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RESIDENTIAL SPACE COOLING BEHAVIOUR – RESULTS FROM A COUNTRY-WIDE REPRESENTATIVE SURVEY IN CENTRAL EUROPE

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Abstract

Building space cooling (SC) demand has increased steadily in Europe for decades and is expected to rise even further. The CoolLIFE project aims at better understanding SC technologies, and passive, active and lifestyle measures. Literature on occupant behaviour in residential buildings with the focus on indoor air quality and heating energy use is available, while data on the penetration of SC devices and their usage, as well as indoor summer temperatures in dwellings is scarce and ambiguous. The paper presents results of a representative, multidisciplinary survey developed by engineers and social scientists that has been conducted in Hungary. The residents' interaction with SC devices and building elements to reduce their thermal discomfort, and specifically, their actions to restore thermal comfort through personal measures in summer were investigated and presented.

1. INTRODUCTION

Building space cooling (SC) demand has increased steadily in Europe, the average 10% European residential penetration rate has nearly doubled to 19% in 2022, which is expected to rise even more due to climate change (IEA, 2023). The CoolLIFE project, founded by the LIFE Programme of the European Union, aims at better understanding SC technologies and measures, including interventions on the levels of buildings, neighbourhood, and urban planning. CoolLIFE not only concerns of active space cooling technologies but aims at comprehensively addressing various aspects of SC technologies, including also passive SC measures and non-technological aspects of comfort, lifestyle, and user behaviour, together with an in-depth investigation into the economic, policy, social, and cultural dimensions associated with SC and actions that can avoid the need for space cooling.

While policies focus on energy efficiency requirements for building design, HVAC and building services, the improvement of the technological aspects alone does not guarantee the low-energy buildings that are needed to achieve the current carbon goals of our society. While climate has a strong influence on the theoretical SC demand, the actual penetration of air-conditioning devices in households not only correlates to climatic conditions, but also, to per capita GDP (Lapillonne, 2019). Occupant behaviour (OB) is one of the six influencing factors of the energy performance of a building (IEA, 2022), and the energy performance gap between the predicted and actual building performance is in the range of −38% and +96%. (Mahdavi et al., 2021). Building occupants perform various actions to satisfy their physical and non-physical needs to achieve acceptable indoor comfort, i.e open or close windows, use blinds, adjust their clothing or turning on the air-conditioning system. Increasing the knowledge base of OB interventions is hence a key factor for the successful implementation of energy efficiency strategies, including the reduction or limitation of SC demand in buildings.

Occupant behaviour in residential buildings has been in focus for space heating and also ventilation, e.g. (Schakib-Ekbatan et al., 2015) (Calì et al., 2016) (Schiela & Schünemann, 2021); however, OB studies on summer thermal comfort and space cooling are unbalanced both regionally, both regarding building types. While many studies exist in the US and in China, limited information is available for Europe. (Stazi et al., 2017) Buildings typologies with high SC dominance are more frequently covered, e.g. offices (Karjalainen, 2009). Among European countries, the study of Mediterranean cities is more frequent (Italy, Portugal, Spain) e.g. (D'Oca et al., 2014), while countries with less dominant SC demand are yet to be addressed.

Literature revealed that the occupants approach maintaining thermal comfort in summer and winter is different. For example, as opposed to setting a setpoint on the thermostat for heating, aiming for a constant space cooling temperature is not widely adopted. Instead, AC devices are operated intermittently, and several temperature thresholds might exist where residents start to take actions. (Zhang et al., 2011) A combination implementing passive measures within the adaptive comfort range is anticipated with activating SC devices only when the thresholds of unacceptable temperatures are reached. There is a growing body of research aiming at obtaining information and link comfort requirements, occupant behaviour patterns, drivers, causes and perceived effects of behavioural parameters, e.g. (Memon, 2022) (Zhang et al., 2018), (Yan et al., 2015), (Deme Belafi et al., 2018). Literature also points out the importance of obtaining

information on contextual factors (e.g., available control options, social factors), to enable a more accurate prediction of occupant thermal response. (Becker & Paciuk, 2009), (Wei et al., 2010). OB in residential buildings was found to be driven by building age and characteristics, and also the level of family income influences an occupant to sustain the desired or comfortable indoor environment. (Memon, 2022). While the occupant's role in the building energy use has been researched by engineers for decades, specialists with behavioural and social science backgrounds are underrepresented in the field (Deme Belafi et al., 2018).
The current work has been done by a team of engineers and social scientists to address the multidisciplinary approach that is needed to identify OB patterns, and gather information on not only the occupant behaviour, but technical aspects and the sociocultural background of the respondents. The composition of the survey has been developed to address the following aspects:

1. What are the main daily household activities related to space cooling and how do they differ in different dwellings?
2. What is the combination of factors that influence the space cooling behaviour on individual and household levels and how they differ across dwellings?
3. What are the characteristics of groups that are less committed to energy-conscious space cooling practices?

As a first step, the research concentrates on the presence of SC infrastructure in dwellings, together with the preferred temperatures, and the extent the inhabitant's implement different passive and lifestyle measures in achieving these. The paper summarizes i.) what drives the occupants in changing their thermal environment ii) what temperatures are maintained during summer, and to what extent are they satisfactory; iii) finally, how are these temperatures maintained: to what extend are SC devices and measures installed, and how are they used in the dwellings. The findings of this study can serve as a baseline for further research on the topic of how to limit and avoid the needs for the growing space cooling energy demand.

2. SPACE COOLING IN HUNGARY

Hungary can be characterized by an average 80 cooling degree days (CDD), which is the 10th largest CDD among EU countries, and is close to the average value of 74.5 considering the whole EU (Eurostat, 2023). When energy performance prediction is considered per the EPBD implementation 7/2006 (V.24.) TNM Decree, the summer comfort requirements can be met without space cooling in residential buildings by meeting the requirements for the limits of overheating, however, if overheating temperature difference limit is exceeded, space cooling needs to be considered with a constant temperature of 26 °C. Additionally, 23-26 °C has been defined as the acceptable temperature range. Hence, Hungary is a good example of a country where SC in residential buildings could be limited and avoided with careful planning and conscious operation, relying on personal actions and user behaviour. However, the air-conditioning penetration rate in dwellings is constantly rising. The estimated penetration was around 3% in 2010 (ENERDATA, 2013), which rose to 26.54% in 2022 (KSH, 2022). In 2018 the Enable.EU project conducted a surveyed confirming 11% AC penetration rate, in line with the statistical data at that time (Galev & Gerganov, 2016). Occupant behaviour in residential buildings in summer has not yet been surveyed on the large scale in Hungary, except for the actual summer temperatures in the dwellings, covered by the Enable.EU project. Hence, there is no representative data on how occupants approach SC and summer thermal comfort needs.

3. METHODOLOGY

A nationally representative survey was conducted, covering external (e.g. infrastructure) and internal factors (e.g. attitudes and habits) that affect both individual and collective space cooling behaviour, thus providing an insight into the factors that influence individual and collective decision-making. For specific topics (energy consumption patterns and everyday space cooling practices), the possible gender-specific perceptions were given special consideration. The questionnaire comprised 75 questions in 5 sections and was to be completed in 20 minutes. Five interrelated topics were addressed:

1. Patterns of energy demand, energy efficiency, and energy use in everyday situations (e.g. home office, use of smart meters, etc.), with a focus on space cooling;
2. Schedules of occupancy, differentiated by weekdays and weekends; The temporal resolution of occupations and practices;
3. Space cooling related comfort requirements; Thermal comfort and practices, including coping strategies with hot weather;
4. Location and characteristics of dwelling: housing type and size, tenure; insulation of dwellings, space heating and space cooling systems, and availability of smart meters;
5. Characteristics of households: socio-economic characteristics as gender, age, education level and financial situation.

The majority of the questions were multiple choice, with some open questions, and also several Likert scale questions (1 = strongly disagree, 5 = strongly agree) were used to capture respondents' opinions. To ensure the same survey can be replicated in further countries in the future, the questionnaire was prepared in English, which was then fully translated to Hungarian. The pilot phase of the survey took place in early April 2023. The final data collection lasted one month between mid-April and mid-May 2023. The survey was conducted online using a pool of 165,000 possible respondents from a survey panel of a market research company. The panel was created using incentives to reward participation in the survey. Unique personal links were sent to the respondents of the panel. The sample consisted of residents 18 years and older. A quota sample was used with a combination of age, gender, education, region (NUTS1) and settlement type. Respondents were selected randomly. The response rate was high: 99.9% of the respondents completed the entire questionnaire.

4. RESULTS

The survey results cover a wide range of factors that determine preferences and choices at both the individual and household level in order to understand the socio-cultural, economic and technological factors that influence the everyday practices of citizens regarding the topic of SC, which cannot be fully presented in the current paper. A first selection of the results has been done, to include the SC infrastructure available to the occupant, and their behaviour in using it.

4.1. Triggers of changing indoor temperatures in summer

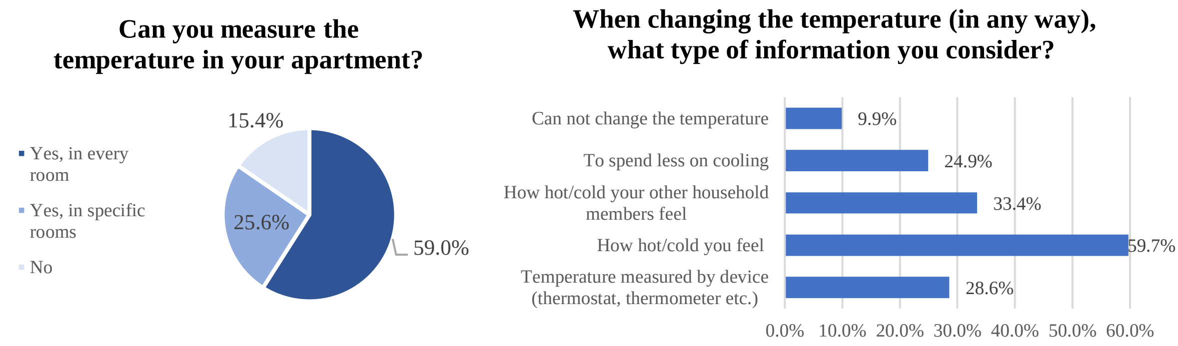
Nearly 85% of the respondents can measure the temperature in their dwellings at least in one of the rooms, however, only 28.6% of the respondents take the measured values into account when initiating a temperature change in the room. The majority of the respondents change the temperature based on how they or their household members feel, instead of considering the measurement data. (Figure 1)

4.2. Actual temperatures in the dwellings and satisfaction with these

The usual temperature in the dwellings was asked during typical day of July, when no one at the household is on holiday and everyone carries out their everyday activities for three occupancy scenarios. (Figure 2) The mode (25°C) and median values (24°C) are the same for daytime, independently of household members being at home or not. The temperatures show a higher diversity at night, the mode value is 20°C and the median value 22°C. The temperature distribution in the dwellings has not changed significantly compared to the results of the Enable.EU project in 2018.
The means of satisfaction with the temperatures was also surveyed, scores were given between: 1=very uncomfortable - 5=very comfortable. The actual temperatures indicated by the respondents were compared with their response on how satisfied they felt with the temperature in their dwelling. (Figure 3). Calculated means of the scores show that all in all up to 24 °C the temperature is considered neither comfortable nor uncomfortable, mean values are close to the middle of the scale. Specific differences, however, reveal that a temperature of 18 °C is considered rather comfortable when household members are at home – both at daytime and at night – as the average is above value 3 in these cases. A turning point can be detected at a temperature of 25 °C since the average scores of feelings of comfort decline sharply from this point on as the temperature rises. This value is lower than what is indicated as the upper limit of the thermal comfort range in the comfort standards.

4.1. Passive space cooling techniques applied in the homes

Almost everyone (97.1%) applies wearing lighter clothing but opening or closing of the windows (86.0%) and shading (82.7%) also prove to be wide-spread techniques. Also, a relatively higher share of the respondents mentioned moving less, resting (76.1%) and taking a cold shower or bath (69.6%). (Figure 4) A high portion of respondents indicated that they use shading during hot days. When narrowing down the answers to the portion of households that have some type of movable shading (89% of all households), 84% of them use it, while 16% responded not to use their movable shading it on hot days. Occupants also take several actions before leaving home: nearly 70% of the respondents shade their windows, but only around 45% closes the windows, followed by 26.9% who turn off the fans.



a) b)

Figure 1. a) Presence of measurement devices in the dwelling b) Information considered when taking actions

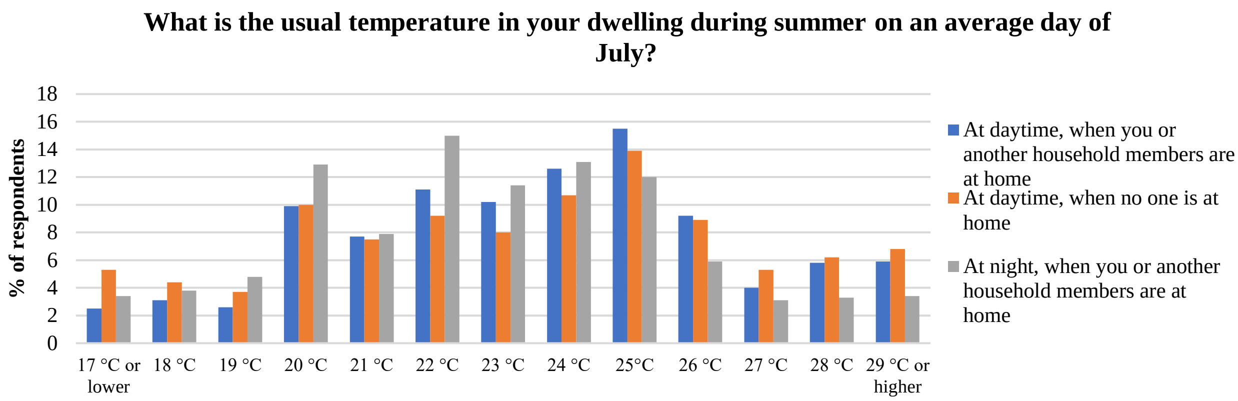


Figure 2. Usual temperatures in the dwelling during summer on an average day of July, when no one at the household is on holiday and everyone carries out his/her everyday activities. (If different in specific rooms, the coldest is indicated)

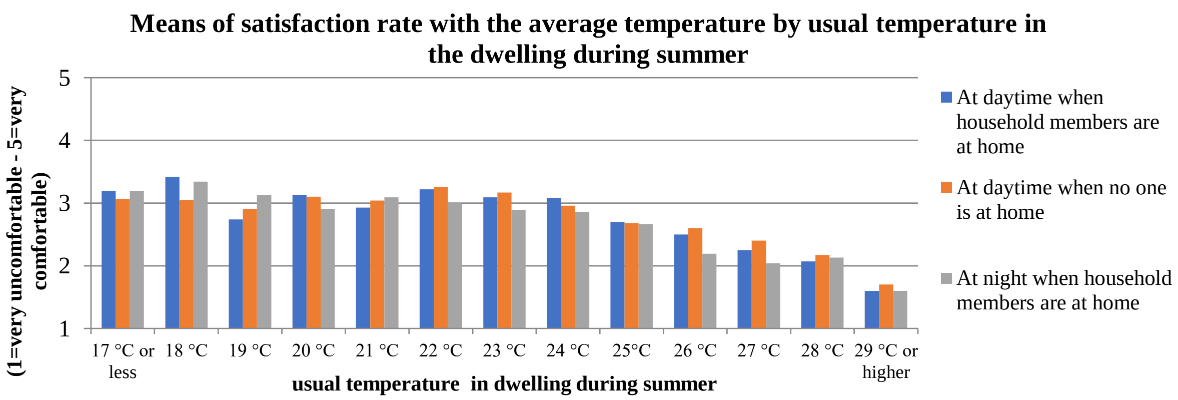


Figure 3. Means of satisfaction rate with the average temperature by usual temperature in the dwelling during summer

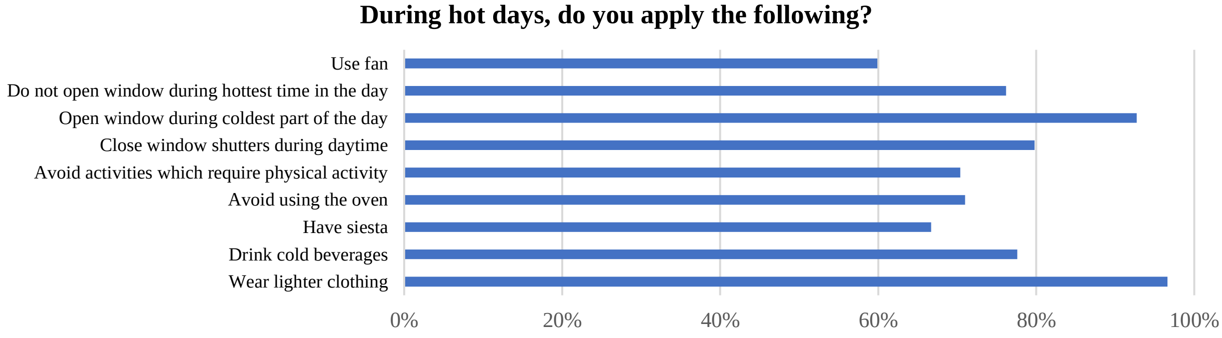


Figure 4. Behavioural measures applied in the households during hot days

4.1. Air-conditioning penetration and use

The questionnaire included answer possibilities for three types of space cooling devices in the multiple-choice question: combined space cooling and space heating devices, air conditioners for space cooling and portable air conditioners. The proportion of dwellings equipped with any kind of air conditioning units is 37.07%, and the highest share is for combined heating and cooling devices (27.3%). (Figure 5) However, when comparing the results of ownership and the use of air-conditioning devices, some inconsistencies were found in the answers for 5.35% of the respondents, all of those who have indicated to have portable air conditioning devices.

The use of the devices is mainly driven by personal comfort, activated when occupants feel warm (52.9%), while further 42.2% answered that they limit the use of SC devices to cases of extreme heat. (Figure 6a) In the "Other" category, 1.87% added they never use the air-conditioning, despite being installed.

As for the habits of the air conditioning use, the highest proportion of the respondents (33.8%) use air conditioning only during the warmest part of the day, but an essentially same rate (33.5%) tends to use air conditioning according to their comfort with an attitude to rather switch it on and off from time to time. (Figure 6b) The air conditioning is used only until the dwelling cools down to the set temperature in the case of 30.0% of the respondents, but a 13.5% operate the device all day, or most of the day. In contrast, 5.6% of the cases do not use the air conditioning during the day, 2.37% in the "Other" indicated a custom response that they use it in the evening or at night, before going to sleep.

The majority of the respondents adjusts the air conditioning to a fixed temperature (53.7%), and the rest of the sample (46.3%) controls it depending on the outside temperature.

From those who apply a fixed temperature, the majority of the respondents indicated that they set the SC device to a temperature between 22-25°C namely: 24°C, 23°C, 25°C, 22°C has been indicated by 20.9%, 17.5%, 17.3%, 16.6% of the respondents respectively. However, a number of people mentioned rather low temperature values below 20°C (7.7%) and value up to 28°C. (Figure 7a) From those, who select temperatures based on the difference of external and internal temperatures, the highest difference was 20 °C, while the most popular responses were 10 °C, 5 °C, 8 °C and 15 °C. (Figure 7b)

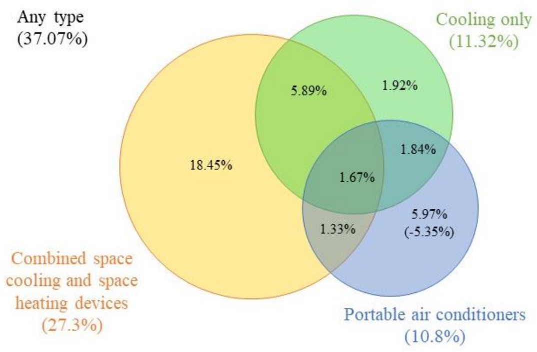


Figure 5. Percentage of dwellings with air conditioning

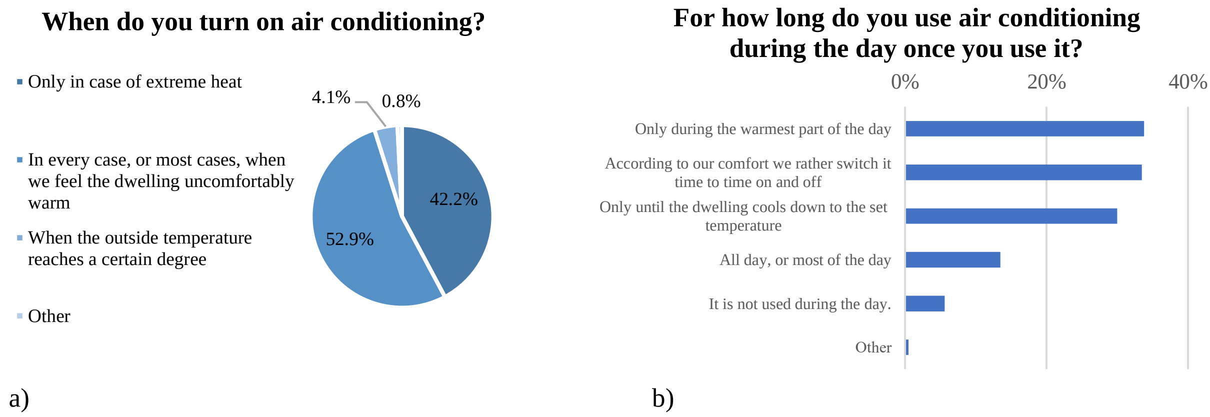


Figure 6. AC usage: a) Triggers of actions for turning on air-conditioning, b) Length of time using air conditioning

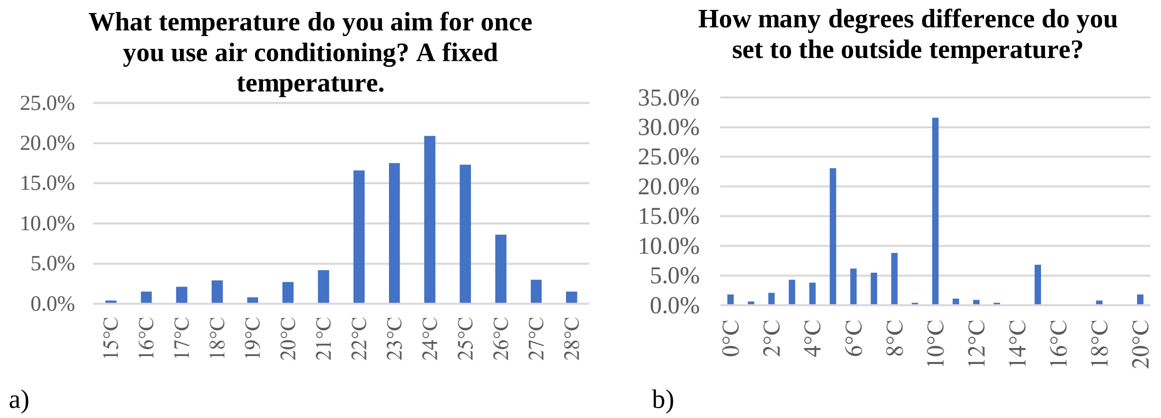


Figure 7. The preferred indoor temperature setpoint a) when setting the air conditioner on a fixed temperature b) when defined by a temperature difference compared to the outdoor temperature

When the respondents were asked what actions they take before leaving home, the majority said they switch the device off, while some respondents only change the temperature setpoints. These latter indicated temperatures in a range of 15 °C-28 °C, values that were from 4 °C lower up to 3 °C higher than what was indicated as a setpoint by the same respondents, when at home, as seen above.

5. DISCUSSION

The portion of the air conditioning equipment in households was found to be higher than the statistical values found in the literature, however, still much lower than the theoretical maximum of 69.4% calculated based on the country specific CDD values. (Jakubcionis & Johan, 2017). (Figure 8)

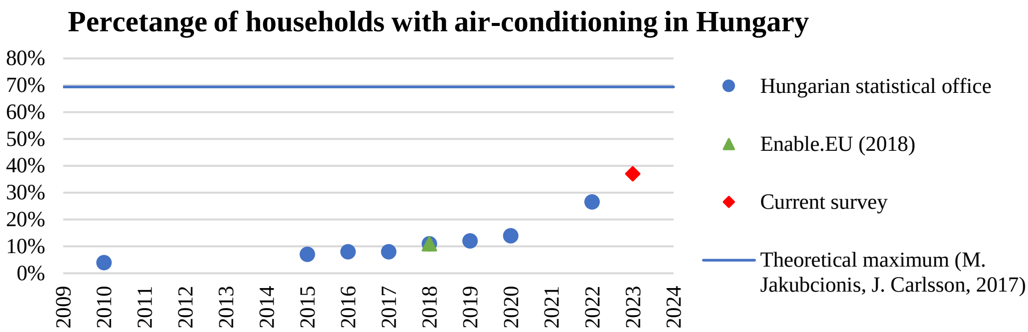


Figure 8. Percentage of households equipped with some type of air-conditioning (ENERDATA, 2013) (KSH, 2023) (KSH, 2022) (Galev & Gerganov, 2016) (Jakubcionis & Johan, 2017)

There are several assumptions for the reasons of this. Firstly, the most recent values in the literature are from 2022, already showing a rising percentage of dwellings with AC compared to the 2020 data. This can be explained by the effect of the increased occupancy of residential buildings during the pandemic. Since 2022, due to the energy crises, a disproportionate rise in the Hungarian domestic gas and electricity prices was experienced, steering the residents towards electricity instead of gas. While this trend was driven by the rising heating energy costs, it has also led to a 5-10 times higher customer demand towards combined heating-cooling equipment, which investment were not viable in the previous economic environment. Consequently, it is reasonable to assume that the amount of SC equipment in households has also risen steadily in the last year. Secondly, when using the terminology of air-conditioning equipment in homes within the statistical surveys, only a general "air-conditioning" had been considered. In the current survey the three most widespread equipment types had been included, which might have captured answers that remained hidden previously. Nevertheless, some responses might not cover reality, due to not understanding, or misunderstanding the abstract notions for energy systems used in the questionnaire. (Börcsök et al., 2020) Finally, the survey has been completed via internet. The sample is thus representative of households with internet access. According to the National Media and Communications Authority, (Nemzeti Média- és Hírközlési Hatóság, 2022) 15% of households does not even have a mobile internet connection by 2022. Among households without internet access, households in small villages, with uneducated head of the family and with an older age composition are overrepresented. This segment of households is therefore underrepresented in the sample.

Regarding the indoor temperature values, the mode and median values for the actual temperatures in the dwellings are within the comfort ranges that are indicated in the EN16798 standard, and also the values considered in the energy performance calculation for Hungary. The nighttime temperatures are however lower than the standard values and the satisfaction with the indoor temperatures also shows that people tend to find environments even cooler than the standards comfortable. As the majority of the households do not have any air conditioning devices it is confirmed that these values are reached by passive measures, possible do to the high application of window opening at night.

The setpoint temperatures for the majority of respondents, who use the air conditioning, was indicated to be between 22-26 °C, resulting in an average temperature of 22.67 °C and the median is 23 °C. While these values are within the comfort range, they are lower than the values used in energy calculations for the energy performance certificates. Additionally, the respondents have indicated setpoint values in a much wider range of, between 16 °C and 28 °C. Despite aiming for the given temperatures, only a small portion of the respondents use the mechanical SC devices all day, which is in line with the findings in the literature that AC devices are operated intermittently, in contrast to how heating is operated, and how cooling is considered in energy predictions. Also, in the majority of the cases it is justified that some setback in the setpoint temperature is applied when the building is unoccupied, however, also precooling the home while being away is applied to some extent.

6. CONCLUSIONS

The current work has been done by a team of engineers and social scientists taking a multidisciplinary approach towards surveying space cooling related occupant behaviour in dwellings in Hungary, covering a wide range of questions. The results presented here were limited to the penetration of SC devices in dwellings, their usage patterns, implementation of active, passive and user behavioural measures, together with the achieved temperatures and satisfaction with those. The results show that the majority of the occupants prefer temperatures that are within or lower than the comfort standard range, however, these are achieved mainly by passive means. The penetration of mechanical space cooling devices in dwellings has been measured to be higher than the estimations and statistical data retrieved from previous studies, which can be mainly associated with recent socio-economic trends, as well as the more detailed questioning methodology.

7. ACKNOWLEDGEMENTS

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