Constant air volume (CAV) mechanical supply (17°C) and exhaust ventilation system, Heat recovery efficiency: 0.65	Mechanical exhaust (CAV) ventilation
	total air exchange rate of the building: 0.52 ACH.	
Split cooling unit (not in all the cases)	COP: 3, Living rooms, the Cooling capacity of the units: 45 W/m²	

A mechanical exhaust constant air volume (CAV) ventilation system is used in the old building with specific fan power (SFP) of 0.7 kW/m³/s. The ventilation system of the new apartment building is a CAV mechanical supply and exhaust ventilation system with the SFP of 1.8 kW/m³/s. 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. There is no mechanical cooling in the air handling unit (AHU). The AHU is equipped with a district-heated reheat coil which is used for heating supply air. The floor plan, room types, and exhaust airflow rates (negative values) in different rooms of the old and new apartment

Figure 1. The geometry of the building.

and supply airflow rates (positive values) in each room of the new building are shown in Fig. 3. The air leakage rate of building envelope q_{50} at 50 Pa pressure difference is 4 m^3/hm^2. The total ventilation air exchange rate of both buildings is 0.52 ACH.

The occupancy density is 1 occupant per 28 m^2. The activity level is assumed to be 1.2 MET and an adjustable clothing level of (0.85 ± 0.25 CLO) is used in the simulations. 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 people.

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%. 70/40°C water radiators with a heat distribution efficiency of 80% are used. However, the space heating system capacity is 65 W/m^2 in the new building and 100 W/m^2 in the old building. The temperature setpoint for the space heating is 21 °C in the living spaces and 22 °C in the bathrooms. The setpoint of space heating is 17 °C for the staircase and basement floor. It is assumed that the living room of each apartment is equipped with a split cooling unit with a Seasonal Coefficient of Performance (SCOP) of 3 and a cooling capacity of 45 W/m². The temperature setpoint of space cooling is 25 °C in the apartments. However, there are some simulation cases in the new building without a mechanical cooling system which will be discussed in the next section.

The annual net heating demand of domestic hot water (DHW) in both buildings is 35 kWh/m^2, per total heated net floor area. The DHW is heated via the district heating system and its 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/m^2, per heated net floor area. The electric power of the appliances (W/m^2) is evenly distributed by the floor area of all the spaces of 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/m^2, per total heated net floor area. The

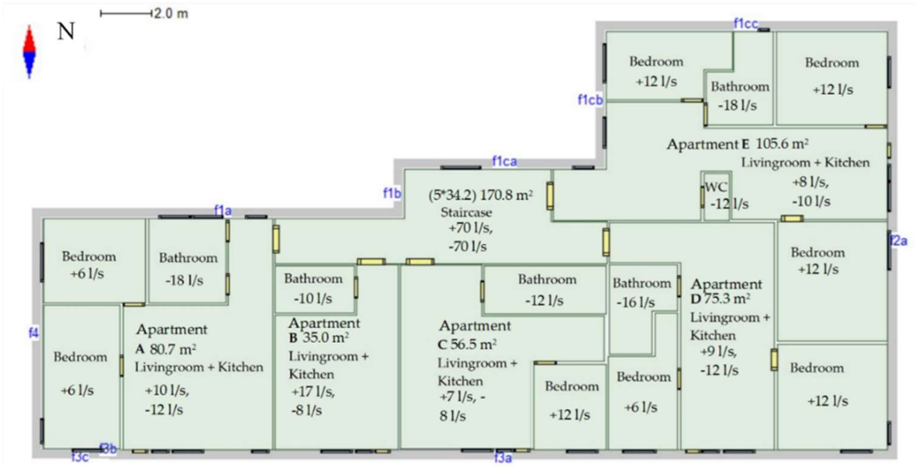

Figure 3. Floor plan and room types in the studied building**.**

electric lighting power (W/m^2) is assumed to be evenly distributed by the floor area of all the spaces in the apartments and by the floor area of the staircase. It is assumed that 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 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 m^2 for the bathroom door, doors between the apartments and the staircase, and the outdoor door of the staircase, respectively.

Except for some of the simulations cases, there are no blinds for the windows. Additionally, the buildings are not equipped with lighting controls as any typical apartment building in Finland.

2.2 Climatic data and simulation tool

The study is done using the validated dynamic simulation tool IDA-ICE 4.8 [4]. The time resolution of the simulation results is 1 hour.

The test reference year (TRY2020) of the Helsinki-Vantaa weather station describing the current climatic conditions of Southern Finland was used in the study.

2.3 Simulation cases

Three groups of simulation cases are defined for both the old and new buildings. First, the reference cases are as described in the previous section. Second group, passive solutions: manual blinds, solar protection (S.P) windows, and the combination of S.P windows and manual blinds. Third, automated solutions: automated blinds, automatically controlled openable windows, automatically controlled awnings, and electrochromic windows. All these cases are simulated with the mechanical cooling system in the living rooms in both buildings. Table 2 describes these simulation cases. Moreover, the base case, the case with the combination of S.P windows and manual blinds, and all the automated solutions in the new building are simulated without the mechanical cooling system to see the effects of the solutions on indoor air temperature. These cases are shown by * in Table 2. All over, there are 8 cases in the old building and 14 cases in the new building.

2.4 Target values of indoor air temperature

The target value is used in this paper to compare the effects of the solution on indoor temperature conditions. Thus, the requirements suggested by the Ministry of the Environment are used. As in the design phase, the maximum allowed design indoor air temperature is 27°C [6]. The annual hourly indoor air temperature profiles for the warmest bedroom of each building are simulated. In the cases without mechanical cooling, the annual degree hours above 27 °C are calculated and compare

3 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 buildings to find out the effects of each solution on indoor conditions.

3.1 Energy consumption

A summary of the breakdown of space and AHU district heating and space cooling electricity consumption in the old and new buildings are presented in Tables 3 and 4, respectively. The effects of each solution on district heating demand for space heating and the reheat coil of ventilation and cooling electricity will be discussed for each building.

Table 2. Brief description of simulation cases.

Cases		Description
Base Case	Old-Base	The reference case.
	New-Base*	
Passive solutions	Old-Manual blind	Manual blinds between the outer windowpanes according to the occupancy schedule during the whole year, all the windows except the staircase windows.
	New-Manual blind	
	Old-S.P windows	Solar protection windows, U value: 1 W/m^{2}K, g-value: 0.19, ST: 0.16
	New-S.P windows	
	Old-Manual blind & S.P. windows	Combination of manual blind and solar protection windows.
	New-Manual blind & S.P. windows*	
Automated solutions	Old-Auto blind	Blinds Between the outer windowpanes are in use when the intensity of solar radiation on the façade exceeds 100 W/m^2 for all the windows except the staircase windows.
	New-Auto blind*	
	Old-Openable windows	10% of the largest window of each room (cross ventilation) opens when the outside air temperature is between 12 °C and 22°C and the zone air temperature is between 23 °C and 25°C. Not in the staircase.
	New-Openable windows*	
	Old-Auto awning	Electrically controlled awning. Awnings on the windows without a balcony open when the wind speed is less than 8 m/s and outdoor air temperature exceeds 15 °C meanwhile the intensity of solar radiation on the façade exceeds 100 W/m^2. All the windows except the large atrium windows, small windows of the atrium at the street level have awnings. The depth and height of the awning are equal to 30% of the window height.
	New-Auto awning*	
	Old-Electrochromic windows	Electrochromic windows. U value 0.97 W/m^{2}K, when the outdoor solar radiation on the façade exceeds 450 W/m^2 the darkest state of the glazing is on ST: 0.29-0.01, g-value: 0.31-0.05, Tvis: 0.61. All the windows.
	New-Electrochromic windows*	

As Table 3 shows, the space heating and AHU district heating consumption in the cases with solar protection windows and the combination of solar protection windows and manual blinds in the passive group and the case with electrochromic windows in the automated group, has decreased by 3-4% (around 5 kWh/m^2) in the old building. The lower U value of these windows compared to the existed poorly insulated windows has caused this decrease. While in the new building (Table 4) with the existing well-insulated windows, these cases have caused an increase of 2-3% (around 1 kWh/m^2) in district heating consumption because of the reduction in solar gains. Manual blinds have slightly increased the district heating consumption in both buildings. Compared to electrochromic windows, other automated solutions have had a smaller effect on district heating consumption in both buildings. This difference is because of the lower U value of these windows in the old building and their lower solar gains in the new building.

On the other hand, all the solutions have decreased the space cooling electricity consumption in both buildings. However, the absolute value of the cooling electricity is small (around 2 kWh/m^2), even if the percentage of decrease caused by each solution is high. The highest decrease levels in the old building are for the cases with solar protection windows and the combination of solar protection windows and manual blinds, electrochromic windows, and openable windows, with more than 60%. In the new building, the case with the openable windows has the lowest cooling electricity consumption (0.4 kWh/m^2). The next two cases with the lowest cooling electricity consumption are the ones with solar protection windows and a combination of solar protection windows and manual blinds with a more than 30% decrease. Manual blinds had the lowest effect on cooling electricity consumption in the new building with around 9%.

In the cases with openable windows, the windows are open when the indoor temperature is between 23-25 ℃. The simulation results showed that the indoor temperature of the old building is in this range for a shorter period than the new building. Thus, the effects of this solution in the new building are more significant.

Table 3. Breakdown of annual energy consumption in the old building (kWh/m^2).

Systems	Old-Base	Old-Manual blind	Old-S.P windows	Old-Manual blind & S.P. windows	Old-Auto blind	Old-Openable windows	Old-Auto awning	Old-Electrochromic windows
Space heating + AHU	136.1	136.7	131.7	131.9	138.1	136.5	136.3	130.6
Space cooling electricity	2.1	1.8	0.8	0.7	1.1	0.8	1.5	0.8
Difference (%) of Space heating + AHU in comparison to Base case		0.4	-3.2	-3.1	1.5	0.3	0.1	-4.0
Difference (%) of Space cooling electricity in comparison to Base case		-14.3	-61.9	-66.7	-47.6	-61.9	-28.6	-61.9

Table 4. Breakdown of annual energy consumption in the new building (kWh/m^2).

Systems	New-Base	New-Manual blind	New-S.P windows	New-Manual blind & S.P. windows	New-Auto blind	New-Openable windows	New-Auto awning	New-Electrochromic windows
Space heating + AHU	34.9	35.0	36.1	36.1	35.0	35.1	34.9	35.7
Space cooling electricity	2.3	2.1	1.6	1.5	1.9	0.4	2.0	1.8
Difference (%) of Space heating + AHU in comparison to Base case		0.3	3.4	3.4	0.3	0.6	0.0	2.3
Difference (%) of Space cooling electricity in comparison to Base case		-8.7	-30.4	-34.8	-17.4	-82.6	-13.0	-21.7

3.1 Indoor temperature conditions

The indoor air temperature is analyzed in all the cases in both buildings with the mechanical cooling system. Then the degree hours above 27 °C in the cases with the lowest energy consumption without the usage of the mechanical cooling system are calculated and compared in the new building.

The indoor air temperature in the warmest bedroom of both building types is investigated. The warmest bedroom is in Apartment D, on the middle floor, and faces to the south and is shown in Fig.4.

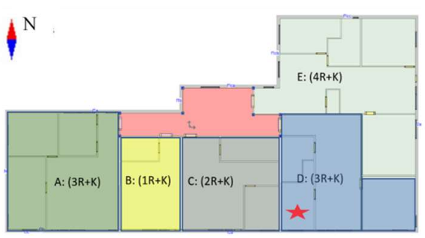

Figure 4. The location of the warmest bedroom (red star) in the buildings.

The indoor temperature duration curves for the old and new are shown in Fig.5 and 6, respectively. As the figures show, the maximum temperature in the old building is higher than in the new building but the new building is warmer most of the time.

Among the passive solutions, the cases with solar protection windows (combined with manual blinds or alone) have the most effects on indoor temperature conditions in both buildings, and manual blinds have not been effective. Regarding the automated solutions, all of them have decreased the indoor air temperature in both buildings. openable windows, electrochromic windows have had the highest effect. Among all the passive and automated solutions, it seems that openable windows, the combination of solar protection windows, and electrochromic windows are the most effective ones in both buildings, respectively.

Since the curves are close together, for a more detailed comparison between the effects of passive and automated solutions on indoor temperature conditions, the degree hours above 27 °C are calculated in the new building. Table 5 reports the degree hours above 27 °C in the cases with the lowest energy consumption without the usage of the mechanical cooling system in the new building. The openable windows have decreased the degree hours above 27 °C by 100%. The combination of solar protection windows and manual blinds, as well as electrochromic windows, are the next solutions with a 58% and 43% decrease. Auto blinds and auto awnings are also effective. However, the percentage of decrease in degree hours above 27 °C is around 30% in the cases with these two solutions.

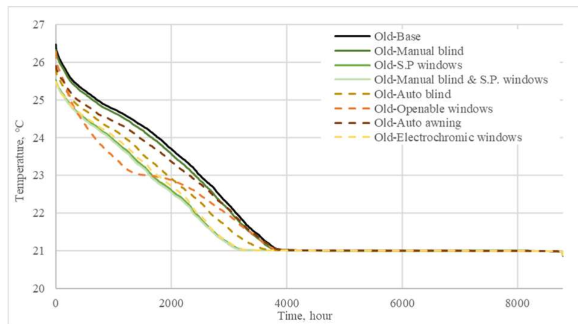

Figure 5. Indoor air temperature duration curve of the old building.

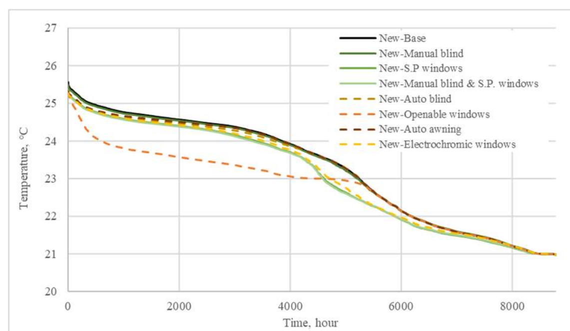

Figure 6. Indoor air temperature duration curve of the new building.

Table 5. Degree hours above 27 °C in the selected cases of the new building without the usage of mechanical cooling.

Cases	Degree hours above 27 °C	The decrease in degree hours (%) in comparison with the Base case
New-Base	3938	-
New-Manual blind & S.P. windows	1636	58
New-Auto blind	2568	35
New-Openable windows	0	100
New-Auto awning	2770	30
New-Electrochromic windows	2232	43

5 Conclusions

This study defined the energy efficiency of intelligent envelope solutions in Finnish old and new apartment buildings along with their effects on indoor temperature compared with passive solutions.

The lowest district heat consumption is for cases with electrochromic windows and solar protection windows in the old building. While these two solutions may increase the district heat consumption in the new building. Other solutions have no noticeable effect on district heat consumption in both buildings.

The three lowest cooling electricity is for cases with electrochromic windows and solar protection windows, and electrically controlled openable windows in the old building, respectively. The electrically controlled openable window is the case with the lowest cooling electricity consumption in the new building. Cases with solar protection windows and electrochromic windows are the next two.

Considering indoor temperature conditions, the maximum temperature in the old building is higher than in the new building. However, the new building is warmer in general.

The three best solutions with the lowest indoor air temperature in the old building are the cases with the combination of solar protection windows and manual blinds, solar protection windows, and openable windows, respectively. While in the new buildings the case with openable windows is the one with the lowest indoor air temperature with zero degree hours above 27 ℃ and the cases with the combination of solar protection windows and manual blinds and solar protection windows are the next two ones.

All over, among the passive solutions, solar protection windows can reduce the energy consumption (both district heating and cooling electricity) in the old building. However, they may increase the district heating consumption in the new building, despite the decrease in the cooling electricity consumption. In both of the studied buildings, solar protection windows are among the best solutions with the lowest indoor air temperature. Among the automated solutions, in both studied buildings, openable windows, can reduce the cooling electricity consumption without any noticeable change in district heating consumption. Alongside, they are among the best solutions with the lowest indoor temperature in both buildings. However, they may cause some difficulties such as excessive noise and air pollution coming from outside the spaces. The next automated solution may be the electrochromic windows with the lowest energy consumption in the old building.

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