Investigating Overheating of Nursing Homes to Support Heatwave Risk Analysis Methodology

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Abstract

The duration and frequency of summer heatwaves in Europe have substantially increased recently due to climate change. A clear correlation can be shown between the rise in outside temperature and the risk of mortality. The aim of our research is to examine the nursing homes in Budapest from this point of view. Therefore, a survey was conducted in which we analysed the building structures and examined the preventive methods used in these homes. After evaluating the results, one of the most vulnerable building was analysed using dynamic whole-building simulation. During the simulations, the summer internal conditions in the buildings with different user habits were analysed. We also examined the models according to future IPCC scenarios. In the study, we determined the most important parameters for internal air temperature and later on with additional parameters and city-level data. This can lead to the creation of a more complex hazard risk model.

Keywords: *summer overheating, heatwave, dynamic simulation, survey*

1 Introduction

The European Union has set itself a long-term goal of reducing greenhouse gas emissions [1] to mitigate the effects of climate change, and tightening requirements in the building industry [2] has effects on refurbishment of non-residential buildings [3]. Climate change has significant effect on the ecosystem, but its influence on health is also decisive. High temperatures may cause various diseases, including: skin rash, fatigue, sudden fainting or heat stroke, symptoms which indicate that the body's heat regulation system is not working properly. There are several general pieces of advice for prevention: sufficient amount of liquid consumption avoiding high-caffeine and alcoholic drinks, night-time ventilation and daytime shading, changing people's daily routine.

In the case of Hungary, in the decade through 2016, the number of heatwave days reached 14 per year, which represents a 6-day increase compared to the beginning of the last century. If we look at the future climate, we can expect a clear increase in the number of summer days where the temperature exceeds 25 °C at maximum – expected to be 16–20 days between 2021–2050 [4].

As the frequency of extreme weather phenomena is expected to increase in the next century, it is a very important task to examine the effects of heatwaves in detail, develop local warning strategies and develop an effective prevention plan. Several research papers analyse the excess-death due to climate change [5][6]. In Italy, it has been shown that there is a change in the number of excess deaths after applying a heat prevention plan [7]. It can be seen that the action plan introduced helped cut the number of deaths. In order to reduce the negative impacts of climate change, cities need to create a vulnerability index that involves not only the spatial relationship between different socio-economic, demographic, health and environmental variables but also the results of dynamic analysis. Several dynamic simulations have been made [8], [9] to analyse the overheating of buildings, the purpose of which was to examine the building structures, adaptation strategies or different climates. When examining the shading of buildings (especially in case of office buildings), it is important not to forget about the additional costs of artificial lighting. Different shading and ventilation strategies can greatly alter the interior comfort of buildings.

The aim of the paper is to analyse the internal temperature of an existing nursing home using dynamic simulations. During the examination of the building we analysed not only the user habits, but also examined the changes in the internal temperature using future climate.

2 The survey

During the research, we made a database containing all the elderly homes in Budapest. After that, we created a questionnaire that was sent to the executive manager of the homes.

Our primary purpose was to evaluate the state of the buildings in Budapest and the methods and experiences of the institutions on summer overheating. During the compilation of the questionnaire, it was a primary consideration to prepare a quick fill-in form that summarizes useful information relevant to the topic. We have used open and closed questions with alternative, selective and scale response options, we have also given the opportunity to describe individual opinions.

The response rate was greater than expected, with 30 respondents from the 73 elderly homes. These results contribute to the accurate assessment of the buildings in Budapest and the preventive methods applied in summer.

2.1 Results

Based on the results of the survey, it can be seen that the type, condition and age of Budapest's nursing homes are very diverse (Fig. 1). The classification of the construction periods was based on the National Building Energy Strategy. Most of the buildings were built in the period 1946–1979, and close to a quarter in the early part of the century. The proportion of newer homes (after 1990) is 33%. Comparing the results with the completed database, it is also apparent that most of the homes participating in the survey are newly built, so the result cannot be fully applied to the entire Budapest stock.

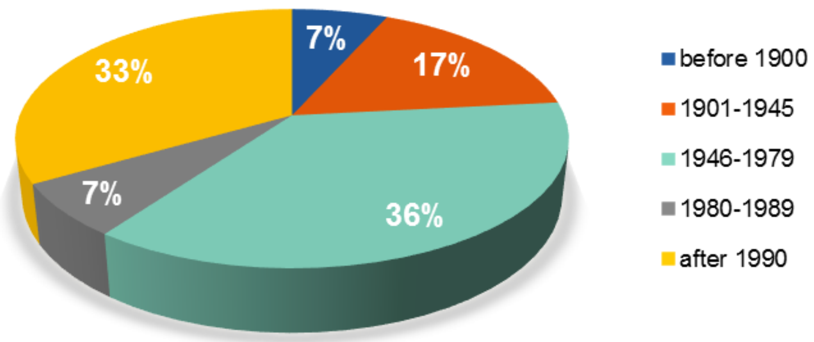

Fig. 1 *Construction period of the buildings*

2.1.1 Size of the homes

The size of the homes is also quite diverse, the questionnaire mainly includes institutions with higher capacity, but smaller homes (less than 50 people) are also relatively common in Budapest. 30% of the homes are suitable for 75–100 people, and a little more than 30% can accommodate more than 100. In total, the elderly homes surveyed can accommodate 3085 people, which is about half of Budapest's capacity based on the data of National Employment Service [10]. Based on these data, the total capacity available in the country is 51,345 people, of which Budapest accounts for 12%.

2.1.2 Retrofitting options

In the majority of the buildings in the survey, 20 energy-related retrofits have taken place in the last 10 years, while 4 of the remaining 10 are planning to renovate the building in the next 4 years.

The frequently used retrofit measures (Fig. 2) were the replacement of doors and windows and the modernization of the heating system. 25% of the buildings renewed the electrical system too. These solutions were generally combined: in case of one building, all 5 measures have been applied.

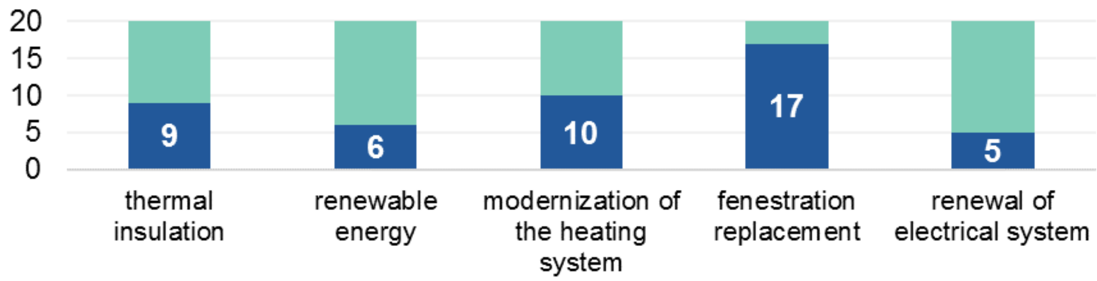

Fig. 2 *Retrofitting options applied in the homes*

2.1.3 Air conditioning

There are only two examples of air conditioning in the buildings, which is mainly due to high investment and operating costs. In some cases, separate rooms have air conditioning, because of the health conditions of the inhabitants.

The use of air conditioning systems in the elderly homes is a really important question; due to the clear link between daily temperatures and mortality, it is worth considering a more detailed examination of its application [11].

2.1.4 Internal temperature, health conditions

The situation is critical in the case of the temperature measured in the upper floors. More than 66% of the respondents say it is really hot or warm in the rooms, even though the building has been renovated. It is also talkative that none of the 30 homes have chosen a "pleasant temperature" option and only 10% of them are relatively comfortable with temperature on the upper levels of the building.

It is the most difficult task to judge emerging health problems. 43% think that problems are more likely to occur when heatwaves occur, 26% cannot judge, while 30% do not notice the difference. In this respect, the survey shows consistency with the data in the literature. In general, it can be said that higher temperatures increase the health risk.

Fig. 3 *Internal temperature on the upper floors*

2.1.5 Equipment of the homes

In the remaining part of the survey, the energy saving and the most useful equipment during heatwaves (Fig. 4) were also evaluated. More than half of the nursing homes use LED light sources, and shading solutions can be found in 80% of the buildings. However, 26% of the homes have electric fans and 13% have some kind of automatic ventilation (e.g. air inlet in windows), which rate is quite low.

Residents and practitioners often underestimate the role of fans during heatwaves. Public health guidelines often say the fan is not so effective as the air temperature exceeds the skin's surface temperature, but according to O. Jay et al. [12], it is worth considering their use as they help to reduce heat-related morbidity and mortality.

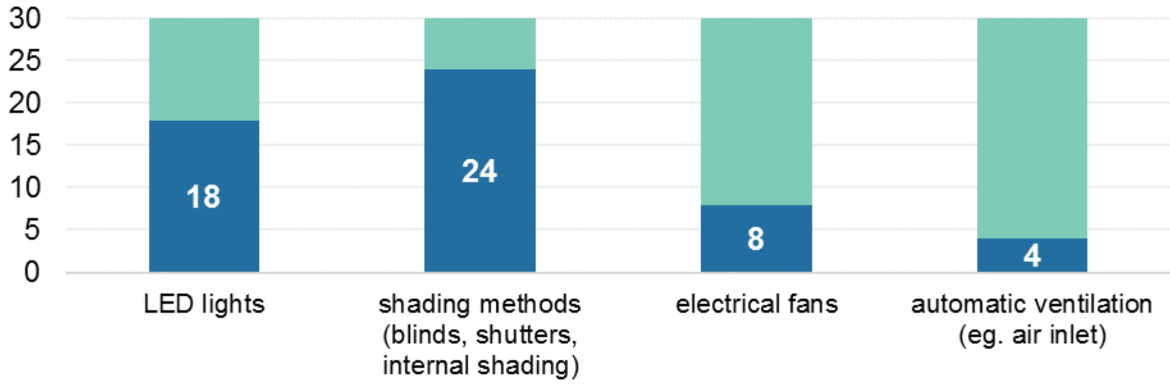

Fig. 4 *Equipment of the homes*

2.1.6 Used methods during summer

In the last section, we evaluated the methods used during the summer and heatwaves (Fig. 5). The most commonly used solution is the use of daytime shading, night-time ventilation and cold refreshments. 56% of the homes change the daily routine regularly during summer, that is, the time of daily activities, exercise classes and walks are modified due to the summer weather. More than half of the respondents regularly ventilate during the daytime in the summer heat, even though night-time ventilation is preferred. 30% of the buildings have an air-conditioned room where residents can spend a few hours.

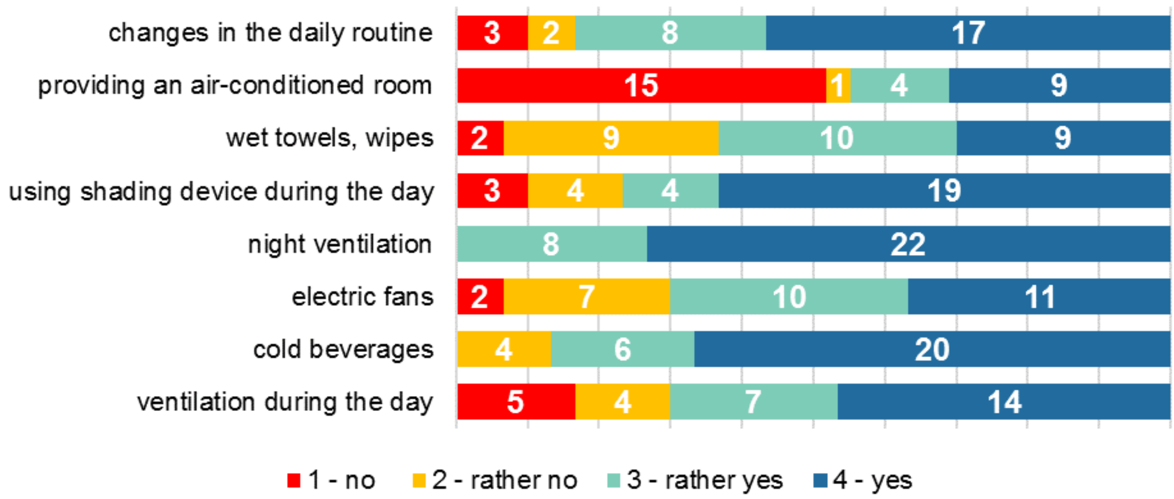

Fig. 5 *Methods used during summer and heatwaves*

2.1.7 Major conclusions

Using this survey, we learned a lot of useful information about the nursing homes in Budapest.

- We can say that most respondents work in a building built between 1946–1979, and most of the buildings in Budapest do not have air conditioning.
- 67% of the building stock have undergone some kind of energy-related renovation, but only 10% of respondents say that temperatures are relatively pleasant on higher floors.
- In general, 80% of homes have shading solutions and 60% of them use LED light sources.
- Over 80% of the nursing homes change their daily routine in hot weather and where shading is available, 76% of them use it during the day.
- The most popular methods include cold refreshments (86%), with wet wipes and towels used in 63% of the cases.

3 Overheating of buildings

There are a several factors which are influencing the overheating of a building, including internal gains, user habits, building structure, location and shading strategies. With dynamic whole-building simulation, we can assess the indoor temperatures, so we can determine how comfortable the conditions are for a given building.

In this case, overheating of the examined building was investigated by the ODH_{26} indicator, which was used in some previous research [13]. ODH_{26} is the number of hours with temperature above 26 °C, which determines the duration and the extent of the indicated overheating (unit of measure Kh/a). The analysis was performed using the validated WUFI Plus whole-building simulation software [14] in accordance with EBC Annex 41 guidance [15].

3.1 Analysed building

Building stock of the elderly homes in Hungary is very diverse, not possible to create a typology. Here we analyse one building with a large capacity, it was built in the period 1946-1979, accommodating 131 people. Several energy-related renovations have taken place, such as the installation of thermal insulation, the doors and windows have been replaced and solar panels installed. The building was mainly built of prefabricated concrete panels, the current plastic windows are made of double-layered glass with low-E coating. Only floor plans were available for the building, so the composition of the layers was partly based on on-site measurements and the typical constructions of the era. The thermal transmittance values of the structures can be found in Table 1.

Tab. 1 *Thermal transmittance of the main structures*

Structure	Thermal transmittance (W/m^2K)
basement walls	2.156
ground contact floors	2.874
façade wall	0.366
internal slab	0.859
roof slab	1.313
division wall (conc. block)	2.065

After defining the building geometry, we had to create the investigated zones. In this part we wanted to focus on the rooms where the elderly live, so the building was divided into a total of 5 zones per floor (in total 3 floors): south left, south right, north left, north right, and an “other” zone (corridor, mechanical room, staircase) as seen on Fig. 6.

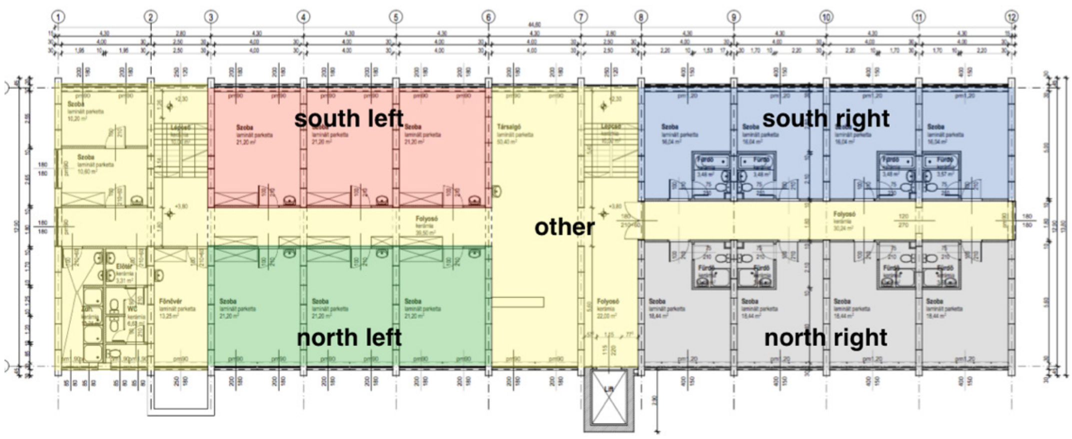

Fig. 6 *Zone distribution of a floor*

3.2 Boundary conditions

In the case of the ventilation 0.1 1/h infiltration was assumed with 0.5 air change rate during a day, while in the summer time increased air exchange (2 1/h) was used in the night hours (between 8 pm. and 6 am.). Regarding the internal gains, the values were individually set, taking into account the number of people in the zones and the activities taken. This means generally sitting or a light sitting activity and some slow walking according to the capacity of the rooms.

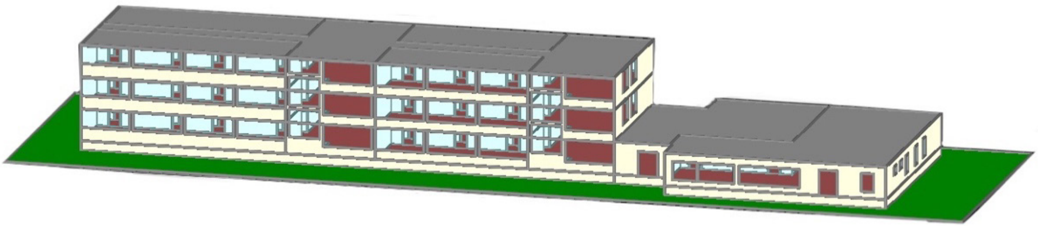

Fig. 7 *3-dimensional model of the building*

The most important boundary condition was the weather. The generated climate file used for the simulation is based on measured data. In the research we also examine the effect of the future climate, for this we used the generated weather data by IPCC A2 scenarios for 2050 and 2100.

Based on Fig. 8 the air temperature rises significantly in all future climates, the average annual temperature is 12.38 °C in 2018, 14.38 °C in 2050 and 16.44 °C in 2100. This warming is also visible at minimum temperatures (-11.7 °C, -8.6 °C, -6.5 °C) and maximum values (34.8 °C, 38.5 °C, 41.9 °C, respectively). The value of the relative humidity is approximately the same for all scenarios (Fig. 9). With respect to precipitation, the annual amount is 546 mm in 2018, 537 mm in 2050 and 491 mm in 2100.

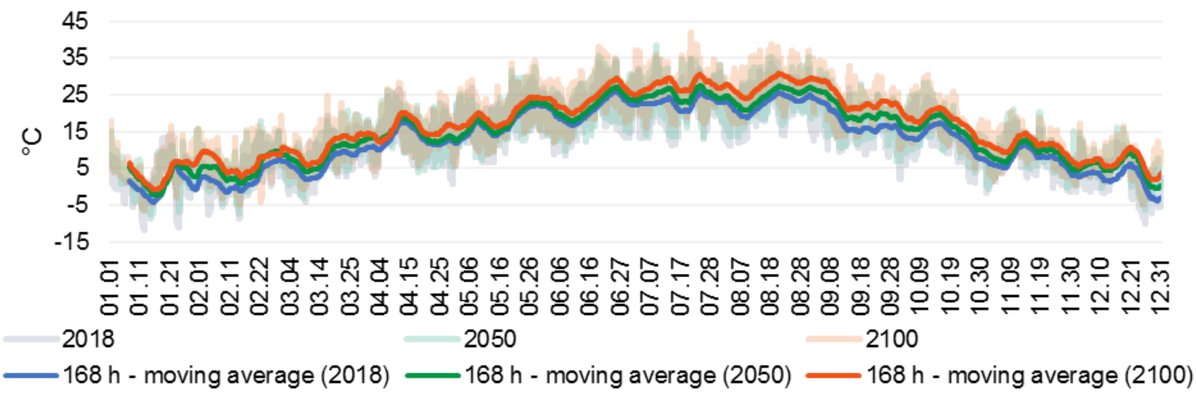

Fig. 8 *Temperature values according to the 3 scenarios*

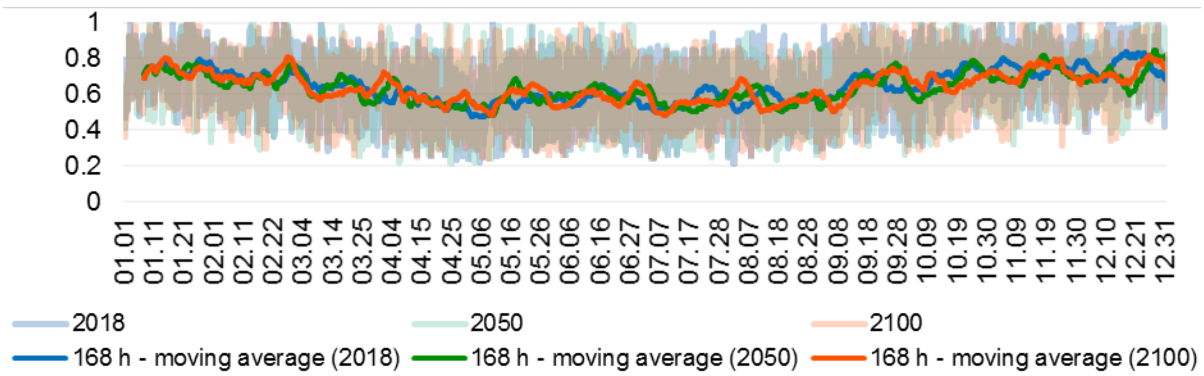

Fig. 9 *Relative humidity values according to the 3 scenarios*

Compared to the basic model (REF), we have also looked at several types of user habits that effect the value of summer overheating. We analysed the effect of air change rate and different shading options according to the software. The summer night-time ventilation rates were raised to 4 1/h and 6 1/h, and in case of shading, three different methods were used: limit radiation value (LRV), reduce overheating (REF) and schedule (SCHED) options. In case of the reference model (REF), and the optimised user behaviour model (OPT) all three climates have been investigated. From the 2-year simulation, we used the last year's data in the comparison process.

3.3 Results

The results were evaluated according to the ODH_{26} indicator. The value of the indicator was very high in the reference model – this can be seen in Fig. 10 grouped by zones and climates. Looking at the same structure for the weather in the 2050s, the value increases up to 1.5-fold. It can be seen that this value in the expected climate of 2100 – without artificial cooling – will be 2.5 times higher.

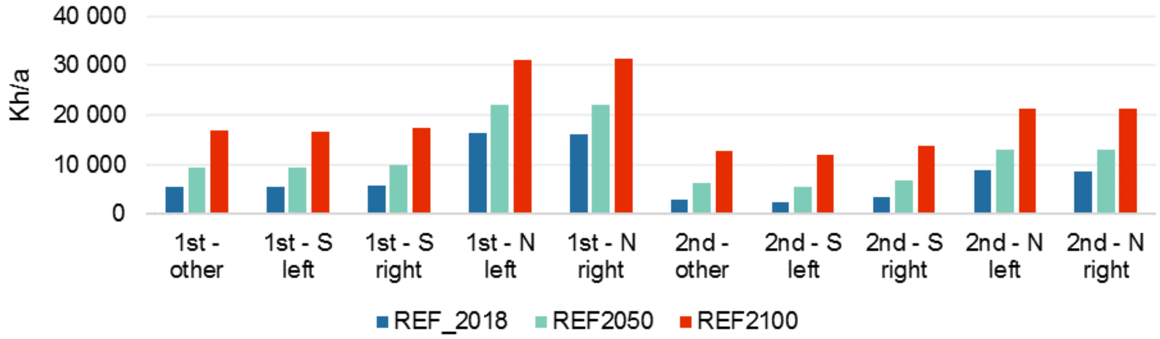

Fig. 10 *ODH_{26} values in the zones of reference building according to 3 climate scenarios*

Figure 11 shows the internal air temperatures measured in the south right zones at different levels. Generally speaking, the temperature on the 1st floor was the hottest in the same type of zone. One of the possible explanations is that the second floor without a thermally insulated roof could cool down faster during the night.

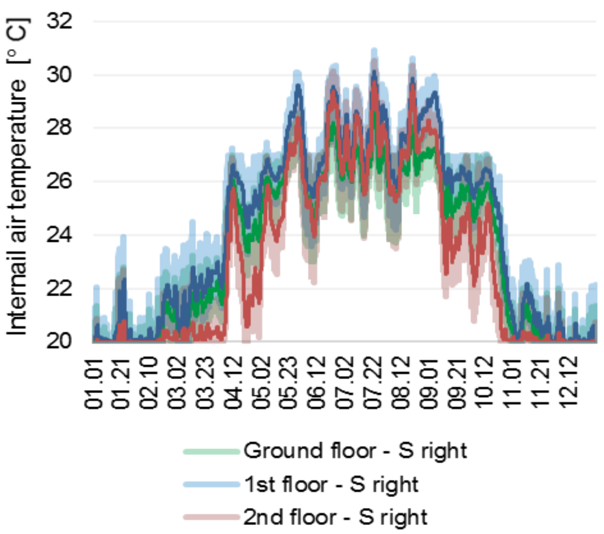

Fig. 11 *Internal air temperature fluctuation in the reference model*

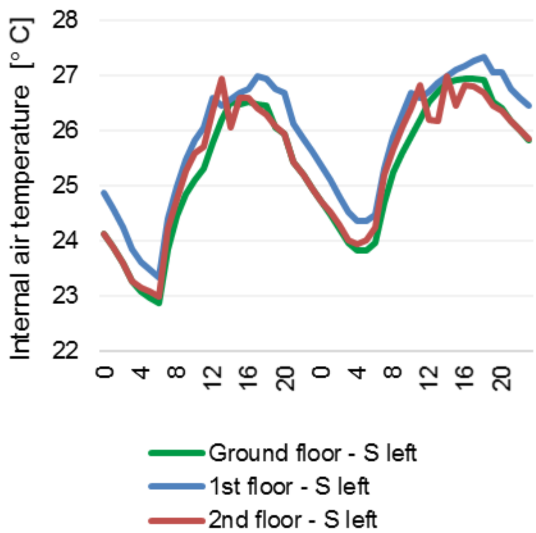

Fig. 12 *Internal air temperature fluctuation (4 1/h model)*

Increasing the rate of night ventilation significantly reduced the number of overheated hours, by using a value of 4 1/h by 36% and using a value of 6 1/h by 52%. Figure 12 shows the internal air temperature for 2 days. It can be noticed that night-time (between 8 pm. and 6 am.) elevated ventilation greatly helps to cool down the zone's internal temperature.

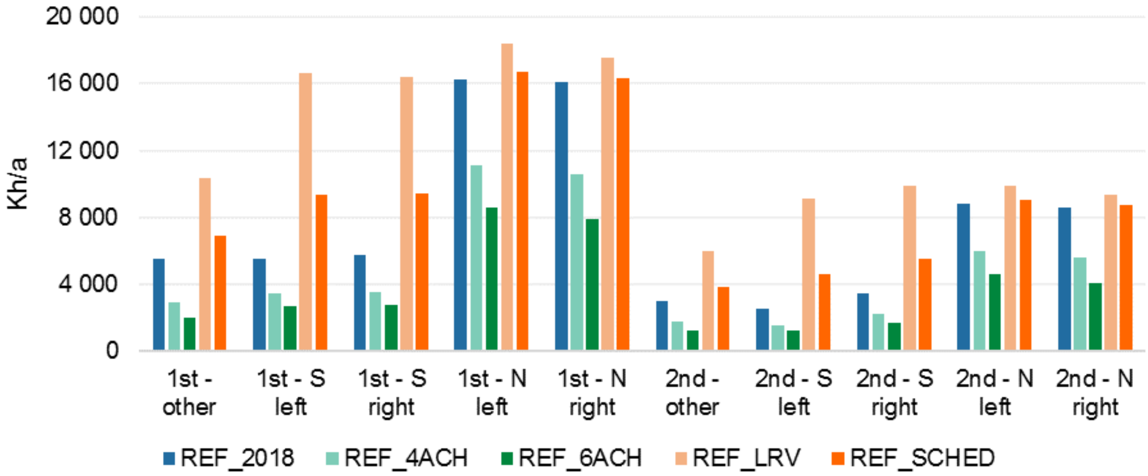

Fig. 13 *ODH_{26} values in the reference building and with different ventilation/shading*

In case of shading options, the "reduce overheating" method was the most effective, where the sunscreen device was closed as long as the maximum temperature defined in the design conditions was exceeded. With the "Limit radiation value" a maximum radiation can be entered. As long as the solar radiation exceeds this value, the device will stay closed. In this case this maximum radiation value was set to 500 W/m^2. In the last setting, during the summer period a schedule was given where the shutters were gradually lowered. They were rolled down in the morning and most of the time in the afternoon. ODH_{26} indicator values achieved by different user habits are shown in Figure 13.

With these results we created an optimized model, where the highest air change rate and the optimal shading method were used simultaneously, furthermore we used the future climate scenarios too. Based on Figure 14, it can be said that the optimized model managed to reduce the number of overheated hours by 50–75%.

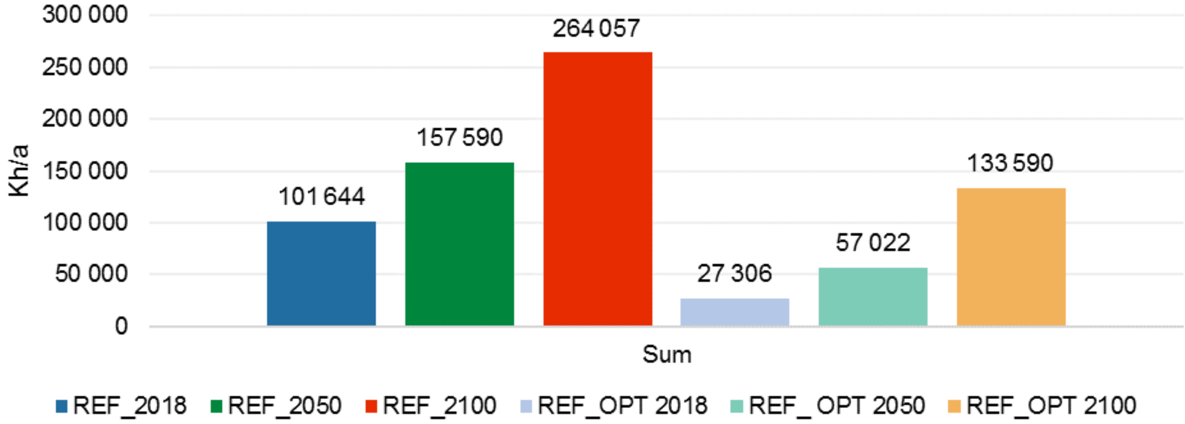

Fig. 14 *ODH_{26} values in the reference building and in the optimized model according to 3 climate scenarios*

4 Conclusions

This research contributed greatly to the assessment of the condition of Budapest's nursing homes. About half of Budapest's capacity submitted the forms and shared their opinions on the subject. Based on the results of the survey, it can be said that this group of buildings is quite vulnerable. In many cases an energy-related renovation had been carried out, but the majority of the homes are not satisfied with the indoor temperature in the buildings.

Based on the survey, the summer overheating of buildings is a very serious problem today in Hungary and it is of utmost importance to address not only the reduction of winter heating energy demand but also the overheating of buildings in summer.

The database created during the research can form the basis of subsequent analyses and can help create a vulnerability index.

Based on the results of the dynamic simulation, we determined the main parameters that play a major role in reducing the internal temperature in the summer. They can provide useful guidance for improving the overheating of a "free-running" type building during summer. Since the results clearly reveal the importance of user habits, it may be worthwhile to draw the attention of residents to the proper building management habits and their importance.

There is no analysis of artificial cooling in this paper, but it may be interesting to analyse it, as it may be an important factor in setting the internal optimum temperature in the future. It is necessary to examine the effect of the building structure on the building's warming, which would allow conclusions to be drawn on the whole of Budapest with the examination of several other buildings.

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