D3.2 Analysis of Behavioral Interventions Across Europe

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List of Acronyms

AC	Air conditioning
AMV	Actual Mean Vote
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BACS	Building Automation Control System
BREEAM	Building Research Establishment Environmental Assessment Methodology
CPP	Critical Peak Pricing
EED	Energy Efficiency Directive
HER	Home Energy Report
IAQ	Indoor Air Quality
IEA	International Energy Agency

LEED	Leadership in Energy and Environmental Design
NCM	National Calculation Methodology
NZE Scenario	Net Zero Emissions by 2050 Scenario
OB	Occupant behaviour
PMV	Predicted Mean Vote
RTP	Real-time pricing
SC	Space cooling
TOU	Time-of-use tariff
TUS	Time of Use Survey

EU country codes	
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czechia
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia

HU	Hungary
IE	Ireland
IT	Italy
FI	Finland
LV	Latvia
LT	Lithuania
LU	Luxembourg
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
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SK	Slovakia

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Keywords list

- Occupant behaviour
- Space cooling interventions
- Thermal comfort
- Schedules of operation
- Shading control
- Window opening
- Night time ventilation
- Equipment use
- Monetary incentives
- Information provision
- Nudges

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Executive Summary

For decades, building space cooling (SC) demand has increased steadily in Europe (EU27), and is expected to rise even more in the coming years (2030/2050). The CoolLIFE project has set an objective to contribute to a better understanding of Space Cooling (SC) technologies and measures to reduce SC demand, including interventions on the levels of buildings, neighbourhood, and urban planning. In order to achieve this objective a taxonomy of a wide range of SC measures has been created in *WP2 – Technologies, measures, and energy demand assessment*, to be outlined in *D2.1 Taxonomy of space cooling technologies and measures*. However, the reduction of SC demand cannot be guaranteed by new technologies alone, as the effectiveness of these systems is highly dependent on the way occupants use them. Energy performance gap between the predicted and actual performance has been reported in the range of −38% and +96% [1], of which a high portion is associated with the presence and behaviour of the building occupants. Increasing the knowledge base of occupant behavioural interventions is a key factor for the successful implementation of energy efficiency strategies, including SC demand in buildings.

The current deliverable has two focuses regarding lifestyle and user behaviour aspects of space cooling: first, i) how people use building SC systems and what do they use to avoid/limit the need for active SC; and secondly, building on this ii) how this behaviour can be changed.

The deliverable is structured as the following:

Section 1 includes the rationale and relevance of the topic, and outlines the methodologies used during the literature review.

Section 2 and 3 focus on the occupants' role in the SC demand of the buildings, considered as a bottom-up approach towards lifestyle and user behaviour interventions. These sections identify the patterns of occupant behaviour (OB) based on a wide literature review on standards, legislative and empirical data, which helps understand how the occupant is considered in the theoretical calculation of SC demand – and how they behave in reality. Section 2 is focused on the occupant presence, while Section 3 includes the reasons, drivers and also obstacles of a specific intervention aspect. The literature review covers the residential and service sector of Europe, main sources are summarized in *Annex I. - Summary of occupant behaviour surveys in European countries.* As Laaroussi et al [2] conclude, the human behaviour in residential and tertiary buildings are affected by the same motivational drivers, thus the behaviour of individuals are similar for different building types when window opening, shading control, space cooling setpoints, equipment use and thermal adaptations and expectations are concerned. However, to study the time-related aspect of SC in specific building types an in-depth analysis of the OB patterns in building types where the OB has the highest influence on SC demands was done. Based on an evaluation considering the nature of the time spent in each building type, the freedom of the occupant in restoring their thermal satisfaction (by interacting with SC devices and building elements, and adopting by personal measures to restore thermal comfort) three types of buildings: residential, office and educational have been selected for an in-depth analysis. These building types are expected to have the highest potential in reducing SC demands thanks to interventions that change user behaviour. The regional differences and time related aspects collected within this task is valuable inputs for the CM2 and CM6 of the CoolLIFE tool as well.

Building on the findings of the first part, the second part of the document (Section 4) focuses on interventions in the literature that can successfully shift occupant SC behaviours towards more sustainable ones. This top-down approach covers examples of successful interventions that impact the SC factors analyzed in Sections 2 and 3. Top-down behavioural interventions have been compiled following a review of the literature concerning residential and service sector energy behaviour-change. This includes examples of successful interventions that impact: (i) usage of electricity-powered SC appliances (i.e.: indoor fans, air conditioning systems, etc.), (ii) interaction with thermostat or A/C SC set-points, (iii) uptake of natural ventilation measures (i.e.: window opening, night-time ventilation), (iv) shading practices, and (v) occupant presence and heat-generating equipment use in the building.

Three categories of interventions with a high potential for changing SC behaviours were identified, namely:

- Monetary incentives (i.e.: dynamic pricing) to shift peak load, encourage pre-cooling, and promote energy conservation of SC appliances.
- Providing feedback and information on energy consumption to promote energy conservation of SC appliances (and other appliances that generate heat loads), encourage setting higher SC set-points, motivate the uptake of natural ventilation (including night-time ventilation), and encourage adaptive health-related behaviours during extreme heat events.
- Nudging occupants, through social comparisons or default settings, to conserve electricity in their usage of SC appliances (and other appliances that generate heat loads), set higher SC set-points (together with default dress codes that encourage the use of breathable fabrics), motivate the uptake of natural ventilation measures, and adopt efficient shading practices.

This report is readily available for consultation, mainly for policy-makers, to understand the necessary regulation environment but also the adoption practices when it comes to behavioural choices.

Summary of findings and recommendations

The current chapter provides a summary of the findings and recommendations for the policy makers. Table 1 shows the factors influencing SC demand that are dependent on the occupant lifestyle and user behaviour. The drivers, patterns and obstacles of factors were studied in detail during the literature review.

Factor	Significance for SC demand	
	What?	**How?**
Occupant presence	Internal load	Direct effect: person dissipates heat increasing SC demand Indirect effect: equipment use is higher when occupants are present
	Cooling setpoints	Higher comfort expectations when occupants are present
Equipment use	Internal load	Contributing to internal heat gains which increases SC demand
Perceived thermal comfort and adaptation	SC setpoints	Occupant actions, clothing and possibility to control the thermal environment by passive measures effects the temperature expectations in a space leading to SC demand
	Internal load	Higher metabolic rates mean higher interal loads
Space cooling set-point preferences and schedules	SC setpoints	Lower setpoints increase SC demand Setbacks in unoccupied periods can decrease SC demand
Window opening and ventilation strategies and schedules	Cooling loads	Ventilation has a complex effect on SC demand. It can either increase and decrease SC demand, depending on the internal and external conditions
Shading types and operation schedules	Solar loads	Solar heat loads through transparent façade elements are a major contributing factor in SC demand Shading can however also increase lighting, heating energy demand

Table 1. Occupant dependent factors influencing SC demand

Theoretical and realistic input data has been collected on occupant presence in both the residential sector and selected building types in the service sector. Regional differences in occupancy patterns have been identified and compared to the profiles implemented in standards and legislations.

The literature review revealed that the assumptions regarding the occupant presence in standards and legislation are not season or region specific but provide a simplified approach to considering occupancy rate and duration. Table 2 summarizes the findings on existing behavioural patterns and the intervention possibilities of occupant presence in order to reduce SC demand.

Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
Residential buildings: - is highly stochastic: high diversity due to occupant type - low diversity in regional patterns identified - no robust data on annual diversity patterns - increasing trend after COVID-19 Office buildings: - low diversity in daily patterns due to space type - low diversity in annual patterns - no robust data on regional patterns - decreasing trend after COVID-19 Educational buildings: - high regional diversity in annual patterns - some regional diversity in daily patterns Suggested occupancy patterns in standards do not capture the diversity of occupancy presence as the empirical data in literature suggests.	Limiting the presence in buildings or restructuring occupancy hours to avoid presence in periods with peak loads	Allowing flexible workplace occupancy during summer months, i.e.: "Summer Fridays". Altering start-dates and scheduling in educational institutes to reduce cooling load [3].	Develop a set of representative occupancy patterns, addressing also regional differences. Adopt policies that shift of occupancy patterns in public buildings and workplaces towards more sustainable ones, such as early closing hours in summer months. Provide information on“cool-places” for residents to go in cases of extreme heat waves.

Table 2. Intervention possibilities to limit SC demand due to occupant presence

The large scale data on residential building use collected show that these buildings typically have higher average occupancy ratios than what is suggested in the standards. Small regional differences can be seen in the daily patterns of occupancy due to different cultural habits of taking lunch breaks or siestas at home. The occupied hours and occupancy rates in the individual dwellings show high variation, and the inhabitant's socio-ecomonic, family or age status causes a much higher influence than the geographic location. From the literature, daily patterns could be identified and also differences in weekends and weekdays were shown, however, no data on seasonal patterns had been found.

For office building a more balanced pattern was found, but numerous studies were identified showing the deviation from standard approaches. The average presence shown in the empirical data is somewhat lower than what the standards suggest. Furthermore, trends in building use from the previous years has been identified, which shows a reduction in occupancy in office buildings, together with a rise in residential buildings that on one hand is caused by the hybrid-office concepts gaining more popularity, that has been accelerated by the higher penetration of home office in the post-COVID-19 era.

For educational buildings the number of annual school days, the different start and end dates, and duration of holidays in the cooling season have been collected, together with the daily patterns of use, i.e. the distribution of instructional hours. The occupancy duration shows heterogenity throughout Europe, however, for considering annual SC demand, the period of occupancy within the time of the year that is subject to space cooling is not reflected in the suggestions for energy prediction of these types of buildings.

Regarding the top-down interventions, we report examples of limiting occupant presence in commercial buildings by restructuring occupancy hours to avoid SC demand in periods with peak loads, both for office and educational buildings. Morevoer in cases of extreme weather episodes, examples of special recommendations were found to limit occupant presence in residential buildings, when the potential within the dwelling to reduce indoor temperatures is limited. These recommendations entail for example encouraging individuals to go to 'cool places' (such as parks with a pond, or an air-conditioned library or shop), during heat waves.

The collected data can serve as a baseline for policymakers to develop a set of representative occupancy patterns, addressing also regional differences. Also, it is suggested that during design, instead of using one occupancy profile, a set of profiles should be used to have robust feedback on the expected SC demand. The collected data will also feed into *T.3.3 Quantification of behavioural interventions for space cooling reduction*, where the differences arising from the identified occupancy profiles will be quantified. .

Section 3 focused on the behavioural aspects within the building. The occupants interaction with SC equipment, building elements, or taking adaptation actions is a result of a complex set of drivers, that depends on a combination of environmental factors, time dependent aspects, psychological, phsychological, cultural, habitual etc. Occupants motivation can result from discomfort (thermal, air quality, visual) or other needs that are context dependent and difficult to identify. In residential buildings the occupant has the highest freedom to interact or adapt. For the service sector in the literature it has been concluded, that the drivers for interacting with building elements is similar to residential buildings, however, the use of these are a result of a group behaviour, where not all occupants have the same level of influence on the actions. Specifically, in educational buildings the teacher has been identified as the main active occupant, responsible for taking action on heating/cooling equipment use, temperature setpoint, window opening or closing the blinds. Taking these actions are generally aligned with the daily routine of the lectures and breaks, but also influenced by the habits of the teacher.

The first presented aspect is equipment use, summarized on Table 3.

Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
High regional diversity. High diversity per household type. Reduction of equipment use in summer months: washing/drying, cooking, while the energy use of cold appliances increases.	Reduction of the use of heat generating equipment	Monetary incentives: Dynamic pricing [4]. Information provision: Feedback [5], high-involvement information [6]. Nudges: Social comparisons [7], Gamification approaches [8]. Several examples specific to reduction in SC appliances including personal fans [9] and AC systems [10].	Provision of infrastructure to implement passive drying or outdoor cooking. Inclusion of personal feedback and peer comparisons in energy bills (recommended in Energy Efficiency Directive, EED), as well as real-time information delivered through web-interfaces, or in-home devices. Adoption of Real-time pricing (RTP) schemes to shift peak loads, especially during summer months (being mindful to not affect energy vulnerable households).

Table 3. Intervention possibilities to limit SC demand due to equipment use

Similarly to the occupancy pattern the individual households have high diversity in the equipment use pattern depending on the occupant type. Equipment use highly depends on the user habits which is not addressed in the calculation methodologies, thus when considering SC predictions this variable should also considered as a set of different options tested for robustness. When reduction of SC demand is concerned, occupants have freedom in limiting the use of heat generating equipment to reduce cooling demand, and as also shown in *D3.1 Knowledgebase for occupant-centric space cooling* 71% of the occupants in Hungary do limit the use of the oven in hot weather. Limiting indoor cooking and avoiding the use of electrical dryers directly contribute to the reduction of SC demands. One study fok UK has shown that the use of appliance has a seasonality effect, that was around approximately 2% of the total average household energy use. Extensive literature on interventions is available and has been presented, from monetary incentives to nudges, which can decrease electricity usage and appliances and results in a reduced SC demand.

Next, the findings regarding perceived thermal comfort and adaptation is summarized on Table 4.

Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
A wider range of accepted indoor conditions is seen with passive cooling and ventilation, and if adaptation is possible. Change in clothing. Change in activity levels. Adaptation by consuming cold food/drinks. Ability to control the thermal environment	Increase the usage of adaptive measures to limit periods when active SC equipment need to be used.	Flexible workplace attire in summer months (i.e.: "CoolBiz") [11]. Health-related information on adaptive behaviours during heat-waves (i.e.: hydration, using cold-packs, wet towels, etc.) [12].	Built environment: Provision of passive cooling measures to extend periods without using mechanical SC Relaxing dress codes in institutional buildings. Fostering innovation in "cooling fabrics" and encouraging more widespread market adoption of breathable clothing. Provide health-related information on adaptive behaviours during heat waves, ideally through high-involvement actions (consulting, audits, targeted information, public events).

Table 4. Intervention possibilities to limit SC demand by shifting perceived thermal comfort and adaptation

As outlined in *D3.1 Knowledgebase for occupant-centric SC* as well, the thermal comfort sensation is dependent on a wide range of social, adaptational and health factors. While the acceptable thermal comfort limits for conditioned spaces are well aligned through Europe, the avoidance of the use of SC demand has lower emphasis, nevertheless can be enhanced by conscious use of adaptational measures. The main influential factors and regional practices have been summarized in the referred deliverable. Lifestyle and behavioural interventions cover environmental changes, e.g. operation of building elements (shading, openings), or turning appliances on/off, personal adjustments that change the sensation of comfort (e.g. changing clothing or taking cold drinks), and psychological adaptations (acclimatization), as detailed in *D2.1 – Taxonomy of space cooling technologies and measures*. Change in clothing, change in activity levels, adaptation by consuming cold food/drinks and ability to control the thermal environment have been studied in detail, and findings of the CoolLIFE survey also show that in residential buildings implementing these measures has high penetration. While the change of clothing is widely possible in residential buildings, office and educational buildings may have stricter rules. Intervention examples collected have shown successful focus on generating energy savings by relaxing dress codes and providing health-related information on adaptation measures during extreme weather events.

When thermal comfort is not met with adaptation, space cooling may be acitvated. Table 5 summarizes the findings on existing behavioural patterns and the intervention possibilities to the space cooling set-point preferences and schedules in order to reduce SC demand.

Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
Requirements are standardized, however, in the residential sector diverse setpoints are implemented High regional diversity in the ratio of installed SC devices installed in the residential sector Setpoints are not implemented continuously, but adaptive methods are used, then SC devices are activated intermittently on full power	Decrease SC usage by implementing higher setpoints Adjust SC patterns to the needs	Setting higher default set-points in thermostats [13] [14]. Provide framed information on the energy and health implications of lower temperature set-points [15].	Education campaign on the usage of SC devices. Encourage the inclusion of "interactive feedback" in thermostats (i.e.: including information on efficiency of chosen set-points, and environmental/health implications).

Table 5. Intervention possibilities to limit SC demand by shifting space cooling set-point preferences and schedules

The cooling setpoints in buildings have a direct effect on the energy used for achieving thermal comfort. In comfort standards and legislation throughout Europe the setpoint considered for SC is generally 26°C operative temperature, when active cooling is concerned. However, as outlined in *D3.1 Knowledgebase for occupant-centric space cooling* the cooling setpoints alone are not representative on how SC devices are used, as these devices are installed in only a fraction of relevant spaces and are operated intermittently. Information has been compoled on the drivers and patterns of AC usage. The empirical data available suggests that setpoints in many cases are set to low temperatures, even around 17°C. However, the literature review also revealed that the temperature setpoint indicated on the SC devices may not be corresponding well to the actual temperature, thus the desired temperature in the dwelling. Lower setpoints are anticipated to result in faster decrease of the temperature by the occupants, while it seems that this tempeture is not achieved in the dwellings. The operation of SC devices in dwellings is driven by event related factors like arriving home or leaving the house.The Hungarian case study shows that 79.1% of the respondents turn off AC devices or adjust setpoint temperatures when leaving the house, the others do not take any action, and leave the device running. The thermal sensation is an important factor in turning on the devices, while the indoor temperature is not concerned as an objective value in the majority of the cases. The literature suggest that the probability of turning on AC devices increases around 25-30°C internal temperature or 36°C external temperature.

Although the setpoints cannot be taken as an objective value of indoor temperature, shifting towards an accpetance of higher temperatures and consequently increasing setpoints has a direct effect on reducing SC demand, which has been proven to be successfully initiated by setting higher default setpoints on thermostats and providing different types of feedback.

The fourth occupant action summarized is window use, which has a complex effect on the SC demand, however, the guidelines for the consideration of the dynamic effect of window opening is rarely set in the energy prediction methodologies. Window opening is clearly driven by indoor and outdoor temperatures, but also poor indoor quality (CO_2 concentration) has influence. Also, window opening is dependent on the time of the day/occupancy and the season, and events like arrival at home, while closing the window additionally is driven by security reasons. Lifestyle factors have also been identified affecting ventilation strategies, like smoking, which is banned in most of the EU countries in commercial buildings, but is hard to limit in residential buildings. Summer night time ventilation potential is high in most parts of Europe, especially in rural locations, however, the practical implementation of this passive SC measure is hindered by safety and security reasons as well as comfort (noise) issues, as highlighted in the literature. A possible direction in increasing night time ventilation is through improving the night time urban environment to allow for safe and comfortable ventilation. To increase the uptake of this measure also framed feedback information can be provided. Table 6 summarizes the findings on existing behavioural patterns on window opening and ventilation strategies and schedules in order to reduce SC demand.

Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
Window opening is driven by environmetal (temperature, air quality, humidity, noise) and habitual/time related patterns: arrival,departure, morning, cooking. Diversity in regional potential: Night cooling has higher potential in middle-northern Europe Night cooling is hindered by noise, burglary, inconvinience, discomfort (draught, light).	Summer comfort driven use of windows: utilize cooling potential, but limit heat loads Increase night time ventilation	Framed feedback on optimal window-interaction behaviours, including peer comparisons [16].	Design guidelines/requirements for effective natural ventilation. Facilitation of night cooling by enhancing urban quality: e.g noise reduction, increased safety. Increasing night cooling potential by reducing heat island effect. Provide easily accessible information (i.e.: on energy bills) highlighting desirable social norms around passive cooling behaviours (i.e.: "the majority of people use shading and night-time ventilation to cool their homes").

Table 6. Intervention possibilities to limit SC demand by shifting window opening and ventilation strategies and schedules

Finally, intervention potential with solar shading is summarized on Table 7. Solar shading, and especially external shading is an effective measure to reduce SC demand, pilot projects demonstrating that such systems can enable energy savings up to 60% for lighting, 20% for space cooling and 26% for peak electricity [17]. While requirements in the EU exist for maximum g-values of transparent building elements, providing shading devices alone do not guarantee notable reductions in SC demand. Many studies discuss the optimal operation sequence of shading devices from rule-based controls based on one environmental parameter to complex algorithms. However, as shown through the literature review, the operation of shading systems when left to manual control is less than fully effective. Regarding the residential sector, the CoolLIFE survey revealed that up to 19.8% of the respondents who have manual shading devices in their home do not apply these on hot days, while this value is lower, however, still around 8 % when electric roller shutters are provided. For commercial buildings the operation frequency when left to manual control is even worse, one study evidenced that blinds were moved less than 2 times a week, regardless of the orientation or season [18]. The main drivers for using blinds and shading were found to be visual or thermal discomfort, while to reduce SC demand, a combination of the environmental parameters of solar radiation on the facade, internal and external temperature are proven to provide higher benefits, which requires a more complex decision making process from the occupant. Thus, the operation of shading devices can be considered as a measure where it can be argued that efforts to promote more sustainable SC should also focus on automation, rather than aiming to change inefficient behaviours.

.Existing behavioural patterns	Field of intervention	Example of successful intervention	Suggestions for policy makers
Shading in residential buildings is an important passive measure. Manual shading control results in suboptimal, or even increased annual energy use. Shading usage is mainly driven by visual discomfort and interaction with shading is rare. Optimal shading control algorithms for automated shading are present in the literature: solar irradiance, illuminance, indoor and ambient temperature and occupant presence are driving factors.	Increase interaction frequency and concious control Always shade when building/space is unoccupied	High-involvement information on the optimal use of shading system. Optimal settings of shading system set as default in offices [19].	Design guidelines/requirements for effective shading technologies. Educational/feedback campaign for more concious shading control. (e.g. close blinds when leaving home) Incentives for shading automation. Encourage the adoption of optimal shading settings as default in public buildings and workplaces.

Table 7. Intervention possibilities to limit SC demand by through solar shading control

1. Introduction

As described by the IEA [20], occupant behaviour is one of the six influencing factors of the energy performance of a building. Occupants' interactions with the energy system shape building operations and thus the energy use and indoor comfort. Moreover, new technologies alone do not guarantee a reduction in energy consumption in buildings, mainly because of i.) adoption challenges due to the interaction between humans and technologies, and ii.) the rebound effect. Therefore, increasing the knowledge base of occupant behavioural interventions is a key factor for the successful implementation of energy efficiency strategies in buildings.

The concept of energy-related occupant behaviour in buildings can be defined as occupants' behavioural responses to discomfort, presence and movement, and interactions with building systems that have an impact on the performance (energy, thermal, visual, and Indoor air quality - hereafter: IAQ) of buildings. These can cover as adjustment of thermostat settings, opening or closing windows, pulling up or down window blinds, or adaptive routine practices, among others.

Energy performance gap has been reported to be somewhere between −38% and +96%, of which is in a high portion associated with the presence and behaviour of the building occupants. [1] A Lithuanian study on space heating use compared different occupancy profiles as an input for energy modelling in a residential building, and showed an increase of 30%-43% energy consumption for space heating, 1%-30% increase for electricity for auxiliary equipment and between a reduction of 25% to an increase of 7% for lighting, when changing the assumed inhabitants from 4 persons (two adults, 2 kids) to 2 person households: actively working and pensioners. [21] Moreover, behavioural changes can also reduce the number of discomfort hours, e.g. implementing night-time cross-ventilation instead of ventilating only the bedrooms was predicted to reduce discomfort hours by 26% in Hungary [22], which combined with higher tolerance to higher temperatures can help eliminate the need for space cooling devices in countries with limited space cooling needs.

Measures that can affect space cooling energy performance have been collected for the report *D2.1. Taxonomy of space cooling technologies and measures*. Lifestyle and behavioural interventions cover environmental changes, e.g. operation of building elements (shading, openings), or turning appliances on/off, personal adjustments that change the sensation of comfort (e.g. changing clothing or taking cold drinks), and psychological adaptations (acclimatization).

For this deliverable, we have analyzed the occupants role in space cooling demand, through a top-down and bottom-up approach. The bottom-up approach is the behaviour driven by the occupants themselves, where they interact with the building elements and systems to maintain their thermal comfort. By top-down we mean interventions that are not initiated by the occupant directly, but motivated externally, let it be policy or financial incentive, that pushes the occupant to interact. In other words, bottom-up is the occupant behaviour (OB) itself, whereas top-down are interventions to shift specific behaviours that impact space cooling demand. Consequently, to understand the effectiveness of a certain top-down action, the bottom-up motivation needs to be mapped beforehand.

Case studies, surveys and monitoring results have been collected and compiled, to understand how buildings are used, and how behavioural and lifestyle interventions adopted by building occupants can affect on one hand space cooling needs, or help to adapt to thermal discomfort in residential and commercial buildings.

The goal of this research is to set a basis for quantifying these aspects, and set a basis for defining their impacts on the building energy use. Relevant daily occupancy patterns, user interventions and their impacts related to space cooling are mapped. To compare the effect on the building energy use, the country specific regulations and standards are also compiled that serve as a baseline for simulation. We cover scientific literature and global standards and guidelines, as well as previous projects' open databases. However, the current deliverable is not meant to cover all types of regulations implemented in Europe regarding space cooling, this will be analyzed in WP4 and presented in *D4.1 – Review and mapping of legislations and regulations on sustainable space cooling at EU and national levels.*

After collecting behavioral measures in Chapter 3, Chapter 4 Interventions to reduce energy use for space cooling) of this report will summarize policy interventions (especially considering nudges and successful implementation examples) that lead to changing the behaviour of the occupants.

1.1. Rationale and relevance

A key global milestone for behavioural change in the building sector in the Net Zero Emissions by 2050 Scenario (NZE Scenario) from the International Energy Agency (IEA) requires space heating temperatures to be limited to 19-20°C and space cooling temperatures to 24-25°C by 2030, alongside reductions in hot water temperatures. [23] Occupant behaviour (OB) and space cooling (SC) are mutually linked. On the one hand, OB is one of the greatest influences on building energy performance, which can contribute to the performance gap of the actual and predicted energy use in the order of magnitude of 50-100%. On the other hand, SC decisions can influence comfort and health, through which they deliver a wide variety of socioeconomic co-impacts beyond the field of energy. To address these, there has been a recent paradigm shift in the way occupants are considered, from passive users to autonomous agents who respond to environmental quality through adaptive actions. One main objective of this project is to increase the uptake of occupant-centric design and decision-making in the SC sector. This can be broken down into four main challenges that we will address: (1) providing a better understanding of how culturally influenced lifestyles and adaptive comfort interact with SC performance, (2) providing a knowledge base for multiple (professional, private, public, citizen) actors on how to transition to a more sustainable SC through behavioral interventions, (3) providing a better understanding of the social and economic co-impacts of SC, and (4) expanding the data and knowledge base of SC in the largely unexplored residential sector [24]. The current report focuses on 1) and 2) of the above list.

This thorough investigation of OB will provide a better understanding of the necessary regulation environment but also the adoption practices when it comes to behavioral choices. This task will also feed T.3.3, for the quantification of energy differences arising from the identified behavioral interventions.

1.2. Methodology

For this task, we adopted a traditional methodology for the literature review, in which we identified key academic research articles and standards from the field, based on databases and our own knowledge. We derived to more literature as we define the research questions, and further refined our search based on the findings.

The research questions we established emerged from the objectives of the Task 3.2 as described in the project's Grant Agreement and the theoretical framework of the investigation:

Occupant behaviour:

- What types of behavioural and lifestyle interventions are adopted by building occupants to i.) reduce SC needs, and ii.) adapt to thermal discomfort?
- What are the patterns of the daily interventions and how can these impact SC?
- What are the regional differences in adopting these patterns?
- What are the differences when residential sector (single-family houses – SFHs, multifamily houses – MFHs, and apartment blocks – ABs – with > 4 floors) and service sector (offices, trade, education, health, hotels and restaurants, and other non-residential buildings) is concerned?
- What is the difference between the anticipated occupant behaviour used during the design of SC systems and the real presence or behaviour of occupants?

The latter question helps close the gap between the simulated and real energy demand, which will be feed into *D3.3. Multiple, socioeconomic impacts of sustainable space cooling*.

Behavioural interventions:

- What types of policy interventions exist, especially considering nudges and successful implementation examples?
- What is the expected impact of these regarding SC demand?

With these questions in mind, we started the search for academic articles in different databases, such as Web of Science, Scopus, Google Scholar, and Science Direct. As was the case of T.3.1, we cover scientific literature and global standards and guidelines, as well as previous projects' open databases (e.g. Culture-E, inBETWEEN, eTEACHER, energychange, BEHAVE, etc). As we conducted a manual search, we relied on our expertise and previous knowledge of the topic. We defined selection criteria that will help us decide which articles to consider and include in our work. The criteria were:

- Language: English (consider other languages if at least two people in the team speak it)
- Geographical area: Europe and/or global (for relevant examples)
- Type of literature: academic publications, grey literature, industry standards, legislations
- Time period: literature not older than 15 years (with exceptions in cases of key publications)
- Academic relevance

To cover the regional aspect the literature search was aimed at finding examples from different countries representing different climate zones and regions, by focusing on the following countries as a priority: Italy, Germany, Hungary, Austria, Netherlands, Sweden. However, where lack of data was found, further sources were considered.

2. Occupancy patterns in buildings affecting space cooling demand

Based on Laaroussi et al, [2] the human behaviour within buildings is characterized by two aspects: i) the presence of occupants inside the buildings which causes direct CO_2 emissions, heat and vapour dissipation. The presence of occupants then lead to ii) the occupants' interaction with their environment. The use of the various systems in buildings (heating, ventilation and air conditioning, windows, shading, lighting and domestic hot water) affects the energy consumption and related to the occupants' needs and preferences. The effect of the occupant on the space cooling demand has been summarized in Table 8.

Factor	**Significance for SC demand**	
	What?	**How?**
Occupant presence	Internal load	Direct effect: person dissipates heat increasing SC demand Indirect effect: equipment use is higher when occupants are present
	Cooling setpoints	Higher comfort expectations when occupants are present
Equipment use	Internal load	Contributing to internal heat gains which increases SC demand
Perceived thermal comfort and adaptation	SC setpoints	Occupant actions, clothing and possibility to control the thermal environment by passive measures effects the temperature expectations in a space leading to SC demand
	Internal load	Higher metabolic rates mean higher interal loads
Space cooling set-point preferences and schedules	SC setpoints	Lower setpoints increase SC demand Setbacks in unoccupied periods can decrease SC demand
Window opening and ventilation strategies and schedules	Cooling loads	Ventilation has a complex effect on SC demand. It can either increase and decrease SC demand, depending on the internal and external conditions
Shading types and operation schedules	Solar loads	Solar heat loads through transparent façade elements are a major contributing factor in SC demand Shading can however also increase lighting, heating energy demand

Table 8. Occupant dependent factors influencing SC demand

To understand how the occupants' lifestyle and user behaviour intervention can influence the space cooling demand in the building first, we have to understand when occupants are present in the building. In this chapter we give an overview of how the occupants use the different types of buildings, on different parts of Europe, also concerning the seasonal or daily variations that might affect space cooling needs. In the second part we will analyse how the occupants can interact with building elements, and what are their drivers in doing this.

While the intervention is limited with one's habits regarding the presence in buildings, with targeted action or campaigns these can be also changed in order to survive extreme situation. The current work helps understand how the buildings are occupied in reality to get more precise inputs in planning. In the lack of building automatization, which is the base case for residential buildings, the presence of the occupant also has a direct effect on the use of other equipment and building elements, like cooling equipment or window opening.

2.1. Relationship of occupancy, occupant behaviour and space types

A wide literature review on OB surveys has been done to identify sources of occupant patterns, drivers of occupants for different space types. While the literature of occupant behaviour is constantly growing, the territorial and functional diversity of those are limited. Where possible information that is specific for Europe was collected. The OB surveys done on this topic in Europe have been summarized in the Annex I. As a summary it is seen that office and residential buildings are widely represented in the literature, while for other functions the research is limited. Based on the review we have investigated the cause of this, by identifying the relationship of occupant behaviour and space types. In this section the main characteristics of the buildings and the means how occupants use these spaces is summarized. The evaluation is based on the degree of freedom the occupants have in controlling their indoor thermal environment and implement user, lifestyle of behavioral measures to maintain their thermal comfort. This section indefies for each building type:

- Can the occupant directly control SC, windows, or shading within a building type?
- Can the occupant change their thermal sensation by applying adaptation methods, as summarized in Deliverable D2.1 – Taxonomy of space cooling technologies and measures e.g. having a drink, changing clothing, changing position in space?
- Does the occupant action dependent on multiple users within a group of people?
- Are the actions freely accessible throughout the time spent in that particular building, or is the freedom limited in time.

Table 9 summarizes the evaluation of the above aspects using the building typology used in the CoolLIFE tool [25].

		Turn on SC device/ adjust setpoimt	Open/close shading or curtains	Open/close windows	Operate ceiling fan	Turn on/off appliances	Putting on/taking off clothing	Changing activity level	Changing posture of human body	Moving to a different location	Hot/cold drinks or food	Taking a cold shower
Residential	SFH	++	++	++	++	++	++	++	++	++	++	++
	MFH	++	++	++	++	++	++	++	++	++	++	++
	AB	++	++	++	++	++	++	++	++	++	++	++
Service	offices	+ +[1]	+++[1]	++ -[3]	+	+	+	-	+	- +[4]	++	-
	trade: services	+[1]	+[1]	+[1] /-[3]	+[1]	-	+	-	-	-	+	-
	trade: retail	-	-	-[3]	-	-	+	-	-	+	+	-
	education: school, university	+[1]	+[1]	+[1]	+[1]	-	+	+[2]	-	-	+[2]	-
	education: daycare, kindergarten	+[1]	+[1]	+[1]	+[1]	-	+[1]	+[1]	++	+[1]	+[1]	-
	healthcare: in-patient	+[1]	+[1]	+[1]	+[1]	-	+	-	-	-	+	+
	healthcare: out-patient	-	-	-[3]	-	-	++	-	-	-	+	-
	hotels, hospitality	++	++	++	++	+	++	++	++	+	++	++
	restaurants, cafes, bars	- +[1]	- +[1]	- +[1]	-	-	+	-	-	++	++	-
Other	sports and leisure	-	-	-	-	-	++	++	+	+	++	-
	industrial buildings	-	-	-	-	-	+	-	- / + [2]	- / + [2]	+	- / + [2]
	transport facilities	-	-	-	-	-	+	-	-	-	-	-

Legend:
++ high degree of freedom
\+ low degree of freedom
\- no freedom
1 interventions done centrally or by proxy, not by individual user (e.g. customer)
2 possible at certian times only
3 operable windows are not imperative of these building types
4 agile offices only

Table 9. Degree of freedom of building users to control their thermal environment and implement adaptation measures in maintaining thermal comfort

2.1.1. Residential buildings

The residential sector can be broken down to single-family houses – SFHs, multifamily houses – MFHs and apartment blocks – ABs – (with > 4 floors), where the former consists of one dwelling unit, the latter two of multiple individual units. With one dwelling unit the occupants have high freedom in adapting to their thermal environment: they can open windows, close shading (if provided), change clothing, change metabolic rates. They have a high degree of freedom in changing their position in space, limiting the use of heat consuming equipment.

Occupants in SFHs have the highest degree of freedom in changing their thermal sensation, compared to the other types of residential buildings. SFHs are characterized by a higher floor area per building occupant which allows more freedom in avoiding spaces with higher thermal loads. Especially in case of SFHs, facilities can be provided for the occupants to move to an outdoor or semi-open space locations, e.g. terraces for every day activities, e.g resting, eating, or even cooking, which reduces the need to control indoor thermal environments. This option is less viable for ABs and dense urban locations.

The ratio of dwellings equipped with air conditioning units in 2010 was between 1-99% , with the highest share of buildings in Spain, Malta and Greece (55%, 56% and 89% respectively). [26]. SC demand in residential buildings is constantly increasing. While space cooling only accounted for 1.6% of the household electricity consumption at EU level in 2019, the consumption is constantly growing. The the average consumption per dwelling changed from 19 kWh/household in 2000 to 59 kWh/household in 2019. [27] The highest consumption per dwelling is seen in Croatia, Bulgaria, Cyprus and Malta.

The occupancy of the dwellings throughout the year is continuous, showing a pattern that is aligned to the daily habits of the inhabitants. Seasonal differences in occupancy rate can be associated to different habits, for example, travelling on summer holiday can reduce space cooling demand. However, regarding this, regional differences exist. As Eurostat concluded, in 2019, 29% of Europeans could not afford even one week's holiday. At the high-end of the list countries with high space cooling demand are seen e.g Greece (49%), Croatia (48%), Cyprus (45%) and Italy (44%), while in contrast, at the lower-end of the scale, Sweden, Denmark and Luxembourg, Finland, Germany and Austria were seen with 10%-13% of people not able to afford a one-week annual holiday. The effect of the summer holiday on the SC demand is seen as ad hoc, and cannot be taken as a general effect. [28]

2.1.2. Service buildings

In contratry to residential buildings, in these types of buildings the main users, i.e. employees, customers, patients do not directly benefit from the achieved savings. Thus the motivation for changing the individual occupant behaviour is much lower than for residential buildings. Moreover, the occupants' freedom in adaptation to the thermal environment is also limited. Indoor environmental parameters in these types of buildings are either defined to provide comfort of the occupant – thus lead to a higher customer satisfaction, productivity and eventually, income - or the technological aspects, e.g strict conditions for food security and safety, health, or industrial processes.

Office buildings are the main types of buildings that are studied within OB researches. Occupants spend a high portion of their time at workplaces, and are involved in sedentary activities. Providing a comfortable thermal environment in offices is important as it increases productivity. However, with increasing requirements for building energy performance and sustainability and by recognizing the gap between the predicted and actual energy use has driven attention to the importance of occupants' behavioral and presence patterns. The literature regarding OB studies is the most widespread among space usage types.

In office buildings, the space usage can be in form, in cellular or open space layouts. The occupant freedom in the former is higher, while in the latter the group behaviour is predominant. In the last few years a growing trend of agile workplaces give a much higher freedom to users than traditional office layouts.The freedom of occupants to intervene with building elements and SC equipment is more constrained that in residential buildings, however the adjustment of SC setpoints, shading and windows where provided, blinds are typically assessable for the building occupant, however, the actual use of these does not only depend on the individual preferences, but is also influenced by the group dynamics. Limited freedom is given to the occupants in changing their clothing, especially in offices where dress codes are implemented. Further measures like taking a shower or decreasing metabolic rates is less feasible in most of the offices. The reduction potential in the use of particular heat generating equipment is also limited as equipment heat load is coming from the use of equipment needed to carry out work activities.

Educational buildings: Compared to office and residential buildings one of the most studied space type in the field of OB research are educational buildings. This is not surprising, as Lala and Hagishima [29] conclude, students typically spend more than 15,600 hours (hs) in classrooms by the time they graduate from high school. IEQ in classrooms is important as a close relationship exists between student's learning abilities, psycho-social development, problem-solving abilities and health and the Indoor environment quality (IEQ) in schools. In Table 9 we have separated kindergartens and daycares from schools and universities due to the different nature of the space usage. In kindergartens and daycares the biggest group of occupants, i.e. children have limited authority in adapting to the thermal environment, however, the nannies and teachers have the responsibility in taking into account their preferences. While not driven by the users individually, drinks, clothing adjustments are widely applied together with changing locations and activity levels to cope with summer conditions. The regular daily outdoor activities that are emphasised in these types of buildings reduce the necessity of space cooling the building itself.

For schools and universites the daily and spatial use of the building is more strict with a strong daily pattern of lectures and breaks, which limits the occupants' ability to move and change their activities. Studies on OB in educational buildings noted that the teacher was identified as the main active occupant in school buildings, responsible for taking action on heating/cooling equipment use, temperature setpoint, window opening or closing the blinds. [30], [31] Furthermore, the decision-making relies mostly on collective needs and school rules, and according to [32] is also driven by habits, instead of based on indoor environmental conditions or thermal comfort perceptions. The temporal distribution of implementing these actions also has a strong daily pattern. While the use of residential and office buildings is continuous, when concerning occupancy in educational building it should be noted that the operation of the buildings is broken by a summer holiday defined locally, which has an affect on SC needs.

In trade buildings, let it be service or retail buildings, and also restaurants, the customer has no direct influence over the indoor environmental conditions, as these are defined by the managers of the space type and are defined by technological aspects as well as the expected thermal comfort of the customer. However, in service functions or restaurants the discomfort of the customer can trigger a change in the local conditions, i.e. operation of fans, opening closing window or drawing blinds. Concerning the summer behaviour in restaurants, the use of external spaces for the customer areas are high compared to other buildng types. However, in kitchen areas that have the highest heat loads within this space type the degree of freedom to change environmental conditions or implement adaptation technologies is low.

In hospitality buildings the potential use of rooms is similar than what is provided in residential buildings: generally, the rooms are equipped with controls for the thermal environment and also passive measures; clothing, activities, positions can be freely decided by the occupants. However, the motivation of occupants is very much different from residential buildings, which is reflected in the energy use patterns. As summarized by Palani et al, [33] the main differences compared to residential buildings is that hotel guests are not responsible for paying their electrical bills, and they feel less restricted with their daily life routine in hotel buildings especially when traveling for vacation. On the other side hotel owners are motivated by hotel guest satisfaction which leads to targeting maximum comfort for their guests. The occupants in hotel rooms change dynamically which makes the investing in the education of them not worthwhile for hotel managers.

In healthcare buildings the thermal indoor environment is maintained that minimizes health related issues. According to Shi et al [34] a high ventilation rate is provided in order to minimize the cross-infection risk. Occupant behaviour is also limited due to the patients's physical and psychical state and ability to move, while comfort perception is also biased by health issues - e.g. fever. Patients are dependent on others in changing clothing or implementing other adaptation measures. In hospitals the patient group is not fixed and each person has different habits. If possible, window opening is a result of collective behaviour.

In cultural, leisure buildings, and also transportational facilities a certian the user spends limited time in the facility, whith no control upon the building's systems. Their adaptation to the hot environment is mainly limited to the individual measures in changing their clothing or taking drinks.

In industrial buildings the process is the predominant determinant of the indoor environmental conditions, limiting the freely adjustable spaces to the social areas where only short time is spent. Clothing is often influenced by the safety and security aspects leaving no freedom to the occupants to selecting the level of clothing. In buildings where the indoor conditions are out of the thermal comfort limits, the national health and safety codes oblige the employer to provide measures e.g. drinks, or by limiting the time spent in the environment, to avoiding health impacts.

2.1.3. Conclusion

The role of occupant behaviour has been compiled according to different building functions and space usage types. In the following chapters occupant behaviour and occupant interventions influencing SC demands will be studied for the following types of buildings: residential, office and education. The reason for this is that these building types are the ones where:

- occupants have high freedom in implementing lifestyle and behavioural measures in order to adapt to summer temperatures, and also adjust their thermal environment;
- the same occupants spend a high portion of their time in these building, thus changing their behaviour has the highest possible long term impact for that particular space;
- a high percentage of educational and residential buildings are not currently equipped with SC technologies, however the increasing penetration of active SC technologies within these sectors needs attention, thus intervention with behavioural measures regarding these should be defined.

2.2. Occupancy in buildings in relation to SC demand

The building occupancy pattern is a key input for SC system design and also demand side management and response. In the current subchapter the occupancy patterns of the seleted building types: residential, educational and office is collected and regional differences throughout Europe are outlined in order to have specific information on when buildings are used, which information is inevitable for defining reduction of SC demand. The following aspects are studied, and local/regional differences are deemed to be identified, regarding their influence on SC demand:

- what are the occupancy patterns in the standards used for energy prediction?

- what are the actual daily and annual usage patterns?

This information will be useful for energy modellers, planners and policy makers to have realistic usage patterns for a certain country or climate and building functions, thus information will be reflected in calculation module 3 (CM3) of the CoolLIFE tool. Also, the findings of this chapter will be used during the modelling task of T.3.3.

2.2.1. Residential buildings

The occupancy patterns of residential building changes from unit to unit, patterns are stochastic and depend on the individual inhabitant. Several authors have tried to find what are the predominant characteristics that define occupancy patterns. Fu et al conclude that the most common characteristics that are associated with family routines and occupancy patterns are income level and household size, but also, it is difficult to systematically recognize a family's demographic characteristics correlated with occupancy pattern. Also, the use of building change in time due to demographic and social factors, like child birth, aging etc. [35], [36]. Thus, to have appropriate information, measuring and identifying patterns of dwellings should be done on a large scale.

In this review aggregated data on the large scale is collected to identify local trends and differences within Europe regarding the occupancy of residential buildings. However, it should be noted that the results are only valid on the large scale, while when individual buildings are analyzed, a custom schedule needs to be defined for the specific type of inhabitant. The time profiles found in the literature that represent residential buildings are shown in detail in Annex II.

Regulations and standards

Standards that provide EU wide recommendations for implementing occupant presence in the energy simulations are summarized.

The EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings specifies requirements for indoor environmental parameters for thermal environment, indoor air quality, lighting and acoustics [37] specifies how to establish these parameters for building system design and energy performance calculations. This standard sets criteria for the indoor environment based on existing standards and reports listed under normative references or in the bibliography. This European Standard includes design criteria for the local thermal discomfort factors, draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperature. The Standard is applicable where the criteria for indoor environment are set by human occupancy and where the production or process does not have a major impact on indoor environment. The criteria in this European Standard can also be used in national calculation methods.

The Informative Annex C in the second part of the Standard specifies default schedules for occupancy, that are examples that can be used as inputs for energy calculations if specific values are not available. Example schedules are given separately for weekends and for weekdays, for the following residential profiles:

- Residential apartment, retired,
- Residential apartment
- Residential detached house

The EN 15665:2009 Ventilation for buildings - Determining performance criteria for residential ventilation systems [38] sets out criteria to assess the performance of residential ventilation systems (for new, existing and refurbished buildings) which serve single family, multifamily and apartment type dwellings throughout the year. This standard also includes usage profile examples for 1, 2, or *n* occupants, outlining their presence and activity (sleeping or active) in each room, on a 15 minute basis. The total hours of occupancy for the Residential, apartment and detached house on weekdays is 14.4 hours, 20.8 hrs on weekdays, which equals and average of 16.22 hrs a week per person.

For Sweden the Swedish User Data for Residential buildings prepared by the Sveby gives a recommendation of 14 hours per day per person [39]. As Zhang et al describe: SVEBY stands for "Standardize and verify energy performance in buildings", which is a development program run by the construction and real estate industry, aiming for definition and verification of buildings' energy performance. In SVEBY's reports, user behaviour is continuously updated over time since 2012 in order to obtain continuity and clarity in verification. They have compiled schedules also of Office buildings, Retail shops and Schools.

Their results are based on the results of the Statistics Norway, that conducted a study in 1996 in 179 households from different types of locations and parts of Sweden, where the residents themselves were asked to record their habits in a diary. The presence time indoors in the home is reported to be an average of 61.5% on weekdays and 73.1% on weekends, which corresponds to 14.76 resp. 17.54 hours per day, resulting in an average 15.5 hours of attendance per day per person for a week. They conclude however, that the average, especially on weekdays, is pulled up somewhat by the over 65 age group. In another diary study in 21 single-family homes, attendance time was recorded from Thursday to Sunday [40]. On average, each person was at home 15.8 hours per day. An assessment of average attendance time over a whole week gives approximately 14 hours per day per person, as the survey studies two weekdays and two weekends.

In France, TH BCE 2012, [41] which is the official French calculation method for the energy performance of new residential and commercial buildings includes a simplified schedule for taking into account occupant heat loads for one particular building type, the 90m^2 single family house. This approach consideres that the metabolic rate, thus the occupant heat dissipation is smaller when sleeping. The schedule suggest that between 10 a.m. and 6 p.m. the building is unoccupied.

Empirical data

The occupancy schedules are very much dependent on the individual occupying the building, which makes it difficult to draw conclusions from case studies with low sample size. For this variable, only studies of large scale were searched for identifying the occupancy profiles. Time Use Surveys (TUS) have been conducted throughout Europe regularly since the 1970's, where statistical data on the daily routine of people of a high sample size are collected. TUSs have been used by several authors to profile profile occupancy patterns and energy-related daily activities of occupants [8], [42], [43]. The space context of time use considers the place where individuals spend time at different hours of the day.

The analyzed TUS data include averaged data for the surveys population for France and Belgium, while a number of authors have also proposed certain type of clustering to gain information on different resident groups. The UK data has been clustered based on the number or people in the household [44], while IT data is presented per gender and the day of the week (weekday or weekend), and also provided total time spent at home distributed among age groups. Based on the Belgian data the probabilistic occupancy profiles included activity types clustered into 3 categories: awake, sleeping or absent. Similarly, Richardson et al [45] used the TUS UK 2000 database to derive profiles for active occupants. Active occupants are defined as being awake and and in the house.

Figure 1 shows ISTAT data for occupancy schedules in Italy [42], the time spent at home per gender and age group. A high variation of the data between 13:00 to nearly 22:00 hours can be seen. A similar statistic has been published for 8 European countries on Figure 2, showing a similar range. The same trend is seen that younger people occupy their homes for approximately 40% less time.

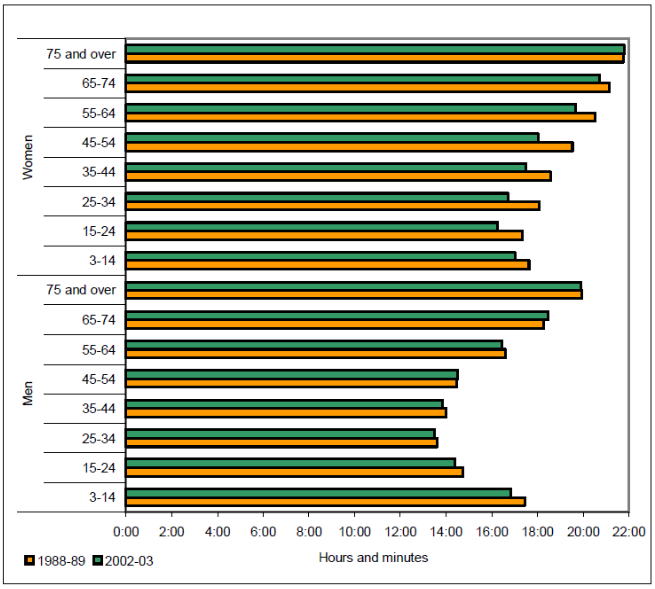

Figure 1. Time spent at home among persons aged 3 years and over by gender, age group and survey year on an average day - Years 2002-2003 (Source: ISTAT [42])

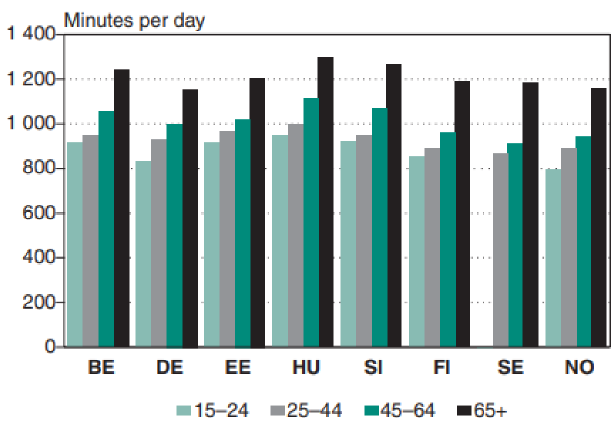

Figure 2. Time spent at home by age. The upper age limit of the survey was 79 in Norway, 84 in Hungary and Sweden, and 95 in Belgium. There was no upper age limit in the other countries. Years for data: 1998-2002 Source: Eurostat [46]

The occupancy profiles derived from the Time of use surveys for Ireland based on the UK Time of use Survey 2014–15 distingushied profiles based on the number of occupants in the households. [44] Their proposed schedules show lower occupancy rates in the morning than suggested by the standards.

The research paper "Development of Dutch Occupancy and heating profiles for building simulation" carried out by O. Guerra-Santin and S. Silvester [43] aimed at developing country-representative occupancy and space heating patterns for the Netherlands based on the Woononderzoek Nederland (WoON) dataset 2012, a nationwide survey carried out by the Dutch Ministry of the Interior and Kingdom Relations (BZK). These schedules were defined on a present/not-present scale.

Time spent at home and time spent sleeping based on Time Use Surveys in 1998-2002 have been compared for ten European countries, Belgium, Germany, Estonia, France, Hungary, Slovenia, Finland, Sweden, the United Kingdom and Norway by Eurostat which shows regional differences in spending time at home. [46]

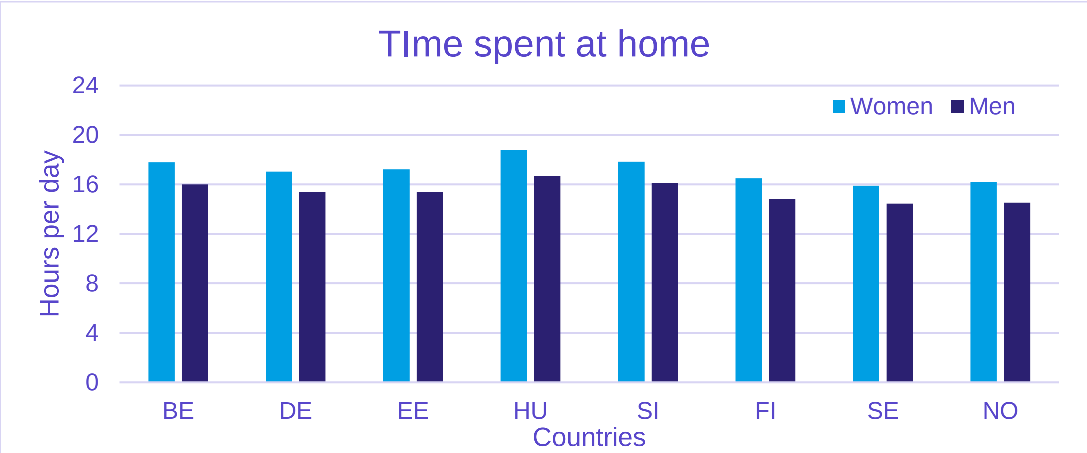

Figure 3. Time spent at home of men and women aged 20 to 74, Data: 1998-2002 Source: Eurostat [46]

Based on the data of the Belgian Time of Use Surveys, Aerts et al [47] developed a probabilistic model that generates individual occupancy sequences that include three possible states: (1) at home and awake, (2) sleeping or (3) absent. They identified seven typical occupancy patterns for simulations:

- mostly absent
- mostly at home
- very short daytime absence
- night-time absence
- daytime absence
- afternoon absence
- short daytime absence

A survey has been conducted in Portugal with a limited number of reponses via internet, (30 valid answers) which were predominantly of men aged 21-40 years old. [48] While this study cannot be used as a representation of large scale statistical data, it is interesting to compare the findings of a particular group of people to the large scale. Whlie on weekdays the lowest occupancy rate was below 10% on weekdays, close to 20% of the repondents spent time at home at having lunch.

The CoolLIFE household survey documented in D3.1 for Hungary found that on an average weekday in the summer, when no one at the household is on holiday and everyone carries out his/her everyday activities, 57.3% of the people resonded to be at home at daytime as well.

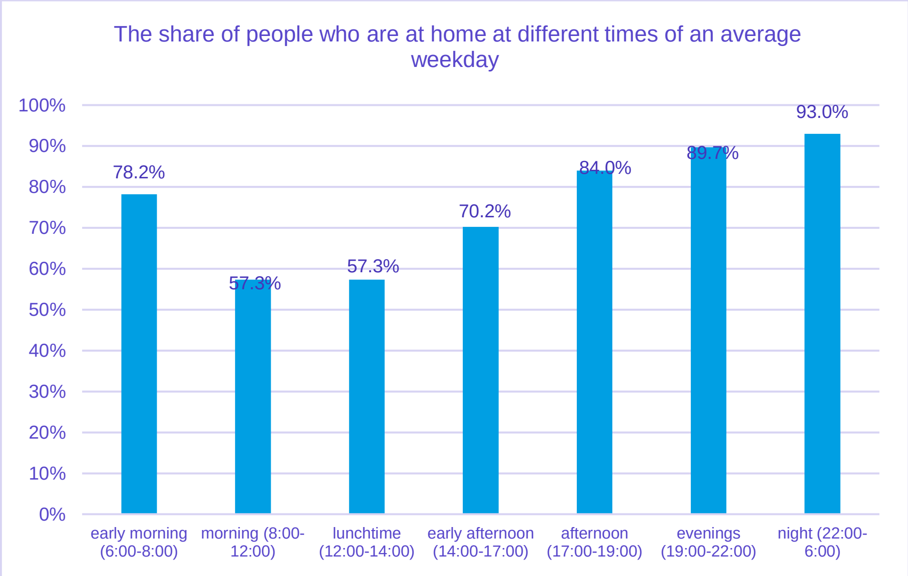

Figure 4. The share of people who are at home at different times of an average weekday in July in Hungary
Source: CoolLIFE survey

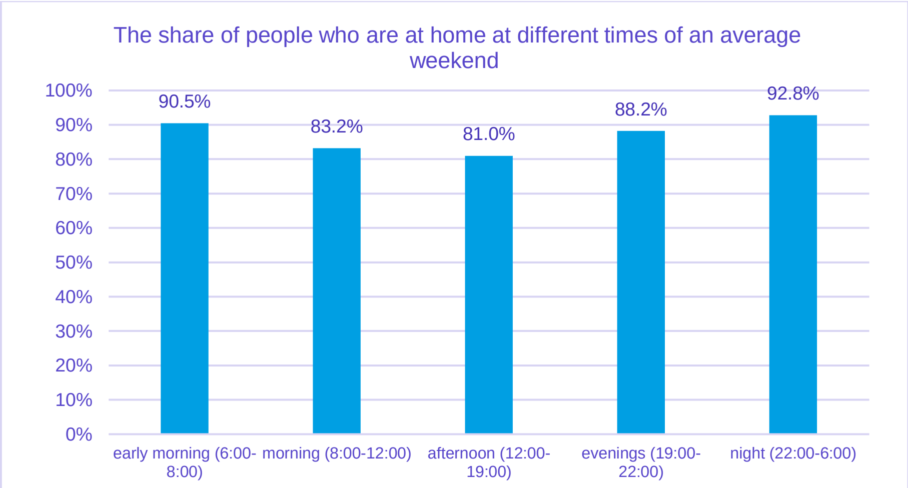

Figure 5. The share of people who are at home at different times of an average weekend day in July in Hungary
Source: CoolLIFE survey

Summary

The occupancy profiles found in the literature have been compared on Figure 6, and a comparative analysis is given on Table 10 andTable 11. It is seen that high variation exist in the data, also due to the distribution of results per population group presented in different studies. The average occupancies are higher at day time than what is implemented in the standards for non-retired people. The pattern also shows that people in e.g Italy tend to spend more time at home after lunch, which is not reflected in the standards.

			Hours of daily occupancy *range of occupancy ratio*		
Profiles	Country	Source	Weekdays	Weekend	Average
Residential – retired, example for energy modelling	EU	[37]	24 *100%*	24 *100%*	24
Residential – apartment, example for energy modelling	EU	[37]	14.4 *10-100%*	20.8 *80%-100%*	16.2
Residential – detached house, example for energy modelling	EU	[37]	14.4 *10-100%*	20.8 *80%-100%*	16.2
Residential – 1-2 people, example for ventilation calculation	EU	[38]		14 *0-100%*	
Residential – n>3 people, example for ventilation calculation	EU	[38]		16 *0-100%*	
Residential, design recommendation	Sweden	[39]		14 -	
Schedule for occupant heat loads ($90m^2$ SFH)	Portugal	[7]		16 -	

Table 10. Summary of the residential occupany profiles within standards and recommendations for energy calculations

Surveys or statistical data

			Hours of daily occupancy *range of occupancy ratio*		
Profiles	Country	Source	Weekdays	Profiles	Country
Residential, statistics	Norway	[39]	14.8 -	17.5 -	15.6 -
Single family houses, survey	Norway	[39]	4 days' average : 15.8 -		14 -
Residential schedules for heating simulations, for different family types (suggestion based on TUS)	Netherlands	[43]	15-24 0-100%	7-10 0-100%	13.6-18.3
Residential, TUS statistic, Distribution give per gender and age group	Italy	[42]	13.7 – 21.9 *m : 20%-97%* *w :35-98%*	13.7 – 21.9 *m : 39%-97%* *w :48-98%*	13.7 – 21.9 -
Residential, based on TUS	Belgium	[47]	- 40%-100%		16.9 -

Table 11. Summary of the residential occupany profiles from large population surveys or TUSs

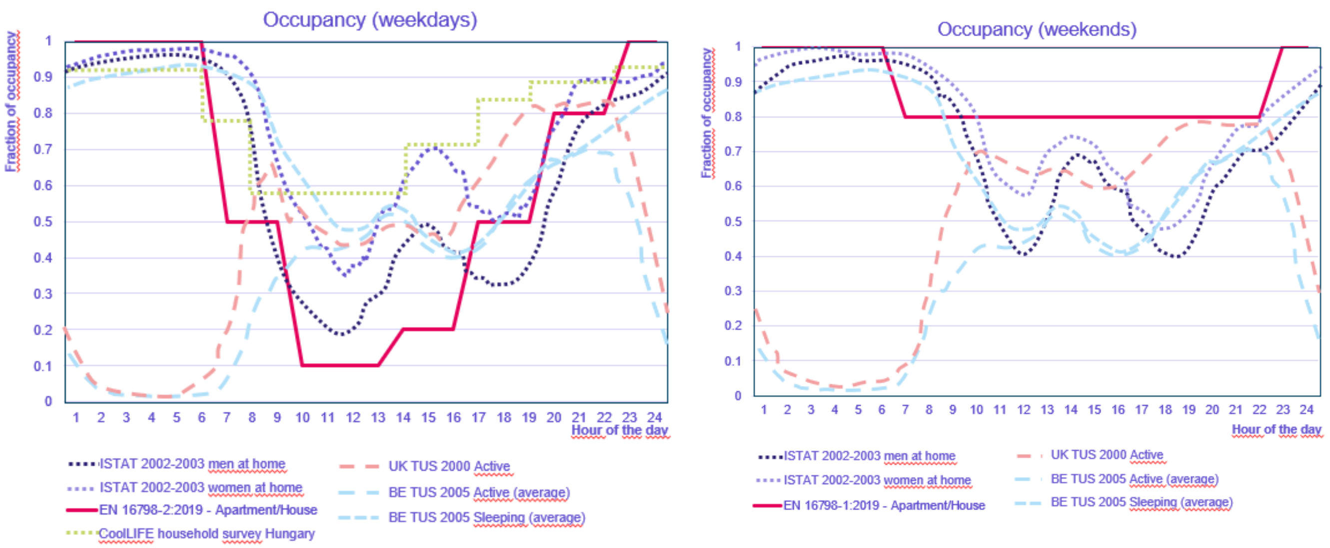

Figure 6. Comparison of occupancy profiles for weekdays and weekends: EN 16798-1 standard, ISTAT 2002-2003, UK TUS 2000 data, BE TUS 2005 data and CoolLIFE household survey for Hungary. Source: Own image based on data from: [42], [45], [47]

2.2.2. Office buildings

Regulations and standards

The time profiles for non-residential building are also included in the informative Annex C of the EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings standard, for the following space types relevant to office buildings:

- Office, landscaped
- Office, single
- Meeting rooms

The most relevant standards used for determining the occupancy profiles of office building are the DIN standard 18599-10, which includes daily and annual hours for specific spaces within a building. For building simulations in the lack of specific data several studies have followed the NCM in the UK and ASHRAE 90.1. For Sweden the Swedish User Data for Office buildings prepared by the Sveby gives a recommendation of [49] 9 hours of daily occupancy, 250 office days per year (225 after deduction of holidays) and an occupancy rate of 70% of the time.

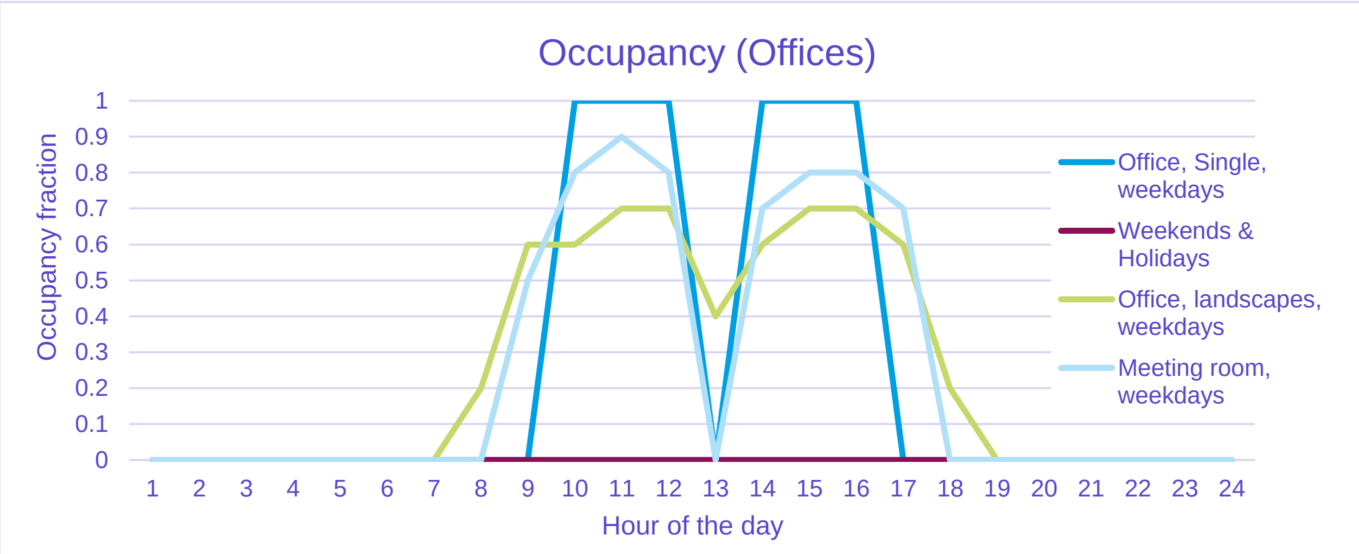

Figure 7. Suggested occupancy profile in the informative Annex C of the EN 16798-1:2019

			Usage				Occupancy ratio
Source		**Country**	**Start**	**End**	**Hours daily**	**Days annual (hours)**	
EN 16798-1:2019 office	[37]	EU	7:00	18:00	11	260 (2868 hrs)	0- 70%
EN 16798-1:2019 meeting room	[37]	EU	7:00	18:00	11	260 (2868 hrs)	0-90%
DIN18599-10	[50]	DE	7:00	18:00	11	250	-
Sveby	[49]	SE	-	-	9	250 / 225[1]	70%
Notes:	[1] after deduction of holidays						

Table 12. Summary of the office occupancy profiles within standards and recommendations for energy calculations

Empirical data

Office buildings show a strong daily and weekly pattern of occupancy. This type of building is the most studied in the user behaviour researches. Detailed occupancy profiles are included in Annex II, while main findings are presented here. Duarte developed occupancy diversity factors for multiple space types based upon a 23-month dataset from a large multi-tenant commercial office building in the US, and found that the peak average diversity rate in open plan offices was around 85%, while for private offices only around 50%. [51] The ASHRAE-90.1 profiles considered a higher occupancy rates for office buildings than the EN standards. The tendency in Duarte'a work is different than what is condidered in the standard, private offices tend to be less occupied than landscaped offices. In contrary, in the EN standards assuption the private offices are considered to have the highest occupancy, up to of 100%. Studying the seasnal effects of holiday on the profiles an approximately 0.1 point change between the lowest and highest month was seen: August and April are the months with the lowest occupancy, corresponding to Easter and summer holidays. Also, he indicated a weekend usage reaching even 10% on Saturdays, and an evening peak on weekdays. Peaks on all days are lower than suggested by the EN standard for both landscaped private offices, and weekend occupancy is considered to be 0.

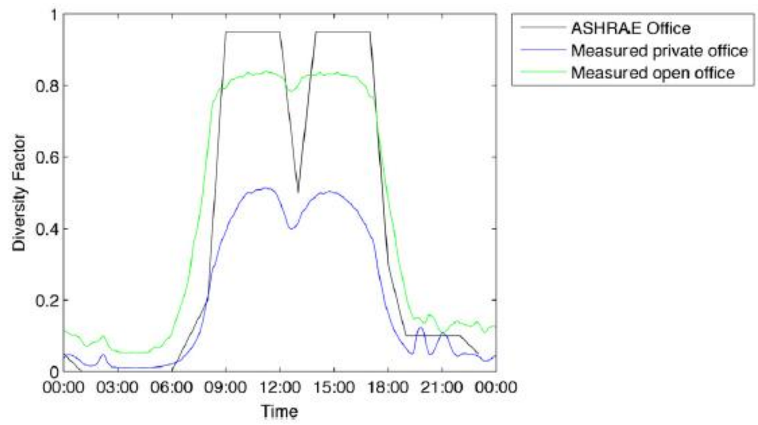

Figure 8. Comparsion of ASHRAE 90.1 2004 references to the measured occupancy profiles by [51]

2.2.3. Educational buildings

Regulations and standards

The time profiles for non-residential building are also included in the informative Annex C of the EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings standard, for the following space types relevant to educational buildings:

- school, classroom (Figure 9)
- day-care, kindergarten

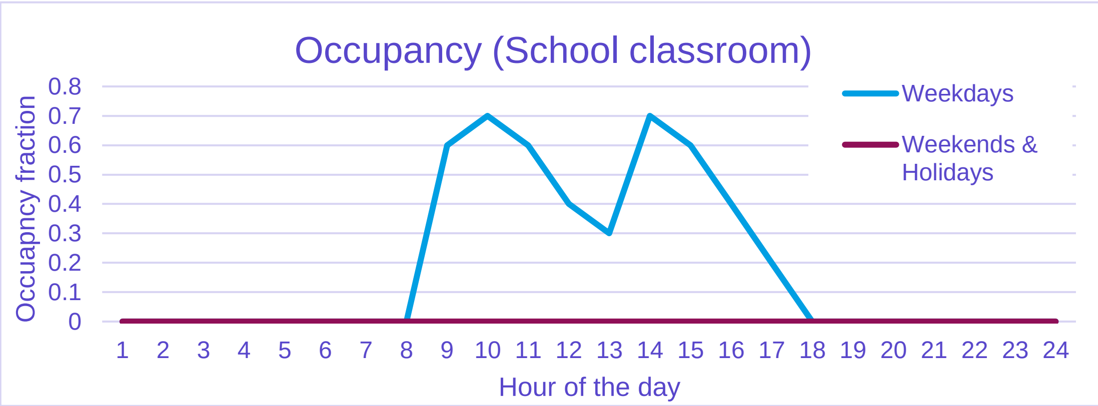

Figure 9. Occupancy schedule implemented in the EN 16798 standard for classroom [37]

Daily and annual occuapancy ratio, start and end dates given as guidelines in the standards are shown in Table 13.

			Usage				Occupancy ratio
Source		Country	Start	End	Hours daily	Days annual (hours)	
EN 16798-1:2019, school, classroom	[37]	EU	8:00	17:00	9	260 (2346)	0- 70%
EN 16798-1:2019, kindergarten	[37]	EU	7:00	19:00	12	260 (3129)	0-80%
DIN18599-10	[50]	DE	7:00	18:00	11	250	-
Sveby	[52]	SE	-	-	7	-	-[1]
Notes:	[1] National Calculation Method of Great Britain developed by the BRE is suggested to be followed						

Table 13. Comparison of occupancy assumptions in legislation and standards

Empirical data

The annual usage patterns and seasonal differences of occupancy the literature of occupant behaviour is very limited, however, this information is crucial as opposed to the occupancy of residential and office buildings the seasonal variation is limited, when concerning occupancy in educational building the operation of the buildings is broken by a summer holiday when the buildings are unoccupied, which has an affect on SC needs. The operation of the educational buildings varies throughout Europe both regarding the duration of the school year and also the number of lecture days per week through EU countries which has local historical causes; it is the result of policies and actions in progress in different education systems, which, in turn, are based on diverse social, political, pedagogical and/or cultural arguments [53]. To understand the SC demand and summer thermal comfort in educational buildings, the regional differences in daily and annual operation hours have been mapped.

Variations in annual operation

A comparative study done by European Commission/EACEA/Eurydice, in 2019 for the reference year 2019/2020 compiled information on primary and general secondary education for the 38 countries participating in the EU's Erasmus+ programme (28 Member States, Albania, Bosnia and Herzegovina, Switzerland, Iceland, Liechtenstein, Montenegro, North Macedonia, Serbia and Turkey). [54] They found that the most common range of number of school days was between 170 and 190, with the shortest duration of 157.5 days and the longest 200 days, which period is interrupted by a number of holidays. Autumn, Christmas, Spring holidays are usually provided. For the CoolLIFE project the most important holiday is the summer holiday as it has the highest influence on the (lack of) SC demand. [54]

The length of the summer holidays varies significantly between countries: from 6 weeks in some German *Länder* (regions), the Netherlands, the United Kingdom (England and Wales) and Liechtenstein, up to 15 weeks in Bulgaria (for primary education). The most typical length of holiday is between 12-13 weeks. The holiday length is the same in most countries independent from the level of education. However, in Bosnia and Herzegovina secondary schools start the holidays earlier than primary schools; while in Albania, Bulgaria, Greece and Serbia students in primary education have the priviledge to start holidays earlier.

The school year generally ends between the end of May and the second half of July, Mid-June being the start of the holiday the most often. The end of the summer break and start of the new school year varies between August and the end of September. The most typical start of the school year is the beginning of September.

On Figure 10 and the annual distribution of the school holidays in the cooling season is shown. Detailed data has been included in Annex II.

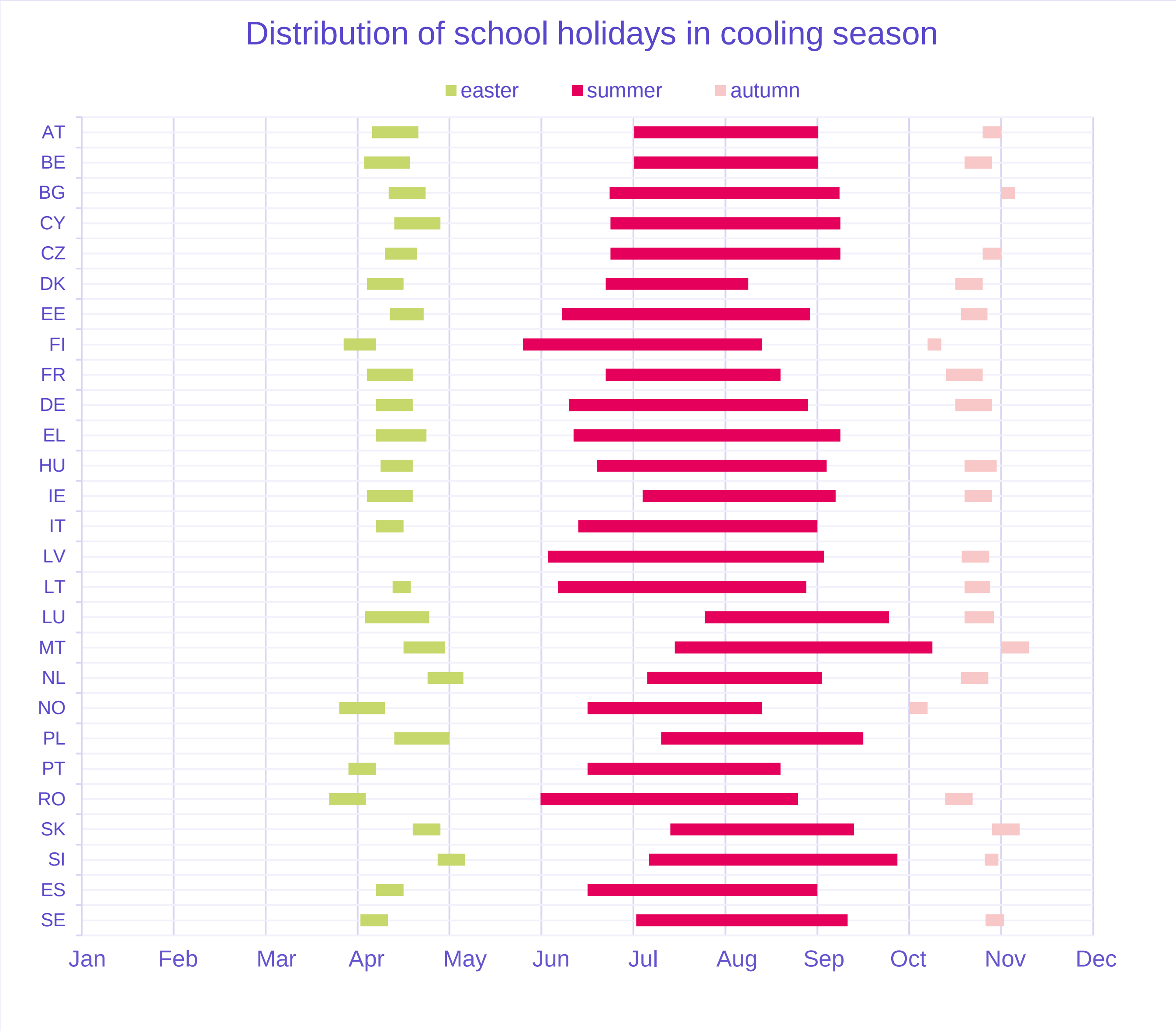

Figure 10. Distribution of school holidays during the cooling season, Based on: European Commission/EACEA/Eurydice, 2019 [54]

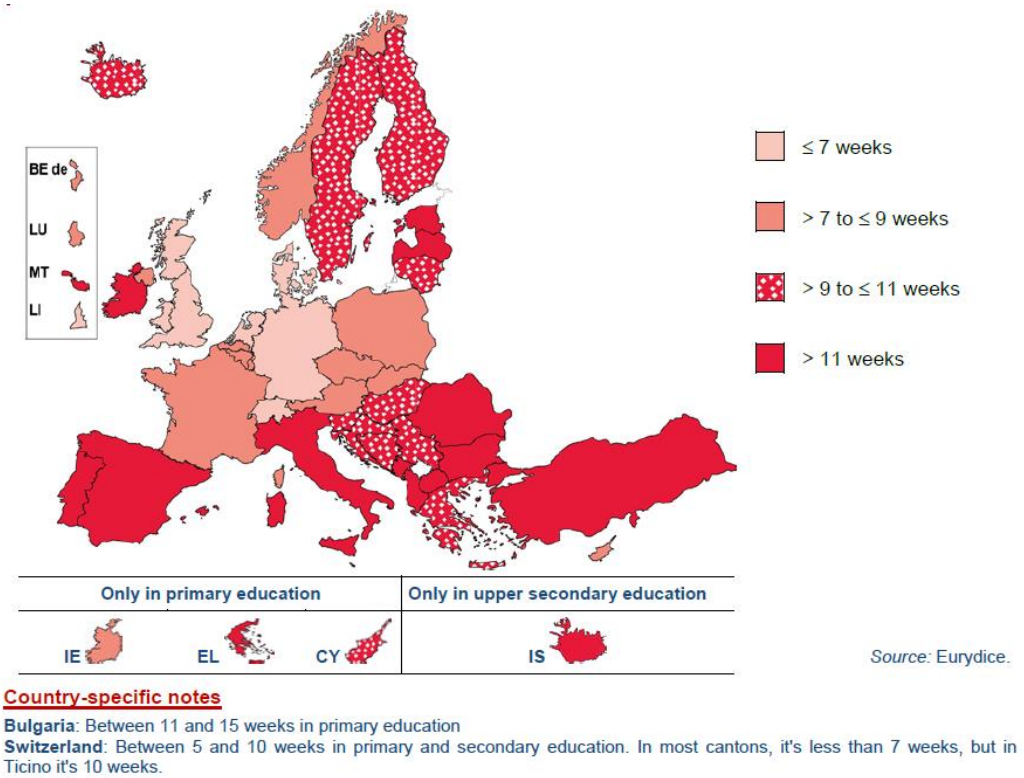

Figure 11. Length of summer holidays in weeks, primary and secondary general education, 2019/2020 [54]

Weekly operation: According to a comparative study from 2020 [54] of the school day in 15 european union countries the 5-week (Monday to Friday) schoolweek is prevailing, however, four and six-day-week schools are also implemented. In specific countries, e.g. Belgium, Netherlands or France Wednesday afternoon is free.

Daily operation: According to the same study, findings on the school day in 15 European Union countries the compulsory school day classes usually start between 8 am and 9 am and the compulsory instruction time varies between 5 to 6 hours per day. The school day is organized into one or two sessions devided by a lunch break, resulting in half-day or full-day activities.

It is also important to note that the above study concentrated on mandatory, curricular activities of students. When considering the operation of the education buildings, it should be noted that extracurricular activities, study groups, facultative lectures can also take place in the educational buildings, which might extend the operation of the buildings into afternoon hours. These activities are expected to result in partial operation (e.g. only considering the sports hall), however, the presence of these are dependent on the management of the individual institution, thus are unpredictable on a large scale.

2.2.4. Change in occupancy patterns

It is important to note that occupancy patterns have changed in the last years. In the office industry the concepts of activity-based workplaces, flexible office, desk sharing, hybrid office and agile offices are popular notions that are reshaping office building use. Office occupancy rate is considered to be around 60%-70% in traditional office spaces which together with a more flexible space usage allows occupants to select locations which are more comfortable.

Additionally, as a cause of COVID-19, the higher penetration of home office possibilities throughout Europe, which is not reflected in the standards or the statistical data found in the literature. This change reduces the time spent in offices, which could lead to energy savings reaching up to 50% energy reduction in comparison to the pre-pandemic situation. [55] However, as the time spent at home increases, this causes an increased demand in space cooling in homes, which is not yet fully explored. Todeschi et al [56] calculated energy use for three residential neighborhoods located in the Canton of Geneva, Switzerland during the partial and full lockdown due to COVID-19. Their study anticipated a 17% increase in residential energy demand for space cooling during the partial lockdown and 28% in the case of the full lockdown. These values cannot be considered as a prediction for the current situation, however, it shows that the order of magnitude of increase is worth examination.

Eurostat concluded, that during the COVID-19 crisis, a large proportion of employed people was faced with changing patterns of work – including working from home. In 2019, approximately 1 in 20 (5.5%) employed people aged 20–64 years in the EU usually worked from home. The impact of the COVID-19 crisis was apparent as this share more than doubled in 2020 to 12.3% (+6.8 percentage points; pp). To a lesser extent, there was a further increase in the share of people usually working from home in 2021, as it reached 13.5% (+1.2 pp). Clear regional and country specific differences can be seen onFigure 12 and Figure 13.

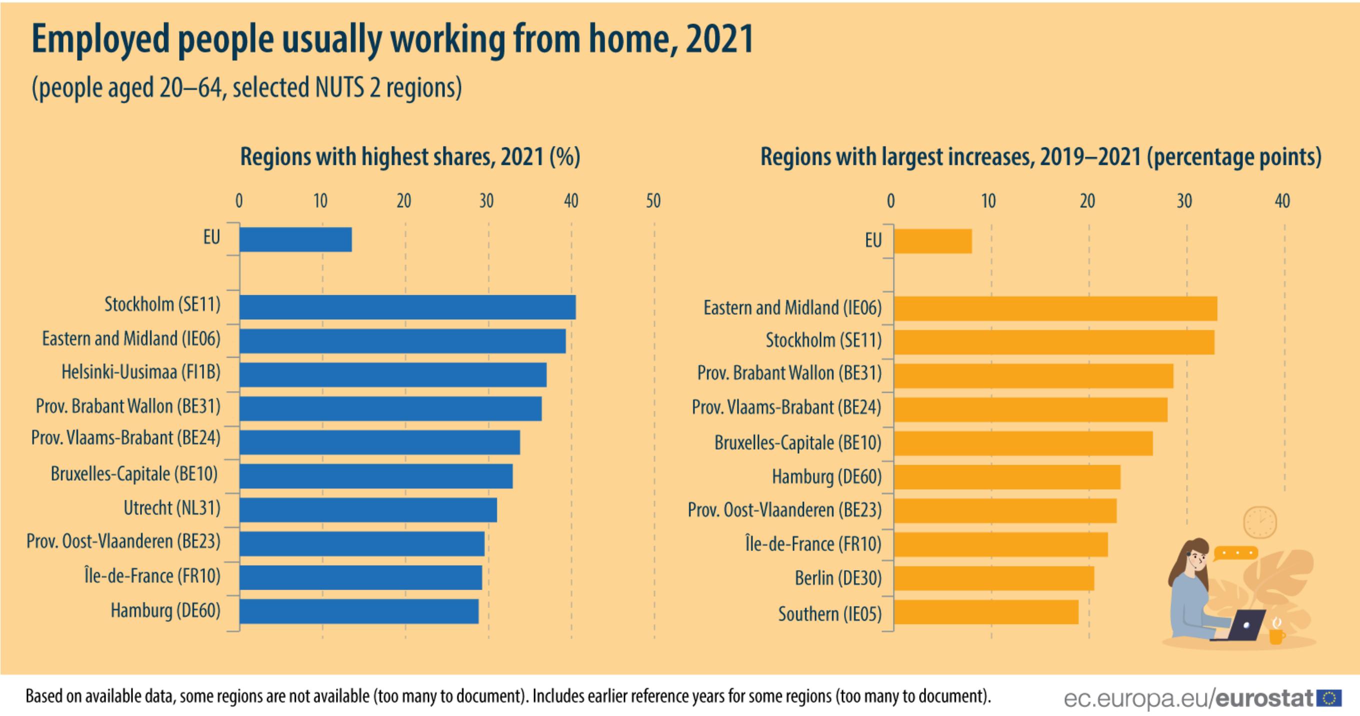

Figure 12. Employed people usually working from home, regions with highest shares in 2019 and largest increase between 2019-2021 Source: Eurostat [57]

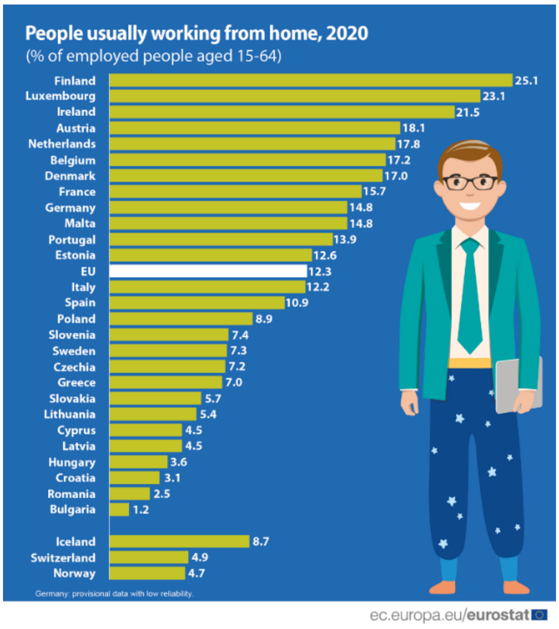

Figure 13. Employed people usually working from home, 2021 Source: Eurostat [58]

2.2.5. Conclusions and recommendations

During the literature review both the residential sector and the service sector of the EU building stock were analyzed from the occupancy perspective. An evaluation of the occupants role in different building types regarding their influence on SC demands has been completed, based on which the building types subject to detailed evaluation was identified, by selecting the ones offering the highest potential for OB interventions. Based on the evaluation considering the nature of the time spent in each building type, the freedom of the occupant in adjusting their thermal environment by interacting with SC devices and building elements and adopting by personal measures to restore thermal comfort

- residential,
- office and
- educational buildings

have been selected for an in-depth analysis.

The literature review revealed that for the consideration of occupancy for the purpose of energy simulations as defined in standards only exist as examples or recommendations. These standard assumptions for energy prediction (in particular SC, where available) have been collected and compared to statistical and case study data available in the literature. Regional differences in occupancy patterns have been identified and compared to the profiles implemented in standards and legislations. The average daily occupancy in residential buildings varies between 13.6 and 24 hours, while the occupancy rate defers highly depending on the type of occupant. However, seasonal variations are not considered.

The use of residential buildings shows daily and weekly patterns, on the large scale a lower occupancy ratio is seen on weekdays during daytime, and higher occupancy in the evenings, night time and during weekends. However, when comparing statistical data to the examples in the standards it can be seen that large differences can occur on the detail level: the TUS surveys in Italy and Belgium revealed that mid-day peaks can occur, however, at different times of the day: in Belgium a peak has been found around noon, while in Italy it is shifted towards the afternoon hours. When considering SC demand this peak is important as it occurs at the time when also SC demand is highest.

In the literature, where more detailed, clustered occupancy profiles are drawn, these are based on the number of people in the household and/or differentiated based on the life stage/family status, and in some instances, on the day of the week. Implemeting these clustered data can be done when the characteristics of a particular dwelling I known.

The occupancy of office buildings shows a more balanced pattern, here numerous studies were identified showing the deviation from standard approaches. Recent trends in occupancy patterns has been presented that reduce the occupancy rate in offices and at the expense of increasing occupancy in dwellings. The ratio of people working in home-office has increase from 2019 to 2021 up to 32%.

For educational buildings the distribution of instructional hours and days around the year has a high heterogeneity throughout Europe. When considering SC demand, beside the number of school days, the different start and end dates, and duration of summer holidays has been collected, together with the daily patterns of use. The period of occupancy within the time of the year that is subject space cooling is not reflected in the suggestions for energy prediction of these types of buildings, however, the local conditions should be considered.

As a conclusion, it can be stated that the assumptions regarding the occupant behaviour in standards an legislations are not season or region specific but provide a simplified approach to considering occupancy rate and duration.

The large scale data collected show that residential buildings have a higher average occupancy than what is suggested in the standards, which is also the case for office buidings. For educational buildings the occupancy patterns show high variation with limited use in summer, that is not included in the standards.

Recommendations

It is suggested that during the prediction of SC demand the regional differences are taken into account and the realistic occupancy profiles are implemented. When considering SC of educational buidings the distribution of school time in that particular region should be considered as the different distributions of summer holidays has a direct effect on SC demands.

For residential buildings the use of a particular dwelling unit g can defer from the average profiles drawn from the large scale datasets, influencing SC demands. Thus, for residential buildings, instead of implementing a standard occupancy profile, implementing characteristically different profiles to test the effect on SC demand can lead to a more robust approach. From the literature profiles clustered based on different aspects (age, household composition, dwelling size) have been found.

Regarding the use of the occupancy profiles when suggesting interventions, it can be difficult to intervene with one's habits regarding the presence in their own home. Nevertheless, in section 4 successful intervention campaign have been shown. The current work helps understand how the buildings are occupied in reality to get more precise inputs in planning. The collected data can serve as a baseline for policymakers to develop a set of representative occupancy patterns, addressing also regional differences. Also, it is suggested that during design, instead of using one occupancy profile, a set of profiles should be used to have robust feedback on the expected SC demand. The collected data will also feed into *T.3.3 Quantification of behavioural interventions for space cooling reduction*, where the differences arising from the identified occupancy profiles will be quantified. .

3. Occupant behaviour in buildings affecting SC demands

In the previous chapted data has been collected on the daily and seasonal variations of when the occupants are present in residential, office and educational buildings. In this chapter we give an overview of how the occupants interact with building elements, and what are their drivers in doing this. The relationship between drivers, needs and occupant behaviour actions has been described by Laaroussi et al in 2002 [2] as shown on Figure 14.

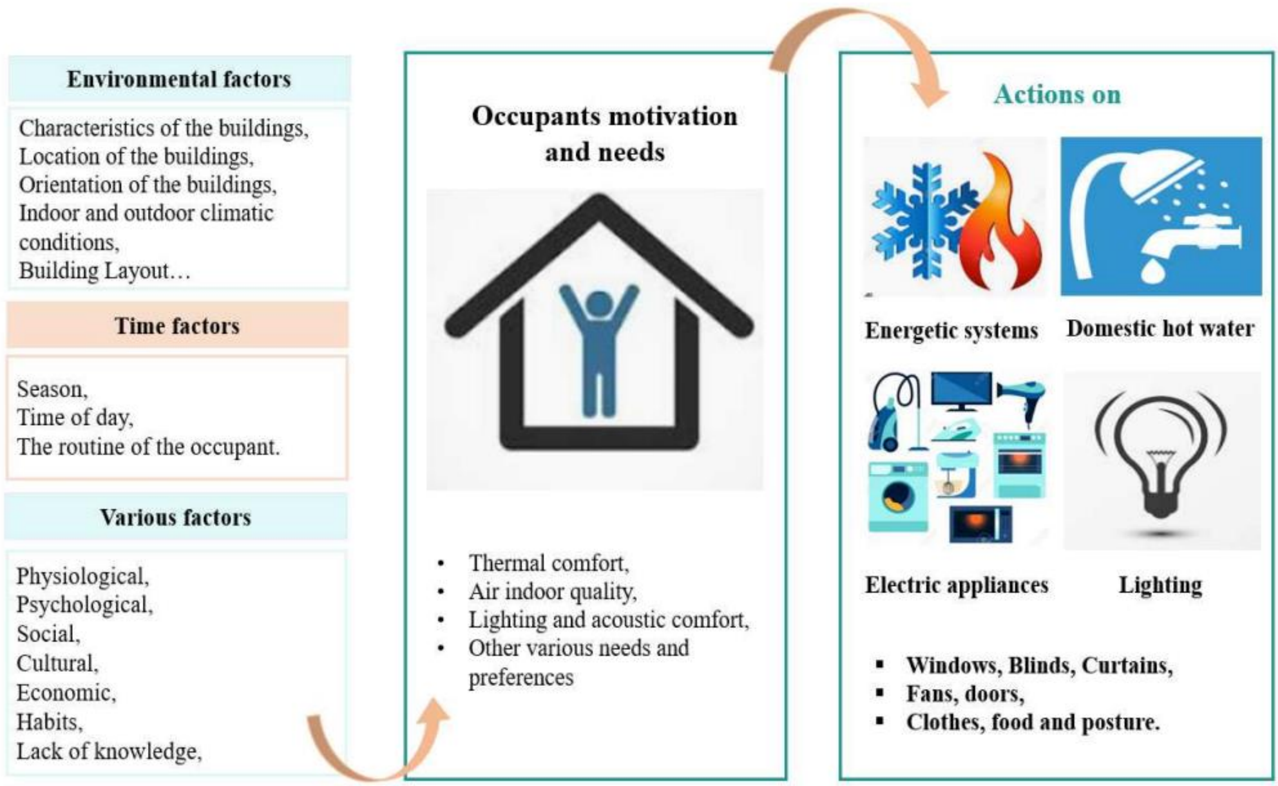

Figure 14. Layout of drivers, needs and occupant behaviour actions Source: Laaroussi et al [2]

The comprehensive literature review has been done in identifying survey that address OB in buildings, as seen in 0Annex I. The compilation of studies shows that a limited number of occupant behaviour surveys exist for educational and residential buildings, compared to office buildings. One possible reason for this could be is that OB research is mainly driven by the goal to increase energy efficiency by understanding the behaviour of occupants and to reduce the performance gap between design and actual building energy performance for commercial reasons.

However, Laaroussi et al conclude that the human behaviour in residential and tertiary buildings are affected by the same motivational drivers. They argue that the differences in interacting with building systems differently in residential and tertiary buidings lies in the schedules of occupancy, type of the systems and the access given to the occupants for their manipulation. The complexity of OB in residential buildings compared to tertiary buildings is increased, as according the authors they are characterized by: i) the variance of occupancy hours and activities, ii) in residential the interaction can be done in several spaces (contrary to the office buildings where the interaction occurs in single space), and iii) the occupant activity is also is characterized by more options, i.e. the occupant is present and active or the occupant present but inactive (e.g. sleeping).

Stazi et al in 2017 [59] analysed driving factors and contextual events influencing occupants' behaviours in buildings. From their review the following interactions are identified that have effect on space cooling needs:

- Windows use
- For using blinds and shadings,
- The use of air-conditioning units
- The use of fan
- Use of doors

While the influence of the latter two on their own are negligible compared to the other systems, their management can affect users' thermal perception and so modify the interaction with other building controls (i.e. windows and AC units). Hence, mention is given to their findings in this report.

Numerous studies have shown that occupants sub-optimally use such controls to improve comfort during times of significant discomfort, but are much more passive when the source of discomfort is alleviated. One study also states that one cause for people to act in energy-intensive ways is if they encounter prolonged and consistent discomfort. Another fact is that occupants prefer to have control over their environment no matter they are connected or not (placebo controls) to actual HVAC equipment. [60]

The findings summarized in this report will serve as a basis for defining typical occupant behavioural measures in residential and commercial buildings that are needed for the accurate modelling of occupant behaviour for space cooling needs, reflected in *D3.3. Multiple, socioeconomic impacts of sustainable space cooling.*

Each section in this chapter is structured as the following: i) first, the requirements and recommendation in the selected countries are overviewed and summarized, which are implemented during design of buildings and HVAC systems, and are also implemented in energy modelling, ii) secondly by reviewing the literature and case studies, the differences from the design parameters and the drivers behind the occupants behaviour are summarized.

Regarding the collection of legislations and standards this report provides an overview of the main assumptions adapted throughout Europe regarding the types of behavioural interventions. A detailed review on EU policy background and national measures will be completed within *Work Package 4: Policy, financing, and recommendations*, as a next step in the CoolLIFE project.

3.1. Equipment use

The occupant can interact with a wide range of elements and appliances while being at home, and also specific appliances are operating regardless of the occupancy. The heat loads from electrical and other appliances that generate heat directly contribute to the SC demand of the buildings, if heat is not removed through passive measures.

In this section the schedules applied for taking into account the equipment heat loads during the prediction of energy use are collated, and statistical data and case studies are collected to define how occupants tend to use these appliances. These two types of equipment are considered:

- Lighting
- Operation of process appliances, ie. household appliances in dwellings

The use of equipment and lighting can differ highly from household to household. As concluded in the Culture-E project, electricity consumption in domestic buildings is affected by socio-economic, dwelling and appliance related factors. Jones et al found that 13 socio-economic factors, 12 dwelling factors and 37 appliance factors have been studied in the literature as having effect on the energy consumption. Four of the socio-economic factors, seven of the dwelling factors, and nine of the appliance related factors were found to unambiguously have a significant positive effect on electricity use. They found that:

- Type and size of dwelling, as well as number of occupants can explain 30–40% of the variation in Danish electricity consumption, whereas the Belgian data could only explain 10–30% of the variation.
- In Denmark, 64% of electricity consumption can be attributed to the number of adults in the house, the number of children, appliance consumption and the total floor area.

Regulations and standards

The Informative Annex C in EN 16798-1:2019 Energy performance of buildings – Ventilation for buildings specifies default schedules for lighting and appliances, that are examples that can be used as inputs for energy calculations if specific values are not available. Example schedules are given separately for weekends and for weekdays, for the following profiles:

- Office, landscaped
- Office, single
- Meeting rooms
- School, classroom
- Day-care, kindergarten
- Department store
- Restaurant
- Residential apartment, retired
- Residential apartment
- Residential detached house

In Figure 15 it is visible that the schedules are the same for all three types of residential buildings, and no distinction is made between the days of the week, or seasons. 3 W/m2 is suggested for equipment use but the standard states that the lighting should be defined based on the installed lighting power per room. Further guidance on lighting power can be found in EN 15193-1 Energy performance of buildings – Energy requirements for lighting – Part 1: Specifications, Module M9 and FprCEN/TR 15193-2 Energy performance of buildings – Energy requirements for lighting – Part 2: Explanation and justification of EN 15193-1. The lighting and equipment use schedules for office and educational functions are aligned with the occupancy profiles presented above.

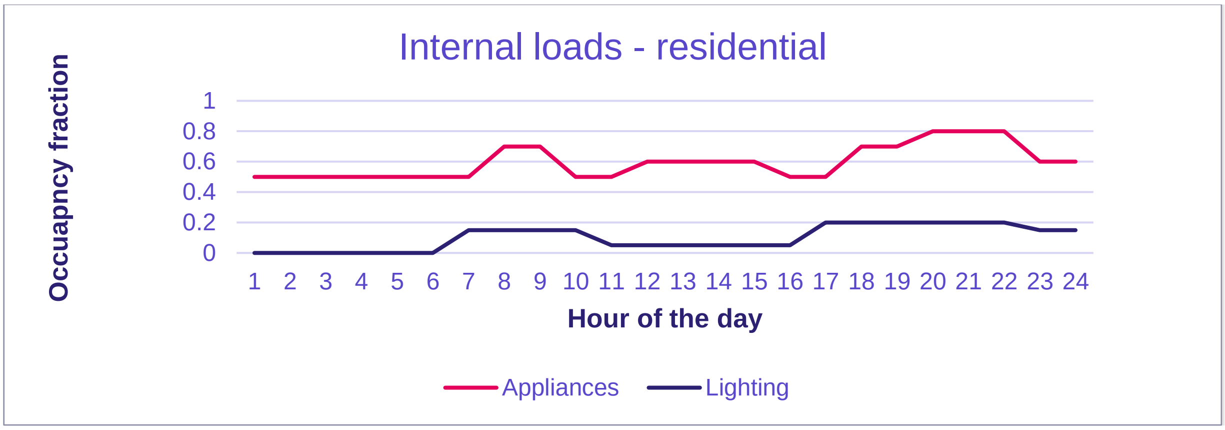

Figure 15. Example equipment and lighting schedules for residential buildings, source: EN16798-1

Empirical data

Statistical data on household electricity consumption shows aggregated data including the electricity consumption of all electrical equipment in households. The aggregated data found for the EU seen on Figure 16 shows regional variation in the consumption. It is seen that lighting and electrical appliances add up to 7.2-32.5% of the final energy consumption in residential buildings throughout the different countries in EU, with an average of 14.5%. Together with cooking this reaches 11.1%-50.7%.

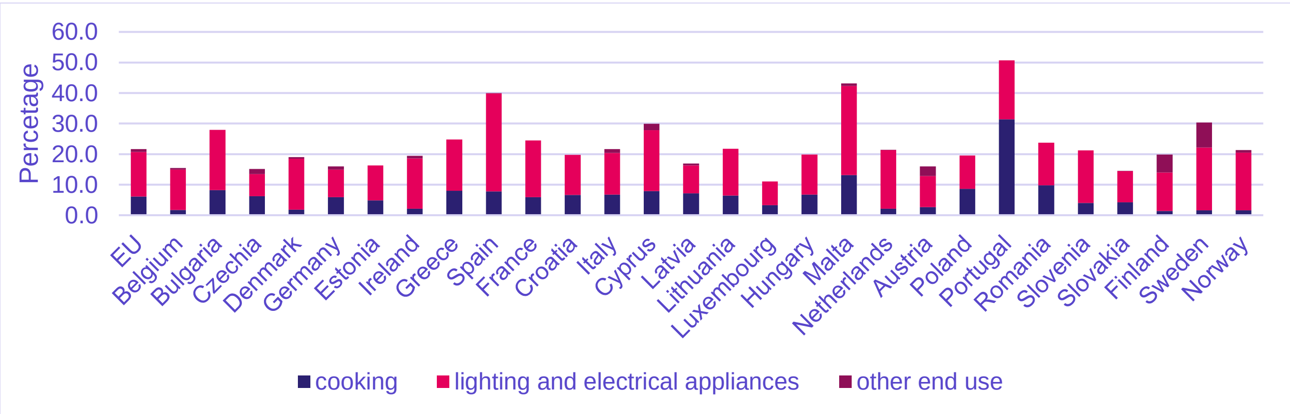

Figure 16. Share of final energy consumption in the residential sector by type of end-use, 2020, Data Source: Eurostat [61]

The household electricity survey done in the UK provides data on the annual electricity consumption of households per m2, a result gathered from 251 households in the UK between May 2010-July 2011 [62]. This data set also contains the electricity needed for space cooling, if provided for the dwelling. The distribution of data monitored for all households on Figure 17 shows that the consumption of the individual households can be 5-times higher or lower than the average.

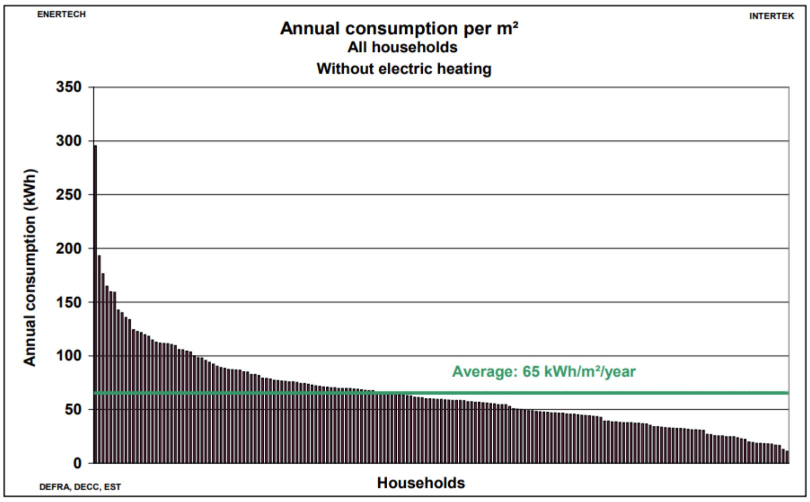

Figure 17. Total annualized electricity consumption per m^2 – all households. Source: Household electricity survey [62]

The same survey provides valuable data on the average heat load curve for the whole measurement period, per appliance use categories. This shows that the highest consumption can be seen in the evening, where cooking, lighting and audio-visual equipment are used. It is interesting to see that the peaks do not occur at the same time as suggested by the EN standard. The lowest hourly value is approximately 30% of the peak hourly values. This shows a higher variance in the values compared to what the example in the standard suggests.

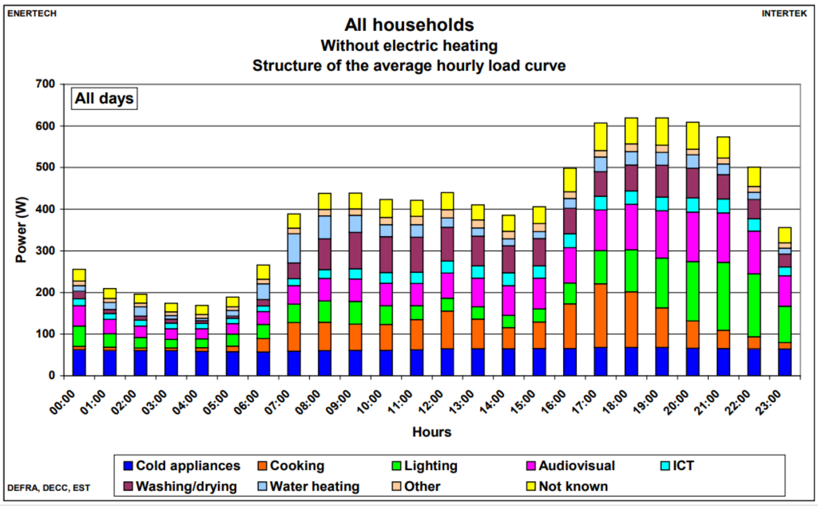

Figure 18. Structure of the average hourly load curve – all days – results from 251 households in the UK between My 2010-July 2011 Source: Household electricity survey [62]

The survey results were also analysed whether seasonality effects of the usage of household appliances can be found. The graphs shown on Figure 19 have been derived from the survey data of 26 households that were monitored for one year. Lower energy use for washing and drying, cooking, lighting was found for the summer periods, while the energy use of cold appliances increased. They had not found seasonal effect on the usage of audio-visual elements.

This trend could be explained by people utilizing natural drying instead of using driers in the summer, and limiting the cooking when the temperatures are higher. However, the cold appliances use more energy as the temperature rises.

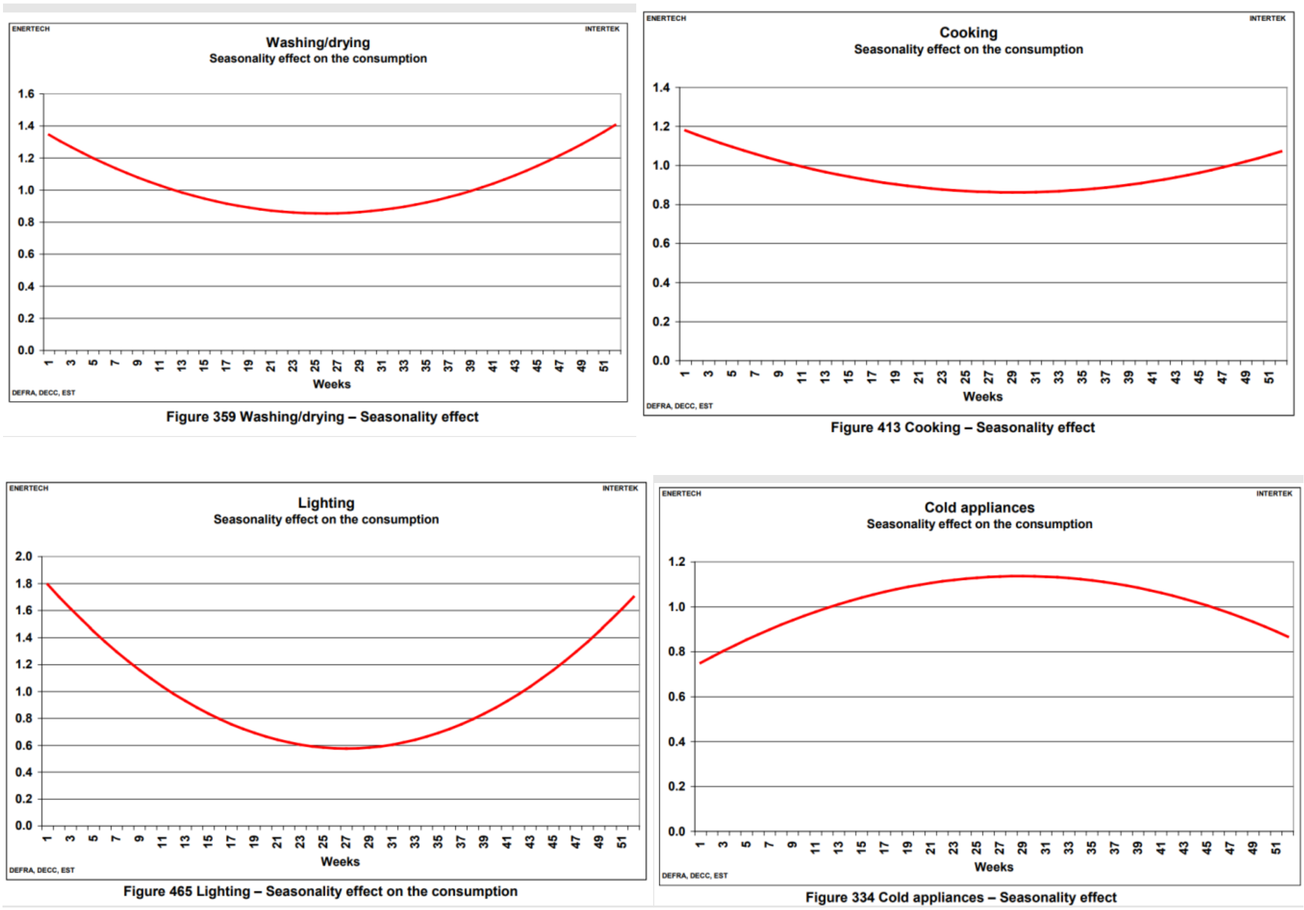

Figure 19. Seasonality effect of washing/drying, cooking, lighting, cold appliances. Results from 26 households in the UK between My 2010-July 2011 Source: Household electricity survey [62]

Within the D3.1 survey for Hungary building occupants have been asked what types of measures they implement in their dwellings on hot days. In average, 71% of the occupants have replied to avoid using the oven. When looking at the distribution of responses per age group the respondents who were 60 years old or higher tend to implement this measure,

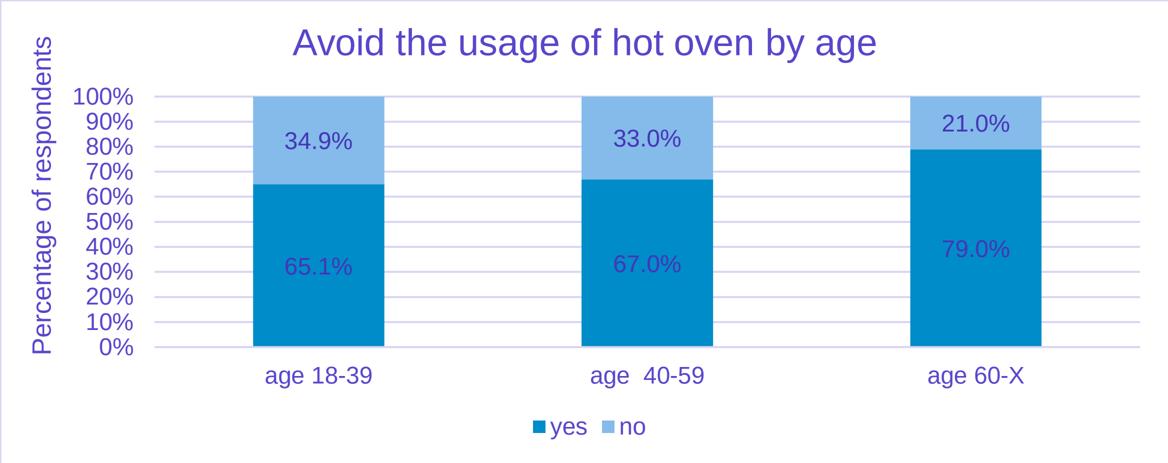

Figure 20. Percentage of respondents avoiding the use of hot oven by age group in the CoolLIFE household survey in Hungary

Conclusions and recommendations

While it is difficult to find data for each country/region based on the annual/daily distribution of energy use, a number of examples of trends have been compiled.

Similarly to the occupancy pattern the individual households have high diversity in the equipment use pattern depending on the occupant type. Equipment use highly depends on the user habits which is not addressed in the calculation methodologies, thus when considering SC predictions this variable should also considered as a set of different options tested for robustness. Limiting indoor cooking and avoiding the use of electrical dryers directly contribute to the reduction of SC demands. One study fok UK has shown that the use of appliance has a seasonality effect, that was around approximately 2% of the total average household energy use. As expected, also the lighting energy use shows seasonality, which is highly location dependent. The daily schedule of the appliance use shows peaks in the afternoon, when cooking and audio-visual equipment use is higher.

Trends have been identified that show that people tend to limit some activities that produce heat in in the dwellings when the temperatures are high. For example, as shon in the CoolLIFE survey, 71% of the occupants in Hungary do limit the use of the oven in hot weather, and implementing this increases with the age of the respondents. Nevertheless, equipment use in dwellings is highly dependent on the users background habits, thus when considering SC predictions this variable should be a factor whose effect is studied through a sensitivity analysis. Predictions should be sensitive to contextual factors and data on equipment use schedules.

3.2. Perceived thermal comfort and adaptation

While occupants of residential and commercial buildings have similar preferred neutral temperatures, occupants of residential buildings will accept temperature variations from thermal neutrality between four and five times greater than those of commercial buildings while still remaining comfortable. The reasons for this are not fully understood, but are thought to lie in occupants' perceived control over their environment. If energy use is to be reduced, and demand response increased in buildings, occupants will need to accept lower/higher ambient temperature and be empowered to adapt through changing their clothing and local environment to remain comfortable. This adaptation can be facilitated by giving users control over how they dress, how active they are, and how they manage their local environment.

In *D3.1 Knowledgebase for occupant-centric space cooling* detailed information has been collected on the comfort standards, perceived comfort and adaptation measures relating to the different countries and regions is Europe.

Regulations and standards

The main standards implemented across Europe for thermal comfort are ISO 7730, EN 16798-1:2019, as detailed in *D3.1 Knowledgebase for occupant-centric space cooling*. The calculation methods and limits implemented for thermal comfort are based on activity, clothing, and environmental parameters (e.g. operative temperature). Four IEQ categories can be defined for the operative temperature. The thermal comfort requirements and their limitation in their applicability to residential building are discussed more in D3.1. summarized, the thermal comfort standards based on the thermal comfort model of Fanger are widely aligned not only in Europe, but around the globe. No evidence was found that a country adapted different standards.

The thermal comfort models have been developed based on steady state conditions and include detailed criteria for standard metabolic rates and clothing. In reality the occupant actions and clothing cover not only a wider range but can also change dynamically. These can either be influenced by the occupants' desire to return to a comfortable state, but also are dependent on actions out of control (e.g. higher metabolic rate due to movement).

The standards do not cover people when they are sleeping. While generally lower temperatures are recommended for sleeping this is highly affected by the habits or clothes worn at night and bedclothes. A research done by Fan et al focused on whether high temperatures have an adverse effect on productivity by assessing the subjectively rated sleep quality in a climate chambre. They concluded that sleep quality decreased significantly when the air temperature increased from 24°C to 28°C. [63] Sekhar and Goh [64] also studied night temperatures and perceived comfort, and colcuded that the degree of acceptability depends on each individual and while some may find it difficult to fall asleep in slightly higher temperatures others may deem it as comfortable. However, their survey showed that people in naturally ventilated bedrooms in hot humid environment without air conditioning (AC) use a pedestal or table fan to provide a general level of air circulation in the room but would not direct the air flow straight at their face.

Empirical data

As outlined in *D3.1 Knowledgebase for occupant-centric space cooling* as well, the thermal comfort sensation might deviate from the temperatures that are considered neutral, based on a wide range of social, adaptational and health factors. The main influential factors and regional practices have been summarized in the refered deliverable. In this section we analyze more in detail the temporal distribution and drivers behind implementing behavioural aspects.

Change in clothing

The literature shows that behaviour towards changing clothing is different for offices and dwellings. A survey conducted in Denmark for dwellings showed that in summer the main adaptive action was to adjust clothing, both when occupants felt too hot, or too cold. Secondly, adjusting the set-point a little, and opening the window as the third most common action. [65]

The results of Baker and Standeven [66] suggest that clothing insulation is not adjusted vividly. They conducted a survey in seven buildings in *Athens* and *Lyon* and asked the occupants if they had made clothing adjustments within the last hour. Change only occurred 62 times out of the 864 observed hours. The same authors found that office occupants rarely altered their clothing ensemble on an hourly basis. [66] They concluded that people tend to select their clothing based on outdoor conditions in the morning, but except in dwellings, people rarely alter their clothing during the day.

Clothing in residential buildings is free to choose, in the CoolLIFE household survey for Hungary 98.8% of the respondents said they implement this measure when temperatures are hot. However, in offices dress codes can hinder this type of adaptation. While school uniforms in Europe are limited to the UK, Ireland and Malta, school houserules may include dress codes prescribing a minimum level of clothing.

Morgan and de Braer observed that the standard clothing in administrative offices where dress codes were implemented during Mondays through Thursdays were remarkably homogenous, with daily averages falling consistently between 0.7 and 0.8 clo. However, when casual Friday was implemented, when the office workers were permitted to dress casually, there was a much greater variability in thermal insulation being worn. In summer weather the clothing in Fridays was 0.2 clo lighter compared to Mondays through Thursdays. They also indicated that cca. 0.45 clo is deemed as socially acceptable minimum level, where the degrees of freedom for clothing behavioural thermoregulation diminish [67]. With taking into account the chair insulation value of an office chair with an average insulation increment of 0.15 clo, this equals approximately 0.6 clo. They argue that a relaxation of dress codes could lead to a 40% percent saving in heating, cooling and fan energy.

The effect of bed clothing on the operative temperature has been found high by Lin and Deng [68]. They suggest that instead of maintaining a relatively low indoor air temperature, people should use as little sleepwear and bedding (or cover as less body surface area by bedding) as possible to lower the total insulation of a bedding system.

Change in activity levels

The metabolic rate is the metric used in the comfort standards to express activity levels. The details of the metabolic rate is defined in ISO 8996. 1 metabolic unit = 1 met = 58.2 W/m^2. Seated, relaxed ctivity corresponds to 1.0 met, while 1.9 met corresponds to walking on level ground with 2 km/h. The ISO 7730 standard concludes that elderly people often have a lower average activity than younger people.

The activities in residential buildings can vary on a range of sleeping to physical excersize. Regarding the actions taken by residents, the CoolLIFE survey confirmed that on average 76.1% of the respondents implement a reduction in activity levels on a hot day. 70.4% of total reposndents avoid activities which require physical activity, 66.7% even have a siesta. When comparing the subgroup of the respondents, women (73.2%) and individuals over 60 years old (80.1%) protect themselves in the highest proportion by avoiding physically demanding activities.

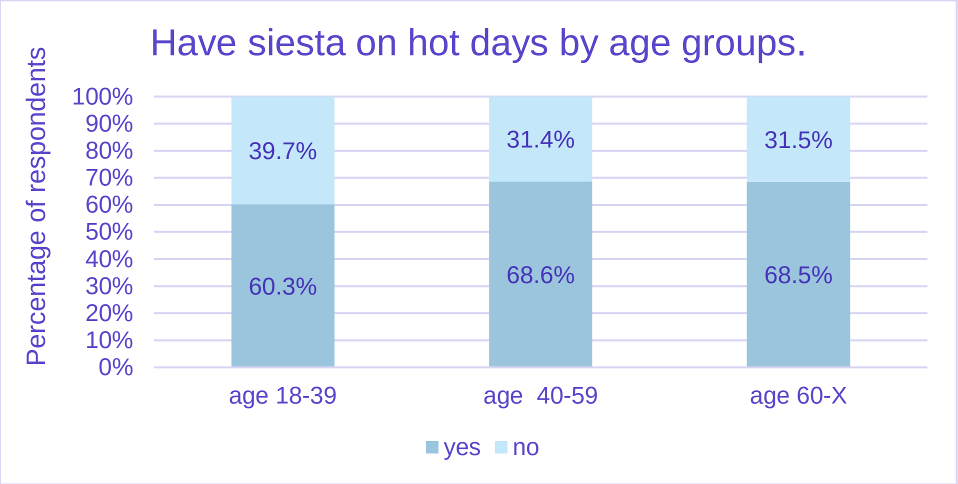

Figure 21. Percentage of respondents having a siesta by age group in the CoolLIFE household survey in Hungary

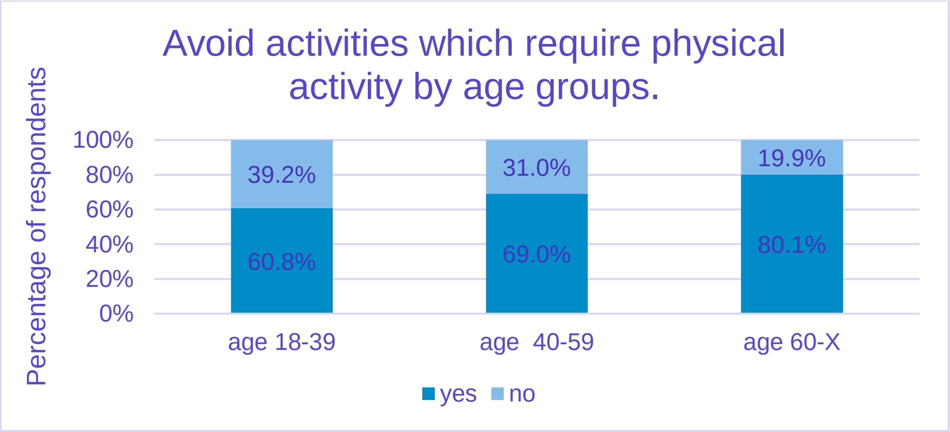

Figure 22. Percentage of respondents avoiding physical activites by age group in the CoolLIFE household survey

The activity levels in residential buildings that affect thermal comfort perception change throughout the day are hardly considered in thermal standards - especially when regional differences are being conerned. Sleeping/resting time is considered in the Eurostat data, which shows approximately 1.5 hour shift between the average daily sleep schedules of the studied eight countries. The report concludes that Hungarians and Slovenians wake up earlier and go to bed earlier than others, while Norwegians go to sleep later than the rest. They found the sleeping rhythms of women and men during weekdays similar in the investigated countries. Within the comparison countries that are typically implementing siesta have not been studied, however, in the data daytime naps or rest have been shown also for France, Hungary and Germany, usually taken between 1 and 3 pm. [46]

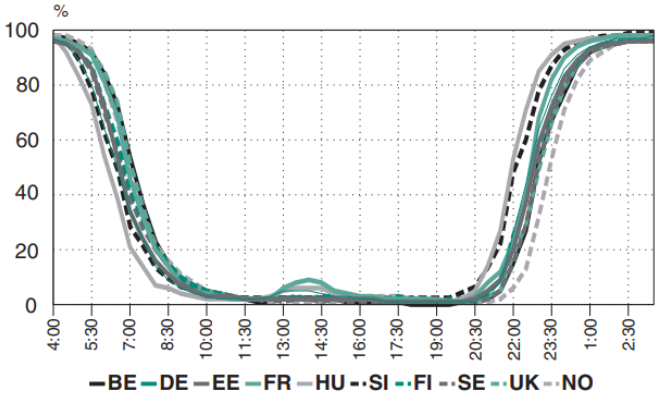

Figure 23. Daily sleep rhythm of men and women aged 20 to 74, Data: 1998-2002 Source: [46]

The standard metabolic rate considered for office use is 1.2 met. Toftum et al [69] concluded that shifts from seated to standing posture may increase by 0.3 met corresponding to a decrease in preferred temperature of approximately 2.4 °C when studying office buildings. Similarly, Bourdakis et al [70] argue that most people will have an increased activity level (higher than sedentary) when coming to work. This may result in a feeling of warmth arriving in an office controlled for sedentary comfort. This can also be the case when arriving home to the residential buildings, which triggers an interaction with the cooling equipment even if the temperatures is within the acceptable range.

Adaptation by consuming cold food/drinks

Consuming cold food or drinks helps the body cool down and reduces metabolic rates, approximately by 0.12 met according to BRE. In the CoolLIFE survey 77.6% of the respondents confirmed that they implement this measure on a hot day. The implementation frequency of this adaptational measure was lower as age increased, presumably due to the prevention of health related issues. Only 61.3% of the 60 years and over group confirmed this as opposed to the 85.1% of the youngest, 18-39 age group.

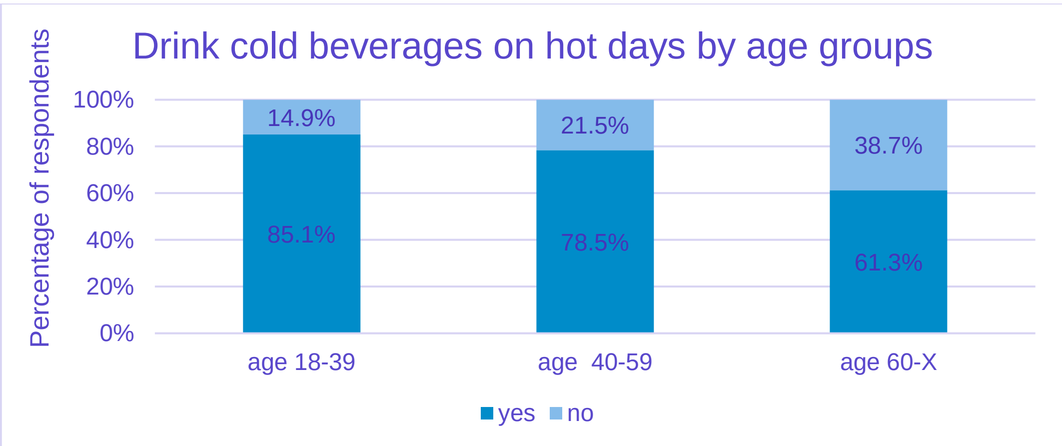

Figure 24. Percentage of respondents avoiding physical activites by age group in the CoolLIFE household survey

Ability to control the thermal environment

One study examined occupant behaviour and adaptive comfort in a naturally ventilated office building over two seasons in the U.S. They found that while two occupant groups, one with and one without control possibilities over their environments, experienced surprisingly similar thermal environments, the reactions of the group which had higher degrees of control over the window openings were different. Despite the similarity of thermal exposures the ideal comfort temperatures (defined by the “neutral” temperature) for the occupants with higher degrees of control were much closer to the temperatures they actually experienced.

Conclusions and recommendations

It has been found that the thermal comfort models are widely aligned not only in Europe, but around the globe. The two main models are the PMV model from Fanger, one that is used for buildings that are mechanically cooled and ventilated. The other model is the adaptive comfort model which allows higher temperatures as a function of the running mean outdoor temperature when the building is not mechanically cooled. However, it is well documented that thermal comfort sensation can defer from the predicted thermally neutral conditions predicted in comfort standards, which is also dependent on the individual.

Occupants in residential buildings have a wide range of possibilities to alter their metabolic rates and clothing to maintain thermal comfort, changing activity levels, taking cold drinks and changing clothing levels are widely adapted by the building inhabitants to cope with hot summer weather. At night time, limiting the heating effect of bedclothing should result in higher accepted temperatures. This would result in a relatively higher indoor air temperature maintained in bedrooms without losing thermal comfort at night, and consequently, reduced energy use for air conditioning for sleeping environments.

In office and educational buildings this potential is lower due to the nature of the activities in the building. Taking cold drinks can be implemented, however, there is a limitation of the minimum clothing levels around 0.45 clo, coming from social acceptance and reflected in the standards. However, in offices and educational buildings this lower limit cannot in all cases be reached due to the dress codes implemented in certain institutions and workplaces. Allowing a more relaxed requirement in these types of buildings can help the occupants adapt naturally to warmer environments thus SC demand can be reduced.

When entering a room with different thermal environment from the previous one may cause thermal discomfort, also caused by an elevated metabolic rate. To reduce SC needs in buildings attention should also be paid to this type of short term discomfort and possible adaptation, as detailed in *D3.1 Knowledgebase for occupant-centric space cooling*. Occupants could be stirred in a direction to overcome the urge of switching on space cooling as the first reaction when arriving home.

3.3. Space cooling set-point preferences and schedules

Understanding the occupant’s preferences towards space cooling setpoints are key in quantifying SC energy demand. In *D3.1 Knowledgebase for occupant-centric space cooling*, a literature review was done on the preferred temperatures, together with the local and regional SC setpoints implemented in EU countries. In *Work Package 4 Policy, financing, and recommendations* further mapping of the legislative requirements will be done. Here we only present a short summary of the standard setpoints, and concentrate on analyzing the patterns of using individual, user controlled air-conditioning units and the drivers behind.

Regulations and standards

The detailed information - The informative Annex B of the EN16798-1 standard - suggest default categories for design of mechanically heated and cooled buildings. For residential buildings, living spaces, (bedrooms, living rooms, kitchens, etc) with sedentary activity (1.2met, 0.5clo) the maximum cooling setpoint in are shown in Table 14. For other spaces in residential buildings no requirements are recommended. For unoccupied hours the informative Annex C recommends 32°C. Schedules for operating space cooling devices are not implemented in the standard, as the target temperatures are anticipated to be reached throughout the occupied period.

IEQ category	Operative temperature - Maximum for space cooling (summer season) approximately 0,5 clo
IEQI	25.5 °C
IEQII	26 °C
IEQIII	27°C
IEQIV	28°C.

Table 14. Default design values of the indoor operative temperatures in winter and summer for buildings with mechanical space cooling systems

It can be concluded that there is no significant difference in the values for space cooling setpoints implemented throughout the energy performance predition methodologies in different countries, and the daily variation in the temperature setpoints are not considered, but a single value is included for occupied and non-occupied periods. As showed in D3.1, the thermal standards adopted throughout Europe do not include regional variations, but the national codes include several approaches. Where active space cooling is applied, 26 ºC is the most common upper limit as a setpoint for SC devices. However, where the avoidance of space cooling is the intention of the policy makers, when single temperatures are given, the requirements are relaxed, up to 28°C; or instead of using a single temperature, overheating limits are defined as a function of the building structure, or together with the maximum number of hours when this is allowed.

Empirical data

While constant space cooling setpoints in the occupied periods around 26°C are widely adapted for energy calculations in EU countries, the case studies show that - especially for residential buildings - when SC is operated, the lower setpoints are selected for the local AC units and the usage of the SC equipment is intermittent. Fokaides et al. [71] point out that there is an important difference between the operation of the heating and cooling devices of the dwelling. During the heating period, usually the entire building is heated, whereas during the cooling period, only the occupied spaces (usually one or two) are cooled. They point out that is due to the fact that air conditioning by split units has a different impact on the thermal conditions of the space, and particularly acts directly on the temperature of the room air. It is true, while the standards and regulations state requirements for operative temperatures, in reality the target temperature that is indicated on the split-unit air conditioners that are mainly adopted in residential buildings is air temperature measured at the cooling device. The operative temperature, as defined in the standards is the *uniform temperature of an imaginary black enclosure in which an occupant would* *exchange the same among of heat by radiation plus convection as in the actual non-uniform environment*. Simply put, when calculating operative temperatures, the temperature of the surrounding structures, e.g. walls, floors, windows need to be considered. In summer conditions, when the structures are close to the temperature of the air before implementing SC, this means to reach the suggested operative temperatures, the temperature on the SC device needs to be lower than the operative setpoint targeted.

Studies from outside Europe on behaviour regarding SC revealed that the occupants' approach to setting a constant space cooling temperature is also not adopted, on contrary to how heating setpoints are maintained by using a thermostat. For example, Kempton et al concluded that their initial hypothesis of people turning on an air-conditioners when they feel hot and set it to a temperature at which they will be comfortable was proven to be wrong through the field studies. [72] Instead, they revealed that when turning on devices, some residents set the thermostats to such a low setpoint that the thermostatic cutoff of the device – indicating that the setpoint had been reached – was not experienced before the residents manually turned the unit off. Similarly, Sekhar and Goh surveyed and measured AC usage at night in Singapore [64] and revealed that while the temperature of the air-conditioning unit was set to 20°C for 12 cases, the temperature only reached this value for one case according to the measurements. The measured mean temperatures fluctuated between 22.5°C and 26.5°C, which indicates similar to the findings of Kempton et al. that the SC devices in dwellings might not be sized right or controlled based on preferred temperatures, and operating these devices do not in fact mean that the intended temperatures are reached. Several authots in the literature suggested a schedule based cooling approach instead of using a constant setpoint through the day. [73] [71]

In 2017, Stazi et al [59] concluded that the literature focused on AC usage is not as wide as that studying windows, blinds and light switching behaviours. Their findings are based on 7 studies that are all outside Europe, however, we consider their results as approximations for the case of Europe, that is supplemented by the information gained in the survey conducted within *D3.1 Knowledgebase for occupant-centric space cooling*. Regarding the schedules on how occupants use space cooling devices daily patterns were found for air conditioning units, which interaction is also a consequence of the different life style between singles and families, of the day of the week and of particular events (i.e. sleeping and cooking). They found both indoor and outdoor temperatures as influential on the air conditioning use in living rooms and bedrooms. The turn-on probability found in their review became significant at 25°C–30°C indoor temperature, while the turn-off behaviours start when the indoor temperature reduces to the range between 30°C and 27°C. The correlation to outdoor temperature was expressed as the T50 (i.e. the temperature at which half of the persons use AC-units) value that can vary from 23°C to 29°C, while the most of AC units are switched on when outdoor temperature is 36°C for living rooms and 27°C for bedrooms. For the daily pattern they identified that during weekdays switch-on peaks occur around 6 p.m. and the off-events usually happen from 6 to 12 p.m., while adjustments in weekends are operated along the all day. They indicate that switching activity is more frequent before sleeping and eating, while the probability of turn-off is higher after getting up and when leaving the room.

These daily patterns relate to the occupancy patterns of working adults in residential buildngs, which are however only representative of some parts of the society. They also conclude that the lifestyle and the daily routine are predominant features in AC use: differences were assessed between singles, families and students have been identified. Also, the usage of the AC depends on the socio-economic background of the user, where comfort might not be the main trigger, as outlined for the Spanish social housing case studies [74].

Regarding the time profile of AC usage at night Sekhar and Goh found for the hot-humid climate of Singapore [64] that 58.3% of the subjects did not switch on the air-conditioning unit at all when sleeping, 33.3% of the respondents seldom switched on the air-conditioning unit, while 8.4% of the respondents slept in an air-conditioned environment frequently. Of the subjects who have the tendency of switching on the air-conditioning unit, it was observed that only

40% switched on throughout the night and another 40% and 20% of the subjects switched on the air-conditioning unit for 2-4 h and 4-6 h respectively.

They also found that while the temperature of the air conditioning unit was set to 20°C for 12 cases, the temperature only reached this value for one case according to the measurements. The measured mean temperatures fluctuated between 22.5°C and 26.5°C. This indicates that the units did not have any capacity to cool down the rooms. The cause for this is either their lack of appropriate maintenance, or as SC units in existing residential buildings are not installed based on HVAC designers calculations, AC units might be undersized for a certain space.

The efficiency of the AC units in Europe are indeed a question worth investigating as it can affect users to increase their SC demand. The survey of the Enable.EU project indicated that only 2.8-16% of the homes are equipped with AC units that are up to 3 years old in the studied 11 European countries, while 1-27% of the homes have equipment that are 4-10 years old, and 0- 20.3% that are even older than 10 years. While regular maintenance is needed to maintain the efficiency of all HVAC equipment, the level of implementation defers from country to country.

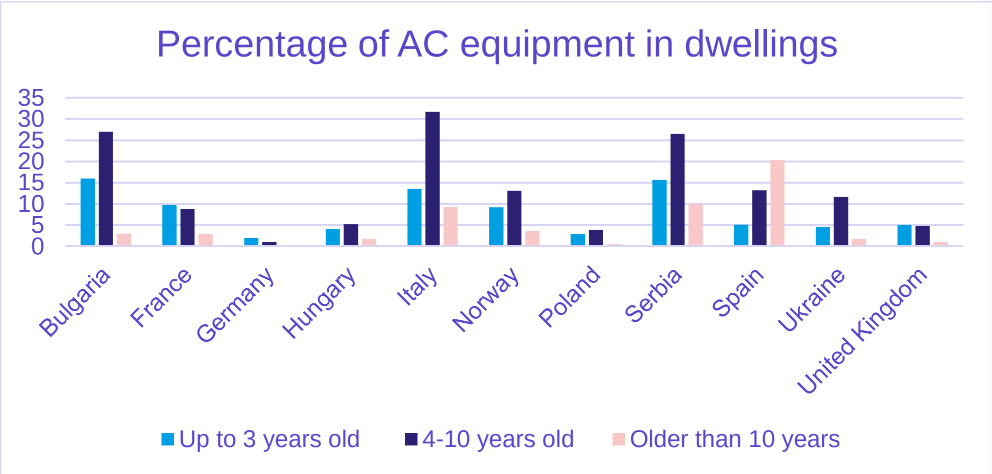

Figure 25. Age distribution of air conditioning units in homes, percentages based on the total number of respondent, Data source: Enable.EU [75]

Resuts from the CoolLIFE household survey in regards to selection of setpoints has been evaluated from different aspects. Firstly, the existence of temperature measurement devices has been survey, and approximately 85% of the inhabitants responded tp have some type of measurement for indoor temperatures, of which 10% of the people rely on the SC device, while 71% have a thermometer, 8.9% have portable thermostats. While the most important driver for turning on the SC device is the thermal discomfort, 28.6% of the respondents rely on the temperature measurement of the device as well. It is however important to note that the placement of the thermometer has a high influence on the measured temperature and mislead the occupant in the actual value of temperatures.

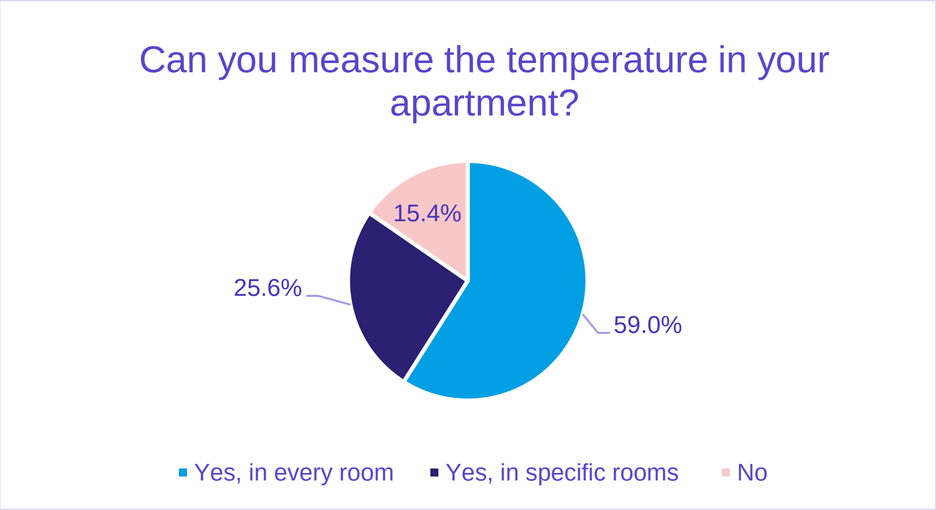

Figure 26. Percentage of respondent according to the availability of temperature measurement devices in the CoolLIFE survey

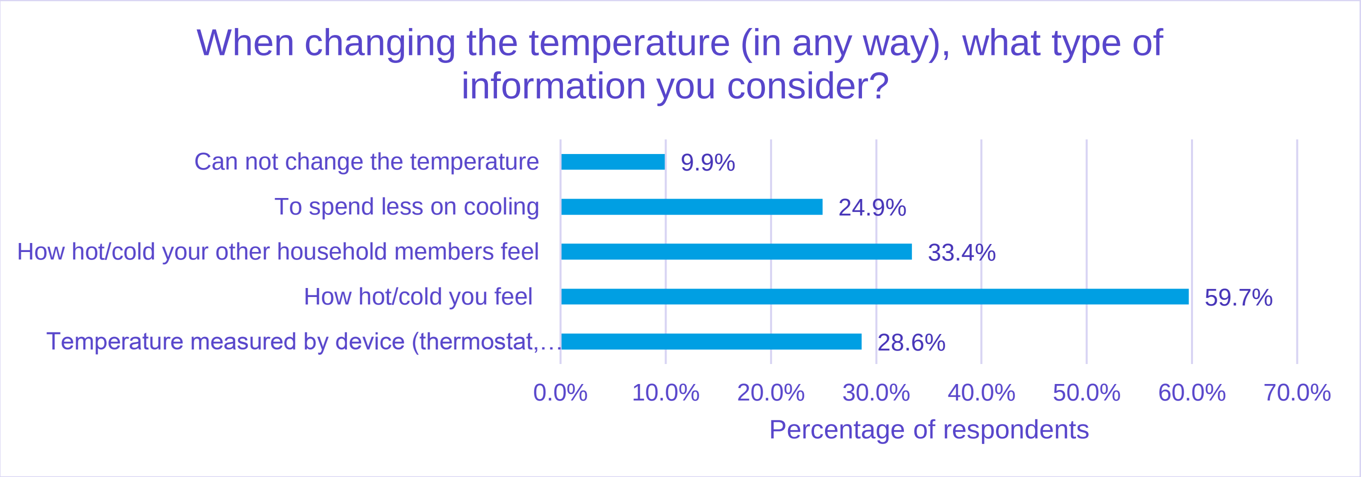

Figure 27. Information considered by the respondents when changing the temperature in the dwelling in the CoolLIFE survey

In the CoolLIFE household survey 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. A number of people mentioned rather low temperature values below 20°C – and also relative higher values, even 28°C also appeared. This wide range of setpoints from the respondents can indicate a wide range of the preferred temperature, however, it can also indicate that the occupants are not fully aware on the notion of the temperature setpoint for space cooling devices, as outlined in D3.1. Many people think that by setting the temperature at 16°C (or the lowest one), their AC will cool faster, however, AC units will only run longer as they already run on full capacity until they reach the temperature setpoint. Nevertheless it is seen that the majority of the answers fall within the thermal comfort range of the EN 16798 standard, and are maily lower than the suggested setpoints in the legislations, that is mostly 26°C. However, the responses do not show a normal distribution,a high step can be seen between 21-22°C. Please see Figure 28:

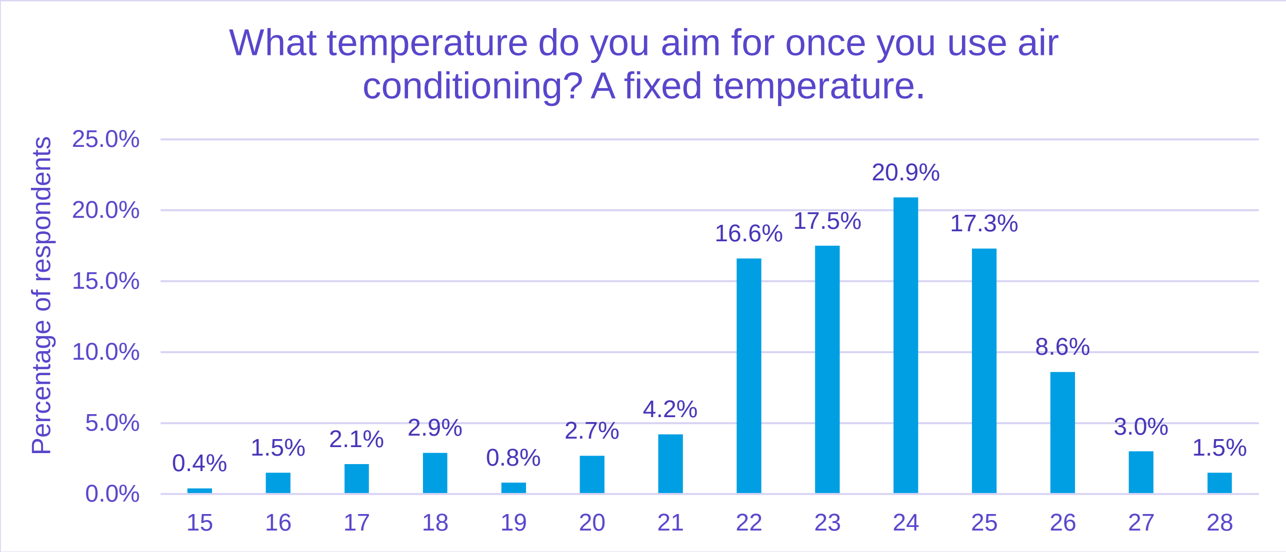

Figure 28. SC temperature setpoints by CoolLIFE household survey respondents who set a fixed temperature

A number of respodents indicated that they select AC temperatures based on the external temperature. The two most popular responses were 5°C and 10°C. As these to round number have been selected by the vast majority of the people this cannot be taken as objective data, but is biased based on their perception of what a 5 or 10 percentage step should mean.

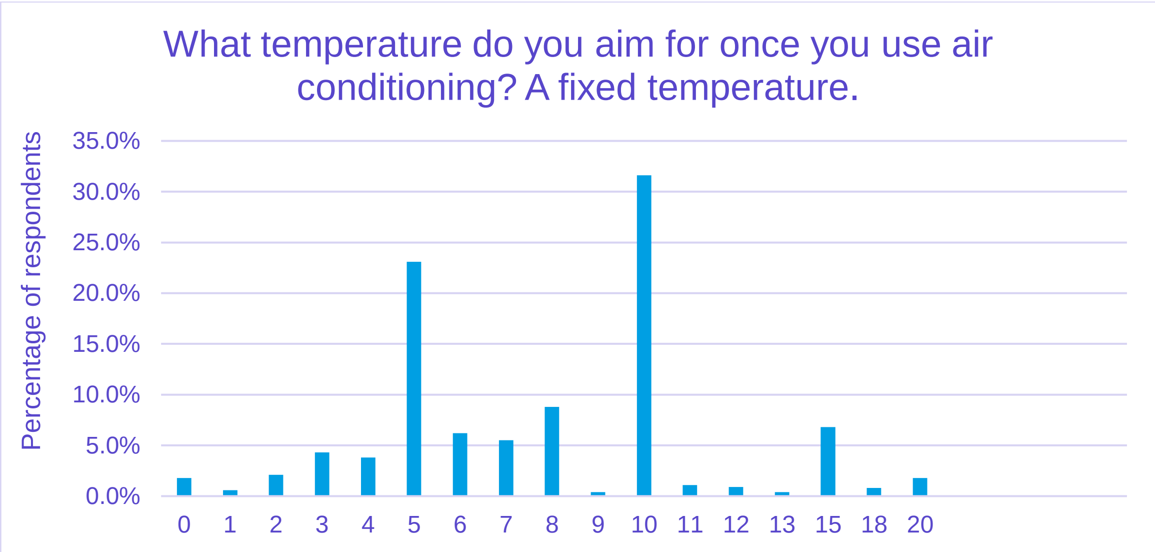

Figure 29. SC temperature setpoints by CoolLIFE household survey respondents who set temperatures based on the external temperatrure

This type of behaviour due to the lack of knowledge has also been seen in the literature, resulting in unexpected behavioural patterns. A study in the US monitored the use of room AC equipment in a multi-family building in New Jersey together with conducting a survey. [72] The finding of the study showed that seasonal air conditioner energy consumption varied by two to three orders of magnitude across physically similar apartments with the SC units having the same control capabilities, while interior temperature varied by only between 2.4°C to 3.7°C. The authors named one of the main causes for this that many residents were not aware that their units had thermostats. The following usage patterns were identified:

- The least-frequent users ran their units only on peak hours of the hottest days of the summer, thus their behaviour did not reduce peak electricity demand.
- Three-quarters of the residents did not use their thermostats, controlling cooling instead by switching their units on and off manually, and only one resident consistently let his air conditioner operate thermostatically.

Residents were not billed separately for electricity, however, they limited their use of air conditioning on the basis of many non-economic factors. According to the authors this included: "*daily schedule, folk theories about how air conditioners function and the body's heat tolerance, personal strategies for dealing with all machines, and beliefs and preferences concerning health, thermal comfort, and alternative cooling strategies."* An interesting finding of this study was that the prevailing non-thermostatic mode was initially thought to indicate a need for user education, however the authors conclude that the issue is more due to that the controls do not correspond to the user needs, as those were not labelled in degrees Fahrenheit of temperature, and no feedback was given on the set temperature.

For selecting low temperature setpoints this type of behaviour might be the cause in the CoolLIFE survey as well. However, it is also seen in the survey results that the respondents who identified to have low (17-18°C) summer temperatures in the dwellings also found it similarly comfortable as the respondents who identified the usual temperature being 23-24°C.

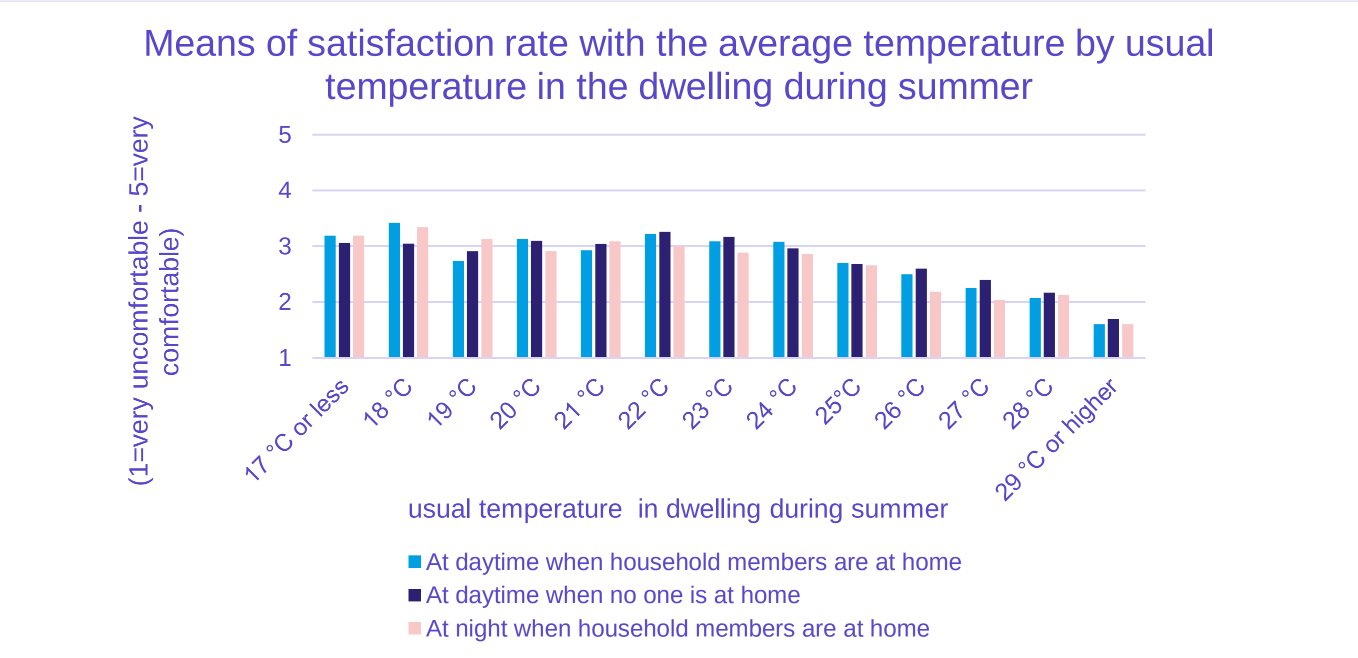

Figure 30. Relationship of satisfaction rate and usual temperature in the dwelling in the CoolLIFE survey

Regarding the use of the SC units the majority of the respondents in the CoolLIFE survey indicated that they turn on AC units in case of extreme heat or in every case when they feel discomfort. The outside temperature as a driver for using the AC was only indicated in 4.1% of the cases.

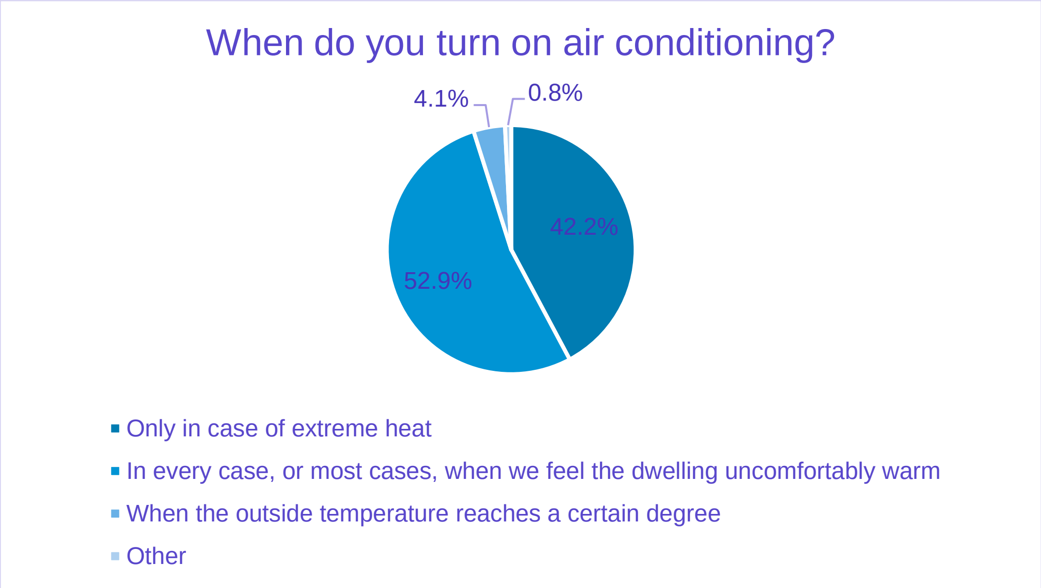

Figure 31. AC usage triggers in the CoolLIFE survey

The behavioural pattern of turning AC off when leaving the house had also been investigated. The operation of SC devices in dwellings is driven by event related factors like arriving home or leaving the house. While 69.1% of the respondents turn off AC devices 10% only adjust setpoint temperatures when leaving the house, and the others do not take any action, and leave the device running.

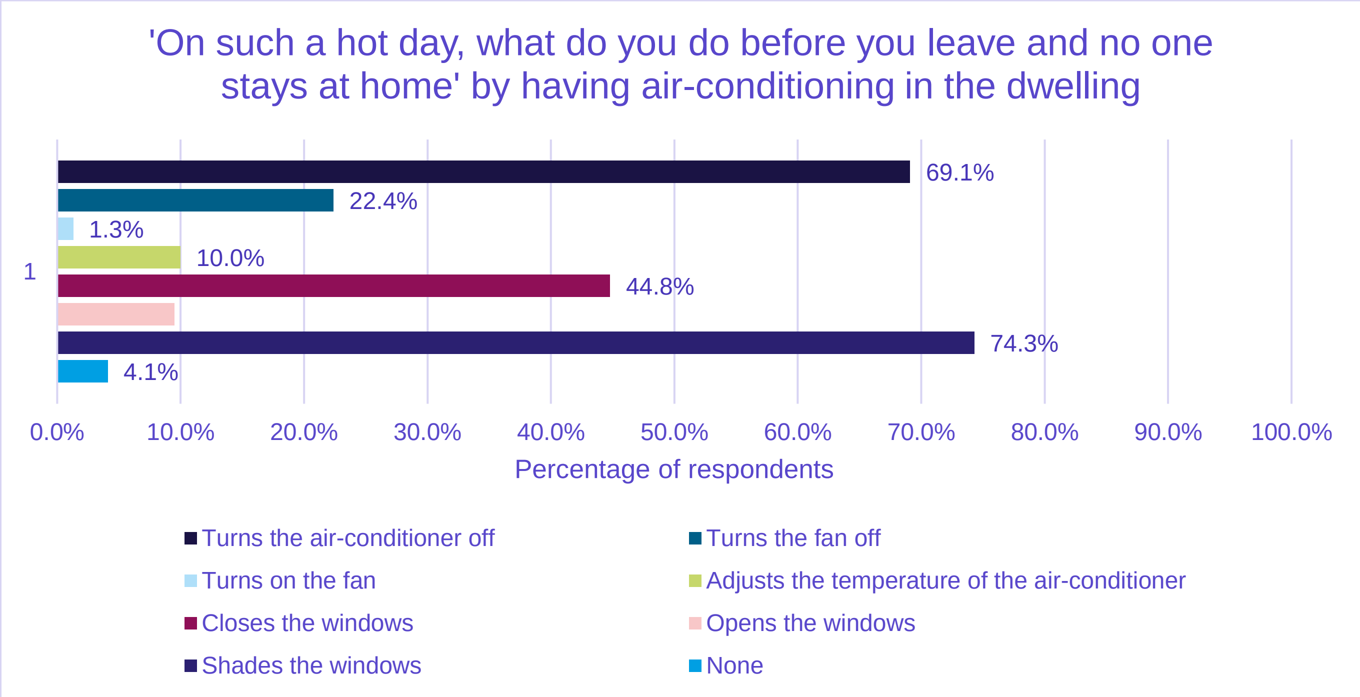

Figure 32. Actions taken by occupants before leaving home, respondents who have AC unites at home from the CoolLIFE survey

According to the literature a successful strategy towards reducing space cooling energy demand could be to pre-cool spaces during periods with lower external temperatures resulting in a more effective use of the space cooling devices. Implementing these solutions depend on the building occupancy pattern. As seen in the literature this strategy is more applicable to office and commercial buildings.

Bourdakis et al [70] stated that the temperature achieved with night precooling in offices might also be lower in summer than what the operative temperatures accepted in the comfort standards. As detailed above,they argue that as office workers will usually have a slightly elevated metabolic rate when arriving at work, they find room air temperature at the beginning of the occupancy between 20°C – 21.5°C comfortable, which then could increase steadily at a rate of 1.5K/0.5h to reach the comfort range of 23°C – 26°C.

Braun and Zhong in 2004 [76] developed and evaluated of a night ventilation precooling algorithm that could be integrated at low cost within a controller for packaged air conditioners that employ economizers, such as rooftop units for small commercial buildings. They studied the effect of changing from conventional night setup control, where the zone temperature setpoint was increased at the end of the occupied period, to a night ventilation precooling where outside air during the unoccupied period could be utilized when the ambient temperature is sufficiently cooler than the zone temperature. When the equipment is turned off at night the zone temperature can float above the daytime setpoint. In their approach, if possible, the zone temperature is cooled to a lower (precooling) setpoint and then the fan cycles to maintain this setpoint. They argue that night time ventilation leads to lower building surface temperatures, which tend to reduce the heat gains to the air during the daytime and the associated energy and peak power consumption for the mechanical cooling equipment. The annual electrical energy savings varied between about 0 and 8%.The greatest percent savings in their study occurred in cooler coastal climates having smaller total loads but significant opportunities for night ventilation precooling.

For office buildings, Karjalainen concluded on the current use of office thermostats that designers frequently overestimate occupants' understanding of thermostat usage. Therefore, user guidelines should be developed and distributed to office workers. [77]

Conclusions and recommendations

As seen also in D3.1, there is limited reliable data within the residential sector in Europe on the temperature setpoints, drivers and schedules of local air conditioning units. The available reports addressing summer thermal preferences indicate higher preferred temperatures than the external temperatures, and also setpoints that are under the setpoints achieved with heating in winter. The cause for this is anticipated to be that in many areas in Europe these temperatures can be achievable without mechanical space cooling, thus these results do not indicate that those would be maintained when mechanical space cooling would be applied. However, the literature review also revealed that the temperature setpoint indicated on the SC devices may not be corresponding well to the actual temperature, thus the desired temperature in the dwelling, due to that the equipment is only serving a fraction of the dwelling, and also because the occupants only switch it on when they feel too hot, while the equipment has not been sized to reduce temperatures as the occupants believe. Hence, the trigger point for using SC devices has been explored and drivers indicated based on the available international literature.

Occupants' adjustments on AC units are performed to decrease indoor temperature, especially during the hot season, affecting not only thermal comfort but also energy consumption. In comfort standards and legislation throughout Europe the optimal setpoint for SC is around 26 °C operative temperature. However, the empirical data suggests that this value is more theoretical and hard to relate to in the individual dwellings, as the use of SC devices in dwellings is intermittent with setpoints in many cases set to low temperatures, even around 17°C. The literature review also revealed that the temperature setpoint indicated on the SC devices may not be corresponding well to the actual temperature in the dwelling, and also to the operative temperature setpoint defined in the standards. The causes for this is that the control of AC units is not fully understood, lower setpoints are anticipated to result in faster decrease of the temperature, which is however not the way AC units work. Also, a discrepancy of the setpoint could be found due to undersizing of the units or the lack of maintenance, which based on the age of the AC units throughout Europe would be inevitable.

The operation of SC devices in dwellings is driven by event related factors like arriving home or leaving the house.The Hungarian case study shows that 79.1% of the respondents turn off AC devices or adjust setpoint temperatures when leaving the house, the others do not take any action, and leave the device running. The thermal sensation is an important factor in turning on the devices, while the indoor temperature is not concerned as an objective value in the majority of the cases. The literature suggest that the probability of turning on AC devices increases around 25-30°C internal temperature or 36°C external temperature.

A recommendation to change occupant behaviour would be the education of the occupants on how SC devices work, together with the overview of the ease of comprehending the control of SC devices would be beneficial.

Increasing set-point temperature can lead to a sensible reduction in the annual electricity consumption, which is a fundamental principle that needs no further explanation. Also, overheating during wintertime and overcooling during summertime may have adverse health impacts which should be emphasised during educational campaigns. For example, when entering/exiting an air conditioned building from/to outdoors people may suffer not only thermal discomfort but also even potential health problems.

For office buildings the space cooling setpoints are more aligned with the standards and controlled centrally with a limited degree of freedom for the individual spaces.

It has been indicate in the literature that the placement and easy accessibility of elements and associated controls to regulate thermal comfort sensation is important for the occupants to use them effectively. Also here literature suggests that the working of thermostats are not fully understood by occupants, and the actual setpoints are not selected deliberately.

For educational buildings the control of the SC devices - where present - are done by the teachers, thus their education on behaviours should be the focus of reduction of SC needs in these building types. However, as the educational buildings are closed for a notable time of the year, the installation of SC devices is expected to have lower penetration than other sectors.

3.4. Windows opening factor and schedules

Window opening can reduce heat loads in the building by introducing cooler air to the interior space, but also it has an effect on perceived thermal comfort: with air movement higher operative temperatures can be found comfortable, also, in the lack of space cooling devices the adaptive comfort model can be applied.

In residential buildings with natural ventilation the occupants' ventilation behaviour is the most important variable in the determination of the air change rate. In spaces with mechanical space cooling the window opening affects internal loads. However, it is seen in the literature, that window opening is rarely driven by the intent to reduce space cooling needs. Opening a window can be due to wide range of environmental/psychical factors (humidity, high heat loads, etc), with a strong emphasis on the habits of the individual, which can result increasing the space cooling demand. In a window opening review, Fabi et al. included the importance of contextual factors e.g. orientation, building insulation as well.

With regards to the windows and openings of building, a number of different types of openings have been identified, which not only provide different airflow rates, but, based on the literature can have an effect on the ventilation and airing habits of the occupants. The types can be summarized as the following:

Opening/ventilation types and controls

- casement windows:
    - wide open (vertical hinging) – provides a higher level of airflow
    - tilted/pivot – lower level of airflow, but higher weather protection
- grilles, trickle vent: trickle vent is a device usually fitted at the top of a window that allows fresh air to circulate naturally through a room, and allows polluted air out. They are controllable, to give the option of having them open or closed.
- ventlight/fanlights: Traditionally, fanlights are small windows above doors, usually semi-circular, elliptical or rectangular. They were originally an architectural device to bring natural light into an entrance hall. They can be used similarly to tilted/pivot windows
- door – used in combination with windows for cross ventilation
- ventilator – enhances natural ventilation

- balanced mechanical ventilation

Regulations and standards

Ventilation rates for natural ventilation

The regulations and standards reviewed define minimum airflow rates for spaces with mechanical ventilation, e.g. EN EN 15665, EN 13779 or EN 16798, based on area specific/person specific ventilation rates. Based on these Brelih and Seppänen [78] calculated the required ventilation rates for test dwellings and concluded that the resulting air change rate was between 0.23 h^{-1}-1.21 h^{-1}. However, the ventilation rates in case of natural ventilation are not defined in these standards. For calculation with opening areas for ventilation the EN 16798 states that the design opening areas for residential buildings can be considered as predefined airflow rates but need specific data on local climate and building characteristics.

A review by Dimitroulopoulou [79] on the European standards and measurements of ventilation rates of dwellings found the minimum value of air change rate in dwellings is typically 0.5 air changes per hour. This can be reported as a threshold below which associations to negative health effects of vulnerable groups (children and elderly people) may occur. Studies in the Nordic countries showed that at ventilation rates greater than 0.5 h^{-1}, there is no direct association between air change rates and asthma or allergy among children. However, he suggests that this value should not be considered as a recommendation for the minimum ventilation level, based on health criteria. They also conclude that ventilation measurements showed that in Nordic countries a large percentage of the monitored dwellings did not fulfil the minimum requirement of 0.5 h^{-1}. However, ventilation rates greater than 0.5 h^{-1} were reported in the Netherlands as well as in the Mediterranean countries (Greece and Portugal). Up to 1.5 h^{-1} in Greece and 1.2 h^{-1} in Portugal. The naturally ventilated British dwellings were better ventilated in summer than in winter, showing that the occupants behaviour (window opening in the warmer months) affects the whole building ventilation. Higher ventilation rates were measured in the mechanically ventilated dwellings compared to the naturally ventilated dwellings in a number of countries (e.g. Netherlands, Portugal, Sweden).

The comparative study done by BPIE in 2015 on the analysis of residential building regulations regarding indoor air quality and thermal comfort in eight EU member states (BE, DE, DK, FR, IT, PL, SE, UK) found that specific countries have adopted mandatory requirements for implementing mechanical or natural ventilation. At the time of the survey mandatory mechanical ventilation was in effect in two cases, i.e. for multifamily (DK) and high-rise (PL) buildings. For the other cases, there are recommendations for mechanical ventilation in two countries (Br-Region in BE, DE), while in Italy, especially in warmer regions, natural ventilation is encouraged. Minimum efficiency requirements for heat recovery systems were in place for Sweden, Poland, Italy when new mechanical ventilation systems are installed. Airtightness requirements differ largely across the EU.

For the Netherlands another study found that the reliability of natural ventilation should be at least 83% of the time, inhabitants must have the possibility to reach the flow rates required, based on the 2003 Dutch building decree.

For energy calculation purposes a number of country codes also define design values without mechanical ventilation. For example, in Italy the Legislative Decree 192/2005 and UNI EN 15251 recommends whole building airflow rates for naturally ventilated between 0.3 – 0.6 h^{-1}. In Hungary, the 7/2006 (V.24) TNM Decree defines the minimum airflow rates for buildings where mechanical ventilation is installed for both non-residential and residential buildings. For residential buildings the air change rate of n=0.5 h^{-1} is defined as a constant value, but this should only by applied for the heating season. This value is valid for both occupied and unoccupied periods. This can be increased by 0.05 h^{-1} based on the (low) air tightness of the building and wind exposure. The decree however considers natural ventilation in summer when the overheating risk is determined, by applying different air change rates based on the opening distribution and the application of night time ventilation.

		Openings	
		on one facade	on several facades
Night time ventilation	not allowed	3	6
	allowed	5	9

Table 15. Air change rate (h^{-1}) for evaluating the overheating risk in case of naturally ventilated buildings in Hungary. Source: 7/2006 (V.24) TNM Decree Appendix 3. Table II.1.

It is also different in each country whether the windows can be accepted as sufficient means for ventilation. Requirements for minimum opening size in relation with natural space cooling have been researched. In the Netherlands a study done by AIVC reported that in top hung windows 1.8 m above floor level can be assumed as ventilation provisions and also for airing, while other large openings are assumed to be only for airing. In Hungary design requirements only define the minimum area of transparent surfaces for occupied rooms (1/8 of floor area), but there is no requirement that this should be operable for ventilation.

Industry guidelines

In the lack of national recommendations international best practices, green building standards have been reviewed whether the contain information on opening size.

The BREEAM NC 2016 Health and Wellbeing Issue 02 defines sufficient size for natural ventilation when the openable window area in each occupied space is equivalent to 5% of the gross internal floor area of that room or floor plate. For room or floor plates between 7m-15m depth, the openable window area must be on opposite sides and evenly distributed across the area to promote adequate cross ventilation. Additionally, the natural ventilation strategy should be capable of providing at least two levels of user control on the supply of fresh air to the occupied space.

The LEED BD+C v4.0 requirements state the following minimum ventilation rates for projects in Europe:

	Continuous ventilation	Intermittent ventilation
Single-sided	0,35 m^2 / person	1,05 m^2 / 10 m^2 room area
Cross-ventilation	0,2 m^2 / person	0,6 m^2 / 10 m^2 room area

Table 16. Minimum ventilation area for natural ventilation in LEED BD+C

The provided areas are the sum of supply an exhaust areas for an applicable room depth up to 10m. For the calculations use the number of people in the ventilation zone during use. To calculate ventilation area, if the window is covered with louvers, insect screens, or otherwise obstructed, the openable area must be based on the free unobstructed area through the opening.

The standard applied in the LEED for international project is the AHSRAE 62.1, which states: naturally ventilated spaces shall be permanently open to and within 8 m, of operable wall or roof openings to the outdoors, the openable area of which is a minimum of 4% of the net occupiable floor area.

Empirical data

Window opening schedules are not defined in either of the above standards. Additionally, in case openings are present in the building, these can be operated in many was based on the occupant preferences. The schedules of opening differs with the opening type. Opening behaviour can be triggered based on indoor temperatures, or other variables. Also, in residential buildings different window opening areas and opening degrees can apply for different rooms, which can cause one-sided ventilation, or cross ventilation. The tendencies in different regions/countries have been studied through literature review reports and case studies.

Stazi et al [59] found a pattern of the interaction with windows in offices that shows temporal distribution: opening is greater at arrival, decreases substantially in intermediate periods and is related to closings before departure. However, they conclude that in residential buildings their use is often a consequence of specific domestic activities, which are usually performed in the same time lapse.

They conclude that temperature and indoor air quality requirements are the main environmental stimuli that trigger window adjustments, but a general agreement on whether the main triggers are indoor or outdoor conditions has not been reached yet. Their findings based on the correlations with environmental parameters compared from previous studies:

- Outdoor temperature: few openings occur when the outdoor temperature is less than 10-15 °C, the percentage increases when the temperature rises over 15 °C until 30 °C, reaching the maximum between 25 °C and 30 °C
- Indoor temperature: people tend to open windows when indoor temperature overcomes 20 °C. Some studies found that when the temperature exceeds about 27 °C openings are reduced to avoid the heat entrance from the outside.
- CO_2 concentration: the variable is mainly related to residential buildings. Many studies found a significant statistical correlation between openings and the CO_2 increasing.

An interesting finding is that for closing actions the outdoor temperature appeared to be main trigger parameter also for closings: when outdoor temperature decreases the probability decreases; but also closing actions are more frequent when the indoor temperature decreases, especially during the heating period.

The interaction between users and windows in buildings secondarily driven by time-related events, dependent from the building usage typology. Figure 33 summarizes these patterns for a) office b) residential buildings c) school classrooms. It clearly appears that the opening frequency increases at specific times.

Openings can be seen when people arrive at work, as they might perceive an impression of stuffiness in comparison to fresh and windy outdoor air, and after lunch, which corresponds to the results of surveys saying IAQ requirements are main stimulus both in summer and winter as concluded by Warren and Perkins [80]. Belafi et al [32] confirmed the same that for an office building in Hungary the primary driving factor of window opening behaviour is to have fresh air in all seasons, while the regulation of indoor temperature levels is a dominant secondary driver (56%) during the summer season.

Window closing events are strongly connected to departures. Users intervene less with windows in the time in between and so the position remains unchanged during intermediate periods.

The opening of windows are limited in time in educational buildings. Based on monitoring 62 classrooms of 27 naturally ventilated schools in Athens, Greece, Santamouris et al [81] found that daily routine affects window use in school classrooms, where the arrival time and the breaks can be seen. This was also seen in Hungary during a case study implementing long term monitoring of two school classroom. [32] They however also concluded that window opening and closing behaviour drivers differ significantly due to the different habits, schedules and general school rules applied by different teachers using the same type of classrooms. In Classroom A, temperature levels showed correlation with window use, while for Classroom B, windows were opened based on a regular time series based on the habits.

Review in the UK [30] suggests that in schools windows' ease of use and access and the proximity to windows facilitate windows' operation. They suggest that in schools windows at low heights that are manually-operated and accessible by children can provide more opportunities for children's window operation. Schools that provide high opportunities for window operation have many numbers of windows in two different sizes and levels, have a low windowsill (≤1m), are manually operated and are located within the length of the classroom.

For residential buildings, Stazi et al [29] confirmed that window use is affected by time of the day too. Peaks in opening recur during the morning and the evening, because they are related to specific activities (e.g. showering and cooking). In the following section we will present findings on the window opening schedules and drivers in dwellings in detail.

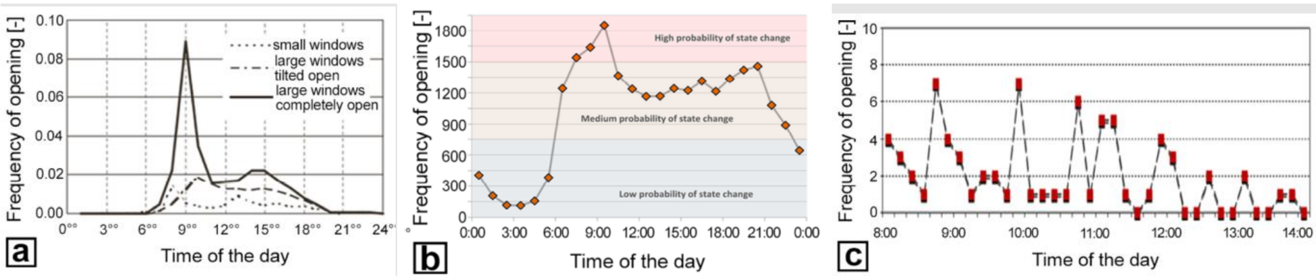

Figure 33. Frequency of window opening a) offices b) residential, c) schools Source: Stazi et al [59]

A research done by the IEA in 1988 summarized in the Technical Note AIVC 23 [82] studied the window use throughout the year in dwellings in Duisberg (Germany), Schiedam (Netherlands), South London Consortium Energy Group (UK) [82]. They expressed the results in number of open windows per dwellings (N_{ow}), that can be regarded as the mean value of the actual number of windows open per dwelling. In Germany N_{ow} was around 1 in June and July and close to 1.3 in August. In the NL project it was above 3, reaching 3.5 in the summer months. In London it was close to 1 in June and between 1.5-2 in July and August. While the pattern in summer was not shown, the findings of the winter studies showed the following pattern for opening the windows:

- Maximum window opening in the morning
- During cooking in the early afternoon but decreases gradually until the evening
- Around 5pm a peak is seen probably due to returning home
- Afterwards window opening decreases gradually and remains fairly constant at the night.

The windows were opened to the following degree:

- In the Dutch projects the window opening tended towards a wide opening of the windows
- In Belgium slightly open windows were more common
- In Switzerland the windows were generally closed
- Grilles tended to be left open, followed by fanlights and then casement windows. Balcony doors were open much longer than front doors.

An interesting finding of this study was that that inhabitants in Germany did not consider that tilted windows were a ventilation measure.

Stazi et al [59] found trends that in summer windows are often kept open, during intermediate seasons the status is frequently modified and in winter the actions' occurrence is very low. The season affects the interaction with windows also for a time-related reason, under the same conditions but in different seasons, the same people act in a different manner. This is similar to the approach taken in the adaptive comfort theory where thermal acceptance is based on the sliding average of the outdoor temperatures.

Several early studies confirmed that windows are also opened to maintain thermal comfort in summer. Brundrett [83] found that in winter the goal is to remove body odour, in spring and autumn it is to provide moisture control, and in summer to allow for space cooling [80] showed that a significant motivation during summer was to avoid overheating.

The Technical Note AIVC 23 within IEA Annex VIII [82] on the occupant behaviour and attitudes with respect to ventilation of dwellings based on surveys done in the Netherlands and Sweden found that with respect to the question on how occupants ventilate, among others, it has been found that if air inlets are present, they are used on a variable way, but no difference between summer and winter periods. During summer the windows are opened on average longer and more widely to cool. In winter the ventlights were open for about 50-60% of the time in the bedrooms. They found that the ventilation behaviour is only partly related to the type of ventilation system. In the bedrooms the behaviour tends to be independent of the system installed. In winter slotvents were open around 68-70% of the time and never opened 6-16% of the time.

In the Netherlands a number of factors was distinguished which appear to influence the use of windows during summer. Authors summarized these as:

- The presence of the occupants: on the corridor side of the apartments the windows or ventlights were opened maximal half an hour on average and on the balcony side maximal 1.4 hour when nobody was home. Fear for burglary as a matter of course plays a role here, but also for escaping of dogs and cats.
- The daily household and lifestyle patterns:

- The outdoor climate: temperature, windspeed, wind direction.
- The indoor climate: draught.
- The quality of the outdoor environment: air pollution (odour) and noise.

With respect to the different rooms:

- the percentages of opened windows and the mean outdoor temperatures
- windows in the kitchen appear to be opened relatively independent the outdoor temperature. This use is closely connected with the daily cooking and washing patterns, as well as with the prevailing wind direction, causing draught or enabling the dwelling to cool off.
- With respect to the ventlight in the living-room and bedroom it appeared that their use was very stable
- However, in contrast with the use of the situation in the living-room, the use of the casement window(s) in the bedrooms appeared not to be related to the outdoor climate conditions. The bedrooms seem to be used as a sluice to ventilate the whole apartment.

In Sweden, the Swedish User Data for Residential buildings prepared by the Sveby compiled the results of several window opening studies and surveys in Sweden. [39] They concluded that 64-85% of the residents ventilate daily. 11-30% of the residents ventilate all the time, 34-50% ventilate a few hours a day, and 20-39% percentage of the residents ventilate for a few minutes with cross ventilation. and 1-3% of the people never ventilate.,

A Danish survey on dwellings showed that people tend to open windows in summer to have more air movement as the most important trigger, and because it was it as the second. However, window closing is mainly triggered by a need to leave the dwelling, secondly reaching the satisfying temperature, then and closing it as it is too cold, or feeling a draught. [65]

In the UK a further cause of closing windows was that they are often routinely closed by occupants on departure or by cleaning or security staff, often to signal "job done" or for security. [84]

Dimitroulopoulou [79] concluded that the residents play an important role in the ventilation level in their own homes. Surveys of occupants showed that people generally think ventilation is important, but their understanding of the ventilation systems in their houses is low.

Stazi et al [59] also summarized the control of fans and doors, which have a little direct influence on building energy consumptions, but their use is significant for users' thermal perception. They can promote cross ventilation, increase the air movement inside the rooms and reduce the perceived indoor temperature. They found that fans are switched on when the temperature overcomes 15-20°C, and their use is almost global when the temperature is higher than 30 °C. Another study found relationship between the window opening and the door opening.

The CoolLIFE survey conducted of Hungarian households showed that in summer on a hot day people open the windows mostly at dawn (34.2%) and at night (31.4%), and also almost a one-fifth share said they open it after dusk (17.3%) – please see Figure 34. When people were asked whether they implement specific behaviours on hot days regarding windows more than 90% replied that they open windows at the coldest parts of the day, and more than 75% of them indicated to avoid ventilation in the hottest parts of the day.

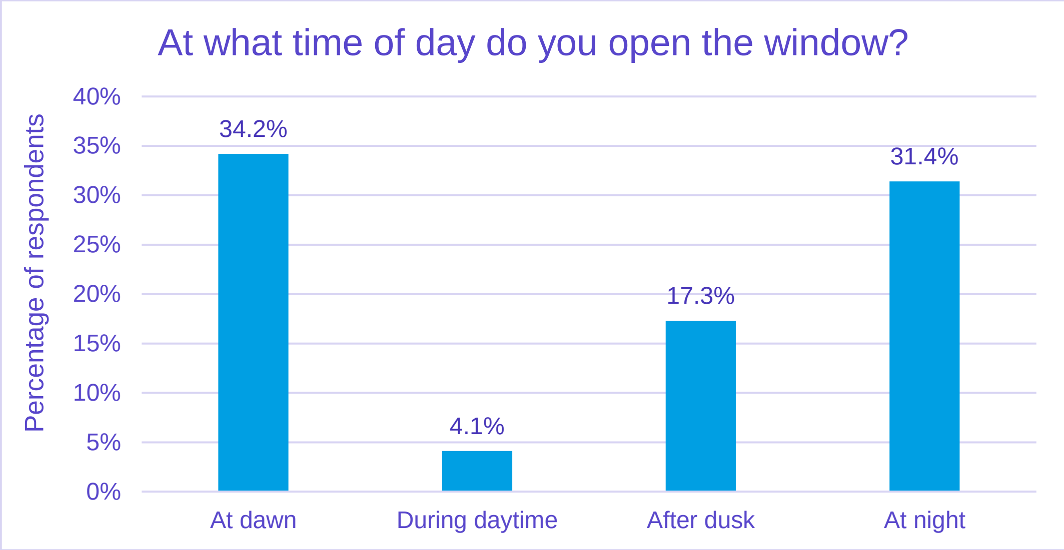

Figure 34. Time of the day when occupants tend to open the window in their dwellings, responses of the CoolLIFE survey

Effect of lifestyle - smoking

A research conducted in 1988 in the Netherlands and in Belgium [82] showed a clear correlation between smoking behaviour and airing and ventilation of the living rooms. In the Netherlands the windows of smokers were open twice as long as the non-smokers. However, another study showed that as contrasted with the use of windows during the winter periods (smokers ventilate twice longer on average), in summer smoking behaviour did not influence the length of time the windows are opened. However, this finding concerns naturally ventilated buildings in a climate where cooling is not the base case in summer, thus opening the window does not have adverse effects. In mechanically cooled spaces smoking indoors and consequently opening the windows can have a direct effect on the SC demand.

In Europe the number of daily smokers of cigarettes among persons aged 15 and over are still between 6.4-28.7%, Figure 35. The number of smokers varies from country to country, the most smokers in Bulgaria and the least in Sweden. It is worth mentioning that a number of countries with high space cooling demands, i.e. Greece, Spain are on the first third of the list.

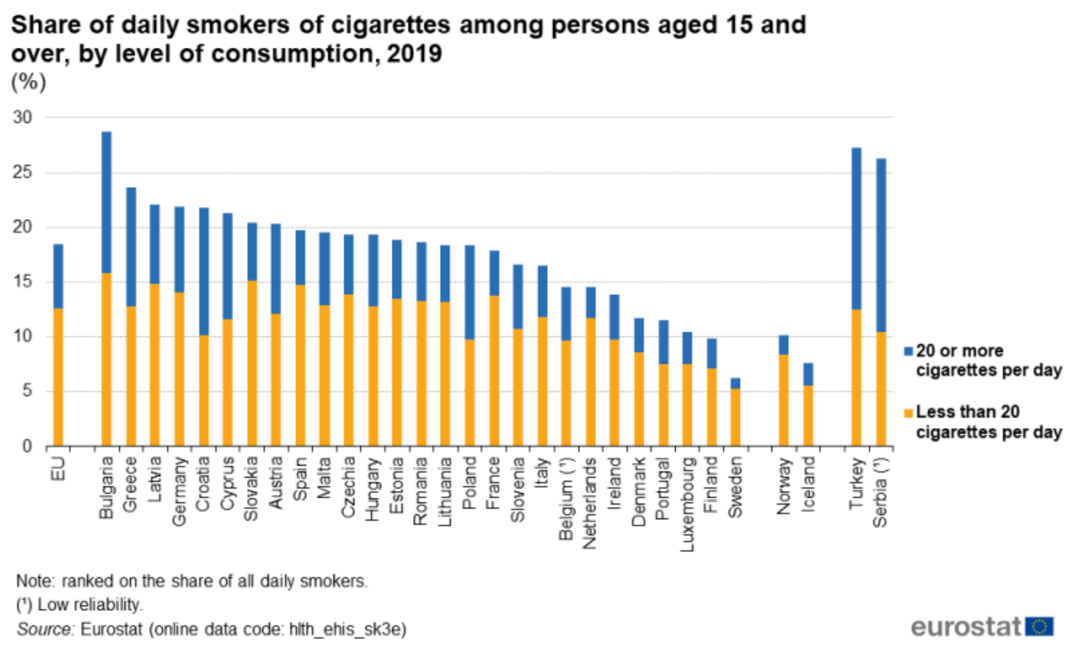

Figure 35. Share of daily smokers of cigarettes among persons aged 15 and over, by the level of consumption, Source: Eurostat [85]

Night time ventilation

Regarding window opening behaviour a specific topic is the night time ventilation. Passive cooling by night-time ventilation in residential buildings is implemented in moderate or cold climates of Central, Eastern and Northern Europe. The basic concept of space cooling the building structure overnight in order to provide a heat sink that is available during the occupancy period is also being studied for non-residential buildings.

Night time ventilation has been implemented in the Hungarian building regulations as strategy against overheating, and the implementation of this has been proven by the survey as well. Surveys in the Netherlands and Sweden also confirmed window opening even for the night, and in winter.

Schiela and Schünemann [86] conducted a survey in two German cities Dresden and Erfurt regarding window ventilation behaviour on hot (outside temperature > 30 °C) and average summer days to determine how, when and for how long ventilation is actually implemented in residential buildings. The results showed that approximately 80 % of respondents ventilate their living rooms and bedrooms mainly at night and/or in the early morning on both hot and average summer days – although the individual window ventilation behaviour may vary significantly. Additionally they asked what are the obstacles for opening windows at night. Burglary, driving rain and outdoor noise were identified.

Artman et al [87] studied the potential for passive cooling of buildings by night-time ventilation by developing a method to compute the climatic potential, by analysing climatic data of 259 stations. He suggests that night time ventilation can be effective when the night temperature is below 20°C. It was shown that, in the whole of Northern Europe (including the British Isles), there is very significant potential for passive cooling of buildings. In Central, Eastern and even in some regions of Southern Europe, the climatic cooling potential is still significant, but due to the inherent stochastic properties of weather patterns, a series of warmer nights can occur at some locations. For these cases either higher temperatures need to be accepted or additional space cooling systems are required. In regions such as southern Spain, Italy and Greece, climatic space cooling potential is limited. Nevertheless, passive cooling of buildings by night-time ventilation might be promising for hybrid systems.

A study in the UK [86] showed some practical reasons that hinder the use of windows appropriately. For example, if the element of the window designated for night ventilation is more difficult to operate than another element, the other element will be used instead. Also, the window design should be suitable for being left open overnight, otherwise problems with security, rain or occasionally insects or, squirrels can be seen.

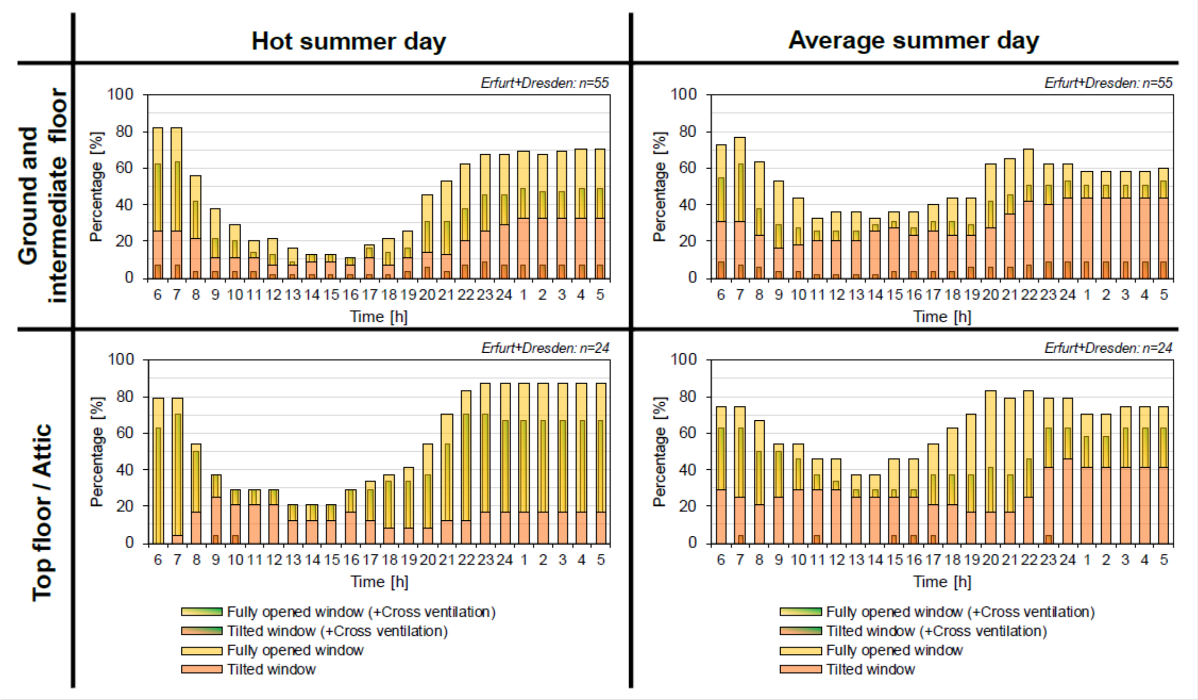

Figure 36. Evaluation of window ventilation behavior in the living room on hot and average summer days for different floors. The indented columns show the proportion of respondents combining a tilted (red) or fully opened window (yellow) with cross-ventilation Source: [86]

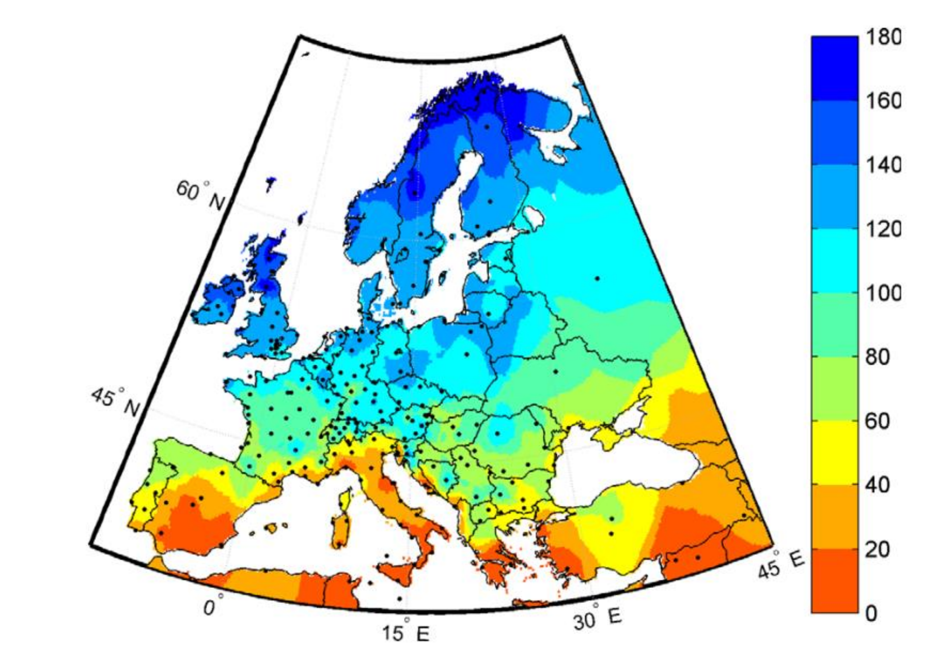

Figure 37. Map of mean climatic cooling potential (Kh/night) in July based on Meteonorm data Source: Artman et al [87]

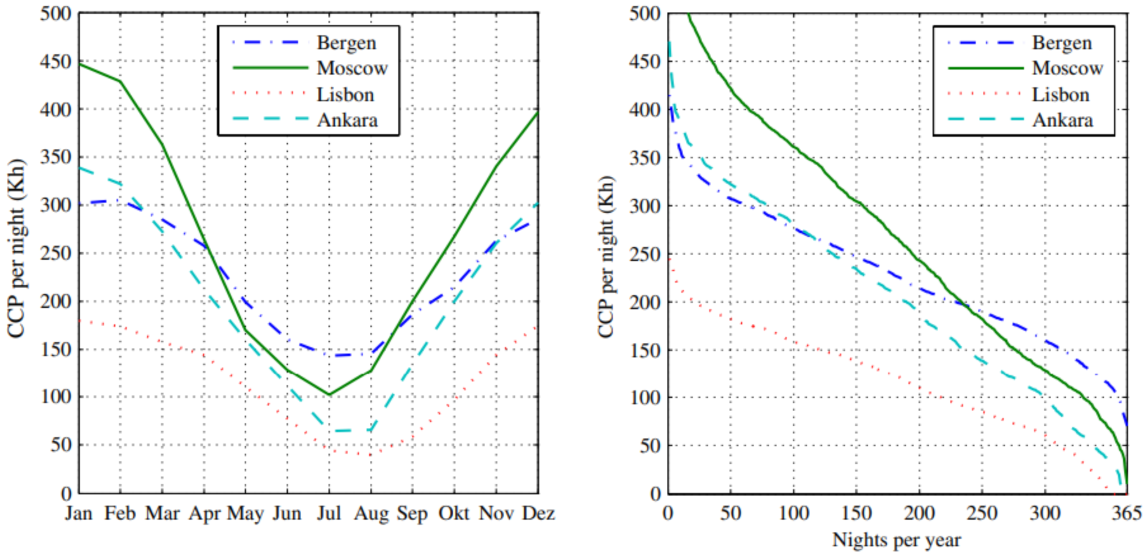

Figure 38. Monthly mean climatic cooling potential per night (left) and cumulative frequency distribution (right) of climatic cooling potential for different locations based on Meteonorm data, Source: Artman et al [87]

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Conclusions and recommendations

Window use has a complex effect on the SC demand, however, the guidelines for the consideration of the dynamic effect of window opening is rarely set in the energy prediction methodologies. The window opening frequency varies by season and climatic locations. The research revealed the following pattern in EU countries of window opening behaviour:

- The window opening shows time dependent patterns, which change according to the building function, depending on arrival patterns, activities, people tend to close windows upon cold temperatures, or when leaving the building.
- Outdoor temperatures, indoor temperatures and CO2 levels were found to be the factors that window opening correlates to.
- Weather events also influence window opening patterns, but mainly closing them, e.g. rain, wind.

Lifestyle factors have also been identified affecting ventilation strategies, like smoking, which is banned in most of the EU countries in commercial buildings, but is hard to limit in residential buildings. Summer night time ventilation potential is high in most parts of Europe, especially in rural locations, and mean climatic cooling potential found in the literature have been presented. However, the practical implementation of this passive SC measure is hindered by safety and security reasons: fear for burglary, escaping of dogs and cats, or intrusion of insects or even squirrels, as well as comfort (noise) issues, as highlighted in the literature. A possible direction in increasing night time ventilation is through improving the night time urban environment to allow for safe and comfortable ventilation.

It has been shown that windows are not always used as intended ergonomics play a role. E.g. if the element of the window designated for night ventilation is more difficult to operate than another element, the other element will be used instead.

A shift in window opening patterns can help reduce SC needs in the following ways:

- Appropriate, accessible design of windows is needed for ease the opening for the occupants. It has been highlighted in the section that windows are more likely to be opened for the night if they are easy to reach. The element that is easier to operate will be used more often.
- When the outdoor temperature is lower than the indoor temperature: increased window opening is suggested. This can be enhanced by giving feedback to the people should on the appropriate outdoor and indoor temperatures, as detailed in the Chapter 4.
- When outdoor temperatures are higher than the indoor temperature: window opening is influenced by the indoor activities and the IAQ and humidity indoors. A shift towards activities with lower heat loads/ vapour generation can lead to lowering the needs for additional window opening.
- Night time ventilation: windows should be opened in the night when temperature is colder than the comfort temperature. Openings that allow safe and secure ventilation should be provided. Also draught should be avoided.
- Cross ventilation: a number of the studies reported that windows/ openings are open the whole time. A more appropriate strategy in hot periods should be to ventilate for short time, but utilizing cross ventilation.

3.5. Shading factors and schedules

Shading a passive measure that can limiting solar loads on the building facade. Effective use of solar shading can contribute to the reduction of overheating, space cooling demand and air conditioning use, improved thermal insulation of fenestration and thereby lower space heating load in European buildings. Shadings and blinds are used by people for different purposes and can provide combined functions: heat and glare protection, maintenance of adequate visual and thermal comfort conditions on sunny days and reduction of space cooling loads and lighting demands. However, the usage of solar shading is not only dependent on the solar loads on the façade, but are also affected by daylighting preferences, and can serve as devices for providing privacy.

The International Energy Agency identifies the importance of solar shading in realizing the potential of energy efficiency in the advanced building envelope and recommends as necessary and of high priority that exterior shading with proper orientation and dynamic solar control should become standard features globally in new buildings and can also be applied to existing buildings. Pilot projects have demonstrated that such systems can enable energy savings up to 60% for lighting, 20% for space cooling and 26% for peak electricity [17].

Solar shading solutions cannot function to their full potential, be optimized and fulfil their role in cost-optimal building solutions in the absence of effective control. Operation of shading systems when left to manual control is known to be less than fully effective.

The shading factor and effectiveness of the shading is highly dependent on the shading typology used. However, the studies focusing on shading control are limited to venetian blinds or roller blinds, while in the residential sector roller shutters are more widespread, which however do not provide the same level of visual comfort when activated. The type of shading also defines to what extent can the occupant control the incoming solar radiation. Thus, when evaluating the interaction with shading by the users, it is inevitable to have correct assumptions on what and how the user can control.

According to the Sonnergy report 15/498 [88] the most common external products include roller blinds, drop arm awnings, Venetian slats and shutters, while roller blinds and Venetian slats are common internal shade products. Additionally, many building employ drapes and screens for internal use, however, the solar shading efficiency of these are low. Shading can be passive or active. The former does not change its properties throughout time, for the latter, the activation can happen based on the change of a boundary condition, e.g. thermochromic glazing, where the optical properties of the glazing system changes in response to changes in temperature; or can be triggered by human activity, either by a manual intervention or by some control.

A detailed shading typology in incorporated in *D2.1 Taxonomy of space cooling technologies and measures (M12)* However, the most important types of shading with their control possibilities is listed in Table 17.

With venetian blinds effectiveness can be achieved by regulating the inclination of the slats in order to reduce solar gains and ’romote user's visual comfort. With a cut-off angle st’ategy slats' can cut-off the transmission of direct solar radiation with providing daylight at the same time. Shutters, roller shutters have limited possibilities in maintaining visual comfort, thus their application in reducing solar loads is limited when occupants are present and visual tasks need to be fulfilled.

Table 17. Typology of typical shading elements controllable by occupants.

Shading type	Description	Control variables	Typical use	Picture
Shutters	Slats combined into a frame, that is openable in a horizontal angle	opening angle	Residential Historical Mediterranean	
Venetian blind	A series of typically opaque, metal slats that can be drawn and rotated from horizontal to vertical cut-off angle: slat angle beyond which no direct solar radiation is transmitted through the slats. Daylight can be maximized and discomfort glare can be minimized	slat angle draw ratio	commercial – external –esidential - internal	
Roller shutters	Consisting of slats (or sometimes bars or web systems) hinged together. Transmission of radiation in the holes between the slats is possible when not drawn totally Black-out possible	draw ratio	Residential/ non-residential commonly used in e.g. Hungary, Germany and Spain,	
Shutters with tiltable area	Allows daylight to enter with limiting solar gains	tilt angle	Residential/ non-residential Historical Mediterranean	

Shading type	Description	Control variables	Typical use	Picture
Drop arm awning	Translucent material that allows daylight to enter	tilt angle and/or draw ratio	Residential/ non-residential	
Pleated /Roller blinds	Internal translucent fabric material, movable vertically	draw ratio	Residential/ non-residential	
Drapes	Internal translucent fabric material, movable horizontally	draw ratio	Residential/ non-residential	

Regulations and standards

The technical specifications of shading are usually defined by the combined g-value (according to EN410) of the shading and the glazing it is attached to. The operation principle of the shading is however not defined.

In Hungary the Appendix 1. of the 7/2006 TNM Decree defines the technical requirements for the minimum building energy efficiency. Paragraph 7 defines a maximum g-value for rooms with space cooling, depending on the position of the transparent surfaces of the room. If the tilt angle of the transparent openings is lower than 45°, or the tilt angle is higher than 45°, but the orientation angle is more than 30° from North (i.e. Azimuth is between 330°-30°), SC can only be installed if solar protection on the transparent opening is provided for the operation of cooling, where g-value <0.3. [89]

Based on the study on IEQ legislations by BPIE [90] the following regulations for shading could be identified:

- In Belgium, for Brussels-Capital Region starting from January 2015, overheating (defined as temperatures of more than 25 °C) has to be limited to 5% of the time during the year. For an optimum level of comfort Bruxelles Environnement recommends the stricter value of 3%. Until end of 2014, each unit has to meet the requirement to limit the risk of overheating described in Chapter 8 of Annex II.123 For new buildings, the PEB (Building Energy Performance) regulation takes into account systems such as solar protection. Active cooling is only required if the overheating indicator is higher than 6500 Kh (Kelvin-hour). On the contrary, if the overheating indicator is less than 1000 Kh, active cooling is not needed. In order to meet the passive contribution, it is recommended to provide efficient solar shading (g<0.5) for glazing surfaces larger than 4 m^2 facing the sun.

- In France, the windows of any of the premises used to sleep and included in the CE1 category (roughly, CE1 category includes all buildings apart from dwellings, schools and office buildings located in noisy areas in the hottest regions of France) of buildings have to be equipped with mobile solar shades. Solar factor is defined based on the orientation of the window and the noise level. For North façade a g-value<0.25-0.65, other orientation g-value <0.15-0.45, roof g-value <0.1-0.25 [90]

- In Germany the EnEV in summertime requires a building to be in line with an indicator for maximum solar gains ("Sonneneintragskennwert") calculated according to DIN 4108-2. For single-family homes and semi-detached houses no calculation is required if shading elements (e.g. blinds) (reduction rate $F_C \leq 0.3$) are installed or a maximum share of window area is not exceeded: roof windows, 7%, other windows, 10% (south, west, east) or 15% (north) in relation to the floor space. The DIN V 18599, Part 2 includes calculation methods for seasonal shading efficiency based on the types of shading.

- In Italy external shades are mandatory for new buildings and deep refurbishments; and may be omitted if a technical report on economic unsustainability is provided and if the windows have a solar factor ≤ 0.5. A number of regional legislation has explicitly defined the minimum percentage of window surface for which shades have to be provided. Percentage of shades per windows area ranges from 70%-100% in these areas. In 324 Building Regulations shading for windows with orientation to south-east/south-west are required.

In Sweden there is no mandatory requirement for shading, however, the National Board of Housing, Building and Planning (Boverket) proposes measures such as installation of windows and modification of their size, solar shading and sun protective glazing to be considered in order to reduce the cooling needs [39]. As a recommendation, the Sveby, a Swedish cross industry initiative to develop voluntary guidelines on energy use suggests a shielding factor of 0.5 to be applied in addition to the window solar transmission, that takes into account also the shading that is controlled by the occupant.

Empirical data

As seen above the standards and regulations approach the shading with performance values, however, the usage of those is not specified. Effective use of solar shading can contribute to the reduction of overheating, SC demand and air conditioning use, improved thermal insulation of fenestration and thereby lower space heating load in European buildings. Achieving good performance is highly dependent on the user.

When annual energy demand is being calculated, a control strategy needs to be employed to regulate the position of the shade with respect to the glazing for both external and internal shading situations, where the shade needs to be raised or lowered. The most common approaches for blind control principles in the literature are summarized.

The most common approach seen in the literature is to draw shading to the level of the solar irradiance, G, incident on the outside surface of the glazing, a given as a W/m^2 setpoint. This setpoint varies between 50/m^2-400W/m^2, where shading is fully drawn up under this limit, and is lowered above this limit. In the most basic control the slat angles are fixed.

- Illuminance when shading is drawn falling on the façade was 15 kLux (G_i=150 W/m^2), double skin facades in Lisbon in Portugal, Paris in France, Stockholm in Sweden Eriksson and Blomsterberg. The slat angle of the Venetian blinds were 30 degrees for Stockholm, 20 degrees for Paris and 10 degrees for Lisbon. [91]

- Roller shade control strategies were tested where low solar setpoint was 95 W/m2, medium solar setpoint was 189 W/m^2, and high solar setpoint was 400 W/m^2 for Minneapolis.

- Herkel et al [92] studied different strategies for a highly glazed, single skin office building with venetian blinds in Germany (slat angle 72° corresponds to fully closed) Blinds were closed when vertical illuminance on the façade: activated by 25000lux, reopened at 15000lx.

In some instances, while the trigger for drawing shading was still solar irradiance, a more detailed approach was followed:

- In the Sonnergy report 15/498 [88] authors used two thresholds based on the same variable, where three conditions are allowed. The same control strategy was applied to all 8 orientations. Their findings were that for glazings located between South Eastern and Western orientations, the percentage of time for which the glazing is fully or partially shaded is high, in Rome ~ 45%, Brussels ~ 28%, Stockholm ~ 33%, Budapest ~ 44%. For the North orientation neither location was fully shaded, but windows remained unshaded for 91.4-95.5% of the time.

  (i) Unshaded: $G < 200$ W/m^2
  (ii) Fully Shaded: $G > 400$ W/m^2
  (iii) Partially Shaded : $200 < G < 400$ W/m^2.

The most complex shading controls consider internal temperatures, movable slat angles, or occupancy presence:

- **“**work plane protection” - Ying-Chieh Chan, Athanasios Tzempelikos [93] employed a strategy in which shades are controlled to intermediate positions to prevent direct sunlight from falling on the work plane area, but for daylight maximization the shades never close completely, and they are often completely open if the window does not see the sun.

- **“**sun path (cut-off)” - Herkel et al [92] studied different strategies for a highly glazed, single skin office building with venetian blinds in Germany (slat angle 72° corresponds to fully closed) blinds were closed outside office hours, in office hours: vertical illuminance on the façade: activated by 25000lux, reopened at 15000lx, cut-off slat angle is calculated in 5° steps

- manual: Herkel et al [92] also used the Lightswitch 2002 algorithm, based on the trend that users tends to close the blinds if direct sun light hit the working desk and accepts higher luminance values if they can achieve a good look out. The algorithm separates two cases: Low sun height angle (< 60°): The user closes the blind, if a specific set point for the luminance is exceeded. High sun height angle (> 60°): The blind remains open.

- An indoor temperature-based control strategy was tested by Liu et al [94] and significant energy reduction was shown. Blind is drawn if the indoor air temperature is above Ti=24°C, and the tilt angle of the blind is set to cut the direct solar radiation in occupied periods, while closed in unoccupied periods.

- Dama et al employed a strategy where outside temperature above a 23 °C was also taken account as a threshold for, combined with irradiance threshold of 200 W/m^2. Lamella angles were adjusted based on sun angles, but also targeting to to keep internal illuminance above the requirements. [95]

- Gelesz et al [96] compared irradiance-based controls with different setpoints to controls based on internal temperature, daylight responsive slat angle control and occupant presence and showed that the most sophisticated control could increase annual energy savings by 11-14% depending on orientations compared to the simple irradiation based controls.

However, the use of the blind in reality can deviate from the above assumptions highly. In the literature several examples show that the occupants tend adjust shading infrequently. Authors comparing window blind use in a conventional and an energy-efficient office building in the UK found that occupants' preferences for the blind position are based on a long-term perception of sunlight and the built environment they are accustomed to. [97], [98] A study done by the Swiss federal office for energy/Estia SA, Lausanne implemented webcam observations to identify the actual use of sunscreens in administrative buildings over a nearly 1 year period, observing 125 openings, e.g. more than 500,000 individual blind positions analysed. [18] They showed that when manual operation was provided, sunscreens were adjusted infrequently: less than 2 movements blinds / week regardless of the orientation or season. The consequence of this misuse is that the contribution of natural light is far from being optimized. With an optimized algorithm for automating blinds several kWh/m^2 per room and per year could be saved. They also found that the number of slat angle changes is four times higher on the west façade than on the other ones, which confirms glare as a driving factors. The lowest number of blind movements was seen on the south façade: during most of summer, the blinds are down and the slats horizontal, blocking the sun all day long. The weighted average of the blind coverage was 60% in summer for the three analysed façades (South 78%, West 55%, East 48%).

Stazi et al [59] concluded that researchers have been studying shading and blind use since 1978, however, in their review literature for office buildings had only been found. The main drivers defined by Inkarojrit [99] in addition to those environmentally related were:

- Physiological (e.g. individual sensitivity to brightness),
- Psychological (e.g. needs for privacy or view) and
- Social (e.g. organization policy) factors

Additionally, blind use is highly dependent on the physical layout of the building in evaluated: building exposure and orientation, shadings' typology and desks' position.

Blind and shading use is more seasonal than day dependent: the daily adjustments are very rare and the position is kept constant until a discomfort situation occurs. Some studied found that in non-residential buildings blinds position remains usually unchanged for weeks and months. In contradiction to the window usage, no significant correlation with time of the day was noted. It is suggested that actions on shadings and blinds are partially related to time drivers but they are highly influenced by occupants' habits.

The following list reports the identified triggering variables:

- Illuminance/glare: related to visual discomfort seems to be the major driving factor to modify the blind position. Many studies concluded that "block direct sunlight" was a stimulus to intervene on blinds, others found glare on computer screens and reduce the brightness of work surfaces as a second reason. Where detailed, lowering actions occurred mainly when indoor horizontal illuminance was about 1200 lux, while raisings increased around 200 lux.
- Solar radiation: In one study external illuminance of 15,000 lux was found to be the value at which 50% of venetian blinds were lowered. Differences suggest that users' behaviours can be very different for similar physical quantities.
- Indoor and outdoor temperature: three studies, reporting temperature stimuli, recorded an increase in blind use when both these temperatures rose. For indoor temperature 26 °C was reported as the limit for lowering blinds

A blind “hysteresis phenomenon” was also highlighted: occupants close blinds at illuminance levels higher than that at which they open them.

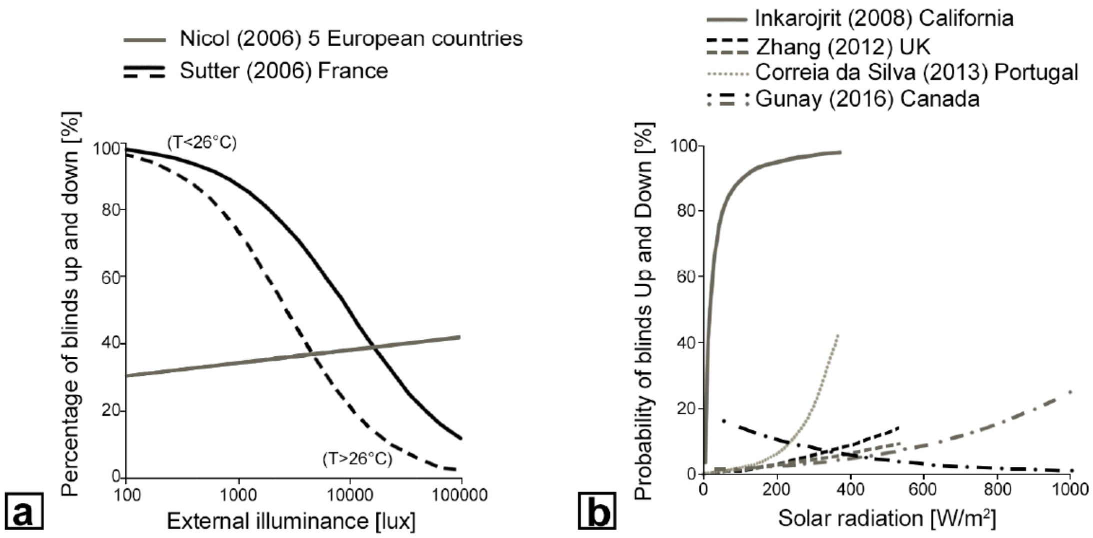

Figure 39. Shading control correlation found by Stazi et al. a) correlation of percentage of blinds up and down to external illuminance, b) Correlation of the probability of blinds up and down to external solar radiation. [59]

In *D3.1 Knowledgebase for occupant-centric space cooling* the results of the representative residential survey were included. As the occupant behaviour literature is highly focused on office buildings, where adjustable blinds are implemented, this survey gives a unique insight on the residential buildings in Hungary. The high majority, 82.7% of the respondents said that on a hot day they implement some form of shading. The most widespread shading element in Hungary are the rolling shutters, which were found to be installed in 72% of the dwellings: manually controlled shutters were predominant, 68.3% of all dwellings have this type of shading, while the proportion of electrically controlled rolling shutters is only 3.5%. 38% of the apartments are shaded by thick curtains – please see Figure 40.

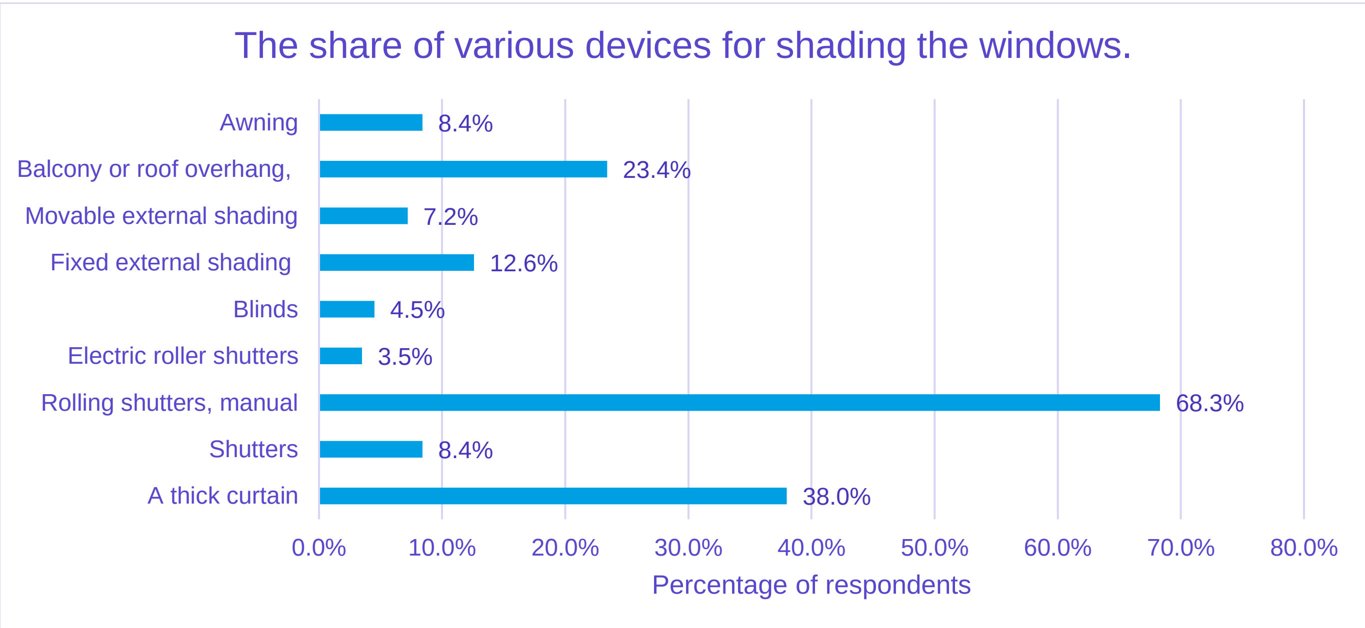

Figure 40. Share of various shading devices in Hungarian households source: CoolLIFE survey

Regarding the activation of the shading, 68.8% of the respondents replied that on a hot day in summer they shade the windows when no one is at home. Most of the respondents use shading anytime they feel they need it (63.8%) Almost one-fourth of the sample (22.8%) answered that they apply shading during specific part(s) of the day, and only 13.3% does not shade the home. The percentage of the respondents who have electrical roller shutters and venetian blinds tend to shading it more than others, however, 8.1-8.5% of them still responded that they do not use them at all – please see Figure 41.

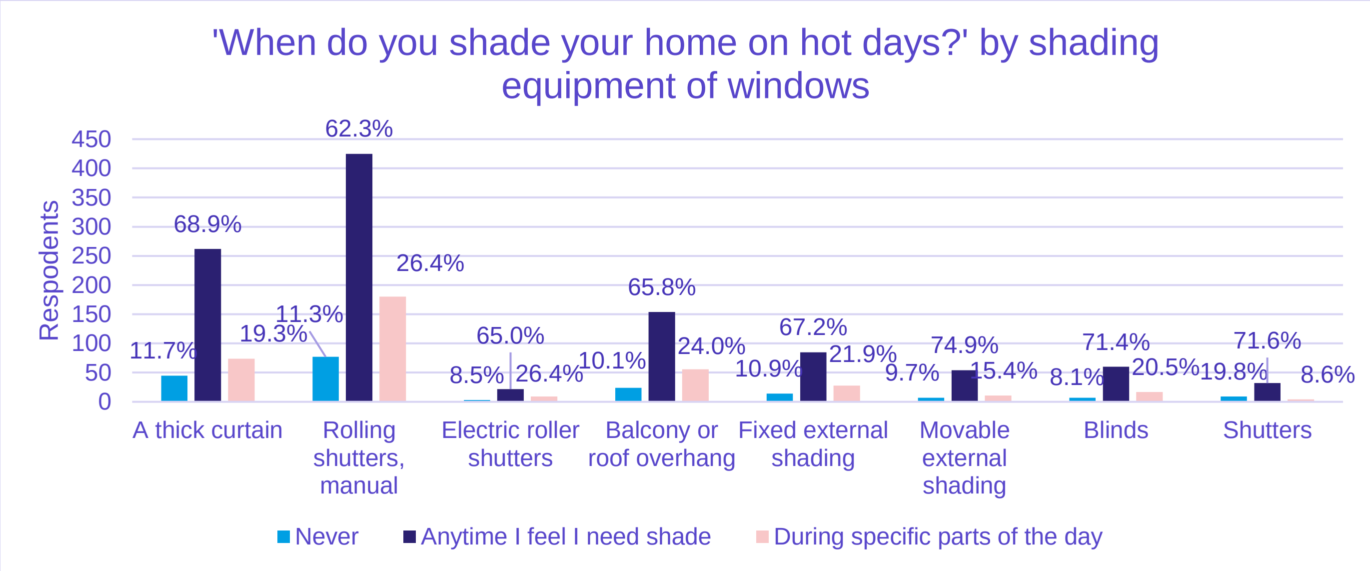

Figure 41. Shading practices of different shading equipment owners source: CoolLIFE survey

The respondents who have external shading (overhangs or awnings) tend to find the indoor temperatures more comfortable in summer, compared to the respondents who do not have any external shading- please seeFigure 42. However, no difference is seen between the repondents who have fixed or movable shading. Also, it is seen that the occupants who have some type of shading tend to apply it before leaving home on a hot summer day – please see Figure 43. This questions received a higher positive response rate than closing the window or switching off the AC upon departure.

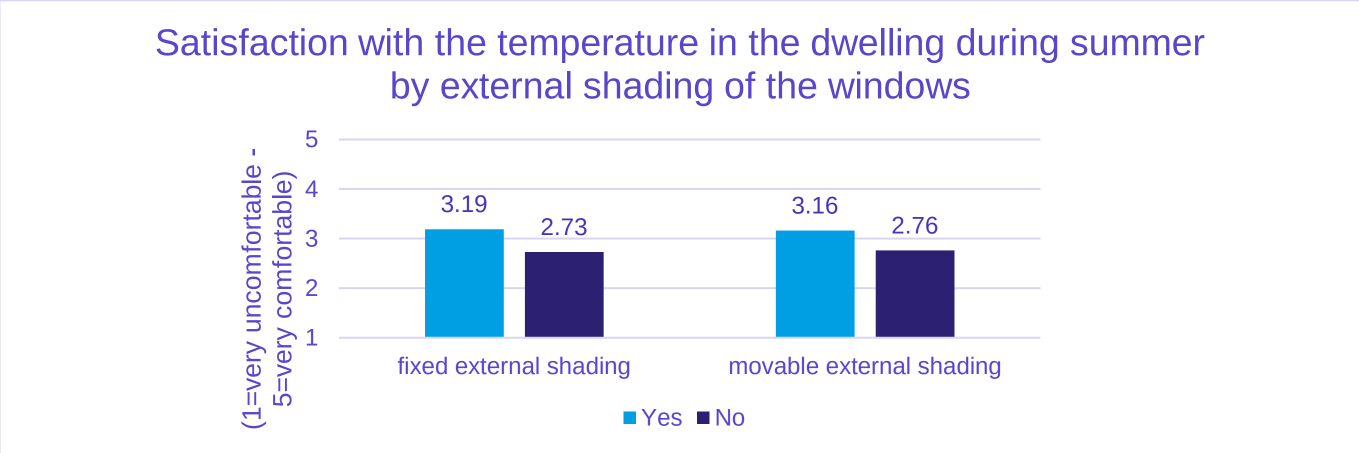

Figure 42. Satisfaction with the internal temperature in July as a function of having external shading or not, responses of the CoolLIFE survey

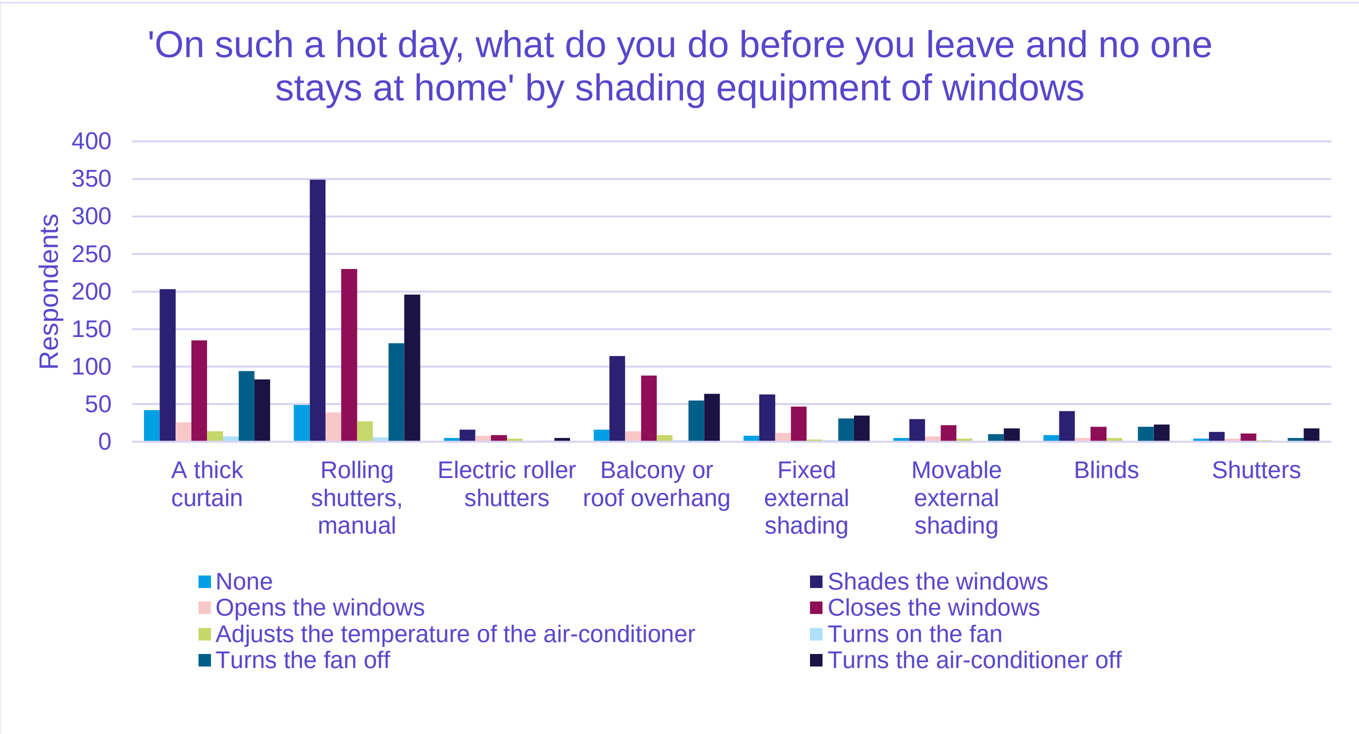

Figure 43. Respondents taking a particular action on a hot day as a function of shading type, responses of the CoolLIFE survey

Conclusions and recommendations

Solar shading, and especially external shading is an effective measure to reduce SC demand, pilot projects demonstrating that such systems can enable energy savings up to 60% for lighting, 20% for space cooling and 26% for peak electricity. While requirements in some countries in the EU exist for maximum g-values of transparent building elements (generally below g≤0.5), providing shading devices alone do not guarantee notable reductions in SC demand. Most common movagle shading types have been presented, where the means of interaction is however different. Within the building simulations automated shading has been considered in a number of studies with various rule-based or advanced controls based on environmental, occupancy related variables, or as probabilistic prediction methods. These mainly cover roller blind and venetian blind usage, which can provide daylight or view out to some extent when activated, thus can be used with less compromise between visual or thermal comfort, or space cooling energy demand. However, when the occupants are in charge of interacting with the shading, their actions result in sub-optimal use triggered by mainly visual discomfort, that affects SC demands adversely.

The main drivers for using blinds and shading were found to be visual or thermal discomfort, while to reduce SC demand, a combination of the environmental parameters of solar radiation on the facade, internal and external temperature are proven to provide higher benefits, which requires a more complex decision making process from the occupant. Occupants tend to leave shading as it is for longer periods than windows, and only interact with them when a next discomfort occurs.

Regarding the residential sector, the CoolLIFE survey revealed that up to 19.8% of the respondents who have manual shading devices in their home do not apply these on hot days, while this value is lower, however, still around 8 % when electric roller shutters are provided. For commercial buildings the operation frequency when left to manual control is even worse, one study evidenced that blinds were moved less than 2 times a week, regardless of the orientation or season.

Thus, the operation of shading devices can be considered as a measure where it can be argued that efforts to promote more sustainable SC should also focus on automation, rather than aiming to change inefficient behaviours, as consideration of a combination environmental parameters: solar radiation on the facade, internal and external temperature requires a more complex decision making process from the occupant. The easiest action to implement would be for of users to operate shading based on occupancy, when rooms are unoccupied, shading should be applied to a higher extent to limit the solar heat loads on the façade.

3.6. Combination of strategies and preferred order of actions

Above the schedules and drivers of different actions have been analysed one by one. When a change in the thermal environment occurs, such as to produce discomfort, people react in different ways which tend to restore their comfort. There are limited number of studies completed in Europe on the topic of the preferred order of occupant actions in maintaining their comfort in summer, thus case studies from also the US have been compiled throughout the literature review.

In the UK, it was found by Wei [100] that occupants have different preferences and order of actions when they use adaptive opportunities to adjust their surrounding thermal environment. Occupants the to open/close windows and adjusting clothing insulation before opening/closing doors, adjusting solar shading devices, blinds/curtains, adjusting air diffusers, drinking cool/hot drinks, adjusting heaters, or operating private fans.

Langevin et al. [101] conducted a one-year longitudinal case study of occupant thermal comfort and related behavioral adaptations in an air conditioned office building in the USA. Their results show substantial between-day clothing adjustments and elevated metabolic rates upon office arrival, which may affect subsequent thermal comfort and behaviour trajectories. Behaviour sequencing appears complex, with multiple behaviours sometimes observed within a short time period and certain behaviours subject to contextual constraints. They reported the clothing insulation as a predominant element both in naturally ventilated and air-conditioned buildings, but in the former actions on windows occur first than that on fans, while in the latter the sequence is inverted. They also suggested that, in offices, people tend to use first nearest and most personal devices, to avoid undesirable consequences.

Rijal et al [8] says that even if their results seems to propose the trend windows-fans-AC, there is a great difference among building's controls and managements and users' possibility to interact with the devices, make quite difficult to define a unique sequence [102]. An office case study in Hungary showed that occupants preferred to open the window first, when they were feeling hot during summer season and then secondly they prefer to have a cold drink. This is followed by closing the shading and clothing level adjustments. Whereas in case they feel cold during summer season, respondents indicated that they first increase clothing levels, then close the windows and these are followed by having a hot drink. [103]

Within the CoolLIFE survey we also investigated whether occupants tend to implement one or more measures in their dwellings. More than 50% of the respondents replied to apply one or more lifestyle and user behaviour measure during a hot summer day in Hungary. The most implemented measures are to wear lighter clothes and to open the windows in the coldest parts of the day (more than 90%). The least implemented measures is the use of fans (59.9%). As seen previously, there is a difference in the implementation of each measure rearding age groups. The 60+ age group tends to avoid using the hot oven, pull down the shutters and blinds and open the windows in colder periods. One cause for this could be that due to their higher presence in the dwellings they tend to be more conscious in avoiding the overheating of the dwelling.

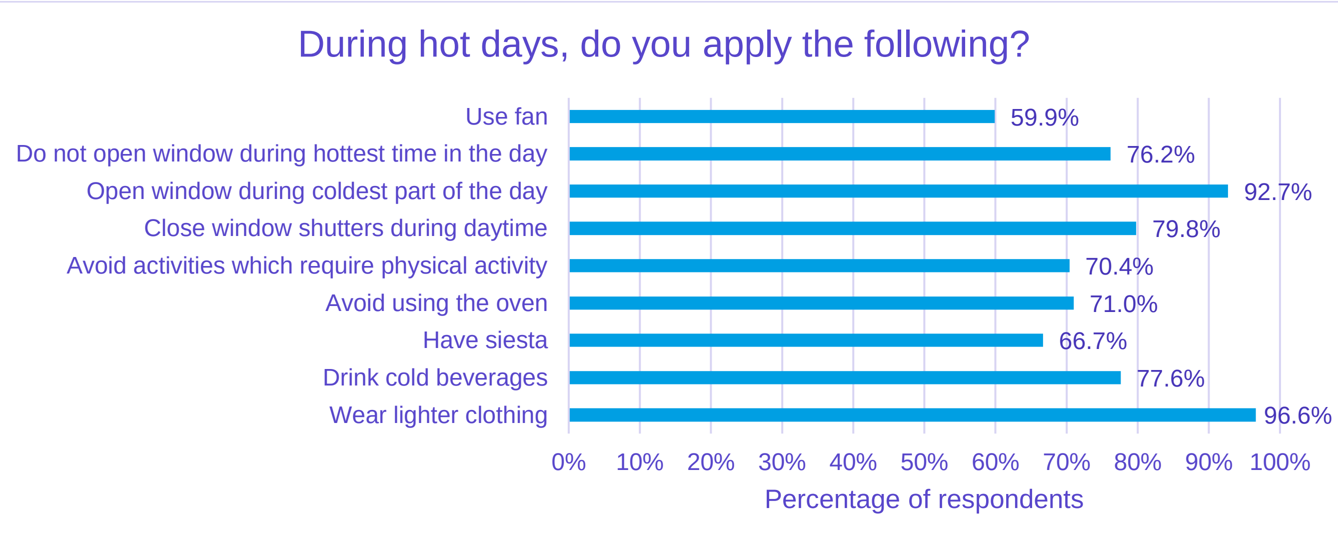

Figure 44. Application of various lifestyle and user behaviour measures on hot days in July responses of the CoolLIFE survey

3.7. Conclusions

In the above sections the behaviour of occupants was analysed in managing their thermal environment. It is seen that occupant behaviour is much based on habits and non-environmental factores which result in sub-optimal use of the buildings increasing SC needs. Not all actions are implemented to the same frequency and also differences are seen regarding building type.

While the occupants can adapt to the changing environment more easily by adopting to the changing thermal environment, measures taking a cold shower or drink does not resolve their thermal comfort on the long term, as it does not solve the initial problem of overheating of an occupied space. Thus, when the reduction of space cooling demand is considered, acting in a way to avoid the cause of overheating of a space in timely manner is a key to tackle thermal discomfort on the long run in an environmentally conscious way. It is suggested that when occupant behaviour interventions are concerned, emphasis should be done on interacting with the building elements that attenuate the cause of discomfort, e.g closing shading, with higher priority than implementing adaptive measures. However, in the literature it is seen that the occupants tend to interact with shading infrequently, which is can be due to their lack of understanding the importance of this and/or the lack of easily accessible, ergonomic shading controls.

It is seen in the CoolLIFE survey that within the 60+ age group the implementation of measures that reduce the overheating risk of the building are implemented in higher percentage than in the age groups. This can be due to the fact that they spend more time at home and are more concious in maintaining an acceptable thermal environment.

Building occupants surveyed in Hungary tend to use passive measures like night time cooling and shading when leaving the houses. Regarding the use of AC devices however, users tended to indicate lower temperature setpoints than what is suggested in the energy performance calculations in Europe; however, the majority of the respondents indicated values that are within the summer operative temperature comfort range. Nevertheless a notable percentage of occupants indicated setpoints even below 20°C. As also highlighted in the literature on the AC control, the occupants might not fully understand how the controls change the temperature (e.g. in lack of temperature scale on the device), thus they will use it as it is the most convenient, which can result in higher energy demand.

The findings of this chapter can also drive policy makers in the direction to make easily accessible, well usable windows or shadings the recommended baseline for residential buildings, and motivate people to use them in oreder to reduce SC demand. The overview of intervention types resulting in change occupant behaviour and the successful implementation examples are presented in the next section.

4. Interventions to reduce energy use for space cooling

The preceding sections have discussed behaviours and user lifestyle habits that impact cooling demand in buildings. The present section provides an overview on behaviour-change interventions aimed at promoting more sustainable SC behaviours. We identify important tools for the reduction of energy use for SC from an individual behaviour-change perspective and highlight key considerations. The context is placed primarily on residential buildings, but non-residential buildings (i.e.: office spaces) will also be considered. In this report we provide a first overview of main types of behavioural interventions and measures. A review of the EU policy background and national measures will be done in a next task of the project.

Key behaviours that impact SC demand in the residential sector are: (i) usage of electricity-powered SC appliances (i.e.: indoor fans, air conditioning systems, etc.), (ii) interaction with thermostat or A/C SC set-points, (iii) uptake of natural ventilation measures (i.e.: window opening, night-time ventilation), (iv) shading practices, and (v) occupant presence and heat-generating equipment use in the building. These behaviours impact technical parameters of SC, namely: thermal comfort, set-point preferences, window-opening factor, shading typology, and schedules of occupancy. Most of the behaviour-change literature in this domain focuses on interventions that target the first two behaviours and the use of heat-generating equipment, yet we will also discuss studies that consider in some capacity how to increase the uptake of natural ventilation measures and the adoption of more efficient shading practices.

An important aspect to note is that there is a wealth of empirical literature testing interventions that aim to reduce electricity use in general, often without considering SC specifically. However, considering that SC represents the fastest growing use of energy in buildings [104], it can be reasonably assumed that any intervention with a marked impact on reducing electricity consumption in the presence of SC appliances can contribute to lowering SC demand. For example, a large literature on feedback has shown that providing information on past consumption can lead to sustained energy conservation efforts [6], [105]. More recently, studies found that feedback is useful to reduce energy use for SC specifically [15], [10]. Additionally, as discussed in section 3.1, reduction in energy used for household appliances and lighting, which generate heat loads, directly contributes to lowering the need for SC in buildings. Accordingly, here we consider interventions that have been studied to promote the uptake of efficient energy behaviours broadly, even if the focus of the research is not specific to SC, so long as the behaviours they aim to promote are relevant for the reduction of SC demand. As an example, studies testing interventions that promote more efficient interaction with thermostat setpoints in winter months are included [14], as their findings can reasonably be expected to translate to efficient interaction with SC set-points in summer months. Of course, we give priority to studies where the focus is specifically on SC.

A synthesis of studies that are considered in the review can be found in Table 18. In Annex III. we report a larger list, considering also studies whose focus is on general electricity usage.

Study	Year	Intervention Type	Type of study	Focus of study	SC target behaviour	Geographic Context	Building context	Relevant finding
Allcott [106]	2011	Dynamic pricing (RTP)	Empirical study.	Electricity use for air conditioning.	Use of electricity-powered SC appliances	US	Residential	5% average reduction in peak electricity consumption. No significant reduction in off-peak hours reported.
Brown et al. [14]	2013	Default thermostat setting	Empirical study.	Thermostat use in winter months.	Interaction with SC thermostat or A/C set-point.	France	Office	0.38°C decrease in chosen thermostat-setting with a 1°C default reduction in winter months.
Ornaghi et al. [16]	2018	Feedback, framing & social norms	Empirical study.	Window-opening behaviour in winter months.	Uptake of natural ventilation measures	UK	Office	34.5 - 50% reduction in fraction of windows left open after start of interventions.
Yoon et al. [107]	2018	Dynamic pricing (ToU, CPP, RTP) & Demand response controller	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	US	Residential	10.8% potential reduction in energy–costs. 12.8 - 24.5% average peak load curtailment.
Xiangling & Changxu [15]	2019	Feedback & framing	Empirical study.	Thermostat use during summer months.	Interaction with SC thermostat or A/C set-point.	China	Office	1.14°C increase with efficiency framing, 1.52°C increase wth health framing.
Bator et al. [10]	2019	Feedback & social comparisons	Empirical study.	Electricity use for air conditioning.	Use of electricity-powered SC appliances	US	Residential	5.3% reduction in electricity consumption over 12 months.
Parkinson et al. [13]	2020	Default thermostat setting (policy implication)	Empirical study.	Validation of ASHRAE 55.	Interaction with SC thermostat or A/C set-point.	Global	All building types.	The authors suggest gradual changes in default thermostat-settings targeting 24-27°C range.
Amin et al. [108]	2020	Dynamic pricing (ToU, CPP, RTP) & optimal control strategy	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	Australia	Office	7.9 - 26.8% potential reduction in peak demand, contingent on occupant preferences.

Study	Year	Intervention Type	Type of study	Focus of study	SC target behaviour	Geographic Context	Building context	Relevant finding
Li et al. [9]	2021	Feedback & social comparisons	Empirical study.	Use of indoor thermal cooling device.	Use of electricity-powered SC appliances	UK	Office	15% reduction in energy use after the introduction of intervention.
Göette et al. [109]	2021	Feedback & social comparisons	Empirical study.	Electricity use for air conditioning.	Use of electricity-powered SC appliances	Singapore	Residential	27.39% reduction in air conditioning use only in lowest 20th-percentile in usage of air conditioning.
Kim et al. [110]	2022	Feedback & gamification	Empirical study.	Thermostat use during summer months.	Interaction with SC thermostat or A/C set-point.	US	Residential	Increase in median room air temperatures.
Scorpio et al. [19]	2022	Information provision & default shading system settings.	Empirical study.	Use of lighting and shading system.	Use of shading	Italy	Office	Engagement strategy led to improved use of lighting and shading system.
Wo-Shem et al. [111]	2023	Dynamic pricing (ToU, CPP, RTP) & optimal control strategy	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	US	Residential	52.9% potential reduction in electricity consumption

Table 18. Synthesis of studies on behaviour-change interventions to reduce SC demand.

Our review of the literature highlights three main categories of intervention that have been studied to effectively reduce SC energy use in residential buildings: monetary incentives, information provision, and nudges [112]. Monetary incentives refer primarily to price strategies (i.e.: dynamic pricing). Information provision can refer to giving households individual feedback on their SC energy consumption, as well as interventions aimed at increasing awareness about SC/summer comfort (including information aimed at increasing awareness on sustainable AC use, passive cooling measures, and health-related information in the case of extreme weather events). Nudges are instead a type of non-price, non-coercive interventions that operate by changing seemingly irrelevant aspects of the choice environment [113]. In other words, nudges are a type of intervention that try to incentivize behaviour change through non-pecuniary means. An example would be setting an efficient default SC set-point in a programmable thermostat.

These three approaches form the backbone of the review; however, they are not mutually exclusive. Feedback is often provided in conjunction with social comparison nudges [114]. Moreover, nudges can be used to promote the uptake of dynamic pricing schemes [115]. The division of these interventions is for illustrative purposes.

4.1. Monetary incentives to reduce space cooling demand

Monetary incentives refer to the provision of financial incentives to reduce energy demand. In a residential context, this primarily refers to dynamic pricing schemes (also known as price-based residential demand response, or implicit demand response), including Time of use tariffs (TOU), Critical peak pricing (CPP), and real-time pricing (RTP). These schemes are primarily designed to shift electricity consumption patterns from peak periods to off-peak periods [116], as well as encouraging conservation. This is particularly relevant for SC, as shifting electricity consumption patterns to periods with lower prices (which could in turn reflect moments of high renewable generation) can trigger more sustainable SC behaviours, such as pre-cooling. In the field of SC, this applies mostly to buildings equipped with active SC systems (including also fans and mobile AC devices). While the equipment rate is increasing quickly, it is not as high as in the United States. Moreover, while the peak load can be in summer in the early afternoon in some US states, the peak load in European countries is usually in the evening in winter. The potential and the experience in this field are therefore lower in Europe compared to the US.

Early assessments of dynamic pricing schemes have found them to be successful on average, with TOU leading to reductions in peak electricity usage of 4% and CPP of 36% [117], though CPP are rare events with much higher prices. A more recent literature review [118] finds average shifts in peak electricity demand ranging from 4.2 to 24.7% for RTP schemes. Studies highlight how households with smart meters, in-home devices, and central air conditioners can benefit the most from dynamic pricing [119].

A review by [120] finds that in general dynamic pricing has historically not been adopted as widely in Europe as in the US. However, in recent years, increasingly more EU Member states are adopting some form of dynamic pricing as smart meter rollouts take place [121]. This is further highlighted in the Clean Energy for All provisions, entitling all final consumers with a smart meter installed to have access to dynamic electricity prices [122]. A review of European pilot projects [4] identifies several instances of successful residential dynamic pricing projects in Italy, Germany, Belgium, Sweden, and the UK. The effectiveness of these pilots in shifting average load ranges from 1% to 8.7%, with significant reductions in peak hour consumption being reported for some projects (14% in CLNR project in the UK).

As dynamic pricing becomes more adopted in Europe, it is important to take note of findings from the US where these schemes have historically been used to reduce SC peak demand. In [106], a large-scale randomized field experiment on an RTP programme in the US is evaluated. Households previously participating in an AC replacement programme were recruited. The author finds evidence of conservation during peak hours, with no increase in average consumption during off-peak times. These results suggest that dynamic pricing can be a useful tool to reduce the use of electricity-powered SC appliances, specifically.

As highlighted in [4], automation of HVAC systems is also shown to be important in reducing peak consumption under the presence of dynamic pricing. For example, [107] find up to 10.8% cost savings with a demand response controller under a RTP programme, focusing only on HVAC systems. Similarly, [111] report in simulations almost halving energy consumption with an optimal HVAC control strategy and dynamic pricing in the residential sector. In [108] the authors also propose an optimal price-based demand response strategy for HVAC systems in office buildings. The authors report that the proposed strategy could lead to reductions in peak demand ranging from 7.19% to 26.8%. These studies highlight the potential for dynamic pricing to reduce peak consumption from HVAC systems together with automation, however further empirical findings are needed.

It is important to note that while dynamic pricing can be a useful tool in the energy flexibility toolkit, it is not without its potential downsides. Criticisms concerning the ethics of dynamic pricing, particularly if applied in vulnerable populations such as the energy poor, have been ongoing in the literature, representing an important aspect to consider when adopting these schemes [123], [117]. Additionally, it is important that dynamic pricing does not “lock-in” energy consumers to retailers, acting as barrier for the adoption of explicit demand response [121]. Finally, some evidence suggests that dynamic pricing schemes can be more effective in changing the consumption behaviours of homeowners, rather than renters [4] which can be a barrier to the wide implementation of these schemes.

4.2. Information provision to reduce space cooling demand

Information provision refers to providing individuals with information on good practices related to SC to achieve a good summer comfort in a sustainable way, including energy-related information to promote a reduction in SC energy use, and information to increase awareness of passive cooling measures.

The most widely studied example is individual feedback provided to households on their current or historical levels of energy consumption [112]. These feedback interventions have been tested in numerous contexts, delivered through electricity bills [124], [125], online web portals [125], [126], [127], [128], or in-home devices [129], [130]. Meta-analysis on these types of interventions have found that they are overall effective at reducing general electricity use, with a mean effect size – roughly 7 - 12% [6], [105], [131]. A meta-analysis focusing specifically on Europe and North America found on average a reduction in direct electricity consumption of 9% from feedback, based on 18 applications in Europe [5]. Frequency is important, with more frequent feedback generally leading to higher reductions [132]. In line with studies finding an important impact of personal feedback, the EU’s Energy Efficiency Directive (EED) requires Member States to supply accurate and systematic energy consumption information for final energy users through metering and billing. As outlined in [5], an analysis of Member States’ National Energy Efficiency Action Plans (NEEAPs) reveals that a large majority of EU-28 Member States have already transposed the billing provisions of the EED. Despite this fact, the smart-meter roll-outs progress at differing speeds, limiting the potential for providing frequent, smart feedback to residential energy consumers.

Personal feedback is often studied in relation to framing. The idea is that feedback can be framed in different ways, to leverage different motivators for energy conservation. For example, feedback can be framed in terms of financial losses from foregone savings, which has generally been found to be effective in promoting conservation. [133], [134] Moreover, feedback can also leverage pro-environmental attitudes by referring to the environmental impact of energy use. [135] This can be effective especially in cases where users do not pay for electricity consumption, though there are some mixed results. [136] Finally, feedback can be framed in terms of the health impacts, for example of thermostat settings or related to the emissions associated with high consumption. [135]

Most studies focus on the impact of feedback on energy use in general, but often in contexts where electricity is used specifically for SC [137]. This suggests that the approach can be effective at reducing energy use from AC units, or other SC appliances. A handful of studies consider the impacts of feedback on SC specifically. In [15] for example, the authors test different types of feedback on thermostat usage during summer months in a simulated workplace setting with controlled thermal environment. They provide “efficiency” and “health” levels associated with different thermostat settings through the thermostat window, labelling this approach “interactive feedback”. Their results show that this type of immediate, framed feedback results in higher temperature settings during cooling periods and motivates individuals into a more deliberate-thinking mode, rather than habit-driven. Similarly, [110] use a feedback and gaming platform to promote the uptake of energy-conserving thermostat settings in multi-unit residential buildings, finding the intervention effective at increasing indoor temperature setpoints during the summer. Other studies also investigate the effects of feedback together with social comparison nudges on the interaction of thermostats, air conditioner use, and window opening [9], [10], [16].These will be described below.

Another type of information intervention refers to providing energy advice. These can include interventions with the goal of improving general energy awareness, or sharing specific tips on curtailment actions that a household can take, which may be general or targeted [112]. In general, literature on energy literacy suggests that increasing knowledge on the impact of curtailment actions (so called "action energy literacy") does predict energy conservation efforts [138]. For example, providing simple decision-rules on how to generate energy savings can lead to better energy management decisions, as suggested in [139]. However, it is important to distinguish between high-involvement information actions (i.e.: through energy audits or consulting), and low-involvement (i.e.: providing non-contextualised tips). A meta-study by [6] considering studies from 1975 – 2012 finds in general that high-involvement actions are effective at reducing energy use, while the simple provision of tips in isolation is not. However, a wealth of research tests strategies that complement energy saving tips with other interventions, for example the provision of personal feedback [127], or social comparisons [114], often with positive results. Therefore, it seems that energy saving tips can be effective when complemented with feedback, or other types of behavioural interventions. In isolation however, information on sustainable SC should ideally entail high-involvement actions.

Information provision on SC can go beyond energy-related measures. An example is information campaigns on behaviours to adopt to prevent negative health impacts of heat waves. Numerous examples exist across Europe, enacted by local and national governments including France [140], Italy [141], UK [142], Germany [143], and many others. The suggested interventions can for example relate to maintaining high levels of hydration or using cold packs or wet towels to reduce body temperature. The suggested actions can also include going to "cool places", such as shaded parks or air conditioned public and commercial buildings, impacting occupancy patterns. This is especially relevant when the situation of a dwelling is not deemed conducive to allow for an acceptable level of indoor thermal comfort. It is worth noting that it is almost always the health or civil protection public bodies that release this information, which exemplifies how information provision for sustainable SC behaviours can go beyond energy policy and involve health policy. While there is no systematic review on the impacts of health-based behavioural information in extreme heat waves, specific regional evidence does suggest that the provision of behavioural information can be effective at reducing excess deaths during summer months [12], [144].

In [19] the authors investigate the effectiveness of a non-invasive daylighting and lighting system installed in office buildings, which crucially include two roller shades (semi-transparent and blackout). Amongst the aspects considered, the authors test several behavioural interventions to promote more efficient use of the shading and lighting system. One of the tested interventions includes a communication and engagement strategy whereby an external researcher would explain users how to use the installed technology and explain the importance of using daylight when possible. Results from open-ended surveys suggested that this high-involvement information was appreciated by participating users and led to better use of the lighting and shading system. This finding tentatively suggests that targeted information on how to optimally interact with shading typologies can lead to the uptake of more sustainable shading behaviours.

While interventions that involve information provision are widely considered effective, it is worth noting that some research suggests the simple provision of information can in some cases not be enough, or even risk to backfire [145]. It is therefore important to note that behavioural information should ideally always be contextualised to the recipient (I.e.: energy auditing can be more effective than general information on energy conservation), be frequent (such as in the case of immediate feedback from smart-metering technologies), and complemented with other interventions (I.e.: social comparisons in the case of energy feedback).

4.3. Nudges to decrease space cooling demand

As highlighted above, nudges represent a specific type of non-pecuniary intervention that aims at shifting behaviour through changing seemingly irrelevant factors (according to standard economic theory) of the decision environment. In recent years, nudges have received widespread attention with regards to policy application [146], with one of the most prominent examples being residential energy demand [147]. In this vein, two approaches stand-out as most promising in the literature to promote reduced energy use: social comparisons of energy behaviours amongst different individuals, and default thermostat settings.

Social comparisons refer to the process of providing individuals feedback on how their own energy behaviours compare to a group of peers, with the aim of promoting the uptake of energy-efficient behaviour. The most widely studied example is a large randomized controlled trial ran by the US utility OPower, whereby households received Home Energy Reports (HERs) together with their energy bills. In these reports, households would receive feedback on their personal level of electricity consumption, compared with the average of similar neighbours [148]. These interventions have the aim of addressing biased beliefs on how one's own consumption relates to an established norm [7]. At the European level, the EED explicitly integrates social comparisons by encouraging that energy bills to include a comparison with an average user. [149]

These interventions are often also complemented with curtailment tips, both general and tailored. They also often include appeals to social acceptability of conservation actions through emoticons, such as a smiling face included with the social information if a household consumes below the norm. This is due to early findings suggesting that these normative appeals help avoid the "boomerang effect", whereby low-consuming households increase their consumption once informed that they are consuming below the norm. [148]

Findings from the OPower trials show a reduction in energy consumption of 2% in the short-term [114], which persisted in the long run with only marginal decreases in treatment effectiveness. [150] These successful results have been replicated in many other contexts [151], [152], and with different mediums of delivery such as in-home devices. [153], [154] There is also evidence of similar social comparison interventions having an effect reducing electricity behaviour in hotels [155], where one of the highest uses of energy is air conditioning.

Specifically with regards to SC, [9] in a laboratory experiment study how a feedback-based social comparison intervention impacts the usage of a thermal comfort appliance, namely a personal fan in a shared office space. In an environmental room controlled to maintain a neutral-warm temperature, the authors introduce information on how the participant's own consumption compares to an efficient average energy user, through a laptop. They find the strategy to be effective for reducing usage of the fan. Results from surveys on subjective thermal comfort suggest that this reduction is driven by a degree of "thermal toleration", whereby participants were willing to tolerate some level thermal discomfort while having preferences for a cooler temperature.

Similarly, several studies test social comparison interventions with a focus on air-conditioning. In [10] for example, the authors test the effectiveness of social comparisons, together with curtailment tips, delivered door-to-door to low-to-moderate income households in multi-apartment buildings. The intervention aimed to reduce consumption during summer months, specifically the use of air conditioning units. They find a short-term reduction in consumption of 5.4%, and a longer-term reduction (12 months) of 5.8%, highlighting the effectiveness of these approaches specifically towards reducing the use of electricity for SC. Similarly, [109] test a modified social comparison intervention, highlighting the proportion of similar residents with more efficient air conditioning behaviours, in university dorms. They find the intervention to be effective in reducing consumption relative to a control group, but only in the residents who were pre-intervention already in the lowest percentile of consumption.

Finally, a recent paper considers the impact of social comparison interventions in promoting better window-interaction behaviours. In [16], the authors test a social comparison intervention aimed at promoting window-closing behaviour in an office setting during winter months. The intervention is found to almost halve the percentage of windows left open in the considered buildings. Although the finding concerns window interactions during winter months, it shows the large potential for social comparison feedback to promote the efficient uptake of natural ventilation measures. More research is needed to replicate these findings in the domain of SC, especially how feedback and social comparisons might lead to efficient night-time ventilation.

The second nudging approach that can reduce energy use for SC are defaults. These interventions refer to the setting of an optimal decision as the default choice. Individuals however still retain the possibility of actively changing this default. Defaults are often considered the most effective nudges across a variety of domains. [156] For example, in the choice of household and business electricity contracts, evidence suggests that setting a green energy default contract results in 80% of consumers sticking to the default. [157]

An application with relevance to SC is the setting of default thermostat or AC setpoints. This can be particularly useful in non-residential contexts, such as workplaces or public buildings. For example, [14] in a field experiment in OECD offices find that reducing the default thermostat temperature during winter months from 20°C to 19°C led to a significant reduction in the chosen setting of 0.38°C, reducing energy use in the building. More specific to SC, in a recent paper [13] provide a “quality assurance check” to the adaptive thermal comfort model using data from the ASHRAE Global Database 2. In the paper, they also discuss potential nudging strategies to the adaptive model, providing evidence in support of increasing default cooling set-points in air-conditioned office buildings: “the evidence presented in this paper indicates that cooling setpoints in AC buildings are currently too low by any standard” (p. 12). They support the implementation of using adaptive comfort algorithms to set internal temperatures, recognizing occupants’ ability to adapt to different thermal conditions. While the authors don’t recommend any one specific set-point, they use insights from the ASHRAE data to tentatively suggest a range of setpoints 24-27°C.

Furthermore, there are examples of policies that aim to encourage even higher reductions in energy use for SC by introducing dress codes that allow for the setting of higher default set-points while preserving thermal comfort. An example is the CoolBiz campaign in Japan, whereby set points during summer months in public offices were set at 28°C, and office workers were encouraged to wear lighter clothing, and more breathable fabrics during work hours. [11] The initiative has been widely regarded as a success and was reported to avoid from 1 –3 million tonnes of carbon emissions per year.

Defaults could additionally be useful to promote the uptake of other behaviours that lead to a reduction in energy use for SC, such as the use of shading. The lighting and shading interventions implemented in [19] for example included defaults in the setting of roller blinds. This intervention was found to be important in lowering energy use. Although the intervention was aimed to reduce energy use for lighting, not SC, it is an indication that the use of shading can be nudged by the setting of efficient defaults. Overall, the application of nudging approaches holds great promise for policymakers and practitioners aiming to promote behaviours that reduce energy use for SC.

Overall, the application of nudging approaches holds great promise for policymakers and practitioners aiming to promote behaviours that reduce energy use for SC. While social comparisons and defaults have received the most research attention, they are not the only approaches. For example, the use of gamification holds great potential for reducing energy use and encouraging better interaction with thermostat setpoints [110] [8], [158]. More traditional nudges such as setting specific energy saving goals have also been found to be useful. [159], including in reducing enegy use from washing and drying machines [160], which generate heat loads.

Finally, although not typically considered as a nudge (we consider it here however as it is still an example of a non-pecuniary intervention that alters seemingly irrelevant aspects of the decision environment), policies that aim to shift occupant presence in public or office spaces during the hottest hours of the day can be effective to reduce SC demand during summer months. As highlighted in section 2.2, occupancy patterns can significantly contribute to SC demand, so there is scope for interventions that attempt to shift schedules of occupancy towards more sustainable ones. There is not a wealth of empirical literature testing interventions to shift occupancy patterns (likely because they are perceived as habit-driven, and influenced by numerous external factors that may be difficult to change), however some notable examples of such interventions exist for the educational and workplace sector. For example, shifting starting dates in educational institutions, together with automated set-points, has been suggested to lead to a reduction in energy consumption of up to 50% in cooling/heating load throughout the year [3]. Other examples in the education sector include rescheduling outdoor recess times due to extreme heat [161], or cancelling school during days of extreme heat (i.e.: “heat days” [162]). In office spaces, interventions that limit occupancy during summer months such as “Summer Fridays” (I.e.: allowing employees to leave the office early on Fridays during the summer) reduce the need for active SC and may therefore contribute to reducing SC demand if complemented with occupancy-based SC controls [163]. Overall, while there is yet not many studies considering how to shift occupancy schedules for more sustainable SC in the summer, this seems to be a promising strategy. It is worth acknowledging however that these strategies will only be effective overall, if they are not met by an increase in SC demand in residential buildings.

As mentioned above, one of the most obvious benefits of nudges is that they tend to be cost-effective, with the general consensus being that they often compare favourably in contrast to traditional interventions like monetary incentives. [164] However, there are important aspects that should be considered before implementing a nudge. As the result in [109] highlights, the impacts of nudges can often be heterogeneous. For example, [165] suggest that social comparison nudges can be considerably less cost-effective in Europe than the US, where much of the original literature is based. In [14] the authors also find that while a 1°C decrease in the default thermostat setpoint was effective in reducing energy use, a 2°C decrease was less effective. These findings highlight the importance of testing an intervention in the target population before rolling it out widely, an activity sometimes labelled “in-situ testing”. [166] While this is important for all kinds of behaviour change interventions, it is particularly important for nudges, as so much is yet unknown about the psychological and motivational channels by which many nudges are effective.

4.4. Conclusions

Our review of the literature on behaviour-change interventions for sustainable SC has revealed several effective strategies. Many of these have already been adopted across Europe in the form of concrete policies (I.e.: the EED directive on the inclusion of feedback in energy bills), while others still need further research.

Evidence, primarily from the US but with several examples also in Europe, shows that monetary incentives in the form of dynamic pricing schemes can be effective to reduce energy use for SC from active systems like AC, both in residential and industry contexts. The effectiveness of these approaches however seems to vary, depending on the type of tariff scheme as well as the presence of automation.

A wealth of literature shows that providing feedback also proves effective to reduce the energy use from active SC systems, as well as promote energy conservation in general which reduces heat loads generated from the use of appliances and lighting. Information provision, both related to energy-consuming SC systems, as well as passive measures such as shading practices, can also be effective. In this case however, it is preferable that the information is of high involvement, for example in the case of energy audits. Finally, health-related information on behaviours to adopt in the case of heat waves is also crucially important for the purposes of achieving a good summer comfort in a sustainable way and avoiding health-impacts of extreme heat.

Nudges such as social comparisons and defaults have also been researched in relation to SC. Appeals to social behaviours have been shown to reduce the use of energy-consuming SC systems and can increase the effectiveness of energy feedback. The use of efficient defaults can also lead to an increase in chosen temperature set-points during summer months. Complemented with information and setting dress codes that encourage the use of lighter, more breathable fabrics, higher default set-points can have an immense impact on energy use in summer months, particularly in office spaces. There is also some evidence showing how nudges such as social comparisons and defaults can encourage passive SC behaviours, such as promoting better window-opening behaviour and adopting more efficient shading practices.

The literature review also highlights that there is still much we do not know on how behaviour-change interventions can impact SC demand specifically. As with literature considering general energy use, contextual factors seem to matter greatly [167], and more research specifically on SC is needed to assess the drivers of this heterogeneity. Additionally, while there is some research that considers how to promote sustainable passive SC behaviours, there is still a bias towards behaviour-change with regards to active systems. While we can assume that many of the interventions aimed at reducing air conditioning use also lead to increased uptake of passive measures, there is scarcely any literature that explicitly investigates this. More research that specifically looks at how to promote sustainable window opening behaviours, and shading practices during summer months is needed.

Finally, while this review has focused on behaviour-change, it can be argued that efforts to promote more sustainable SC should also focus on automation, rather than aiming to change inefficient behaviours. Building Automation Control Systems (BACS) are generally regarded as more efficient and are recommended by the EPBD. As mentioned in section 4.1, they can additionally be very efficient when coupled with dynamic pricing schemes, and some authors argue that automation should extend also to passive SC measures, including window opening and shading. [168] However, in several typologies of buildings it might be unfeasible or undesirable to implement automated systems for SC. Behaviour-change interventions are therefore crucially important when automation is not desirable. For example, evidence suggests that people prefer to be in control of thermostat settings in their homes, even if they do not change the default setting post-installation. [169] Therefore, as our review of the literature suggests, implementing policies that set efficient SC defaults, for both active and passive SC, can be a highly efficient way in settings where automation is unfeasible.

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Annex I. - Summary of occupant behaviour surveys in European countries

Survey data						Building type					Monitored/surveyed data													Environmental data												Sample data							
Country	Source (author)	Source	Date survey	Date published	Representative?	SFH	ABs	Office	Education	Hotel	Occupancy	Season	Time of the day	Cotnrol of cooling	Control of windows	Window tilting angle	Air change rate	Control of shading	Type of user (active /	Use of domestic	Discomfort actions	Clothing adjusment	Motivation / drivers	Indoor temperature	Outdoor temperature	Indoor humidity	Outdoor humidity	Rainfall	Wind speed and direction	Atmospheric pressure	Solar radiation	Number of sunny hours	Volatile organic	Smoke / smoking	CO2 concentation	Heating only	Building age / typology	Ownership	Gender of respondant	Age of resp’ ndant	Region	Children's health	Social background
UK	**Raja et al.**	**[170]**	**1996. 06 - 1997 08.**	**2001**	**no**			**x**			**x**				**x**			**x**			**x**			**x**	**x**																		
UK	Rijal et al.	[102]	1996. 03. - 1997. 09.	2007	no			x			x				x				x					x	x																		
UK	Wei et al.	[171]	3 periods (from 20 July 2010 to 20 Nov. 2011)	2013	no			x			x				x						x		x	x	x						*						x		x				
DE	Herkel et al.	[172]	2012. 07. 01. - 2013. 07. 31.	2008	no			x			x	x			x									x	x						x												
DE	D’Oca and Hong	[173]	Annex 53. database	2014	yes			x			x	x	x		x	x								x	x	x	x	x	x		x				x								

Survey data						Building type							Monitored/surveyed data											Environmental data													Sample data						
Country	Source (author)	Source	Date survey	Date published	Representative?	SFH	ABs	Office	Education	Hotel	Occupancy	Season	Time of the day	Cotnrol of cooling	Control of windows	Window tilting angle	Air change rate	Control of shading	Type of user (active /	Use of domestic	Discomfort actions	Clothing adjusment	Motivation / drivers	Indoor temperature	Outdoor temperature	Indoor humidity	Outdoor humidity	Rainfall	Wind speed and direction	Atmospheric pressure	Solar radiation	Number of sunny hours	Volatile organic	Smoke / smoking	CO2 concentation	Heating only	Building age / typology	Ownership	Gender of respondant	Age of resp' ndant	Region	Children's health	Social background
DE	Schakib-Ekbatan– et al	[154]	2004. 01. 01. - 2009. 12. 31.	2015	no			x			x				x									x	x	x	x	x	x		x				x								
DE	Cali et al.	[174]	2012. 01. - 2012. 12.	2016	no		x						x		x	x								x	x	x	x		x				x		x								
DE	Schiela and Schüneman n	[86]	2019.	2021	no		x				x		x		x	x							x		x												x	x		x			
IT	Stazi et al.	[59]	2015. 03. 19. - 2015. 04. 29.	2017	no				x		x				x									x	x				x		x				x								
IT	D'Oca, Corgnati and Buso	[175]	2013	2014	no	x								x	x									x		x																	
GR	Santamouri s et al.	[81]	2003-2007	2008	no				x						x									x											x								
GR	Papakostas and Sotiropoulo s	[176]		1997	no	x					x				x				x	x				x																			

Survey data						Building type					Monitored/surveyed data													Environmental data													Sample data						
Country	**Source (author)**	Source	**Date survey**	**Date published**	**Representative?**	**SFH**	**ABs**	**Office**	**Education**	**Hotel**	**Occupancy**	**Season**	**Time of the day**	**Cotnrol of cooling**	**Control of windows**	**Window tilting angle**	**Air change rate**	**Control of shading**	**Type of user (active /**	**Use of domestic**	**Discomfort actions**	**Clothing adjusment**	**Motivation / drivers**	**Indoor temperature**	**Outdoor temperature**	**Indoor humidity**	**Outdoor humidity**	**Rainfall**	**Wind speed and direction**	**Atmospheric pressure**	**Solar radiation**	**Number of sunny hours**	**Volatile organic**	**Smoke / smoking**	**CO2 concentation**	**Heating only**	**Building age / typology**	**Ownership**	**Gender of respondant**	**Age of resp' ndant**	**Region**	**Children's health**	**Social background**
NL	O. Guerra-Santin and L. Itard	[177]		2010	no	x									x					x																x							
DK	Andersen et al.	[178]	2006. 09. - 2007. 03.		no	x					x			x	x	x			x		x				x				x		x	x							x	x			
DK	Fabi et al.	[179]	2008. 01. - 2008. 08.	2012	no	x	x				x				x	x								x	x	x	x		x		x				x		x	x					
DK	Andersen et al.	[180]	2008. 01. - 2008. 08.	2013	no	x	x				x				x									x	x	x	x		x		x				x		x	x					
DK	M. Frontczak, R. V. Andersen, and P. Wargocki	[181]	2011	2012	no	x	x				x			x	x						x																						
DK	G. Bekö, J. Toftum, and G. Clausen	[182]		2011	no	x	x								x		x																									x	
FI	S. Karjalainen	[183]		2009	no	x		x						x	x			x			x	x																		x			x

Cool LIFE

Survey data						Building type						Monitored/surveyed data												Environmental data												Sample data							
Country	Source (author)	Source	Date survey	Date published	Representative?	SFH	ABs	Office	Education	Hotel	Occupancy	Season	Time of the day	Cotnrol of cooling	Control of windows	Window tilting angle	Air change rate	Control of shading	Type of user (active /	Use of domestic	Discomfort actions	Clothing adjusment	Motivation / drivers	Indoor temperature	Outdoor temperature	Indoor humidity	Outdoor humidity	Rainfall	Wind speed and direction	Atmospheric pressure	Solar radiation	Number of sunny hours	Volatile organic	Smoke / smoking	CO2 concentation	Heating only	Building age / typology	Ownership	Gender of respondant	Age of resp’ ndant	Region	Children's health	Social background
CH	Fritsch et al.	[184]	1983. 10 - 1984. 05.	1990	no			x							x																												
CH	Haldi and Robinson	[185]	2006. 06. 13. - 2006. 09. 26.	2008	no			x							x									x		x																	
CH	Haldi and Robinson	[186]	2001. 12. 19. - 2008. 11. 15.	2009	no			x			x				x									x		x	x	x	x														
CH	Schweiker et al.	[187]	2007. summer - 2008. summer	2012	no		x								x									x		x	x	x		x													
NO, PL, UK, IT	Galev, Gerganov	[75]		2020	ye s	x	x							x	x						x		x	x													x			x			x
FR, DE, HU, ES	Galev, Gerganov	[75]		2020	ye s	x	x							x	x						x		x	x													x			x			x
BE, GE, NL, CH, UK	Dubrul et al.	[82]		1988		x					x				x		x		x				x	x	x	x								x			x						x
HU	Deme Bélafi	[60]		2018	no	x		x	x		x			x				x			x																x						

Cool LIFE

	Survey data					Building type							Monitored/surveyed data											Environmental data														Sample data					
Country	**Source (author)**	Source	**Date survey**	**Date published**	**Representative?**	**SFH**	**ABs**	**Office**	**Education**	**Hotel**	**Occupancy**	**Season**	**Time of the day**	**Cotnrol of cooling**	**Control of windows**	**Window tilting angle**	**Air change rate**	**Control of shading**	**Type of user (active /**	**Use of domestic**	**Discomfort actions**	**Clothing adjusment**	**Motivation / drivers**	**Indoor temperature**	**Outdoor temperature**	**Indoor humidity**	**Outdoor humidity**	**Rainfall**	**Wind speed and direction**	**Atmospheric pressure**	**Solar radiation**	**Number of sunny hours**	**Volatile organic**	**Smoke / smoking**	**CO2 concentation**	**Heating only**	**Building age / typology**	**Ownership**	**Gender of respondant**	**Age of resp' ndant**	**Region**	**Children's health**	**Social background**
AT, BE, CZ, DK, FR, FI, DE, IR, IT, NL, NO, SE, CH, UK	D'Oca et al	[188]	2014. - 2017.	2017	no	x	x	x			x			x	x			x			x																			x			

Annex II – Occupancy profiles

Residential occupancy schedules

EN-16798 and EN 15665 – EU - daily

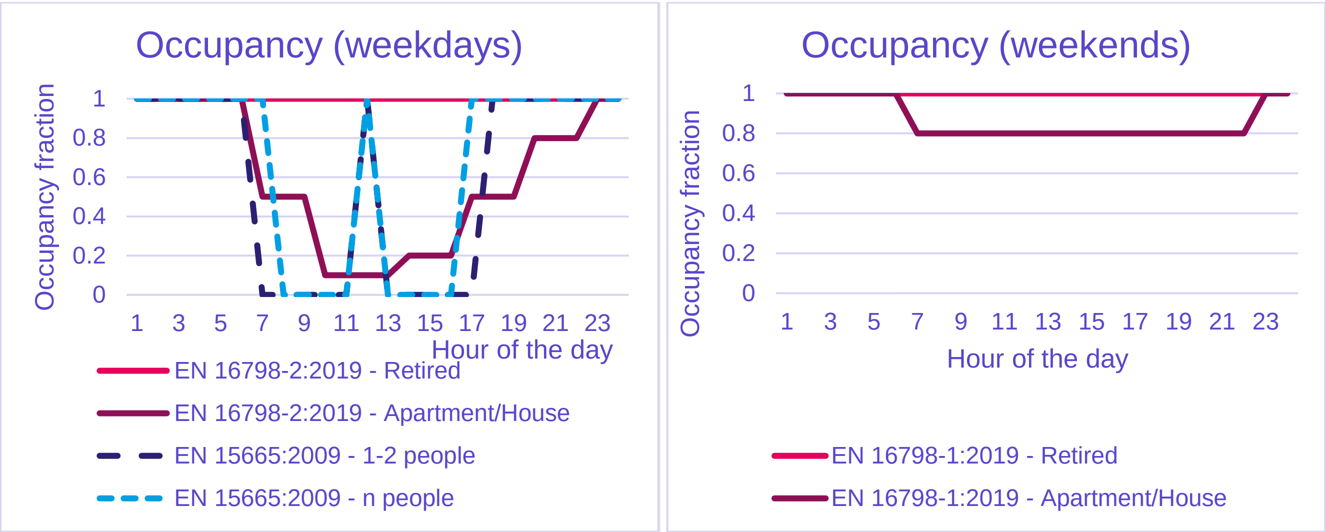


Figure 45. Occupancy schedules implemented in the EN 16798 and EN 15665 standards for residential buildings for weekdays and weekends

Th-BCE 2012, France – residential, daily

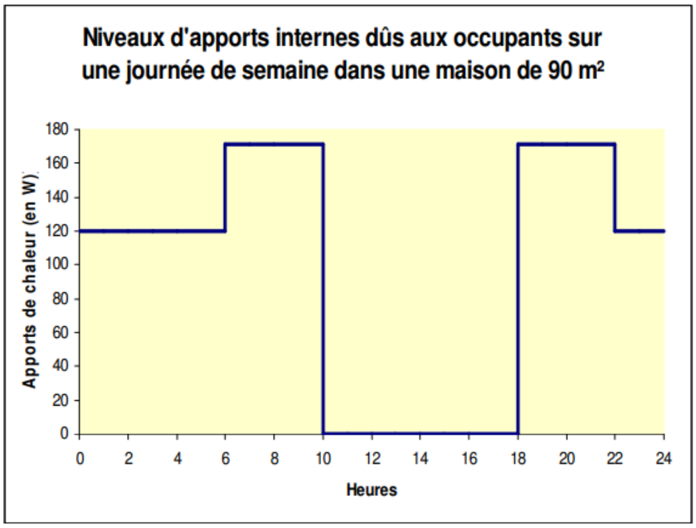
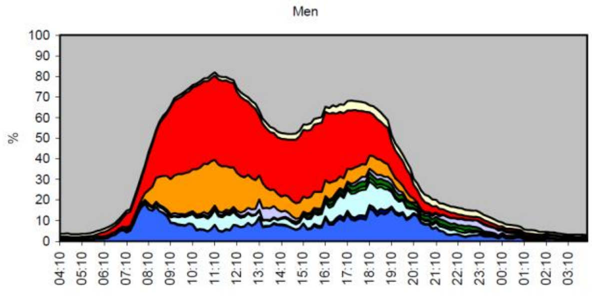
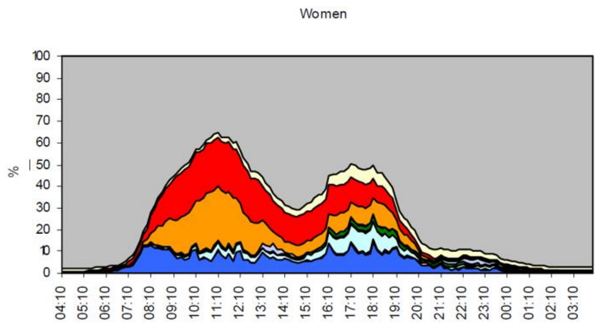


Figure 46. Occupant heat load in a 90m² single family house according to Th-BCE 2012 [41]

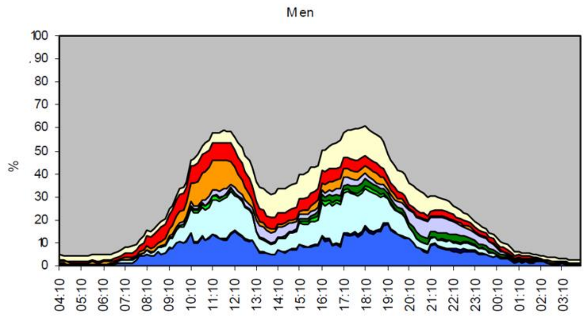
TUS Italy – residential, daily



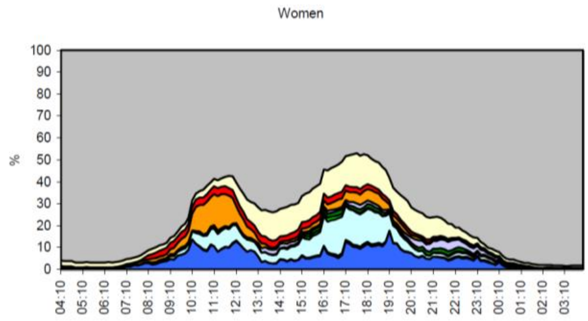
We–kdays – men



Weekdays - women



We–kends – men



Weekends - women

Legend:

- Non-place (travel)
- Other place
- Outdoor in the street
- Outdoor recreational, cultural and sports
- Indoor recreational, cultural and sports
- Restaurants
- Indoor services
- At the workplace
- Others' house
- At own home

Figure 47. TUS based schedules of where people spend their time for Italy [42].

The daily routine survey was carried out from April 1, 2002 to March 31, 2003. A sample of 21,075 households was surveyed for a total of 55,773 individuals (51,206 diary days). The collected data regards the type of activity and presence at home registered every 10 mins in 24h diaries.

TUS France- residential, daily

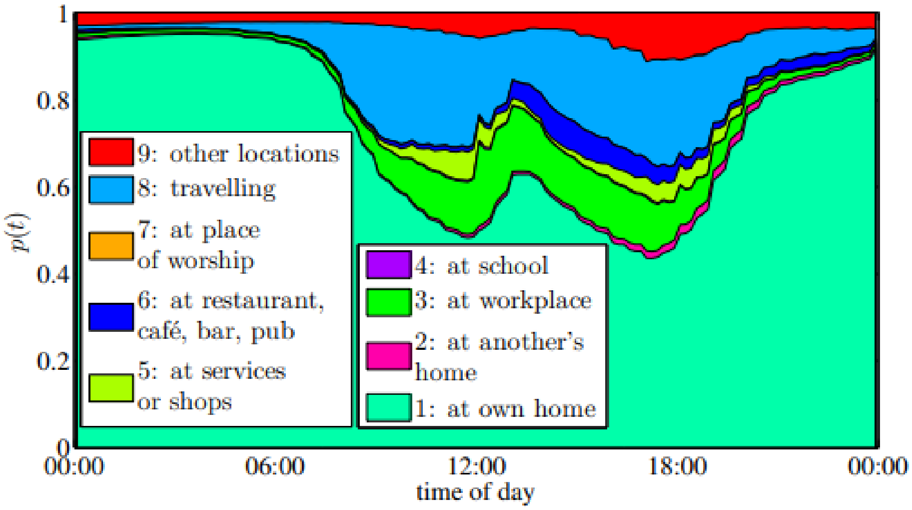


Figure 48. Presence profile for the different types of places in the France TUS (1998-1999) [189]

This dataset relates to a subset of the French population of n = 15441 individuals from 7949 households, whose recorded diary plans are in 10 min time increments throughout 24 h, starting and ending at midnight. [189]

TUS UK – residential, daily

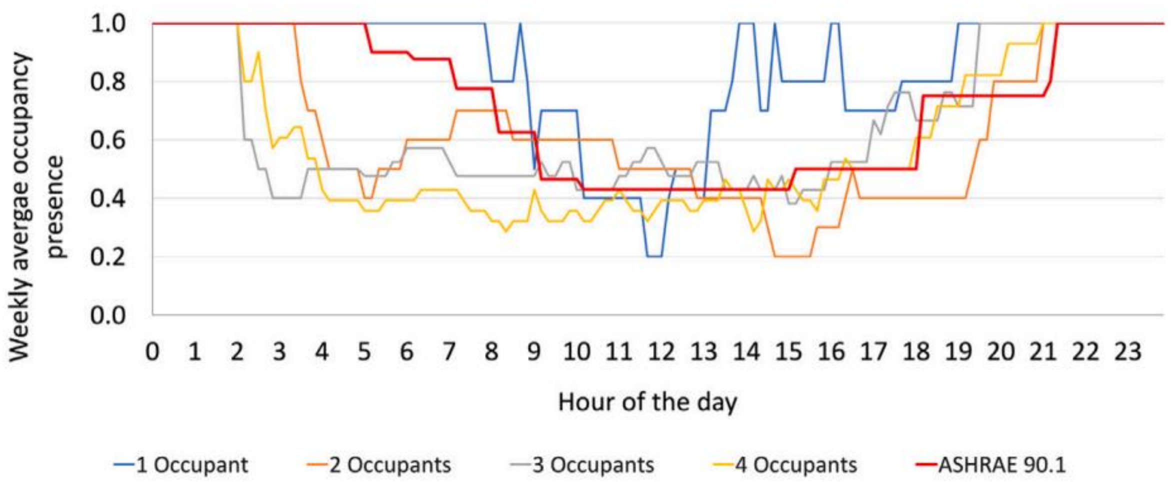


Figure 49. Comparison of average availability schedules throughout the year for different occupancy in dwellings in Ireland extracted from the UK TUS data with the standard schedules provided by ASHRAE. Source: [44]

The study of Sood et al [29] was conducted across cities in England, Scotland, Wales, and Northern Ireland, which are among the biggest and most densely populated regions in the UK. As the study did not distinguish between urban and rural areas, using these profiles to represent the whole country is a reasonable assumption. [44]

Another profile has been provided by Richardson et al on the UK data [45]:

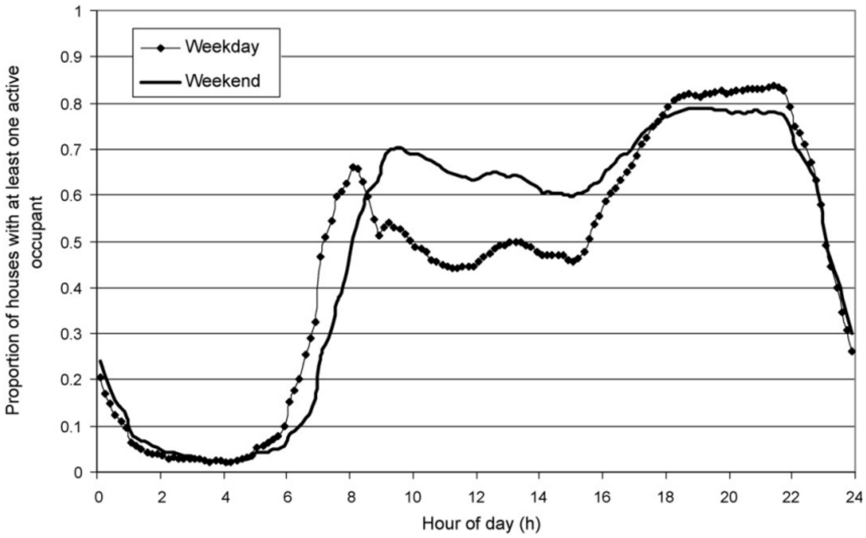


Fig. 3. Aggregated active occupancy for all survey participants by weekday and weekend days.

Figure 50. Aggregated active occupancy for all survey participants by weekday and weekend days Source: [45]

TUS Belgium – residential, daily

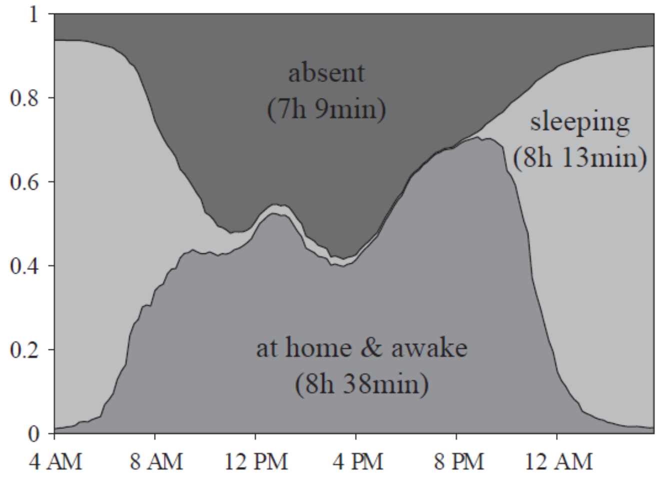


Fig. 1. The average occupancy profile indicates the overall probability that individuals are at home and awake, sleeping or absent.

Figure 51. The average occupancy profile indicates the overall probability that the individuals are at home and awake, sleeping, or absent [47]

As authors [47] conclude: “The model was calibrated with a Belgian time-use survey, that contains detailed information on the whereabouts and activities of 6,400 respondents from 3,455 households during one weekday and one weekend d–y.”

TUS DK – residential, daily

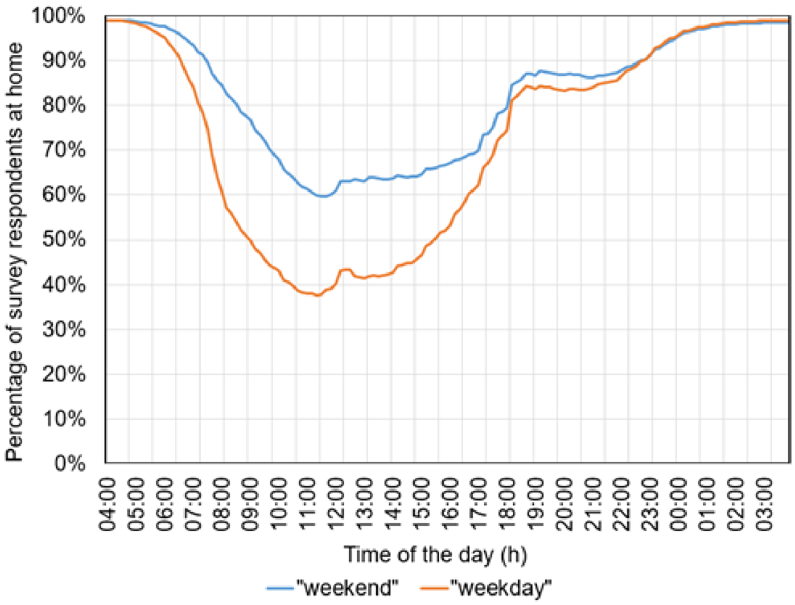


Figure 52. Occupancy patterns during weekdays and weekends [190]

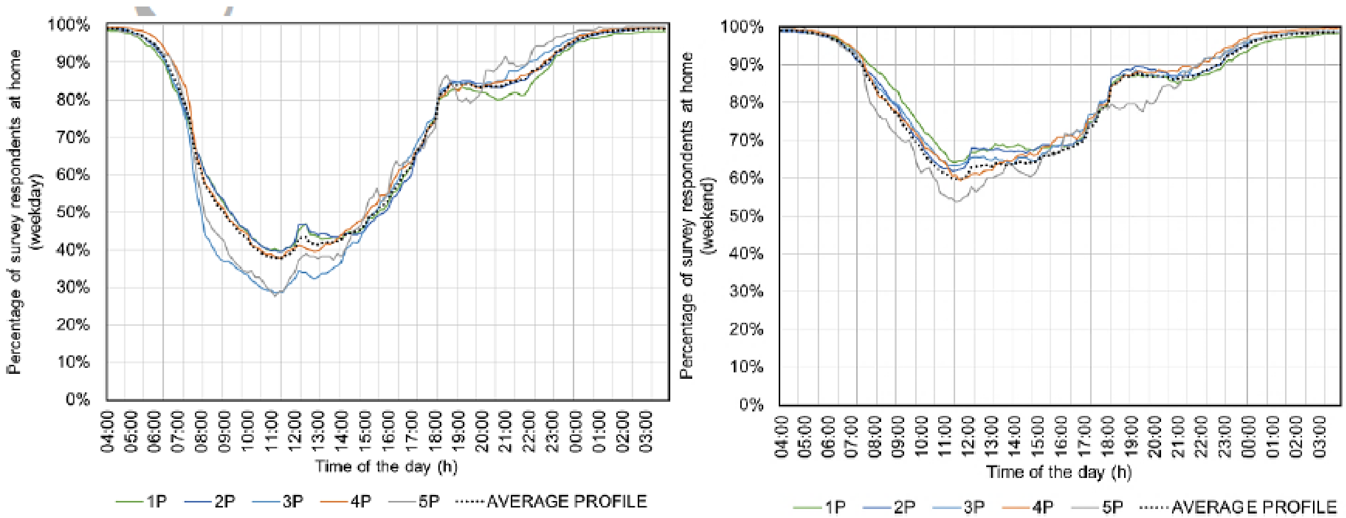
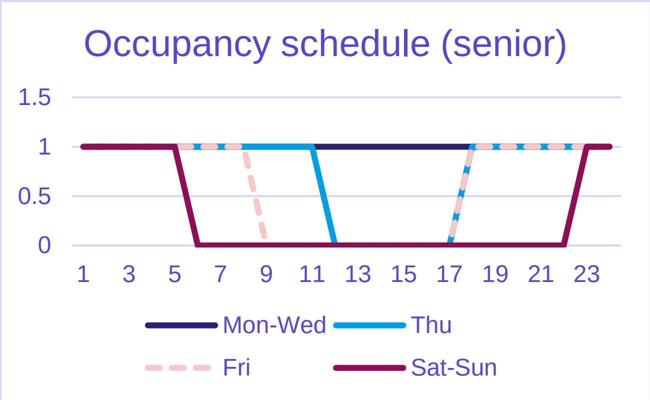
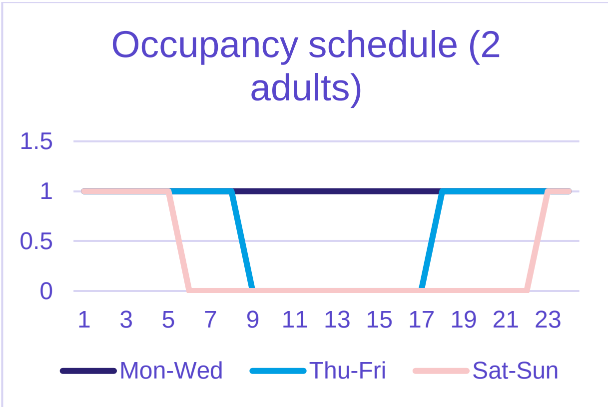


Figure 53. Occupancy patterns for different household compositions (n*P=number of household members) during (a) weekdays and (b) weekends. [190]

Woononderzoek Nederland (WoON) dataset 2012 – residential, daily

Schedules were developed based on a nationwide survey carried out by the Dutch Ministry of the Interior and Kingdom Relations (BZK). Netherlands. The dataset consists of the compilation of 4,800 dwelling audits and over 69,000 household questionnaires, which are also linked to external data. They provided occupant profiles for 7 types of households, for each day of the week.





Internet survey – Portugal – residential, daily

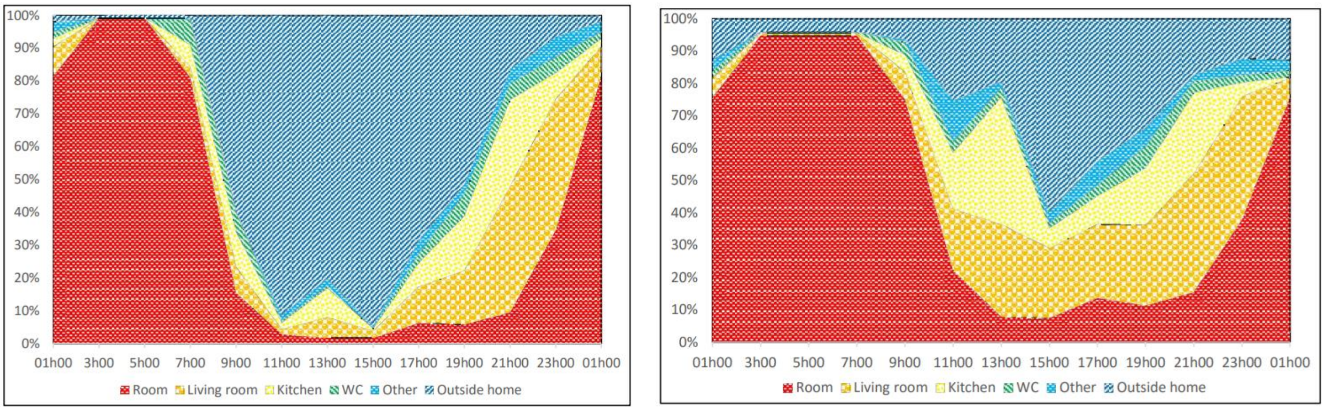
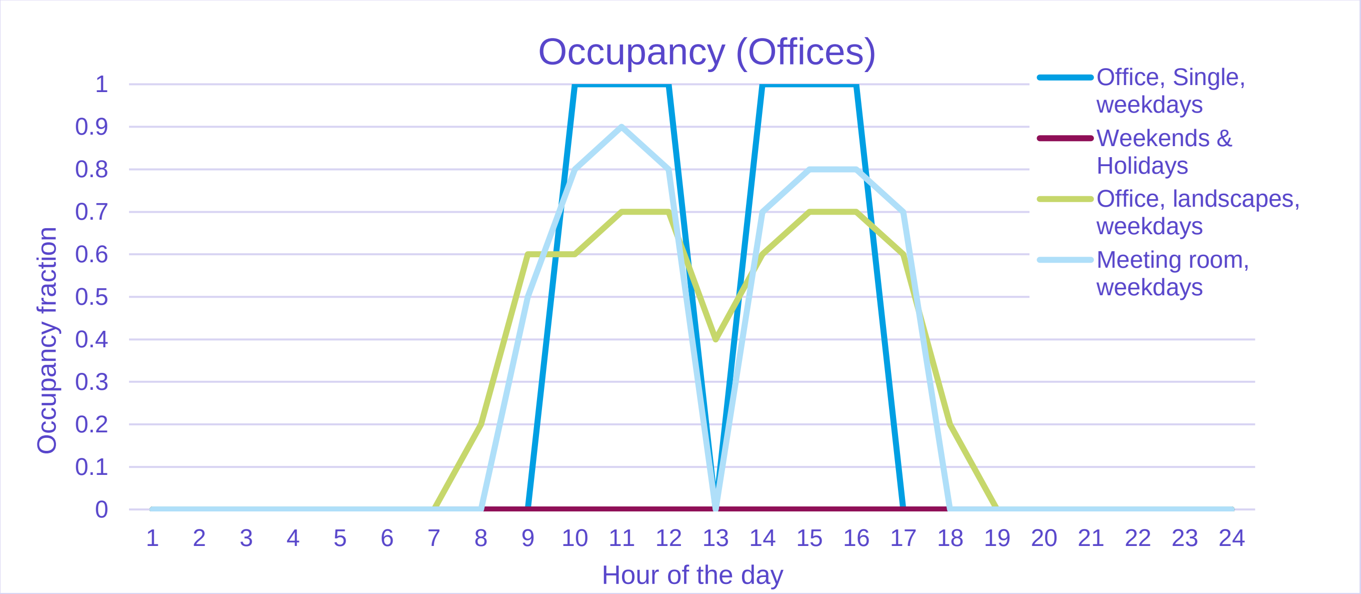


Figure 54. Occupancy profiles in Portugal in a) weekdays and b) weekends or holidays Source: [48]

The questionnaire was distributed online by email and using social media. It was estimated that the questionnaire reached approximately 100 persons, and 31 responses. All the participants were from the Minho and Douro Litoral regions of Portugal. Moreover, 73% of the participants were male and 27% were female; 3% were younger than 20 years old, 77% aged between 21 and 40 and 20% were older than 41 years old.

Occupancy profiles – Office

EN-16798 – occupancy in office spaces



Hungary – annual average occupancy in office spaces of a HQ

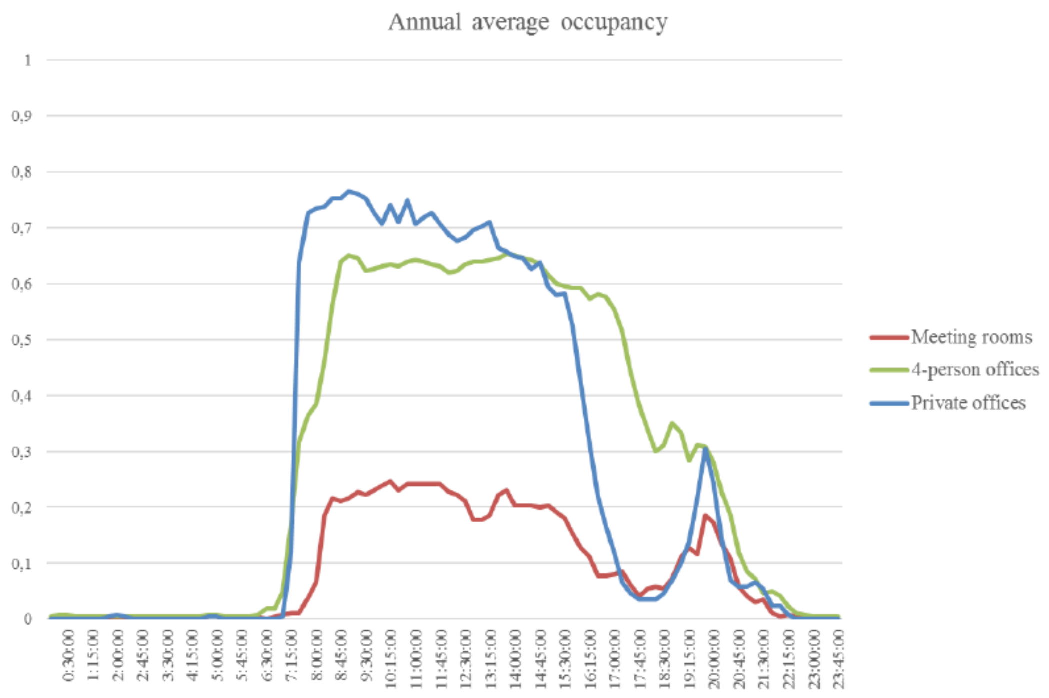


Figure 55. Annual average office occupancy in three types of office spaces in a headquater in Budapest [191]

USA – annual average occupancy in office spaces of a commercial office

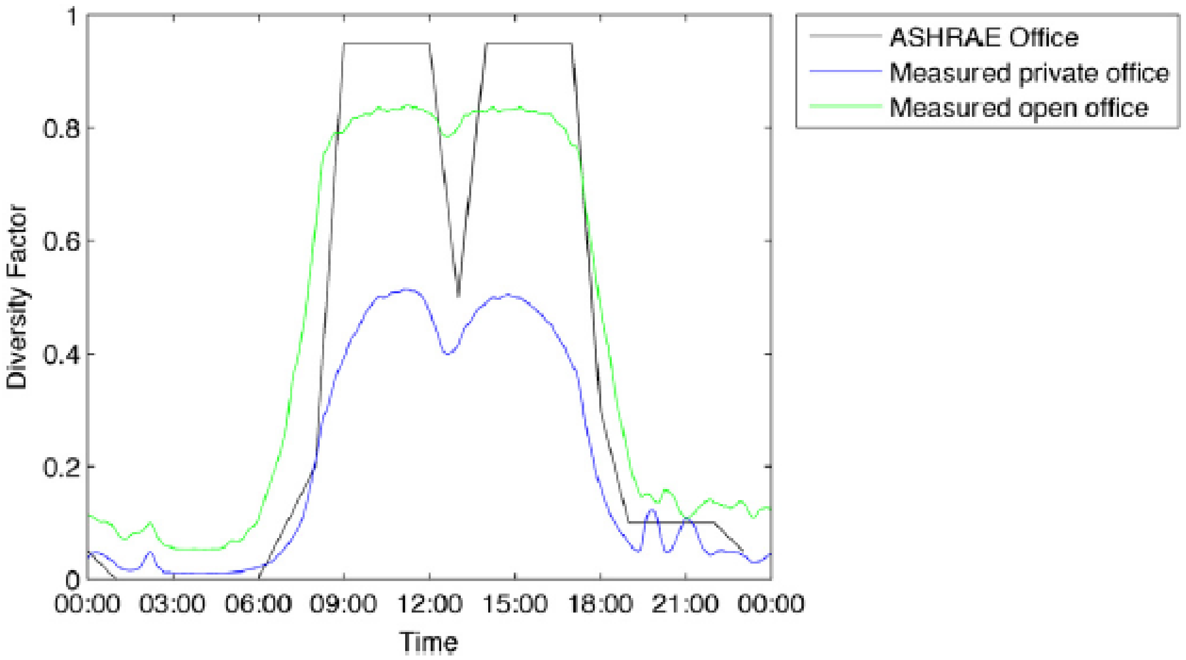


Figure 56. Comparsion of ASHRAE 90.1 2004 references to the measured occupancy diversities by Duarte [51]

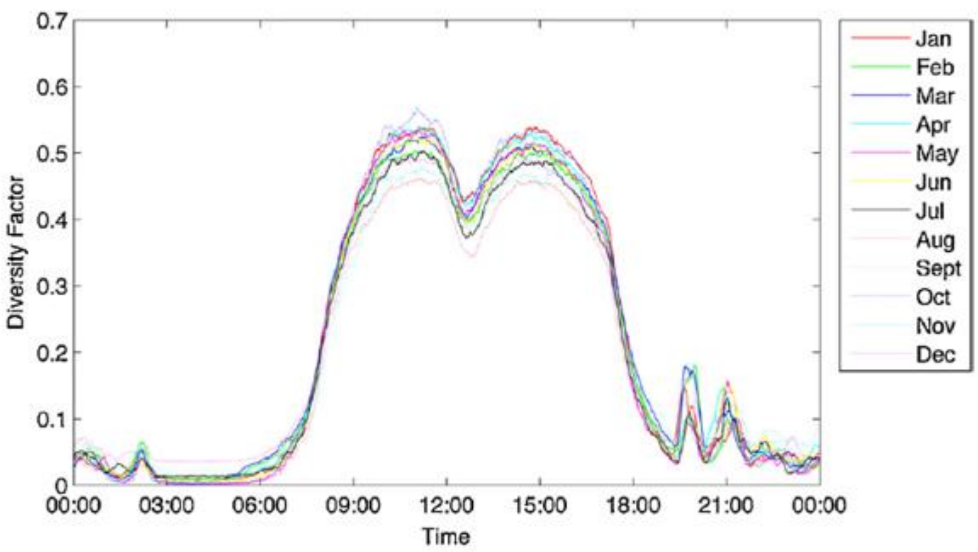


Figure 57. Private office diversity factory for each month by Duarte [51]

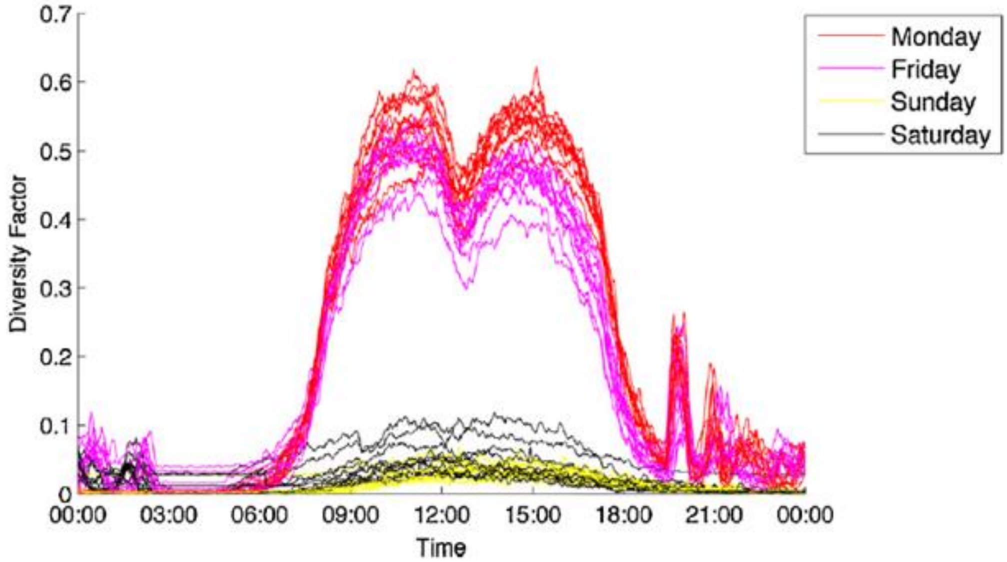


Figure 58. Private office diversity factor by weekday for each month. [51]

Occupancy patterns – Educational buildings

Daily pattern - Finland

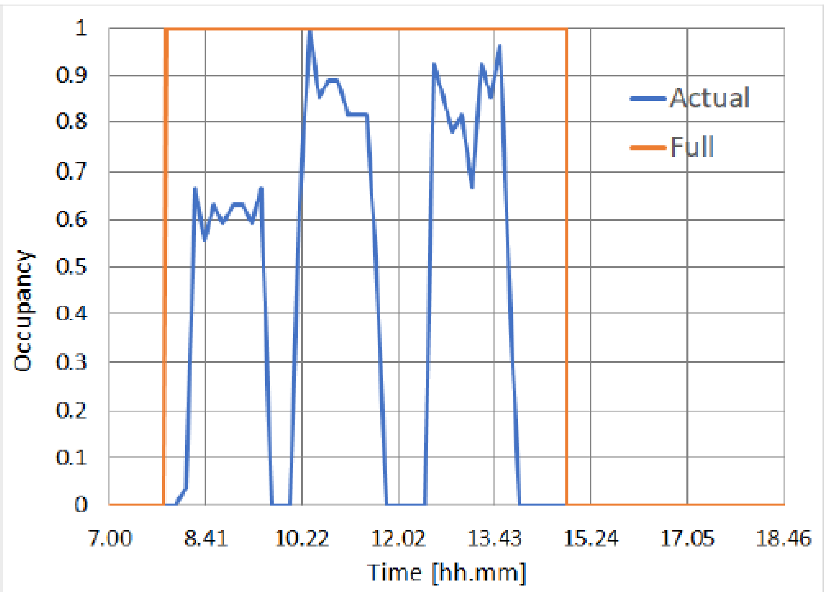


Figure 59. Occupancy schedule of a typical school day in Finland Source: Ferrantelli [192]

Regional differences in school holidays

Source: [54].

Summer holidays						
	Primary school			Secondary school		
Country	**Summer holiday start**	**Summer holiday end**	**Total duration (Weeks)**	**Summer holiday start**	**Summer holiday end**	**Total duration (Weeks)**
AT	4-11July	6-13 Sept	9	4-11July	6-13 Sept	9
BE	01.July	31.Aug	9	01.July	31.Aug	9
BG	29 May - 30 June	14.Sept	10 to 15	30.June	14.Sept	10
CY	18.June	31.Aug	10	18.June	31.Aug	10
CZ	18.June	11.Sept	11	01.July	31.Aug	8.5
DK	01.July	31.Aug	8	01.July	31.Aug	8.5
EE	27.June	06.Aug	5	27.June	06.Aug	5
FI	10.June	31.Aug	11.5	10.June	31.Aug	11.5
FR	29.May	15.Aug	11	29.May	15.Aug	11
DE	05.July	31.Aug	8	05.July	31.Aug	8
EL	22 Jun-30 July	1 Aug-12 Sept	6	22 Jun-30 July	1 Aug-12 Sept	6
HU	16.June	10.Sept	12	01.July	10.Sept	10
IE	16.June	31.Aug	11	16.June	31.Aug	11
IT	30.June	01.Sept	9	01.June	31.Aug	12
LV	01.June	5-15 Sept	12-14	1 June/July	5-15 Sept	12-14
LT	01.June	31.Aug	13	01.June	31.Aug	13
LU	no exact date	31.Aug	-	no exact date	31.Aug	-
MT	16.July	14.Sept	8	16.July	14.Sept	8
NL	29.June	24.Sept	11	29.June	24.Sept	11
NO	4-18 July	16-30 Aug	6	4-18 July	16-30 Aug	6
PL	27.June	31.Aug	8	27.June	31.Aug	8
PT	31.July	10-13 Sept	12-13	25.July	10-13 Sept	13-14
RO	13.June	09.Sept	12	13.June	09.Sept	12
SK	01.July	31.Aug	8	01.July	31.Aug	8
SI	25.June	31.Aug	10	25.June	31.Aug	10
ES	15.June	05.Sept	11-12	15.June	15.Sept	11-12
SE	15.June	25.Aug	10	15.June	25.Aug	10

Spring holidays						
	Primary school			Secondary school		
	Spring holiday start	Spring holiday end	Total duration	Spring holiday start	Spring holiday end	Total duration
AT	04.Apr	13 -14 Apr	1 Week	04.Apr	13 -14 Apr	1 Week
BE	06.Apr	19.Apr	2 Weeks	06.Apr	19.Apr	2 Weeks
BG	11.Apr	20.Apr	1 Week	11.Apr	20.Apr	1 Week
CY	9-10 Apr	10-17 Apr	Day to 1 week	9-10 Apr	10-17 Apr	Day to 1 week
CZ	13.Apr	24.Apr	2 Weeks	13.Apr	24.Apr	2 Weeks
DK	03.febr	15.Mar	1 Week	03.febr	15.Mar	1 Weeks
EE	04.Apr	13.Apr	1 Week	04.Apr	13.Apr	1 Week
FI	20.Apr	26.Apr	1 Week	20.Apr	26.Apr	1 Week
FR	10.Apr	13.Apr	4 Days	10.Apr	13.Apr	4 Days
DE	5 or 12 or 19 Apr depends on the region	19 or 26 Apr or 3 May	2 Weeks	5 or 12 or 19 Apr depends on the region	19 or 26 Apr or 3 May	2 Weeks
EL	2 Mar-19 Mar	2 Apr-24 Apr	1-2 Weeks	2 Mar-18 Mar	18 Mar-24 Apr	1-2 Weeks
HU	13.Apr	26.Apr	2 Weeks	13.Apr	26.Apr	2 Weeks
IE	09.Apr	14.Apr	1 Week	09.Apr	14.Apr	1 Week
IT	06.Apr	17.Apr	2 Weeks	06.Apr	17.Apr	2 Weeks
LV	09.Apr	14.Apr	5 Days	09.Apr	14.Apr	5 Days
LT	16.Mar	20.Mar	1 Week	23.Mar	27.Mar	1 Week
LU	14.Apr	17.Apr	4 Days	14.Apr	17.Apr	4 Days
MT	04.Apr	19.Apr	2 Weeks	04.Apr	19.Apr	2 Weeks
NL	08.Apr	17.Apr	1.5 Weeks	08.Apr	17.Apr	1.5 Weeks
NO	25.Apr	03.May	1 Week	25.Apr	03.May	1 Week
PL	09.Apr	14.Apr	6 Days	09.Apr	14.Apr	6 Days
PT	30.Mar	13.Apr	2 Weeks	30.Mar	13.Apr	2 Weeks
RO	04.Apr	21.Apr	2.5 Weeks	04.Apr	21.Apr	2.5 Weeks
SK	09.Apr	14.Apr	6 Days	09.Apr	14.Apr	6 Days
SI	27.Apr	03.May	1 Week	27.Apr	03.May	1 Week
ES	03.Apr	17.Apr	5-7 Days	03.Apr	17.Apr	5-7 Days
SE	30.Mar	07.Apr	1 Week	30.Mar	07.Apr	1 Week

Autumn holidays						
	Primary school			Secondary school		
	Autumn holiday start	Autumn holiday end	Total duration	Autumn holiday start	Autumn holiday end	Total duration
AT	28.Oct	31.Oct	4 Days	28.Oct	31.Oct	4 Days
BE	28.Oct	03.Nov	1 Week	28.Oct	03.Nov	1 Week
BG	01.Nov	03.Nov	3 Days	01.Nov	03.Nov	3 Days
CY	28 to 30 Oct	31.Oct	1-3 Days	28-30 Oct	31.Oct	1-3 Days
CZ	-	-	-	-	-	-
DK	28.Oct	30.Oct	2 Days	28.Oct	30.Oct	2 Days
EE	12.Oct	20.Oct	1 Week	12.Oct	20.Oct	1 Week
FI	21.Oct	27.Oct	1 Week	21.Oct	27.Oct	1 Week
FR	2-5 Days in Oct	2-5 Days in Oct	2-5 Days in Oct	2-5 Days in Oct	2-5 Days in Oct	2-5 Days in Oct
DE	20.Oct	03.Nov	2 Weeks	20.Oct	03.Nov	2 Weeks
EL	30 Sept-16 Oct	16 Oct- 31 Oct	3 Days to 2 Weeks	30 Sept-16 Oct	16 Oct- 31 Oct	3 Days to 2 Weeks
HU	-	-	-	-	-	-
IE	28.Oct	03.Nov	1 Week	28.Oct	03.Nov	1 Week
IT	28.Oct	01.Nov	5 days	28.Oct	03.Nov	1 Week
LV	-	-	-	-	-	-
LT	21.Oct	25.Oct	1 Week	21.Oct	25.Oct	1 Week
LU	28.Oct	31.Oct	4 Days	28.Oct	31.Oct	4 Days
MT	26.Oct	03.Nov	1 Week	26.Oct	03.Nov	1 Week
NL	01.Nov	05.Nov	5 Days	01.Nov	05.Nov	5 Days
NO	12-19 Oct	20-27 Oct	1 Week	12-19 Oct	20-27 Oct	1 Week
PL	-	-	-	-	-	-
PT	-	-	-	-	-	-
RO	26.Oct	03.Nov	1 Week	-	-	-
SK	30.Oct	31.Oct	1 Day	30.Oct	31.Oct	1 Day
SI	28.Oct	03.Nov	1 Week	28.Oct	03.Nov	1 Week
ES	-	-	-	-	-	-
SE	28.Oct	01.Nov	5 Days	28.Oct	01.Nov	5 Days

Annex III. - Literature review on top-down interventions to promote sustainable space cooling behaviours

Study	Year	Intervention Type	Type of study	Focus of study	SC target behaviour	Geographical Context	Building context	Relevant finding
Abrahamse et al. [132]	2005	Feedback, goal-setting, information campaigns & social comparisons	Review.	Electricity use.	Use of electricity-powered cooling appliances	Global (specific countries not specified)	Residential	5.1% reduction in electricity consumption.
Darby et al. [131]	2006	Feedback	Review.	Electricity use.	Use of electricity-powered cooling appliances	Global (North America & Europe focus)	Residential	5 - 15% reduction in electricity and gas consumption.
Faruqui et al. [117]	2010	Dynamic pricing (ToU, CPP, RTP)	Review.	Electricity use.	Use of electricity-powered SC appliances	US, France, Australia, Canada	Residential	4% average reduction in peak electricity usage from TOU. 36% reduction from CPP.
Allcott [106]	2011	Dynamic pricing (RTP)	Empirical study.	Electricity use for air conditioning.	Use of electricity-powered SC appliances	US	Residential	5% average reduction in peak electricity consumption. No significant reduction in off-peak hours reported.
Delmas et al. [6]	2013	Feedback, social comparisons, audits & energy advice.	Review.	Electricity use.	Use of electricity-powered cooling appliances	Global (13 countries)	Residential	7.4% reduction in electricity consumption.
Brown et al. [14]	2013	Default thermostat setting	Empirical study.	Thermostat use in winter months.	Interaction with SC thermostat set-point.	France	Office	0.38C decrease in choosen thermostat-setting with a 1C default reduction in Winter months.
Karlin et al. [105]	2015	Feedback	Review	Electricity use.	Use of electricity-powered	Global (specific countries not specified)	Residential	8 - 12% reduction in electricity consumption.

Study	Year	Intervention Type	Type of study	Focus of study	SC target behaviour	Geographical Context	Building context	Relevant finding
					cooling appliances			
Hu et al. [120]	2015	Dynamic pricing (ToU, CPP, RTP)	Review	Electricity use.	Use of electricity-powered SC appliances	US, Ireland, Netherlands.	Residential, commercial & industrial	Qualitative information only.
Kessels et al. [4]	2016	Dynamic pricing (ToU, CPP, RTP)	Review.	Electricity use.	Use of electricity-powered SC appliances	Germany, UK, Italy, Belgium, Sweden	Residential	1 - 8.7% reduction in peak electricity consumption across several pilot projects.
Morganti et al. [8]	2017	Applied gaming interventions	Review.	Energy efficiency behaviours.	Use of electricity-powered SC appliances	Global	Residential & Offices & Schools	Qualitative information only.
Andor & Fels [7]	2018	Social comparisons, goal-setting, labelling	Review.	Electricity use.	Use of electricity-powered SC appliances	Primarily US. Including also the Netherlands, UK, Finland, Australia, Japan	Residential	1.2 - 30% reduction in electricity use from social comparisons.
Ornaghi et al. [16]	2018	Feedback, framing & social norms	Empirical study.	Window-opening behaviour in winter months.	Uptake of natural ventilation measures	UK	Office	34.5 - 50% reduction in fraction of windows left open after start of interventions.
Yan et al. [118]	2018	Dynamic pricing (ToU, CPP, RTP)	Review.	Electricity use.	Use of electricity-powered SC appliances	US, Sweden, Ireland, Italy, Canada, Germany, New Zeland, France, Norway, Iran)	Residential	4.2 - 24.7% reduction in peak electricty demand from different individual studies.
Yoon et al. [107]	2018	Dynamic pricing (ToU, CPP, RTP) & Demand response controller	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	US	Residential	10.8% potential reduction in energy costs. 12.8 - 24.5% average peak load curtailment.
Xiangling & Changxu [15]	2019	Feedback & framing	Empirical study.	Thermostat use during summer months.	Interaction with cooling thermostat set-point.	China	Office	1.14°C increase with efficiency framing, 1.52C increase wth health framing.

Study	Year	Intervention Type	Type of study	Focus of study	SC target behaviour	Geographical Context	Building context	Relevant finding
Bator et al. [10]	2019	Feedback & social comparisons	Empirical study.	Electricity use for air conditioning.	Use of electricity-powered SC appliances	US	Residential	5.3% reduction in electricity consumption over 12 months.
Zangheri et al. [5]	2019	Feedback	Review	Electricity use	Use of electricity-powered SC appliances	Europe and North America	Residential	9% reduction in electricity consumption in Europe.
Parkinson et al. [13]	2020	Default thermostat setting (policy implication)	Empirical study.	Validation of ASHRAE 55.	Interaction with SC thermostat set-point.	Global	All building types.	The authors suggest gradual changes in default thermostat-settings targeting 24-27°C range.
Amin et al. [108]	2020	Dynamic pricing (ToU, CPP, RTP) & optimal control strategy	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	Australia	Office	7.9 - 26.8% potential reduction in peak demand, contingent on occupant preferences.
Li et al. [9]	2021	Feedback & social comparisons	Case study (experimental, cooling specific)	Use of indoor thermal cooling device (individual fan in shared office space)	Use of electricity-powered SC appliances	UK	Office	15% reduction in energy use after the introduction of intervention.
Göette et al. [109]	2021	Feedback & social comparisons	Case study (experimental)	Electricity use for air conditioning.	Use of electricity-powered SC appliances	Singapore	Residential	27.39% reduction in air conditioning use only in lowest 20th-percentile in usage of air conditioning.
Kim et al. [110]	2022	Feedback & gamification	Case study (pilot)	Thermostat use during summer months.	Interaction with cooling thermostat set-point.	US	Residential	Increase in median room air temperatures.
Scorpio et al. [19]	2022	Information provision & default shading system settings.	Case study (pilot)	Use of lighting and shading system.	Use of shading	Italy	Office	Engagement strategy led to improved use of lighting and shading system.
Wo-Shem et al. [111]	2023	Dynamic pricing (ToU, CPP, RTP) & optimal control strategy	Simulation	Electricity use for HVAC.	Use of electricity-powered SC appliances	US	Residential	52.9% potential reduction in electricity consumption

Table 19. Studies on behaviour-change interventions to reduce SC demand.