MOBISTYLE

MOtivating end-users Behavioral change by combined ICT based modular Information on energy use, indoor environment, health and lifeSTYLE

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Publishable executive summary

The aim of this report is to evaluate the impact of MOBISTYLE project in all demonstration buildings, and to validate if the qualitative and measurable quantitative objective of this project has been achieved:

> *Qualitative objective: ''To deploy and validate the developed solutions and services in different building types and user types, demonstrating a significant reduction of final energy use, prompted by these solutions.''*
>
> *Quantitative objective: ''Change in consumer behavior and lifestyle will reduce energy use by at least 16%, prompted by combined smart metering and other consumption feedback systems on energy, IEQ and health.''*

The monitoring in MOBISTYLE covers the following real-life environments:

1. A complex of residential buildings (Denmark);
2. A campus of university buildings, more specifically, four faculty buildings – Faculty for Economics, Faculty for Arts, Faculty of Computer Science and Informatics, and Faculty for Chemistry (Slovenia);
3. A hotel (Italy);
4. An open plan office building (Netherlands);
5. A housing district connected to a common electricity grid (Poland).

The overall MOBISTYLE objective is to motivate behavioural change by raising consumer awareness and by providing attractive personalized combined pro-active knowledge services on energy use, indoor environment, health and lifestyle, by ICT-based solutions. Measurable benefits raises behavioural change by the awareness of feedback loops. This awareness will support and motivate end-users to well informed proactive behaviour towards energy use and health, thus empowering consumers and providing confidence of making the right choices. The combination of awareness on energy, health and lifestyle will offer consumers more and lasting incentives than only information on energy use.

In MOBISTYLE there are two Information and Communications Technology (ICT) solutions implemented in order to achieve the MOBISTYLE goal to reduce energy consumption and improve Indoor Environmental Quality (IEQ) and health aspects in the demonstration buildings. These ICT-solutions are GAME and DASHBOARD, developed by Highskillz (HS) and Holonix (HLX) respectively.

The overview for each demonstration case is presented in the following table.

Case	ICT - solution	Comments
Case 1 Kildeparken	GAME	Gamification of the IEQ parameters, heating energy use and water consumption
Case 2 University of Ljubljana	DASHBOARD	Visualization of IEQ parameters
Case 3 Hotel Residence L'Orologio	DASHBOARD	Visualization of IEQ parameters, Electricity for HVAC and appliances, cost
Case 4 Qeske	-	Experimental case study
Case 5 Smart City Wroclaw	GAME	Gamification of the IEQ parameters, electricity use and smart plugs

DASHBOARD is implemented in the Case 2 University of Ljubljana and Case 3 Hotel Residence L'Orologio, where it will visualize current IEQ parameters in the room and motivate user to improve these conditions if necessary. It will be available in a desktop version and in a mobile app version for both - building managers and occupants.

MOBISTYLE GAME solution is implemented in the residential demonstration cases in Poland and Denmark, Case 1 Kildeparken and Case 5 Smart City Wroclaw, respectively. The reasoning behind different ICT solutions for different case buildings is based on the different use of each building. As the end-users in residential buildings are staying in their home for a long-term, therefore the GAME solution at first is implemented only in these case studies. MOBISTYLE GAME will include mission achieving interaction to alternate user behaviors towards energy efficient behavior. GAME app is relying to provide feedback to the user and their practices on the basis of sensor data available in the households.

For application of the Dashboard and Game solution in the demonstration case it was from the beginning decided that information and recommendations should be based on monitored data and that it was important to establish information from all rooms in an apartment or separate offices in an office building and not just from a "representative" room, as it is usually seen.

This decision has clearly resulted in new valuable knowledge about the indoor environmental quality in apartments and offices and provided end-users with much better information, feedback and guidance about their indoor environment. But is also highlighted the weakness of solutions based on general feedback and standard recommendations. It does not fit to well to many of the end-users. If they prefer different conditions than average or prefer different conditions in different rooms in their apartment, they get immune to getting the same recommendations all the time.

The results showed as it has been seen before that there are large differences in temperature and indoor air quality levels (average conditions) between different apartments, but they also revealed that differences between rooms in an apartment are almost as large. Thereby, the results showed that it is very difficult (read impossible) by only monitoring in one room to ensure a representative evaluation of the indoor environmental quality in an apartment or in an office building.

Use time and heat loads showed to be very different in both apartments and offices. And although we had some indication of occupancy it was not very accurate, especially in the apartments. As this has a large impact on energy use and indoor environmental quality such uncertainty makes it difficult to draw definite conclusions.

The application of the ICT solutions in the apartment and the offices seemed to influence the indoor environmental quality level much more than the energy use.

In the Danish Case the heating energy use generally increased by 6,4% for all apartments between the Baseline and the Mobistyle period. All apartments were newly renovated, and the general heating use level was decreased from about 200 kWh/m2 to about 50 kWh/m2, so all end-users had experienced a considerable decrease in heating energy use after moving into the renovated apartments again. This may have influenced their focus on their heating energy use. Also, generally the hot water use increased by 12 % for all apartments. In the polish case the electricity energy use generally increased by less than 5% for all apartments while in the Italian case an energy saving of 9% was achieved between the Baseline and the Mobistyle period.

Apartments with high heating energy use did not have a high hot water use as well or the opposite. Actually, it was more often the case that those with the high heating energy use had a low hot water use and the opposite. This may depend on the number of persons living in the apartment, as more persons use more hot water, but also release more internal heat gains reducing the need for additional heating. However, as no exact registration of use time and persons in the apartments were included in the monitoring campaign a firm conclusion on this cannot be given.

Large differences were found in both heating energy use and hot water use between individual apartments in the Danish case with a factor of about 6 between the apartments with the lowest and the highest use. Differences in electricity use was also seen in the Polish demonstration, but due to lack of information about apartment size and number of persons it is difficult to normalize the values.

The indoor environmental quality clearly changed between the Baseline and the Mobistyle period.

The thermal conditions were very different from room to room in the same apartment and from apartment to apartment or from office to office in the same building. Compared to the standard comfort criteria some rooms, apartments and offices are overheated most of the time and even in the heating season, while others are comfortable all year round. A few apartments and offices suffer from undercooling, especially in the cooling season. However, when we look at the temperature regulation set points in the different apartments and office rooms we see large differences as well as differences between the different seasons. Typically, higher setpoints than expected are used in in the heating season. Generally, the setpoint is much higher than 20 ^{o}C in the heating season and typically between 22-23 ^{o}C, while some also use 24-25^{o}C in their apartments. In the cooling season in the offices the setpoint is generally about 25 – 26 ^{o}C. The differences in set-point regulation actually fit quite well with the monitored thermal comfort levels. So even if, temperature levels according to standards are evaluated as too high, it is a consequence of user actions and set-point regulation and meet occupant preferences. Even though temperatures changed considerably in some of the monitored rooms, we also saw quite modest changes in the overall temperature levels in the monitoring results. In the Danish Case an average decrease of 0,5 ^{o}C was seen in temperature levels in each room, in the Slovenian case an average temperature decrease of only 0,04 ^{o}C in each room, in the Polish case an average increase of 0,9 ^{o}C in each apartment between the baseline and the mobistyle period.

The indoor air quality levels (CO_2 concentration) were also very different from room to room in the same apartment and from apartment to apartment in the same building. In the Danish case a considerable change in average concentration levels was seen with an average decrease of 417 PPM in each room. Especially, the very high values often seen during night-time in sleeping rooms were reduced and a very acceptable indoor air quality levels were obtained in all apartments except one. The opposite outcome was found in the Slovenian case where the indoor air quality levels were quite similar between the offices with an average concentration increase of 300 ppm was measured leading to larger periods with unacceptable conditions during the Mobistyle monitoring period.

Humidity conditions were generally acceptable in all cases and did not vary a lot, neither between rooms, apartments or offices.

The window opening period in the office rooms depends strongly on the season and is used much more in the cooling season than in the heating season. Window opening is also very different from room to room, where the windows are opened rarely in some rooms and in other rooms window are opened almost 50% of the time. By comparing the two measuring periods an average decrease in window opening from 37 % - 28% of the time in each room in the Slovenian Case. This corresponds well to the increased CO_2 levels monitored in the office rooms. The results also showed that window opening time is very different between different apartments but also between different rooms in the apartments. An average increase in relative opening time from 22 % - 33% of the time when data is available was seen in the Polish case, while modest changes in total opening time were seen in the Danish case. As a considerable improvement in indoor air quality was measured, it seems that the window opening periods was chosen more strategically, maybe because of the feedback provided by the game.

The correlation between heating energy use and indoor environmental quality in the apartments in the Danish case was also investigated. A correlation could be found between indoor temperature level and heating energy use, although the relatively small temperature differences in themselves could not explain the large differences found in heating energy use. It was not possible to find a clear correlation between CO_2 concentration and heating energy use, although those with a small heating energy use also seem to have higher CO_2 concentration levels in the apartment. A clearer trend between humidity level and heating energy use was found, indicating that higher humidity levels are found in apartments with low heating energy use. However, the reason for higher CO2 concentration and humidity levels in apartments with a low heating energy use, seemed not to be because of less window opening time.

The data systems used in the project could (have to) be improved for further development. One critical issue is the time needed for data collection, data transfer and data analysis. In the current version of the system the time from an action is carried out until it can be recognized by the user on the ICT solution can take up to 30-45 minutes. This is far too long for users to maintain confidence in the system. Secondly, they were not warned in the case of a data gab, then the information and feedback just did not change. This may be acceptable, if the data gabs are short and rare, but in the present situation the data gabs were quite severe in several of the cases (missing data above 50% sometimes even more) again leading to mistrust in the system.

Table of Contents

1 Introduction

The six tasks (T6.1 – T6.6) within Work Package 6 (WP6) are covering planning, execution, and evaluation stages of the MOBISTYLE project at each of the different demonstration case sites. The overall objective of WP6 is to demonstrate that it is possible to achieve a significant reduction of energy use in different real environments by a sustainable behavioral change.

Deliverable D6.2 *Data on energy use and impact on energy use of the awareness and information campaigns* is the outcome of the task *T6.3 Evaluation of energy and IEQ data* where the main task is to estimate achieved energy savings, improvements of the indoor environmental quality (IEQ) and observe behavioral changes in occupant practices.

Throughout the report two terms will appear frequently – Benchmark definition and Final evaluation. Therefore, in the following it is emphasized what each of the terms mean:

1. **Benchmark definition (E1)** – also called BASELINE, performance results from the reference monitoring period (M0) - without MOBISTYLE ICT-solutions made available to the users;
2. **Final evaluation (E3)** – performance results from the feedback monitoring period with MOBISTYLE ICT-solutions made available to the users.

The further data analysis is a comparison between the two mentioned time periods – before and after the MOBISTYLE ICT-solutions are implemented.

1.1 Aim of the report

The aim of this report is to evaluate the impact of MOBISTYLE project in all demonstration buildings, and to validate if the qualitative and measurable quantitative objective of this project has been achieved:

Qualitative objective: ''To deploy and validate the developed solutions and services in different building types and user types, demonstrating a significant reduction of final energy use, prompted by these solutions.''

Quantitative objective: ''Change in consumer behavior and lifestyle will reduce energy use by at least 16%, prompted by combined smart metering and other consumption feedback systems on energy, IEQ and health.''

2 Summary of monitoring plan for all demonstration cases

In this chapter it is summarized how each case holder is implementing the monitoring plan in their building. A more detailed description of the monitoring action plan (MAP) at each demonstration site is presented in the deliverable D6.1 *Detailed final monitoring, awareness and information campaigns for the five cases*.

The chapter shortly describes the behavioral actions and what feedback is given to the occupants and the differences between the demonstration cases in building typology, occupancy patterns and end-user behavior and requirements to adjust the monitoring activities according to case specific objectives. Furthermore, the added value, relevance, innovation and impact potential of the demonstration cases is outlined. Finally, the overview regarding the timeline and deployment of ICT based solutions is presented in the last section.

The monitoring in MOBISTYLE covers the following real-life environments:

6. A complex of residential buildings (Denmark);
7. A campus of university buildings, more specifically, four faculty buildings – Faculty for Economics, Faculty for Arts, Faculty of Computer Science and Informatics, and Faculty for Chemistry (Slovenia);
8. A hotel (Italy);
9. An open plan office building (Netherlands);
10. A housing district connected to a common electricity grid (Poland).

Table 2.1: Demonstration building description, user interaction with technical systems

Case	Type	Target Area	Area/Occupancy	Technical Systems/ User interaction
Case 1: Kildeparken	Residential	17 apartments	Area: 67-130 m2, 1- 5 persons/apartment	Heating (setpoint), DHW use, window opening
Case 2: University of Ljubljana	Office	8 offices	Area: 15 - 60 m2	Solar shading, window opening, lighting, HVAC setpoints
Case 3: Hotel Residence L'Orologio	Hotel	4 hotel apartment, reception area	Area: 36-39 m2, 2-3 rooms/apartment	HVAC (setpoint), window opening, appliances
Case 4: Qeske	Office	Open plan offices	Area: 200 m2, 8 persons/office	-
Case 5: Smart City Wroclaw	Residential	22 apartments	Area and persons/residence: Varying	Window opening, appliances

2.1 Behavioral action plan

The case specific feedback on energy use, IEQ, health parameters and user behaviour are summarized in the following table.

Table 2.2: Behavioural action plan and feedback strategies

Case	Feedback on energy use	Feedback on IEQ	Feedback to improve Health	Feedback on user practices
Case 1: Kildeparken	Heating, DHW, (Cost)	Temperature, CO_2, RH	Indoor Air Quality	Window opening, heating setpoint, DHW
Case 2: University of Ljubljana	-	Temperature, CO_2, RH	Messages for motivation	Heating and cooling setpoint, window opening, solar shading position, use of appliances, light switching
Case 3: Hotel Residence L'Orologio	Electricity for HVAC and appliances, cost	Temperature, CO_2, RH	Indoor Air Quality	Heating and cooling setpoint, window opening, use of appliances
Case 4: Qeske	-	-	Health parameters	-
Case 5: Smart City Wroclaw	Electricity for appliances and smart plugs, cost	Temperature, RH	Indoor Air Quality	Heating setpoint, window opening, use of appliances

The overall MOBISTYLE objective is to motivate behavioural change by raising consumer awareness and by providing attractive personalized combined pro-active knowledge services on energy use, indoor environment, health and lifestyle, by ICT-based solutions. Measurable benefits raises behavioural change by the awareness of feedback loops. This awareness will support and motivate end-users to well informed proactive behaviour towards energy use and health, thus empowering consumers and providing confidence of making the right choices. The combination of awareness on energy, health and lifestyle will offer consumers more and lasting incentives than only information on energy use.

Monitoring campaign Case 1 Kildeparken, DK
The specific case objective is to combine information regarding IEQ (Indoor Environmental Quality) and energy in order to establish how tailoring information according to different user types helps increase awareness and leads to energy efficient behaviour change.

Monitoring campaign Case 2 University of Ljubljana, SLO

The specific case objective is to provide users with information regarding IEQ in order to influence their short term behaviour and change in long term habits leading towards improved IEQ and energy reduction.

Monitoring campaign Case 3 Hotels Residence L'Orologio, IT
The specific case objective is to monitor IEQ and electricity consumption in order to provide the hotel guests with feedback on energy use and guidance on how to save energy, use smart control of heating and lighting. This could be combined with suggestions regarding healthy daily activities and encouraging energy efficient usage of whitegoods as additional information to increase user awareness, though these are not directly measured.

Monitoring campaign Case 4 Qeske, NL
The specific case objective is to establish a correlation between different indoor environment situations (dynamic temperature profile in comparison to traditional constant temperature setting) affect occupant's health (physiological) response and also how occupants perceive such conditions (psychological). Moreover, to support the main MOBISTYLE objective, an investigation of whether lowered indoor temperatures in the winter season could lead to not only energy savings, but also improved wellbeing, will be conducted.

Monitoring campaign Case 5 Smart City Wroclaw, PL
The specific case objective is to monitor the electricity consumption of users and motivate their behaviour change towards more energy efficient building usage by giving users attractive information about their daily activity (healthy tips), IEQ and energy (recommendations for actions and measured data).

Table 2.3: Demo-case specific objectives related to energy, IEQ, health and user behaviour

Case	Reduce energy use	Improve IEQ	Improve Health	User practices
Case 1 Kildeparken	Heating, DHW	Reduce overheating, improve IEQ	By improving IAQ (better sleeping quality at night)	Optimize heating setpoint adjustments, window opening strategy, DHW use
Case 2 University of Ljubljana	Indirectly, energy use reduction estimated	Reduce overheating, avoid glare, improve IEQ, lighting quality, view to outside	By providing motivation	Improve user interaction with building systems
Case 3 Orologio Living Apartments	Electricity for HVAC and appliances	Reduce overheating, improve IEQ	By improve the sense of wellbeing in relation to indoor environment	Optimize fan- coil setpoints and window opening strategy, use appliances and electric devices
Case 4 Qeske	Indirectly, energy use reduction estimated as a results of reduced heating setpoints		By exposing occupants to different temperature conditions	Investigate response and perceived acceptability of varying temperatures
Case 5 Smart City Wroclaw	Electricity for appliances and plug loads	Reduce overheating, reduce humidity levels	By improving IAQ (better sleeping quality at night)	Optimize HVAC setpoint adjustments, window opening strategy

2.2 Implementation of ICT solutions

In MOBISTYLE there are two Information and Communications Technology (ICT) solutions implemented in order to achieve the MOBISTYLE goal to reduce energy consumption and improve Indoor Environmental Quality (IEQ) and health aspects in the demonstration buildings. These ICT-solutions are GAME and DASHBOARD, developed by Highskillz (HS) and Holonix (HLX) respectively. The overview for each demonstration case is presented in the following table.

Table 2.4: ICT-solution distribution across demonstration cases

Case	ICT - solution	Comments
Case 1 Kildeparken	GAME	Gamification of the IEQ parameters, heating energy use and water consumption
Case 2 University of Ljubljana	DASHBOARD	Visualization of IEQ parameters
Case 3 Hotel Residence L'Orologio	DASHBOARD	Visualization of IEQ parameters, Electricity for HVAC and appliances, cost
Case 4 Qeske	-	Experimental case study
Case 5 Smart City Wroclaw	GAME	Gamification of the IEQ parameters, electricity use and smart plugs

DASHBOARD is implemented in the Case 2 University of Ljubljana and Case 3 Hotel Residence L'Orologio, where it will visualize current IEQ parameters in the room and motivate user to improve these conditions if necessary. It will be available in a desktop version and in a mobile app version for both - building managers and occupants.

MOBISTYLE GAME solution is implemented in the residential demonstration cases in Poland and Denmark, Case 1 Kildeparken and Case 5 Smart City Wroclaw, respectively. The reasoning behind different ICT solutions for different case buildings is based on the different use of each building. As the end-users in residential buildings are staying in their home for a long-term, therefore the GAME solution at first is implemented only in these case studies.

MOBISTYLE GAME will include mission achieving interaction to alternate user behaviors towards energy efficient behavior. GAME app is relying to provide feedback to the user and their practices on the basis of sensor data available in the households.

Due to the fact that ICT solutions are developed by two companies separately, there are slightly different timelines for demonstration cases where GAME or DASHBOARD is deployed.

The demonstration cases had the following proposed timeline for implementing ICT solutions, monitoring and evaluation

Table 2.5: Timeline for GAME App implementation, monitoring and evaluation periods

Case 1 Kildeparken		
	Start	**End**
Reference monitoring	November 2018	October 2019
Implementation of game	November 2019	
Baseline monitoring	December 2018	February 2019
Mobistyle monitoring	December 2019	February 2020

Case 2 University of Ljubljana		
	Start	**End**
Baseline monitoring	February 2018	January 2019
Implementation LED	February 2019	
Implementation of Dashboard	June 2019	
Mobistyle monitoring	February 2019	January 2020

Case 3 Hotel Residence L'Orologio		
	Start	**End**
Reference monitoring	April 2018	June 2019
Implementation of Dashboard for guests and manager	July 2019	
Implementation of Dashboard for receptionist	November 2019	
Mobistyle monitoring	July 2019	February 2020

Case 5 Smart City Wroclaw		
	Start	**End**
Baseline monitoring	January 2018	August 2018
Implementation of game	November 2018	
Mobistyle monitoring	January 2019	August 2019

3 Evaluation Methodology

This chapters describes the methods that are used to evaluate the impact of MOBISTYLE solutions.

In work package 3 (WP3) an overall guidelines and methods on how to evaluate the impact of the MOBISTYLE project are developed. The methodology used in the demonstration cases is partially based on the Deliverable D3.3 *Evaluation method to test the effectiveness of the combined feedback campaigns* which is a basis guideline for the relevant data analytics concerning the energy, IEQ and user behavior. Furthermore, this methodology has to be adjusted to each of the demonstration cases due to different KPIs, building typology, HVAC systems and climatic zones. The specific requirements and calculations at each demonstration site are presented in Appendices 1-5.

3.1 Validation of the monitored data

In order to validate the results, it is important to perform a data check of the monitoring periods for baseline and the Mobistyle evaluation periods. Data loss may occur, for example, due to the wireless sensor connection problems. Therefore, it is important to quantify the percentage of the missing data in order to validate the MOBISTYLE impact. Too high data loss may lead to faulty results, for example when evaluating IEQ.

The data verification procedure is described in chapter 3 of deliverable D3.3. For each demonstration cases are the % of missing data for each of the monitored parameters reported for the two monitoring periods separately. For some parameters the amount of missing data is quite high, which has been taken into account in the evaluation of results and conclusions.

3.2 Understanding the local climate conditions – cooling and heating needs

It is a fact that outdoor climate is affecting the users need for heating or cooling in occupied spaces. Therefore, it is a challenge to account for the change of outdoor climate conditions when comparing the change in energy use. Furthermore, this is a crucial step to validate the ''real effects'' that are caused by a behavioral change and not by the weather change itself (see Figure 3.1), when comparing the initial monitoring period and period when the ICT-solutions are deployed in the demonstration buildings.

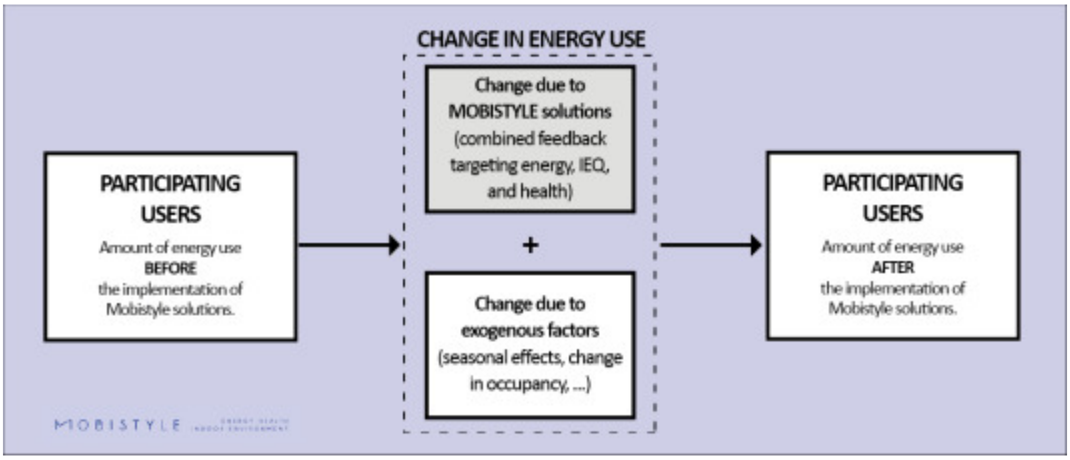


Figure 3.1: Change in users' energy use (D3.3)

Characterization of weather impacts in this project is done by weather-normalization using degree-days: heating degree days (HDDs) and cooling degree-days (CDDs) (see D3.3).

HDDs and CDDs are defined relative to a base temperature or balance point of a building— the outside air temperature — below which a building is assumed to need heating or above which a building is assumed to need cooling. One way how to estimate the balance point temperature of each building is by using energy signature method - by mapping energy consumption of this building (or apartment) against mean outdoor air temperature. In Figure 3.2 the daily heating energy is plotted against the corresponding daily mean temperature for two apartments. This is an example from two apartments from demo-case in Denmark, Kildeparken.

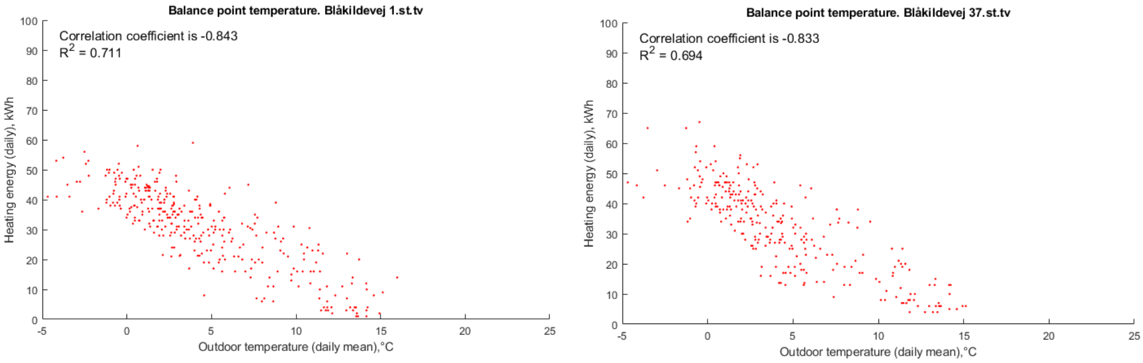


Figure 3.2: Example of using energy signature method to determine balance point temperature for two apartments in Case 1: Kildeparken, Denmark

From these plots, balance point temperature can be estimated to be around 15,5 °C.

HDDs and CDDs are estimated either using local outdoor climate sensors that are installed at the demonstration building sites or the weather station data by the following steps:

- Daily mean outdoor air temperatures are calculated for every day of the monitoring period, $T_{out,mean}$
- For heating degree-days temperature below the base temperature for heating:
  IF $T_{out,mean} < T_{base,HDD}$ THEN number of HDDs = $T_{base,HDD} - T_{out,mean}$

  Example: Daily mean outdoor air temperature in Kildeparken, Denmark is calculated as 10,5 °C. Then the number of heating degree-days for the specific day is calculated: HDDs = 15,5 – 10,5 = 5 HDDs, resulting into 5 heating degree-days
- For cooling degree-days it will be the outdoor air temperatures that are higher than the base temperature for cooling (*22,0 °C)*:
  IF $T_{out,mean} > T_{base,CDD}$ THEN number of CDDs = $T_{out,mean} - T_{base,CDD}$
- Sum all the calculated daily HDDs for the normalization of the heating consumption of the monitoring periods
- Sum all the CDDs for the normalization of the cooling consumption of the monitoring period

After the heating and cooling energy consumption in the relevant monitoring periods is normalized with degree-days, the weather-normalized energy consumption can be compared on a like-for-like basis and thus show, if there are any improvements in the participating users' behavior mainly due to MOBISTYLE solutions.

3.3 Evaluation of the energy use

Energy consumption of each occupied space is normalized with the area of the space. Furthermore, the estimated HDDs and CDDs from the previous chapter can be applied to the actual heating or cooling energy use. This will yield to outdoor climate- and area -normalized results for each monitoring period.

The total amount of energy savings can then be identified in each case study according to the following formula (see D3.3 Ch. 3):

$$Energy\ savings = 100 * \frac{[Energy\ cons.(Baseline) - Energy\ cons.(Mobistyle)]}{Energy\ cons.(Baseline)}\ [\%]$$

3.4 Evaluation of the IEQ

Comfort category limits used to evaluate the indoor environmental quality are based on the European Standard EN 15251, 2007. The original ranges from EN 15251 are presented in Table 3.1. In this project it is chosen to use a modified version of the temperature and relative humidity ranges as presented in Table 3.2. This is done in order to see when the temperatures in occupied spaces are above and when below the certain category limits. This way of presenting the data makes it easier to observe when i.e. the overheating problems are present (>27,0°C).

Table 3.1: Comfort category limits according to EN 15251 for buildings with mechanical cooling, single and open plan offices (Method A in D3.3)

Category	Temperature [°C] (heating season)	Temperature [°C] (cooling season)	RH [%]	CO2 concentration* [ppm]
I	21,0-23,0	23,5-25,5	30-50	<750
II	20,0-24,0	23,0-26,0	25-60	750-900
III	19,0-25,0	22,0-27,0	20-70	900-1200
IV	<19,0-25,0>	<22,0-27,0>	<20-70>	>1200

*CO2 concentration of outdoor air is set 400 ppm while estimating the category limits
**Sedentary activity level 1,2 [met]

Table 3.2: Extended comfort category limits for buildings with mechanical cooling, single and open plan offices (Method A in D3.3)

Category	Temperature [°C] (heating season)	Temperature [°C] (cooling season)	RH [%]	CO2 concentration* [ppm]	VOC*** [ppb]
IV+	>25,0	>27,0	>70	>1200	>100
III+	24,0-25,0	26,0-27,0	60-70	900-1200	80-100
II+	23,0-24,0	25,5-26,0	50-60	750-900	40-80
I	21,0-23,0	23,5-25,5	30-50	<750	<40
II-	20,0-21,0	23,0-23,5	25-30	-	-
III-	19,0-20,0	22,0-23,0	20-25	-	-
IV-	<19,0	<22,0	<20	-	-

*CO2 concentration of outdoor air is set 400 ppm while estimating the category limits
** DS/EN 15251 with sedentary activity level 1,2 [met]
***VOC levels are categorized according to table in this source [LINK]

In naturally ventilated buildings e.g. Danish and Polish demonstration case where the ventilation of the space is provided only by window openings and where users can freely adjust their clothing, the comfort categories for indoor air temperature are coupled together with outdoor air temperature. The procedure of adjusting the comfort category limits that were presented in Table 7 is described in Annex A2 of EN15251 and in the following section below.

1. Θ_{rm} = Outdoor running mean temperature (^{o}C), exponentially weighted running mean of the daily mean external air temperature:

   $$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\,\Theta_{ed\,-2} + 0{,}6\,\Theta_{ed\,-3} + 0{,}5\,\Theta_{ed\,-4} + 0{,}4\,\Theta_{ed\,-5} + 0{,}3\,\Theta_{ed\,-6} + 0{,}2\,\Theta_{ed\,-7})/3{,}8$$

   where

   $\Theta_{ed\,-1}$ is the daily mean external temperature for the previous day, ^{o}C

   $\Theta_{ed\,-2}$ is the daily mean external temperature for the day before and so on until day 7, ^{o}C

2. Comfort category limits are recalculated as follows:

   Category I: $\Theta_{i\,max} = 0{,}33\Theta_{rm} + 18{,}8 + 2$

   $\Theta_{i\,min} = 0{,}33\,\Theta_{rm} + 18{,}8 - 2$

   Category II: $\Theta_{i\,max} = 0{,}33\,\Theta_{rm} + 18{,}8 + 3$

$\Theta_{i\,min} = 0{,}33\ \Theta_{rm} + 18{,}8 - 3$

Category III: $\Theta_{i\,max} = 0{,}33\ \Theta_{rm} + 18{,}8 + 4$

$\Theta_{i\,min} = 0{,}33\ \Theta_{rm} + 18{,}8 – 4$

where

$\Theta_{i\,max}$ is upper limit value of indoor operative temperature, °C

$\Theta_{i\,min}$ is lower limit value of indoor operative temperature, °C

Θ_{rm} is outdoor running mean temperature, °C

Table 3.3: Extended comfort category limits for the indoor operative temperature for naturally ventilated buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the outdoor temperature

Category	**Limit**	**Running mean outdoor temperature, Θ_{rm} [°C]**	
		Θ_{rm} < 10 °C	**10 <Θ_{rm} < 30 °C**
		Θ_{rm} < 15 °C	**15 <Θ_{rm} < 30 °C**
IV+:	**upper**	-	-
	lower	>25	> (0,33 Θ_{rm} + 18,8 + 4)
III+:	**upper**	25	0,33 Θ_{rm} + 18,8 + 4
	lower	24	0,33 Θ_{rm} + 18,8 + 3
II+:	**upper**	24	0,33 Θ_{rm} + 18,8 + 3
	lower	23	0,33 Θ_{rm} + 18,8 + 2
I:	**upper**	23	0,33 Θ_{rm} + 18,8 + 2
	lower	21	0,33 Θ_{rm} + 18,8 – 2
II-:	**upper**	21	0,33 Θ_{rm} + 18,8 – 2
	lower	20	0,33 Θ_{rm} + 18,8 – 3
III-:	**upper**	20	0,33 Θ_{rm} + 18,8 – 3
	lower	19	0,33 Θ_{rm} + 18,8 – 4
IV-:	**upper**	<19	< (0,33 Θ_{rm} + 18,8 – 4)
	lower	-	-

These ranges are when 10 <Θ_{rm} < 30 °C for upper limit and 15 <Θ_{rm} < 30 °C for lower limit. In heating season when running mean outdoor temperature is below <10°C for the upper limits use the same (I, II, III) values as for mechanically cooled buildings (winter upper temperature) and for the lower limits when Θ_{rm} < 15 °C use the same (I, II, III) values as for mechanically cooled buildings (winter under temperature).

Operative indoor air comfort category limits for buildings without mechanical cooling (Danish and Polish demo-cases) are calculated according to table 3.3.

The resulting adjusted category limits are presented in Figure 3.3 where it can be seen that with higher running mean outdoor air temperatures higher indoor air temperature limits are accepted.

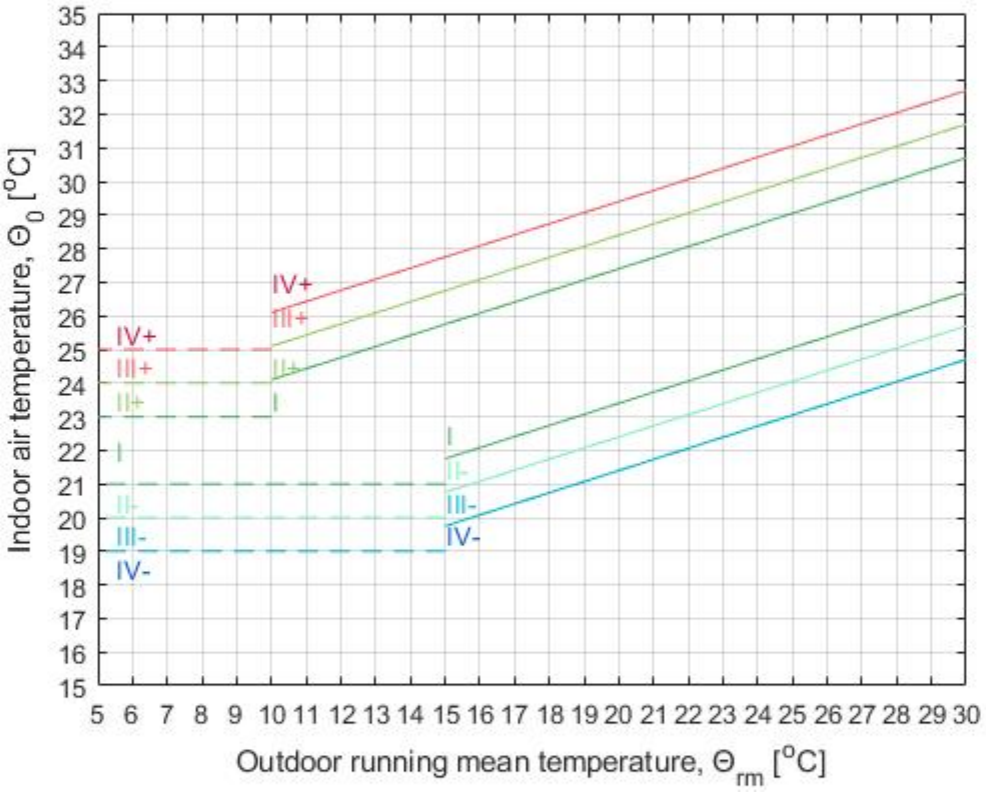


Figure 3.3: Extended category limits for indoor air temperature for buildings without mechanical cooling systems as a function of the exponentially-weighted running mean of the outdoor temperature. [EN15251]

An example of the visualization of the comfort categories is shown in Figures 3.4 and 3.5

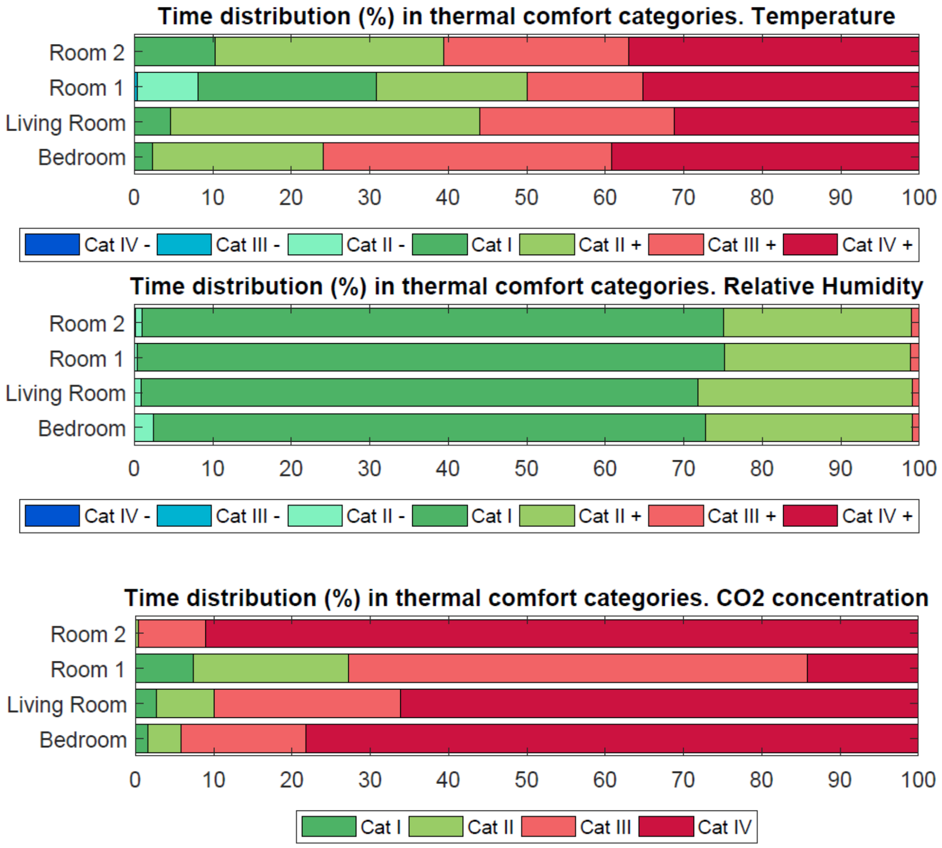


Figure 3.4: Example of time distribution of comfort categories in an apartment of temperature, relative humidity and CO2 concentration

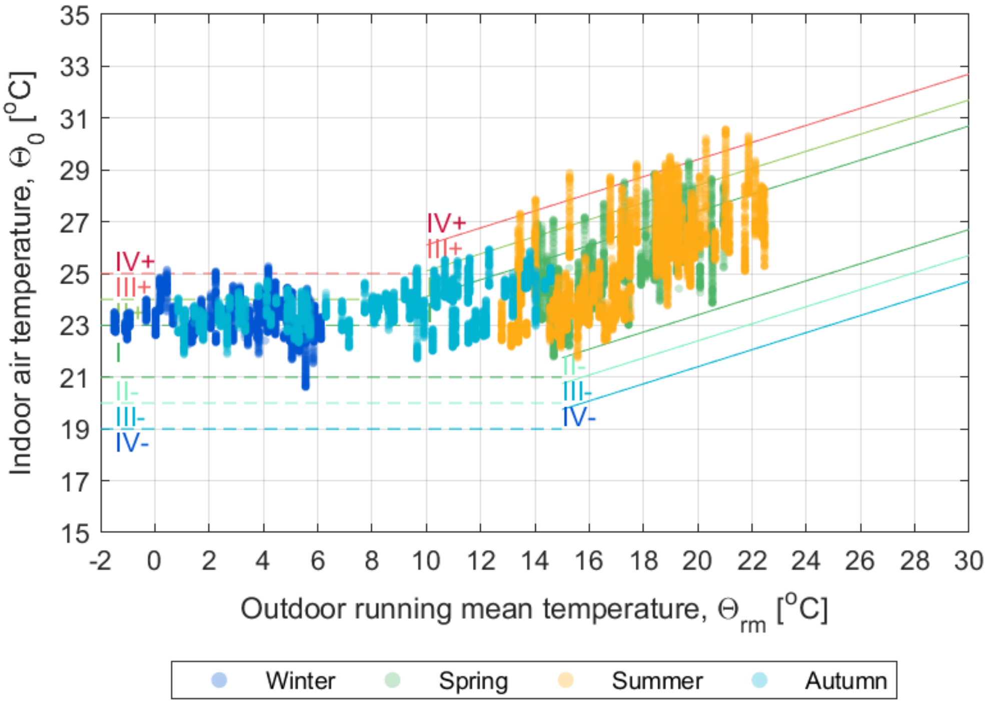
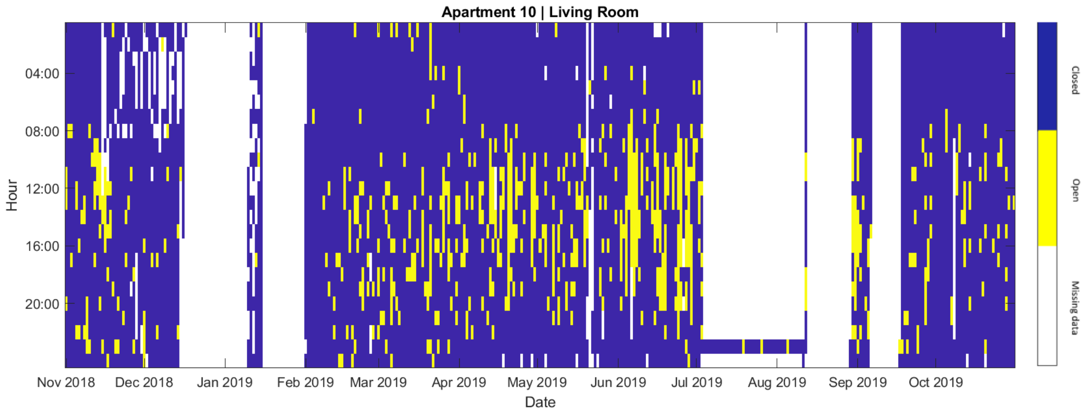


Figure 3.5: Example of indoor air temperature distribution in comfort categories for an apartment in different seasons of the year.

3.5 Evaluation of user behavioral change

For the demonstration cases with window and door opening sensors, the evaluation of the change of window use can be evaluated by using carpet plots. Carpet plots (see a more detailed description in chapter 3.3 in deliverable D3.3) with number of window openings over both monitoring periods can be used to get both a quantitative and a qualitative overview of the behavioral change in the monitoring period. An example is presented in Figure 3.6.



	Heating season	Non-heating season
Total openings	5586,0	4336,0
Time open [%]	7,8	8,9
Time closed [%]	65,6	46,5
Missing data [%]	26,6	44,6

Figure 3.6: Carpet plot for window openings

4 Outcome of Case 1: Kildeparken

4.1 Introduction

Kildeparken is a complex of residential buildings which serves as the Danish demonstration case. There are 24 different residential unit types varying from 67-130 m2 and from 1-5 persons per apartment. The demonstration includes 17 different apartments. These have been selected among the already renovated apartments in the Kildeparken area, which have undergone NZEB standard renovations. 2-5 rooms (living room and bedrooms specifically) per apartment is observed. The specific case objective is to combine information regarding IEQ (Indoor Environmental Quality) and energy in order to establish how tailoring information according to different user types helps increase awareness and leads to energy efficient behavioral change. More detailed information about the case study can be found in deliverable: “D6.1 Detailed final monitoring, awareness and information campaigns for the five cases”.

In all 17 demonstration apartments, measurements regarding energy consumption and indoor environmental quality (IEQ) is monitored, specifically, operative temperature, CO2, relative humidity, and consumption regarding cold and domestic hot water and heating energy, as well as additional parameters like window opening and presence.

The following table summarizes available sensor data at demo site apartments.

Table 4.1: Monitored parameters in apartments

Indicator type	**Indicator name**	**Unit**	**Location**
Energy use	Heat	[kWh]	Apartment level
Water use	Hot water Cold water	[liter] [liter]	Apartment level Apartment level
Indoor Environmental Quality	Temperature Relative Humidity CO_2	[°C] [%] [ppm]	All rooms All rooms All rooms
User practices	Window opening Occupancy	[0/1] [0/1]	All rooms Living room
Outdoor climate	Temperature Relative Humidity	[°C] [%]	One building in Kildeparken area

The 17 apartments of different types and sizes are part of the demonstration see Table 4.2

Table 4.2: Information about apartments and occupants

Apartment No	Size (m^2)	No. of rooms	App installed	Inhabitants
1	111	4	Dec 2019	2 adults
2	110	4	Dec 2019	2 adults
3	91	3	Dec 2019	2 adults
4	72	3	Nov. 2019	1 adult
5	91	4	Dec 2019	2 adults
6	110	5	Dec 2019	1 adults + 2 kids
7	112	5	Dec 2019	2 adults
8	130	5	Nov. 2019	2 adults + 2 kids
9	111	5	Nov. 2019	2 adults
10	111	4	Nov. 2019	2 adults + 2 kids
11	130	5	Nov. 2019	2 adults + 2 kids
12	111	4	Nov. 2019	2 adults
13	67	2	Nov. 2019	1 adult
14	111	4	Nov. 2019	2 adults
15	111	4	Dec 2019	2 adults
16	111	4	Dec 2019	2 adults + 2 kids
17	111	5	Dec 2019	adults + 2 kids

In the demonstration case the MOBISTYLE GAME App developed by HighSkillz is implemented. The MOBISTYLE Game App is a gamified app for behavioural change regarding energy use and indoor environmental quality. The first version of the Android mobile GAME App is made in English.

Gamification includes heat energy use, hot water use, and IEQ parameters. The App includes notifications, if heating and hot water use increases above expected and when a poor indoor environment occurs in the rooms together with advices on how to handle the situation, i.e. nudges for window openings. Furthermore, the GAME App includes point awarding system for successful mission completion.

For the Danish case it has been decided to work with three different evaluation periods for energy use and IEQ that is the Reference period (a full 12 months period), the BASELINE period (selected three months of the reference period, which correspond to the monitoring period for the Game App) and the MOBISTYLE period, which is a three months period with Game App active in all apartments. The three periods include:

REFERENCE: 01/11/2018 – 31/10/2019 (full year)
BASELINE: 01/12/2018 – 28/02/2019 (baseline for comparison and analysis)
MOBISTYLE: 01/12/2019 – 29/02/2020 (application period for ICT solution)

Due the Covid-19 situation in EU in spring 2020, the intermediate evaluation of the ICT solution was not conducted. In consequence the planned upgrade of the ICT solution, which was ought to be based on the feedback from occupants did not take place. This means that occupants were using only first version of the ICT solution.

4.2 Energy consumption evaluation

The following 3 figures present the daily and weekly use of hot and cold water for the 17 apartments during REFERENCE (Figure 4.1), BASELINE (Figure 4.2) and MOBISTYLE (Figure 4.3)

Figure 4.1: Daily and weekly cold and hot water use of the 17 apartments (REFERENCE)

Apartment [No]	Area [m^2]	Cold water use, daily [liters]	Cold water use, weekly [liters]	Hot water use, daily [liters]	Hot water use, weekly [liters]
1	111	156	1096		
2	110	110	774		
3	91	71	499		
4	72	130	914	17	116
5	91	119	833	77	539
6	110	205	1440	88	618
7	112	132	926	31	215
8	130	178	1249		
9	111	148	1040	95	669
10	111	146	1024	43	305
11	130	27	189		
12	111	90	631	5	34
13	67	59	413	23	158
14	111	79	556	32	223
15	111	194	1360	111	776
16	111	102	716	202	1419
17	111	138	967	64	447

Figure 4.2: Daily and weekly cold and hot water use of the 17 apartments (BASELINE)

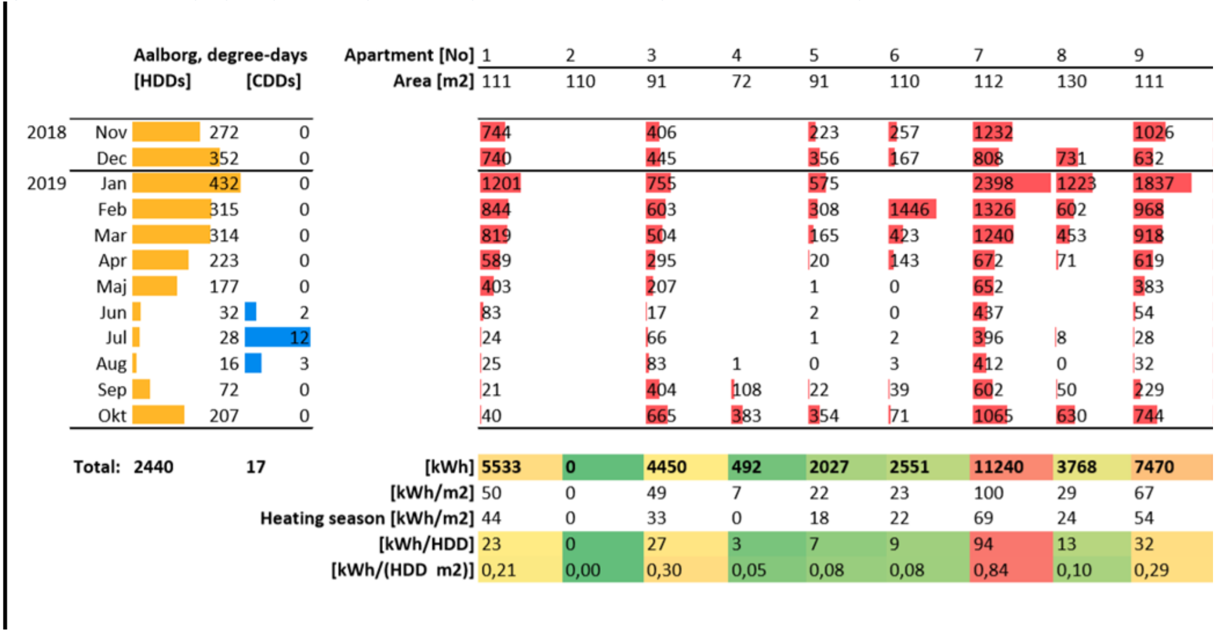
Apartment [No]	Area [m^2]	Cold water use, daily [liters]	Cold water use, weekly [liters]	Hot water use, daily [liters]	Hot water use, weekly [liters]
1	111	187	1307		
2	110	135	947		
3	91	93	650		
4	72	131	920	21	150
5	91	116	811	66	462
6	110	213	1491	85	595
7	112	140	981	36	250
8	130	182	1272		
9	111	148	1037	106	744
10	111	157	1097	50	349
11	130	12	86		
12	111	89	626	8	54
13	67	107	752	19	135
14	111	90	630	45	312
15	111	178	1245	80	562
16	111	125	876	211	1474
17	111	131	915	65	453

Figure 4.3: Daily and weekly cold and hot water use of the 17 apartments (MOBISTYLE)

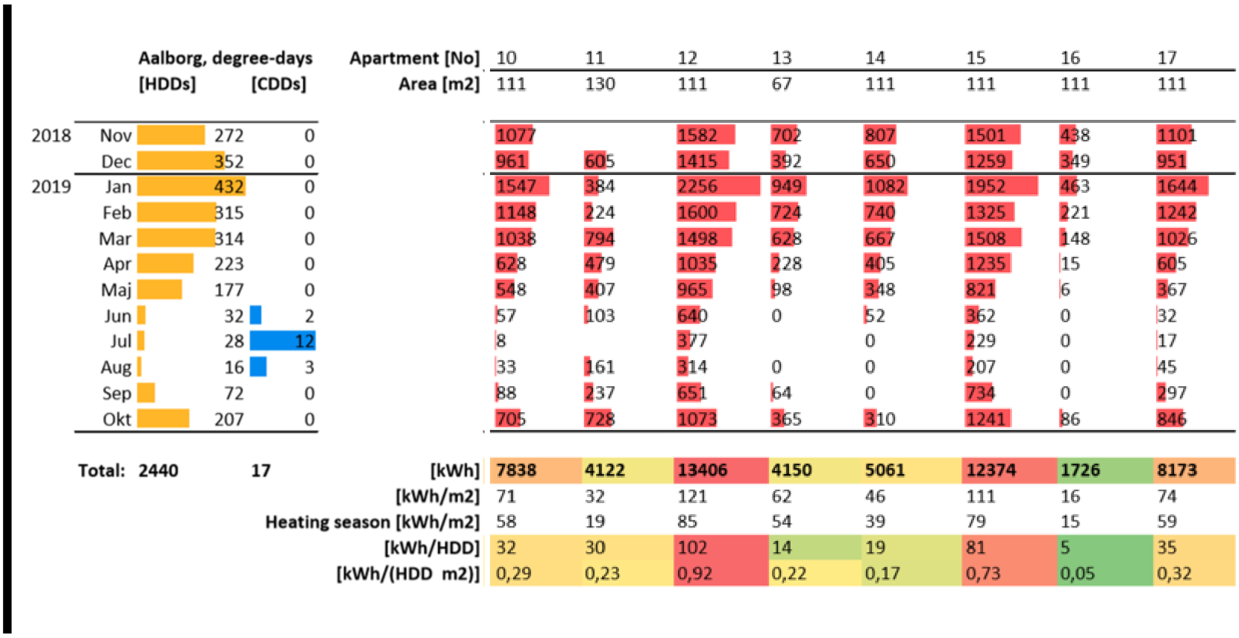
Apartment [No]	Area [m^2]	Cold water use, daily [liters]	Cold water use, weekly [liters]	Hot water use, daily [liters]	Hot water use, weekly [liters]
1	111	48	338		
2	110	42	295		
3	91	65	455	24	165
4	72	130	910		
5	91	115	802	101	705
6	110	258	1803	141	988
7	112	140	977	42	291
8	130	157	1098		
9	111	148	1038	100	700
10	111	140	983	42	292
11	130	36	249		
12	111	81	569		
13	67	41	285	26	181
14	111	95	665	45	317
15	111	194	1357	115	807
16	111	75	526	172	1207
17	111	166	1165	82	573

The following 3 figures present the heat use profile of each of the 17 apartments together with HDD and CDD for the REFERENCE and BASELINE (Figure 4.4) and MOBISTYLE (Figure 4.5) periods

Figure 4.4: Heat use profile of the 17 apartments for the REFERENCE period (Baseline only Dec2018-Feb2019)

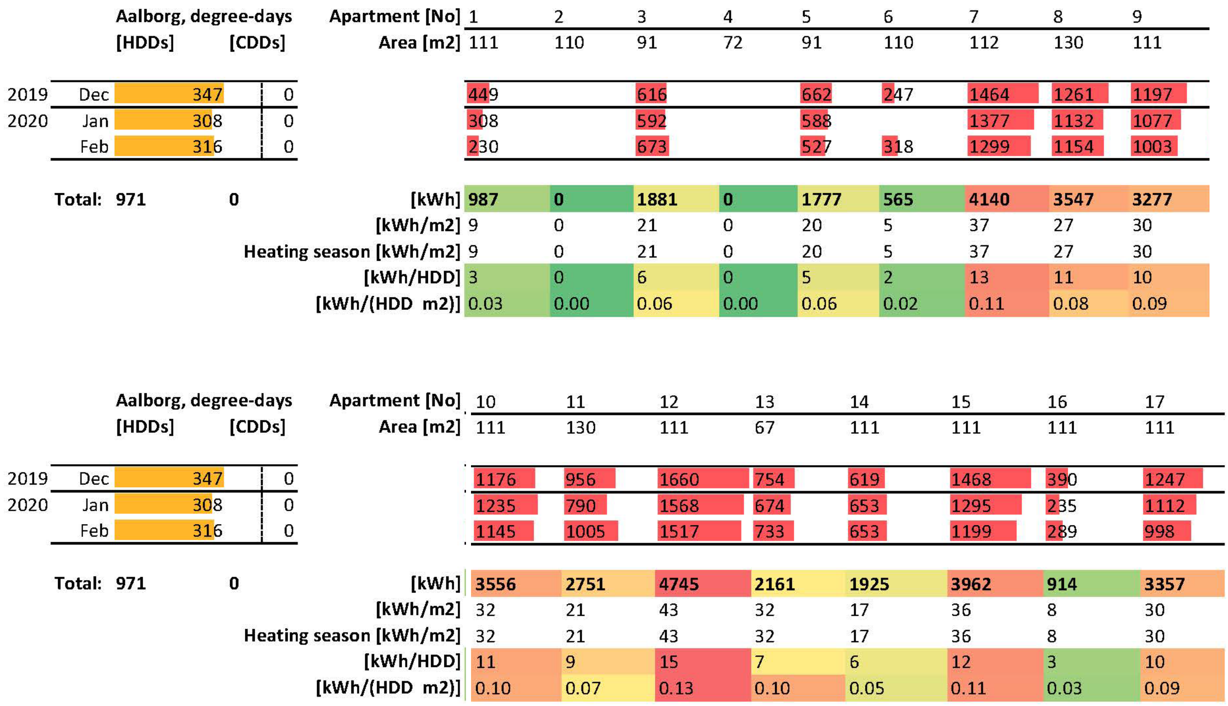


		Aalborg, degree-days		**Apartment [No]**	1	2	3	4	5	6	7	8	9
		[HDDs]	**[CDDs]**	**Area [m2]**	111	110	91	72	91	110	112	130	111
2018	Nov	272	0		744		406		223	257	1232		1026
	Dec	352	0		740		445		356	167	808	731	632
2019	Jan	432	0		1201		755		575		2398	1223	1837
	Feb	315	0		844		603		308	1446	1326	602	968
	Mar	314	0		819		504		165	423	1240	453	918
	Apr	223	0		589		295		20	143	672	71	619
	Maj	177	0		403		207		1	0	652		383
	Jun	32	2		83		17		2	0	437		54
	Jul	28	12		24		66		1	2	396	8	28
	Aug	16	3		25		83	1	0	3	412	0	32
	Sep	72	0		21		404	108	22	39	602	50	229
	Okt	207	0		40		665	383	354	71	1065	630	744
Total:	**2440**		**17**	**[kWh]**	**5533**	**0**	**4450**	**492**	**2027**	**2551**	**11240**	**3768**	**7470**
				[kWh/m2]	50	0	49	7	22	23	100	29	67
				Heating season [kWh/m2]	44	0	33	0	18	22	69	24	54
				[kWh/HDD]	23	0	27	3	7	9	94	13	32
				[kWh/(HDD m2)]	0,21	0,00	0,30	0,05	0,08	0,08	0,84	0,10	0,29



		Aalborg, degree-days		**Apartment [No]**	10	11	12	13	14	15	16	17
		[HDDs]	**[CDDs]**	**Area [m2]**	111	130	111	67	111	111	111	111
2018	Nov	272	0		1077		1582	702	807	1501	438	1101
	Dec	352	0		961	605	1415	392	650	1259	349	951
2019	Jan	432	0		1547	384	2256	949	1082	1952	463	1644
	Feb	315	0		1148	224	1600	724	740	1325	221	1242
	Mar	314	0		1038	794	1498	628	667	1508	148	1026
	Apr	223	0		628	479	1035	228	405	1235	15	605
	Maj	177	0		548	407	965	98	348	821	6	367
	Jun	32	2		57	103	640	0	52	362	0	32
	Jul	28	12		8		377		0	229	0	17
	Aug	16	3		33	161	314	0	0	207	0	45
	Sep	72	0		88	237	651	64	0	734	0	297
	Okt	207	0		705	728	1073	365	310	1241	86	846
Total:	**2440**		**17**	**[kWh]**	**7838**	**4122**	**13406**	**4150**	**5061**	**12374**	**1726**	**8173**
				[kWh/m2]	71	32	121	62	46	111	16	74
				Heating season [kWh/m2]	58	19	85	54	39	79	15	59
				[kWh/HDD]	32	30	102	14	19	81	5	35
				[kWh/(HDD m2)]	0,29	0,23	0,92	0,22	0,17	0,73	0,05	0,32

Figure 4.5: Heat use profile of the 17 apartments for the Mobistyle period



		Aalborg, degree-days [HDDs]	[CDDs]	Apartment [No]	1	2	3	4	5	6	7	8	9
				Area [m2]	111	110	91	72	91	110	112	130	111
2019	Dec	347	0		449		616		662	247	1464	1261	1197
2020	Jan	308	0		308		592		588		1377	1132	1077
	Feb	316	0		230		673		527	318	1299	1154	1003
Total:	**971**		**0**	**[kWh]**	**987**	**0**	**1881**	**0**	**1777**	**565**	**4140**	**3547**	**3277**
				[kWh/m2]	9	0	21	0	20	5	37	27	30
				Heating season [kWh/m2]	9	0	21	0	20	5	37	27	30
				[kWh/HDD]	3	0	6	0	5	2	13	11	10
				[kWh/(HDD m2)]	0.03	0.00	0.06	0.00	0.06	0.02	0.11	0.08	0.09

		Aalborg, degree-days [HDDs]	[CDDs]	Apartment [No]	10	11	12	13	14	15	16	17
				Area [m2]	111	130	111	67	111	111	111	111
2019	Dec	347	0		1176	956	1660	754	619	1468	390	1247
2020	Jan	308	0		1235	790	1568	674	653	1295	235	1112
	Feb	316	0		1145	1005	1517	733	653	1199	289	998
Total:	**971**		**0**	**[kWh]**	**3556**	**2751**	**4745**	**2161**	**1925**	**3962**	**914**	**3357**
				[kWh/m2]	32	21	43	32	17	36	8	30
				Heating season [kWh/m2]	32	21	43	32	17	36	8	30
				[kWh/HDD]	11	9	15	7	6	12	3	10
				[kWh/(HDD m2)]	0.10	0.07	0.13	0.10	0.05	0.11	0.03	0.09

It is seen that the heating energy use follows the HDD. Some apartments, especially those with a high heat consumption, have heating on all year round, while in other apartments heating is completely closed during summer. It can also be seen that there are large differences in both heating and hot water use with a factor of 6-7 between the highest and lowest consumption per year.

The energy use is compared between BASELINE and MOBISTYLE monitoring period for each apartment. Figure 4.6 shows the heating use for each apartment in kWh/HDD m^2 for the two periods. The heating energy use is generally increased by 6,4% for all apartments, but it is only increased in 8 apartments, while it is similar in 4 apartments and it is decreased in 3 apartments. Figure 4.7 shows the hot water use for each apartment in l/week for the two periods. The hot water use is generally increased by 12 % for all apartments, but it is only increased in 4 apartments, while it is similar in 4 apartments and it is decreased in 1 apartment

Figure 4.6: Comparison of heat use of the 17 apartments for the BASELINE and MOBISTYLE period

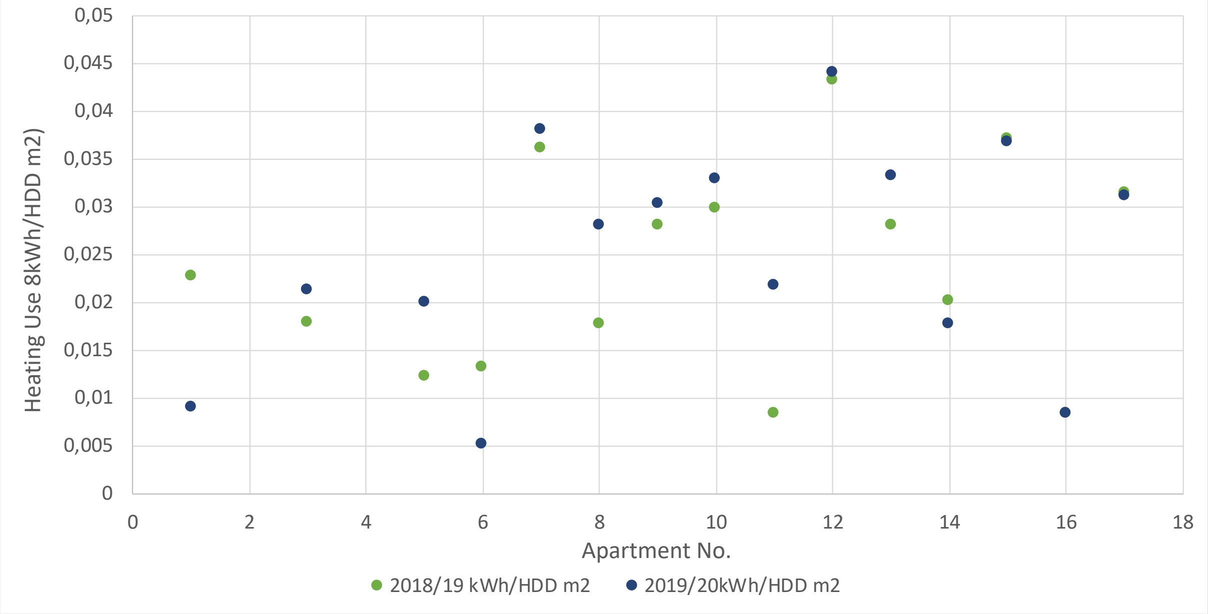
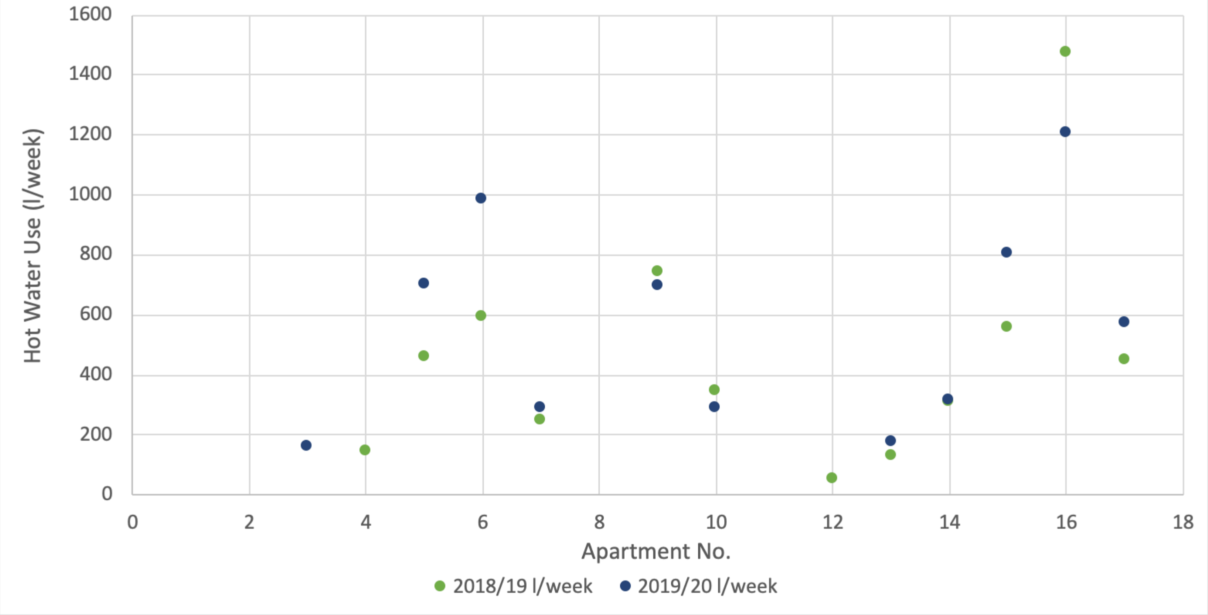


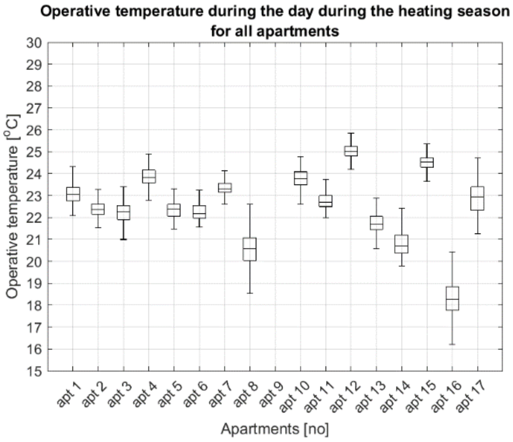
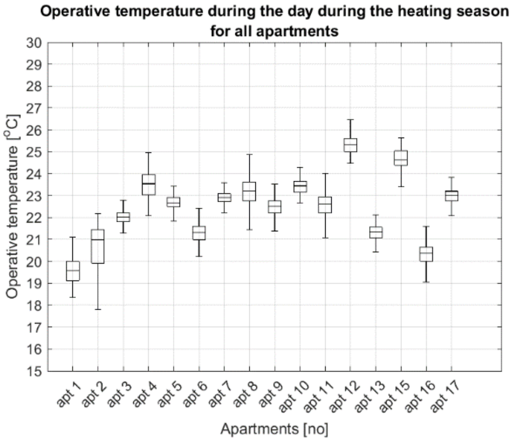
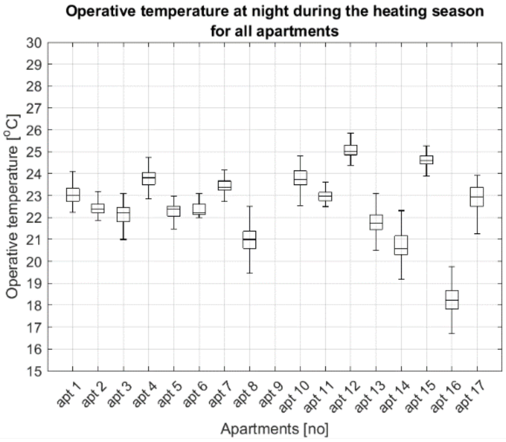
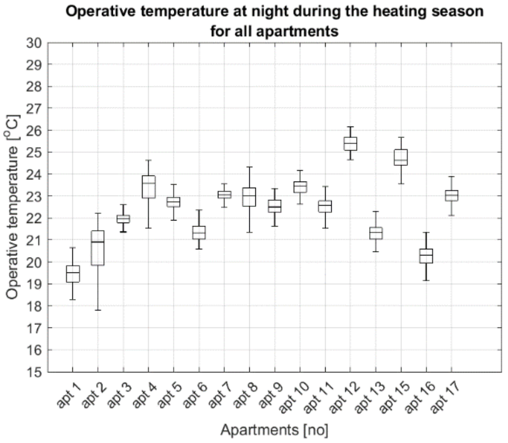
Figure 4.7: Comparison of hot water use of the 17 apartments for the BASELINE and MOBISTYLE period



4.3 IEQ and user behavior comparison between apartments

Figure 4.8 shows the temperature in the apartments (average of all rooms) for day and night and for the Baseline and the Mobistyle monitoring period, respectively. For each apartment the temperature is shown as the mean temperature surrounded by a box representing 50% of the measured values and lines indicating maximum and minimum values measured.

Figure 4.8: Operative temperature during the day and at night for the heating season during the Baseline and Mobistyle period for all apartments.

	Baseline	Mobistyle
Day		
Night		

It can be seen that the temperature levels as well as the temperature variation in time are very different between apartments. All apartments except one have an average temperature level above 20ºC and up to about 25ºC for a couple of apartments. Generally, there is not a big difference between day and night. Generally, for all apartments there is not a big difference between the baseline and the Mobistyle monitoring periods, but for the individual apartments the difference can be quite large in both directions.

Figure 4.9 shows the relative humidity in the apartments (average of all rooms) for day and night and for the Baseline and the Mobistyle monitoring period, respectively. The variation of the average humidity in the apartment is illustrated in a similar way as for the temperature.

It can be seen that the humidity levels are very similar in most of the apartments. The humidity level is only high in 2-3 of the apartments, although not at a critical level. A slight increase in the humidity level is also seen, which may be caused by differences in the outdoor humidity level.

Figure 4.9: Relative humidity during the day and at night for the heating season during the Baseline and Mobistyle period for all apartments.

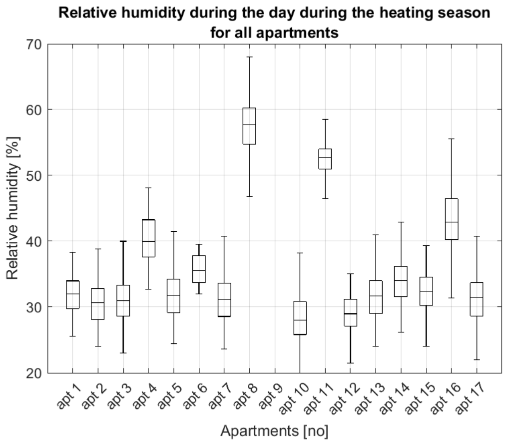
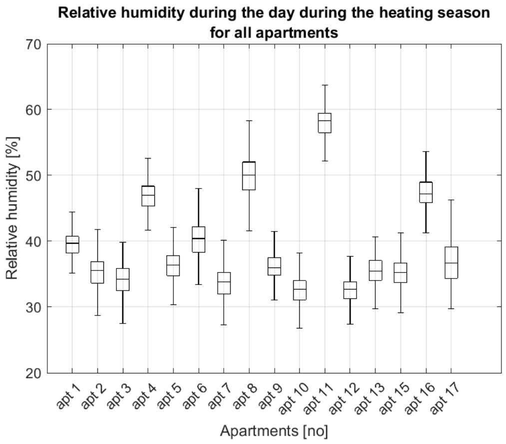
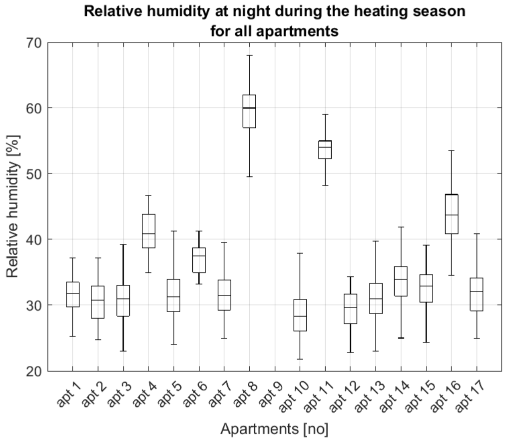
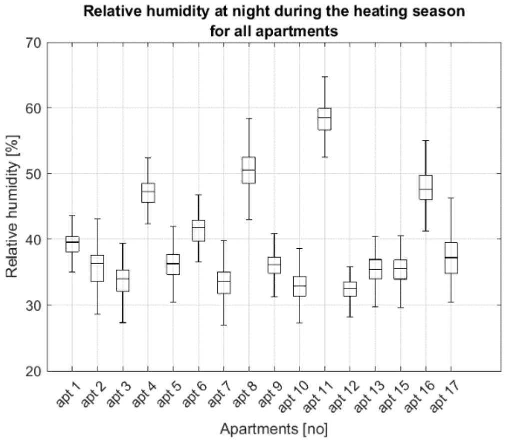
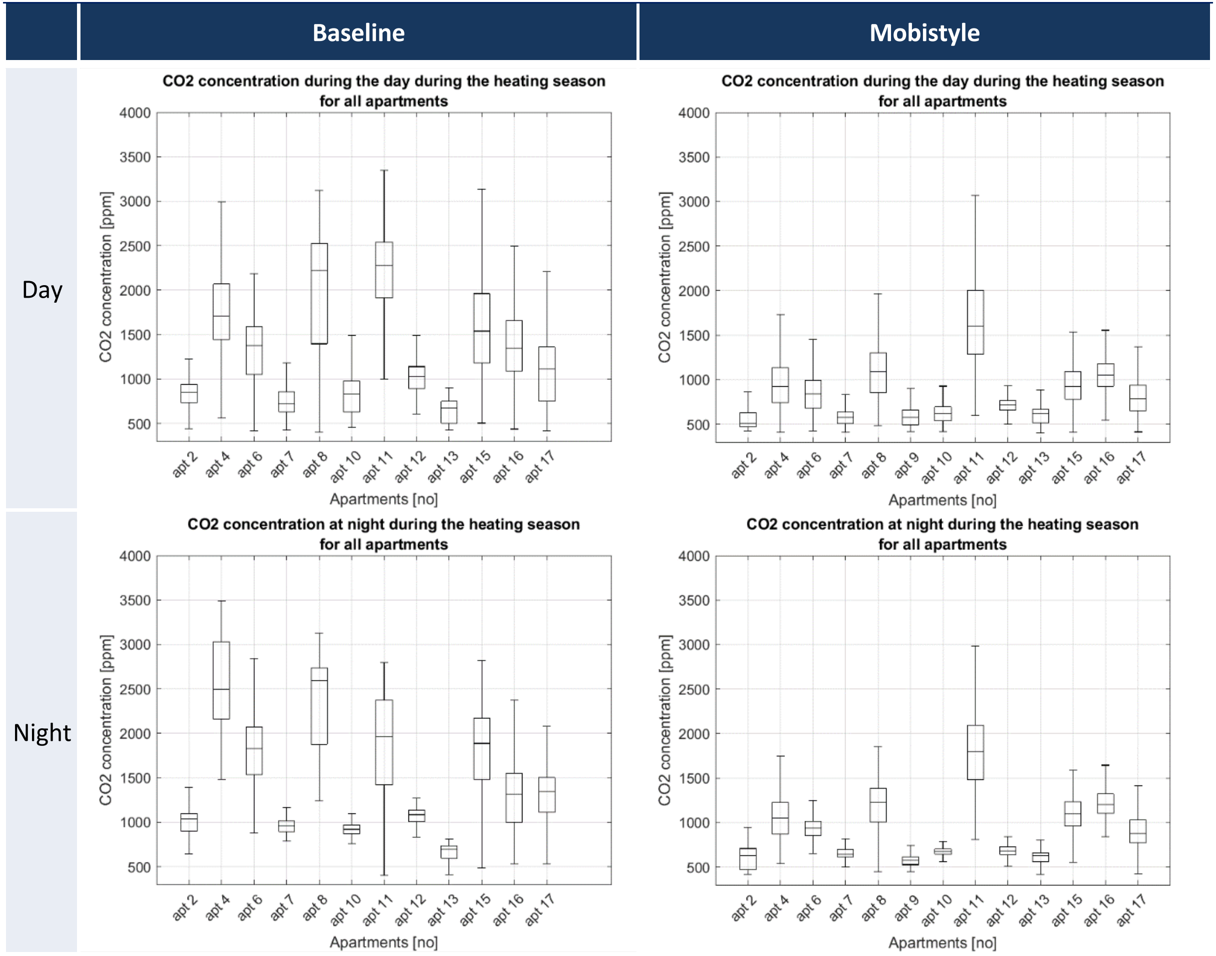
	Baseline	**Mobistyle**
Day		
Night		

Figure 4.10 shows the CO_2 concentration in the apartments (average of all rooms) for day and night and for the Baseline and the Mobistyle monitoring period, respectively. The variation of the CO_2 concentration level in the apartment is illustrated in a similar way as for the temperature.

It can be seen in the Baseline period that the concentration levels as well as the concentration variation in time are very different between apartments. In about half of the apartments an acceptable indoor air quality is achieved with an acceptable average value and a relatively small variation in CO2 concentration levels, while in the other half of the apartments, the concentration levels are higher than recommended and the variation in time also very large with peak values around 3000 ppm. In the Mobistyle monitoring period the CO_2 concentration levels are reduced considerably. It can be seen that the concentration levels as well as the concentration variation in time are much more similar between apartments and that the concentration level is much lower than in the Baseline period, especially in the apartments with high concentration levels. The CO_2 concentration level is in the Mobistyle monitoring period only above the recommended level in one of the apartments.

Figure 4.10: CO2 concentration during the day and at night for the heating season during the Baseline and Mobistyle period for all apartments.



It is documented that there are large differences in indoor environmental quality between different apartments, but it is also interesting to document if differences also appear within each apartment between the different room. The outcome of this investigation is illustrated in figures 4.11 – 4.18.

Figures 4.11 and 4.12 show the average room temperatures in the Baseline and the Mobistyle monitoring period, respectively. It is seen that it is not only between the different apartments that large temperature differences appear, also within the apartments large temperature differences occur between rooms. Generally, at temperature difference of 2°C is seen between rooms in the same apartment, while for a few apartments the difference is either much smaller or much larger. A change in temperature levels can be seen between the Baseline and the Mobistyle monitoring period. An average decrease of 0,5 °C is seen in room temperature levels (increase in 19 rooms, decrease in 38 rooms), while at apartment level an average temperature decrease of 0,4 °C is seen (increase in 5 apartments, decrease in 10 apartments)

Figure 4.11: Comparison of the room temperature level in the 17 apartments for the BASELINE period (missing data 32% of time)

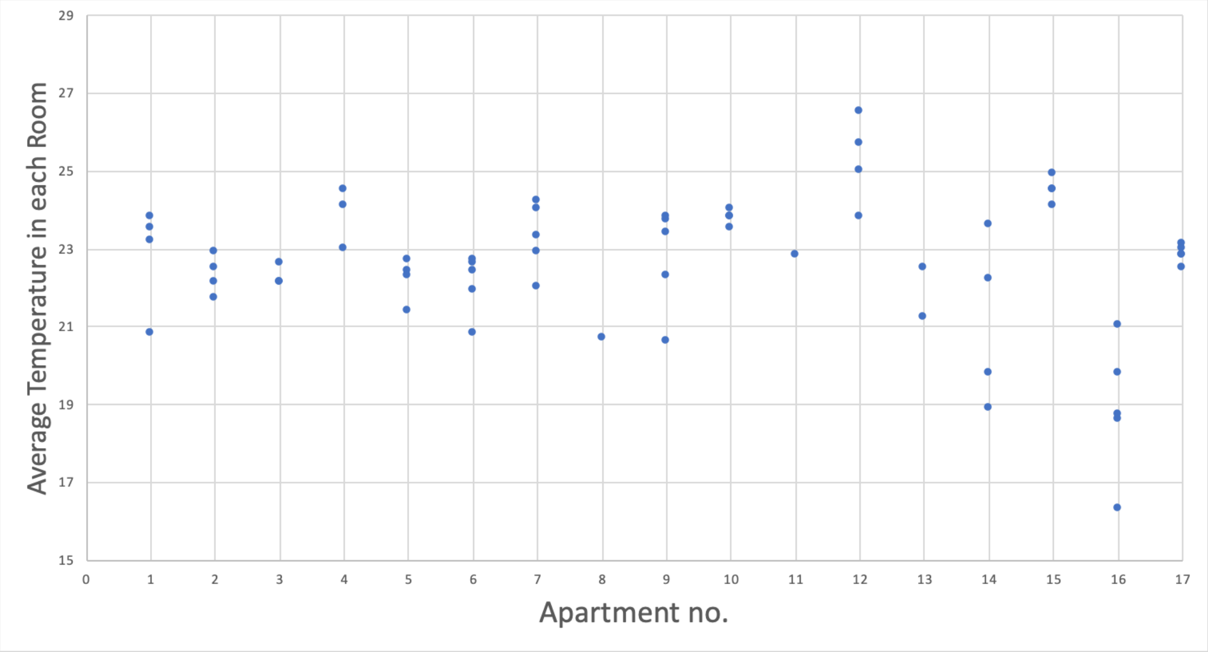
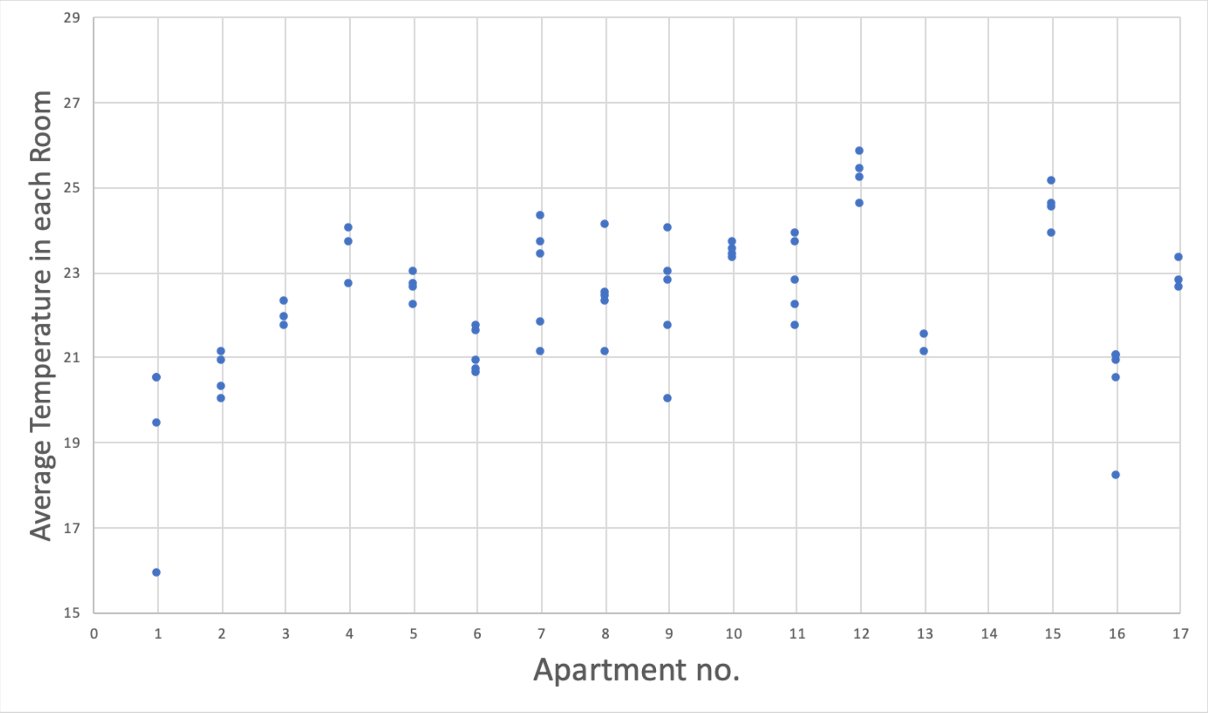


Figure 4.12: Comparison of the room temperature level in the 17 apartments for the MOBISTYLE period (missing data 8,4% of time)



Figures 4.13 and 4.14 21 show the average CO_2 concentration in each room in the 17 apartments in the Baseline and the Mobistyle monitoring period, respectively. As for temperature it is not only between the different apartments that large differences in concentration levels appear, also within the apartments considerable concentration differences occur between rooms. Generally, the difference in average concentration levels in the baseline period can be 500-1000 ppm between rooms in the same apartment. A

considerable change in concentration levels can be seen between the Baseline and the Mobistye monitoring period in almost all apartments. An average decrease of 417 ppm is seen in each room (increase in 6 rooms, decrease in 33 rooms), while at apartment level an average decrease of 390 ppm is seen in each apartment (increase in 0 apartments, decrease in 12 apartments). In the Mobistyle monitoring period high CO_2 concentration levels is only seen in one of the apartments.

Figure 4.13: Comparison of the CO2 concentration level in each room in the 17 apartments for the BASELINE period (missing data 62% of time)

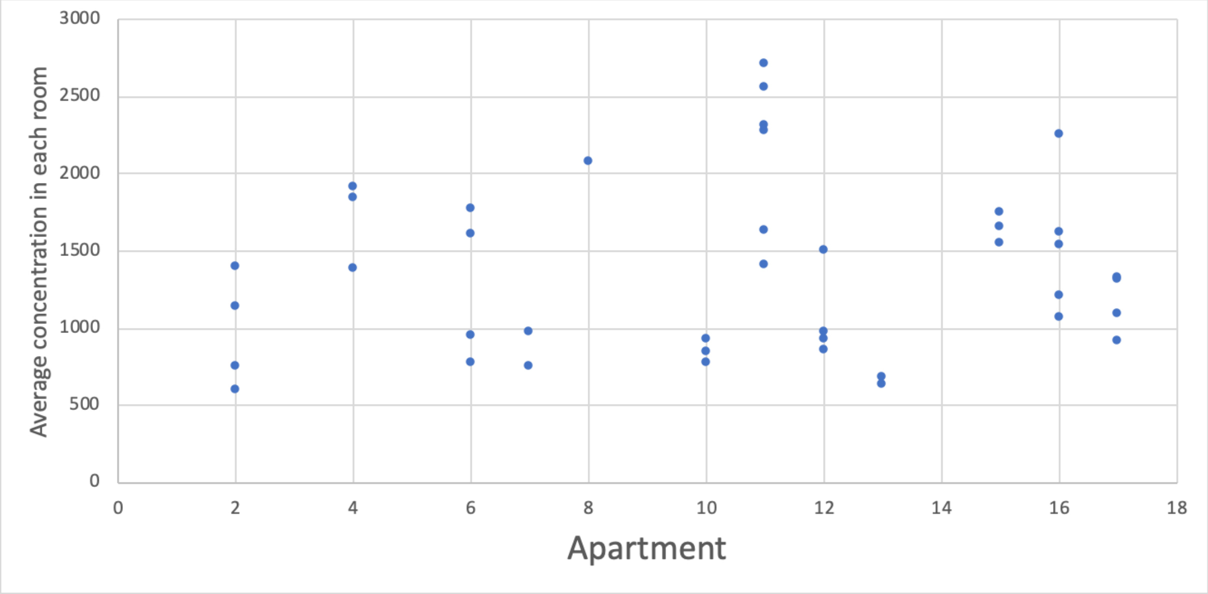
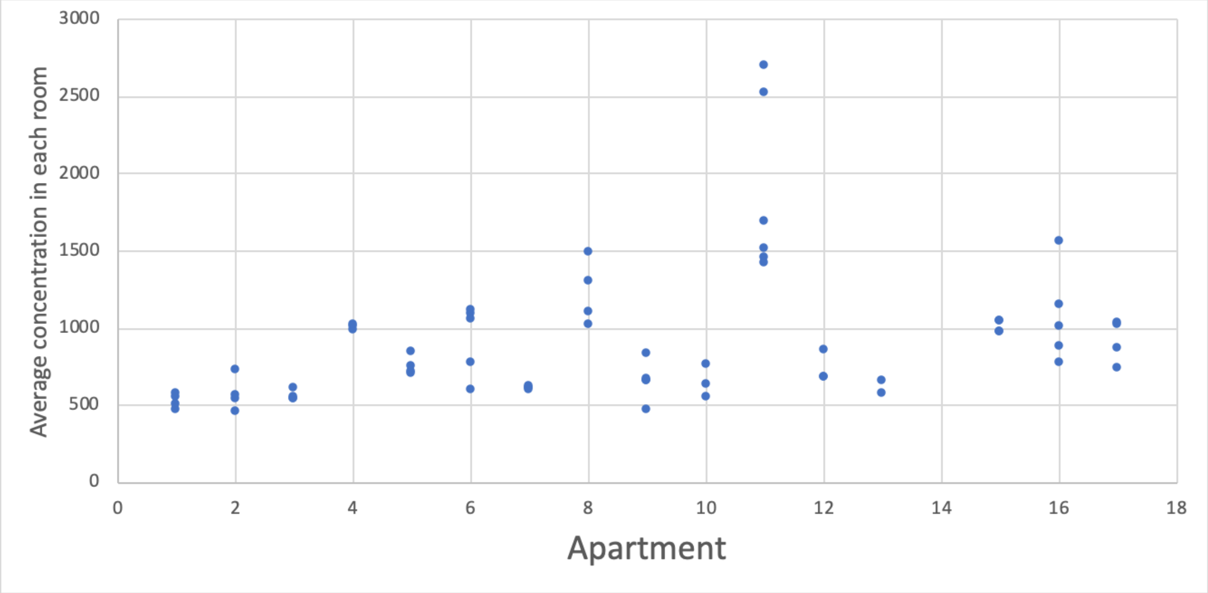


Figure 4.14: Comparison of the CO2 concentration level in each room in the 17 apartments for the MOBISTYLE period (missing data 14% of time)



Figures 4.15 and 4.16 show the average humidity level in each room in the 17 apartments in the Baseline and the Mobistyle monitoring period, respectively. The difference in humidity levels between each room in an apartment is much smaller than between apartments.

A small change in humidity levels can be seen between the Baseline and the Mobistyle period. An average RH increase of 5 % is seen in each room (increase in 55 rooms, decrease in 1 rooms). This is probably more a consequence of different climatic conditions, than changes in end-user behaviour.

Figure 4.15: Comparison of the humudity level in each room in the 17 apartments for the BASELINE period (missing data 32% of time)

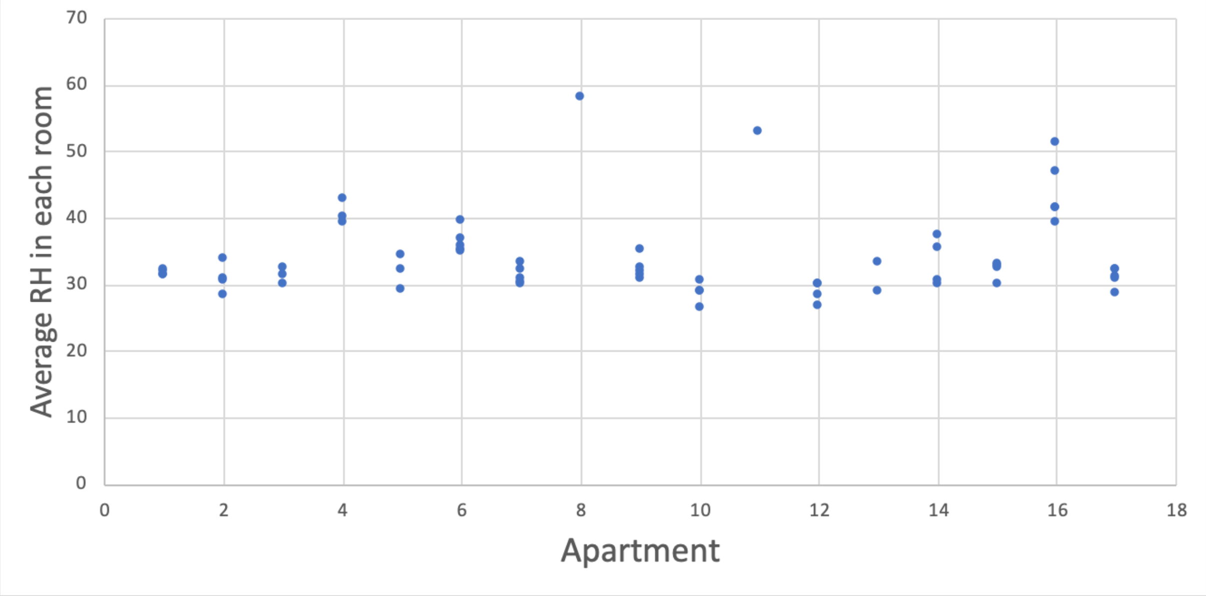
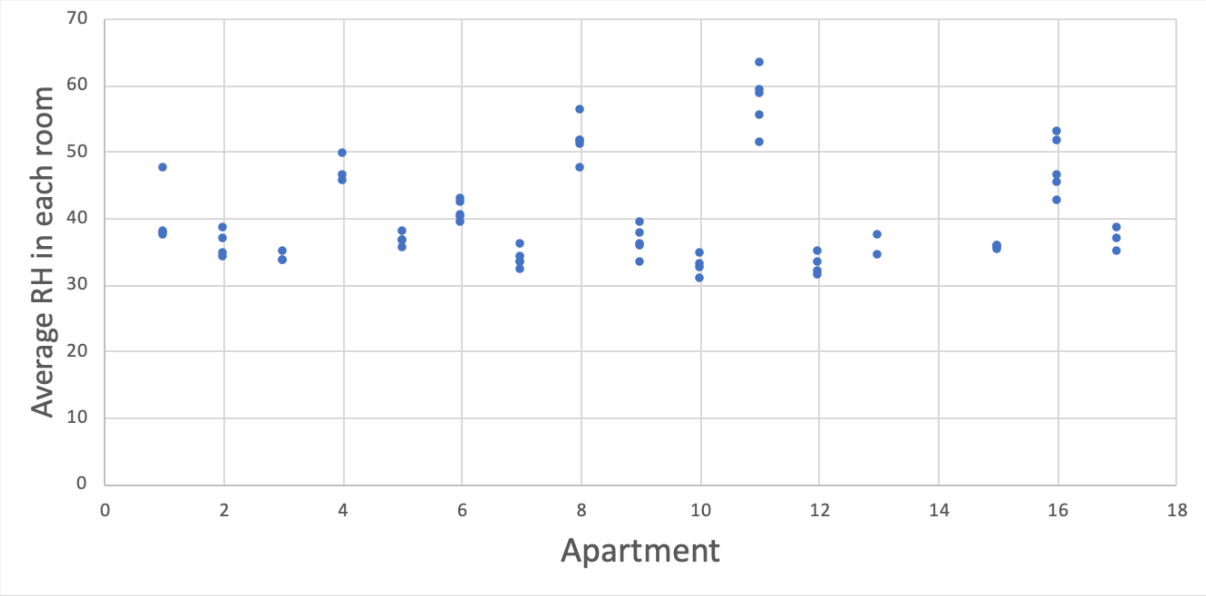


Figure 4.16: Comparison of the humidity level in each room in the 17 apartments for the MOBISTYLE period (missing data 9% of time)



Figures 4.17 and 4.18 show the window opening time in each room in the 17 apartments apartments in the Baseline and the Mobistyle monitoring period, respectively. As it is in the heating season the window opening time is relatively small except in a few bedrooms in a few apartments. An average increase in opening time from 3 % - 6% of the time is seen in each room (increase in 33 rooms, decrease in 18 rooms). However, as the periods with missing data is very different, it is not possible to make a solid conclusion on this.

Figure 4.17: Comparison of window opening time at room level in the 17 apartments for the BASELINE period (missing data 50% of time)

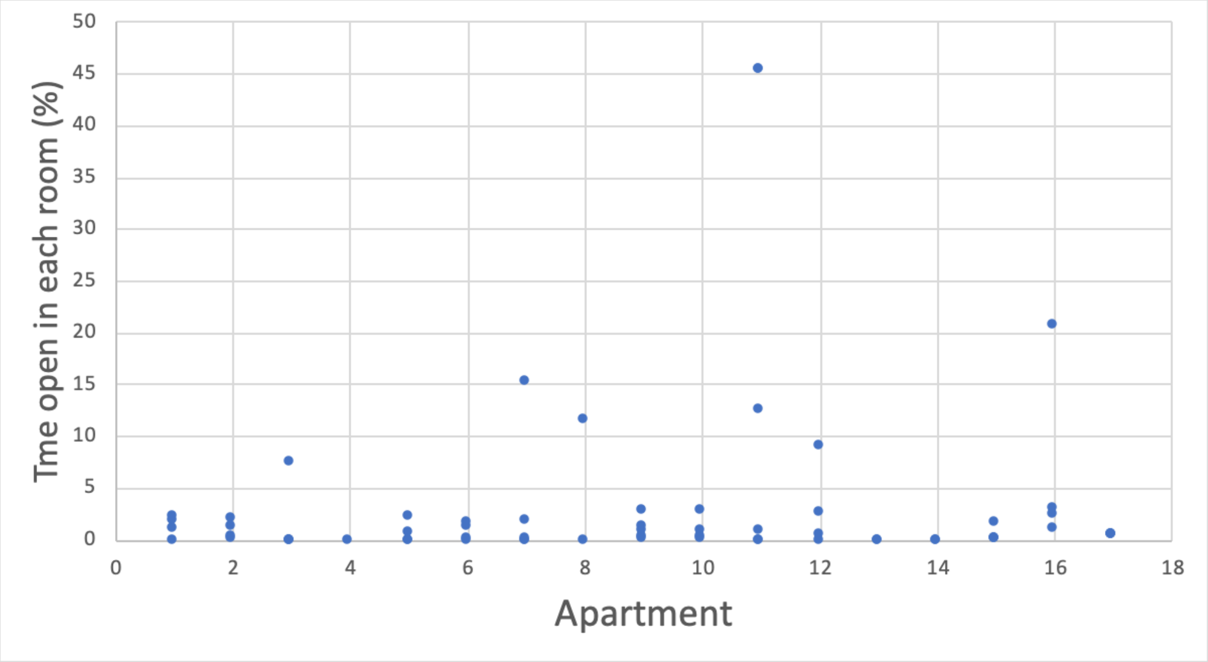
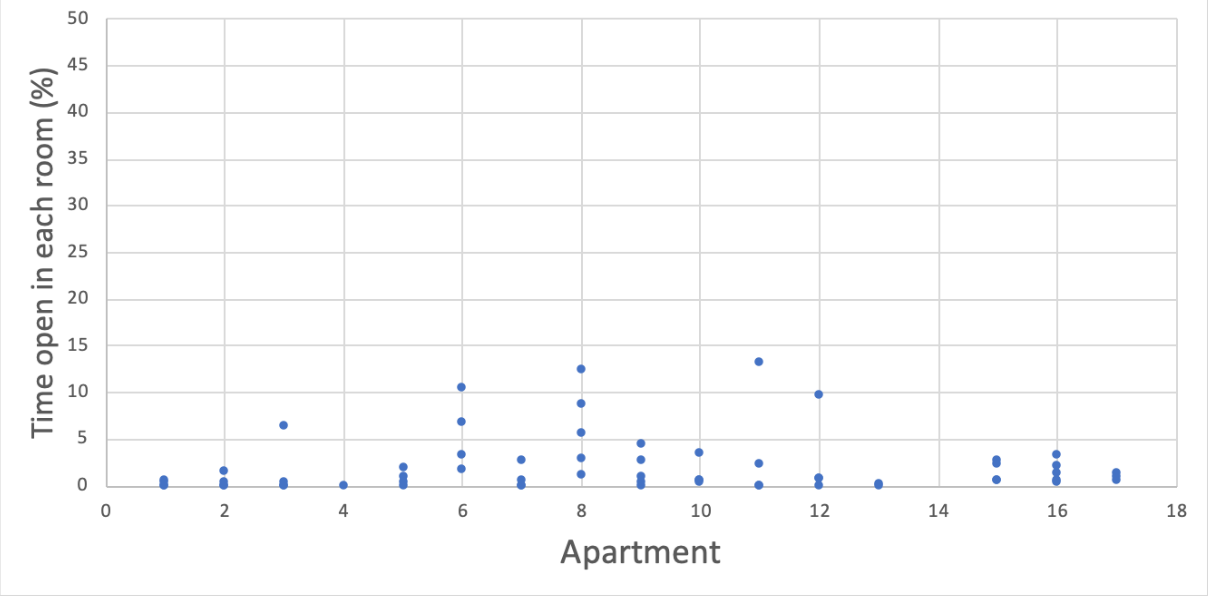


Figure 4.18: Comparison of window opening time at room level in the 17 apartments for the MOBISTYLE period (missing data 10% of time)



4.4 Cross comparison and relations between IEQ and energy use

To investigate the correlation between heating energy use and indoor environmental quality in the apartments, figures 4.19 – 4.22 show different indoor environmental quality indicators at room level as function of the heating energy use on apartment level. It is seen in figure 4.19 that a correlation can be found between indoor temperature level and heating energy use. However, the monitored temperature differences cannot in themselves explain the large differences found in heating energy use. As a rule of thumb a temperature increase of 1°C in an apartment should lead to an increase in heating consumption of about 5%, while the monitored difference is a factor of 6-7. Between some of the apartments with similar temperature levels the difference in heating energy use can be of a factor of 3-4. Therefore, other factors may actually influence heating energy use more that room temperature levels.

In figure 4.20 it is not possible to find a clear correlation between CO_2 concentration level and heating energy use, although those with a small heating energy use also seems to have higher CO_2 concentration levels in the apartment, i.e. indicating smaller ventilation flow rates and ventilation heat loss.

In figure 4.21 there is a clearer trend between humidity level and heating energy use, indicating that higher humidity levels are found in apartments with low heating energy use again indicating smaller indicating smaller ventilation flow rates and ventilation heat loss.

However, figure 4.22 shows that the reason for higher CO2 concentration and humidity levels in apartments with a low heating energy use, seems not to be less window opening time.

Figure 4.19: Average room temperature as function of the heating energy use in the 17 apartments for the REFERENCE period.

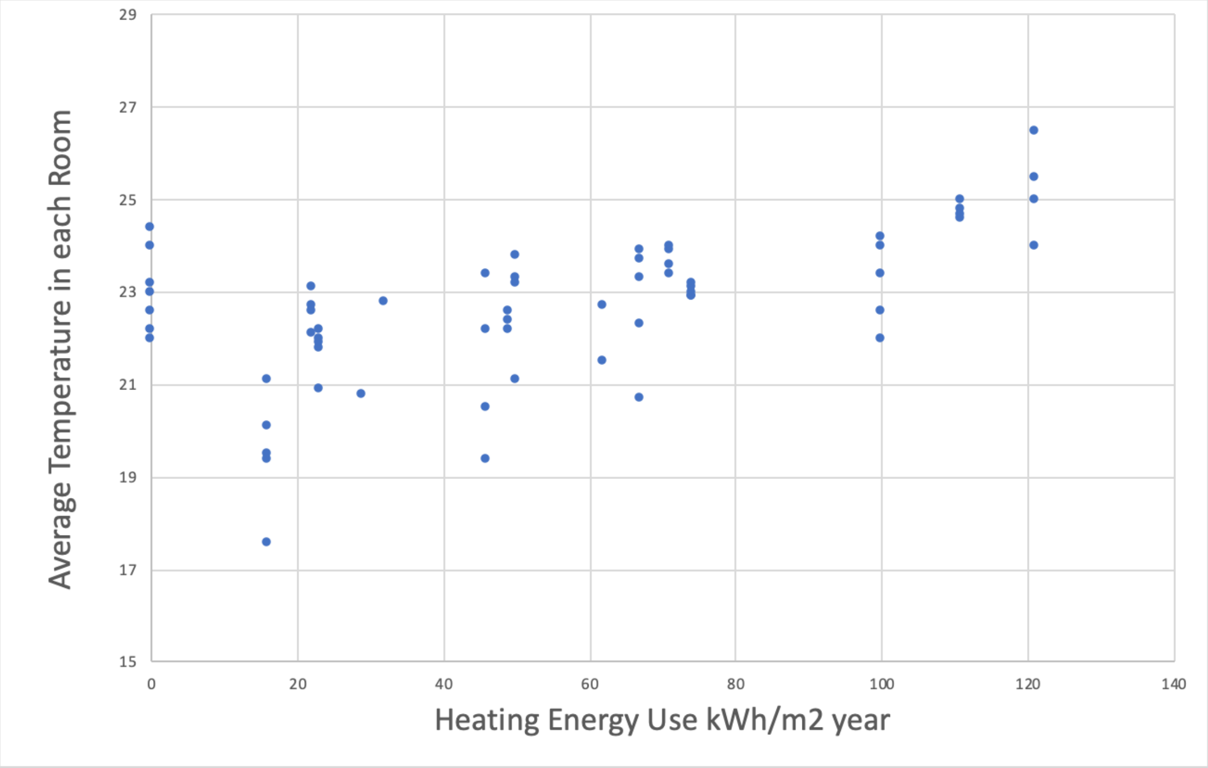


Figure 4.20: Average CO_2 concentration at room level as function of the heating energy use in the 17 apartments for the REFERENCE period.

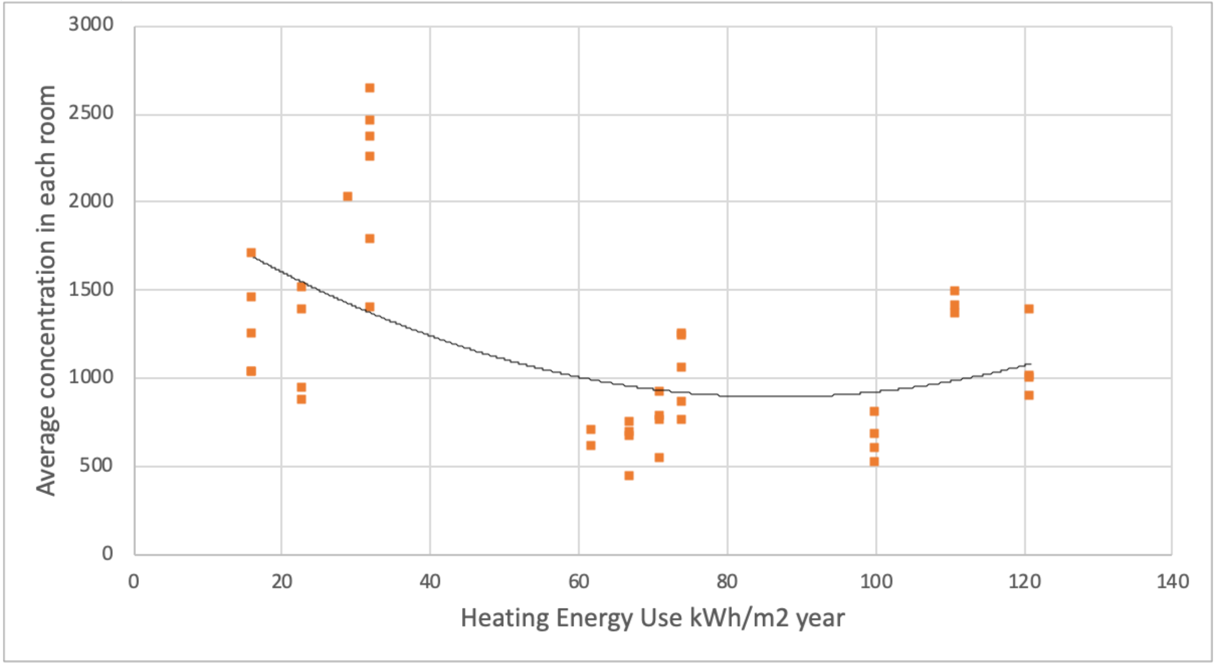


Figure 4.21: Average humidity level in each room as function of the heating energy use in the 17 apartments for the REFERENCE period.

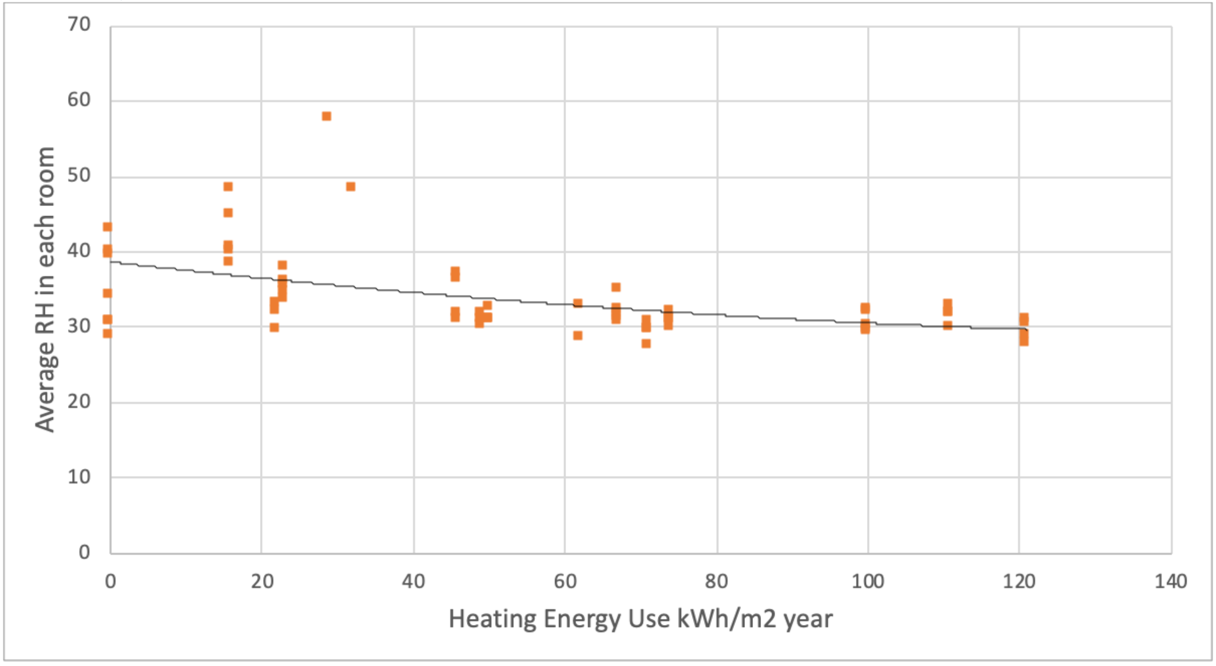
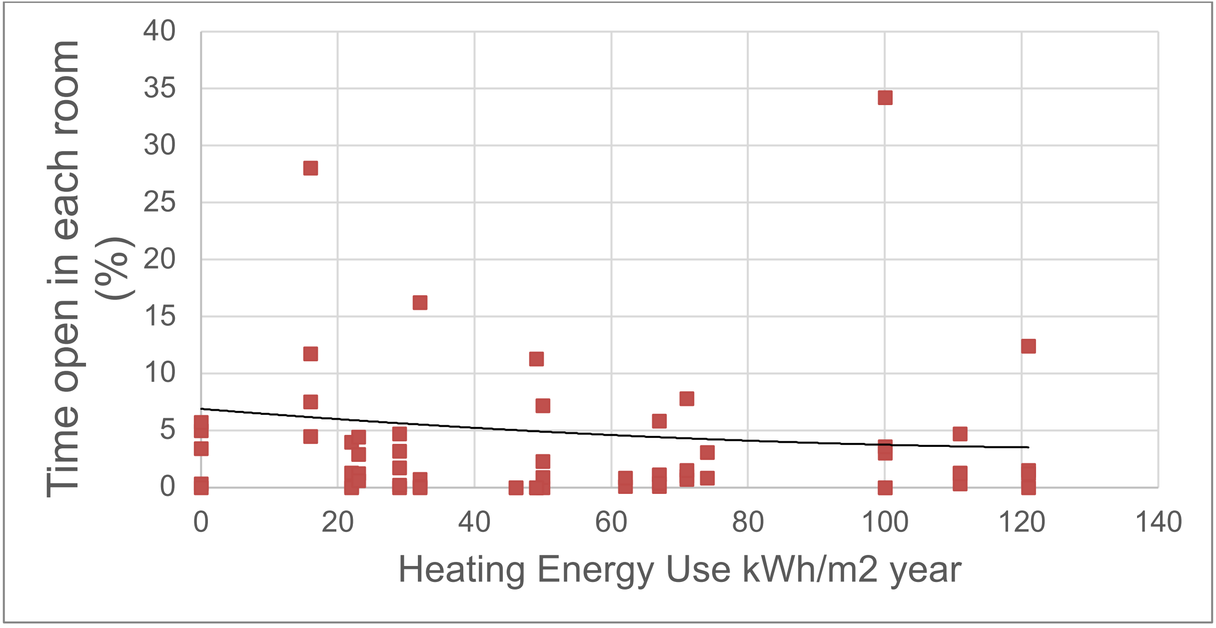


Figure 4.22: Average window opening time at room level as function of the heating energy use in the 17 apartments for the REFERENCE period.



Figures 4.23 and 4.24 shows the correlation between window opening percentage, CO2 concentration and temperature at room level for the heating and non-heating season, respectively.

Figure 4.23: Average window opening time at room level as function of room level CO2 concentration in the 17 apartments for the REFERENCE period in the heating and non-heating period, respectively.

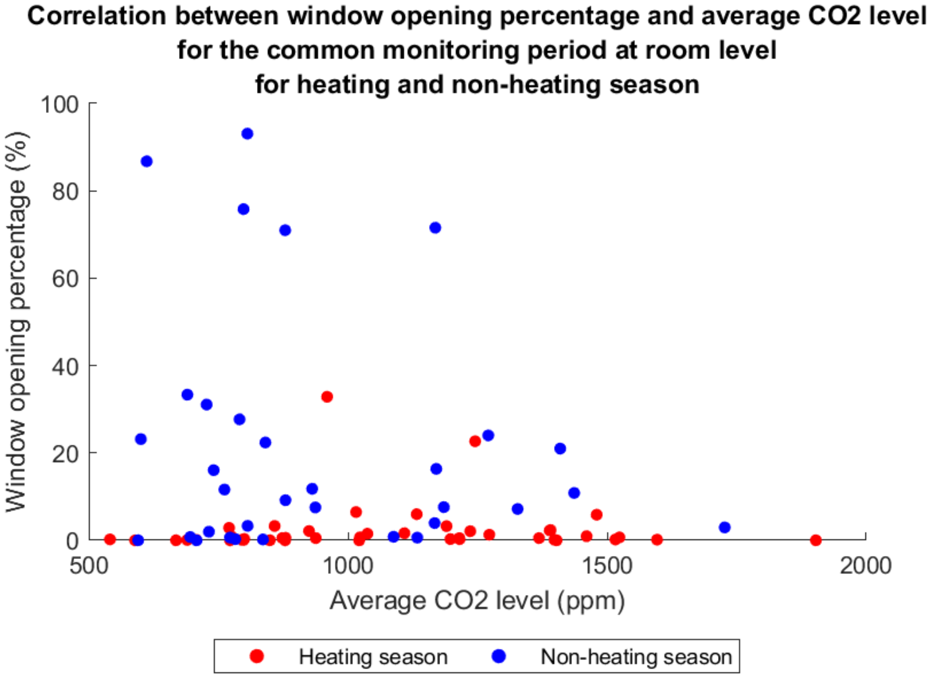
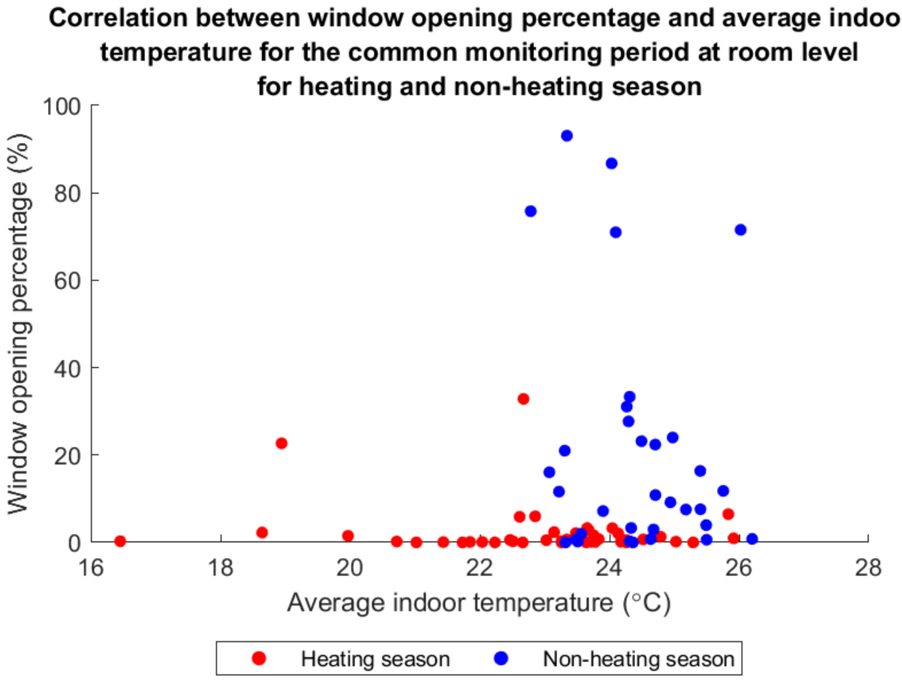


Figure 4.24: Average window opening time at room level as function of average room temperature in the 17 apartments for the REFERENCE period in the heating and non-heating period, respectively.



The window opening level is very different between the heating and non-heating season, but it is not very dependent on the CO2 concentration or indoor temperature level. Even high CO_2 concentration and temperature levels in the heating season does not necessarily motivate window opening for improving the indoor environmental quality.

4.5 Overall discussion and conclusions.

For application of the Game solution in the Danish Demonstration case it was from the beginning decided that information and recommendations should be based on monitored data and that it was important to establish information from all rooms in an apartment and not just from one “representative” room, as it is usually seen in similar projects.

This decision has clearly resulted in new valuable knowledge about the indoor environmental quality in apartments and provided end-users with much better targeted information, feedback and guidance about their indoor environment. The results showed as it has been seen before that there are large differences in temperature and indoor air quality levels (average conditions) between different apartments, but they also revealed that differences between rooms in an apartment are almost as large. The results showed that it is very difficult by only monitoring in one room to ensure a representative evaluation of the indoor environmental quality in an apartment.

The application of the Game in the 17 apartments seem to influence the indoor environmental quality level much more than the energy use. The heating energy use generally increased by 6,4% for all apartments between the Baseline and the Mobistyle period, although it only increased in 8 apartments, while it was similar in 4 apartments and decreased in 3 apartments. All apartments were newly renovated, and the general heating use level was decreased from about 200 kWh/m2 to about 50 kWh/m2, so all end-users had experienced a considerable decrease in heating energy use after moving into the renovated apartments again. This may have influenced their focus on their heating energy use. Also, generally the hot water use increased by 12 % for all apartments. It increased in 4 apartments, while it was similar in 4 apartments and decreased in only 1 apartment.

Apartments with high heating energy use did not have a high hot water use as well or the opposite. Actually, it was more often the case that those with the high heating energy use had a low hot water use and the opposite. This may depend on the number of persons living in the apartment, as more persons use more hot water, but also release more internal heat gains reducing the need for additional heating. However, as no registration of use time and persons in the apartments were included in the monitoring campaign a firm conclusion on this cannot be given.

Large differences were found in both heating energy use and hot water use between individual apartments with a factor of about 6 between the apartments with the lowest and the highest use.

The indoor environmental quality clearly changed between the Baseline and the Mobistyle period. An average decrease of 0,5 ^{o}C was seen in temperature levels in each room (increase in 19 rooms, decrease in 38 rooms), which is modest but still significant. A considerable change in average concentration levels was seen with an average decrease of 417 PPM in each room (increase in 6 rooms, decrease in 33 rooms). Especially, the very high values often seen during night-time in sleeping rooms were reduced and a very acceptable indoor air quality was obtained in all apartments except one. Only a small change in humidity was seen with an average RH increase of 5 % in each room (increase in 55 rooms, decrease in 1 room), probably due to differences in weather conditions.

The correlation between heating energy use and indoor environmental quality in the apartments were also investigated. A correlation could be found between indoor temperature level and heating energy use, although the relatively small temperature differences in themselves could not explain the large differences found in heating energy use. It was not possible to find a clear correlation between CO_2 concentration and heating energy use, although those with a small heating energy use also seem to have higher CO_2 concentration levels in the apartment. A clearer trend between humidity level and heating energy use was found, indicating that higher humidity levels are found in apartments with low heating energy use. However, the reason for higher CO2 concentration and humidity levels in apartments with a low heating energy use, seemed not to be because of less window opening time.

5 Outcome Case 2 University of Ljubljana

5.1 Demo case description

The demonstration case of University of Ljubljana (UL) consists of 4 faculty buildings located in Ljubljana, which are in details described in the preliminary demo description in deliverable “D6.1 Detailed final monitoring, awareness and information campaigns for the five cases”:

- Faculty of Computer and Information Science (FRI)
- Faculty of Chemistry and Chemical Technology (FKKT)
- Faculty of Economics (EF)
- Faculty of Arts (FF)

Since all four buildings have a similar room typology and users, we focus on the FRI FKKT facility for in-depth measurements and complex analysis. Other buildings will be used for verification and generalisation of findings and further implementation of the solution. A specific theme to be addressed in demonstration case is the indoor environment quality (IEQ) in relation to short-term behaviours and long-term habits of different user types.

The demonstration is done in rooms of the fully automated building of FRI FKKT, 8 of them will be monitored in detail (installation of additional IEQ sensors). Available data from the SCADA system will be used and new equipment will be installed as well. Focus will be on rooms where user interaction with building systems is possible – i.e. **offices**. These will be rooms used by teaching staff, researchers, administrative and technical staff (1 each, total 4 + 4 for verification).

The action plan is designed for demonstrating a sustainable behaviour change towards improvement of indoor environment quality and reduction of energy consumption in a real environment by deploying and validating the developed tailor-made solutions and services.
The objective is to validate the approach, tools, and services applied in terms of increase in indoor environment quality and reduction in energy use through user feedback and data analysis. The focus will be on improved indoor environment quality (IEQ) as result of modified behaviour. Energy saving will be achieved in parallel to improved IEQ.

Functionalities is the following:
- For occupants/users: Interactive and attractive information exchange and attractive visualisation of savings, state of IEQ and personal health; relation between energy saving and IEQ.
- For facility managers, building owners: Information of energy performance and diagnostics.

Table 5.1 summarizes available sensor data at demo site.

Table 5.1: Monitored parameters

Indicator type	Indicator name	Unit	Location
Indoor Environmental Quality (IEQ)	Temperature Relative Humidity CO_2 VOC	[°C] [%] [ppm] [ppb]	See table Table 6.3: Spaces description which room have IEQ sensors (INAP sensors)
HVAC system	Cooling media use by valve position of celling cooling convector Heating media use by radiator valve position	[%] [%]	All rooms (SCADA sensors)
User practices	Window opening Access Setpoint temperature Solar shading Light switching	[0/1] [0/1] [°C] [°] [0/1]	All rooms (SCADA sensors)
Outdoor climate	Temperature Relative Humidity Solar illuminance S/E/W	[°C] [%] [klux]	One building (SCADA sensors)

The set of rooms and occupants that are involved in the MOBISTYLE project are described in table 5.2.

Table 5.2: Room description

No	Room ID	Area [m^2]	Occupancy [pers.]	Window orientation [S/E/N/W]	LED sensors** [YES/NO]	MOBISTYLE App Users [YES/NO] [pers.]	IEQ sensors [YES/NO]	Comments
1	K1N0623	18	2	W	YES (31/1-19)	YES [1 pers.] (unknown)	YES	Min direct sunlight
2	K1N0624	18	1	W	YES (12/9-19)	YES [1 pers.] (26/6-19)	YES	Min direct sunlight
3	K3N0605	14	2	N/NE	YES (31/1-19	YES [1 pers.] (29/5-19)	YES	No shading
4	K3N0618	14	1	N/NE	YES (12/9-19)	YES [1 pers.] (11/7-19)	YES	No shading
5	R2N0805	63	~6	W	YES (12/9-19)	YES [1 pers.] (11/7-19)	YES	See section **Fejl! Henvisningskilde ikke fundet.**
6	R2N0634	22	2	E	YES (12/9-19)	NO	NO	See section **Fejl! Henvisningskilde ikke fundet.**
7	R3N0644	16	1	E	YES (31/1-19	NO	YES	See section **Fejl! Henvisningskilde ikke fundet.**
8	R3N0808	63	~6	W	YES (31/1-19	YES [3 pers.] (25/5-19)	YES	Connected with R3N0809

*IEQ sensors measuring CO2, RH, and VOCs
**LED sensors active from 31/1-2019 in rooms K1N0623, K3N0605, R3N0644, R3N0808 IRI-UL enabled additional 4 LED sensors the 12/9-2019 in rooms R2N0634, R2N0805, K3N0618 and K1N624

Some key characteristics of the individual room use profiles are described in the following, which help in the interpretation of the obtained monitoring results.

Room K1N0623:
2 people (woman and man), occasionally 3 (visitor), but not more than 1-2h at the time. They usually arrive in the office at 7.00 in the morning. They state, that they open the window a lot. Every morning, except when it is very cold outside. They do not get direct sunlight. Both of occupants spend a lot of time around the premises, not in the office. It is often empty, and never occupied full 8h/day.

Room K1N0624:
Single person.

Room K3N0605:
1 person (man) from March - December 2018, after December 2018 - 2 persons (+1 woman) in the office (expected increased CO_2 concentration level). Both teaching assistants, so they spend time also in the lab and classroom. Woman states that she is usually in the office until appr. 9.00, than around the premises. She opens the window, when she sees the red light (on the sensor) and thinks App is too time consuming, and she does not use it. In summer the man is more often present. He likes it warmer than her.

Room K1N0634:

Room R2N0805:
They have regular coffee breaks, one around 10am, one around 3pm. Everybody who drinks coffee in the lab comes in, sits around the couch and talks. The first to come into the room opens a window, especially in the summer. One of them says that when he comes into the room in the morning, the light is red, then turns green. In the morning, the air in the room is perceived bad. Otherwise, few people see the light from their workplace. Two of them open the window if the light is red.)

Room R2N0634:
Typical professor, often locked in the room (so he has peace to work). He says that as soon as he arrives, he opens the window, but only for a few minutes to ventilate. In principle, he is happy with everything, has no major comments. He doesn't like to come to work early, so he comes later and leaves later. He sets the external shadinh himself, saying that when they close on their own, he must intervene manually.

Room R3N0644:
Typical professor, rarely in the office, likes to ventilate the room. He only opens windows in April, May and September. He doesn't like draft. He says he uses the thermostat a lot. He prefers light, dislikes shading.

Rooms R3N0808 and **R3N0809**
In **R3N0808**They say they have the window opened almost all the time in summer, after they got the sensor with LED. They have a lot of plants in the room. They often work late. They are

often disturbed by the light, especially the winter and late summer sun, which falls through the shading and is difficult to stop. For example, you can shut shading, but then you're in dark. Rooms **R3N0808** and **R3N0809** are quite different. In the room **R3N0808** they ventilate often, but not in **R3N0809**. Room **R3N0808** is connected with room **R3N0809** where they cool a lot and have lower temperature than their neighbors in **R3N0808**. In **R3N0809** they often work late hours. In **R3N0809** there are students who have their keys and come in whenever they want. In **R3N0809** there are only boys, and more girls in **R3N0808** especially in 2019. If they hang out, they do it in **R3N0809**.

Room occupation varies a lot from office to office therefore the room access data is used to filter the data and analyse the time periods only when the user unlocks the door when entering the room and closes when leaving.

LED lights were enabled in 4 test rooms in February 2019 and in September 2019 in the remaining 4 rooms.

MOBISTYLE DASHBOARD App was deployed in on June, July 2019

BASELINE period:	February 2018 – January 2019
MOBISTYLE period:	February 2019 – January 2020

5.2 Energy consumption evaluation

The cooling season started one month later during the MOBISTYLE period - at the end of May comparing to the end of April during the BASELINE monitoring.

According to maintenance service at FRI FKKT the chillers (cold water producing units for room cooling via celling convectors) were turned ON/OFF at the following dates:

- 21/4-2018 to 22/9-2018 (BASELINE, see Figure 5.1)
- 23/5-2019 to 18/9-2019 (MOBISTYLE, see Figure 5.2)

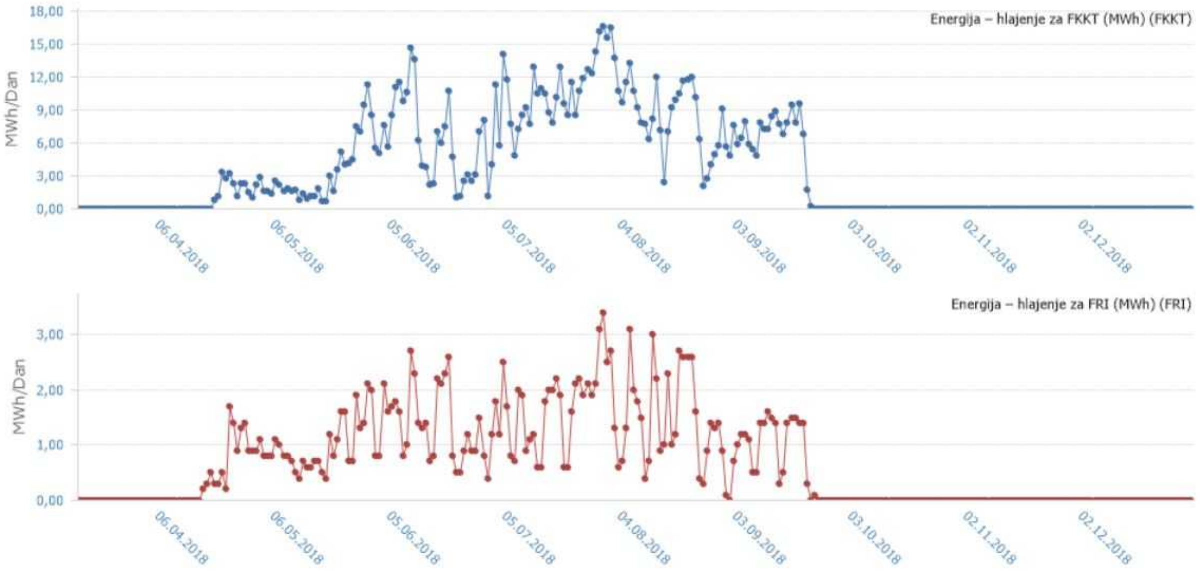


Figure 5.1: Chiller operation, daily cooling energy use at FKKT (top) and FRI (bottom) buildings (2018)

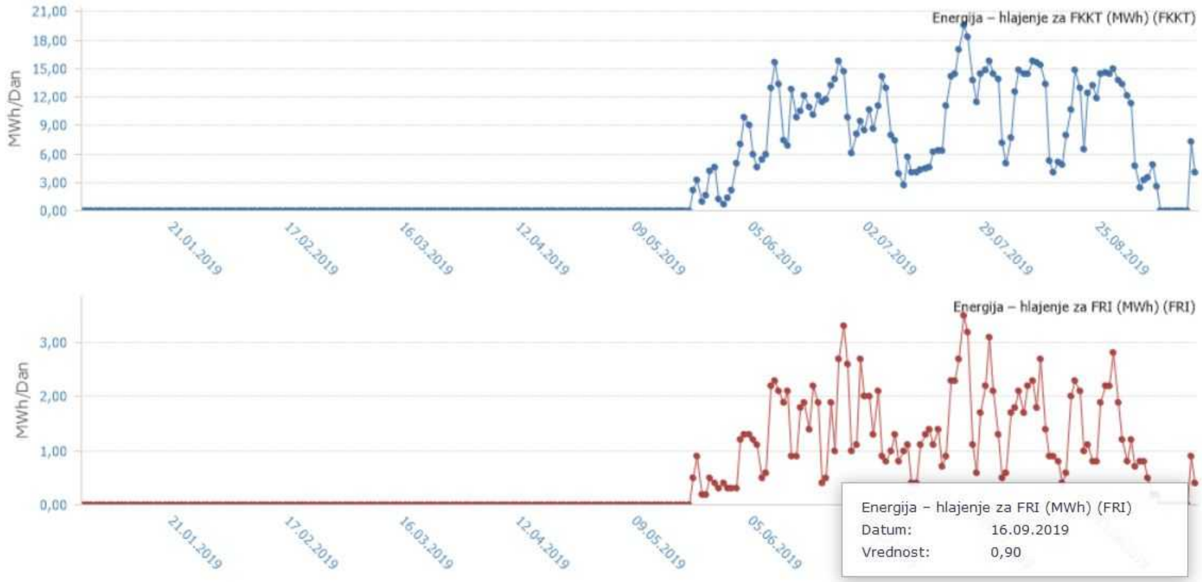


Figure 5.2: Chiller operation, daily cooling energy use at FKKT (top) and FRI (bottom) buildings (2019)

The cooling media activation by the valve position of the celling cooling convector and heating media activation by radiator valve position can be used for a rough estimation of the energy use for heating and cooling.

Figure 5.3, 5.4 and 5.5 show the time distribution of the operation of the heating and cooling systems, namely the total time period when the valve opening is larger than 0%. Even though this data does not represent the energy use itself (only available at the building level), it can give an indication of for example how the temperature regulation decreases or increases the period of time when these systems are active. Furthermore, a correlation between increasing the period of time when window is open could lead to a decreased time of cooling system being active, because BMS with open window shuts down cooling and heating of the room.

It is seen that cooling is active in the heating season is all rooms and actually more often that the heating system in some rooms. Analysis of the results show that the average heating period from the baseline to the Mobistyle monitoring period was reduced from 22 – 19 % of time in each room (increase in 3 rooms, decrease in 4 rooms). Results show that the average cooling period is also reduced, although only from from 23 – 22 % of time in each room (increase in 4 rooms, decrease in 3 rooms).

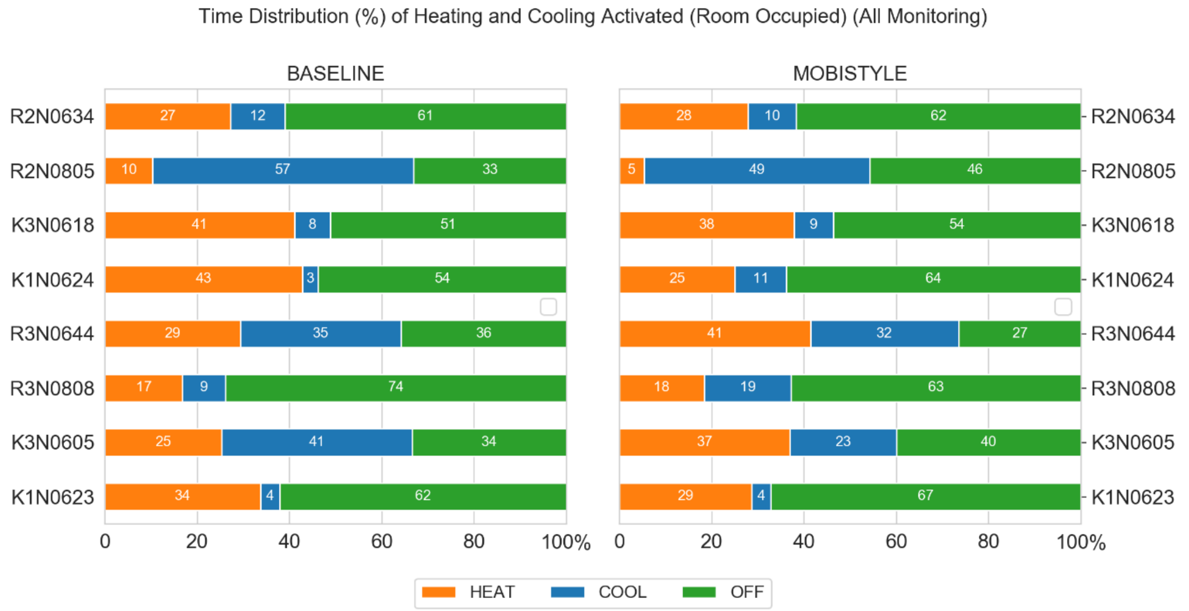


Figure 5.3: Activation of heating and cooling during room occupation. Whole monitoring period of Baseline and Mobistyle period, respectively

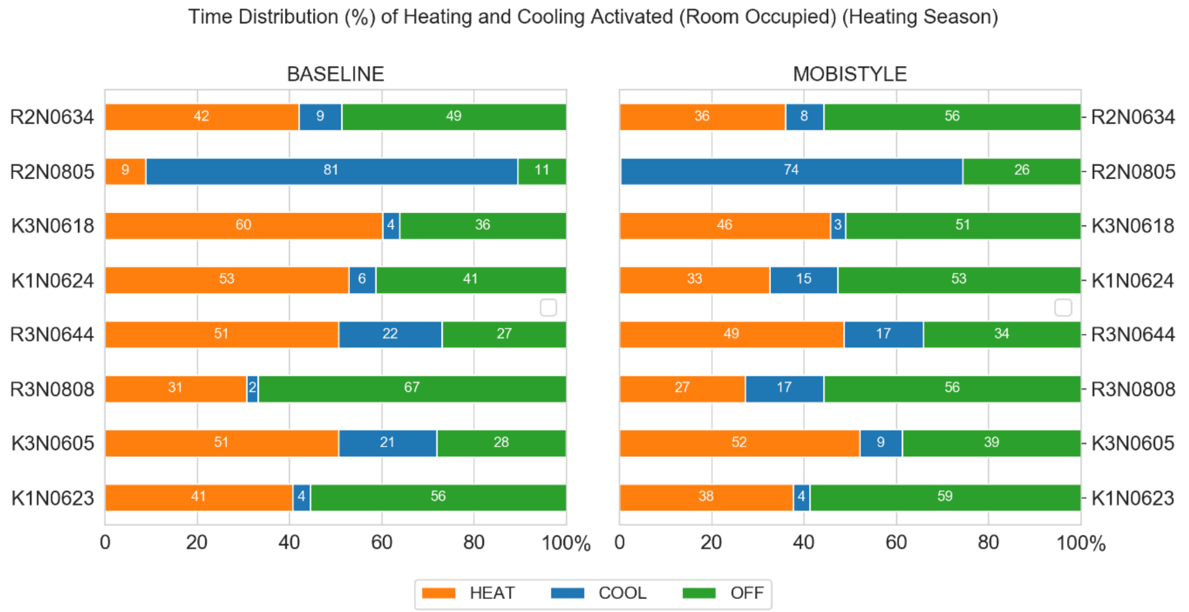


Figure 5.4: Activation of heating and cooling during room occupation. Heating season of Baseline and Mobistyle period, respectively

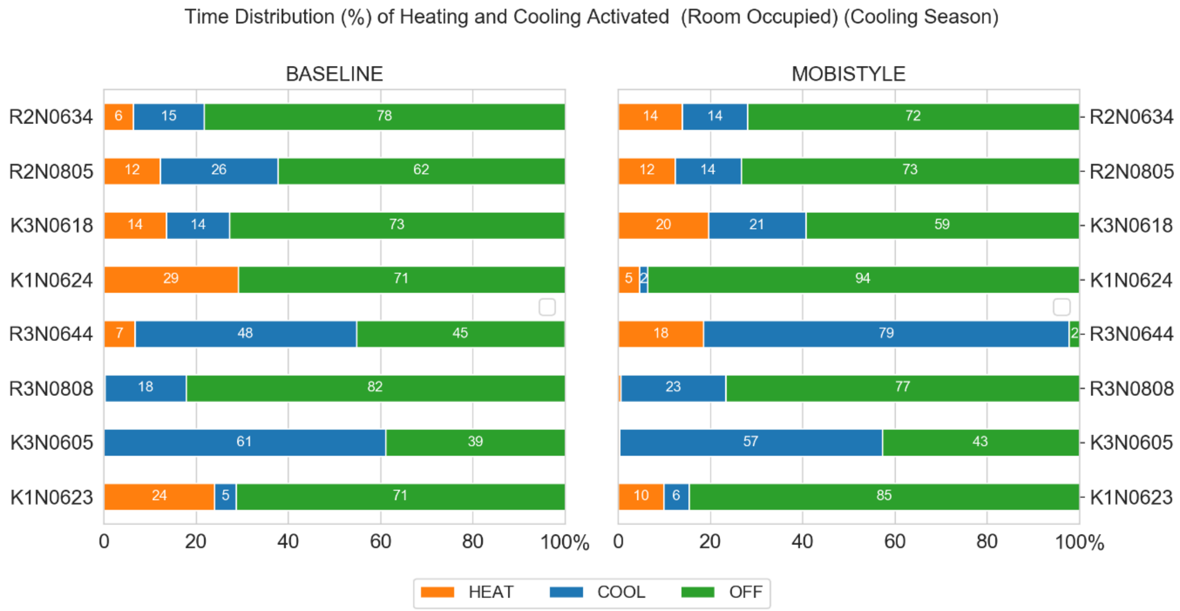


Figure 5.5: Activation of heating and cooling during room occupation. Cooling season of Baseline and Mobistyle period, respectively

5.3 IEQ evaluation

The monitored indoor environmental conditions in the eight office rooms is evaluated both for the whole monitoring period, and also separated into heating and cooling seasons.

For the indoor room temperature data is divided into cooling and heating season as follows for Slovenia:

- Cooling season (generally May, June, July, August)
- Heating season (generally September – May)

In this case the cooling season is determined based on the operation time of the HVAC system, namely chiller operation, which is regulated by the maintenance service at the office building level. Therefore, the cooling period may change from year to year based on the outdoor climate. The dates considered as cooling season in the MOBISTYLE project is shown in section 5.1. Furthermore, the data analysis considers only time when the rooms are occupied.

Figures 5.6, 5.7 and 5.8 compares the time distribution of the thermal comfort categories for the Baseline and the Mobistyle monitoring period for three different periods: the whole monitoring period, for the heating season and for the cooling season. Thermal comfort conditions are very different from room to room. Some rooms are overheated most of the time and especially in the heating season, while others are comfortable all year round. A few rooms suffer from undercooling, especially in the cooling season. In general the temperature level is very similar between the monitoring periods with an average temperature decrease of only 0,04 ºC in each room (increase in 2 rooms, decrease in 3 rooms) from the Baseline to the Mobistyle period.

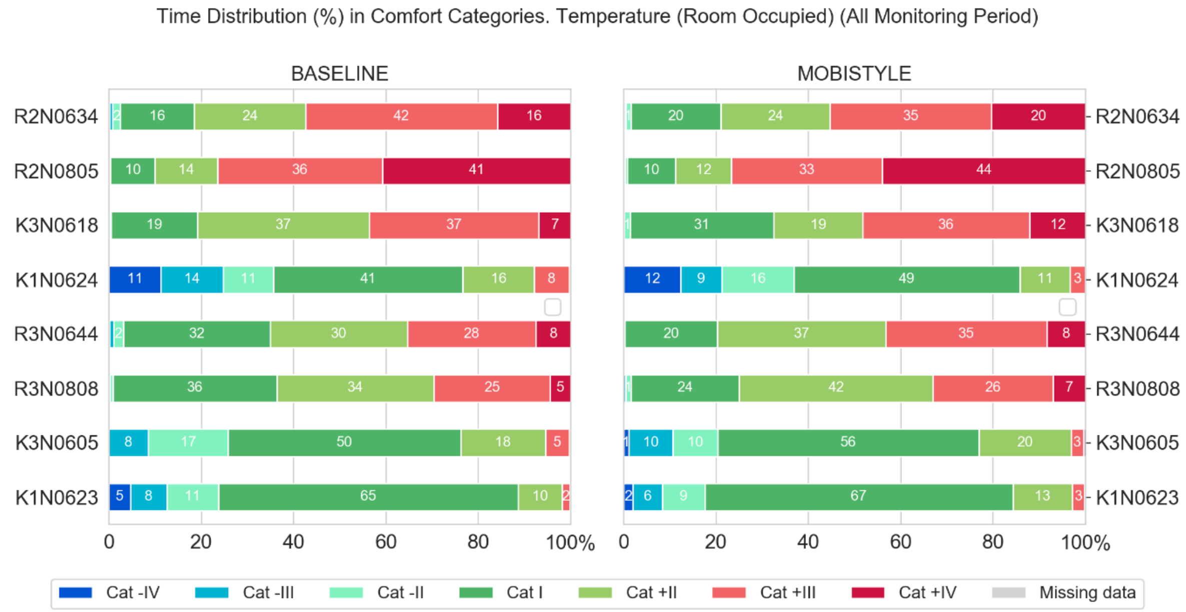


Figure 5.6: Time distribution of thermal comfort categories for the whole monitoring period of Baseline and Mobistyle period, respectively

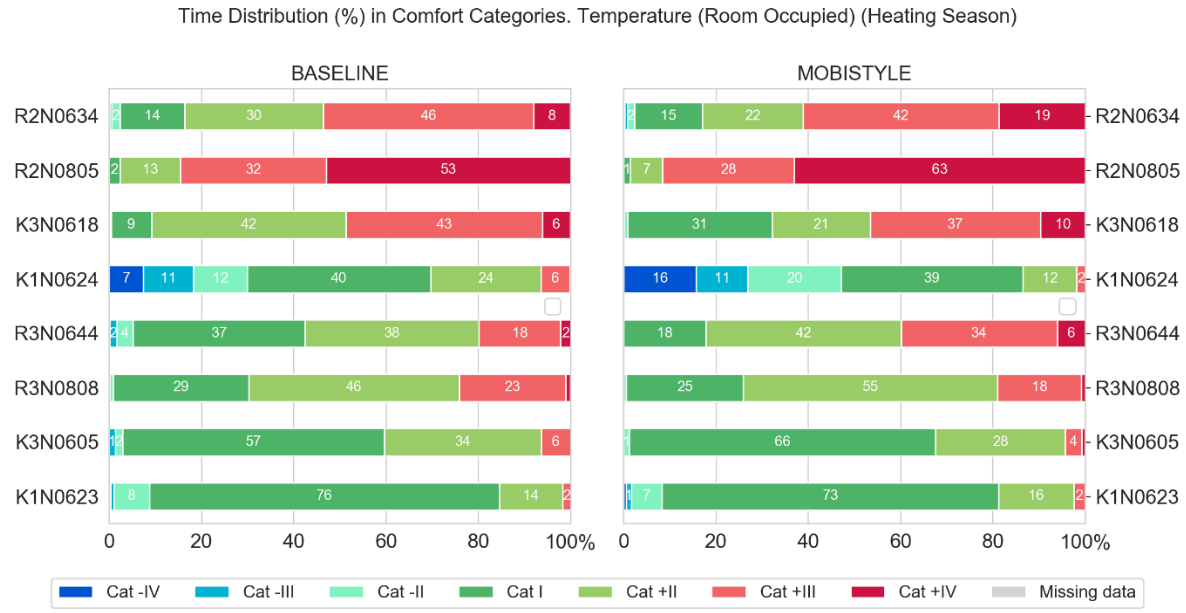


Figure 5.7: Time distribution of thermal comfort categories for the heating season of Baseline and Mobistyle period, respectively

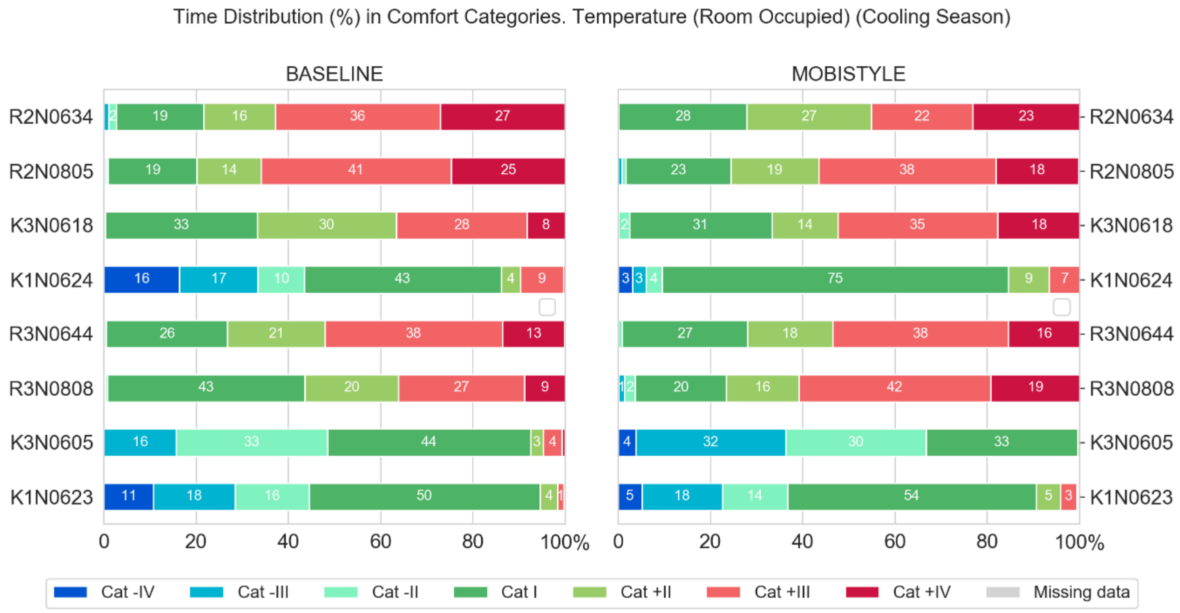


Figure 5.8: Time distribution of thermal comfort categories for the cooling season of Baseline and Mobistyle period, respectively

Figures 5.9 compares the time distribution of the indoor air quality categories (Based on CO_2) for the Baseline and the Mobistyle monitoring periods, respectively. The comfort category IV indicates CO_2 levels above 1200 [ppm]. It is seen that the indoor air quality is quite similar in the different office rooms with good indoor air quality levels obtained in about 50% of the occupied time. Levels above recommended levels are seen in about 25% of the time. Comparing the two periods an average concentration increase of 300 ppm is measured in each room (increase in 7 rooms, decrease in 1 room) from the Baseline to the Mobistyle period - leading to larger periods with unacceptable conditions (red colours).

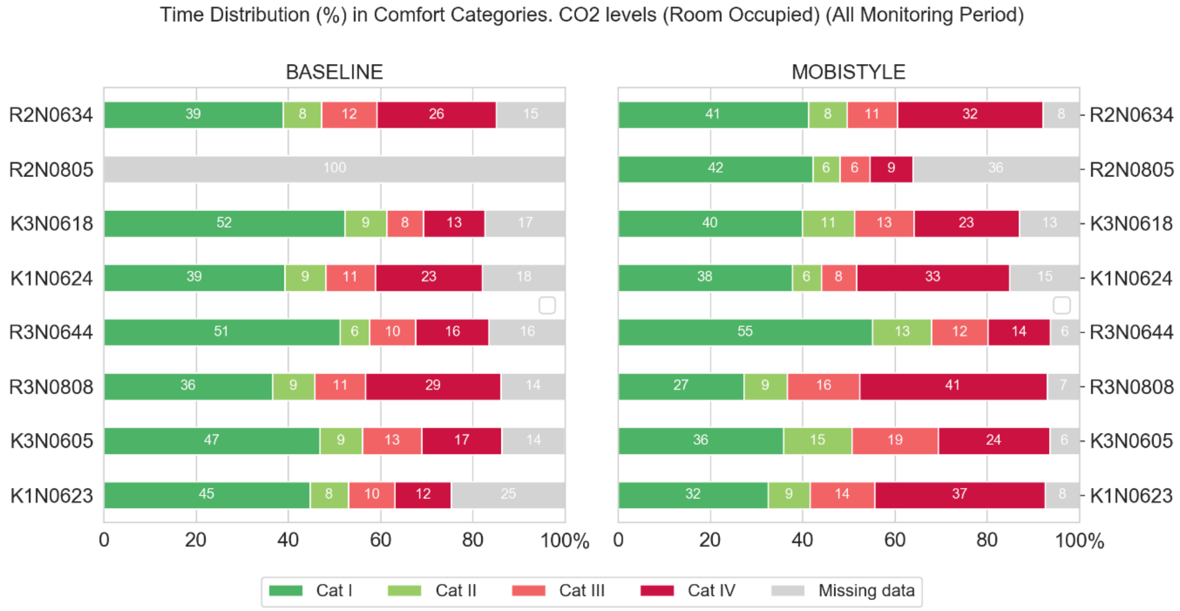


Figure 5.9: Time distribution of indoor air quality categories for the whole monitoring period of Baseline and Mobistyle period, respectively

Figures 5.10 compares the time distribution relative humidity categories for the Baseline and the Mobistyle monitoring periods, respectively. Generally high relative humidity levels (>60%) can cause thermal discomfort for the occupants. These RH levels are represented by the comfort category III+ and IV+. Overall observing the figures on monthly basis no significant issues are detected during the cooling season where RH is maintained between or 25 – 50% in the ranges of the category I and -II, +II. Only during the summer months, the RH is above 50% for a more significant percentage of time.

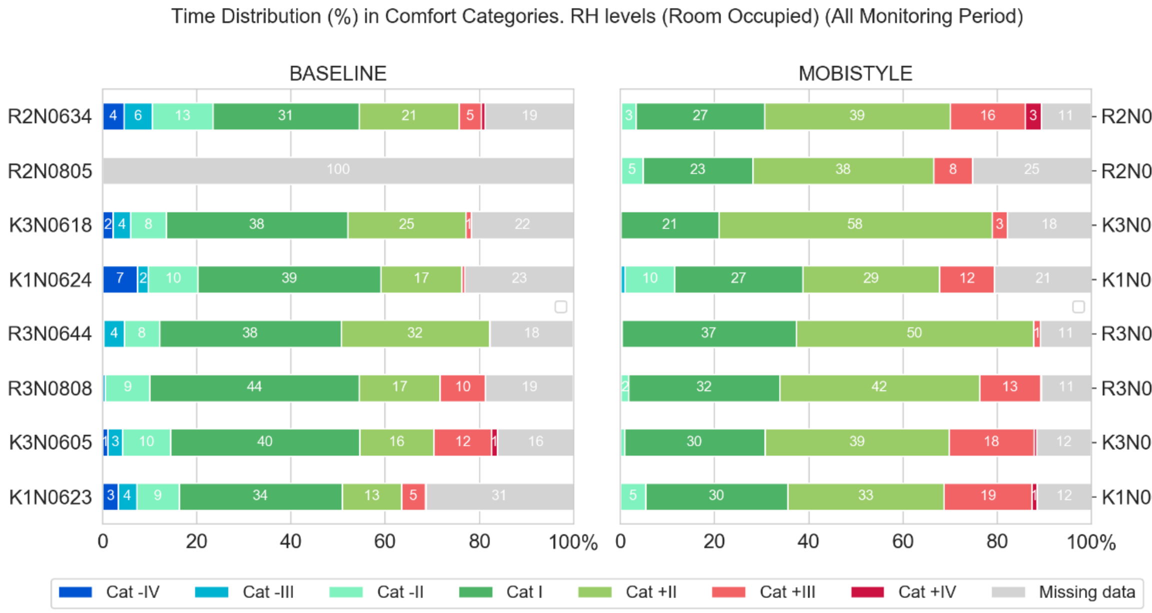


Figure 5.10: Time distribution of relative humidity categories for the whole monitoring period of Baseline and Mobistyle period, respectively

Figures 5.11 compares the time distribution of VOC categories for the Baseline and the Mobistyle monitoring periods, respectively. Comfort Category IV indicates VOC levels above 100 [ppb] where these VOC (formaldehyde) levels could cause sensory, eye and airway irritation with exposure time longer than 1 hour.

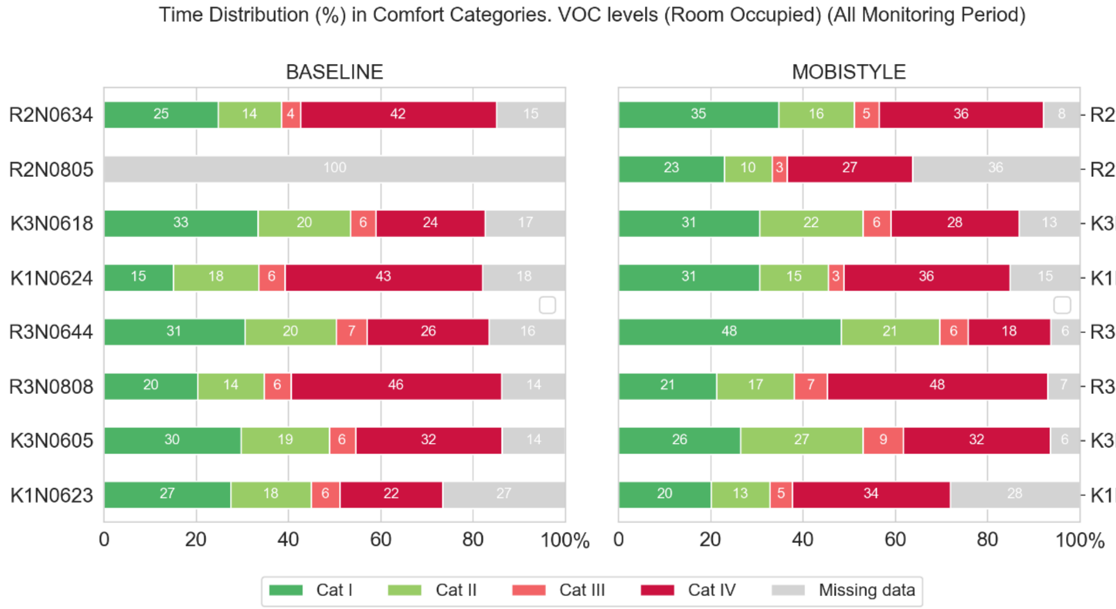


Figure 5.11: Time distribution of VOC categories for the whole monitoring period of Baseline and Mobistyle period, respectively

5.4 User behavior evaluation

University office employee behavior may change in the Mobistyle monitoring period compared to the baseline observations. This includes amount of presence in the rooms, window opening behavior and temperature setpoint regulation, which are separately presented for the heating and cooling seasons as well as for the whole monitoring periods

In order to properly compare results of both monitoring periods, room use must be also considered. For example, if during one monitoring period the employees spent similar amount of time inside the room. SCADA sensors register when the office rooms are locked/unlocked.

Figures 5.12, 5.13 and 5.14 compares the time of use of the rooms for the Baseline and the Mobistyle monitoring period for three different periods: the whole monitoring period, for the heating season and for the cooling season.

The figures show large differences between the use time each office space, as some of the rooms are used by a professor with irregular schedule, and other rooms are group rooms with more people inside and thus with more regular room use profile.

The figures also show that the room use pattern between Baseline and Mobistyle monitoring periods for the individual rooms only has a few percent difference, and therefore the energy use and indoor environmental quality between the two periods can be reasonably compared. The difference in room use between seasons is also quite small for the individual rooms.

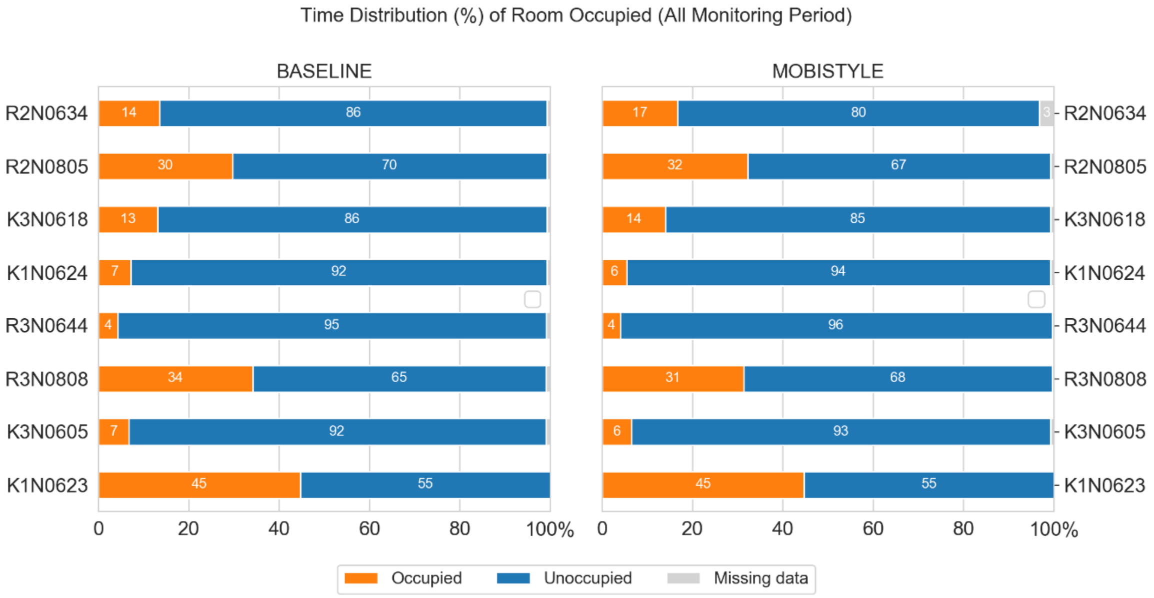


Figure 5.12: Room use time, whole monitoring period

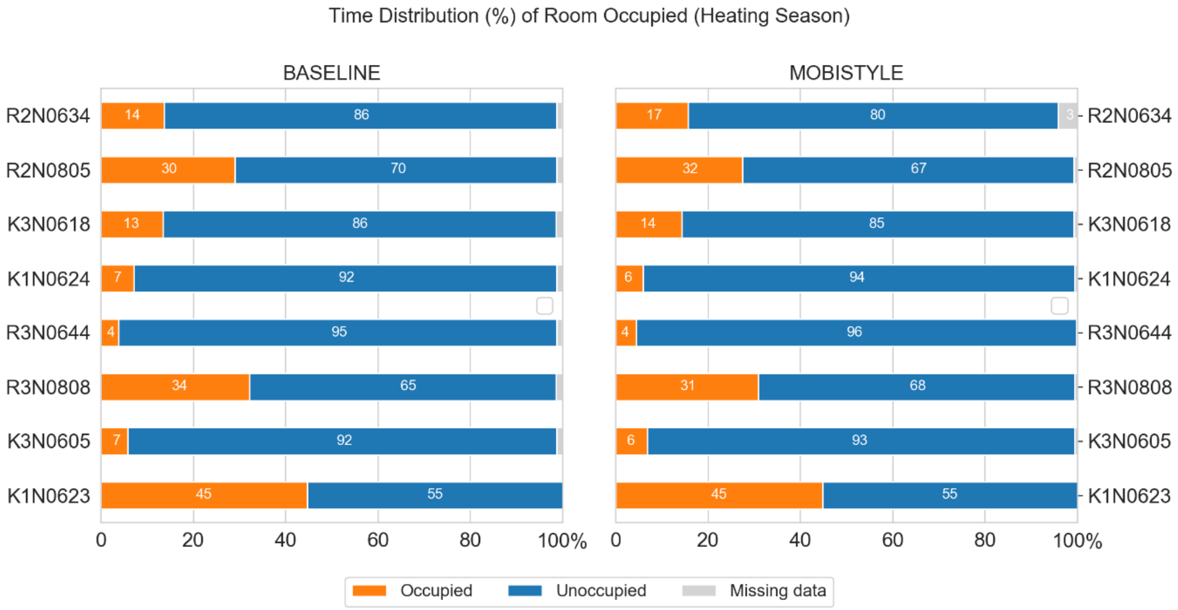


Figure 5.13: Room use time. Heating season

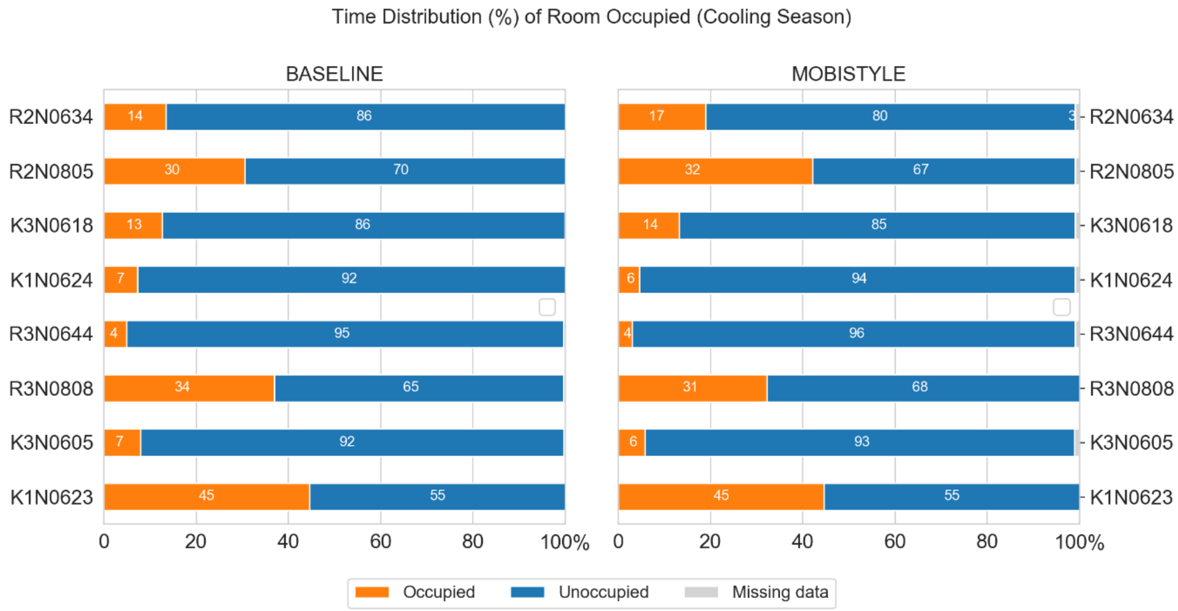


Figure 5.14: Room use time. Cooling season

Figures 5.15, 5.16 and 5.17 compares the time of window use in the rooms for the Baseline and the Mobistyle monitoring period for three different periods: the whole monitoring period, for the heating season and for the cooling season.

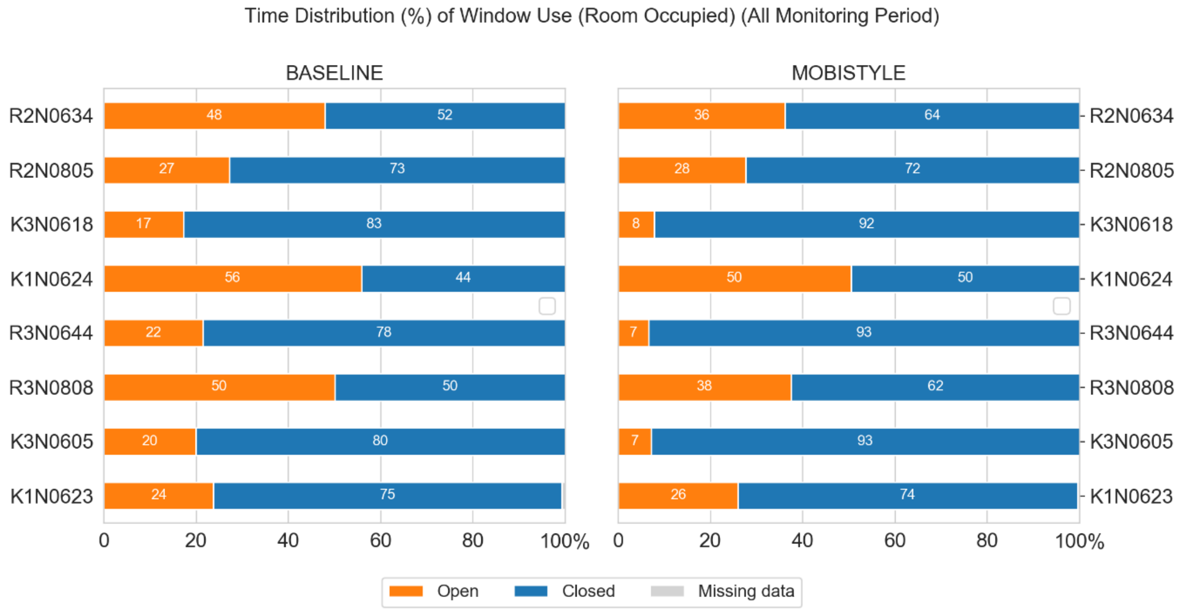


Figure 5.15: Window use. Whole monitoring period

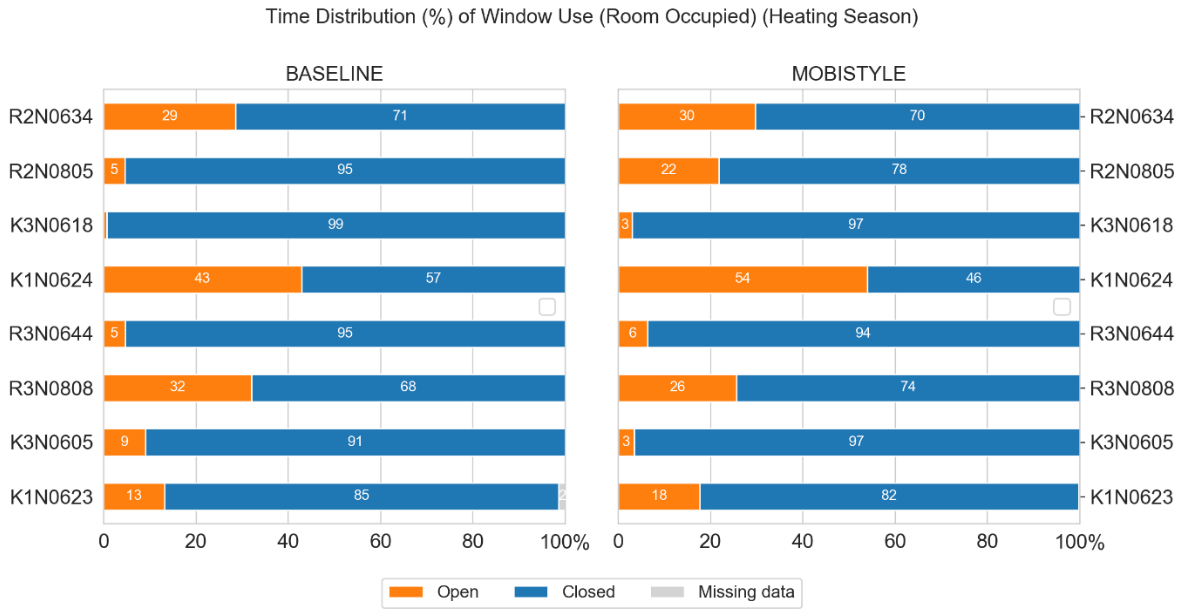


Figure 5.16: Window use. Heating season

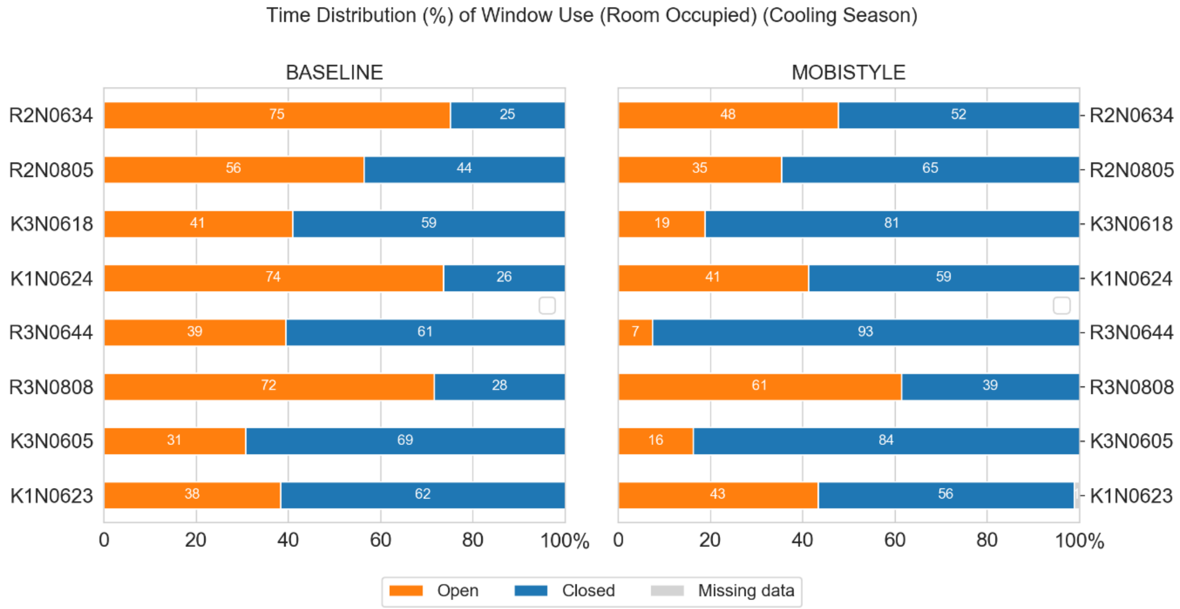


Figure 5.17: Window use. Cooling season

The window opening period depends strongly on the season and is used much more in the cooling season than in the heating season. Window opening is also very different from room to room where the windows are opened rarely in some rooms and in other rooms window are opened almost 50% of the time. By comparing the two measuring periods an average decrease in window opening from 37 % - 28% of the time in each room (increase in 2 rooms, decrease in 6 rooms) is seen. This does correspond to the increased CO_2 levels monitored in the office rooms.

Figures 5.18, 5.19 and 5.20 compares temperature set-point regulation in the rooms for the Baseline and the Mobistyle monitoring period for three different periods: the whole monitoring period, for the heating season and for the cooling season.

The results show also here a large difference between set points in the different rooms as well as between the different seasons, with higher setpoints in the cooling season than in the heating season. Generally, the setpoint is much higher than 20 ºC in the heating season and typically between 22-23 ºC, while in the cooling season the setpoint is generally about 25 – 26 ºC.

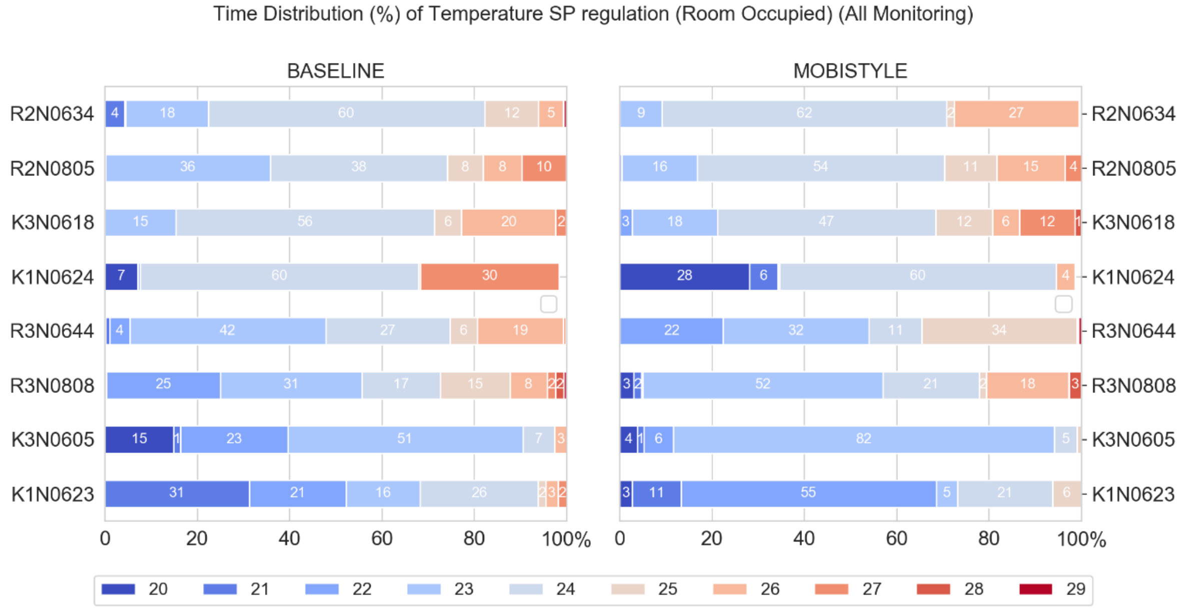


Figure 5.18: Temperature set-point regulation. Whole monitoring period.

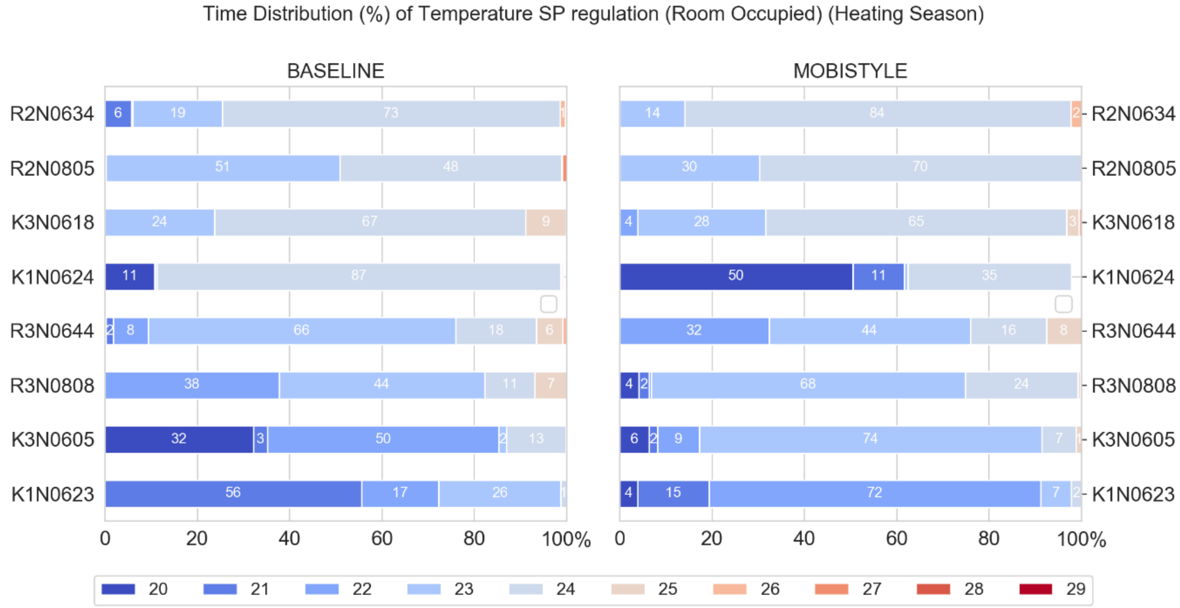


Figure 5.19: Temperature set-point regulation. Heating season

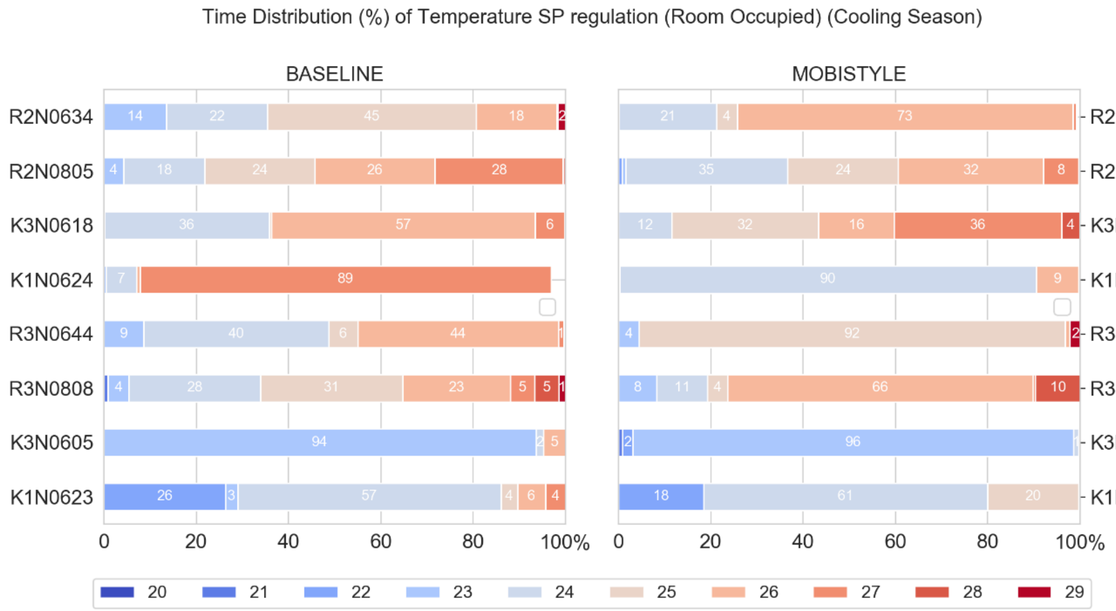


Figure 5.20: Temperature set-point regulation. Cooling season

5.5 Overall discussion and conclusions.

Indoor environmental quality and user behaviour is monitored in eight different office room.

The use time each office space is very different. Some of the rooms are used by a professor with irregular schedule, and other rooms are group rooms with more people inside and thus with more regular room use profile. The room use pattern between Baseline and Mobistyle monitoring periods for the individual rooms only has a few percent difference, and therefore the indoor environmental quality level between the two periods can be reasonably compared. The difference in room use between seasons is also quite small for the individual rooms.

The thermal comfort conditions are very different from room to room. Some rooms are overheated most of the time and especially in the heating season, while others are comfortable all year round. A few rooms suffer from undercooling, especially in the cooling season. It is seen that the indoor air quality is quite similar in the different office rooms with good indoor air quality levels obtained in about 50% of the occupied time. Levels above recommended levels are seen in about 25% of the time. On monthly basis no significant issues are detected during the heating season with regard to humidity levels. RH is maintained between or 25 – 50%. Only during the summer months, the RH is above 50% for a more significant percentage of time.

In general, the temperature level is very similar between the monitoring periods with an average temperature decrease of only 0,04 °C in each room (increase in 2 rooms, decrease in 3 rooms) from the Baseline to the Mobistyle period. However, an average concentration increase of 300 ppm is measured in each room (increase in 7 rooms, decrease in 1 room) leading to larger periods with unacceptable conditions.

The window opening period in the office rooms depends strongly on the season and is used much more in the cooling season than in the heating season. Window opening is also very different from room to room, where the windows are opened rarely in some rooms and in other rooms window are opened almost 50% of the time. By comparing the two measuring periods an average decrease in window opening from 37 % - 28% of the time in each room (increase in 2 rooms, decrease in 6 rooms) is seen. This corresponds well to the increased CO_2 levels monitored in the office rooms.

Large differences between temperature regulation set points in the different office rooms as well as between the different seasons are seen. Typically, higher setpoints are used in the cooling season than in the heating season. Generally, the setpoint is much higher than 20 ^oC in the heating season and typically between 22-23 ^oC, while in the cooling season the setpoint is generally about 25 – 26 ^oC. The differences in set-point regulation actually fit quite well with the monitored thermal comfort levels. So even if, temperature levels according to standards are evaluated as too high, it is a consequence of user actions and set-point regulation and meet occupant preferences.

6 Outcome Case 3 Hotel Residence L'Orologio

6.1 Introduction

The Italian demo case is constituted by a hotel, called "Orologio Living Apartments", which occupies a renovated historical building in a central area of Turin.

Main objective for the Italian demo case was to "monitor IEQ and electricity consumption to provide the hotel guests and staff members with feedback on energy use with guidance on how to save energy while creating a healthy and adequate indoor environment" (D3.2). The spaces involved in the project were 4 guests' rooms (configured as small apartments and therefore called "apartments" in the following) and the reception space, targeting both guests and staff members. To achieve MOBISTYLE objectives, tailored ICT (Dashboard, in Web and Mobile version) and non-ICT tools (some stickers) were developed.

Involved spaces and the timing of the distribution of informative materials and MOBISTYLE tools (ICT and non-ICT) are reported in the following table.

Table 6.3: Spaces description

Room ID	Area [m²]	Occupancy [pers.]	MOBISTYLE ICT-tools [YES/NO]	MOBISTYLE Stickers [YES/NO]	Informative materials [YES/NO]	Set of appliances
Apartment 01	~35	various	YES (22-24/07/19) [1 pers.]	YES (11/11/19)	YES (11/11/19)	TV, oven
Apartment 103	~35	various	NO*	YES (11/11/19)	YES (11/11/19)	TV, washing machine, microwave
Apartment 302	~45	various	NO*	YES (11/11/19)	YES (11/11/19)	TV, washing machine, microwave, dishwasher
Apartment 402	~45	various	NO*	YES (11/11/19)	YES (11/11/19)	TV, washing machine, microwave, dishwasher
Reception	~25	2	YES (11/11/19) [2 pers.]	YES (11/11/19)	YES** (22/07/19)	Printer, laptop

* Regardless the attempts of engagement, no guests used the ICT-tools in this apartment.

** displayed in the reception space to target guests.

Apartments have different dimensions and set of appliances. MOBISTYLE strategy was based on the deployment of ICT-tools and, from November 2019, of the so-called MOBISTYLE stickers with tips related to energy, IEQ and well-being, which were displayed in reception and apartments. Since July 2019 guests were reached by informative materials about the project displayed in reception, and from November 2019 with new ones left in their apartments. ICT-tools were used by only one guest over the duration of the project, while they were used by the staff members (receptionists) starting from 11th November 2019 till the end of the deployment, with 3 access per week on average and an average of 10 minutes spent per each access. While the reception space was occupied from the same two users for the whole duration of the project, occupancy of the apartments changed over time.

Monitored parameters in Italian demo case were identified in the first stages of the project according to a specific behavioural action plan and they were already reported as part of D6.1. To perform the evaluation, the following parameters were studied:

- Electricity consumption for appliances (in relation to apartments)
- Electricity consumption for appliances (in relation to reception)
- Temperature (in relation to apartments and reception)
- Relative Humidity (in relation to apartments and reception)
- CO_2 concentration (in relation to apartments and reception)
- Windows opening (in relation to apartments)
- Outdoor Temperature
- Outdoor Relative Humidity

Appliances in the guests' apartments were individually monitored to support the computation of the Key Performance Indicators (KPIs) displayed to users by the ICT-tools. Their consumptions are included together in the voice "Electricity consumption for apartment", that was used to perform the analyses.

6.2 Methodology

To assess MOBISTYLE outcomes, specific KPIs were identified for the two involved target groups (staff members and guests) and computed in relation to the spaces involved. As above mentioned, while the reception space was occupied by the same 2 persons for the whole project duration, apartments occupation changed over time. For this reason, all the analyses for the apartments were carried out according to a clustering approach for guests. Nine clusters were identified as the combination of two variables of occupancy:

- Guest types: single (S), couple (C), family (F)
- Duration of the stay: short (a), medium (b), long (c)

The duration of the stay was defined according to the following assumptions:

- Short stays (a); until 5 days
- Medium stays (b): between 6 and 14 days
- Long stays (c): 15 days or more

According to the above-reported assumptions, guests were grouped in the 9 clusters to perform the analyses. As a consequence, all the computed KPIs are reported as function of cluster of guests. Distribution of stays in the different clusters is reported in the following pie chart.

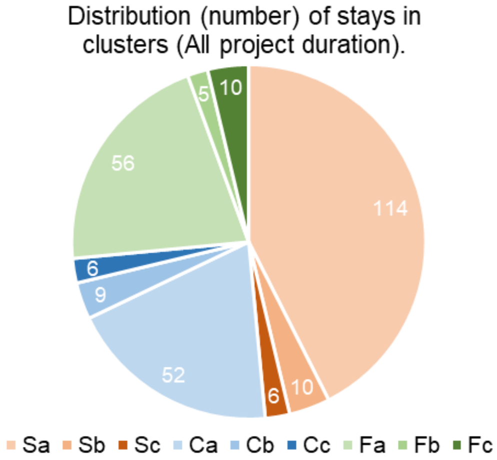


Figure 6.1: Distribution of the total number of stays in the 9 identified clusters of guests

Given this methodological framework, all identified KPIs for energy and IEQ evaluation were computed in the Baseline (corresponding to M0, according to D3.3) and the MOBISTYLE period (M1 and M2) for comparison. For the Italian demo case, description of M0, M1 and M2 requires a particular attention.

In particular, feedback monitoring period **M1** corresponds to the time when the MOBISTYLE strategy targeting guests and based on ICT-tools deployment was put in place, namely from 22nd July 2019. In this period only 1 guest used to ICT-tools. All the other guests were informed about the project thanks to flayers displayed in the reception space.

Feedback monitoring period **M2** saw the beginning of a new engagement strategy, from 11th November 2019, when also non-ICT tools (MOBISTYLE stickers) were deployed to specifically target both guests and staff members.

In summary, **guests (G)** were reached by MOBISTYLE since July 2019 (for a total of 32 weeks), with a change in strategy in November 2019, while **staff members (SM)** since November 2019 (for a total of 16 weeks), thanks to the new engagement strategy. Equal length of monitoring period is selected as baseline to perform the evaluations for reception, while all data gathered before ICT-tools deployment were used to build a solid baseline for guests' clusters. Monitoring periods are depicted in the following figure.

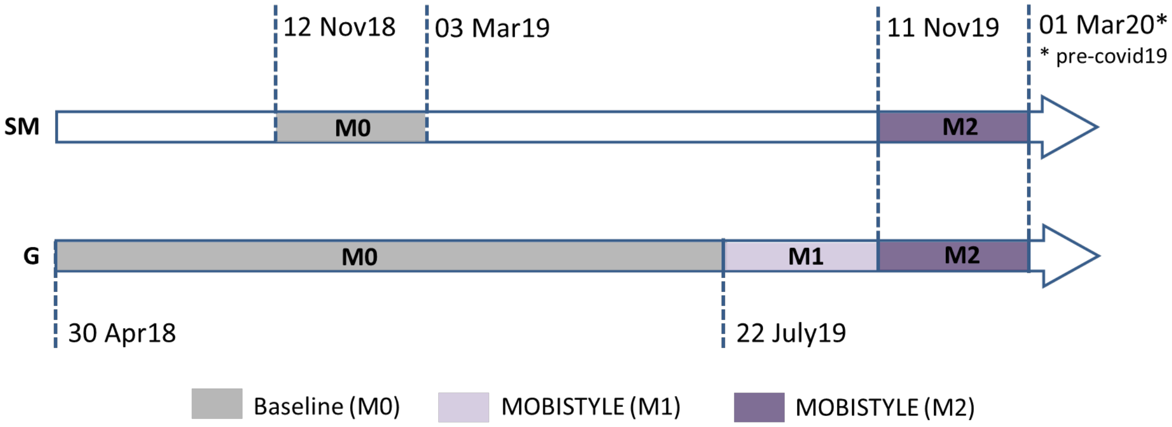


Figure 6.2: Representation of monitoring periods for Staff members (SM) and guests (G) target groups. Dates of beginning and end of monitoring periods are adjusted to be always on Monday and Sunday, respectively, accounting for an exact number of weeks. *March20 was excluded because of the Covid-19 situation.

In relation to M1 period, evaluation was aimed to assess possible impacts of informative materials and general communication on the project targeting guests. In M2 period, evaluation was aimed to assess possible impacts of the introduction of MOBISTYLE stickers, targeting both staff members and guests. New informative material was also displayed to support the engagement. In M2, weekly meetings with the staff members were also successful in making them engaged in using the Dashboard, so outcomes for reception space can be related also to interaction with ICT-tools. On the contrary, only one guest (in M1) used the ICT-tools over the whole duration of the project. More granular analyses related to his stay were performed separately.

Main conclusions obtained are summarized in the following for each target group.

6.3 Results and conclusions

RECEPTION

Baseline (M0): 12th November18 – 3th March19
*MOBISTYLE (M2): 11th November 19 – 1st March20**

Evaluation interested only heating season, since the deployment of MOBISTYLE ICT-tools took place between November 2019 and February 2020.

ENERGY

Energy evaluation focused on **electricity consumptions** for printer and laptop.
The electricity consumption of the printer represents always more than 90% of the total electricity consumptions. It is possible to read a huge difference in consumptions between the M0 and M2 periods in relation to the laptop. This data requires a specific attention to be explained. Reasons for this discrepancy are found in: i) Change of laptop; ii) Use of the smart plug. Thanks to interviews with the receptionists, it was observed that, during the baseline period (M0), they were not using the smart plug properly. For this reasons and in light of the high impact of the printer on the overall electricity consumptions, all the analyses (in terms of identified KPIs) for the reception space were focused only on the printer.

Differently than the smart plug for the laptop, the one for printer was hidden and not accessible to the users, so the monitoring was always continuous.
During MOBISTYLE period (M2), a 9.14% energy savings is observed compared to baseline (M0). The total consumption over 16 weeks is 5.77 kWh smaller than the total consumption registered in M0, resulting in 2.50 kg of CO_{2eq} avoided and 1.21 € saved. This result can be translated in a potential saving of 18.8 kWh over one year and can be easily explained as a more efficient and responsible use of the appliance.

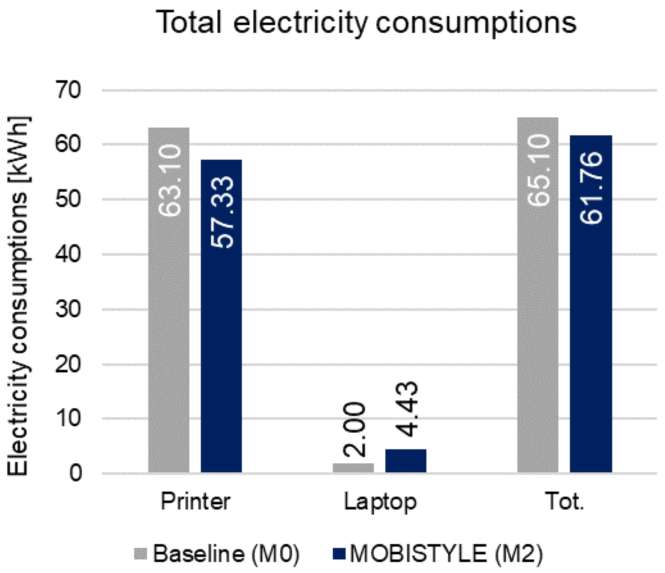


Figure 6.3: total electricity consumptions (per each appliance and total) for baseline (M0) and MOBISTYLE (M2) periods

Table 6.4: total and percentage savings in terms of electricity, emissions and costs for the printer in MOBISTYLE period (M2) compared to baseline (M0)

Description	**Savings**			
	Electricity [kWh]	**Emission* [kg_{CO2eq}]**	**Cost** [€]**	**%**
Printer	5.77	2.50	1.21	**9.14 %**

* emission factor equals to 0.4332 kg_{CO2eq}/kWh
** electricity energy price (tax included) equals to 0.21 €/kWh

Beside to the use of the Dashboard, this outcome of the project can be also related to a specific MOBISTYLE sticker suggesting switching off the printer which was pasted in the reception space during M2 period.

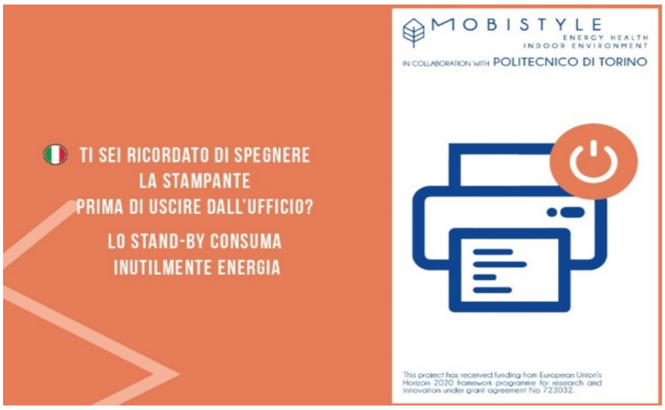
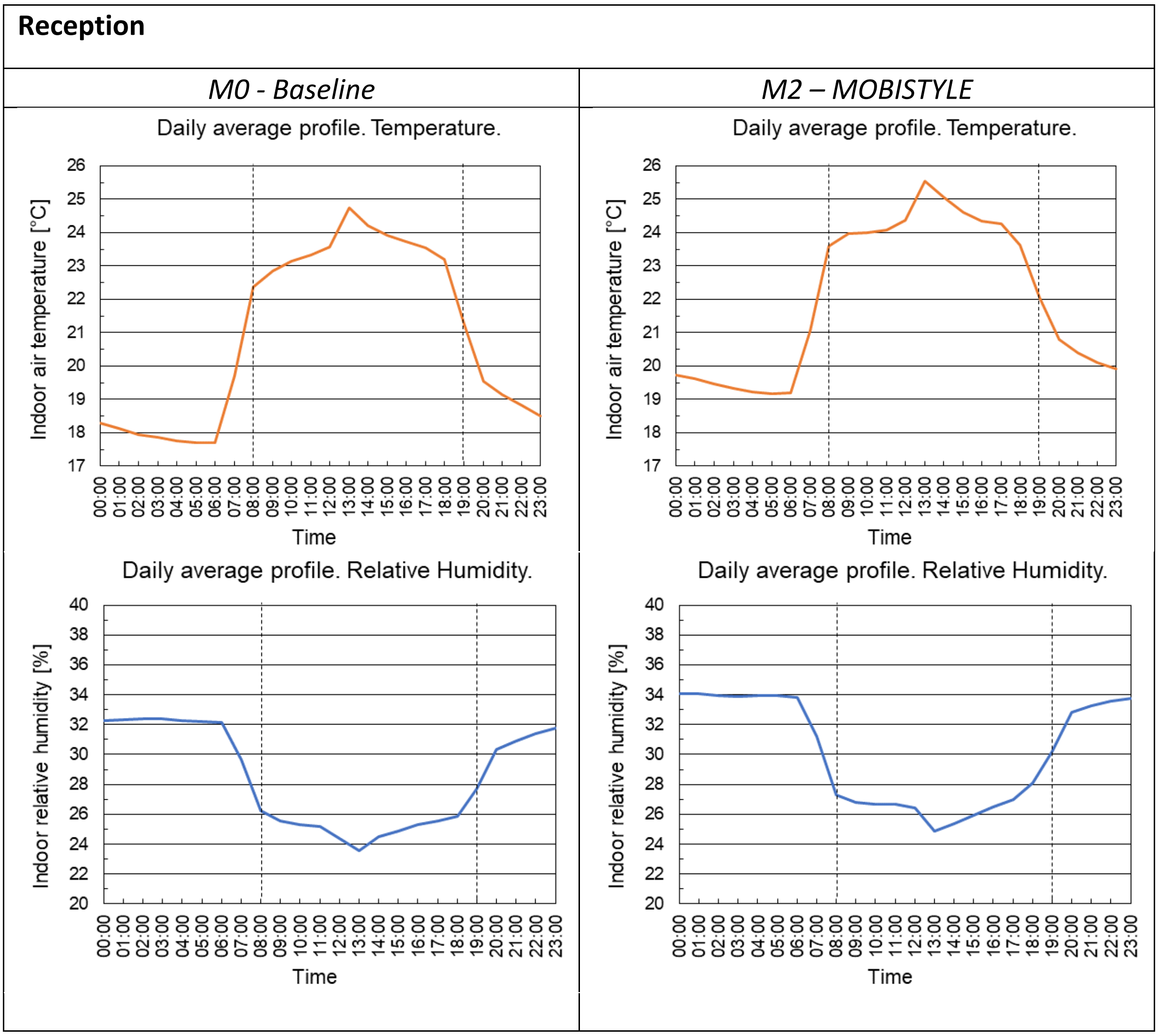


Figure 6.4: MOBISTYLE sticker suggesting switching off the printer. It was displayed in reception space during M2.

INDOOR ENVIRONMENTAL QUALITY

In terms of IEQ, **Temperature** (T), **Relative Humidity** (RH) and **CO_2 concentration** (CO_2) were monitored and analysed. IEQ evaluation was performed considering only occupied hours assumed from working schedules (8am-7pm from Monday to Friday and from 8am to 12am on Saturday).

Hourly values for T and RH are on average higher in M2 period if compared to baseline (M0) (Figure 6.5). This results in less time spent in comfort category I in terms of T (from 19% to 17%, Figure 6.6), but more time spent in comfort category I in terms of RH (from 20% to 31%, Figure 6.7). However, data loss in baseline (M0) period are affecting results.

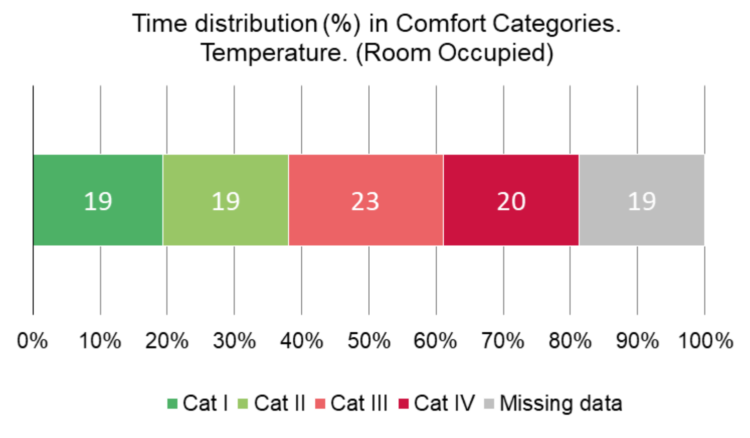


NB: Dotted lines delimit occupied period

Figure 6.5: Daily average profiles of T and RH over M0 and M2 periods

Reception – Temperature

M0 - Baseline



M2 - MOBISTYLE

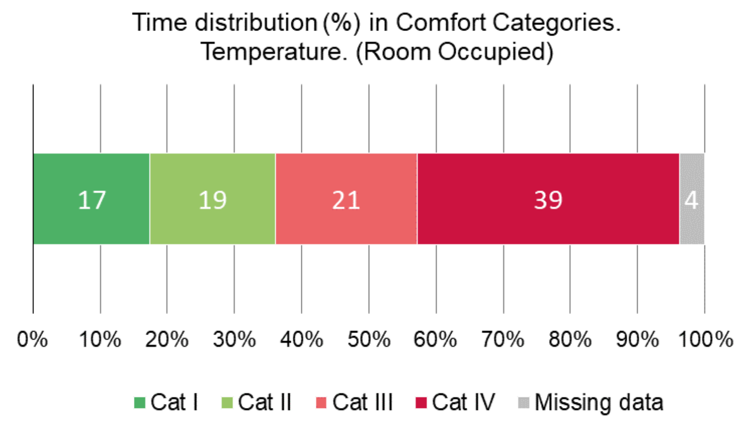
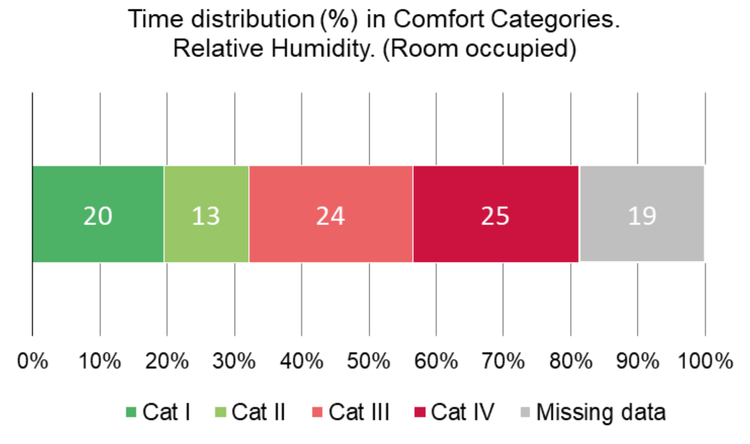


Figure 6.6: Time percentage distribution in comfort categories in terms of T during occupied hours.

Reception – Relative Humidity

M0 – Baseline



M2 - MOBISTYLE

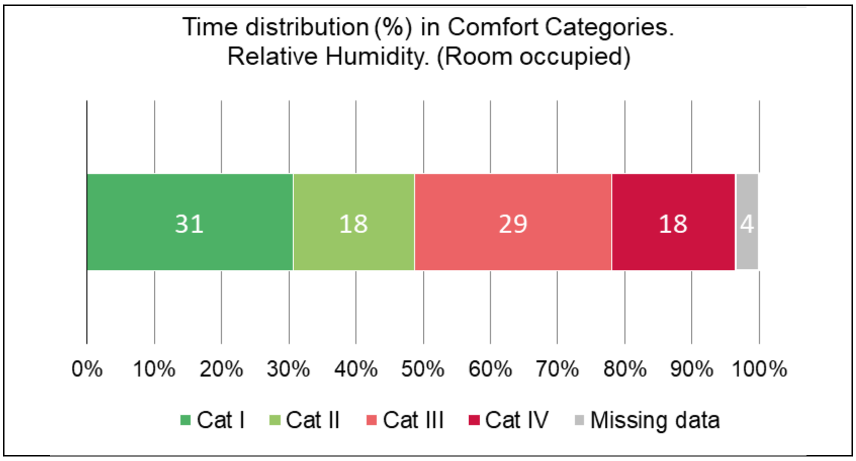
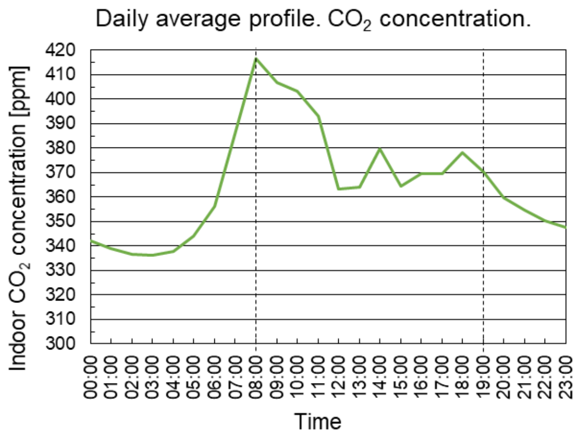
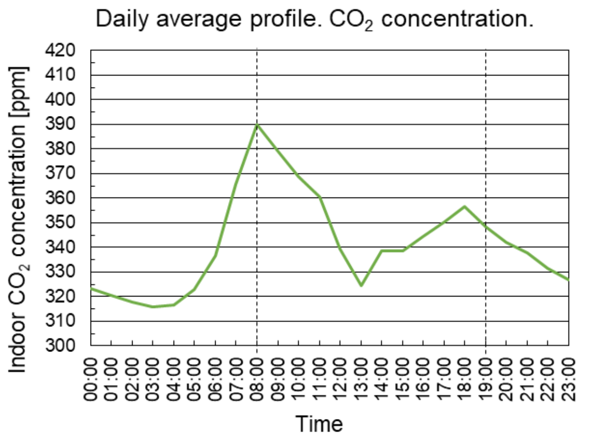


Figure 6.7: Time percentage distribution in comfort categories in terms of RH during occupied hours.

The most significant result is observed in terms of CO_2 concentration. Even if concentration is never high (thanks to receptionists' habit to keep internal door open and to natural ventilation brought by the continuous affluence of people from outside, as understood by personal interviews with the staff), it results even lower in M2 compared to M0 (Figure 6.8). Since the occupation (in terms of hours and number of people) did not change between M2 and M0, a better ventilation can be considered as the cause for lower CO_2 concentration when the two periods are compared.

Reception	
M0 - Baseline	*M2 – MOBISTYLE*
	

NB: Dotted lines delimit occupied hours.

Figure 6.8: Daily average profiles of CO_2 concentration over M0 and M2 periods

Thanks to the understanding of Dashboard actual usage, habits and feedbacks reported personally from the staff members it is possible to conclude the following.

- Despite the interest that staff members self-reported about watching Temperature and Relative Humidity trends thanks to the Dashboard, they did not learn to improve these two parameters.
- Results in terms of lower CO_2 concentration in M2 compared to M0 can be related to the MOBISTYLE sticker displayed in the reception in period M2, that highlights the

importance of a good ventilation in preventing negative impacts of the indoor environment on health.
- Possibly stickers have bigger impact than ICT-tools because they are easily visible without necessity to open an app on a device. Indeed, staff members stated that the poor interest for a more active use of ICT-tools has to be found in the lack of their integration with other services.

Figure 6.9: MOBISTYLE stickers suggesting opening the window. It was displayed in reception space during M2.

APARTMENTS

Baseline (M0): 30th April18 – 21st July19
MOBISTYLE (M1): 22nd July19 – 10th November19
*MOBISTYLE (M2): 11th November19 – 1st March20**

Since variables analysed are seasonally dependents[1], all the identified KPIs were computed for cluster of guests keeping separated heating and non-heating periods, defined by Italian regulation as:

- Heating season: 15th October – 15th April
- Non-heating season: 16th April – 14th October

ENERGY

Energy consumption evaluation was performed using as parameter "**Electricity consumption for apartment**".

Provide for overall conclusions about potential energy savings in a hotel where occupation was changing over time is challenging; it's for this reason that different clusters were defined and analysed. Starting from total electricity consumptions for the different monitoring periods, further analyses were performed to assess consumptions per stay (still affected from variability in length of stays within each cluster, and especially for long stay "c") and average daily electricity consumptions. Analysing how average daily consumptions changed in M1 and M2 in comparison to M0, it was possible to outline some considerations.

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[1] Indoor parameters are influenced by seasons, and also electricity consumptions they included fan coils.

Clusters related to medium stays (Sb, Cb, and Fb) were not well populated because few medium stays occurred. As a consequence, it was considered more relevant to look at short and long ones.

In non-heating period, when MOBISTYLE (M1) and baseline (M0) periods are compared, the only observed energy savings in terms of average daily consumption is for Sc (Table 6.3). However, the result cannot be related to the use of the ICT-tools because no guests belonging to this cluster used them.

Table 6.5: daily and percentage savings in terms of electricity, emissions and costs for clusters of guests in MOBISTYLE (M1) with respect to baseline (M0) – non-heating period

Cluster ID	Savings M1				Savings M2			
	Electricity [kWh]	Emission* [kgCO$_{2eq}$]	Cost** [€]	%	Electricity [kWh]	Emission* [kgCO$_{2eq}$]	Cost** [€]	%
Sc	1.070	0.464	0.225	20%	NA	NA	NA	NA
Cc	NA	NA	NA	NA	NA	NA	NA	NA
Fc	0.144	0.062	0.030	4.1%	NA	NA	NA	NA

NA: not applicable, meaning that the cluster is not covered, or the period is not included

* emission factor equals to 0.4332 kg$_{CO2eq}$/kWh

** electricity energy price (tax included) equals to 0.21 €/kWh

Heating season

In heating season, when MOBISTYLE (M1-M2) and baseline (M0) periods are compared, the only significant energy savings in terms of average daily consumption is observed for Sa (Table 6.4). However, the result cannot be related to the use of the ICT-tools because no guests belonging to this cluster used them in this period.

Table 6.6: daily and percentage savings in terms of electricity, emissions and costs for clusters of guests for MOBISTYLE (M1, M2) with respect to baseline (M0) – heating period

Cluster ID	Savings M1				Savings M2			
	Electricity [kWh]	Emission* [kgCO$_{2eq}$]	Cost** [€]	%	Electricity [kWh]	Emission* [kgCO$_{2eq}$]	Cost** [€]	%
Sa	0.696	0.302	0.146	14%	1.042	0.451	0.219	21%
Ca	0.764	0.331	0.160	20%	-0.466	-0.202	-0.098	-12%
Fa	-1.004	-0.435	-0.211	-28%	-0.568	-0.246	-0.119	-16%

NA: not applicable, meaning that the cluster is not covered

* emission factor equals to 0.4332 kg$_{CO2eq}$/kWh

** electricity energy price (tax included) equals to 0.21 €/kWh

In M2 period, when stickers were introduced, less daily average consumptions are observed for Sa and Fa if compared to M1 period (referring to MOBISTYLE periods without stickers), as shown in Figure 6.10.

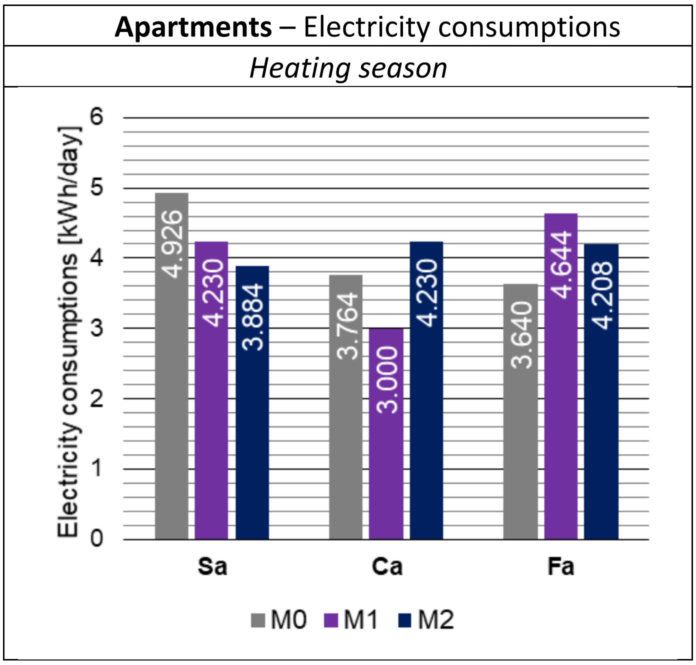


Figure 6.10: average daily electricity consumption per short stays clusters of guest for baseline (M0) and MOBISTYLE (M1, M2) – heating period

Most of the observed outcomes involves singles and short stays. Since medium and long stays refer mostly to regular customers, it is possible to conclude that it is easier to get attention from occasional guests.

A FOCUS on the only guest using the ICT-tools (belonging to cluster Sa) shows that his electricity consumption per stay was 11.7% smaller than the average registered in the same period of his stay for his cluster, and that (over 3 days) a saving of 0.471 kWh was achieved compared to baseline (Table 6.5).

Table 6.7: average daily consumption related of the guest who used the ICT-tools in M1 – non-heating period and savings obtained comparing him with his cluster in baseline (M0) and MOBISTYLE (M1) period

Description	**(M0)**				**(M1)**			
	Electricity [kWh]	**Emission* [kgCO$_{2eq}$]**	**Cost** [€]**	**%**	**Electricity [kWh]**	**Emission* [kgCO$_{2eq}$]**	**Cost** [€]**	**%**
Daily average consumption of MOBISTYLE guest	NA	NA	NA	NA	3.333	1.444	0.700	NA
Savings compared to cluster Sa	0.471	0.204	0.099	12.4%	0.463	0.200	0.097	12.2%

NA: not applicable; MOBISTYLE guest using the ICT-tools stayed at the hotel in M1 period.

* emission factor equals to 0.4332 kg$_{CO2eq}$/kWh

** electricity energy price (tax included) equals to 0.21 €/kWh

INDOOR ENVIRONMENTAL QUALITY

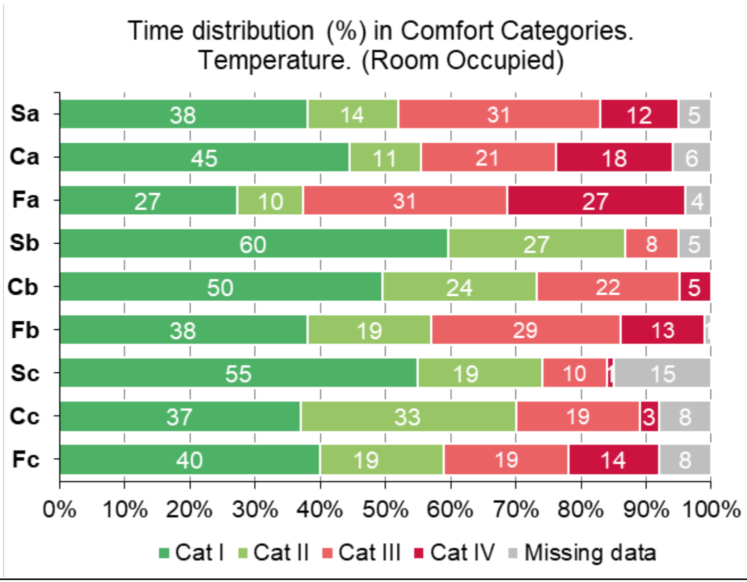
In terms of indoor parameters, the Italian case study focused on **Temperature** (T), **Relative Humidity** (RH) and **CO_2 concentration** (CO_2). IEQ evaluation was performed considering only occupied hours (assumed from standard as before 9am and after 7pm) of days with a reservation (as reported by staff members in anonymous way).

Non - heating season

Concerning non-heating season, time spent in comfort category I in terms of temperature is higher in almost all clusters in MOBISTYLE (M1) period if compared to baseline (M0), as shown in Figure 6.11**.** Accordingly, hourly values of T correspond more frequently to lower temperatures in M1 than in M0.

Apartments – Temperature – Non-heating period

M0 - Baseline



M1 - MOBISTYLE

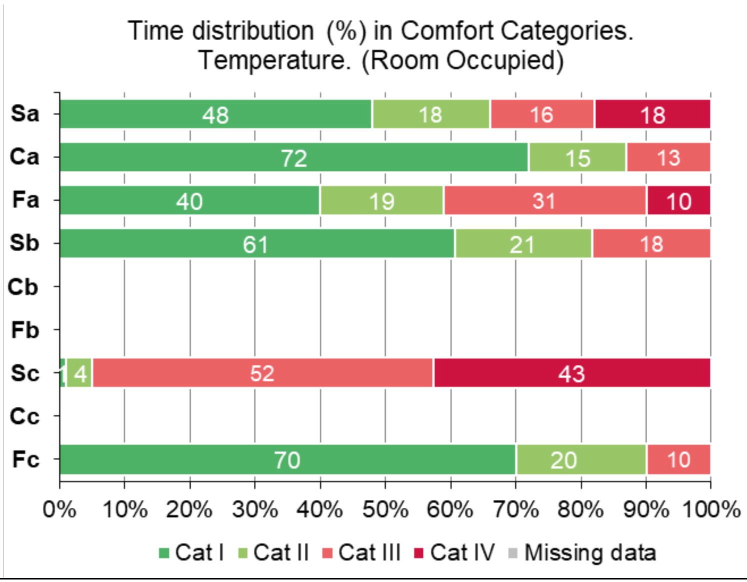


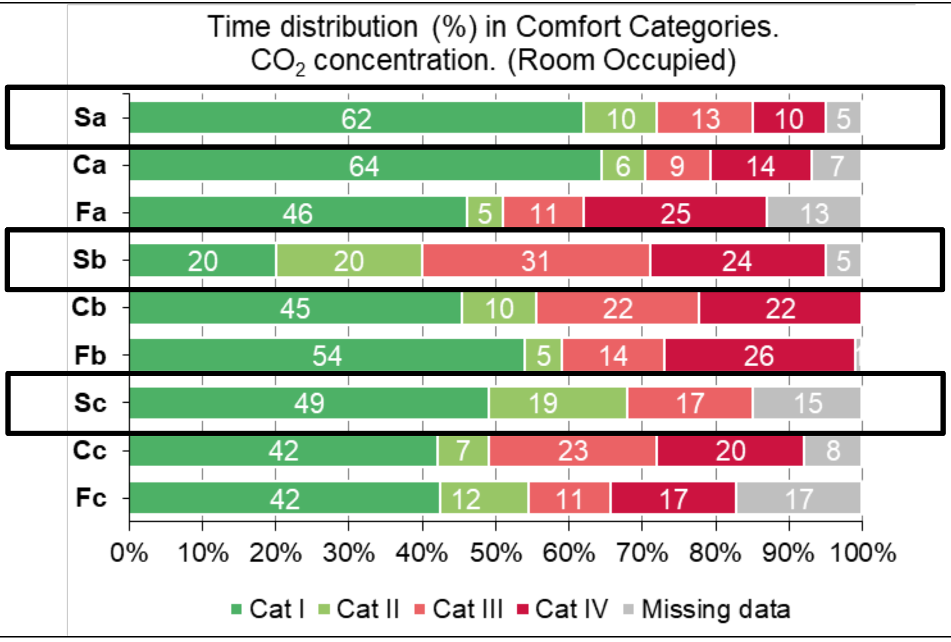
Figure 6.11: Time distribution (%) in comfort categories in terms of T during occupied hours – non-heating period.

However, the result can be influenced by outdoor temperature. Indeed, except for Sa and Sc, outdoor temperatures (in terms of daily average in occupied hours) are higher in M0 than in M1. Result can be affected by the use of the ICT-tools only for Sa. No guests belonging to other clusters used them. The only cluster (Sb) for which less time in comfort category I in terms of Temperature is observed is also the only one which spent more time in comfort category I in terms of RH. Accordingly, it is the only one for which hourly values of RH correspond more frequently to lower relative humidity in M1 than in M0. However, the result cannot be related to the use of the ICT-tools because no guests belonging to Sb used them.

Singles (Sa, Sb and Sc clusters) show more time spent in comfort category I and II in terms of CO_2 concentration in MOBISTYLE (M1) period compared to baseline (M0), as shown in Figure 6.12.

Apartments – CO_2 concentration – Non-heating period

M0 - Baseline



M1 - MOBISTYLE

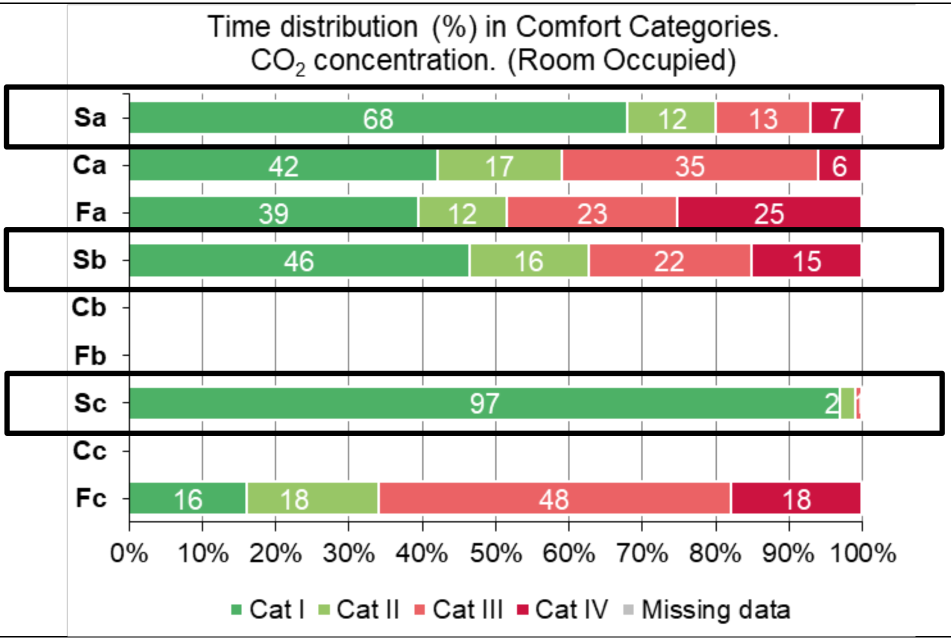


Figure 6.12: Time distribution (%) in comfort categories in terms of CO_2 concentration during occupied hours – non-heating period.

Results cannot be related to the use of the ICT-tools. No guests used them except for a guest belonging to Sa. Thus, only outcomes related to Sa are partially affected by the use of the ICT-tools, but only in relation to the stay of the guest using them.

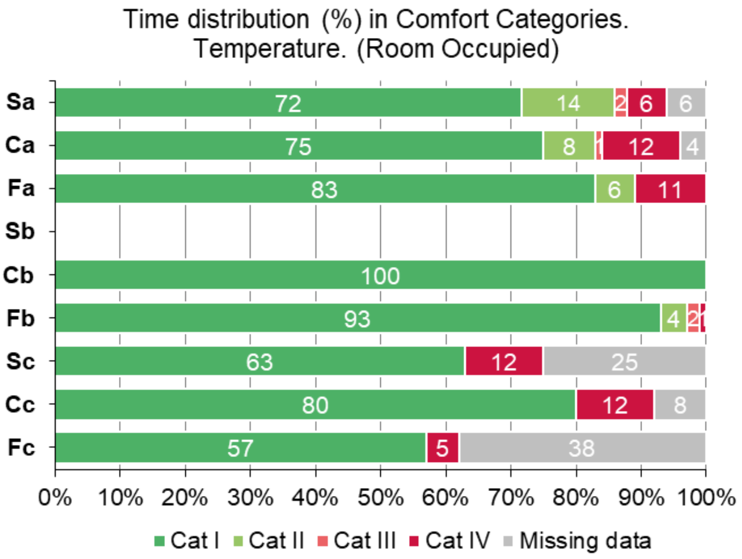
Heating season

During heating season and concerning **Temperature**, Sa is the only cluster whose time spent in comfort category I is always higher in both MOBIYSTLE periods (M1-M2) if compared with baseline (M0), changing from 72% to 83%, as shown in Figure 6.13. Ca and Fc also show more time spent in comfort in M1 compared to M0, even if Fc is characterized by a high percentage of missing data in M0. However, the result cannot be related to the use of the ICT-tools, because no guests belonging to these clusters used them in this period.

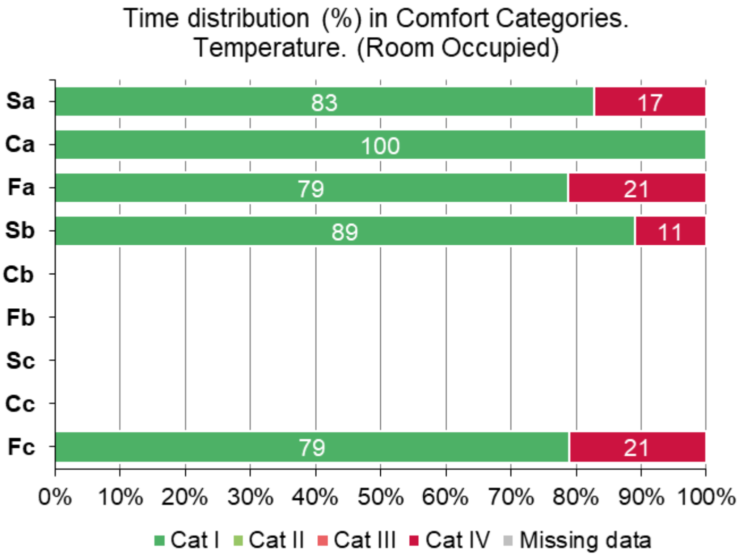
It is possible to observe that Sa and Sb have higher time spent in thermal comfort category I and II in M2 when MOBISTYLE stickers were introduced than in M1 (referring to MOBISTYLE period with no stickers displayed). Moreover, high percentage of time spent in non-comfort (category IV) is due to overheating more than to too cold temperatures. For Sa time in Cat IV changed from 17% in M1 to 7% in M2 and for Sb time in Cat IV changed from 11% in M1 to 0% in M2. This thermal comfort increase can be the result of a MOBISTYLE sticker displayed in apartments that suggests keeping lower setpoint (“*Do you know that excessive indoor temperatures could negatively affect your health? 21°C is a pleasant temperature*”).

Apartments – Temperature – Heating period

M0 - Baseline



M1 - MOBISTYLE



M2 – MOBISTYLE

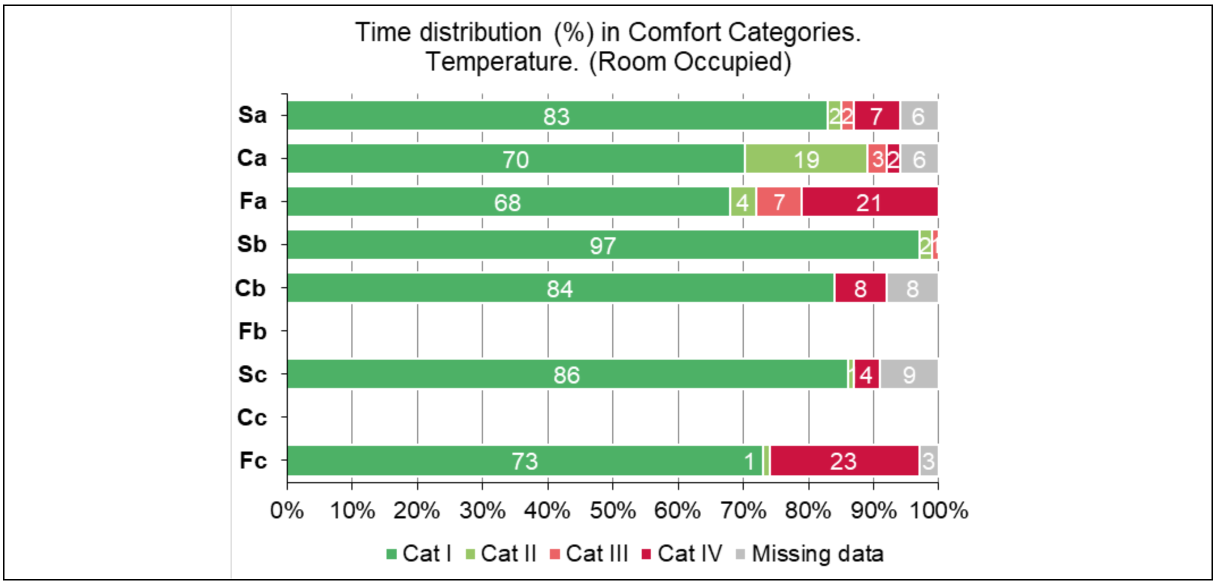


Figure 6.13: Time percentage distribution in comfort categories in terms of indoor air temperature during occupied hours – heating period.

Sa, Sb and Fa also show hourly mean temperatures more frequently shifted to lower values in M2 compared to M1 (Figure 6.14).

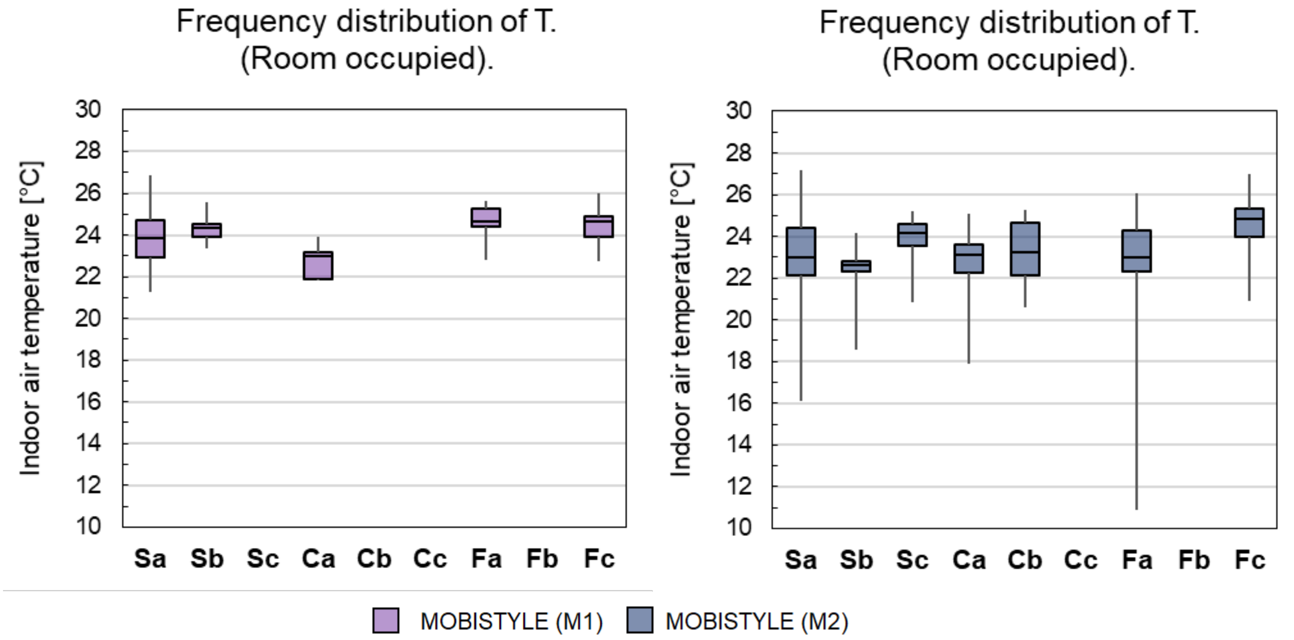
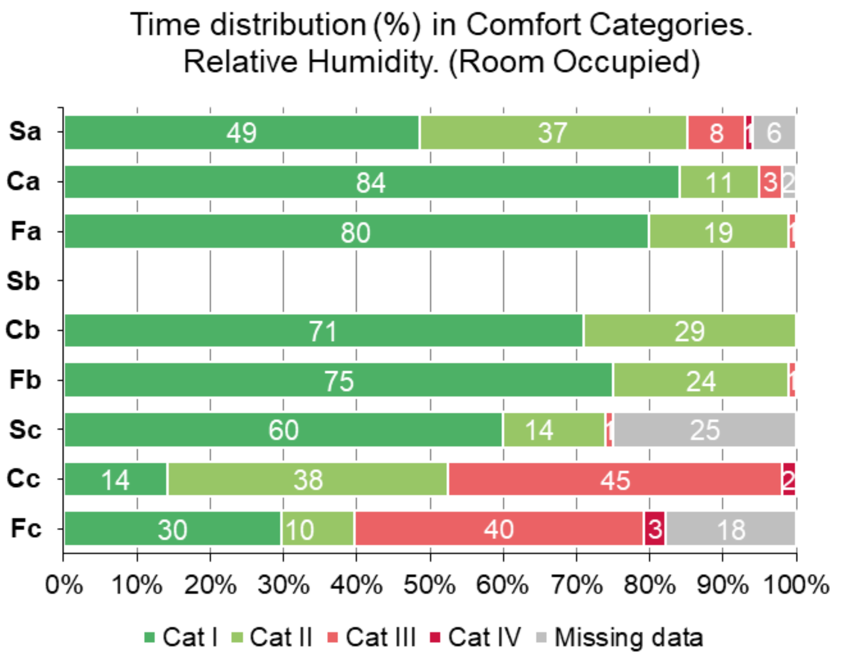


Figure 6.14: Frequency distribution of hourly values of Temperature in occupied hours in MOBISTYLE (M1) and MOBISTYLE (M2) – heating period

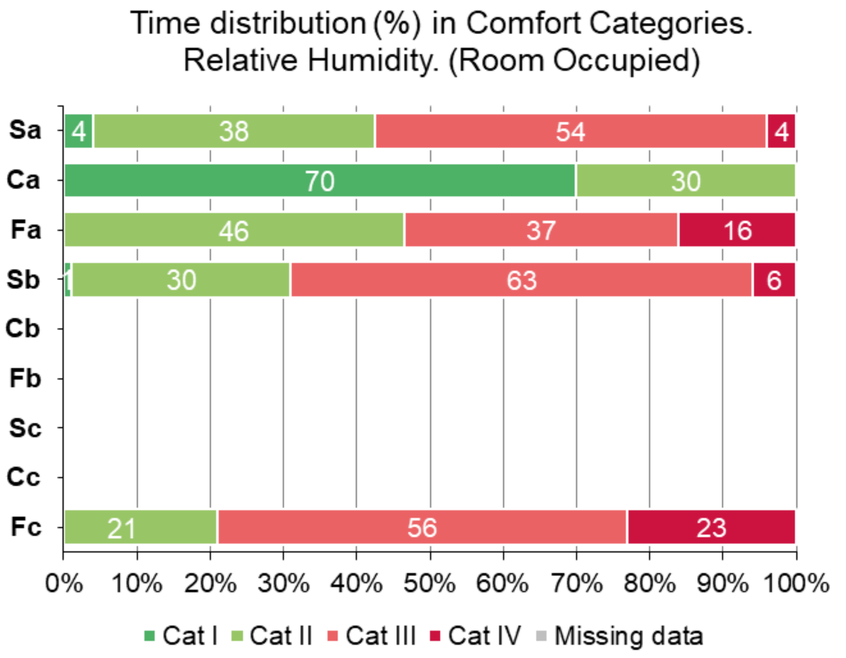
In term of **Relative Humidity**, for almost all clusters time spent in comfort category I is less in M1 period than in baseline M0, while it is higher in M2 than in M0. Moreover, for all the clusters comparison between M2 and M1 shows more time spent in comfort category I during M2 period, as shown in Figure 6.15. These results cannot be related to the use of the ICT-tools because no guests used them in this period, but it’s related to the placement of the stickers.

Apartments – Relative humidity – Heating period

M0 - Baseline



M1 - MOBISTYLE



M2 – MOBISTYLE

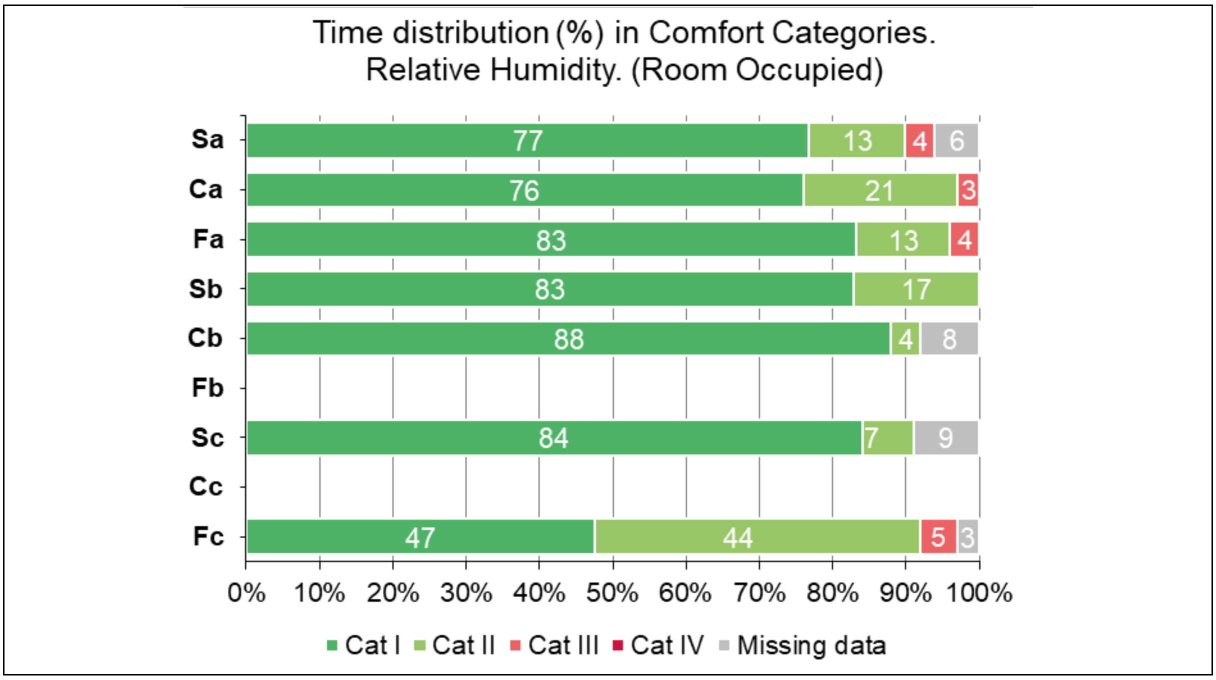


Figure 6.15: Time percentage distribution in comfort categories in terms of Relative Humidity during occupied hours – heating period.

Looking the frequency distribution for RH (Figure 6.16), it is possible to observe that hourly values are in general lower in M2 compared to M1; the same is applicable to daily mean outdoor relative humidity, which were lower in M2 compared to M1.

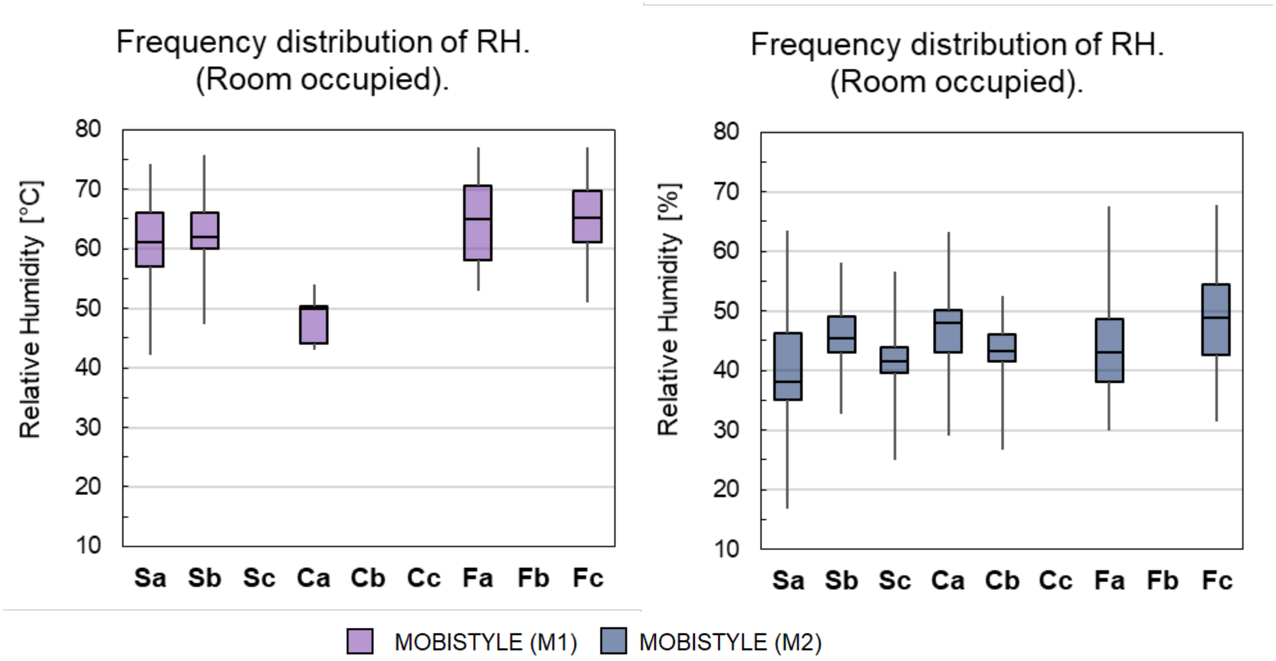
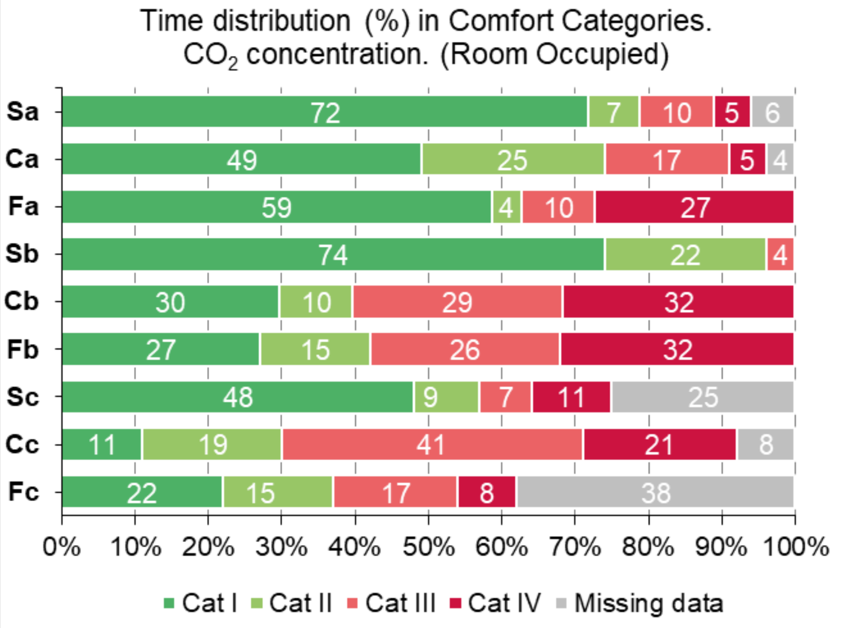


Figure 6.16: Frequency distribution of hourly values of Relative Humidity in occupied hours in MOBISTYLE (M1) and MOBISTYLE (M2) – heating period

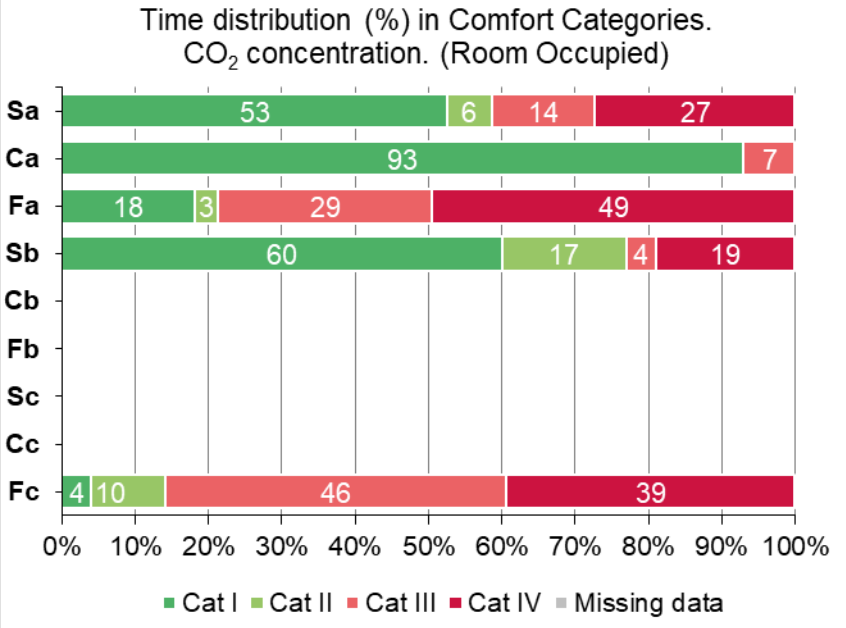
Concerning **CO$_2$ concentration**, Ca is the only cluster with higher time spent in category I in M1 compared to M0, as shown in Figure 6.17. However, the result cannot be related to the use of the ICT-tools because no guests belonging to this cluster used them in this period. Sa, Fa and Fc have higher time spent in comfort category I after stickers deployment in M2 than in M1 (MOBISTYLE period before stickers introduction). MOBISTYLE stickers achieved success in increasing conditions in terms of CO$_2$ concentration.

Apartments – CO$_2$ concentration – heating period

M0 - Baseline



M1 - MOBISTYLE



M2 – MOBISTYLE

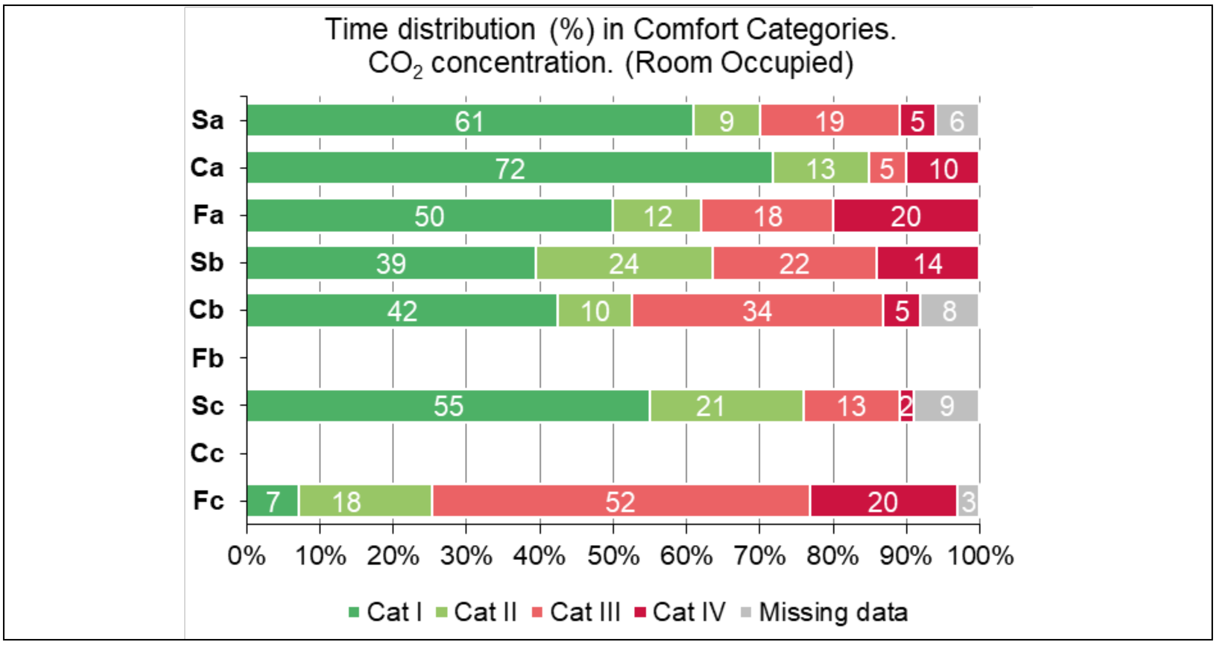


Figure 6.17: Time percentage distribution in comfort categories in terms of CO_2 concentration during occupied hours – heating period.

Accordingly, frequency distribution of CO_2 concentration shows that for Sa, Fa and Fc hourly values are more frequently lower in M2 than in M1.

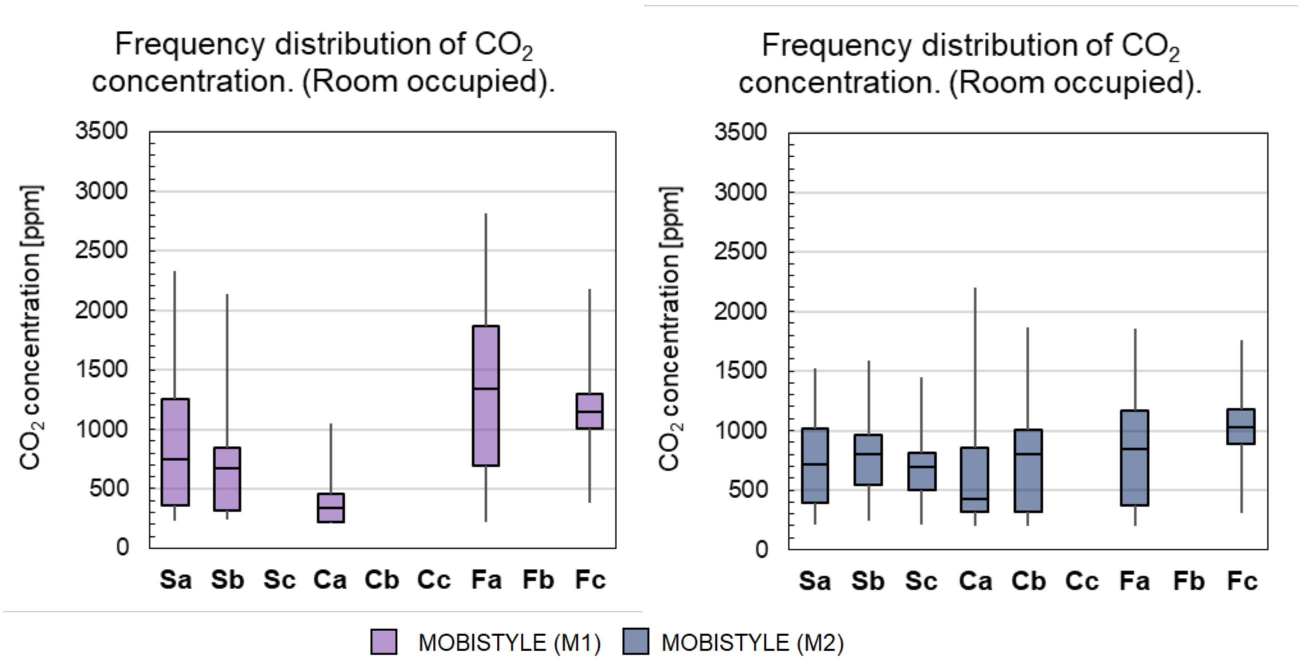


Figure 6.18: Frequency distribution of hourly values of CO_2 concentration in occupied hours in MOBISTYLE (M1) and MOBISTYLE (M2) – heating period

This is particularly interesting for Fc, because it includes a family who visited the hotel both in M1 and M2, occupying the same apartment. Indeed, contents of MOBISTYLE tips provided via stickers stressed on positive impacts on health of a proper ventilation of the room ("*A high level of CO_2 deteriorates the indoor air quality and can cause headache. Ventilate the room a* *few minutes can make you feel better*”). Focusing on this specific guest, the time spent in comfort category I and II increased from 14% in M1 to 34% in M2 (Figure 6.19).

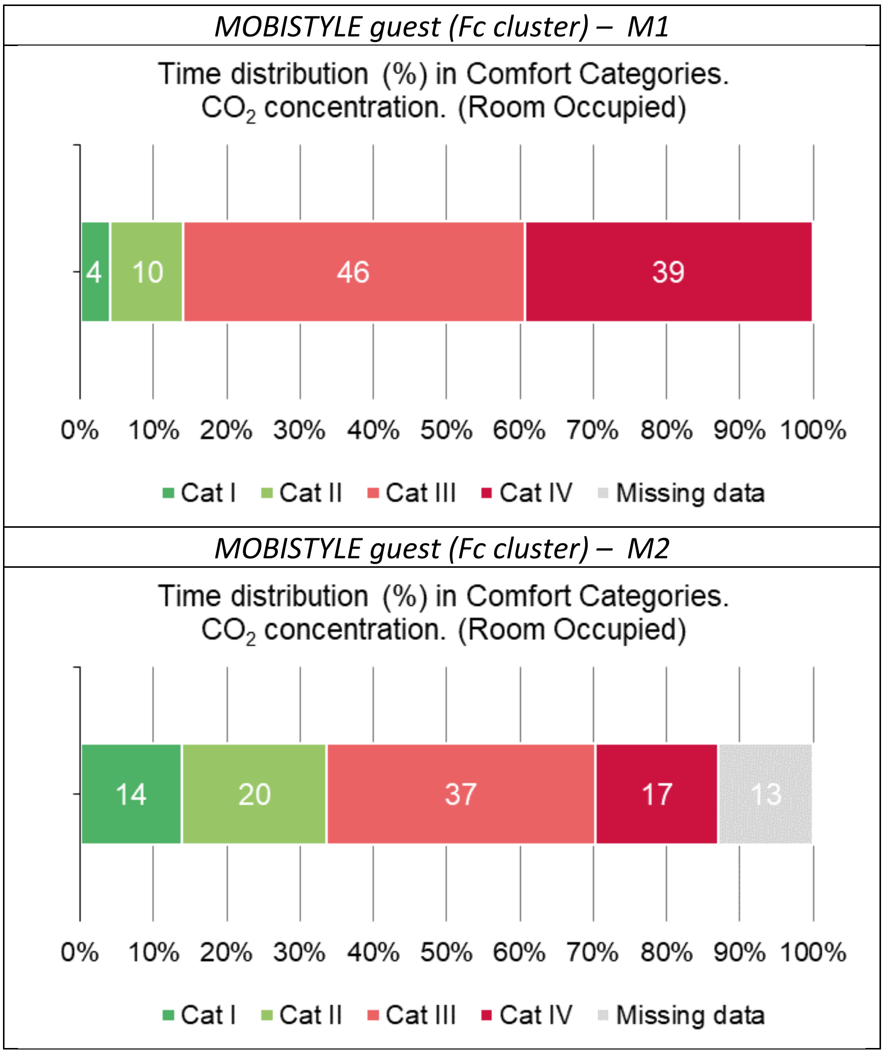
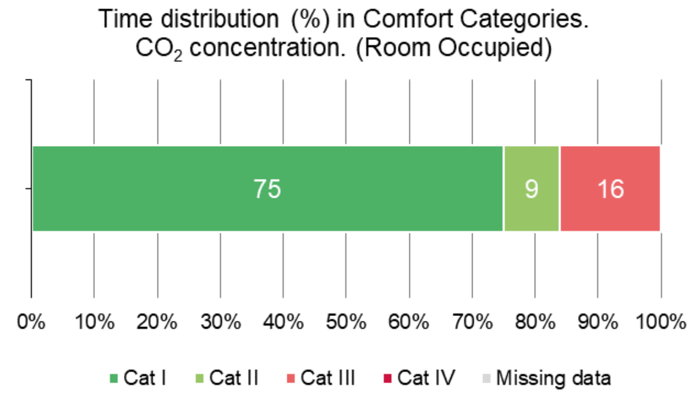


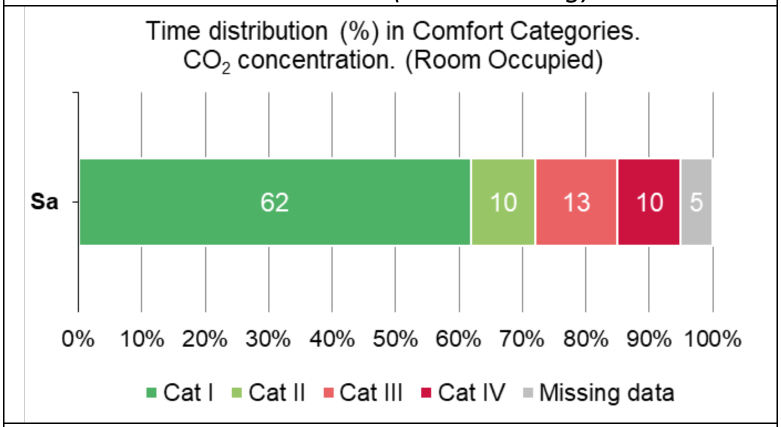
Figure 6.19: Time percentage distribution in comfort categories in terms of CO_2 concentration for a MOBISTYLE guest (Fc cluster) staying at hotel both in M1 and M2 periods.

Finally, the only guest, belonging to Sa cluster, that used the ICT-tools in M1-non heating period, shows positive outcomes only on CO_2 concentration. He spent higher time in comfort category I if compared to Sa cluster in M0 and M1 periods (Figure 6.20).

MOBISTYLE specific guest - M1 (non – heating)



Cluster Sa - M0 (non – heating)



Cluster Sa – M1 (non – heating)

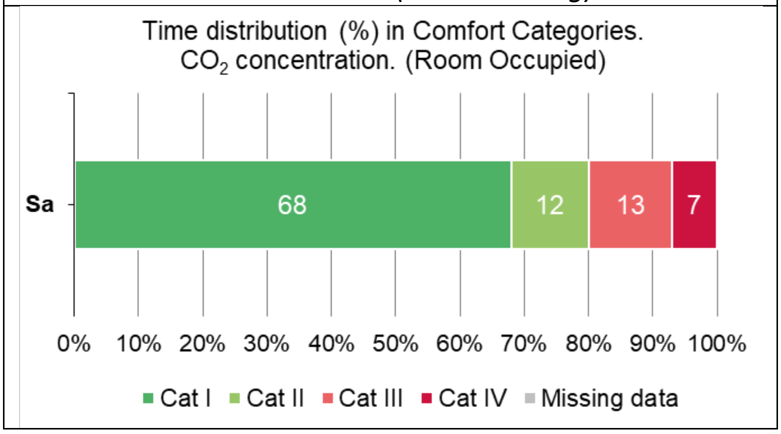


Figure 6.20: Time percentage distribution in comfort categories in terms of CO_2 concentration for a MOBISTYLE guest using the ICT-tools in M1 (non-heating) period. Comparison with results for his cluster in M0 (non-heating) and M1 (non-heating) period.

USERS’ BEHAVIOR

Users’ behavior was evaluated in terms of interaction with windows in apartments in baseline (M0) and MOBISTYLE (M1-M2) periods, assessing average daily windows openings for each cluster.

Analyzing the data it’s possible to make some considerations. In heating period, average daily window openings are smaller in M1 period if compared to M0 for all evaluated clusters. In period M2 they are smaller than in M0 for all evaluated clusters except Cb, but higher than in M1 for all evaluated clusters except Cc. If M1 and M2 are directly compared, increase in average daily window openings in M2 is particularly significant for Ca, Sb, Sc and Fc.

In non-heating period average daily openings are higher in M1 if compared to M0 for all the evaluated clusters except Ca, for which, on the contrary, average daily window openings are smaller in M1 compared to M0.

A limitation in this specific analysis is in the impossibility to assess missing data. Indeed, since data are gathered only at each interaction with the windows, both days with no interactions and days of data loss would result in no data gathered from the system. So, it is impossible to define if a data loss occurred or if no interactions with the windows happened. Days with no data gathered were exclude from the analysis.

7 Outcome Case 4 Qeske

7.1 Introduction

This part of the Mobistyle demonstration is focussing on the effect of a dynamic indoor climate and how that affects the user’s physiology and comfort and sensation. The results from these studies can be used to show the advantages and acceptability of dynamic climate and its usefulness for establishing drifting indoor temperatures, i.e. following outside conditions, in real life (dwelling, offices, etc.). The use of a drifting indoor temperature can save substantially building energy use and, secondly may satisfy more occupants and finally, may reveal a healthier environment.

Being exposed to temperatures outside the comfort zone (outside the thermoneutral zone) affects human heat loss parameters as well as heat production. Cold can induce an increase of our energy expenditure and it has been shown that it also positively affects our glucose and lipid metabolism. It is shown that regular exposure to mild cold increases brown fat (the healthy fat) in healthy people, but on top of that increased insulin sensitivity in patients with type 2 diabetes. Thus, not only the heat production of the body is affected (by shivering and nonshivering thermogenesis), but also the metabolic health, which is very important in these times of increasing prevalence of overweight and related metabolic syndrome. Recently it was also showed that temporal excursions to warm environments affects our metabolic health. Finally, cardiovascular parameters are positively affected by exposure to heat and cold, since by a varying temperature the body adapts by changing the blood perfusion in the skin. This means that the cardiovascular system is challenged. Thus, regular exposures to cold and heat leads to physiological adaptation processes which increase metabolic health end resilience to cold and heat. The latter is extremely important in view of the global warming.

In conclusion, instead of forcing the indoor climate to strict fixed condition, our hypothesis is that it is better for our health, resilience to extreme temperatures, and for the building energy consumption to let the indoor temperature drift within reasonable limits along with outside conditions. In this demonstration case the effect of a dynamic indoor temperature compared to fixed conditions in a well-controlled laboratory condition as well as in two offices (real life living lab conditions) was studied. The lab-study was carried out in the Metabolic Research Unit of Maastricht University (MRUM); the RLLL’s were in the building Qeske (Kerkrade, The Netherlands) and at the office of HIA/Brightlands (Geleen, The Netherlands).

7.2 Laboratory study

The study was performed under more strict controlled laboratory settings, see figure 7.1, and focusses on the effect of a moderate temperature drift on physiological and health parameters as well as subjective perception of the thermal environment. We hypothesize that the temperature drift will increase the body’s energy expenditure and affects cardiovascular parameters, while maintaining thermal comfort.

Figure 7.1. The climate/respiration chamber of the metabolic research unit Maastricht (MRUM)

The study was performed at Maastricht University between July 2018 and May 2019. In total, 16 healthy young men participated on two separate occasions. The two test days differed only in temperature conditions (fixed or drift).

The participants were 16 normal weight healthy males, aged 20-40. The fixed temperature was 21±0.5 °C, and during the drift scenario the temperature ranged from 17-25°C (drift up: 2.3 °C/h; down drift: -2.3 °C/h) Participants completed both conditions (fixed and drift). The order in which participants completed the condition was randomized between participants.

The measurements of the indoor conditions consisted of air temperature and relative humidity. The measurements of the participants were as follows:

- Body core temperature by swallowed telemetric capsule
- Skin temperature at 17 body sites by wireless sensors
- Body energy expenditure (heat production) by means of indirect calorimetry
- Heart rate by ambulant monitor
- Blood pressure
- Physical activity by accelerometery
- Questionnaires for evaluation of the perception of the thermal environment
    - Thermal sensation
    - Thermal comfort
    - Subjective preference

As can be seen in figure 7.2 the mean actual drifting temperature was significantly different from the fixed conditions and ranged from 16-24 °C, while the mean fixed temperature amounted to 20.1˚C. The average temperatures between fixed and drift were not significantly different.

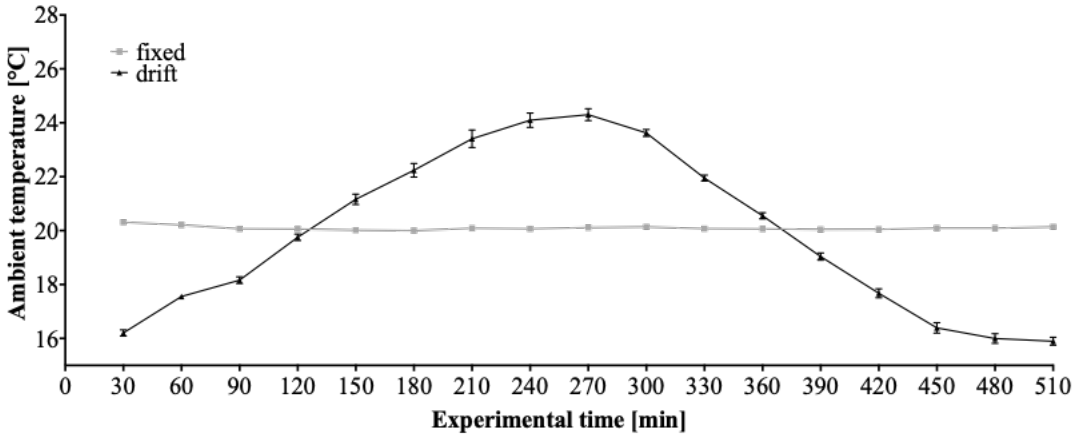
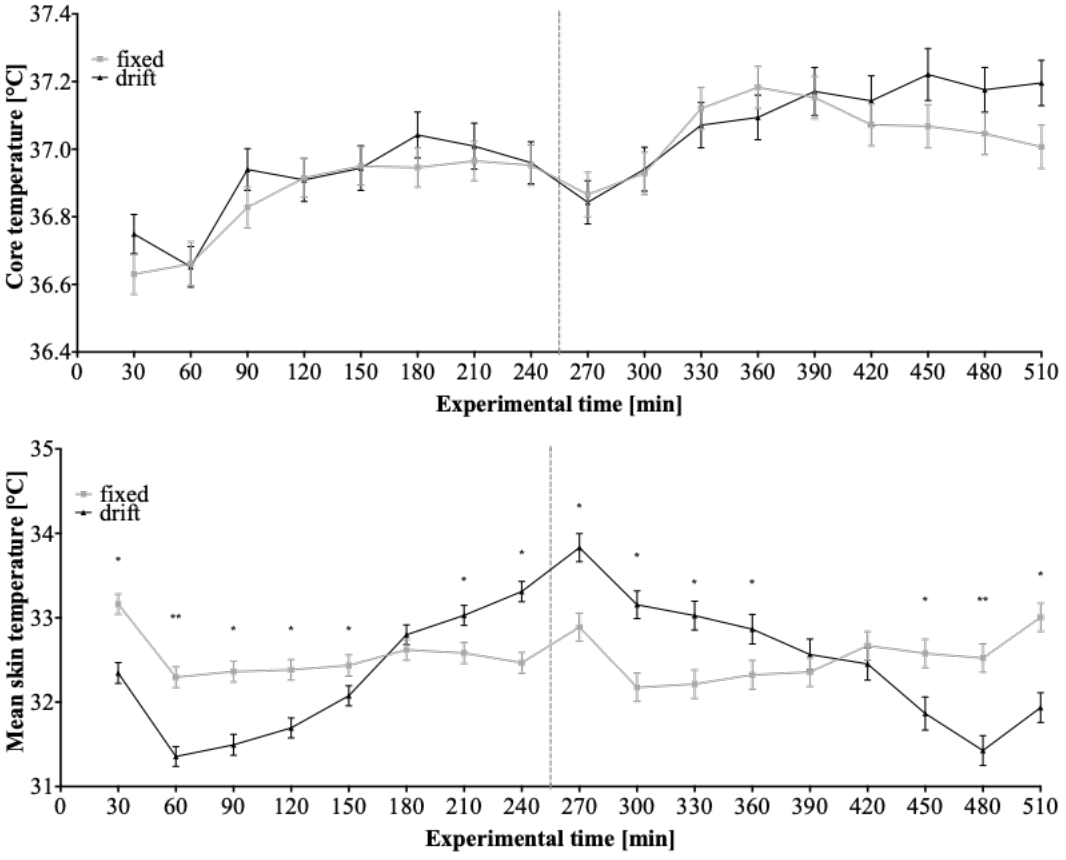


Figure 7.2. Actual temperatures during the indoor temperature scenario's fixed and drift.

Core body temperature gradual increased during the day, following the normal circadian temperature pattern and was not significantly different between drift and fixed scenario's (figure 7.3 top). Interestingly, the skin was significantly lower during the drift temperatures in the first half of the morning and late afternoon but was higher during midday compared to the fixed condition (figure 7.3 middle). This is underlined by the gradient between the fingertip temperature and underarm temperature, indicating cooler fingers in morning and afternoon and warmer during midday (figure 7.3 bottom). This gradient is linked to vasoconstriction of the blood vessels under the skin.



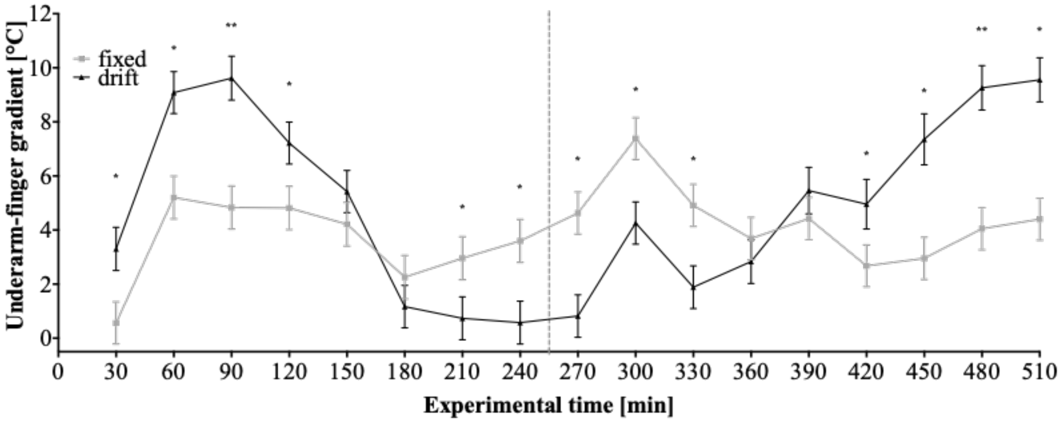


*Figure 7.3. Body core (top), mean skin (middle), and underarm-finger gradient (bottom) during fixed and drift. * P < 0.05; ** P < 0.01 fixed versus drift.*

In the morning mean energy expenditure was significantly higher during the drift than fixed session (Energy expenditure drift: 7.2 ± 0.2 kJ/min; fixed: 6.9 ± 0.2 kJ/min; *P* = 0.02) (figure 7.4 top). This was not the case in the afternoon. Interestingly, physical activity was also in the morning significantly higher during drift than fixed (at t = 150 min) (Figure 7.4 bottom). No significant differences between the two protocols, fixed and drift, were observed during the afternoon. Diastolic blood pressure was slightly higher in the morning only during the drift, compared to the fixed condition (Drift: 73 ± 1.45 mmHg; Fixed: 71 ± 1.46mmHg). No statistical differences in systolic blood pressure and heart rate were evident.

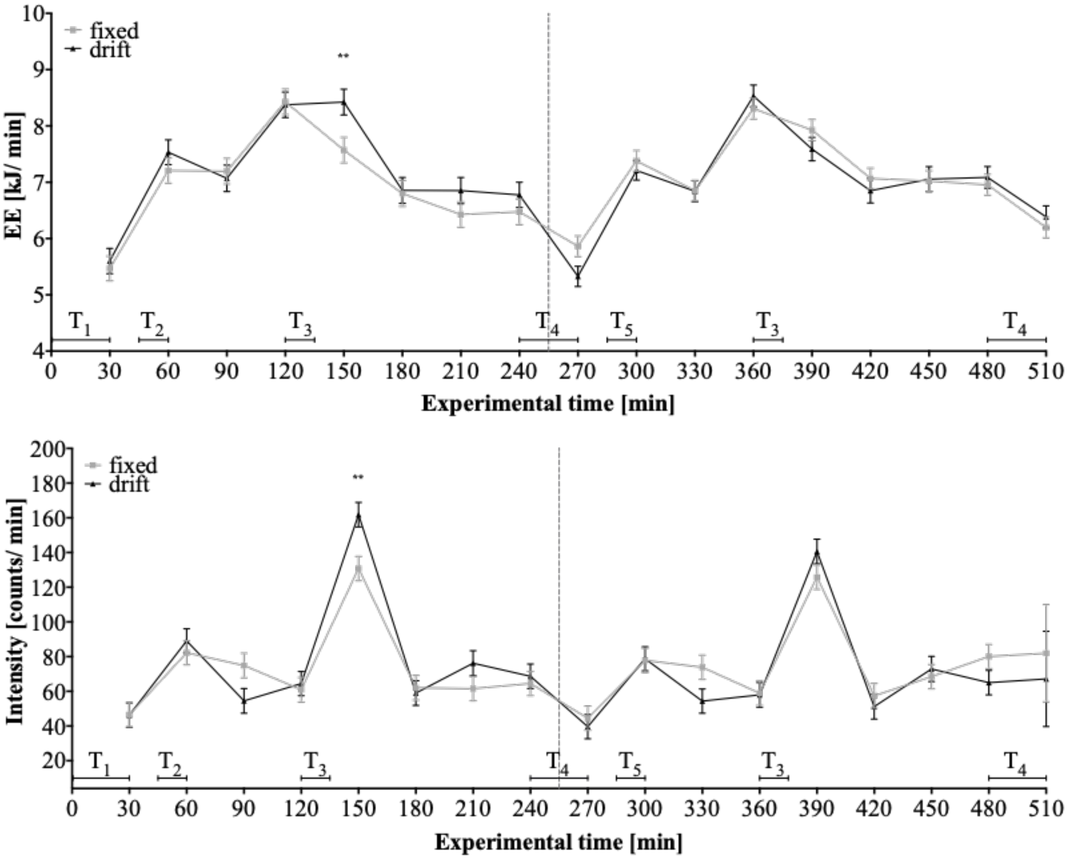


*Figure 7.4. Energy expenditure (EE) (top) and physical activity (Intensity)(bottom) during fixed and drift. * P < 0.05 fixed versus drift.*

With respect to thermal sensation, the participants reported to be cooler in the morning and end of afternoon, and warmer during midday with the drift scenario compared to the fixed condition (figure 7.5). Interestingly, participants felt comfortable during both fixed and drift scenario's, although they felt more comfortable in the morning and second part of the afternoon during the fixed condition. On the contrary, early afternoon revealed the most comfortable situation during the drift scenario.

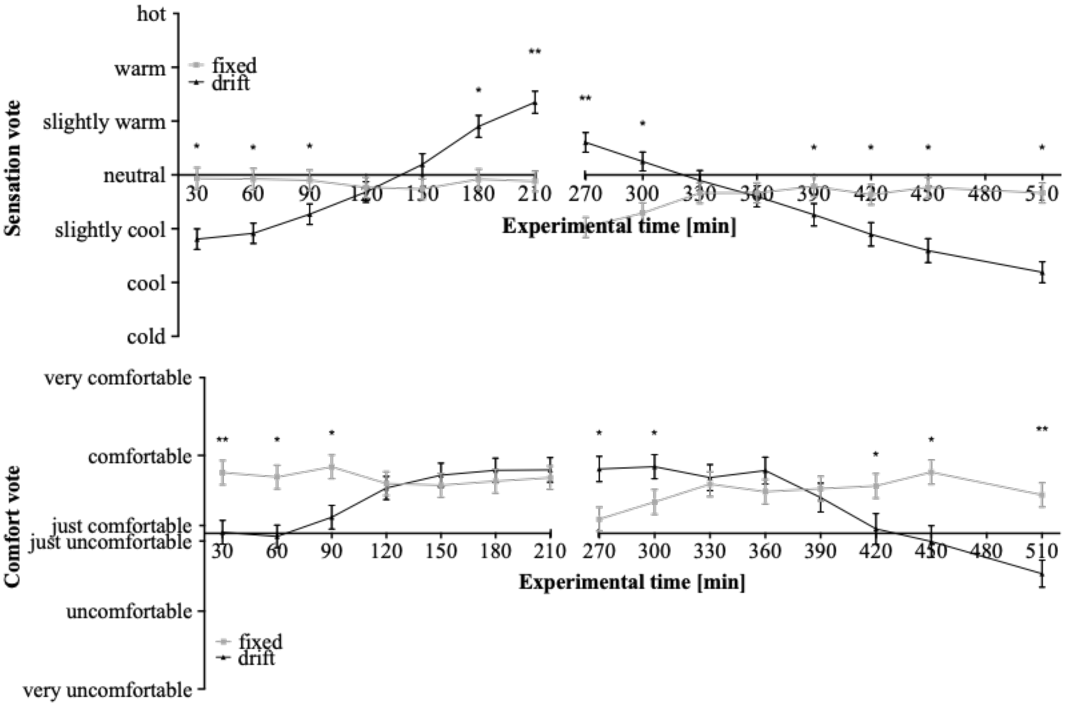


*Figure 7.5. Thermal sensation (top) and thermal comfort (bottom) during fixed and drift. * P < 0.05; ** P < 0.01 fixed versus drift.*

The most important result of this study is that the moderate temperature drift as used in this study does not lead to thermal discomfort. On top of that there is a small, but significant effect on energy expenditure in the morning, being higher under de drift condition, which goes hand in hand with an independent determined increase in physical activity. Another interesting finding is that the skin temperatures follow the drifting temperature conditions. This is more evident in the more distal parts of the body, as can be seen in the results of the finger-underarm gradient changes. The latter is a proven indicator of vasomotion, i.e. the regulation of the perfusion in the blood vessels. Thus, under the drift condition the cardiovascular system is more challenged, which may on the long term improve cardiovascular health.

The study thus indicates that both metabolic health (energy expenditure and physical activity) and cardiovascular health (skin blood perfusion) may be affected positively by a dynamic indoor temperature compared to a fixed scenario, without compromising thermal comfort. The implication for the built environment can be far reaching, meaning that a drifting indoor temperature prevails above the current practise of accomplishing fixed indoor conditions. When the temperatures are allowed to drift with the outside 24 h fluctuations and with the seasons, significant energy savings in the built environments can be achieved.

It should be noted that the tested drift consisted of an upward (morning) and a downward (afternoon) ramp. Even more energy savings can be reached by having the downward ramp in the night, following more natural outdoor temperature drifts and thereby obtaining even more energy savings.

7.3 Real life living lab study 1 - Qeske

The study was performed in an office like environment of Qeske (figure 7.6). The users of Qeske are students, young entrepreneurs and experienced professionals. The participants were mostly young ambitious employees.

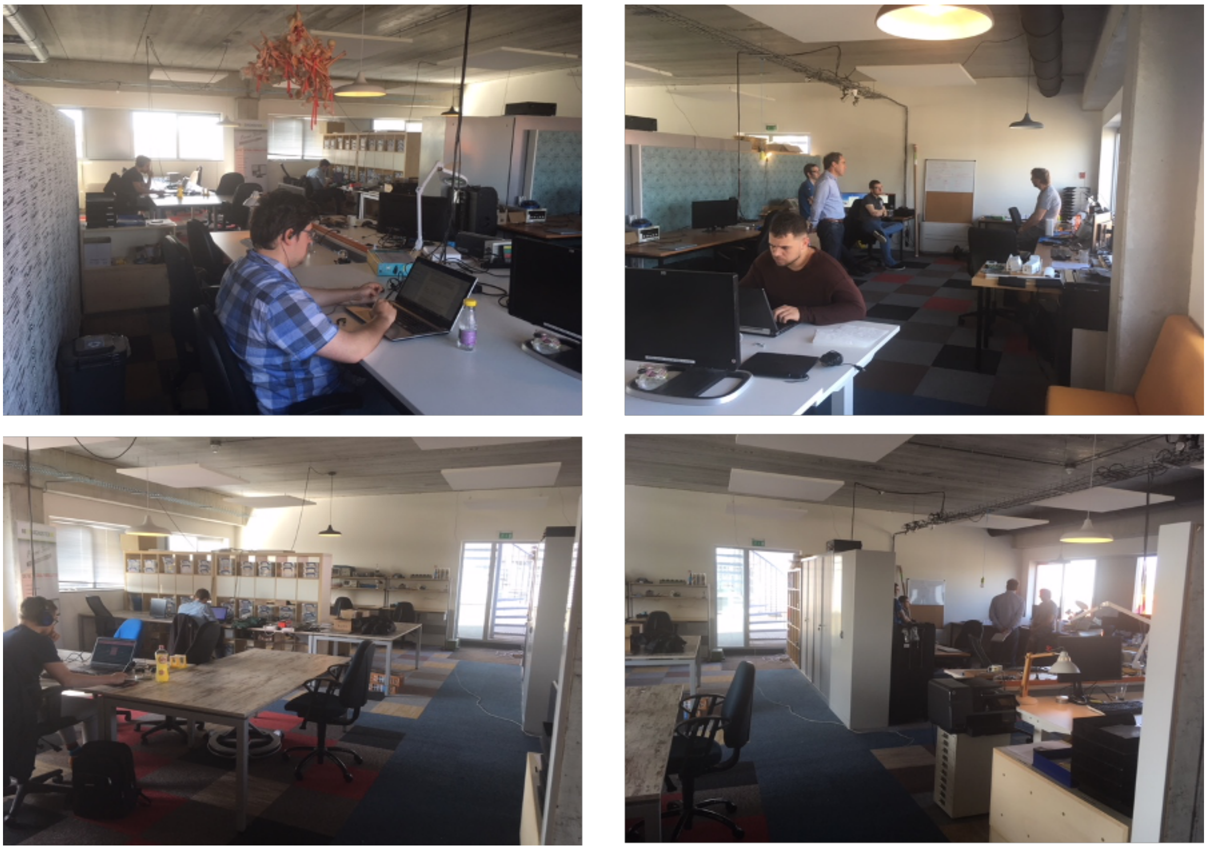


Figure 7.6. The Qeske building (top) and the floor plan of the office (middle), and an impression of the office of Qeske with employees (bottom).

The study was conducted in two parts. The first study was conducted from 15 October until 26 October 2018, the second from 2 December until 13 December 2019. In both years a fixed temperature protocol was tested in the first test week and a dynamic temperature profile was tested in the second test week. In 2018 six subjects participated and in 2019 seven subjects participated.

The outside temperatures (see figure 7.7) were different between the years. For a better fit to the outside climate conditions, slightly different indoor temperatures were selected to account for seasonal differences in the outdoor climate conditions. Questionaires were filled in every hour from 9.00 h untill 17.00 h. Skin temperatures were measured every 5 min using iButtons and heart rate and activity level were measured every minute using Fitbits). For every hour ranging from 9 h until 17 h, the measurements were binned over a time range spanning 15 min before and 15 min after the hour of interest. For instance, to calculate the average heart rate at 9h, all data points were collected between 8:45 h and 9:15 h.

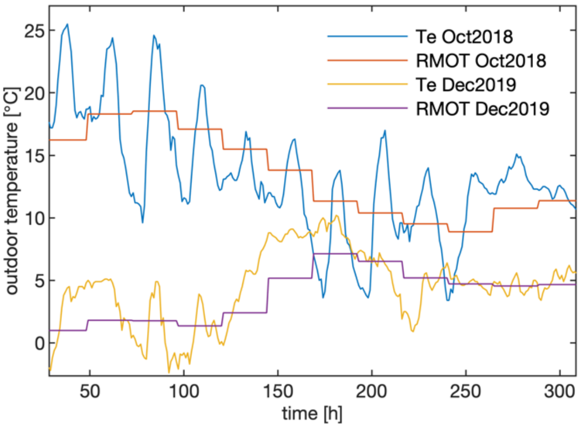


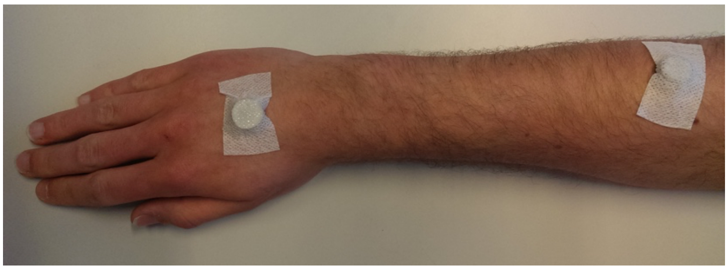
Figure 7.7. The outdoor temperature near the RLLL site of Qeske and Running Mean Outdoor Temperature (RMOT) during the tests in October 2018 and December 2019.

The indoor climate control was achieved by three adapted Daikin units. With these units both fixed and dynamic temperature conditions could be realised. A wifi controller was installed on every unit to make it possible to set a temperature profile. The wireless sensors tags thoughout the room were used as a 'thermostat' to keep the indoor temperatures within exceptable ranges of the desired setpoints. Manual remote controls were overruled by the automated system.

The measurements of the indoor conditions consisted of air temperature and relative humidity by wireless sensors, air velocity and CO2 levels. In addition, external variables that could influence the indoor climate were measured with wireless sensor tags as well, such as floor and ceiling temperatures (concrete structure), ventilation air temperatures and air flow temperatures coming from the fancoil units.

The measurements of the participants were as follows:

- Skin temperature at hand and underarm by wireless sensors (iButtons, Maxim, USA)



- Heart rate by ambulant monitor (Fitbit)
- Physical activity by accelerometery (Fitbit)
- Questionnaires for evaluation of the perception of the thermal environment
    - Thermal sensation

- Thermal comfort
- Thermal acceptance
- Alertness (Karolinska Sleepiness scale)

As can be seen in figure 7.8 the mean dynamic temperature conditions were significantly different from the fixed conditions in both years. In 2018 the temperatures ranged from 19.2-24.2 °C, while the mean fixed temperature amounted to 22.3 °C. In 2019 the dynamic range was 18.2-22.5 °C, while the fixed temperature was 21.3 on average.

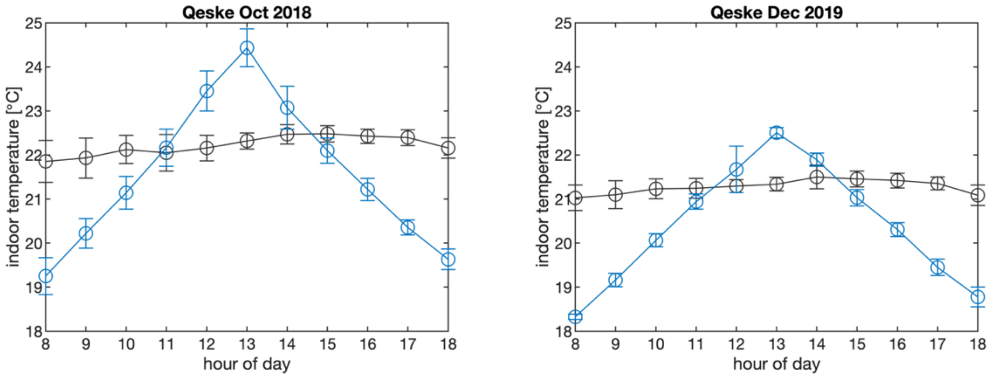


Figure 7.8. The mean indoor temperatures during drift (black line) and dynamic (blue line) conditions for October 2018 and December 2019.

For some individuals, the skin temperature seem to follow the dynamic profile and is more stable during the fixed protocol (Figure 7.9). However when all data are taken together there is no such a difference in the trends of the skin temperature between dynamic and fixed conditions, although at some time points a significance level is reached. During dynamic conditions in the afternoon the temperature is lower. The temperature gradient between underarm and finger tip is not significantly different between dynamic and drift scenario's (Figure 7.10).

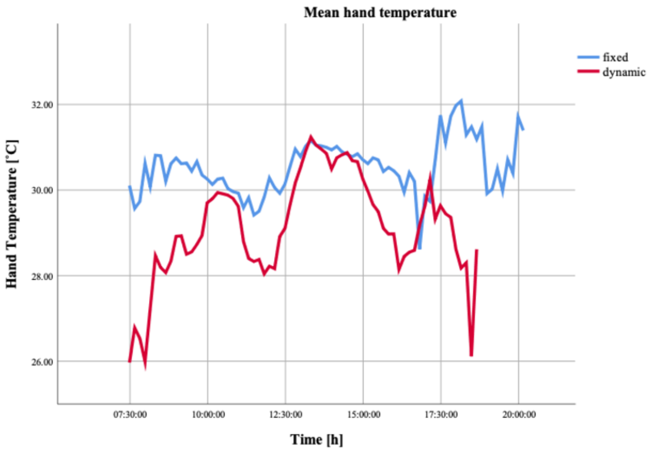


Figure 7.9. Example of the hand skin temperature of one subject during fixed and dynamic prolies in 2018.

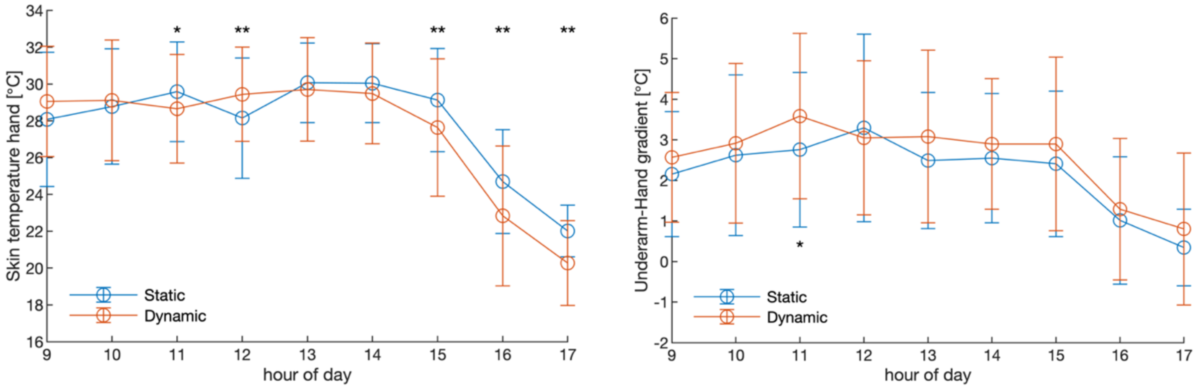


Figure 7.10. Hand skin temperature (left) and Underarm- fingertip temperature gradient (right). Mean±SD.

Mean heart rate trends are comparable between dynamic and drift scenario's, though in the afternoon at certain time points heart rate is slightly, but significantly higher during the dynamic profile (Figure 7.11). Also, the physical activity of the subjects is comparable between the two conditions, although there are some significant differences in the morning, but these differences are not consistent (Figure xx).

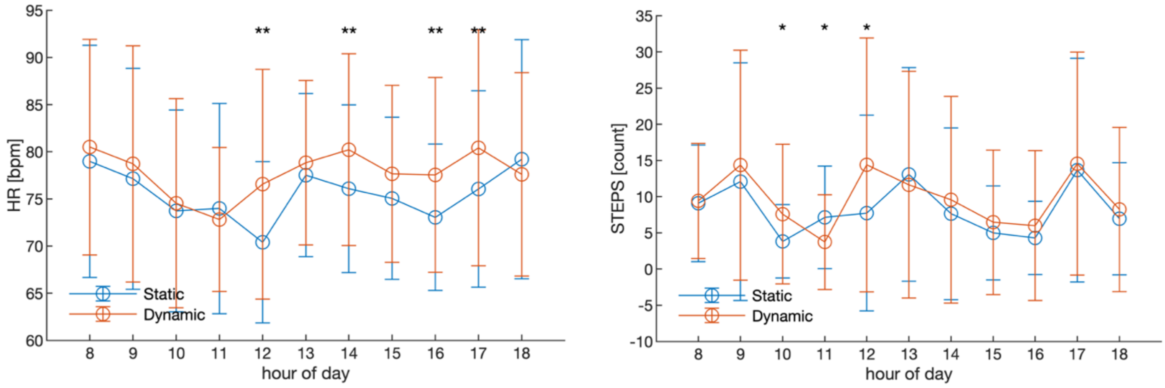


Figure 7.11. Heart rate (left) and activity level (in step counts) (right).

Thermal sensation in the morning does not significantly differ between the conditions, is significantly higher during midday in the dynamic scenario and significanlty lower by the end of the day during the dynamic condition compared to the fixed scenario (Figure 7.12 left). On average during both scenario's the subjects felt comfortable, although one individual felt uncomfortable during the dynamic scenario. There was no sgnifcant difference in the relation between comfort and sensation. Thermal acceptance was high with a slightly smaller range during the fixed scenario (82-98%) compare to the dynamic condition (70-100%) (Figure 7.12).

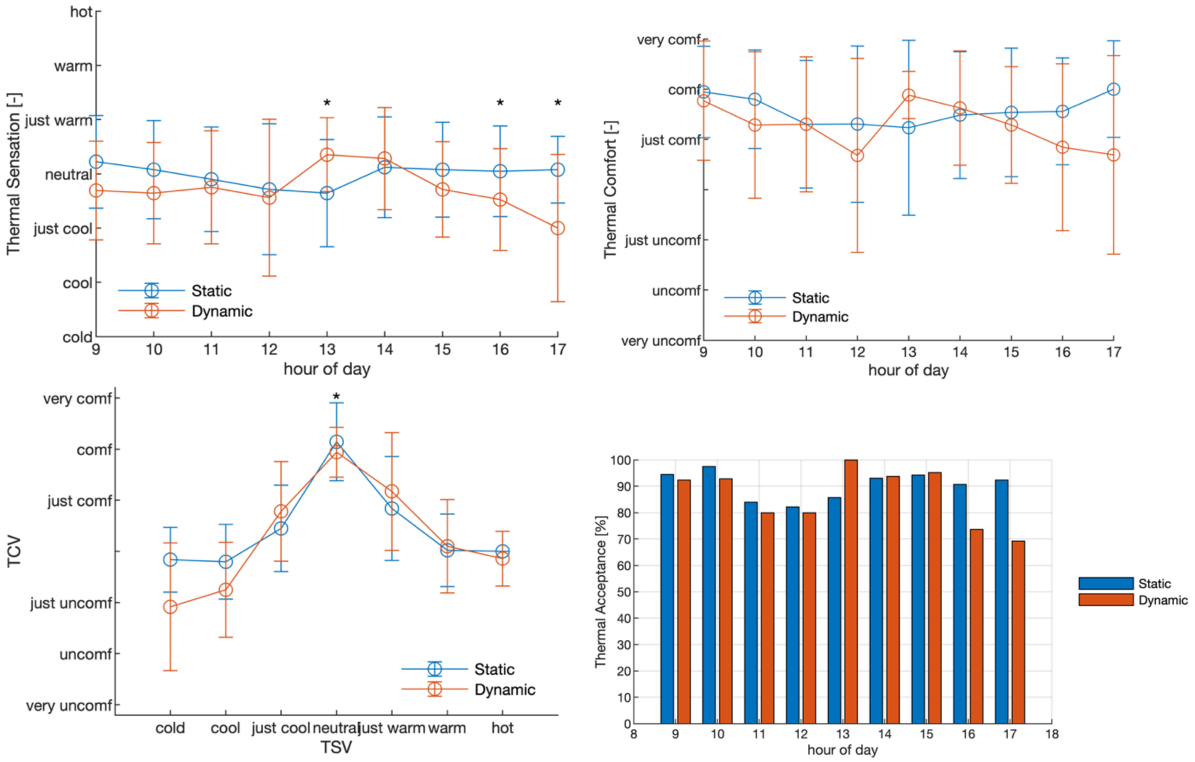


Figure 7.12. Thermal sensation and thermal comfort during the course of the day, and the relation between thermal comfort and thermal sensation. Thermal acceptance.

The main conclusion from this real-life living lab study is that the dynamic temperature profile as used in Qeske did reveal comfortable condition, not significantly different from the comfort levels of the fixed scenario. This is in line with the laboratory study, though the temperature range used was smaller than in the laboratory test. This may be the reason that the other parameters did not differ between the two scenarios as in the lab condition. For instance, in the morning there was no significance between thermal sensation between dynamic and fixed condition. Another reason may be that the volunteers had much more freedom to move and adjust behaviour. This comes up to real life situations, but makes comparisons more difficult than in a laboratory setting.

For instance, the distal skin temperature did not clearly follow the environmental temperature, which can partly be caused by the less dynamic condition, but also by the behaviour of the subjects. They were much less restricted in this respect than during the lab tests. They could change their clothing and also could switch between standing, walking and sitting. They were also allowed to move to other rooms of go outside during short breaks.
Other physiological parameters did not significantly differ between the protocols, although heart rate tended to be higher during the dynamic profile in the afternoon. The difference is very small and may not have physiological significance, although effects on the long term cannot be ruled out (see general discussion below).

All in all, the applied dynamic profile leads to a high acceptance and thermal comfortable conditions.

7.2 Real life living lab study 2 - Brightlands

This study was also performed in an office environment, the new office of Huygen (Figure 7.13). Huygen is a specialised consultancy and engineering firm that is active in engineering, building physics, spatial planning and research. The building is equipped with HVAC systems designed to make a dynamic temperature profile possible. In this study 7 subjects participated.

Figure 7.13. Building 220 on the campus (top), Huygen office is located on the second floor (two lower pictures)

The study was conducted in two parts, that took place right after each other. The measurments took place from 4 november 2019 untill 29 november 2019. The first week a fixed temperature protocol was tested, the same questionnaires were used as in the lab studies and Qeske study. The second week a dynamic temperature protocol was tested also with the same questionnaires as in the lab studies and Qeske study. The participants were not informed about the temperature setpoints. The following two weeks, the same protocol was used as during the first two weeks (one week fixed protocol and one week dynamic protocol), but now the participants had to use the MOBISTYLE Office App instead of the questionaires (see Deliverable 6.4). They could also see the temperature profiles that were set. Questionaires were filled in every hour from 9.00 h untill 17.00 h. Skin temperatures were measured every 5 min using iButtons and heart rate and activity level were measured every minute using Fitbits. For every hour ranging from 9 h until 17 h, the measurements were binned over a time range spanning 15 min before and 15 min after the hour of interest. For instance, to calculate the average heart rate at 9 h, all data points were collected between 8:45 h and 9:15 h.

The measurements of the indoor conditions consisted of air temperature and relative humidity by wireless sensors, air velocity and CO_2 levels. The measurements of the participants were as follows:

- Skin temperature at hand and underarm by wireless sensors (iButtons, Maxim, USA)
- Heart rate by ambulant monitor (Fitbit)
- Physical activity by accelerometery (Fitbit)
- Questionnaires for evaluation of the perception of the thermal environment
    - Thermal sensation
    - Thermal comfort
    - Thermal acceptance
    - Alertness (Karolinska Sleepiness scale)

The two scenarios are significantly different (Figure 7.14). Clearly the dynamic condition revealed lower temperatures during the morning, and higher during midday and afternoon, except for the temperatures at 11.00 h and 18.00 h. The range in temperatures during the dynamic condition is smaller than in Qeske and the laboratory study (3.5 °C).

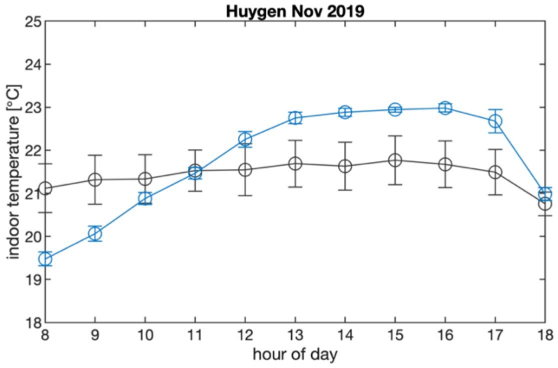


Figure 7.14. The mean indoor temperatures during drift (black line) and dynamic (blue line) conditions.

The skin temperatures reveal no difference in the trends of the skin temperature between dynamic and fixed conditions, although at some time points a significance level is reached (Figure 7.15 left). During dynamic conditions in the morning the temperature is lower. The temperature gradient between underarm and finger tip is not significantly different between dynamic and drift scenario’s (Figure 7.15 right).

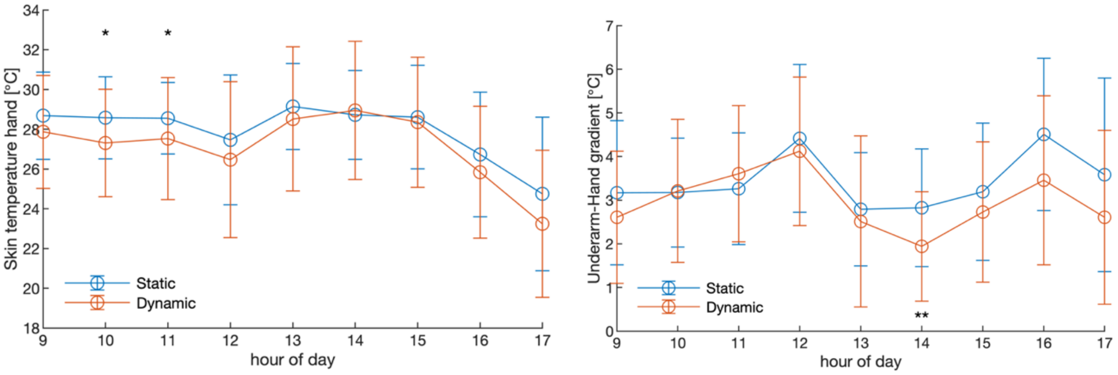


*Figure 7.15. Hand skin temperature (left) and Underarm- fingertip temperature gradient (right). Mean±SD. * p-values < 0.05.*

The statistical RANOVA test revealed no significant difference of the mean heart rates between the two conditions (figure 7.16). If anything, post hoc analyses revealed higher heart rates at some-times for the static condition.

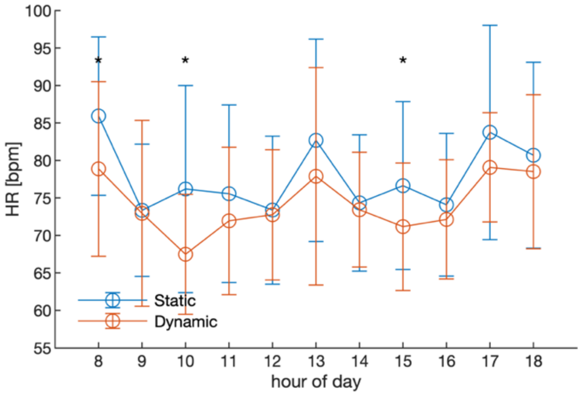


*Figure 7.16. Mean heart rate (HR) during the course of the day. Mean±SD. * p-values < 0.05.*

Thermal sensation did not significantly differ between the conditions, although post hoc analyses revealed at 14.00 h significantly higher TS for the dynamic condition (Figure 7.17 left). Importantly, on average the subjecst felt comfortable during both conditions; there were no significant differences. There was also no significant difference in the relation between comfort and sensation. Thermal acceptance was high with a slightly smaller range during the fixed scenario (88-100%) compare to the dynamic condition (60-100%).

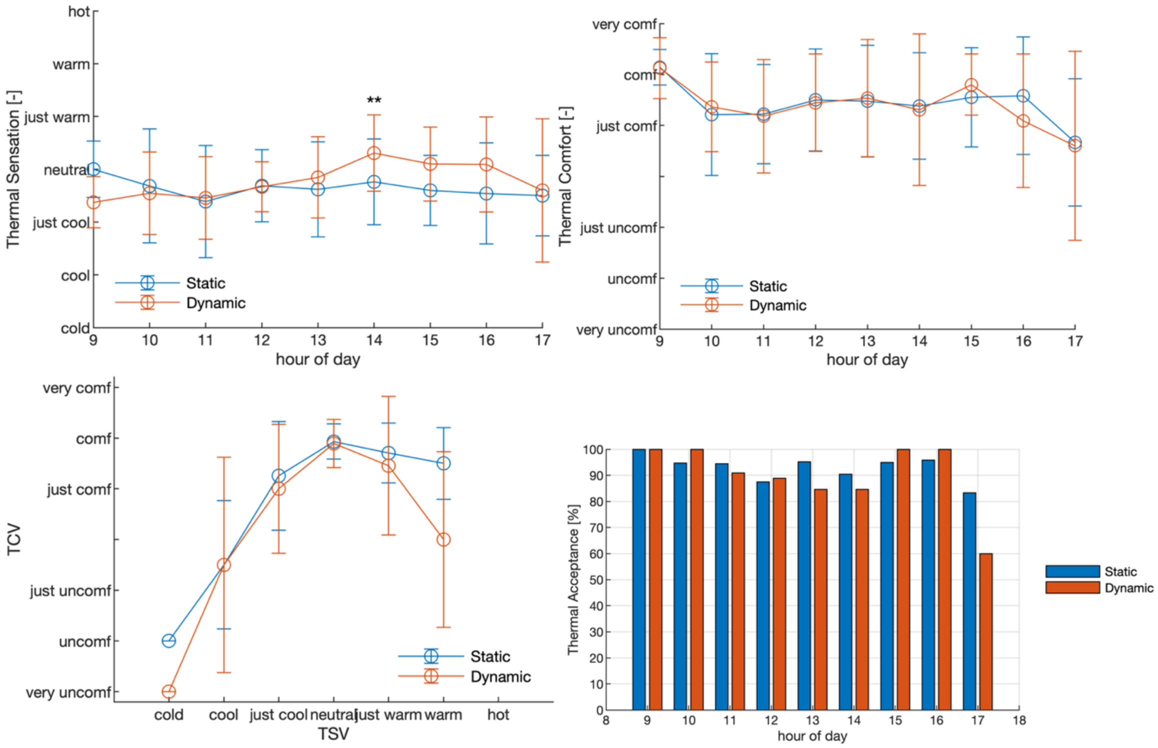


*Figure 7.17. Thermal sensation and thermal comfort during the course of the day, and the relation between thermal comfort and thermal sensation. Thermal acceptance. Mean±SD, ** p<0.01.*

This real-life living lab study of Brightlands again indicates that the dynamic temperature profile is judged comfortable and is not significantly different from the comfort levels of the fixed scenario. This is in line with the laboratory study and the Qeske RLLL study presented above. It should be noted that the temperature range used was smaller than in the laboratory test and the Qeske study. This may be the reason not many differences were found between the scenarios. Even the thermal sensation between dynamic and fixed condition was not different.

The distal skin temperature was only slightly lower in the dynamic condition in the morning. Apart from the small temperature range used, the subjects were much less restricted in their behaviour than during the lab tests. They could have avoided large temperature variations and/or changed clothing.

Other physiological parameters did not significantly differ between the protocols.

In conclusion, in line with the lab study and the Qeske study, the applied dynamic profile leads to a high acceptance and thermal comfortable conditions.

7.4 Energy performance calculation

By applying a dynamic indoor climate, energy performance calculations showed that about 21% of the thermal energy demand can be saved (Table 7.1). This is split in 7% heating energy and 38% cooling energy. The difference in yearly savings is different than the results from the first simple approach

.

Table 7.1. Potential energy savings of the Huygen office by applying a dynamic indoor climate

	Energy demand		**Energy savings**	
	Static	**Dynamic**		
Heating	39.930 kWh	37.111 kWh	2.819 kWh	7%
Cooling	32.910 kWh	20.508 kWh	12.402 kWh	38%
Total	**72.840 kWh**	**57.619 kWh**	**15.221 kWh**	**21%**

This is because the dynamic indoor temperature fluctuates on a daily basis in a similar way to the outdoor temperature. In winter the difference between night and day temperatures is not large, mostly a few degrees Celsius. In summer the difference can be as high as 10-15 degrees Celsius. As a result, the difference between the indoor and outdoor temperature is smaller, which means that the heat loss through transmission, ventilation and infiltration is lower. Therefore, it can be concluded that the dynamic indoor climate can lead to thermal energy savings.

7.5 Overall discussion and conclusion

The most important result of this study is that the moderate temperature drift as used in this study does not lead to thermal discomfort. Indeed, both laboratory study and the RLLL studies show that the dynamic profile is judged comfortable and the comfort ratings do not significantly differ from the traditional fixed indoor climate. On top of that the laboratory study reveals a small, but significant effect on body energy expenditure in the morning, being higher under de drift condition, which goes hand in hand with an independent determined increase in physical activity. This, together with the indirectly observed changes in skin blood perfusion, is in line with earlier temperature acclimation studies in a laboratory environment that show benefits of heat and cold exposure for our metabolic health. From a health perspective, a dynamic indoor climate may prevail on a traditional tight controlled environment. In addition, such a climate saves building energy consumption due to less use of heating and cooling.

The laboratory tests gave more profound effects on both thermal sensation and physiological parameters than the RLLL tests. For instance, during the laboratory study thermal sensation clearly followed the applied indoor temperature. The same was evident for the distal skin temperatures. This was much less evident in the Qeske study and the least in the Brightlands study. There are several reasons for this difference. First of all, the range of air temperatures during the dynamic profile was larger in the lab-study (8 °C) compared to Qeske (4.5-5 °C) and Brightlands (3.5 °C). Secondly, in the lab study physical activity was prescribed and the clothing standard. In the RLLL conditions people were free to move and to change clothing. Finally, the commitment to the study is in general larger in a laboratory study then in a daily living environment. Filling in questionnaires are more punctually performed in a lab study with the investigator always in the vicinity. The laboratory studies clearly show the health benefit of the dynamic profile and the acceptability of such a condition. The RLLL studies confirm the acceptability of a dynamic indoor climate. The RLLL studies did not reveal specific health benefits, but it is very well possible that there may be significant long-term health and temperature resilience effects.

One of the main findings that is evident in the three studies is that the dynamic profiles lead to comfortable conditions, comparable to the fixed indoor temperatures. It is interesting to note that despite the change in thermal sensation from slightly cool to slightly warm (lab-study), the thermal comfort stays within the limits of just comfortable and comfortable. This is an important finding because it means that there is in fact no reason for tight control of the indoor climate. And this in turn has two important implications. Firstly, such a temperature drift may reveal a healthier environment as the thermophysiological literature shows and to some extent is confirmed in the current laboratory study. Secondly, it means energy savings for the buildings, because with less strict control and use of heating and cooling is needed. In addition, it's likely that on the long-term occupants may be feeling better, because there are indications that temperature variation may lead, not only to comfort, but to a higher appreciation or even pleasure. This so-called alliesthesia is a phenomenon that occurs when one is temporally in a less comfortable condition and then exposed to an opposing (uncomfortable) condition (11). For instance, when you move from freezing cold outside to a fireplace inside. Both places are uncomfortable, but after the cold the hot place feels pleasant (for a while). Such effects may be achieved by the dynamic profile and is subject to further investigation. The main advantage for health is that under these opposing conditions the bodies' physiology is challenged, leading to a better metabolism and more resilience to temperature extremes.

In the first two studies a dynamic temperature profile with an upward (morning) and a downward (afternoon) ramp is used. This may not be the optimal profile. Even more energy savings can be reached by having the downward ramp in the night, following more the natural daily outdoor temperature drifts and thereby obtaining more energy savings. In fact, this profile was used in the Brightlands study, however, the applied temperature range was small. Future studies are needed to reveal the energy saving potential of such more naturel drifting indoor temperature.

8 Outcome Case 5 Smart City Wroclaw

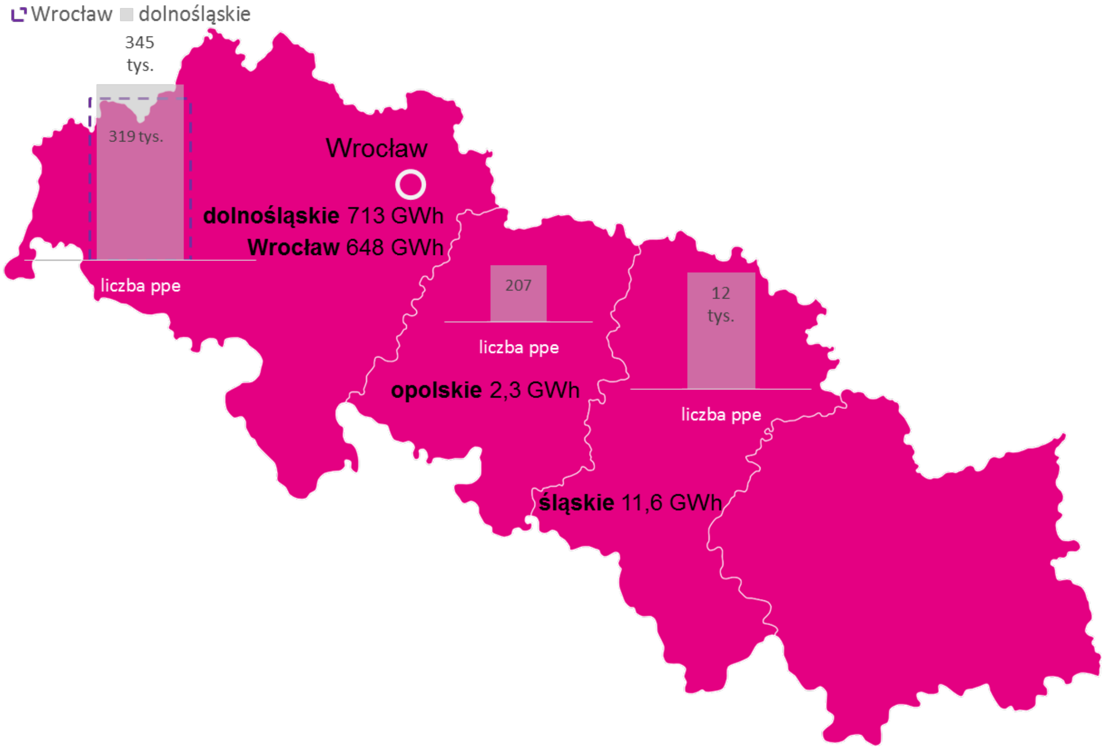
8.1 Introduction

Wroclaw one of the biggest cities in Poland, serves as the Polish demonstration case. The city of Wroclaw is divided on districts with big variety in level of urbanization and residence. There are 22 residential units qualified for the study including two building typologies, i.e. detached houses and apartments in multi-family dwellings. The size of the units varies between 33-180 m2 with occupation between 1-5 persons.

Additional 77 apartments with TAURON customers were included in the study, but due the difficulties and delay with recruitment of customers, and in consequence a very short time without and with MOBISTYLE app (less than a month for both periods, i.e. the Mobistyle monitoring period was shortened due to the COVID-19 pandemic) the collected data were not in sufficient quality to be used for investigations. Anyway, the data from these TAURON customers are presented in chapter 10 of this Appendix, but no analysis is carried out.

Therefore, the following analysis is conducted using the data collected in 22 units, equipped with monitoring devices during the testing phase from January 2018 – September 2019.

Figure 8.21:Wroclaw , Poland



In all apartments, measurements regarding energy consumption and indoor environmental quality (IAQ) is monitored, specifically, operative temperature, relative humidity, and consumption regarding electricity usage, as well as additional parameters like window opening. The following table summarizes available sensor data at demo site.

Table 8.1: Monitored parameters

Indicator type	Indicator name	Unit	Location
Electricity use	Electricity	[kWh]	Apartment level
Indoor Environmental Quality	Temperature Relative Humidity	[°C] [%]	Apartment level Apartment level
User practices	Window opening	[0/1]	All rooms
Outdoor climate	Temperature Relative Humidity	[°C] [%]	From the local weather station

In Polish demonstration case MOBISTYLE GAME App developed by HighSkillz is implemented. The first version of the Android mobile GAME App is made in English.

Table 8.2: Deployment date and operation of the ICT solution

ICT - solution	Deployment date	Comments
GAME App (Android)	January 2019	Gamification of the Electricity consumption and IEQ parameters. This App includes notifications when there is a bad indoor climate in the space together with advices, nudges for window openings. Furthermore, GAME App includes point awarding system for successful mission completion.

It has been decided that the BASELINE and MOBISTYLE periods would be as follow:

BASELINE 0: 01/01/2018 – 31/08/2018
MOBISTYLE: 01/01/2019 – 31/08/2019 (application period for ICT solution)

8.2 Energy consumption evaluation

Figures 8.2 and 8.3 present the daily and weekly use of electricity for the 22 apartments.

Figure 8.2: Daily and weekly electricity use of the 22 apartments during BASELINE period

Apartment [No]	Electricity use, daily [kWh]	Electricity use, weekly [kWh]
701	9.1	64
702	12.9	90
703		
704		
705		
706		
707		
708		
709	3.4	24
710		
711		
712		
713	8.2	57
714		
715		
716		
717		
718		
719	6.2	43
720	8.0	56
721	10.0	70
722		0

Figure 8.3: Daily and weekly electricity use of the 22 apartments during MOBISTYLE period

Apartment [No]	Electricity use, daily [kWh]	Electricity use, weekly [kWh]
701	9	64
702	12	84
703		
704		
705		
706	6	45
707		
708		
709	3	23
710		
711		
712		
713	4	26
714		
715		
716		
717	5	36
718		
719	8	53
720	8	55
721	15	105
722	0	0

It is seen that the electricity use is very different between the different apartments. For the seven apartments with data from both periods a small increase of 2,5 kWh/week is seen from the BASELINE to the MOBISTYLE monitoring period.

8.3 IEQ and user behavior comparison between apartments

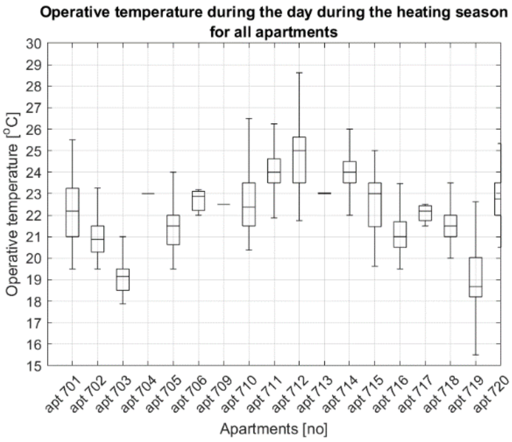
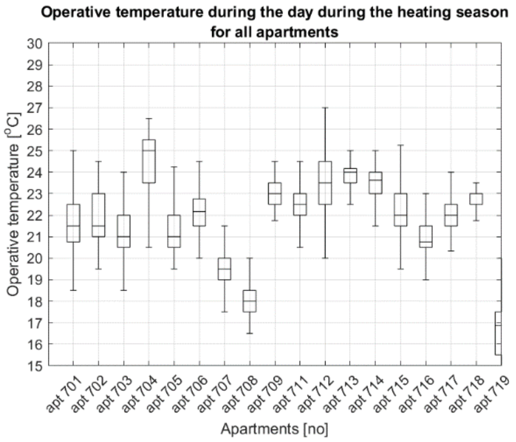
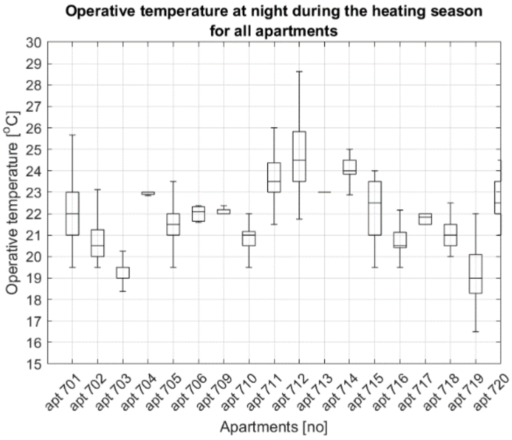
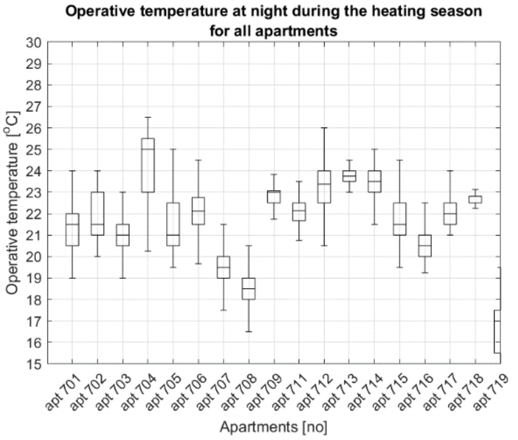
This chapter describes the monitoring results for indoor environmental quality for all 22 apartments for the BASELINE and MOBISTYLE monitoring period. The results on window opening are though described on the room level.

Following results are presented:

- *Good indoor temperature:* Operative temperature during the day
- *Comfortable sleep temperature:* Operative temperature at night
- *Prevent excessive humidity:* Relative humidity during the day
- *Night humidity:* Relative humidity at night
- *Window opening*

Figure 8.4 shows the temperature in the apartments in the heating season for day and night and for the Baseline and the Mobistyle monitoring period, respectively.

Figure 8.4. Operative temperature during the day and at night during the heating season. All apartments. BASELINE and MOBISTYLE period.

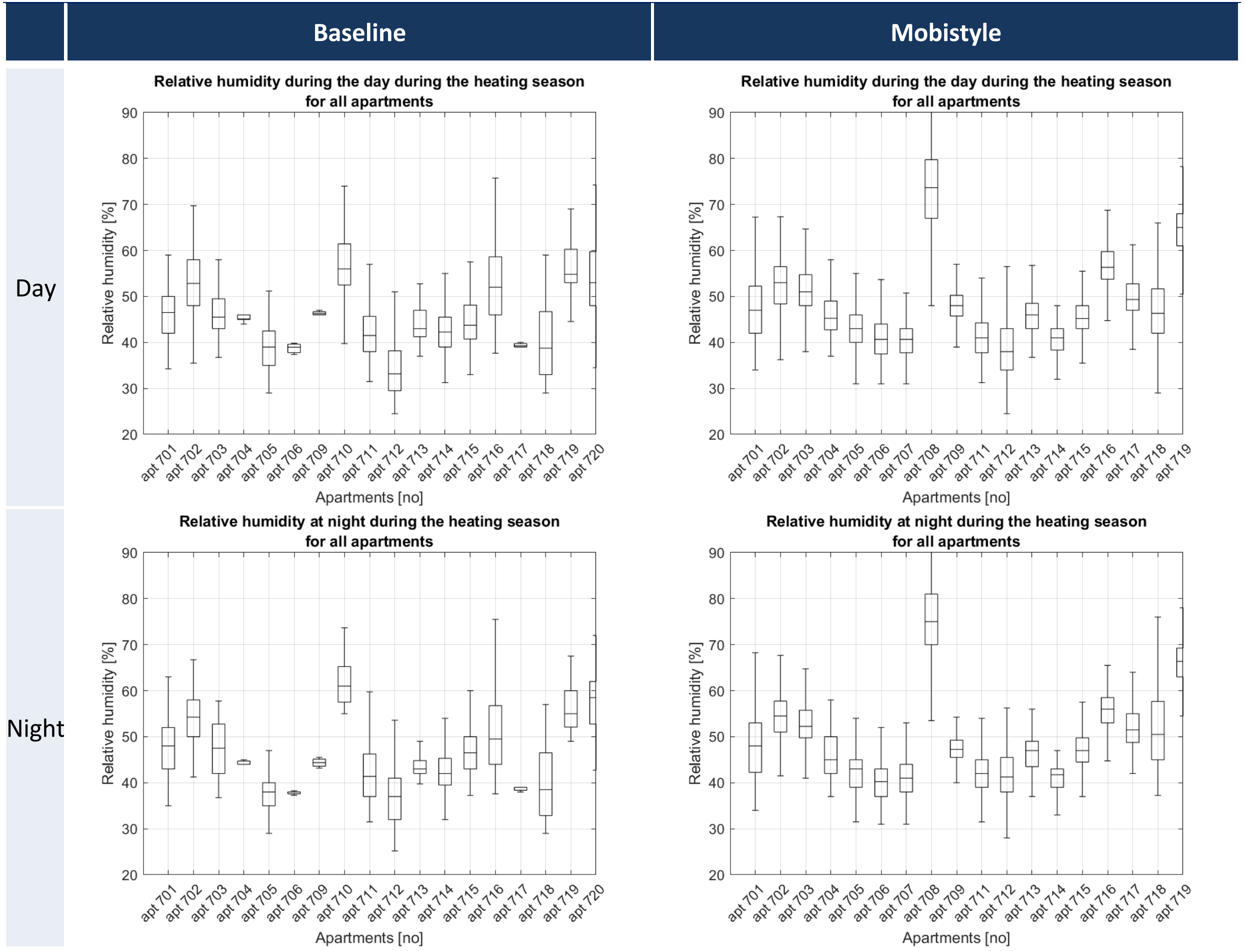
	Baseline	**Mobistyle**
Day	 Operative temperature during the day during the heating season for all apartments 	 Operative temperature during the day during the heating season for all apartments
Night	 Operative temperature at night during the heating season for all apartments 	 Operative temperature at night during the heating season for all apartments

For each apartment the temperature is shown as the mean temperature surrounded by a box representing 50% of the measured values and lines indicating maximum and minimum values measured.

It can be seen that the temperature levels as well as the temperature variation in time are very different between apartments. All apartments except two have an average temperature level above 20°C and up to about 25°C in average for a couple of apartments. Generally, there is not a big difference between day and night. Generally, for all apartments there is not a big difference between the baseline and the Mobistyle monitoring periods, but for the individual apartments the difference can be quite large in both directions.

Figure 8.5 shows the relative humidity in the apartments for day and night and for the Baseline and the Mobistyle monitoring period, respectively. The variation of the average humidity in the apartment is illustrated in a similar way as for the temperature. It can be seen that the humidity levels are similar in most of the apartments. The humidity level is only high in one of the apartments and at a critical level. A very small increase in the humidity level is also seen, which may be caused by differences in the outdoor humidity level.

Figure 8.5: Relative humidity during the day and at night during the heating season. All apartments. Baseline and Mobistyle period.



Relative humidity during the day during the heating season for all apartments

Relative humidity at night during the heating season for all apartments

Figures 8.6 and 8.7 show the average room temperatures in the Baseline and the Mobistyle monitoring period, respectively. Generally, at temperature difference of 3°C is seen between the apartments. A change in temperature levels can be seen between the Baseline and the

Mobistyle monitoring period. An average temperature increase of 0,9 ºC is seen (increase in 6 apartments, decrease in 10 apartments)

Figure 8.6: Comparison of the temperature level in the 22 apartments for the BASELINE period (missing data 78% of time)

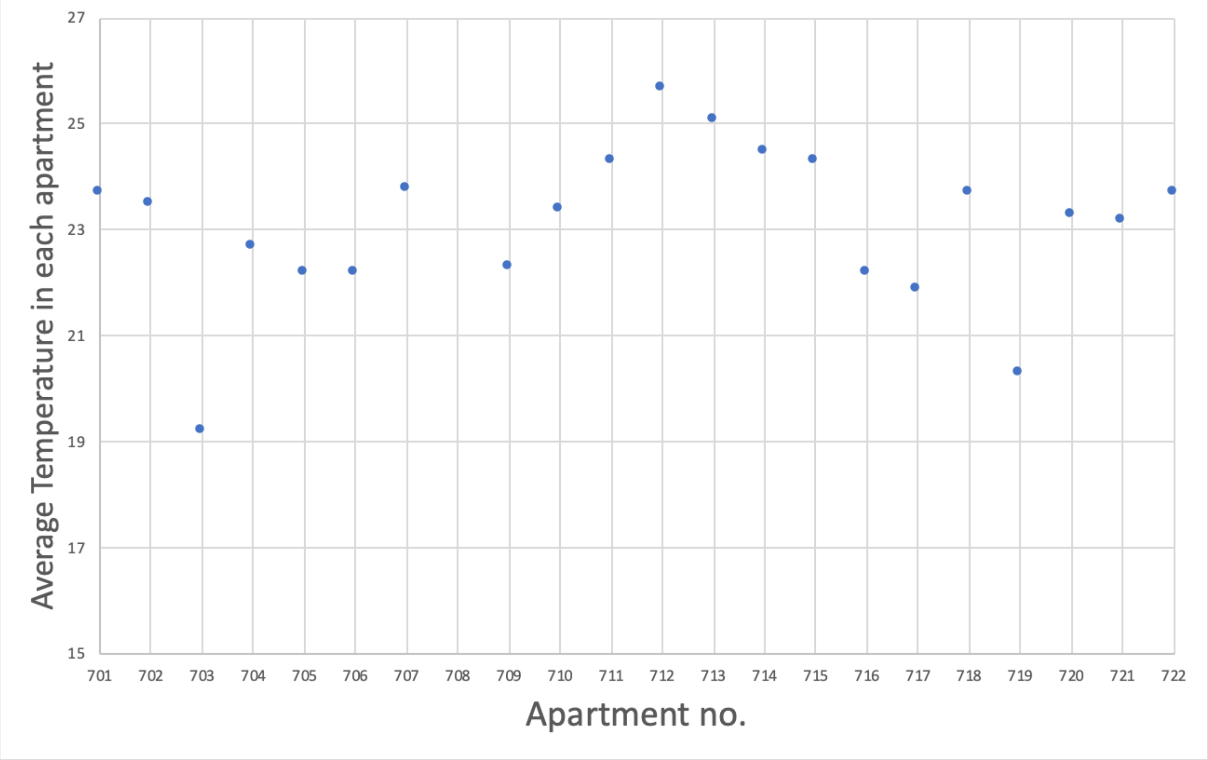
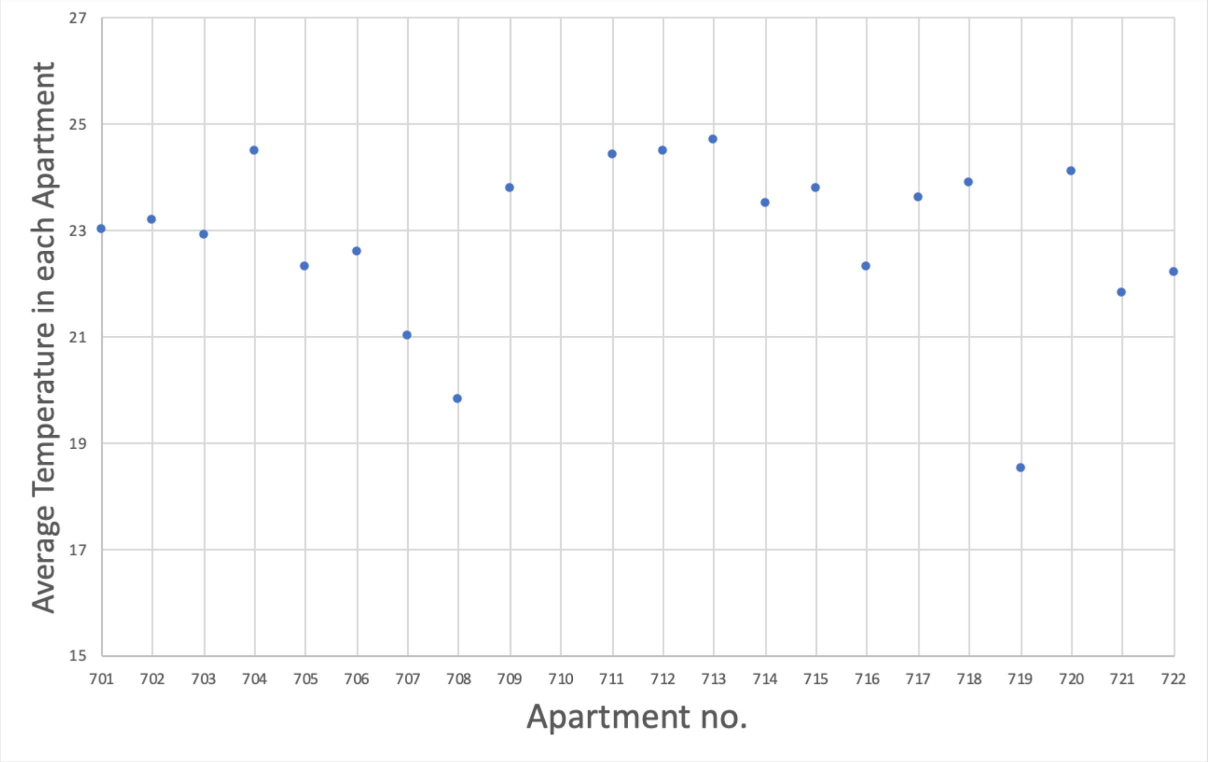


Figure 8.7: Comparison of the temperature level in the 22 apartments for the MOBISTYLE period (missing data 70% of time)



Figures 8.8 and 8.9 show the average humidity level in each of the 22 apartments in the Baseline and the Mobistyle monitoring period, respectively. The difference in humidity levels between the apartments is relatively small. A small change in humidity levels can be seen between the Baseline and the Mobistyle period. An average RH increase of 2 % is seen in the apartments (increase in 10 apartments, decrease in 6 apartments).

Figure 8.8: Comparison of the humudity level in the 22 apartments for the BASELINE period (missing data 69% of time)

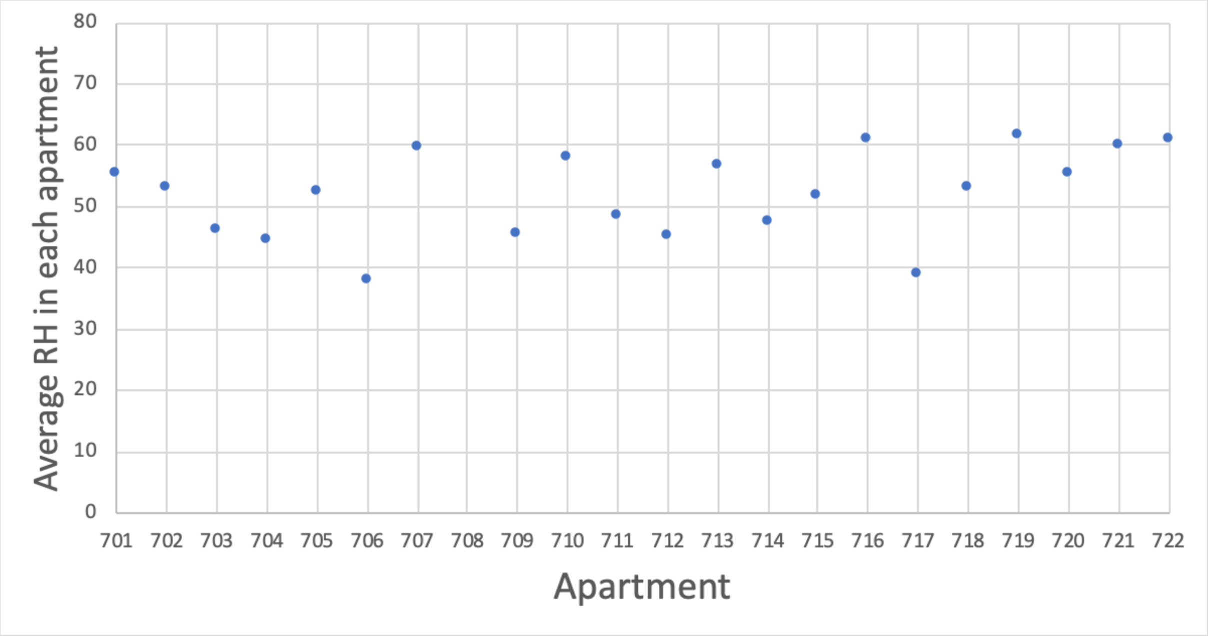
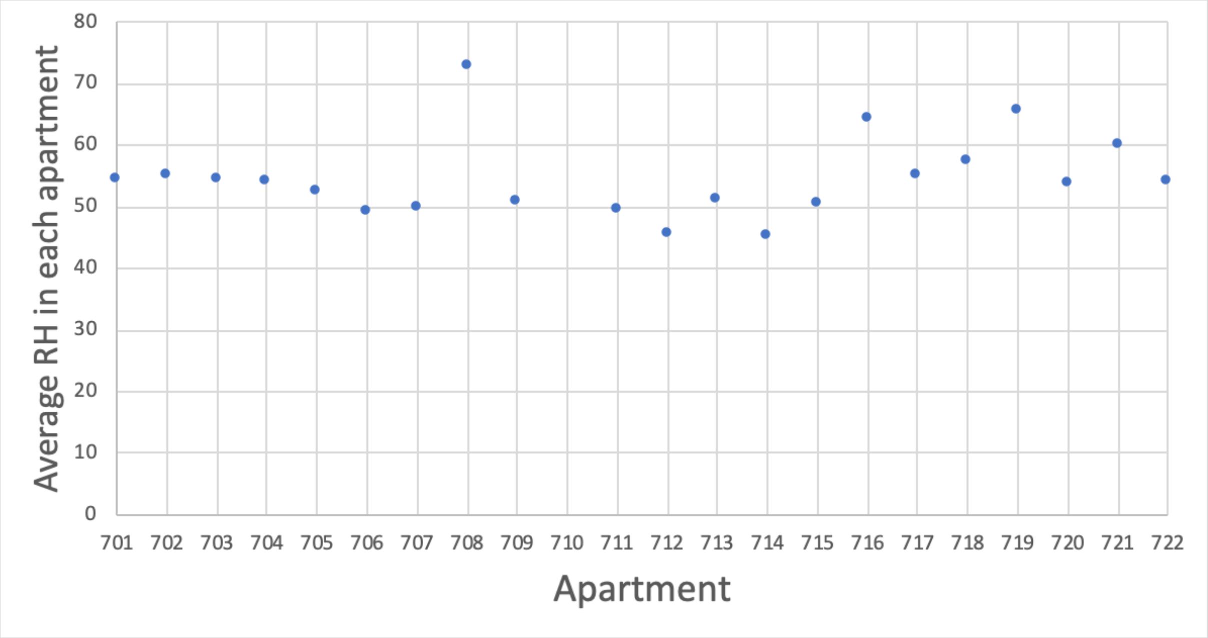


Figure 8.9: Comparison of the humidity level in the 22 apartments for the MOBISTYLE period (missing data 23% of time)



Figures 8.10 and 8.11 show the window opening time in each room in the 22 apartments apartments in the Baseline and the Mobistyle monitoring period, respectively. The window opening time is related to the period where data is available, i.e. 30% means that the window

was open in 30% of the time when data on window opening was available. It is seen that window opening time is very different between different apartments but also between different rooms in the apartments. An average increase in relative opening time from 22 % - 33% of the time when data is available is seen (increase in 23 rooms, decrease in 43 rooms). However, as the periods with missing data for individual rooms is very different, it is not possible to make a solid conclusion on this.

Figure 8.10: Relative window opening time at room level in the 22 apartments for periods where data is available in the BASELINE period (missing data 80% of time)

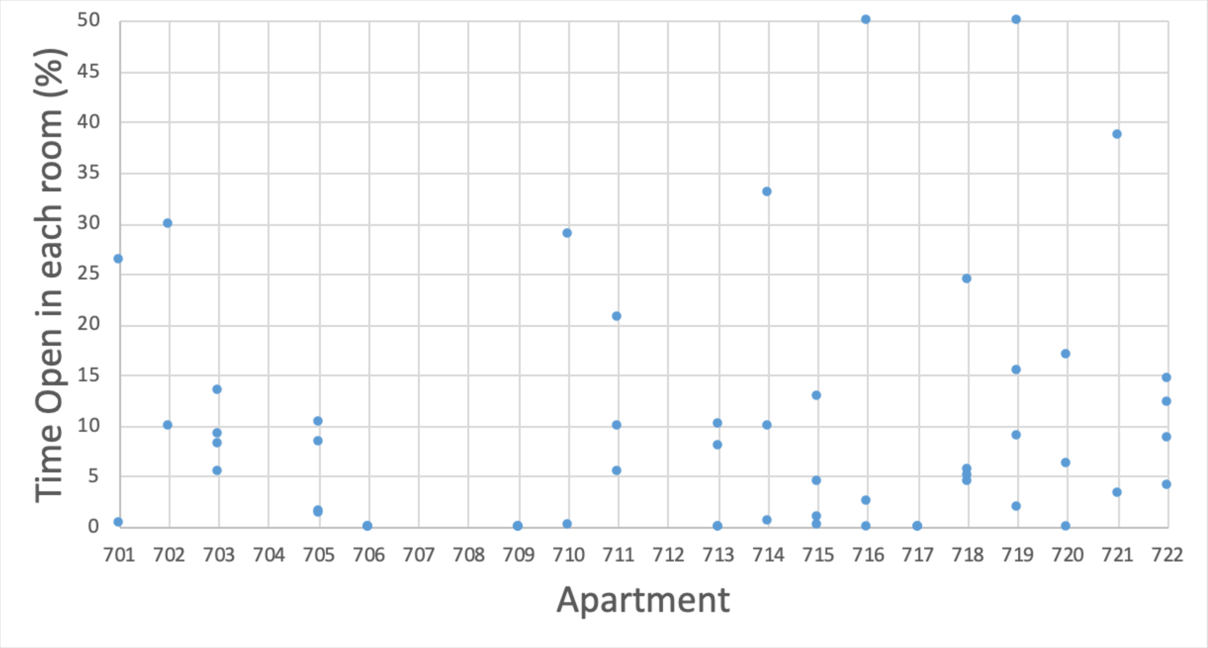
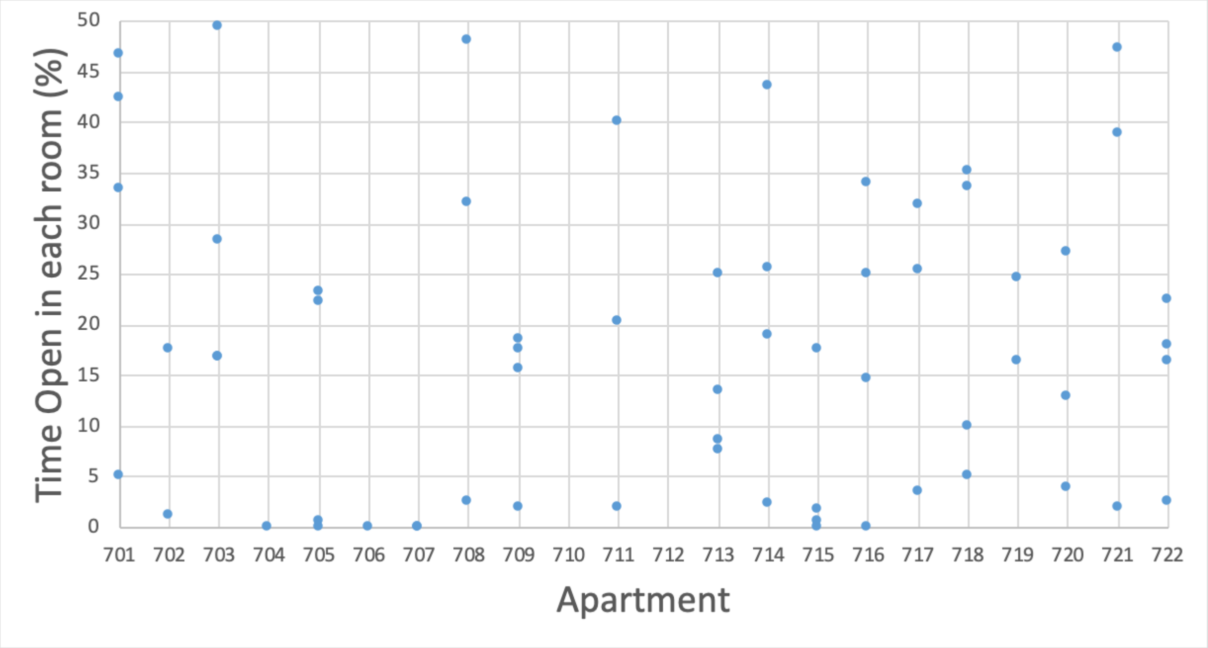


Figure 8.11: Relative window opening time at room level in the 22 apartments for periods where data is available in the MOBISTYLE period (missing data 85% of time)



8.4 Overall discussion and conclusion

The application of the Game in the 22 apartments seem to influence the indoor environmental quality level much more than the energy use. The electricity energy use generally increased by less than 5% for all apartments (only 7 apartments has data for both periods) between the Baseline and the Mobistyle period.

The indoor environmental quality clearly changed between the Baseline and the Mobistyle period. An average temperature increase of 0,9 ^{o}C is seen in the apartments (increase in 6 apartments, decrease in 10 apartments), which is modest but still significant. Only a very small change in humidity was seen with an average RH increase of 2 % in the apartments (increase in 10 apartments, decrease in 6 apartments)., probably due to differences in weather conditions.

The results also showed that window opening time is very different between different apartments but also between different rooms in the apartments. An average increase in relative opening time from 22 % - 33% of the time when data is available is seen (increase in 23 rooms, decrease in 43 rooms).

9 Main results and lessons learned

For application of the Dashboard and Game solution in the demonstration case it was from the beginning decided that information and recommendations should be based on monitored data and that it was important to establish information from all rooms in an apartment or separate offices in an office building and not just from a “representative” room, as it is usually seen.

This decision has clearly resulted in new valuable knowledge about the indoor environmental quality in apartments and offices and provided end-users with much better information, feedback and guidance about their indoor environment. But is also highlighted the weakness of solutions based on general feedback and standard recommendations. It does not fit to well to many of the end-users. If they prefer different conditions than average or prefer different conditions in different rooms in their apartment, they get immune to getting the same recommendations all the time.

The results showed as it has been seen before that there are large differences in temperature and indoor air quality levels (average conditions) between different apartments, but they also revealed that differences between rooms in an apartment are almost as large. Thereby, the results showed that it is very difficult (read impossible) by only monitoring in one room to ensure a representative evaluation of the indoor environmental quality in an apartment or in an office building.

Use time and heat loads showed to be very different in both apartments and offices. And although we had some indication of occupancy it was not very accurate, especially in the apartments. As this has a large impact on energy use and indoor environmental quality such uncertainty makes it difficult to draw definite conclusions.

The application of the ICT solutions in the apartment and the offices seemed to influence the indoor environmental quality level much more than the energy use.

In the Danish Case the heating energy use generally increased by 6,4% for all apartments between the Baseline and the Mobistyle period. All apartments were newly renovated, and the general heating use level was decreased from about 200 kWh/m2 to about 50 kWh/m2, so all end-users had experienced a considerable decrease in heating energy use after moving into the renovated apartments again. This may have influenced their focus on their heating energy use. Also, generally the hot water use increased by 12 % for all apartments. In the polish case the electricity energy use generally increased by less than 5% for all apartments while in the Italian case an energy saving of 9% was achieved between the Baseline and the Mobistyle period.

Apartments with high heating energy use did not have a high hot water use as well or the opposite. Actually, it was more often the case that those with the high heating energy use had a low hot water use and the opposite. This may depend on the number of persons living in the apartment, as more persons use more hot water, but also release more internal heat gains reducing the need for additional heating. However, as no exact registration of use time and persons in the apartments were included in the monitoring campaign a firm conclusion on this cannot be given.

Large differences were found in both heating energy use and hot water use between individual apartments in the Danish case with a factor of about 6 between the apartments with the lowest and the highest use. Differences in electricity use was also seen in the Polish demonstration, but due to lack of information about apartment size and number of persons it is difficult to normalize the values.

The indoor environmental quality clearly changed between the Baseline and the Mobistyle period.

The thermal conditions were very different from room to room in the same apartment and from apartment to apartment or from office to office in the same building. Compared to the standard comfort criteria some rooms, apartments and offices are overheated most of the time and even in the heating season, while others are comfortable all year round. A few apartments and offices suffer from undercooling, especially in the cooling season. However, when we look at the temperature regulation set points in the different apartments and office rooms we see large differences as well as differences between the different seasons. Typically, higher setpoints than expected are used in in the heating season. Generally, the setpoint is much higher than 20 ^{o}C in the heating season and typically between 22-23 ^{o}C, while some also use 24-25^{o}C in their apartments. In the cooling season in the offices the setpoint is generally about 25 – 26 ^{o}C. The differences in set-point regulation actually fit quite well with the monitored thermal comfort levels. So even if, temperature levels according to standards are evaluated as too high, it is a consequence of user actions and set-point regulation and meet occupant preferences. Even though temperatures changed considerably in some of the monitored rooms, we also saw quite modest changes in the overall temperature levels in the monitoring results. In the Danish Case an average decrease of 0,5 ^{o}C was seen in temperature levels in each room, in the Slovenian case an average temperature decrease of only 0,04 ^{o}C in each room, in the Polish case an average increase of 0,9 ^{o}C in each apartment between the baseline and the mobistyle period.

The indoor air quality levels (CO_2 concentration) were also very different from room to room in the same apartment and from apartment to apartment in the same building. In the Danish case a considerable change in average concentration levels was seen with an average decrease of 417 PPM in each room. Especially, the very high values often seen during night-time in sleeping rooms were reduced and a very acceptable indoor air quality levels were obtained in all apartments except one. The opposite outcome was found in the Slovenian case where the indoor air quality levels were quite similar between the offices with an average concentration increase of 300 ppm was measured leading to larger periods with unacceptable conditions during the Mobistyle monitoring period.

Humidity conditions were generally acceptable in all cases and did not vary a lot, neither between rooms, apartments or offices.

The window opening period in the office rooms depends strongly on the season and is used much more in the cooling season than in the heating season. Window opening is also very different from room to room, where the windows are opened rarely in some rooms and in other rooms window are opened almost 50% of the time. By comparing the two measuring periods an average decrease in window opening from 37 % - 28% of the time in each room in the Slovenian Case. This corresponds well to the increased CO_2 levels monitored in the office rooms. The results also showed that window opening time is very different between different apartments but also between different rooms in the apartments. An average increase in relative opening time from 22 % - 33% of the time when data is available was seen in the Polish case, while modest changes in total opening time were seen in the Danish case. As a considerable improvement in indoor air quality was measured, it seems that the window opening periods was chosen more strategically, maybe because of the feedback provided by the game.

The correlation between heating energy use and indoor environmental quality in the apartments in the Danish case was also investigated. A correlation could be found between indoor temperature level and heating energy use, although the relatively small temperature differences in themselves could not explain the large differences found in heating energy use. It was not possible to find a clear correlation between CO_2 concentration and heating energy use, although those with a small heating energy use also seem to have higher CO_2 concentration levels in the apartment. A clearer trend between humidity level and heating energy use was found, indicating that higher humidity levels are found in apartments with low heating energy use. However, the reason for higher CO2 concentration and humidity levels in apartments with a low heating energy use, seemed not to be because of less window opening time.

The data systems used in the project could (have to) be improved for further development. One critical issue is the time needed for data collection, data transfer and data analysis. In the current version of the system the time from an action is carried out until it can be recognized by the user on the ICT solution can take up to 30-45 minutes. This is far too long for users to maintain confidence in the system. Secondly, they were not warned in the case of a data gab, then the information and feedback just did not change. This may be acceptable, if the data gabs are short and rare, but in the present situation the data gabs were quite severe in several of the cases (missing data above 50% sometimes even more) again leading to mistrust in the system.

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Appendices

The appendices present the detailed results for each individual demonstration case and are provided in separate files:

Appendix 1: Kildeparken, Denmark

Demonstration Case "Kildeparken"

Appendix 2 University of Ljubljana, SL

Demonstration Case "University of Ljubljana buildings"

Appendix 3 Orologio Living Apartments, IT

Demonstration Case "Orologio Living Apartments"

Appendix 4 Qeske, NL MAP

Demonstration Case "Qeske"

Appendix 5 Smart City Wroclaw, PL MAP

Demonstration Case "Wroclaw"