TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

MASTER THESIS

Performance Assessment of a Mountain Base Station in a Cold Climate

ausgeführt zum Zwecke der Erlangung des

akademischen Grades eines Diplom-Ingenieurs

unter der Leitung von

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eingereicht an der

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Wien, April 2017

KURZFASSUNG

In dieser Arbeit wurde das thermische und energetische Verhalten der Bergstation am Krippenstein beurteilt. Das Gebäude wurde als Hotel und Restaurant geplant, errichtet und bis 2003 betrieben. In den folgenden Jahren, wurde nur der Seilbahnbereich genutzt und der Rest des Gebäudes kalt gestellt. 2015 wurde eine intensive Renovierung, Adaptierung und Modernisierung des Gebäudes durchgeführt. Das Sanierungsprojekt beinhaltete die thermische Verbesserung der Gebäudehülle, eine Umgestaltung des Restaurantbereichs, eine Modernisierung der Gebäudesysteme und den Umbau von zwei Geschossen zu einer Garage für die Pistengeräte.

Nach dem Abschluss der umfangreichen Renovierung wurde eine Studie mit Fokus auf thermischen Komfort und Luftqualität durchgeführt. Zusätzlich zu diesem Aspekt wurde das neu installierte elektrische Heizsystem auf Basis der Daten von Anfang 2016 untersucht. Der Einfluss des Lastmanagements war dabei von vorrangiger Bedeutung und wurde auf Basis der kälteste drei Wochen genauer untersucht. In diesem Zeitraum traten nur sehr kurzzeitigen Lastverschiebungen auf, da keine wirkliche Leistungsengpässe auftraten. Zusätzlich zu dieser Analyse wurde eine virtuelle Überprüfung auf Basis von historischen extrem Wetterdaten und einer Vorhersage des Einflusses auf den thermischen Komfort durchgeführt.

Die Resultate der Studie zeigen ein gutes Verhalten des Gebäudes hinsichtlich des thermischen Komforts und der Luftqualität. Dieses Ergebnis ändert sich selbst für den virtuellen analysierten Fall mit extremen Wetterbedingungen nicht wesentlich.

ABSTRACT

This study evaluates the energy and indoor environmental performance of the retrofitted Krippenstein Mountain Station. The original building design included a restaurant together with a hotel operating until 2003. In the following years the building was only used as the top station of Krippenstein 2 cable car. The refurbishment and modernisation of the Station were executed in 2015. The project included the thermal improvement of the building envelope, a new design of the Restaurant Area and Seminar Room, an update of the building systems and conversion of the two hotel floors into a garage for the snow groomer.

A detailed investigation of thermal comfort and air quality within the renovated areas was carried out within this study. In addition, analysis of the new radiant electrical heating system and the electric load management approach was performed with data from the first operation period in the beginning of 2016. The behaviour of the electrical loads was analysed for the three coldest weeks of 2016. During that period, the current load management system simply shifted peak demands to the following hours. The used load shedding approach was also virtually analysed with the prediction of extreme cold weather conditions based on historical values, in order to estimate possible negative effects on the thermal comfort.

The results of this study show that the case study building provided satisfying level of thermal comfort and indoor air quality. Moreover, the current load management approach was efficient and does not have negative effects on the thermal comfort. Even the virtual evaluation with more extreme weather conditions showed a satisfactory level of operation.

Keywords

Mountain climate, Building refurbishment, Thermal comfort, Air quality, Load shedding, Load balancing, Load management, Building performance, Building monitoring

AKNOWLEDGMENTS

I would like to truly express my gratitude to all the individuals who contributed to this work.

Firstly, my special and greatest recognitions are devoted to the Department of Building Physics and Building Ecology at Vienna University of Technology, for the knowledge and skills I obtained during my Master studies. I eminently pay my gratitude to Univ.Prof. DI Dr. Ardeshir Mahdavi and Assistant Prof. DI DI(FH) Dr. techn. Matthias Schuß for a very generous and constant guidance and supervision. I may freely say that without their expertise and contribution would be very difficult to realize and finalize this research. I also kindly thank Öberösterreich Seilbahnholding GmbH for the possibility to analyse that very special and unique building. The support of Wolfgang Steiner and the Architect DI Dr. Claus Pröglhöf made it possible to gather the necessary information and data for this study.

Moreover, I must thank my parents Radmila and Dragan, but also my brother Goran Vuk for being my biggest support through life and helping me achieve my goals. I need to add that without your love, guidance and encouragement all of my professional achievements would be very likely impossible.

Finally, my deep sense of gratitude is forwarded to my dear friend Nemanja for his endless support, unselfish optimism and faith in me.

CONTENTS

1 INTRODUCTION

1.1 Motivation

„*Most of the buildings that will exist in the year 2050 are already built. Renovation of the existing building stock is therefore key to meeting our long term energy and climate goals*" (EASME 2016). It is, hence, important to assess how successful the refurbishment project can be in terms of its initially set objectives. Moreover, the research documents that the revitalized buildings instead of new constructions can also offer high comfort quality to the users and have a good building performance.

The peculiarity of combination of building systems applied here, operating all on electricity, leads to the emphasized need of an efficent mutual relation of energy use and comfort parameters. „*Heating and cooling constitutes around half of the EU's final energy consumption and is the biggest energy end-use sector. The challenge is to moderate demand for heating and cooling, to increase energy efficiency in supply, to maximise the use of renewable energy and to reduce the cost of heating and cooling to affordable levels for all*" (EASME 2016). The aim of the research is, hence, also to evaluate how efficient the building systems of this retrofit are in provision of the user comfort with low energy demand.

Finally, the research is dealing with a very specific case study building, located in a distinctive location and within a sharp mountain climate, which adds to its specialty.

1.2 Objective

After the large refurbishment of the Krippenstein Mountain station, a post retrofit evaluation based on the data from the real building operation was of great importance. The targets of the refurbishment were the thermal improvement of the building envelope, an update of the building systems and revitalization of the Restaurant Area and Seminar Room. Within the renewed areas, the building performance was evaluated in terms of thermal comfort and air quality. The refurbishment also included the replacement of the old oil-based heating system with an electric heating system. This contributed to the need for studying the electrical loads within the building. Hence, the research objective also involves the assessment of the current electrical load management with focus on the heating loads, in order to detect the peak load days with load shedding. In addition to the results from monitored data, it is virtually predicted how much the heating load shedding on extreme days would influence the thermal comfort of the Restaurant Area.

1.3 Thesis structure

In the chapter of Introduction, the motivation behind the work (Subchapter 1.1) and its objective (Subchapter 1.2) are presented. The following chapter (Chapter 2) describes the background related to the existing researches in the field, standard recommended values and relevant guidelines of interest. In the third chapter of Methodology, the case study building is outlined (Subchapter 3.2), while also the building monitoring setup and data collection are described (Subchapter 3.3). Subchapter 3.3 in addition demonstrates the layout of the measuring locations and monitoring devices within the building plan. Finally, in the fourth chapter of Results and Discussion, the outcomes of the research regarding single research questions are graphically presented and interpreted in the Subchapter 4.2 Thermal comfort evaluation, 4.3 Air Quality evaluation and 4.4 Electrical load management evaluation. A final conclusion of the building performance evaluation is presented in the Chapter 5.

2 BACKGROUND

2.1 Thermal Comfort

Thermal comfort is widely described and defined so far in the literature. *„Thermal comfort is the condition of the mind in which satisfaction is expressed with the thermal environment*" (ASHRAE 55 2005). *„Thermal comfort is a state in which there are no driving impulses to correct the environment by the behaviour*" (Hensen 1991). While the concept of the thermal comfort is rather clear, its representation within buildings and standardization for the samples of users remain not absolute. Thermal sensations vary between the individuals located even in the same environment, depending on their health condition, age, sex, cultural background, psychological conditions, etc. The main parameters influencing thermal comfort were determined first in 1962 by Machperson. They are the four environmentally measurable variables of air temperature, mean radiant temperature, air velocity and relative humidity in addition to two personal user parameters: metabolic rate and clothing insulation (Djongyang, Tchinda and Njomo 2010).

Thermal comfort standards and models

Although the definition of the thermal comfort stays essentially similar, the various organizations establish their own standards which encounter certain differences. International Organization for Standardization (ISO), American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) and European Committee for Standardization (CEN), stay with their standards ISO 7730, ASHRAE 55 and EN 15251 worldwide pioneers in thermal comfort standardization.

The main evaluation concept of the ISO 7730-2005 and ASHRAE 55-2013 was established back in 1970 by P.O. Fanger. He developed the concept for the calculation of the Predicted Mean Vote (PMV) and the related Predicted Percentage of Dissatisfied (PPD), based on the heat balance of the body (Equation 1, 2, 3, 4 and 5) in order to establish a simple number representing the thermal comfort of the space.

$$PMV= [0.303e^{-0.036M}+0.028] \{(M-W)-3.96^{-8} f_{cl}[(t_{cl}+273)^4-(t_r+273)^4]-f_{cl}\, h_c(t_{cl}-t_a)-3.05[5.73 - 0.007(M-W)-p_a]-0.42[(M-W) - 58.15]-0.0173M(5.87-p_a)-0.0014M(34-t_a)\} \quad (1)$$

with,

$$f_{cl} = 1.0+0.2\ I_{cl} \qquad (2)$$
$$1.05 + 0.1\ I_{cl}$$

$$t_{cl} = 35.7 - 0.0275(M\text{-}W) - R_{cl}\{(M\text{-}W) - 3.05[5.73\text{-}0.007(M\text{-}W)\text{-}p_a] - 0.42[(M\text{-}W) - 58.15] - 0.0173M(5.87 - p_a) - 0.0014M(34\text{-}t_a)\} \qquad (3)$$

$$R_{cl}=0.155I_{cl} \qquad (4)$$

$$h_c=12.1(V)^{1/2} \qquad (5)$$

Where,

e = Euler's number (2.718)

f_{cl} = clothing factor

h_c = convective heat transfer coefficient

I_{cl} = clothing insulation [clo]

M = metabolic rate [W/m^2]

p_a = vapour pressure of air [kPa]

R_{cl} = clothing thermal insulation

t_a = air temperature [°C]

t_{cl} = surface temperature of clothing [°C]

t_r = mean radiant temperature [°C]

V = air velocity [m/s]

W = external work [W/m^2]

The scale of the PMV is in range from -3 to +3 for votes from cold to hot. The standards are recommending a PMV in the range from -0.5 to +0.5 and a resulting PPD limit of 10%. PPD is directly correlated with the PMV, as shown in Equation 6. At zero, or neutral PMV position, PPD tends to be 5% because it is assumed that even at that point some people may feel thermally uncomfortable.

$$PPD= 100 - 95e^{[-(0.3353PMV^4+0.2179PMV^2)]} \qquad (6)$$

However, ISO 7730 allows deviations from this range, via three categories A, B and C, which will be explained later (Table 1).

Apart from the air temperature, mean radiant temperature, air velocity and relative humidity, thermal comfort is influenced by two other parameters, namely metabolic rate and clothing insulation. These are assessed by ISO 8996 for metabolic rate and ISO 9920 for clothing factor, and represent one of the validity issues of the standards and one of the possible reasons of the deviations between actual mean vote (AMV) and predicted mean vote (PMV).

The standards are, unlike adaptive models, criticized not to picture the dynamic reality of the human behaviour, body and environment (Olesen and Parsons 2002). *„Why continue to improve the heat balance equation or develop thermal models when the complexity of 'reality' will undermine any improvement?"* (Olesen and Parsons 2002). Fanger model alludes that environment is considered rather thermally uniform. In modern buildings, however, environments tend to be quite non uniform in the temperature distribution. Because of this, ISO and ASHRAE adopted some directions related to the local thermal discomfort. These, nonetheless, stay as separate guidelines while their total effect on general thermal comfort cannot be weighted (Cheng, Gao and Niu 2011). Draught, big vertical air temperature difference between ankles and head, too warm or too cool floor and high radiant temperature asymmetry are the factors causing local thermal discomfort and shall be assessed in addition to PMV and PPD according to ISO 7730 (2005) and ASHRAE 55 (2013).

Notwithstanding the weak points of the Fanger model when it comes to dynamic environments and dynamic human behaviour, ASHRAE 55 and ISO 7730 still tend to be the best and widely used standards for the thermal comfort evaluation and their guidelines will be taken as proper margins for the evaluation of data. *„In buildings with heating, ventilation and air-conditioning (HVAC), the Predicted Mean Vote Index (PMV) was successful at predicting comfort conditions, whereas in naturally ventilated buildings, only adaptive models provide accurate predictions"* (Orosa and Oliviera 2010).

ISO 7730 (2005) guidelines of interest

ISO 7730 (2005) defines three categories (A, B and C) of the thermal comfort, as shown in the Table 1.

Table 1. Categories of the thermal environment (Source: ISO 7730 2005)

Category	Thermal state of the body as a whole		Local discomfort			
	PPD %	PMV	DR %	PD % caused by		
				vertical air temp. difference	warm or cool floor	radiant assymetry
A	<6	-0.2<PMV<+0.2	<10	<3	<10	<5
B	<10	-0.5<PMV<+0.5	<20	<5	<10	<5
C	<15	-0.7<PMV<+0.7	<30	<10	<15	<10

When it comes to local discomfort, ISO refers to the four possible sources causing it: draught, vertical air temperature difference, warm and cool floors and radiant asymmetry (ISO 7730 2005).

ISO 7730 (2005) explains the Draught Rate (DR) as an immediate percentage of people dissatisfied with the level of draught: *„The discomfort due to draught may be expressed as the percentage of people predicted to be bothered by draught.*" It is calculated using the Equation 7, while Figure 1 shows the Standard categories of the DR in correlation to the air temperature and turbulence intensity.

$$DR = (34 - t_{a,I})(v_{a,I} - 0.05)^{0.62}(0.37 v_{a,I} T_u + 3.14) \qquad (7)$$

For $v_{a,I} < 0.05$ m/s use $v_{a,I} = 0.05$ m/s

For DR > 100% use DR = 100%

Where,

$t_{a,I}$ is the local air temperature, in degrees Celsius, 20°C to 26°C;

$v_{a,I}$ is the local mean air velocity, in metres per second, <0.5 m/s;

T_u is the local turbulence intensity, in percent, 10% to 60% (if unknown, 40% may be used).

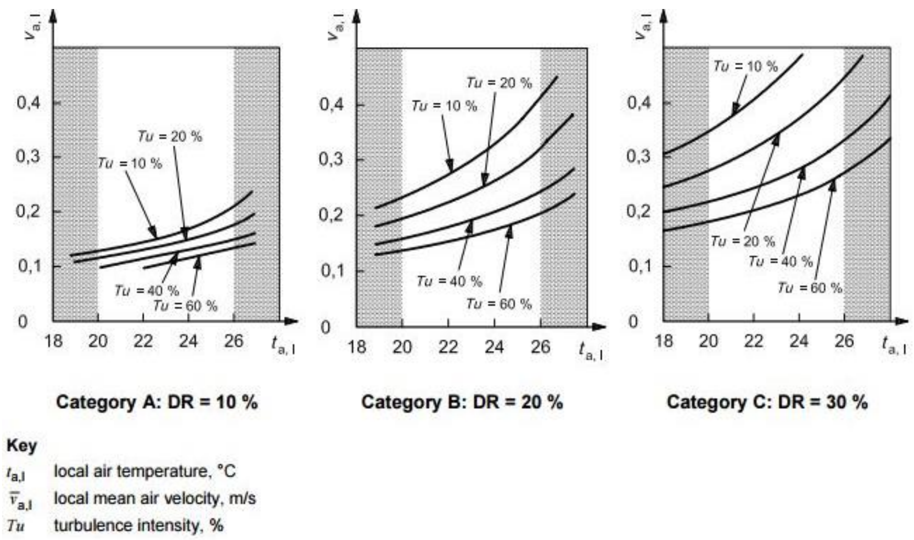


Figure 1. Maximum allowed mean air velocity as a function of local air temperature and turbulence intensity (Source: ISO 7730 2005)

The correlation between vertical air temperature difference and the percentage of dissatisfied people is presented in the Figure 2. The categories of the thermal environment regarding this parameter are assigned as shown in Table 2.

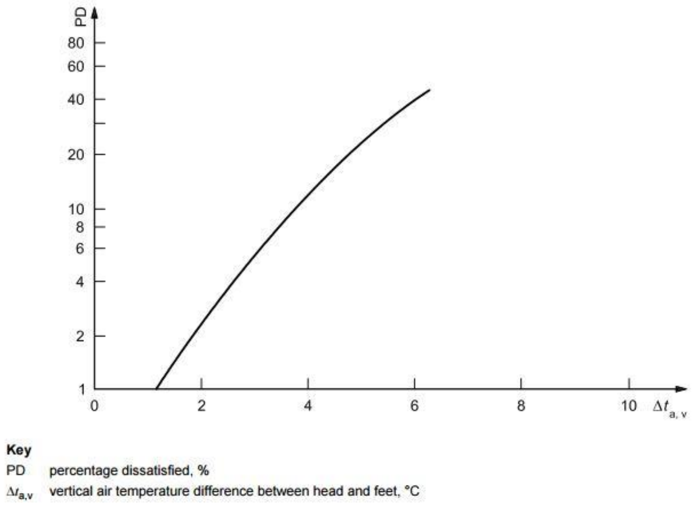


Figure 2. Local discomfort caused by the vertical air temperature difference (Source: ISO 7730 2005)

Table 2. Vertical air temperature difference between head and ankles within categories of thermal environment (Source: ISO 7730 2005)

Category	Vertical air temperature difference [a] °C
A	<2
B	<3
C	<4
[a] 1.10 and 0.10 m above floor	

The Predicted Percentage of Dissatisfied users (PD) is calculated with the following Equation 8, and directly correlates to the Figure 2:

$$PD=100/(1+\exp(5.76-0.856*\Delta t_{a,v})), \quad (8)$$

where $\Delta t_{a,v}$ is vertical air temperature difference between head and ankles.

Warm or cold floor could cause local discomfort because of the influence to the occupant's feet thermal sensation. According to that, ISO 7730 includes graphs to predict the percentage dissatisfied caused by this phenomenon (Figure 3) and recommends maximum and minimum allowed floor temperature (Table 3).

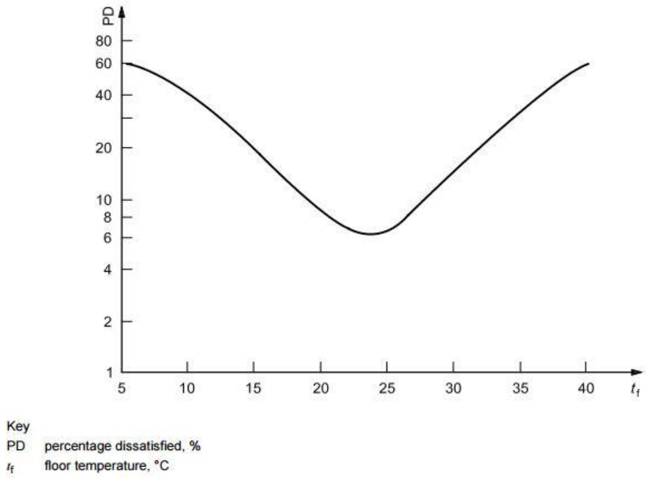


Figure 3. Local thermal discomfort caused by warm or cold floors (Source: ISO 7730 2005)

Table 3. Range of floor surface temperature within categories of thermal environment (Source: ISO 7730 2005)

Category	Floor surface temperature range °C
A	19 to 29
B	19 to 29
C	17 to 31

Finally, the local discomfort can be caused also by radiant temperature asymmetry of the surfaces. ISO 7730 represented its relation with predicted percent of dissatisfied occupants as in Figure 4, while the guideline on maximum temperature asymmetry is shown in Table 4.

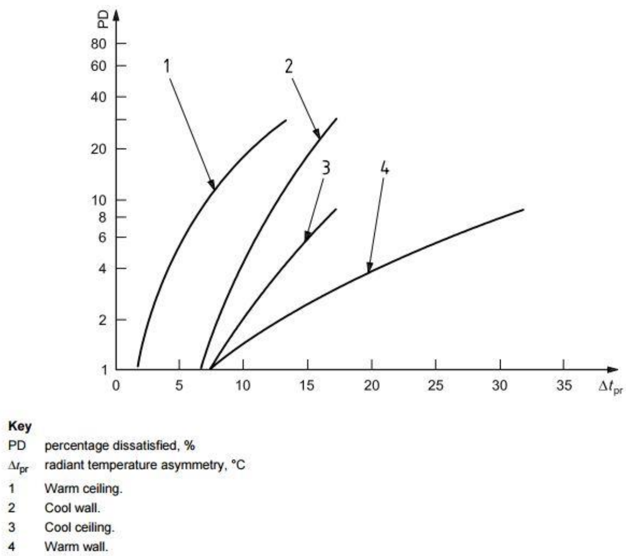


Figure 4. Local thermal discomfort caused by radiant temperature assymetry (Source: ISO 7730 2005)

Table 4. Maximum radiant temperature assymetry within categories of thermal environment (Source: ISO 7730 2005)

Category	Radiant temperature asymmetry °C			
	Warm ceiling	Cool wall	Cool ceiling	Warm wall
A	<5	<10	<14	<23
B	<5	<10	<14	<23
C	<7	<13	<18	<35

2.2 Air Quality

There are many ways of assessing the indoor quality of the buildings, and these are usually highly dependent on the type of the building (residential or non residential function) and types of ventilation provided to the building (natural or mechanically induced ventilation). There is no standard specifying strictly the suggested ventilation rate or CO_2 levels of the naturally ventilated rooms, except for the general recommendations such as Pettenkofer's number. It is considered that in this case, users can always willingly improve the indoor air quality by the opening of the window. Hence, naturally ventilated space is only discussed in general when it comes to the indoor air quality. European Norm for Ventilation for Non-residential buildings-Performance requirements for ventilation and room conditioning systems (EN 13779 2007), together with criteria for the indoor environment (EN 15251 2006) can cover the assessment of the indoor air quality of the non residential and mechanically ventilated case study building, taking into consideration the data collected and assumptions to be made. Indoor air quality assessment regarding the CO_2 levels is suggested when it is assumed that there is no pollutant more dominant in the environment assessed (De Gids and Wouters 2010). EN 13779 and EN 15251 take into account the indoor level of CO_2 which is above the outdoor CO_2 level at the same location. Since the increase of 1 ppm annually was happening within the last decade, and has recently reached 400 ppm within the city, the safe side in assessment of the indoor air quality would always be to take this number as an outdoor level default value in case that there is no value more precisely known (De Gids and Wouters 2010). Moreover, most of the sensors are by their auto calibration function calibrated to 400 ppm. EN 13779 offers the following four categories of the Indoor Air Quality (IDA), illustrated in the Table 5 below, while EN 15251 offers, in addition, corresponding expected percentage dissatisfied and air flow rate per person, as seen in

Table *6*.

Table 5. Maximum CO_2 levels in rooms according to the Indoor Air Quality categories (Source: EN 13779:2007)

Category	**CO_2 level above level of outdoor air in ppm**	
	Typical range	**Default value**
IDA 1	≤400	350
IDA 2	400-600	500
IDA 3	600-1000	800
IDA 4	>1000	1200

Table 6. Indoor Air Quality Categories with expected PPD and required air flow per person (Source EN 15251:2006)

Category	**CO_2 above outdoors (ppm)**	**Expected percentage dissatisfied (%)**	**Air Flow per person (dm^3/s)**
IDA 1	350	15	10
IDA 2	500	20	7
IDA 3	800	30	4
IDA 4	>800	>30	<4

Max von Pettenkofer studied the CO_2 levels in 1860s. His studies proved 1000 ppm of CO_2 concentration as a legit limit not only for the recommended air quality, but also for the CO_2 level healthy for the body. The hospital patients whom Pettenkofer was studying tended to have faster and more profound recovery if they were located within hospital institutions with CO_2 levels up to 1000 ppm. Since then, the number of 1000 ppm is called Pettenkofer's number and is taken as a hygiene limit for the indoor air quality. This value is still widely used as a reference number for the general assessment of the indoor air quality when consulting the CO_2 levels. (De Gids and Wouters 2010).

2.3 Load shedding

„Electricity load distribution may vary throughout the day depending on the time of operations of equipment and processes and the ambient weather conditions. Electricity demand of commercial buildings in urban areas during the daytime in the weekdays is much higher as compared to demands during the night time or weekends" (Rozali, Wan Alwi, Manan and Klemes 2015). Peak loads are predictive scenarios not only for the separate buildings, but also for wider electricity grids on city or country scale. *„Some countries have recently experienced blackouts owing to an imbalance between electricity supply and*

demand, which usually occurs when demand goes up because of severe weather conditions. In order to prevent a crash of the entire electrical grid, the independent system operator (ISO) eventually decided to cut power usage in the state" (Kim, Nam and Cho 2014). *„A rolling blackout is the intentional outage of electricity during peak demand periods in non-overlapping regions to maintain the balance between supply and demand*" (Maqbool et al. 2011). Similar story happens in the singular building contexts, where certain electric circuits are intentionally shut off. In order to prevent these unwanted courses of action and avoid actual shutting off of the entities, load shedding may be applied to the system, with planned and predicted schedules when high loads are expected. *„Power distribution networks are constantly being faced with an ever-growing load demand and/or could constantly experience distinct change from low/high to high/low load level. Although the loads are usually balanced across a three-phase distribution system during installation, the growth of the load demand as well as changes in load demand during a day, results into unbalanced state. Once a feeder is balanced it will initially be in balance but drift into unbalance as time goes on. The need for load balance and power loss minimization has triggered a vast variety of research on load balancing and load scheduling*" (Zdraveski, Todorovski and Kocarev 2015). *„Automatic load shedding is the ultimate countermeasure against imbalance in a power system and can effectively help preventing large blackouts*" (Hauer et al. 2015). Thus, distributing the electricity through the schedules pre-determined by the load balancing units can have positive effect on the power system balance but also on the final cost of the electricity. Electricity cost depends equally on the consumed amount and intensity of the use at given moment. On the city scale, Demand Response could be implemented on electricity markets, which is assumed to have significant annual financial savings (Feuerriegel and Neumann 2016). *„Demand Response allows for the management of demand side resources in real-time; i.e. shifting electricity demand according to fluctuating supply. When integrated into electricity markets, Demand Response can be used for load shifting and as a replacement for both control reserve and balancing energy*" (Feuerriegel and Neumann 2016). On the building scale smart predictive load shifting from the unnecessary peak periods could serve well as an appropriate approach. For example, instead of the sudden turning on of the overall building heating in morning initial occupancy hours, preheating of certain rooms during pre-operation hours could be applied.

3 METHODOLOGY

3.1 Overview

This chapter will demonstrate the methodology of conducting the research. After outlining the case study building (Subchapter 3.2) the building monitoring setup is described referring to the measuring locations and to the processes of data collection and evaluation (Subchapter 3.3).

Firstly, the case study building is addressed, revealing the specifics of its location and surrounding while also focusing on the topics of refurbishment and the related assessment of thermal comfort, air quality and electrical load management. Two main refurbished areas, Restaurant and the Seminar Room, are also introduced in this part.

Secondly, the building monitoring setup is depicted in detail, distinguishing between short term thermal comfort measurements (Subchapter 3.3.1) and long term monitoring (Subchapter 3.3.2). The issues of data collection are explained for all the three assessed topics. The choice of data to be evaluated is justified with comprehensive description of the tools and procedures of data evaluation. The measuring equipment was documented together with its exact locations within the building plan.

3.2 Case study building

The Krippenstein Mountain Station is located at the Krippenstein peak, 2100 m above the sea level, within the Dachstein Mountain belt (Figure 5). The Dachstein Salzkammergut region is for the reasons of its natural landscapes, cultural features (Hallstatt region) and scientific contribution (salt mining and trade from approximately year 5000 BC) in 1997 declared as World Cultural Heritage site by UNESCO. For those reasons, the region is a very popular tourist hot spot and a holiday resort for activities such as hiking and cycling during summer and skiing and free riding during the winter. (Tourismusverband Inneres Salzkammergut 2015)

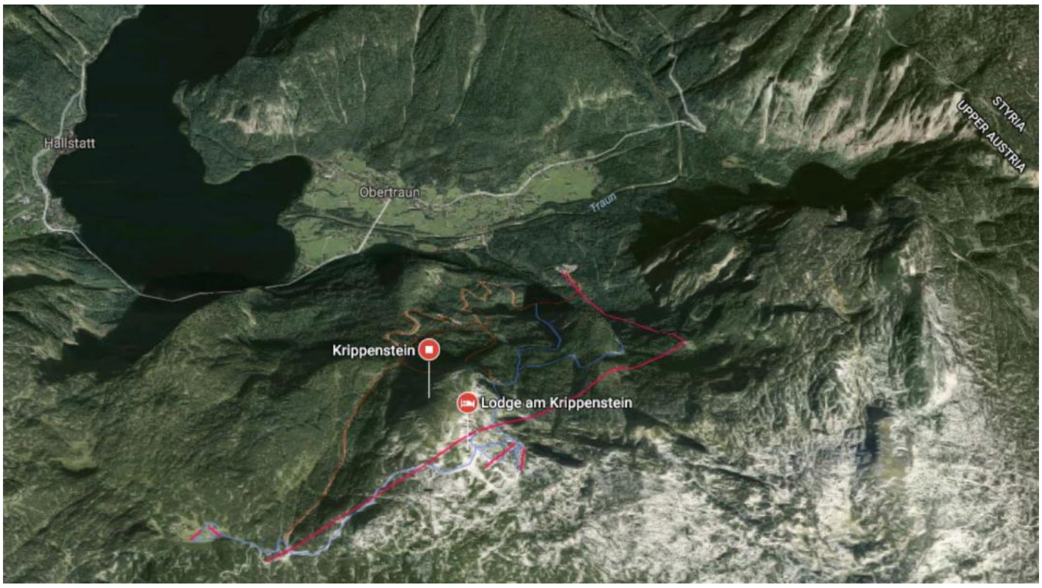


Figure 5. Dachstein Salzkammergut region with Krippenstein Mountain Base location (Source: Google Maps 2016)

Nowadays tourists and employees are transported to the Mountain Station (2000 m) by cable car operating from Obertraun with one stopping station (Mittelstation Schönbergalm), as shown in full black line in Figure 6.

Figure 6. Map of Dachstein Salkammergut region with cable car path, rambling and climbing tracks (Source: Tourismusverband Inneres Salzkammergut 2015)

The Mountain Station was built in 1956 and served until 2003 as a hotel which at that time seemed to be profitless property and was for this reason closed. Since

2003, the building (Figure 7) was serving only as a cable car station and was merely producing costs of about 50 000 Euros annually. Finally, Öberösterreich Seilbahnholding GmbH invested 4 million Euros in the refurbishment project of the station, with an idea to open a 150-seats restaurant and in addition a multi functional conference room (Mein Bezirk 2015). By the end of year 2015, the refurbishment was finished (Figure 8, Figure 9).

As seen from the comparison of the Figure 7 and Figure 8, the main interventions of the refurbishment are visible on the south wing of the building with external changes of the facade (Figure 9). The internal renovation and redesign of the Restaurant Area is shown in the Figure 10 and Figure 11 and of the Seminar Room in Figure 12.

Figure 7. Krippenstein mountain base station before refurbishment (Source: Mein Bezirk 2015)

Figure 8. Krippenstein mountain base station after refurbishment (Source: Dachstein Salzkammergut 2016)

Figure 9. Krippenstein mountain base station's south wing after refurbishment

Figure 10. Restaurant Area after the refurbishment (Source: Dachstein Salzkammergut 2016)

Figure 11. Vestibule of the Restaurant after the refurbishment (Source: Dachstein Salzkammergut 2016)

Figure 12. Seminar Room after the refurbishment

The refurbishment was focusing on three main targets, the reduction of heat transmission losses with strengthened insulation of the building, an improved energy efficient cooperation between heating and ventilation system and finally the application of the electric load management for the electric heating system and other electrical loads of the building. The main construction and the wall skeleton stayed principally the same, apart from the removal of certain windows in the unused floors. Prime focus of the refurbishment was wall optimization for the improvement of the envelope's thermal performance. In addition, the building systems were exchanged for the options relating best to all the aspects of this specific location, UNESCO protected surrounding and background factors. The oil based heating was replaced with the electrical and low energy radiant heating. The transportation and combustion of oil were causing many issues for the local ecosystem. During the refurbishment design process electric heating was chosen as the most adequate option. Such heating, with the existing power connection, was resulting in the lowest investment costs and did not need the water as a medium. In the Restaurant Area, the mechanical ventilation is installed, operating also with the electricity. The final outcome of the refurbishment will be tested throughout the research within the detailed evaluation of the thermal comfort, air quality and electrical load management.

Due to the heating system's operation in the same time with electrical cable car, in excessive load hours some circuits are intentionally shut off. This is done to prevent the peak loads and interruption of the cable car operation. The building's load management will be, hence, the third assessed parameter, in order to test its final effectiveness in heating load distribution, spot the potential weaknesses and, if needed, suggest the modified approach of load management in order to prevent the negative effects on thermal comfort. The scheme of the electrical power feed distribution is shown in Figure 13.

The building's electricity feed is dispensed by two distribution boards (NSHV 400 and NSHV 630) to the subsidiary circuits. Distribution board 1, with the maximum power of 400 kVA distributes its total feed to cable car Krippenstein III, lighting for kitchen and restaurant, kitchen equipment and heating of the Restaurant area and Seminar room. As may be concluded from Figure 13, the load balancing unit is in charge of providing, in the first place, no electricity shortcuts to the cable car due to occasional high loads of other circuits, while in the same time ensuring the thermal comfort according to the data recieved from BMS. Distribution board 2, with the maximum power of 630 kVA, is in charge of dividing the electricity feed to the cable car Krippenstein II, ventilation of restaurant and kitchen, heat pumps but also the heating circuits of other parts of the building (Figure 13). Since Distribution board 1 supplies the heating circuits of the two areas of interest, Restaurant and Seminar Room, the focus of the load balancing assessment will be on it.

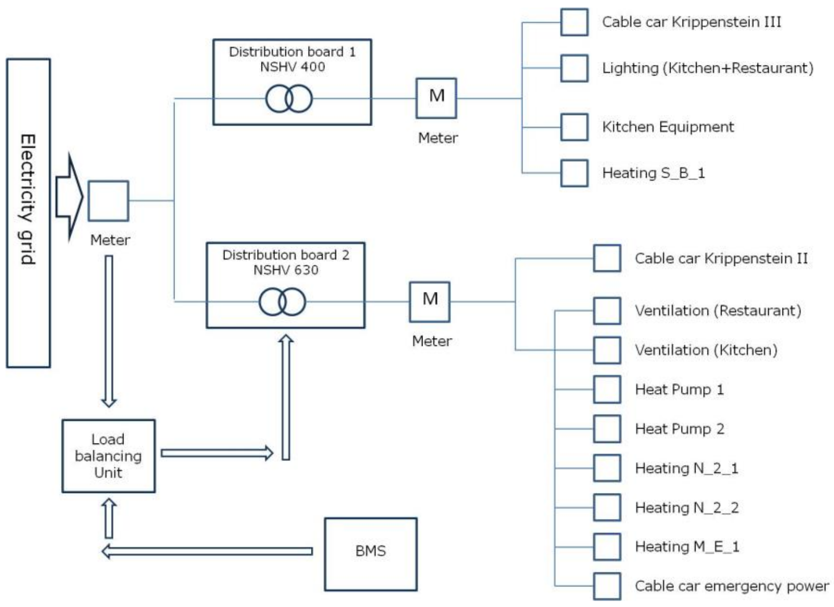


Figure 13. Scheme of the electrical power feed distribution from two of the Krippenstein distribution boards

3.3 Building monitoring setup and data collection

3.3.1 Short term thermal comfort measurments

Thermal comfort and local discomfort measurements were collected on 8th of March and 11th of April at the same locations within the Restaurant Area and the Seminar Room (Figure 14, Figure 23). A standard thermal comfort station (TCS) was used to obtain the measurements of dry bulb temperature, wet bulb temperature, relative humidity, mean radiant temperature, air velocity together with CO_2 levels for air quality evaluation. The sensors were located on the height of 1.10 m. On both days the thermal comfort station was recording short time measurements on the different locations. The recorded data was later processed in MATLAB to obtain the results of PMV and PPD according to the ISO 7730 standard (Subchapter 2.1). In addition, different local discomfort parameters were calculated and evaluated in relation to the recommendations from the Standards (Subchapter 2.1).

The measurements of mean radiant temperature and air velocity were afterwards used for the necessary assumptions for long term evaluation.

Thermal comfort

Air temperature, mean radiant temperature, air velocity and relative humidity were used in addition to assumed metabolic rate and clothing insulation in order to obtain the PMV and PPD. Two user categories were taken into consideration, the employees and guests, for the evaluation of the Restaurant Area. These groups are expected to have different outcomes in the PMV and PPD, caused by two factors, the metabolic rate and the clothing factor. Referring to ISO 7730, workers of the Restaurant are assigned the higher metabolic rate for the purpose of light activity (1.6 met for standing, light activity), while wearing lighter clothes (0.9 clo for underpants, shirt, trousers, smock, socks, shoes). On the other hand, guests are assigned lower metabolic rate (1.0 met for seated, relaxed), with bigger clothing insulation factor (1.3 clo for underwear with long sleeves and legs, shirt, trousers, V neck sweater, jacket, socks, shoes). In case of the Seminar Room, only one category of users (conference participants) was considered, with metabolic rate of seated office activity (1.2 met for sedentary activity) and clo value of 0.9 (underpants, shirt, trousers, smock, socks, shoes) (ISO 7730 2005). Exactly the same values and observations of the metabolic rate and clothing insulation factor were used for the long term comfort evaluation.

Local discomfort parameters

Simultaneously to the thermal comfort, the possible sources of local discomfort were measured on 11^{th} of April, precisely Draught Rate and Vertical Air Temperature difference. Out of four local discomfort parameters suggested by ISO 7730 (Subchapter 2.1), these two were evaluated. The parameter of Cool and Warm Floor (Table 3, Figure 3) was considered not truly applicable and was not evaluated, as it usually relates to homes or some other places where people tend to spend time in lighter shoes. *"For people wearing light indoor shoes, it is the temperature of the floor rather than the material of the floor covering which is important for comfort"* (ISO 7730 2005). Radiant Asymmetry parameter was not expected to give any negative and unexpected results in the sections of warm wall, cool wall and cool ceiling (Figure 4, Table 4), as building is after retrofitting equipped with good thermal envelope and does not consist of any big glass surfaces which might cause the local discomfort due to the Radiant Asymmetry. However, the warm ceiling might have been checked especially in the Seminar Room which has the radiators located on the ceiling. Vertical Air Temperature Difference and Draught were evaluated.

For the Draught Rate the measurements of air velocities and air temperatures were used. The turbulence intensity value was assumed to be 40%, as prescribed by the Standard when that value is unknown. Moreover, the Vertical Air Temperature difference was measured on all the same TCS locations, with standard recommended height of the temperature sensor of 1.10 m for the level of head in seated position and 0.10 m for the level of ankles. An average Vertical Air Temperature difference and the related Predicted Percentage Dissatisfied (PD) were calculated and evaluated referring to the standard.

Measuring locations

The plan of the measuring locations within the Restaurant Area is presented in Figure 14.

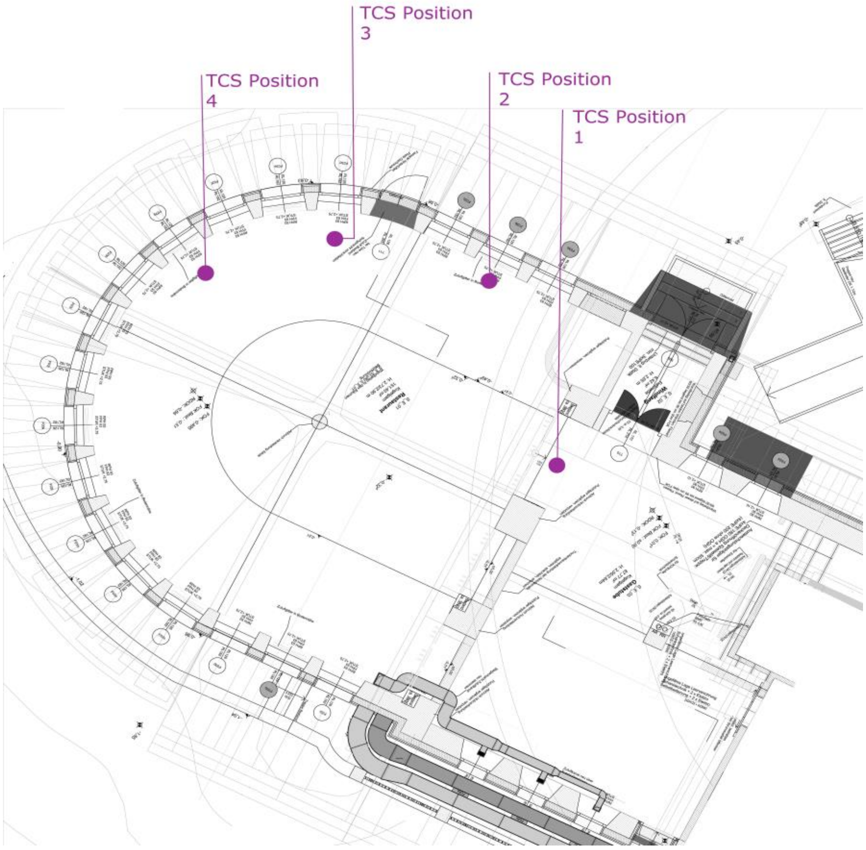


Figure 14. Plan of the Restaurant Area with short term monitoring device's (TCS) locations for 8th of March and 11th of April

The location 1 of the TCS (Figure 15, Figure 16) is set in the northern part of the Restaurant and is not directly exposed to ventilation draft or heating radiation The locations 2 (Figure 17, Figure 18), 3 (Figure 19, Figure 20), and 4 (Figure 21, Figure 22) are chosen close to the south oriented part of the Restaurant.

Figure 15.TCS Pos.1,8th of March, 2016

Figure 16.TCS Pos.1,11th of April, 2016

Figure 17.TCS Pos.2,8th of March, 2016

Figure 18.TCS Pos.2,11th of April, 2016

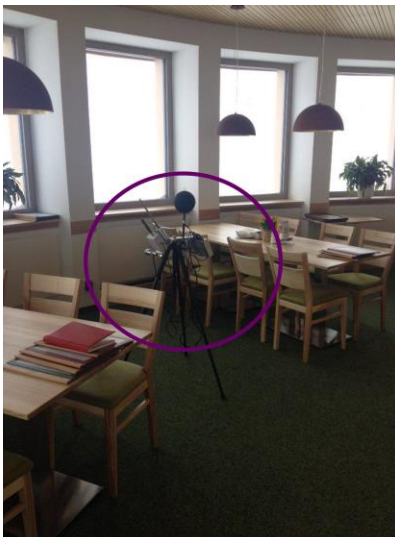


Figure 19.TCS Pos.3,8th of March,2016

Figure 20.TCS Pos.3,11th of April,2016

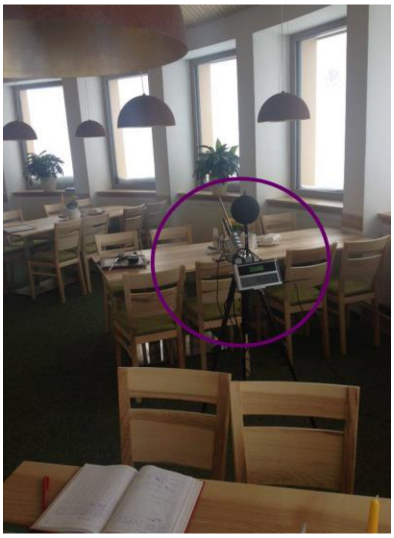


Figure 21.TCS Pos.4,8th of March,2016

Figure 22.TCS Pos.4,11th of April,2016

The thermal comfort measurements were performed also in the Seminar Room with the plan of measuring locations illustrated in Figure 23. The TCS position 1 is represented in Figure 24 and Figure 25. The position 2 shows in Figure 26 and Figure 27, position 3 in Figure 28 and Figure 29 and position 4 in Figure 30 and Figure 31.

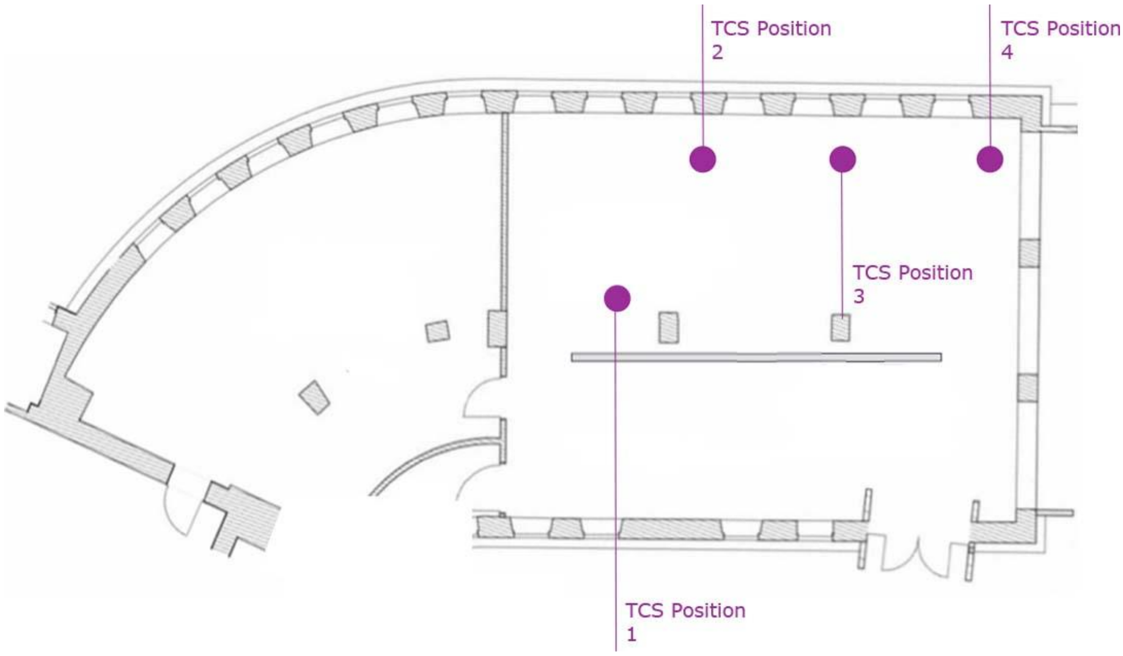


Figure 23. Plan of the Seminar Room with short term monitoring device's (TCS) locations for 8th of March and 11th of April

Figure 24.TCS Pos.1,8th of March,2016

Figure 25.TCS Pos.1,11th of April,2016

Figure 26.TCS Pos.2,8th of March,2016

Figure 27.TCS Pos.2,11th of April,2016

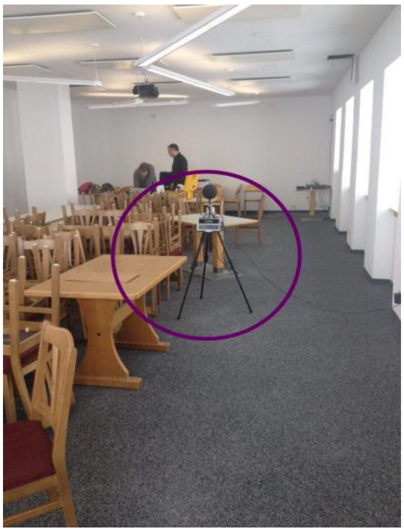


Figure 28.TCS Pos.3,8th of March,2016

Figure 29.TCS Pos.3,11th of April,2016

Figure 30.TCS Pos.4,8th of March,2016

Figure 31.TCS Pos.4,11th of April,2016

3.3.2 Long term monitoring

The refurbishment of the building included the implementation of building management system (BMS) together with the monitoring of the room temperature, heating events and metered electrical values for the different circuits. The BMS data from 26th of January until the 7th of March was used for the long term evaluation of the electrical load management. The additional monitoring sensors were installed within the Restaurant and Seminar Room on 8th of March. This was done to obtain the necessary data for the evaluation of the thermal comfort and air quality, as these devices measured air temperature, relative humidity and CO_2 levels. Moreover, the installation of these sensors meant taking precautions with the consistency and resolution of the data, as their monitoring was regularly controlled.

Thermal comfort

In order to perform the long term evaluation of the thermal comfort and air quality, the data from the additional monitoring sensors was used. The monitoring period from 9th of March until 31st of June was split in three periods, evaluating only the occupancy hours from 08:00 to 16:00. The first period includes the full system performance during the cold wintertime season from 9th of March until 11th of April. The period when the station was closed for the maintenance reasons (from 11th of April until 1st of May) is the second period with setback heating. During the third period, from May until the end of June, weather data already shows certain warm days when there was partial percentage of the heating needed to reach the recommended thermal comfort values. In order to assess the thermal comfort, the long term monitoring was lacking the information about mean radiant temperature and air velocity, as sensors measured only air temperature and relative humidity. Thus, data obtained from the short term monitoring was used as a reliable indication of these values. The assumptions included the fixed air velocity (0.1 m/s) for every iteration in MATLAB. The standard deviations of +0.52 and +2.17 degrees Celsius were used respectively for Restaurant and Seminar Room as a constant offset added to the air temperature in order to obtain mean radiant temperature. These values were obtained by averaging the differences between mean radiant temperature and air temperature on four TCS locations within the rooms. The parameters of clothing insulation and metabolic rate are taken from the ISO 7730 Standard as specified in the Subchapter 3.3.1. The final calculation of the PMV and PPD was also performed in reference to the ISO 7730 (Subchapter 2.1).

Air quality

As already stated, CO_2 was monitored with the same devices as temperature and relative humidity. Thus, air quality evaluation was performed for the same locations and within the same time period split in three previously mentioned seasons. Similarly, only occupancy hours were considered in the air quality evaluation. The average, minimum and maximum CO_2 levels were calculated in MATLAB. The evaluation of the predicted percentage of dissatisfied users (PPD) was done as specified in the Subchapter 2.2. For the Seminar Room, as a fully naturally ventilated space, the evaluation of the air quality was simply made consistent with the evaluation of the Restaurant Area. However, the actual evaluation of the indoor air quality of this space according to the EN 13779 and EN 15251 cannot be fully credulous, as these standards apply only to the mechanically ventilated buildings (Subchapter 2.2). The value of 400 ppm was taken as a default reference of an outdoor CO_2 level. It is the number to which sensors were automatically calibrated. This value is needed as a starting point for obtaining the IDA categories according to the EN 13779 and EN 15251 (Table 5).

Electrical load management

The evaluation of the electrical load management was based on the three coldest weeks of the winter of 2016, in period from 27th of January until 14th of February. The weeks were chosen according to data of outside temperatures from the BMS Weather files. The coldest weeks are most representative for the assessment of the heating system performance with highest loads and spotting the spaces for the improvement of the load balancing schedules if needed. Moreover, in these weeks, loggers registered high resolution and continuous dossier, so this data is considered reliable for the evaluation. The electrical power feed from the Distribution Board 1 was studied on a daily basis throughout the three weeks. Total electrical power and electrical power used only for heating were averaged on the basis of daily time intervals from 00:00-08:00, 08:00-10:00, 10:00-12:00, 12:00-17:00 and 17:00-24:00. These values were compared to the maximum peak load of 400kW and 50kW for total and heating power respectively, in order to obtain their percentage. This was done as a first step for finding the relation between the total electrical and heating load. The days with the highest heating loads were in continuation selected, while also focusing on the peak load intervals where load shedding could have happened. Moreover, the percentages of the turned on heating were calculated on hourly basis in order to find the daily number of full load hours. However, the winter of 2016, although the coldest weeks were chosen initially, was a mild winter in comparison to the historical weather data at this location. With the mild outside temperatures there could be none or rare events of conflicting load balancing between heating circuit and any other electrical circuit. For this reason, the theoretical rising shift of the heating load is introduced, coming from the percentage difference between Heating Degree Days of the standard weather file and actual weather file of the past winter. This percentage difference is applied to the heating loads during the daily time intervals of the two extreme days with highest heating loads. The load management approach is then virtually tested in this hypothetical colder winter at Krippenstein. Finally, the scheme of the alternative load management approach is presented and commented on.

Measuring locations

In the Restaurant Area there are three multi sensor devices located measuring air temperature, relative humidity and CO_2 levels. The plan of the measuring locations (ML) is shown in Figure 32.

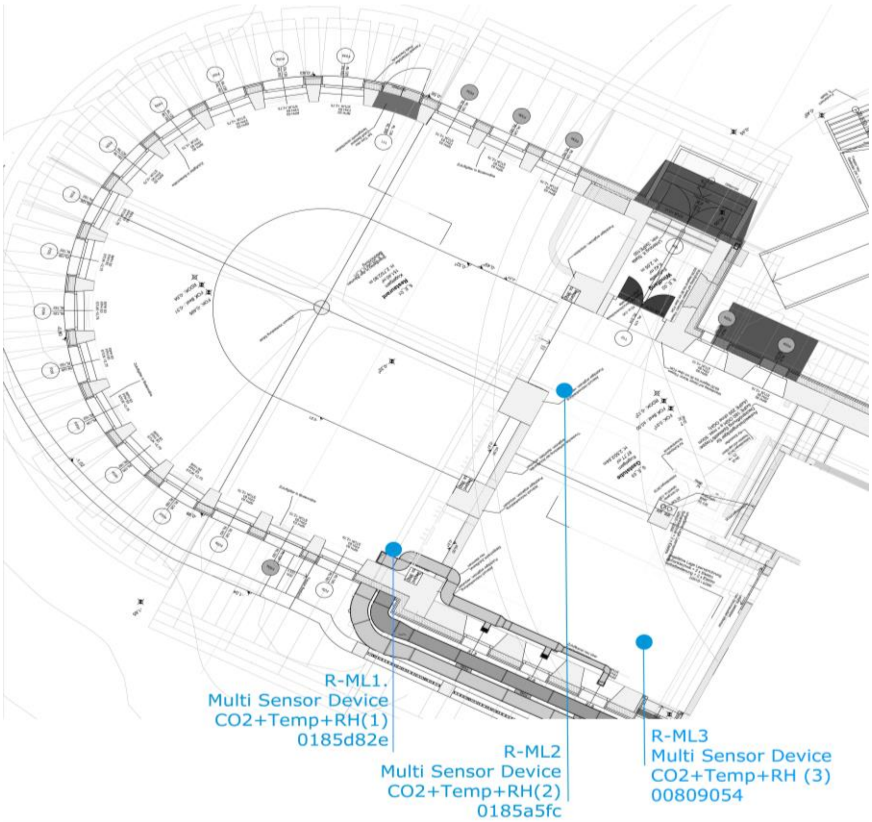


Figure 32. Plan of the Restaurant Area with long term monitoring devices' locations

First Multi Sensor Device is placed close to the south-east wall of Restaurant (Figure 33, Figure 32), while the second one is located in the hallway of the room close to the north-west wall and could be more exposed to the external influences from the double wing door in front (Figure 34).

Figure 33. Restaurant-Measuring Location1. Multi Sensor (Temp, RH and CO_2) Device 1

The third sensor device is mounted in the north part of the Restaurant, near to the kitchen area (Figure 35). The sensor was initially located somewhat closer to the ceiling level and resulted to be under bigger influence of the heating radiation. The temperatures monitored were always higher in comparison to the other two devices. For this reason, the data obtained from this device was finally not taken into consideration for the long term monitoring evaluation of the thermal comfort or air quality of the room.

Figure 34. R-ML2. Multi Sensor (Temp, RH and CO_2) Device 2

Figure 35. R-ML3. Multi Sensor (Temp, RH and CO_2) Device 3

The Seminar Room was also equipped with a Multi Sensor Device for measuring the temperature, relative humidity and CO_2 levels. The device was mounted at the south-east wall of the Seminar Room as shown in the Figure 36 and Figure 37.

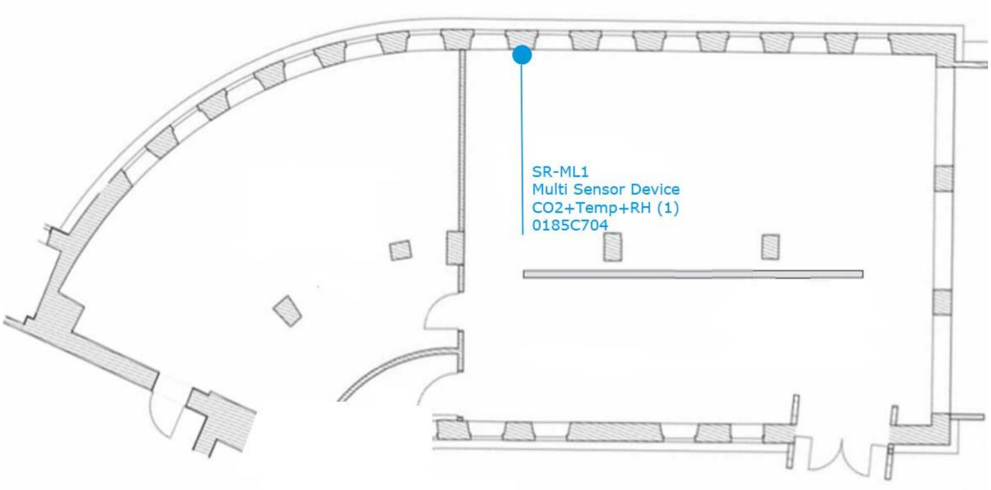


Figure 36. Plan of the Seminar Room with long term monitoring device's location

Figure 37. Seminar Room Measuring Location 1. Multi Sensor (Temp, RH and CO_2) Device 1

4 RESULTS AND DISCUSSION

4.1 Overview

The first part of the chapter (Subchapter 4.2) is outlining the evaluation of building performance regarding the thermal comfort and local discomfort after the short term measurements and long term monitoring. Secondly, in the Subchapter 4.3, the Air Quality is evaluated taking into consideration the CO_2 levels measured during the long term monitoring process. Finally, in the Subchapter 4.4, the electrical load management evaluation is carried out and documented.

4.2 Thermal comfort evaluation

Thermal comfort results are presented distinguishing between short term and long term evaluations which were completed as previously described in the Subchapters 3.3.1 and 3.3.2.

4.2.1 Short term thermal comfort evaluation

Firstly, the results of the general thermal comfort measurements are presented for the Restaurant and Seminar Room for two measurement sessions on 8th of March and 11th of April. In continuation, the local discomfort parameters are evaluated for both of the rooms using the measurements from the second date. Finally, the summed up distribution of general thermal comfort and local discomfort results among ISO 7730 categories is presented as the final point of this subchapter.

Restaurant Area

The TCS measurements are presented in Table 7 and Table 9 for two dates respectively. The thermal comfort assessment parameters are summed up together with PMV and PPD results in Table 8 and Table 10. The measurement resulted in Standard recommended PMVs for almost all of the locations and considering both user categories (Table 8, Table 10).

Table 7. Thermal comfort station measurements, Restaurant area, 8th of March, 2016

TCS Position	Time of measurement	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	Relative Hum. (%)	Mean Radiant Temp. (°C)	Air vel. (m/s)	Turbul. intensity (%)
1	15:45	21.63	10.69	15.5	21.79	0	0
2	15:55	21.90	10.05	13.1	22.79	0	0
3	16:00	22.68	10.71	14.7	23.49	0	0
4	16:10	23.14	10.71	13.4	26.46	0	0

Table 8. Thermal comfort assessment parameters, Restaurant area, 8th of March, 2016

Run No.	User Category	Air Temp (°C)	Mean Radiant Temp. (°C)	Relative Hum. (%)	Air Velocity (m/s)	Metabolic rate (met)	Clothing insul. (clo)	PMV	PPD (%)
1	Guests	21.63	21.79	15.50	0.10	1.00	1.30	-0.36	7.69
	Employees	21.63	21.79	15.50	0.10	1.60	0.90	0.25	6.30
2	Guests	21.90	22.79	13.10	0.10	1.00	1.30	-0.24	6.18
	Employees	21.90	22.79	13.10	0.10	1.60	0.90	0.34	7.40
3	Guests	22.68	23.49	14.70	0.10	1.00	1.30	-0.06	5.08
	Employees	22.68	23.49	14.70	0.10	1.60	0.90	0.47	9.57
4	Guests	23.14	26.46	13.40	0.10	1.00	1.30	0.30	6.94
	Employees	23.14	26.46	13.40	0.10	1.60	0.90	0.74	16.50

Table 9. Thermal comfort station measurements, Restaurant area, 11th of April, 2016

TCS Position	Time of measurement	Mean Air Temp. Height 1.20m (°C)	Mean Air Temp. Height 0.10m (°C)	Relative Hum. (%)	Mean Radiant Temp. (°C)	Mean Air vel. (m/s)
1	13:37	20.60	17.45	23.04	21.18	0.05
2	13:22	21.37	19.26	22.26	22.24	0.05
3	12:52	21.99	19.92	22.02	22.02	0.03
4	13:04	22.79	20.59	21.16	23.38	0.01

Table 10. Thermal comfort assessment parameters, Restaurant area, 11th of April, 2016

Run No.	User Category	Mean Air Temp. (°C)	Mean Radiant Temp (°C)	Mean Relative Hum. (%)	Mean Air Velocity (m/s)	Metabolic rate (met)	Clothing insulation (clo)	Mean PMV	Mean PPD (%)
1	Guests	20.60	21.18	23.04	0.05	1.00	1.30	-0.46	9.36
	Employees	20.60	21.18	23.04	0.05	1.60	0.90	0.17	5.58
2	Guests	21.37	22.24	22.26	0.05	1.00	1.30	-0.26	6.37
	Employees	21.37	22.24	22.26	0.05	1.60	0.90	0.32	7.06
3	Guests	21.99	22.02	22.02	0.03	1.00	1.30	-0.20	5.86
	Employees	21.99	22.02	22.02	0.03	1.60	0.90	0.36	7.64
4	Guests	22.79	23.38	21.16	0.01	1.00	1.30	0.03	5.02
	Employees	22.79	23.38	21.16	0.01	1.60	0.90	0.53	10.88

The user category of guests is assessed as being thermally comfortable and results in recommended PMVs for both dates and all locations (Figure 38). The minimum PMV of -0.46 was measured on 11th of April for the location 1 (Figure 38). On the other hand, on 8th of March the category of employees is assessed with slightly high PMV values on locations 3 and 4. On location 3, PMV is close to the Standard recommended limit, with value of 0.47 (Figure 39). This corresponds to the 9.57 % of PPD (Figure 39). Location 4 gives somewhat more critical result with PMV of 0.74 and corresponding 16.50 % for PPD (Table 8, Figure 39). This comes from the fact that the Mean Radiant Temperature was 26.46 °C for this measurement. The globe thermometer was close to the heating device some minutes before the direct measuring, which resulted in high Mean Radiant Temperature. On 11th of April thermal comfort recommended levels are respected in almost all the measuring locations. Only location 4 shows again slight deviation in the employees' user category, with the mean PMV of 0.53 and corresponding PPD of 10.88% (Table 10, Figure 39).

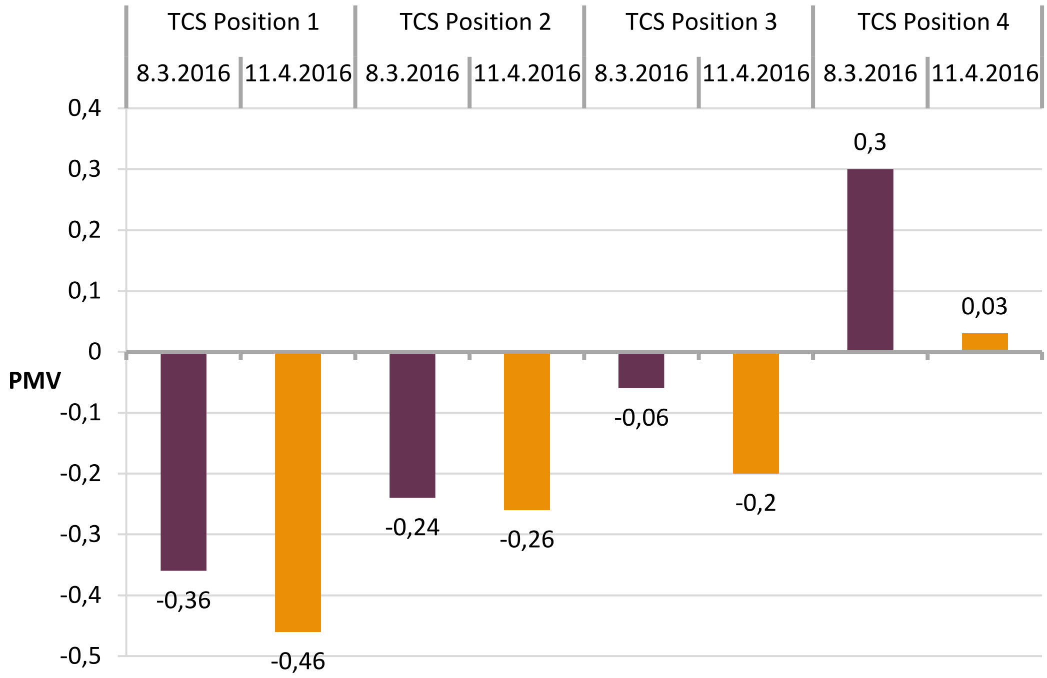


Figure 38. Restaurant short term thermal comfort results. User category: Guests. Dates: 8th of March and 11th of April, 2016

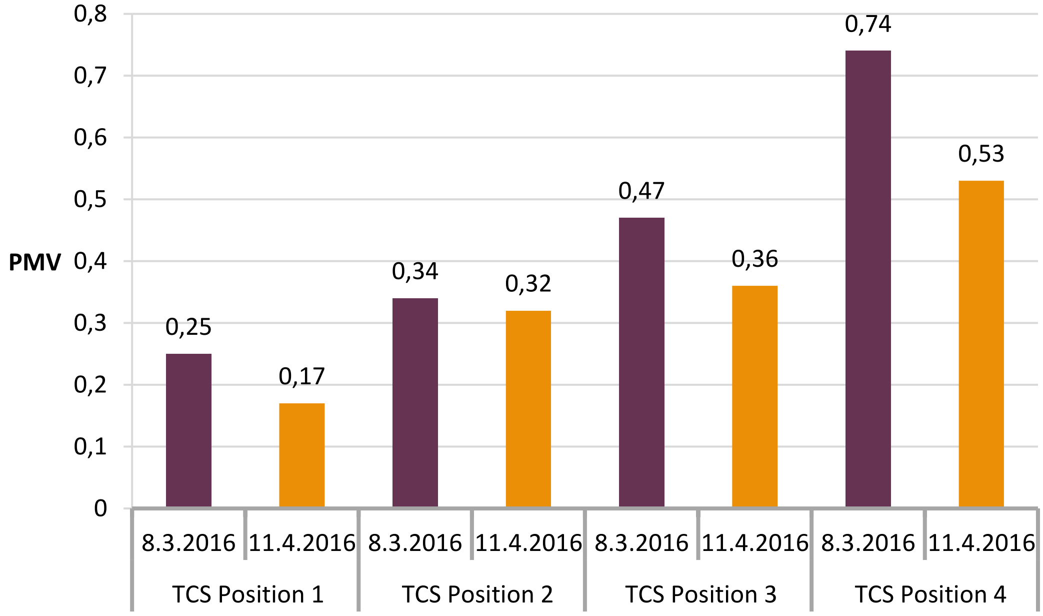


Figure 39. Restaurant short term thermal comfort results. User category: Employees. Dates: 8th of March and 11th of April, 2016

Two categories of users mostly result in opposing PMVs. Employees are mostly evaluated with positive PMVs and warm thermal sensation, due to the higher metabolic rate of 1.60 met. On the other hand, guests result with relatively negative PMVs and cool thermal sensation, although they are assigned higher clothing insulation of 1.3 clo (Table 8 and Table 10). It may be consequently concluded that the assigned metabolic rate has somewhat higher influence on the PMV outcome than the clothing insulation.

On 8th of March the Restaurant was working and the heating was operating in its standard setting. However, on 11th of April it was closed between two seasons and the heating setback was to be activated. The thermal comfort recommendations were on this date still fulfilled because the heating system was actually fully operating at the time of the measurement. This will be further assessed in the Subchapter 4.2.2.

Seminar Room

For the Seminar Room, the PMV and PPD evaluation for the two dates gave quite different results, as might have been expected from the circumstances of measurement. On 8th of March the Seminar Room was regularly heated and had very satisfying results of thermal comfort, with PMVs close to zero (Table 12, Figure 40) and pleasant radiant temperatures from the ceiling radiators (Table 11, Table 12). However, on 11th of April low temperatures were measured (Table 13) and both PMV and PPD do not fulfil the recommendations (Table 14). PMV for all the four locations was approximately -0.80, representing the thermal feeling of cold. The minimum PMV of -0.94 is measured on Location 1 (Figure 40) with corresponding PPD of 23.73%. These results on 11th of April are, however, more reasonable than the results of the Restaurant Area, as both of the rooms were at that time unoccupied and expected to have bad PMV and PPD results.

Table 11. Thermal comfort station measurements, Seminar Room, 8th of March, 2016

TCS Position	Time of measurement	Dry Bulb Temp. (°C)	Wet Bulb Temp. (°C)	Relative Hum. (%)	Mean Radiant Temp (°C)	Air vel. (m/s)	Turbul. Intens. (%)
1	12:05	21.52	9.44	11.70	24.84	0	0
2	12:18	21.10	9.32	12.50	25.11	0	0
3	12:39	19.86	9.63	19.40	25.68	0	0
4	12:50	21.37	9.52	12.80	24.33	0	0

Table 12. Thermal comfort assessment parameters, Seminar Room, 8th of March, 2016

Run No.	Air Temp. (°C)	Mean Radiant Temp (°C)	Relative Hum. (%)	Air Velocity (m/s)	Metabolic rate (met)	Clothing insulation (clo)	PMV	PPD (%)
1	21.52	24.84	11.70	0.10	1.20	0.90	-0.08	5.13
2	21.10	25.11	12.50	0.10	1.20	0.90	-0.09	5.18
3	19.86	25.68	19.40	0.10	1.20	0.90	-0.16	5.51
4	21.37	24.33	12.80	0.10	1.20	0.90	-0.15	5.44

Table 13. Thermal comfort station measurements, Seminar Room, 11th of April, 2016

TCS Position	Time of measurement	Mean Air Temp. Height 1.20m (°C)	Mean Air Temp. Height 0.10m (°C)	Relative Hum. (%)	Mean Radiant Temp. (°C)	Mean Air vel. (m/s)
1	11:20	18.77	18.17	29.00	18.78	0.08
2	11.35	18.98	18.36	28.36	19.17	0.04
3	11:45	19.13	18.63	28.34	19.45	0.03
4	11:55	18.83	18.19	28.69	19.52	0.05

Table 14. Thermal comfort assessment parameters, Seminar Room, 11th of April, 2016

Run No.	Mean Air Temp. (°C)	Mean Radiant Temp (°C)	Mean Relative Hum. (%)	Mean Air Velocity (m/s)	Metabolic rate (met)	Clothing insulation (clo)	Mean PMV	Mean PPD (%)
1	18.77	18.78	29.00	0.08	1.20	0.90	-0.94	23.73
2	18.98	19.17	28.36	0.04	1.20	0.90	-0.88	21.27
3	19.13	19.45	28.34	0.03	1.20	0.90	-0.83	19.57
4	18.83	19.52	28.69	0.05	1.20	0.90	-0.86	20.68

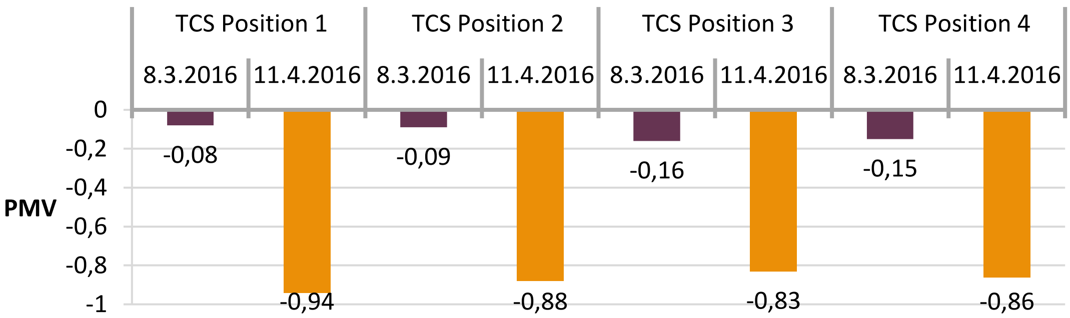


Figure 40. Seminar Room short term thermal comfort results. Dates: 8th of March and 11th of April, 2016

Local discomfort evaluation

Vertical Air Temperature Difference and Draught will be evaluated as possible sources of the local thermal discomfort.

Vertical Air Temperature Difference

In the Restaurant the maximum measured Vertical Air Temperature Difference was 3.13°C at the location 1 with corresponding Percentage Dissatisfied (PD) of 4.38 % (Figure 41). As already stated in the Subchapter 2.1, this result would belong between thermal environment categories B and C according to ISO 7730 (Table 2). Three other locations have the approximate Vertical Air Temperature Difference of 2°C (Figure 41) and belong between categories A and B (Table 2). When it comes to the Seminar Room, the maximum Vertical Air Temperature Difference of 0.65 °C was measured at the Location 4, with corresponding PD of 0.55 % (Figure 42). In all the locations of Seminar Room, Vertical Air Temperature Differences were so low that they all belong to the category A (Table 2). However, it must be highlighted that during the measurement on 11th of April, ceiling located radiators were off in the Seminar Room and the obtained result might not be the most representative one.

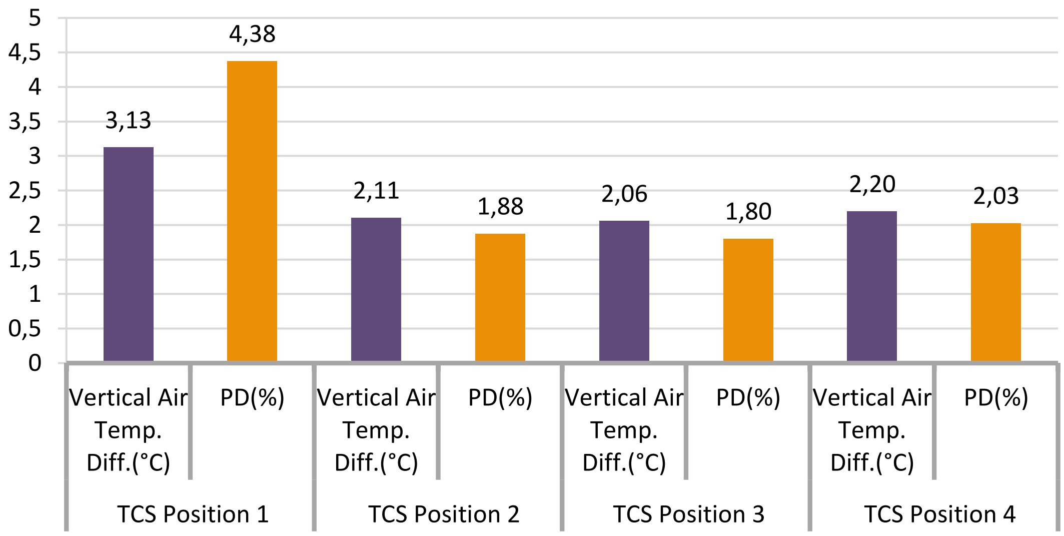


Figure 41. Vertical Air Temperature Difference between 1.10 m and 0.10 m height. Restaurant Area. Date: 11th of April, 2016

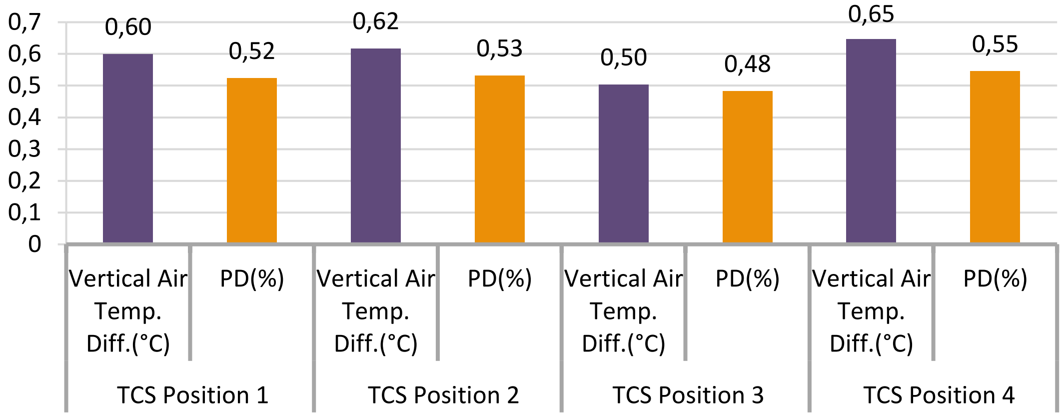


Figure 42. Vertical Air Temperature Difference between 1.10 m and 0.10 m height. Seminar Room. Date: 11th of April, 2016

Draught

When it comes to the DR of the Restaurant Area, four measuring locations offer varying results. Location 1 and 2 of the Restaurant show turbulent Draught Rates with a maximum of 14 % on the Location 2 (Figure 43, Figure 44). With this event the location 2 would belong between A and B category of ISO 7730 (Figure 1). However, since Restaurant Area has the controlled mechanical ventilation, this may be considered a singular event caused by an external factor, such as opening of the entrance door close to the measuring location. Since all the other locations have really low Draught Rates (Figure 45, Figure 46) and belong to the category A, it may be stated that there is no real local discomfort happening in the Restaurant Area. This affirms that the performance of the mechanical ventilation system is quite good in these terms. On locations 3 and 4, the air velocities lower than 0.05 m/s were measured, which results in the DR of minimum zero value at certain intervals (Equation 7).

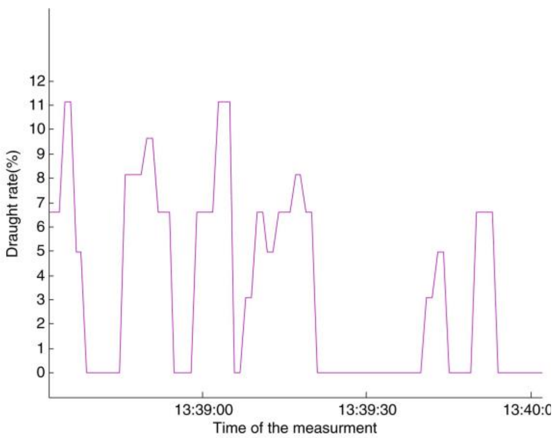


Figure 43. Draught Rate at the TCS Position 1. Restaurant Area. Date: 11th of April, 2016

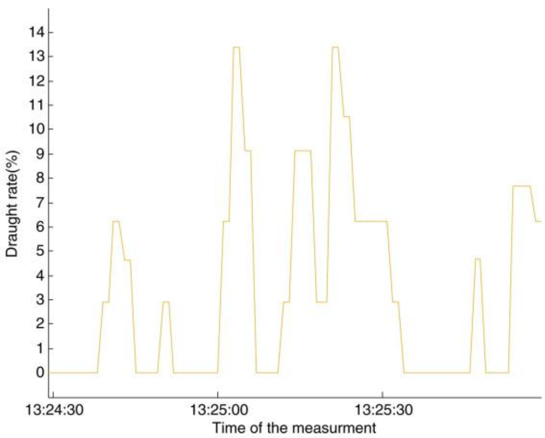


Figure 44. Draught Rate at TCS Position 2. Restaurant Area. Date: 11th of April, 2016

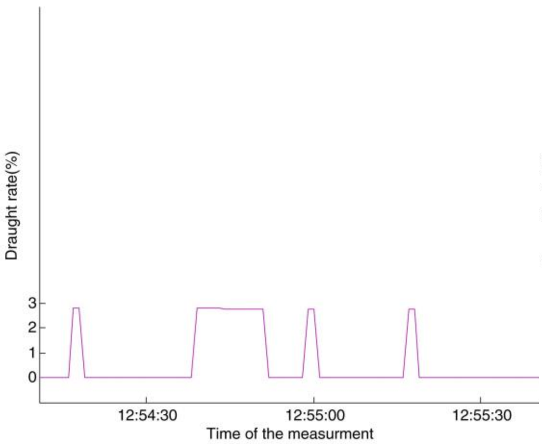


Figure 45 . Draught Rate at TCS Position 3. Restaurant Area. Date: 11th of April, 2016

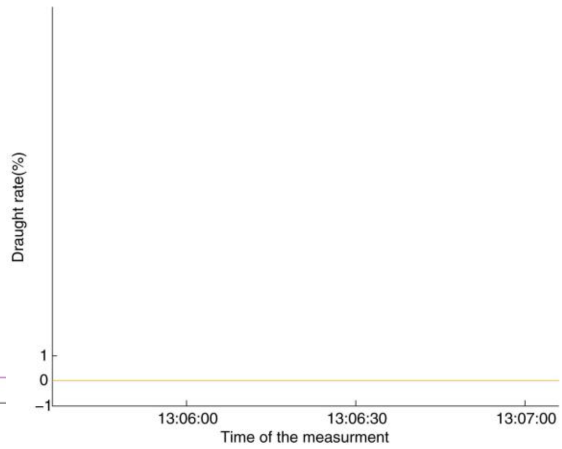


Figure 46. Draught Rate at TCS Position 4. Restaurant Area. Date: 11th of April, 2016

Seminar Room is not mechanically ventilated and varying events of Draught Rates may be present due to opening of the windows. This is also visible in the uneven graphs on all four locations (Figure 47, Figure 48, Figure 49, Figure 50). Maximum DR of 20% was measured at the location 1, which belongs to the B category of ISO 7730 regarding the discomfort caused by Draught. In rest of the cases, monitored DR was between category A and B with no other significant peaks (Figure 1).

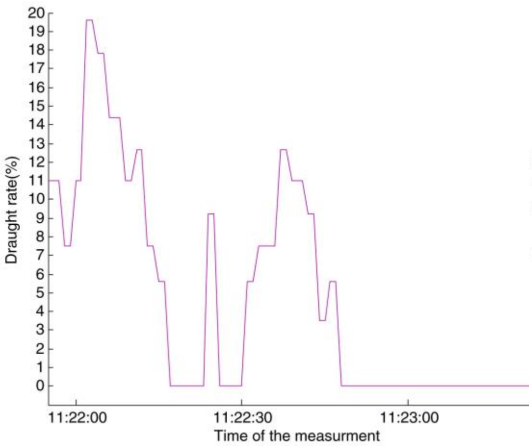


Figure 47. Draught Rate at the Location 1. Seminar Room. Date: 11th of April, 2016

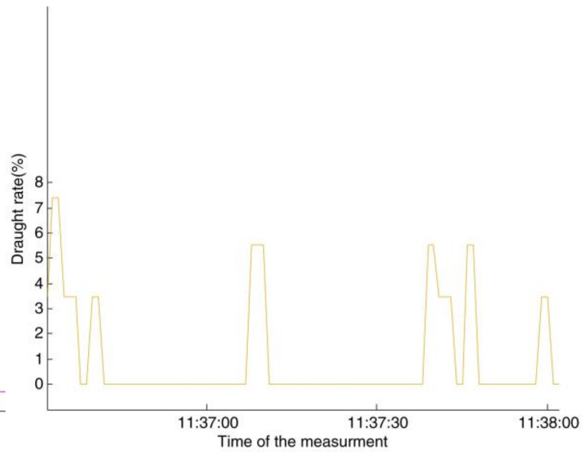


Figure 48. Draught Rate at the Location 2. Seminar Room. Date: 11th of April, 2016

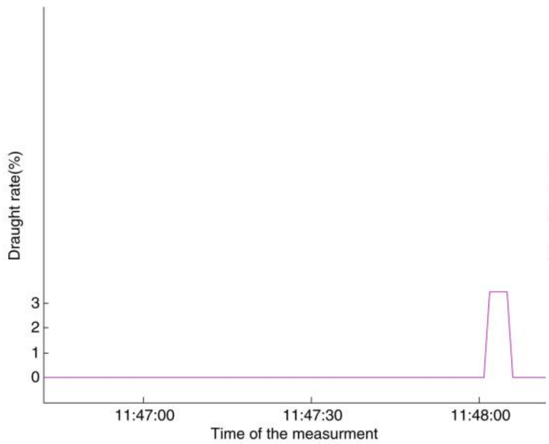


Figure 49. Draught Rate at the Location 3. Seminar Room. Date: 11th of April, 2016

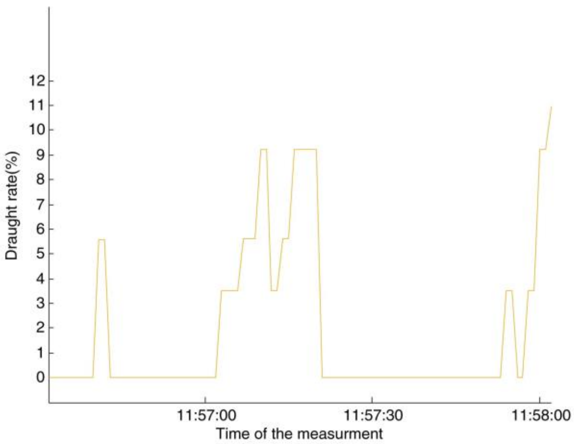


Figure 50. Draught Rate at the Location 4. Seminar Room. Date: 11th of April, 2016

Distribution of short term thermal comfort and local discomfort results over ISO 7730 categories

Finally after the evaluation of general thermal comfort and local discomfort parameters, the results are summed up according to the Table 1. Categories of the thermal environment (Source: ISO 7730 2005). The final distribution of the results among ISO categories is presented in Figure 51 for the Restaurant and Figure 52 for the Seminar Room. 62.50% of the PMV results of the Restaurant Area entered the category B, being between -0.5 and +0.5. One quarter of the results (25%) belong to the category A with PMV between -0.2 and +0.2 (Figure 51). These results illustrate highly comfortable space according to the Standard. In addition, the sources of the local discomfort are very low, since both parameters of Vertical Air Temperature Difference and Draught are evaluated only among the best categories A and B, as may be seen in Figure 51.

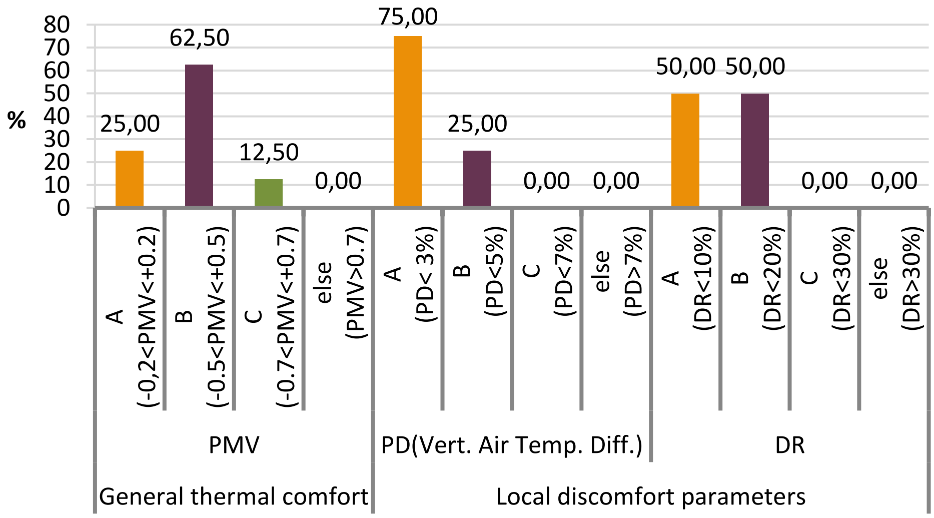


Figure 51. Distribution of short term results of general thermal comfort and local discomfort over ISO 7730 categories of thermal environment. Restaurant Area. Dates: 8^{th} of March and 11^{th} of April, 2016

Seminar Room's results of general thermal comfort and local discomfort were also categorized according to ISO 7730. Although the category A is mostly present for both thermal comfort and local discomfort, the PMV evaluation is rather split between extremes (Figure 52). This is due to the two opposing measuring conditions where on the first date room was heated while for the second measurment that was not the case.

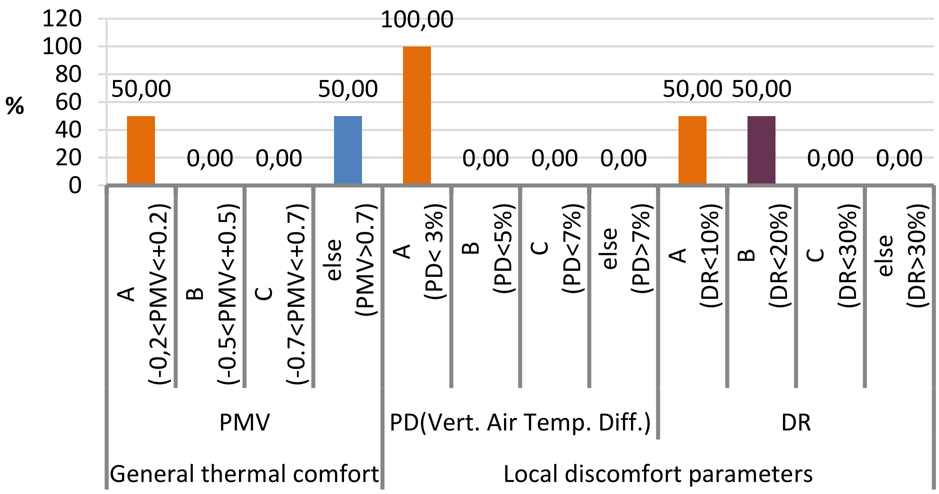


Figure 52. Distribution of short term results of general thermal comfort and local discomfort over ISO 7730 categories of thermal environment. Seminar Room. Dates: 8^{th} of March and 11^{th} of April, 2016

4.2.2 Long term thermal comfort evaluation

Long term thermal comfort results for the Restaurant and Seminar Room are presented in this Subchapter. Two measuring locations are considered for the Restaurant, while one is considered for the Seminar Room. The evaluation is further subdivided by three heating system operation periods and two user categories. As already stated in Subchapter 3.3.2, some thermal comfort parameters from the short term measurment were used as reliable assumptions for the long term monitoring.

Restaurant Area

Long term monitoring in the Restaurant showed varying thermal comfort results of the three different time periods. This was expected and represents in the evocative way the heating system operation through full operation period, setback period and partial operation period, joined with seasonal weather conditions. The user categories also widely influenced the final results of PMV and PPD. Two measuring locations offer some divergence in results in form of the singular events, but they are generally quite overlapping and similar. PMV levels throughout the total measuring period from 9th of March until 31st of June, 2016 are illustrated in Figure 53, Figure 54, Figure 55 and Figure 56. Results will be in detail presented through classifications according to measuring location, period of time and user category. It is immediately seen the distinction of the setback heating season from 11th of April until 1st of May, as PMV results are here mainly outside of the standard recommended values. Two other periods seem to mostly fulfil the standard recommendations. The minimum, maximum and average PMV and PPD together with assessment parameters are shown in Table 15 and will be discussed in continuation.

Table 15. Restaurant Area long term thermal comfort assessment parameters

Device location	Period of time	User Category	Mean Air Temp. (°C)	Mean Rel. Hum. (%)	Min PMV	Max PMV	Aver. PMV	Min PPD (%)	Max PPD (%)	Aver. PPD (%)
R-ML1	09.03-11.04	Guests	21.17	27.15	-0.88	-0.05	-0.35	5.06	21.46	7.87
		Employees	21.17	27.15	-0.13	0.47	0.28	5.00	9.63	6.58
	11.04-01.05	Guests	20.39	28.34	-0.98	0.14	-0.51	5.00	25.20	12.10
		Employees	20.39	28.34	-0.20	0.60	0.13	5.00	12.75	6.20
	01.05-31-06	Guests	20.92	36.89	-0.58	0.14	-0.34	5.00	11.97	7.74
		Employees	20.92	36.89	0.09	0.60	0.26	5.16	12.53	6.59
R-ML2	09.03-11.04	Guests	20.99	28.90	-1.16	-0.04	-0.37	5.04	33.26	8.23
		Employees	20.99	28.90	-0.34	0.48	0.24	5.00	9.73	6.33
	11.04-01.05	Guests	19.19	30.93	-1.22	-0.14	-0.77	5.42	36.24	19.30
		Employees	19.19	30.93	-0.39	0.41	-0.05	5.04	8.43	6.08
	01.05-31-06	Guests	20.42	39.65	-1.03	-0.09	-0.43	5.17	27.59	9.16
		Employees	20.42	39.65	-0.26	0.43	0.19	5.00	8.92	5.85

Note :

Mean Radiant Temperature and Air Velocity are obtained as explained in Subchapter 2.4.1 Long term monitoring

Metabolic rate is considered to be 1.6 met for user category Employees, and 1.0 met for user category Guests as explained in Subchapter 2.4.3 Short term monitoring

Clothing insulation is considered to be 0.9 clo for user category Employees, and 1.3 clo for user category Guests as explained in Subchapter 2.4.3 Short term monitoring

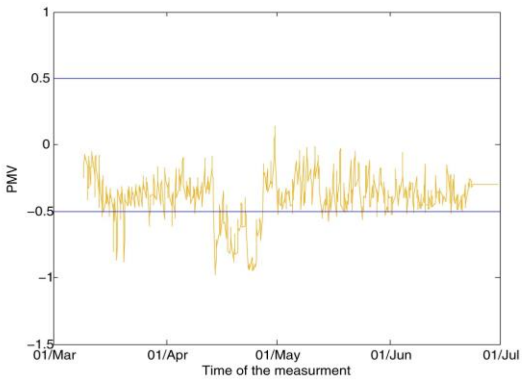


Figure 53. R-ML1. PMV levels for the occupancy hours of the whole period of monitoring (09.03-31.06). User

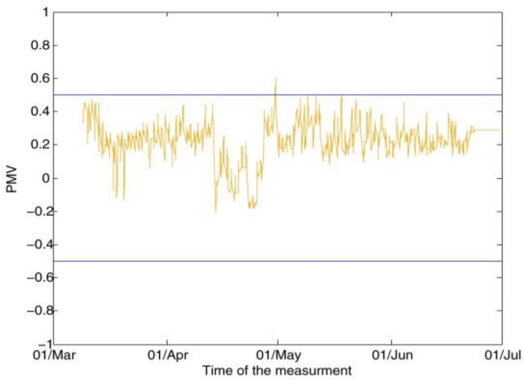


Figure 54. R-ML1. PMV levels for the occupancy hours of the whole period of monitoring (09.03-31.06). User

category: Guests

category: Employees

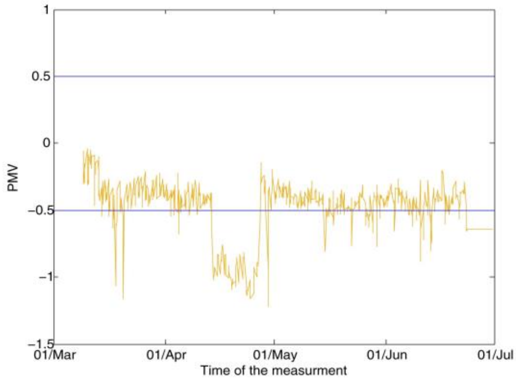


Figure 55. R-ML2. PMV levels for the occupancy hours of the whole period of monitoring (09.03-31.06). User category: Guests

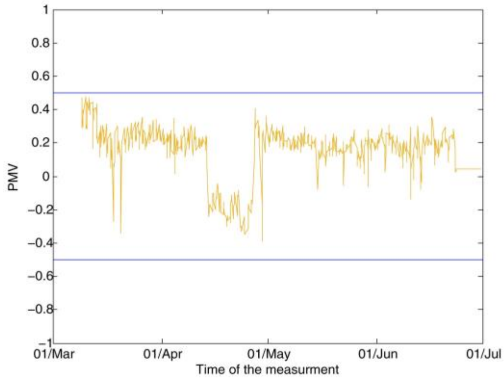


Figure 56. R-ML2. PMV levels for the occupancy hours of the whole period of monitoring (09.03-31.06). User category: Employees

Restaurant area ML1. Period 09.03.2016-11.04.2016. User category: Guests

The full heating operation during the period from 9th of March until 11th of April offers the good results for both user categories. During this period average PMV for the guests was -0.35 with corresponding PPD of 7.87% (Table 15). The PMV and PPD levels (Figure 57, Figure 59) show expected day and night pattern of the heating operation. The PMV values between -0.40 and -0.30 take about 60% of all the results, while values of -0.50 and -0.20 take about 13% (Figure 58). Only about 4% of all the results is outside the temperature and relative humidity range recommended by ISO 7730 (Figure 60). Similar to the short term thermal comfort evaluation, guests tend to result with negative values of PMV, matching the feeling of being cool. This could be argued as a weakness of Fanger static model of thermal comfort evaluation. Although guests are coming from the external winter conditions wearing clothes assigned 1.30 clo, they still feel cool according to the results. This might allude that possibly in this case the adaptive model of thermal comfort would be more adequate.

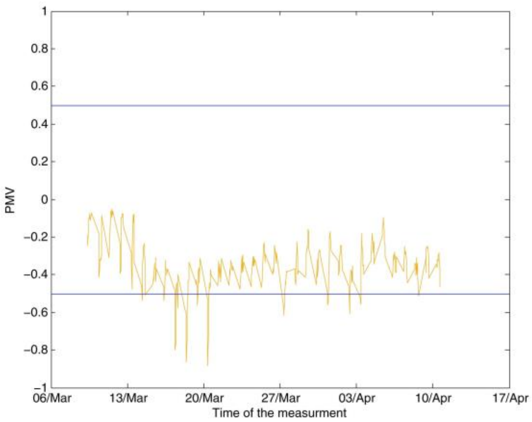


Figure 57. PMV levels. R-ML1. Period:09.03-11.04, occupancy hours. User category: Guests

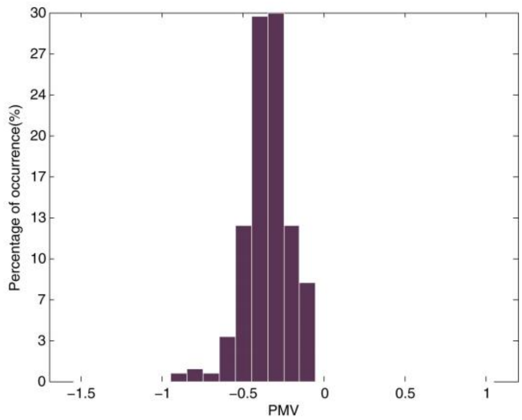


Figure 58. Histogram of PMV levels. R-ML1. Period:09.03-11.04, occupancy hours. User category: Guests

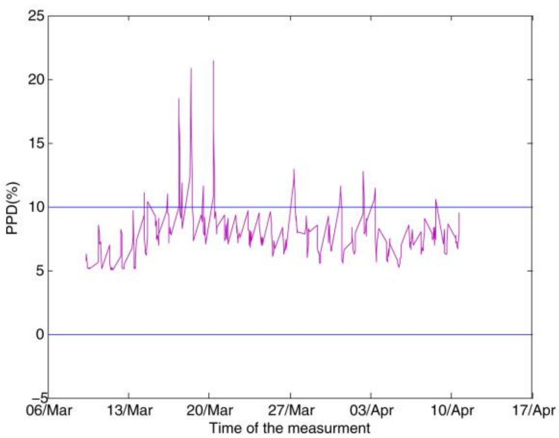


Figure 59. PPD levels recorded. R-ML1. Period:09.03-11.04, occupancy hours. User category: Guests

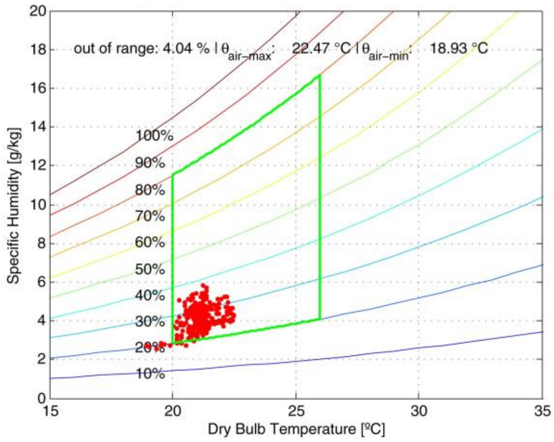


Figure 60. Mollier's Diagram. R-ML1. Period:09.03-11.04, occupancy hours

Restaurant area ML1. Period 09.03.2016-11.04.2016. User category: Employees

In the same location and during the equal time period, employees would result in 100% with the PMV Standard recommended values between -0.50 and +0.50 (Figure 61, Figure 63, Figure 62). About 37% of the results correspond to the PMV of approximately 0.20, while 39% correspond to the PMV of 0.30 (Figure 62). The average PMV is 0.28 and average PPD 6.58% (Table 15). As already stated, employees mainly result in positive PMVs, with warm sensation coming from the higher metabolic rate. Mollier Diagram (Figure 60) is the same for this user category as it does not take into consideration metabolic rate or clothing insulation but only temperatures and relative humidities.

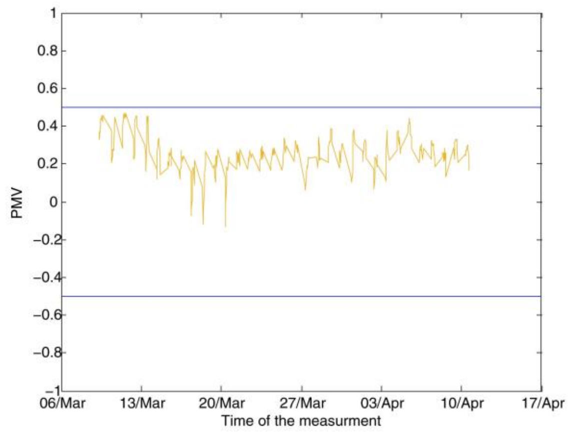


Figure 61. PMV levels. R-ML1. Period:09.03-11.04, occupancy hours. User category: Employees

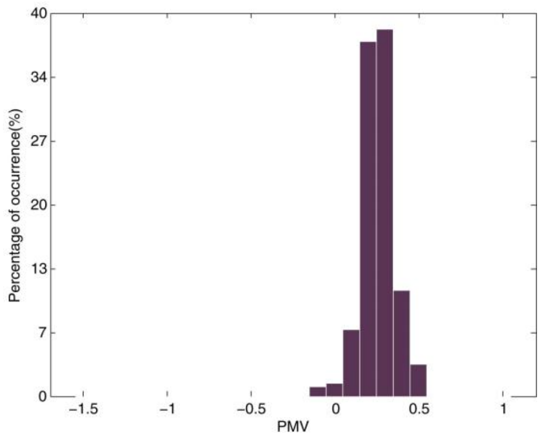


Figure 62. Histogram of PMV levels. R-ML1. Period:09.03-11.04, occupancy hours. User category: Employees

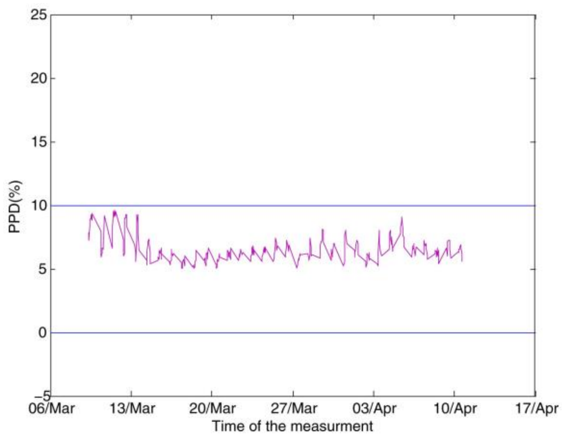


Figure 63. PPD levels. R-ML1. Period: 09.03-11.04, occupancy hours. User category: Employees

Restaurant area ML1. Period 11.04.2016-01.05.2016. User category: Guests

The second period from 11th of April until 1st of May represents the off season period during which heating system was put on setback. During this time, the bad PMV results were expected for both user categories as the Restaurant was unoccupied and closed for maintenance reasons. However, for some days or events, the set point temperature was high enough to result in recommended PMV and PPD levels (Figure 64, Figure 66). Additionally, some external factors, like higher outside temperature caused the natural temperature rise. Finally, less than 50% of the temperature and relative humidity events were outside of ISO 773O recommended range (Figure 67). This possibly indicates that the heating setback could have been put on lower set points and could have been more energy efficient. About 20% of the restults are around -0.60 (Figure 65) with an average PMV of -0.51 (Table 15).

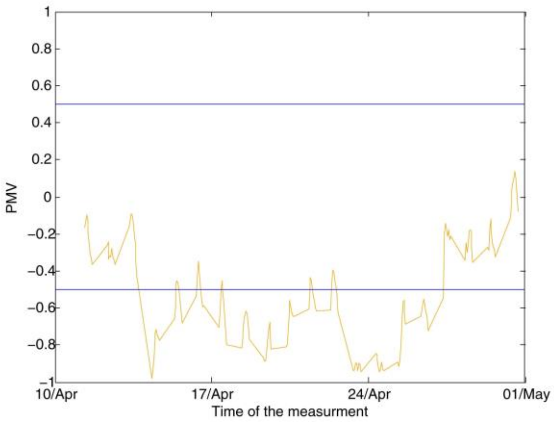


Figure 64. PMV levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Guests

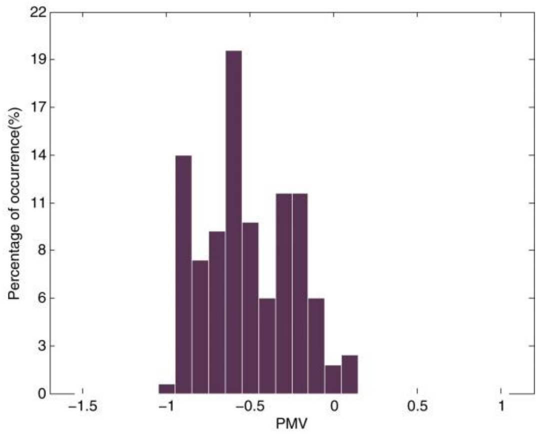


Figure 65. Histogram of PMV levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Guests

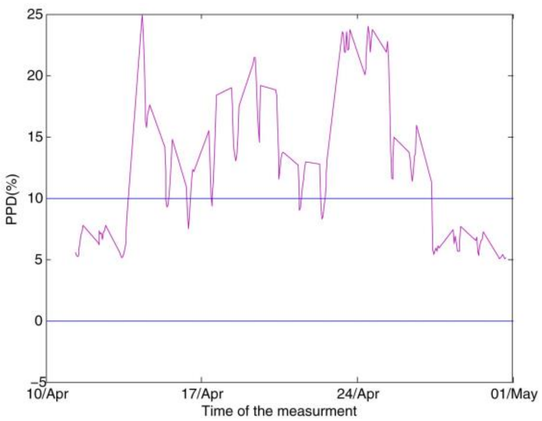


Figure 66. PPD levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Guests

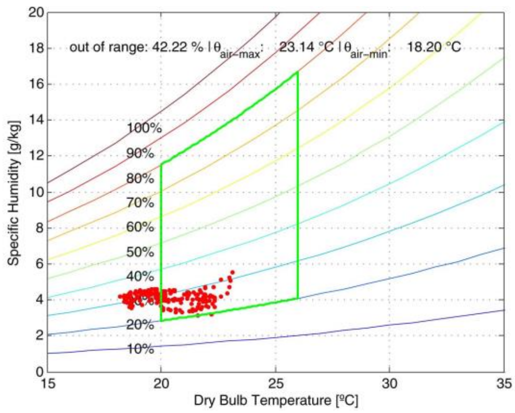


Figure 67. Mollier's Diagram. R-ML1. Period:11.04-01.05, occupancy hours

Restaurant area ML1. Period 11.04.2016-01.05.2016. User category: Employees

For the employees, the results of PMV and corresponding PPD were, even in this period, almost 100% according to the recommended values, due to the higher metabolic rate (Figure 68, Figure 70). Moreover, about 50% of the PMV results are in range from -0.1 to +0.1 and represent the best thermal condition for the user according to the Standard (Figure 69). This additionally suggests how the heating setback could have been better managed in order to save more energy.

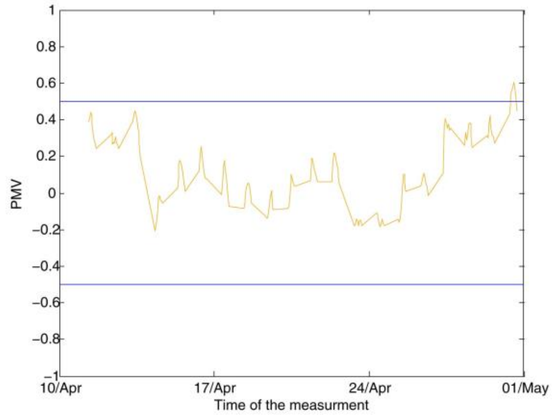


Figure 68. PMV levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Employees

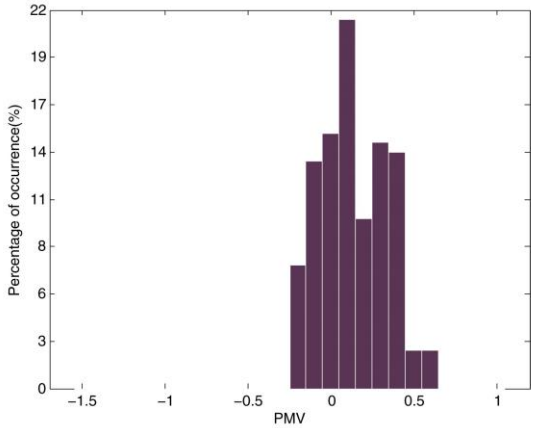


Figure 69. Histogram of PMV levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Employees

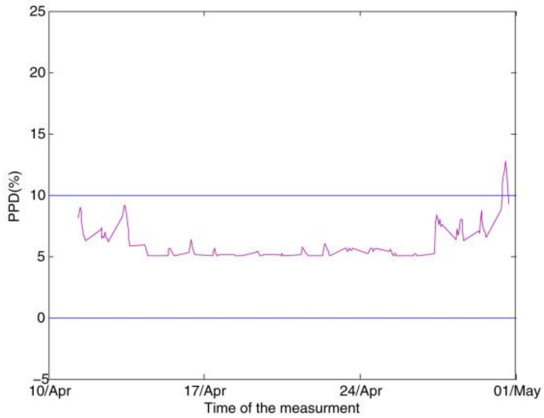


Figure 70. PPD levels. R-ML1. Period:11.04-01.05, occupancy hours. User category: Employees

Restaurant area ML1. Period 01.05.2016-31.06.2016 User category: Guests

The third monitoring period from 1st of May until 31st of June displays similar results to the first one. PMV and PPD trends show constant daily pattern (Figure 71, Figure 73). Guests user category, as in previous cases, results with the negative PMVs with 35% of the values being approximately -0.40 (Figure 72). Average PMV is -0.34 and corresponding PPD 7.74% (Table 15). Practically only 2% of the measurement results were outside of the recommended temperature and relative humidity range (Figure 74).

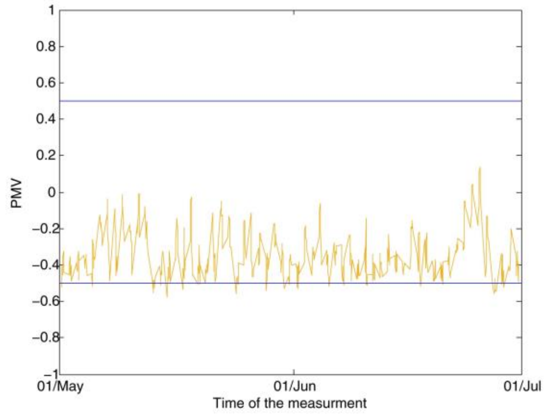


Figure 71. PMV levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Guests

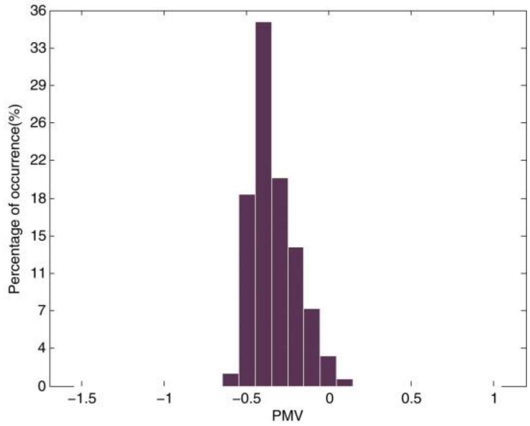


Figure 72. Histogram of PMV levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Guests

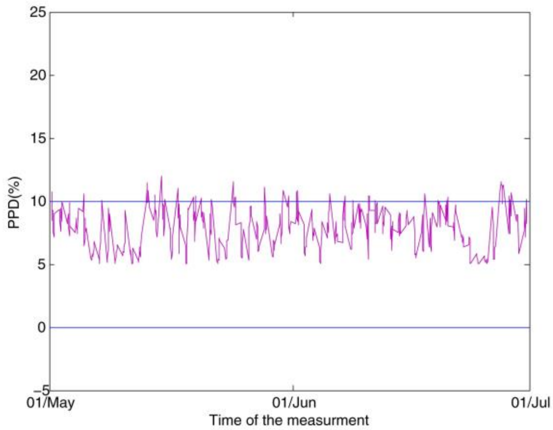


Figure 73. PPD levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Guests

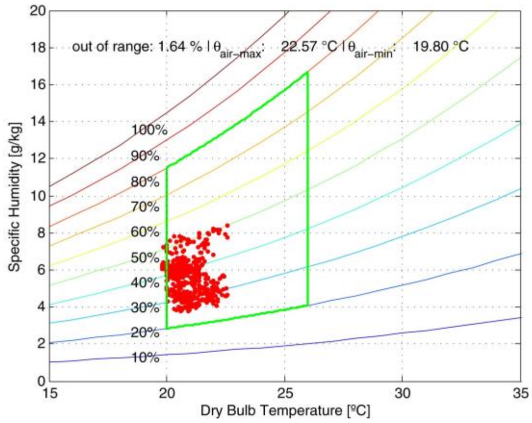


Figure 74. Mollier's Diagram. R-ML1. Period: 01.05- 31.06, occupancy hours

Restaurant area ML1. Period 01.05.2016-31.06.2016. User category: Employees

During the same period, user category of employees also results in being fully satisfied with the room's thermal conditions. Few peaks are noted on the PMV and PPD graphs, which may be coming from the warmer weather conditions (Figure 75, Figure 77). Approximately 47% of the PMV values are about 0.20 (Figure 76) with an average of 0.26 and corresponding 6.59% for PPD (Table 15).

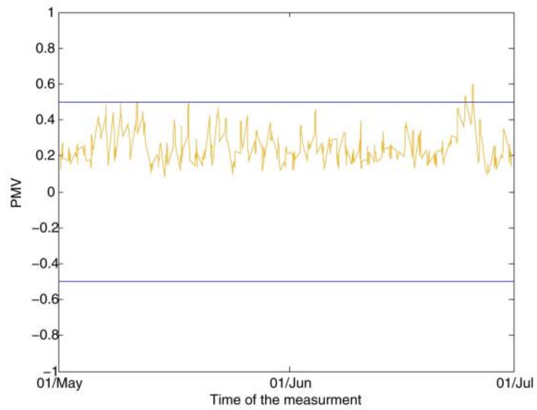


Figure 75. PMV levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Employees

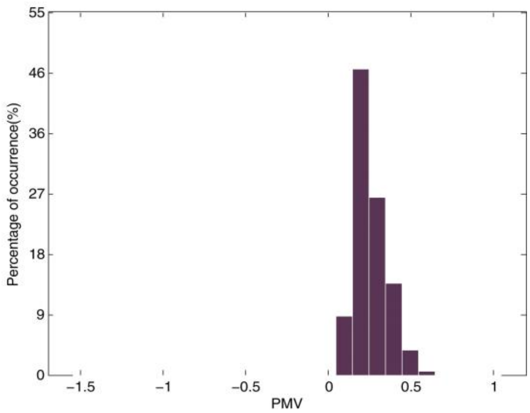


Figure 76. Histogram of PMV levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Employees

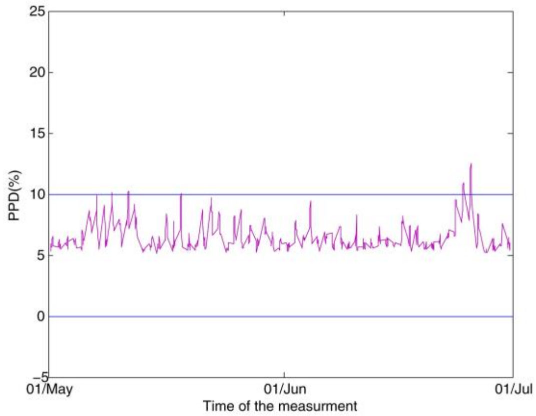


Figure 77. PPD levels. R-ML1. Period: 01.05- 31.06, occupancy hours. User category: Employees

Restaurant area ML2. Period 09.03.2016-11.04.2016. User category: Guests

The results from the ML2 are similar to the first ones, with clear distinction of the three monitoring periods. In case of the first period, 40% of the guests' PMV results are around -0.40 (Figure 79). PMV and PPD pattern is recognisable again, although two events are standing out (Figure 78, Figure 80). PMV minimum value of -1.16 is one of them, with the analogous maximum PPD of 33.26% (Table 15). The reason may be the longer opening of the external doors located in front of the measuring device. However, these events correspond to only 1% of the measurements on Mollier's Diagram which are out of the Standard recommended range (Figure 81).

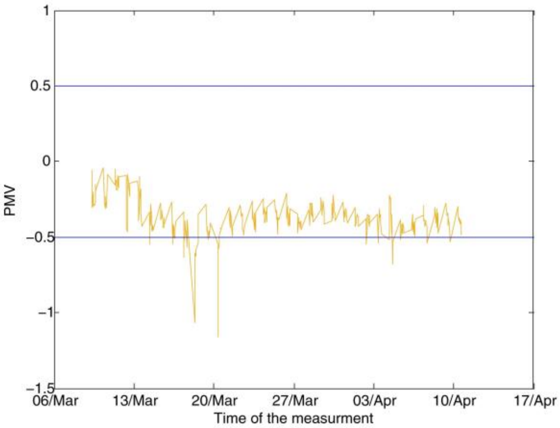


Figure 78. PMV levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Guests

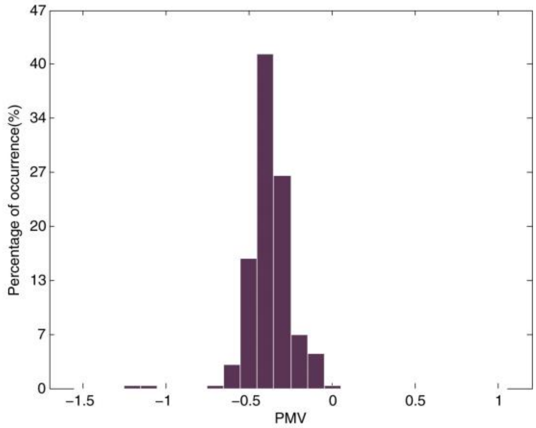


Figure 79. Histogram of PMV levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Guests

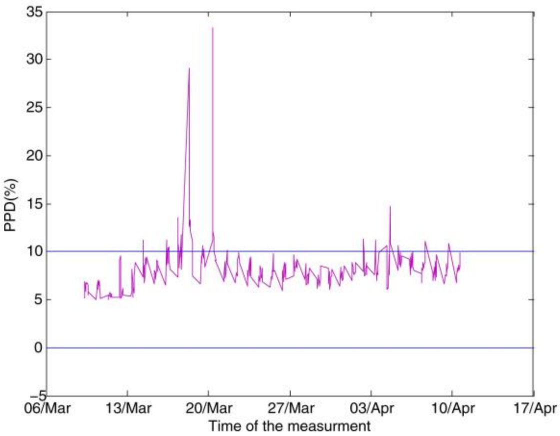


Figure 80. PPD levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Guests

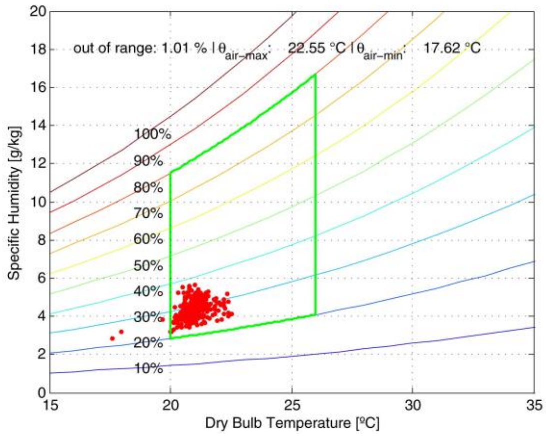


Figure 81. Mollier's Diagram. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours

Restaurant area ML2. Period 09.03.2016-11.04.2016 User category: Employees

Employees again have the PMV results in the warmer range than guests, similar to the logic already explained. Hence, even though the two cold events still show outside of the range on the Mollier's diagram (Figure 81), PMV and PPD levels for this category belong 100% in the Standard recommended range (Figure 82, Figure 83, Figure 84).

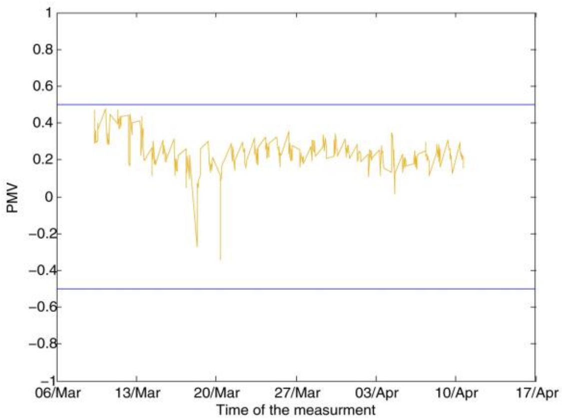


Figure 82. PMV levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Employees

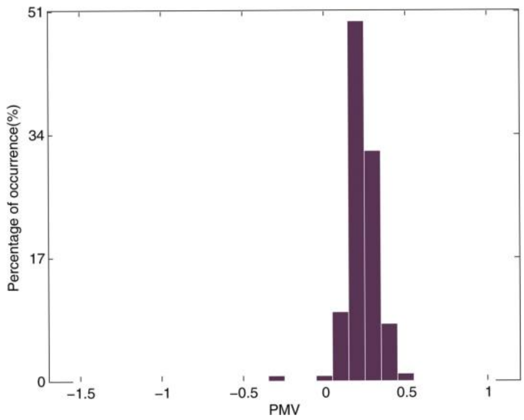


Figure 83. Histogram of PMV levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Employees

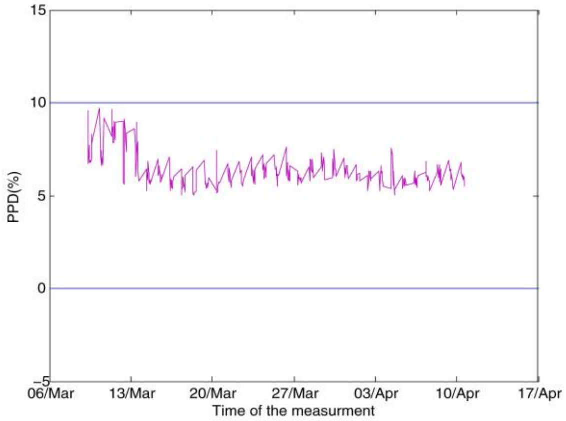


Figure 84. PPD levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours. User category: Employees

Restaurant area ML2. Period 11.04.2016-01.05.2016 User category: Guests

During the second monitoring period, same as for the ML1, guests user category results in being mostly thermally uncomfortable (Figure 85, Figure 86, Figure 87). Minimum PMV is -1.22 and parallel maximum PPD is 36.24% (Table 15). In difference to the ML1, Mollier's Diagram shows that more than 50% of the temperature events, precisely 66.67%, were out of the recommended range (Figure 88). This is probably due to the fact that this measuring device is less affected by the external weather influences like the sun radiation.

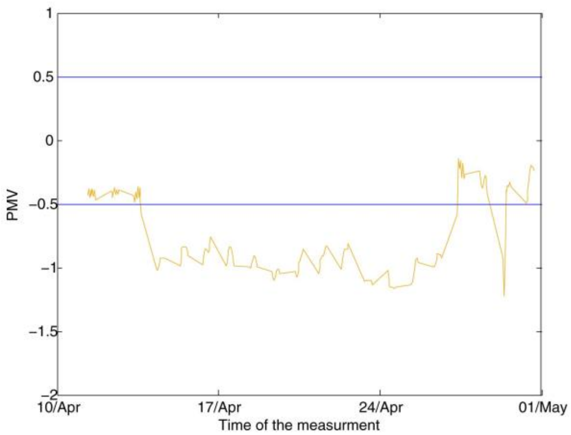


Figure 85. PMV levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Guests

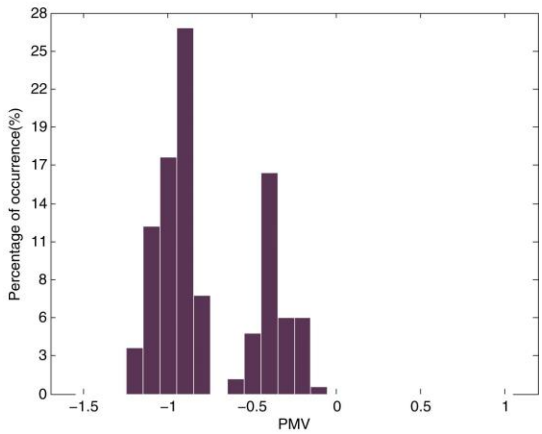


Figure 86. Histogram of PMV levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Guests

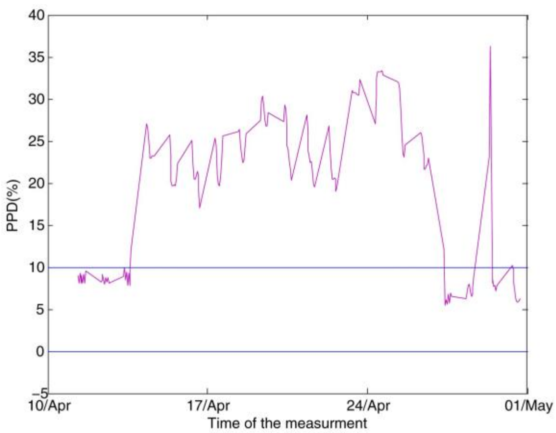


Figure 87. PPD levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Guests

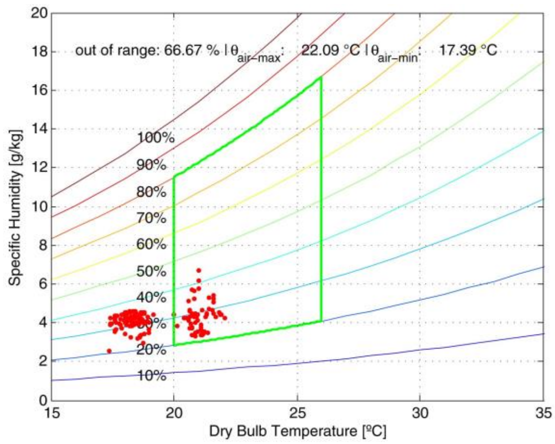


Figure 88. Mollier's Diagram. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours

Restaurant area ML2. Period 11.04.2016-01.05.2016. User category: Employees

The metabolic rate assigned to the employees again moved the trends of PMV and PPD inside the limits recommended by ISO 7730, as may be seen from the Figure 89 and Figure 91. The histogram shows varying PMV values within the range from -0.40 to 0.40 (Figure 90). Repeatedly to the previous discussion, Mollier's diagram (Figure 88) shows that the 66.67% of the temperatures were outside the recommended range although the metabolic rate shifts the final PMV and PPD results.

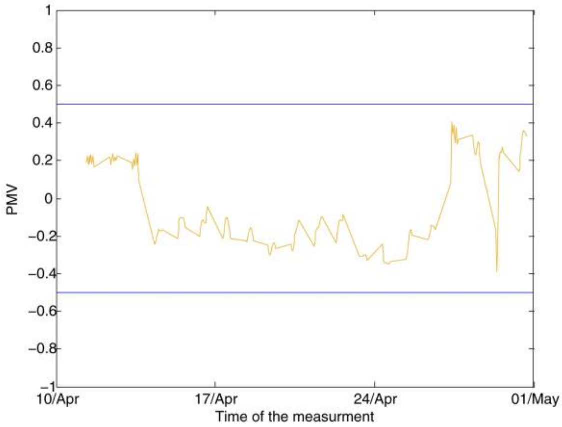


Figure 89. PMV levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Employees

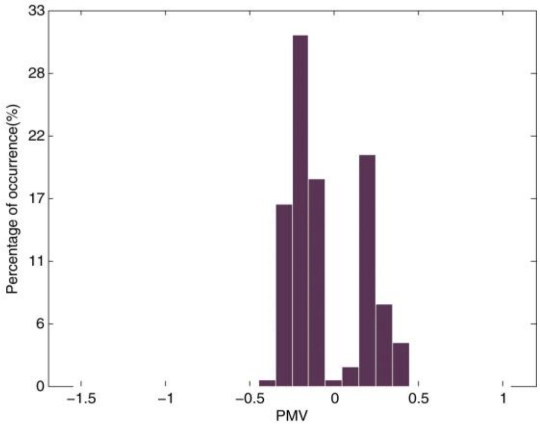


Figure 90. Histogram of PMV levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Employees

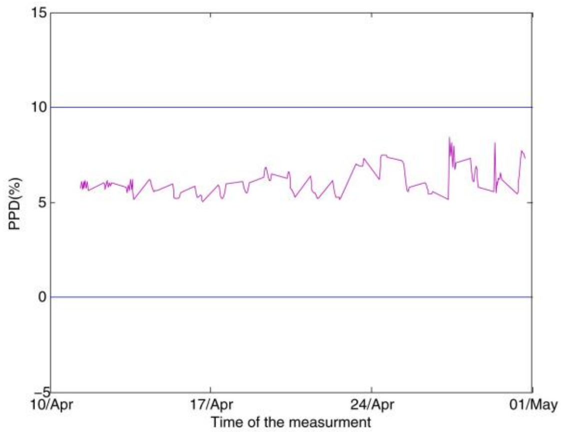


Figure 91. PPD levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours. User category: Employees

Restaurant area ML2. Period 01.05.2016-31.06.2016. User category: Guests

The third monitoring period for the user category of guests and ML2 shows PMV results constantly near to the limit of -0.50 with PPD of 10% (Figure 92, Figure 94). About 45% of the PMV results are around -0.40 (Figure 93), while 12.57% of the temperature events is out of the ISO 7730 recommended range (Figure 95).

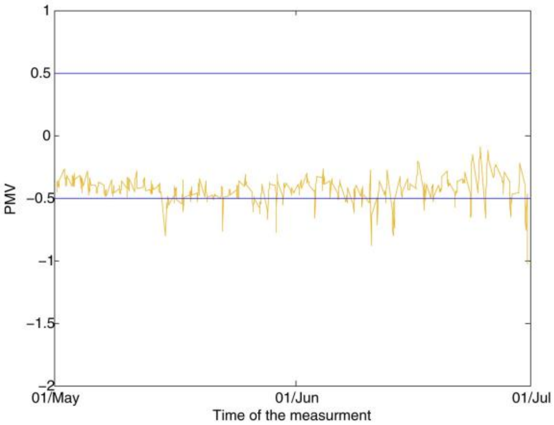


Figure 92. PMV levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Guests

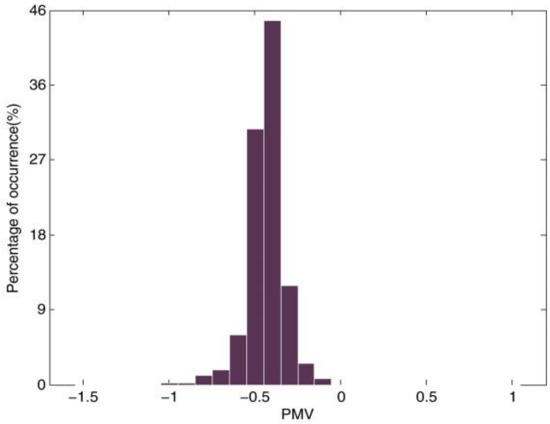


Figure 93. Histogram of PMV levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Guests

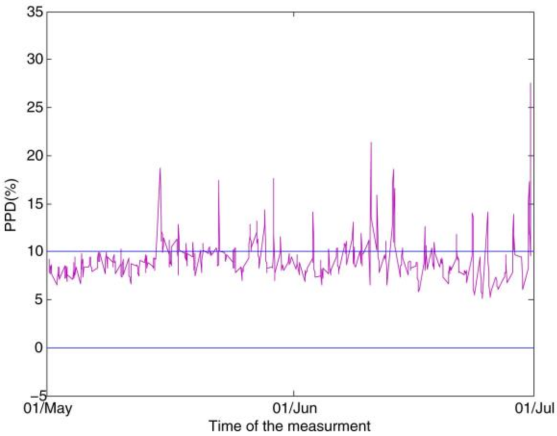


Figure 94. PPD levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Guests

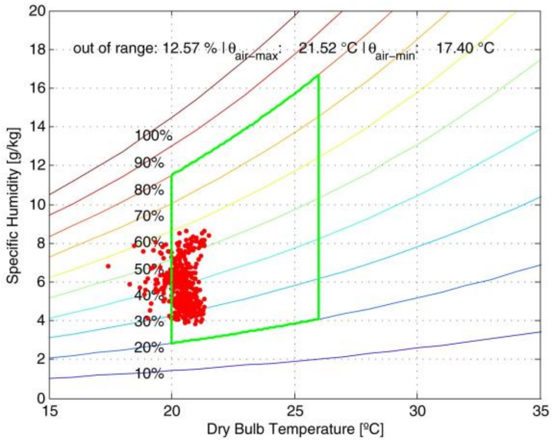


Figure 95. Mollier's Diagram. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours

Restaurant area ML2. Period 01.05.2016-31.06.2016. User category: Employees

Since for the previous user category PMV results were close to -0.50, the results of the employees user category will certainly be between the recommended limits for both PMV and PPD (Figure 96, Figure 98). Although Mollier's Diagram stays the same (Figure 95), 63% of the PMV values are now around 0.20 (Figure 97) with an average PMV of 0.19 (Table 15).

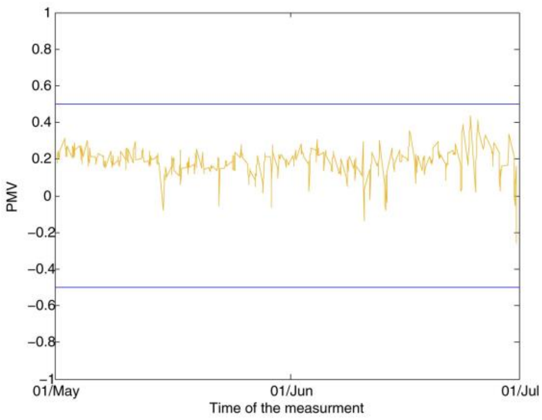


Figure 96. PMV levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Employees

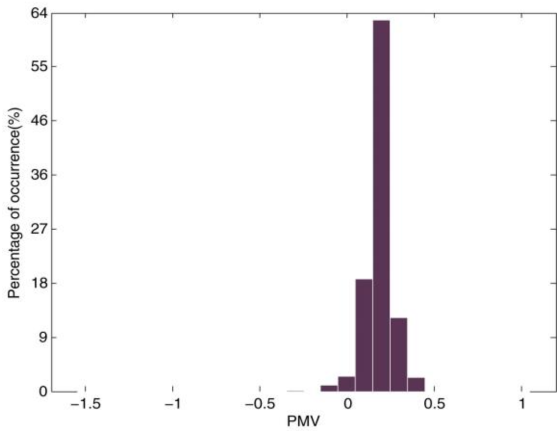


Figure 97. Histogram of PMV levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Employees

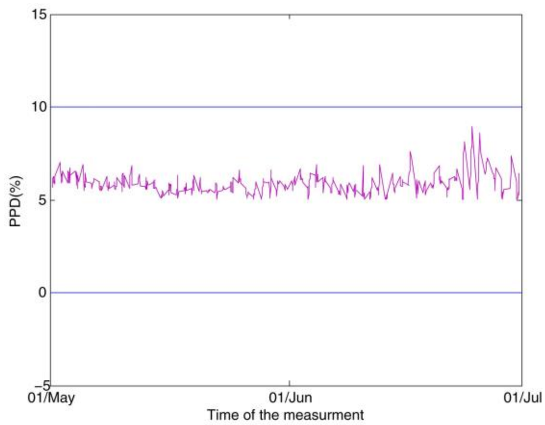


Figure 98. PPD levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours. User category: Employees

Seminar Room

Seminar Room is expected to have unfulfilling results of PMV and PPD as the room is rarely occupied and heating system is almost constantly on setback. The summed up results of minimum, maximum and average PMV and PPD are shown in Table 16. The three measuring periods are separately discussed in continuation. The only pattern visible is the improvement of the PMV and PPD values in the third period from 1st of May until 31st of June, which obviously comes from the higher outside temperatures (Figure 99).

Table 16. Seminar Room long term thermal comfort assessment parameters

Device location	Period of time	User Category	Mean Air Temp. (°C)	Mean Rel. Hum. (%)	Min PMV	Max PMV	Aver. PMV	Min PPD (%)	Max PPD (%)	Aver. PPD (%)
S-ML1	09.03-11.04	Conference Participants	18.70	27.68	-1.18	-0.01	-0.75	5.00	34.29	17.67
	11.04-01.05		17.68	28.97	-1.28	-0.72	-0.98	15.97	39.40	25.60
	01.05-31.06		19.61	35.84	-1.10	0.13	-0.5	5.10	30.60	11.17

Note :

Mean Radiant Temperature and Air Velocity are obtained as explained in Subchapter 2.4.1 Long term monitoring

Metabolic rate is considered to be 1.2 met as explained in Subchapter 2.4.3. Short term monitoring

Clothing inculation is considered to be 0.9 clo as explained in Subchapter 2.4.3. Short term monitoring

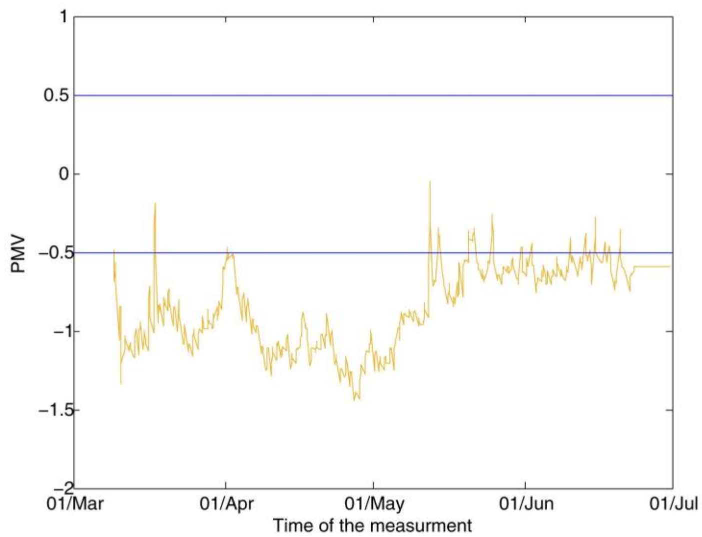


Figure 99. S-ML1. PMV levels for the occupancy hours for the whole period of monitoring (09.03-31.06). User category: Conference participants

Seminar Room ML1. Period 09.03.2016-11.04.2016

During the first monitoring period Seminar Room was occasionally heated which resulted in some events when the PMV level rose to the comfortable zone for the user (Figure 100, Figure 102). This occurred also on 8th of March when the short term measurement was executed. Around 65% of the PMV results are in range from -0.90 to -0.70 (Figure 101) with an average of -0.75 and corresponding average PPD of 17.67% (Table 16). Only around 9% of the temperature events are in the standard recommended range, when the heating was intentionally turned on (Figure 103).

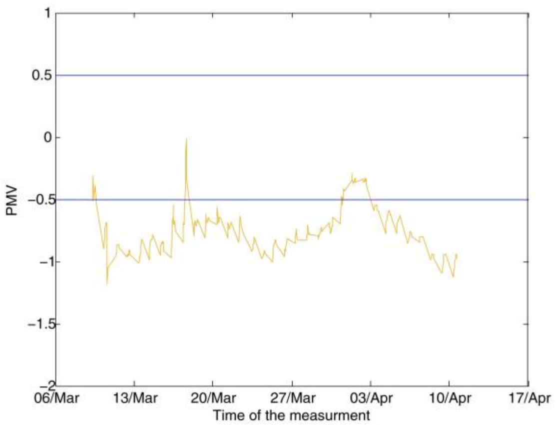


Figure 100. PMV levels. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

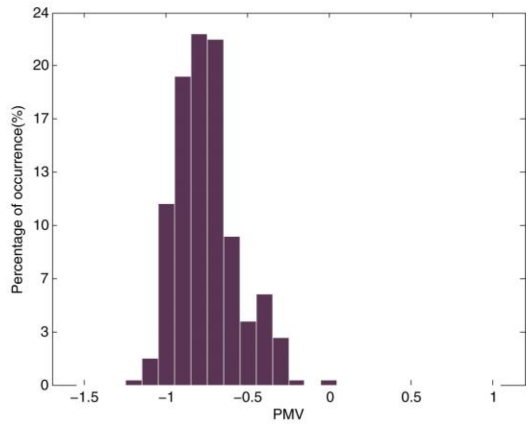


Figure 101. Histogram of PMV levels. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

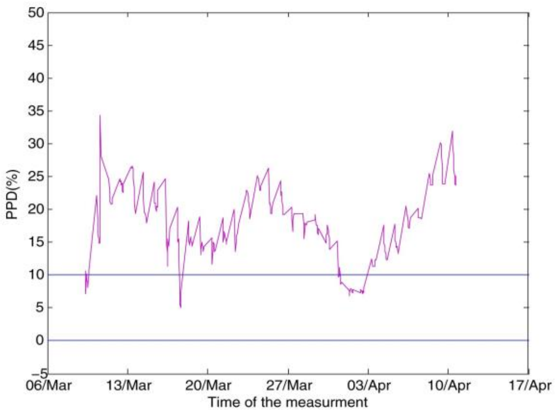


Figure 102. PPD levels. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

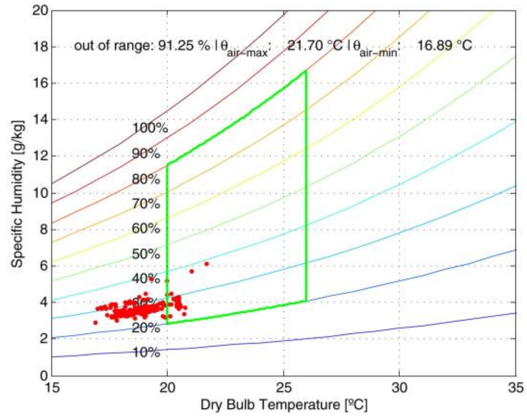


Figure 103. Mollier's Diagram. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

Seminar Room ML1. Period 11.04.2016-01.05.2016

During the second monitoring period from 11th of April until 1st of May, Seminar Room was totally unheated, which resulted in 100% temperature measurements being lower than the Standard recommended limit of 20°C (Figure 107). PMV levels were in 100% under the value of -0.50 and PPD levels higher than 10% (Figure 104, Figure 105, Figure 106).

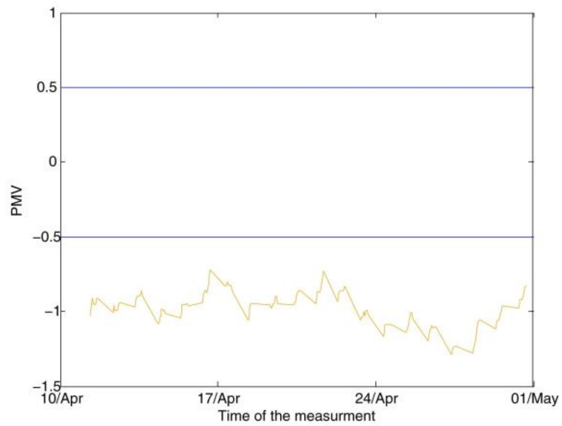


Figure 104. PMV levels. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

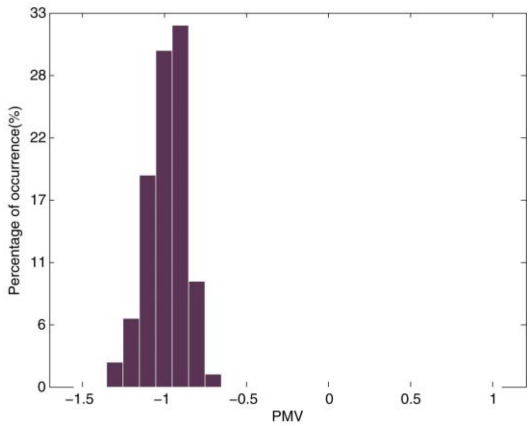


Figure 105. Histogram of PMV levels. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

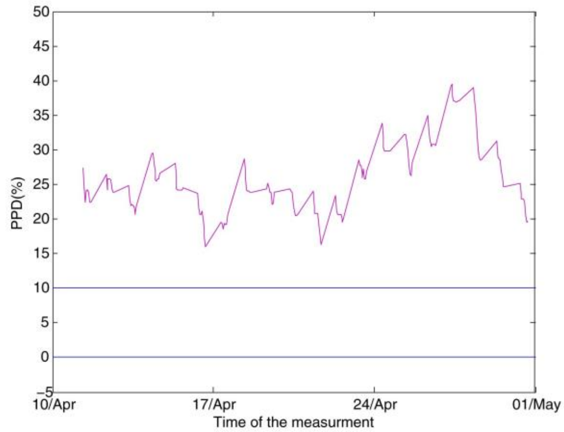


Figure 106. PPD levels. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

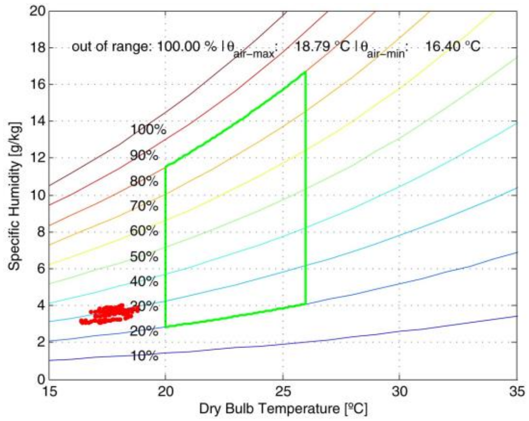


Figure 107. Mollier's Diagram. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

Seminar Room ML1. Period 01.05.2016-31.06.2016

Considering the seasonal weather improvement and higher outside temperatures, in this period PMV levels start to rise while the PPD levels decline (Figure 108, Figure 110). Average PMV is -0.50 with the average PPD of 11.17% (Table 16). About 28% of PMV values are near to -0.50 and 31% near to -0.40 (Figure 109). Approximately 40% of the temperatures which are in the Standard recommended range (Figure 111) indicate that only slight activation of heating system joined with natural sun radiation could have given the thermally comfortable environment if the room was occupied.

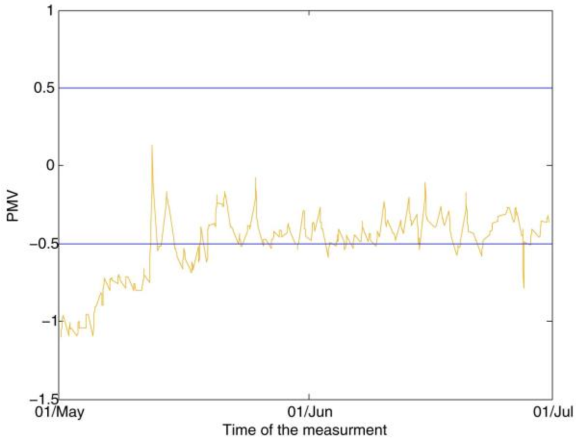


Figure 108. PMV levels. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

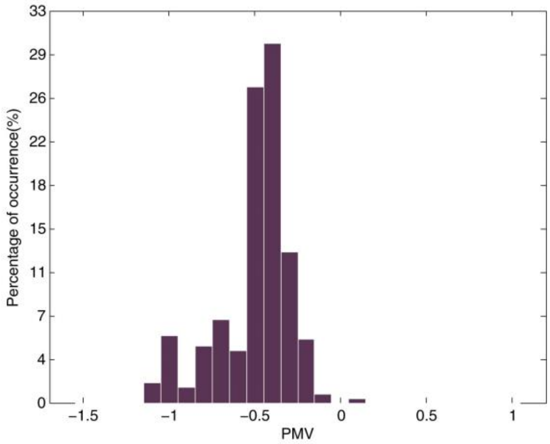


Figure 109. Histogram of PMV levels. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

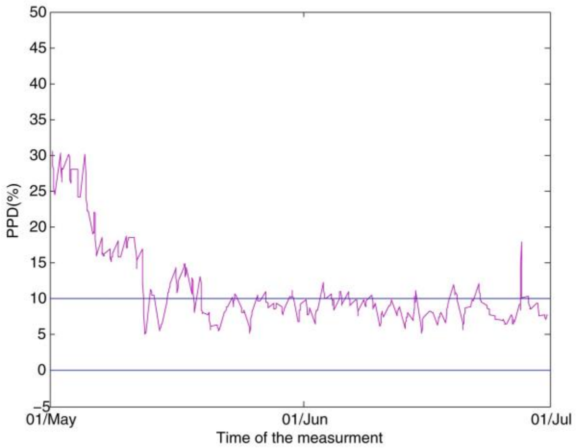


Figure 110. PPD levels. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

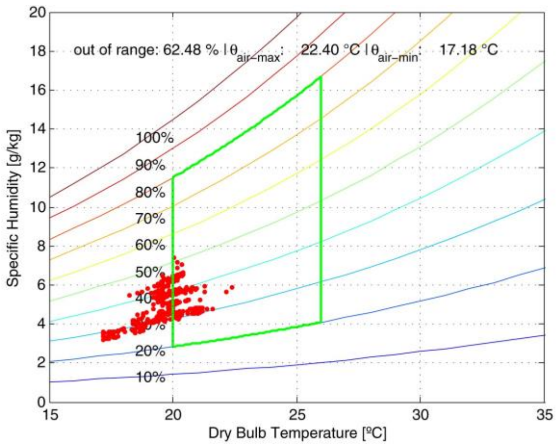


Figure 111. Mollier's Diagram. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

Distribution of long term thermal comfort results over ISO 7730 categories

In order to conclude on the long term thermal comfort evaluation, the PMV results are distributed among ISO 7730 categories of thermal environment (Figure 112, Figure 113 and Figure 114). Categories A, B, C and D are assigned in accordance to the Table 1.

In the Restaurant Area, results from the ML1 and ML2 are classified similarly among categories, as expected. For monitoring period 1, majority of the PMV results (approximately 75% - 80%) belong to the category B (values between -0.50 and 0.50) for both of the categories and both of the measuring locations (Figure 112, Figure 113). Monitoring period 3 has the similar result, with the biggest percentage of results belonging to the B category for the ML1. However, on the ML2, 55% of results are entering the category A for the user group of

Employees (Figure 112, Figure 113). These two monitoring periods in the Restaurant Area are, in conclusion, assessed with very good thermal comfort levels according to the Standard. Monitoring period 2 is still assessed with quite good PMV evaluation, although the heating system was on the setback (Figure 112, Figure 113).

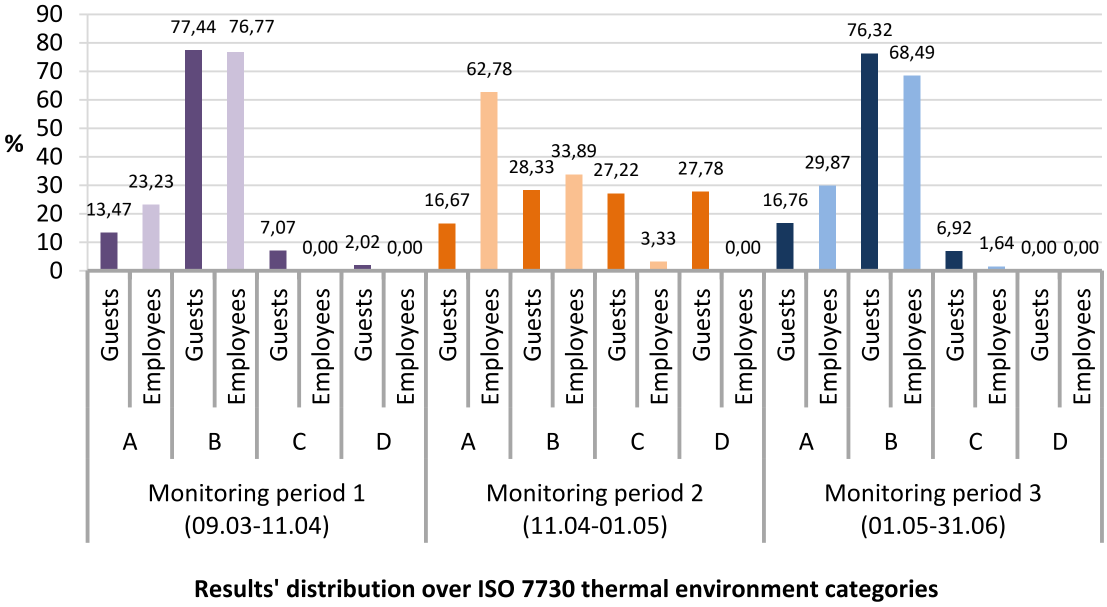


Figure 112. R-ML1. Distribution of long term results of general thermal comfort over ISO 7730 categories of thermal environment

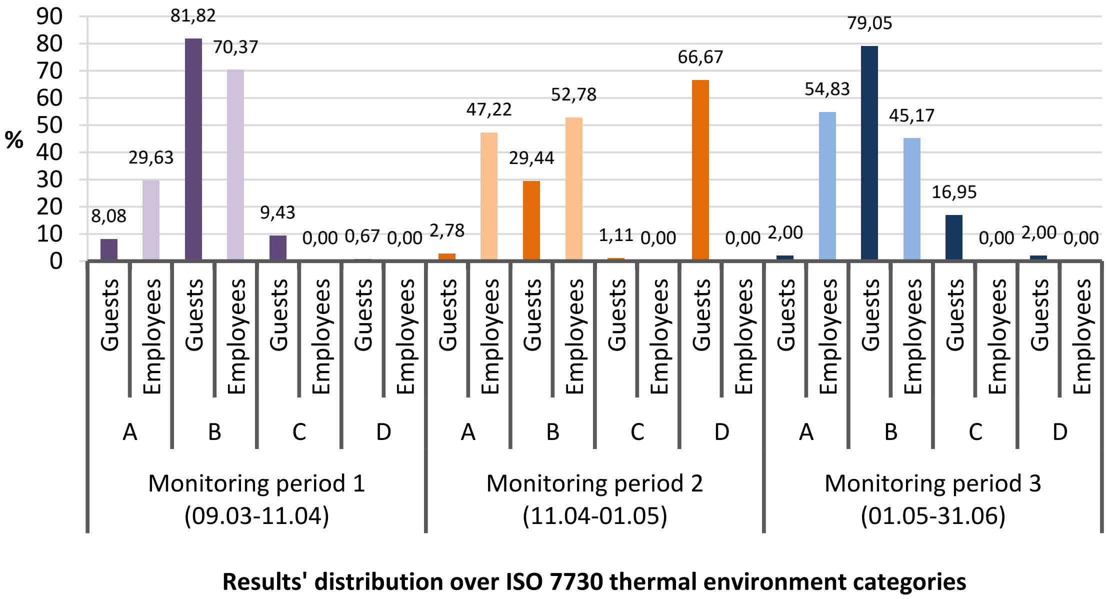


Figure 113. R-ML2. Distribution of long term results of general thermal comfort over ISO 7730 categories of thermal environment

Seminar Room's PMV results are ranked mostly among thermal environment categories with the low level of thermal comfort, as may be clearly seen in Figure 114. This is due to the fact that Seminar Room was rarely heated for the conference events, as already explained. Hence, PMV results from the monitoring period 1 and 2 belong in 63% and 100% to the category D (Figure 114). However, in monitoring period 3, about 61% of results belong to the category B as a consequence of some heating operation combined with higher solar gains (Figure 114).

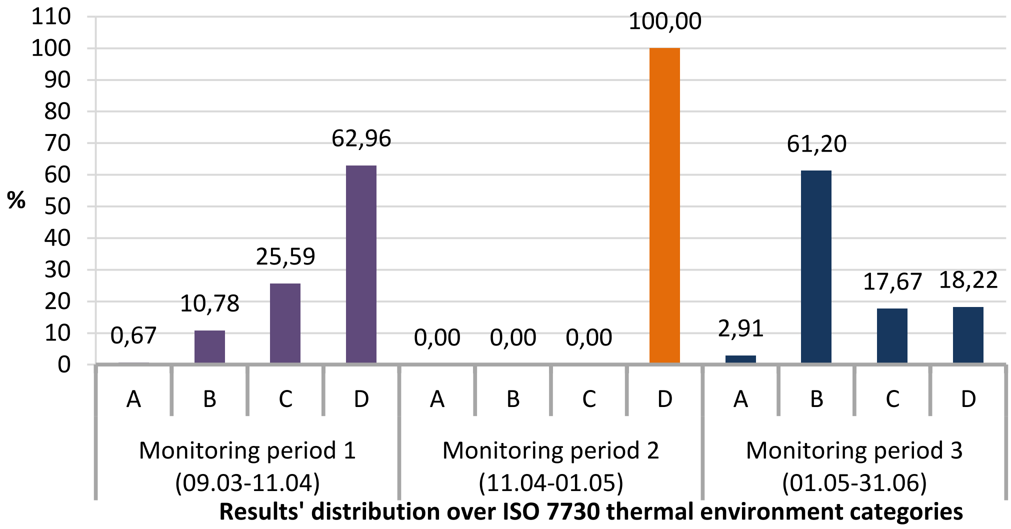


Figure 114. S-ML1. Distribution of long term results of general thermal comfort over ISO 7730 categories of thermal environment

4.3 Air Quality evaluation

The evaluation of the air quality of the Restaurant and Seminar Room is presented in this Subchapter and was performed as explained in the Subchapter 3.3.2. The air quality evaluation was also done on two measuring locations for the Restaurant and one location for the Seminar Room. The three periods with different occupancy rates were separately studied.

Restaurant Area

The Restaurant Area is mechanically ventilated so the CO_2 levels are easier predicted and controlled. This is illustrated in the graphs and histograms listed below. The first period involves the full operation of ventilation system and a full occupancy period of the Restaurant, from 9th of March until 11th of April. However, it is visible that the actual full occupancy stopped after the 4th of April (Figure 115, Figure 121). From that date the CO_2 levels go rapidly down and continue in that trend until 1st of May when they rise again after the Restaurant's reopening (Figure 117, Figure 119, Figure 123, Figure 125). On ML2 slightly higher average CO_2 levels are measured for all the periods, probably because the sensor's location was segregated from the directly ventilated area and the fresh air inlet (Table 17). Minimum CO_2 levels are similar for both locations and are probably measured during the early morning hours (Table 17). Maximum CO_2 occurs for both locations in the same day in June, with 2040 ppm for the location 1 and 2000 ppm for the location 2 (Table 17). The air quality is generally high and assigned in the highest percentage to the IDA category 1 or category 2. This will be further discussed in continuation.

Table 17. Restaurant Area long term (09.03.2016-31.06.2016) minimum, maximum and average CO_2 levels during the occupancy hours

Device location	Period of time	Min CO_2 (ppm)	Max CO_2 (ppm)	Aver. CO_2 (ppm)
R-ML1	09.03-11.04	430	1110	607.32
	11.04-01.05	420	1445	553.92
	01.05-31-06	435	2040	612.55
R-ML2	09.03-11.04	460	1218	636.95
	11.04-01.05	440	1416	646.20
	01.05-31-06	430	2000	617.68

Restaurant Area ML1. Period: 09.03.2016-11.04.2016

During the first monitoring period at the location 1, CO_2 levels show the clear pattern of occupancy for every day. In the night hours they fall down, so when the first measurements are recorded (08:00 o'clock) they show the lowest CO_2 levels. The minimum value for this period was 430 ppm (Table 17). As the room gets occupied, CO_2 levels reach the maximum allowed by the mechanical ventilation and finally start naturally falling down before the closing hours (Figure 115). The reference lines shown in blue in Figure 115 are assigned as explained in the Subchapter 2.2. Histogram in Figure 116 shows that 42% of all the CO_2 levels are around 500 ppm, while 30% are around 600 ppm. These sum up in the majority of measurments and indicate a very good air quality within the Restaurant Area. IDA category 1 relates to the CO_2 levels with up to 800 ppm. According to EN 15251, this category would match 15% of PPD, as already stated in Subchapter 2.2.

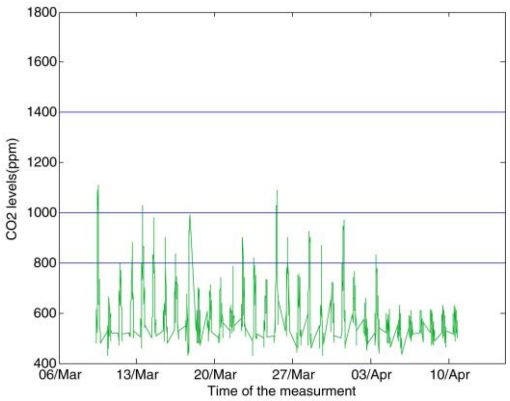


Figure 115. CO_2 levels. R-ML1. Period 09.03.2016-11.04.2016, occupancy hours

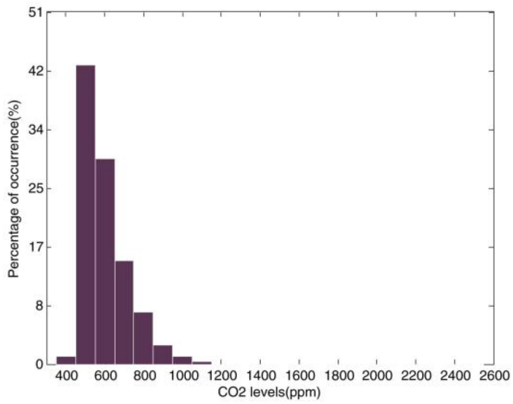


Figure 116. Histogram of CO_2 levels. R-ML1. Period 09.03.2016-11.04.2016, occupancy hours

Restaurant Area ML1. Period: 11.04.2016-01.05.2016

From 11th of April until 1st of May when the Restaurant was closed, the CO_2 levels are for more than 90% under the level of 600 ppm (Figure 117, Figure 118). As already said, this was a period of low occupancy when the ventilation system was not fully operating and is not very representative for the assessment of the air quality of the room.

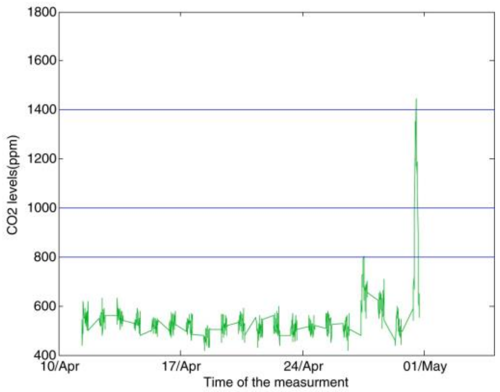


Figure 117. CO_2 levels. R-ML1. Period 11.04.2016-01.05.2016, occupancy hours

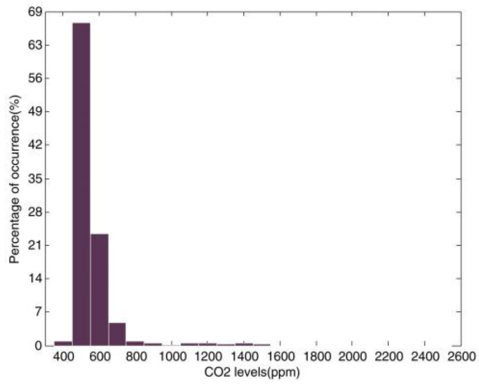
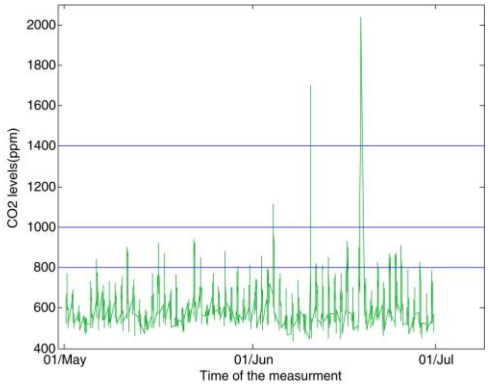


Figure 118. Histogram of CO_2 levels. R-ML1. Period 11.04.2016-01.05.2016, occupancy hours

Restaurant Area ML1. Period: 01.05.2016-31.06.2016

During the period after the reopening of the Restaurant, CO_2 levels are slightly higher than in the period 1, with an average of 612.55 ppm and a peak of 2040 ppm in June (Table 17). This event and the additional one, with around 1700 ppm, enter the IDA category 4 (Figure 119). This category relates to the CO_2 concentration of more than 1400 ppm and PPD of more than 30%, as stated in Table 6. However, also during this period the air quality is assigned with up to 90% to the IDA category 1 (Figure 120, Table 5).



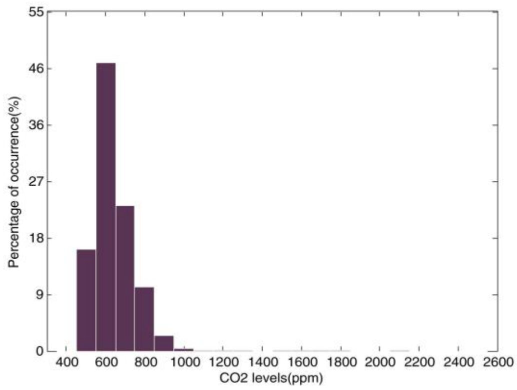
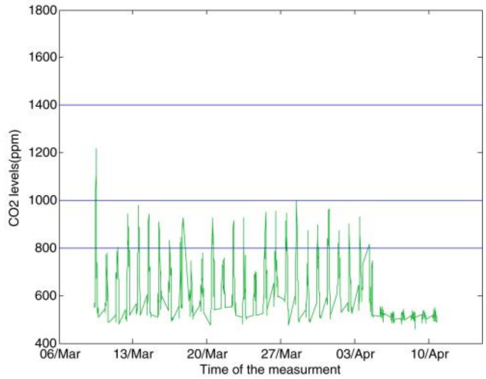


Figure 119. CO_2 levels. R-ML1. Period 01.05.2016-31.06.2016, occupancy hours

Figure 120. Histogram of CO_2 levels. R-ML1. Period 01.05.2016-31.06.2016, occupancy hours

Restaurant Area ML2. Period: 09.03.2016-11.04.2016

Sensor located in vestibule of the Restaurant registered moderately higher CO_2 levels than the sensor located directly in the Restaurant area, as it was further from the fresh air inlet. This is the reason why 8% of its CO_2 levels are around 900 ppm (Figure 121, Figure 122). According to EN 15251 these results would be classified to the IDA category 2, with expected 20% of PPD (Table 6). Almost all the rest of the CO_2 levels belong to the IDA category 1, describing an area with high air quality.



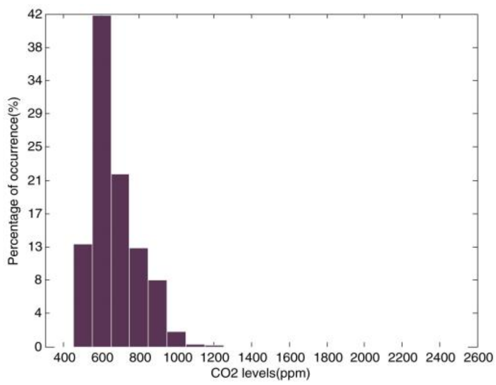


Figure 121. CO_2 levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours

Figure 122. Histogram of CO_2 levels. R-ML2. Period 09.03.2016-11.04.2016, occupancy hours

Restaurant Area ML2. Period: 11.04.2016-01.05.2016

Equivalently to the ML1, the second period on this location was defined with the low and non representative CO_2 levels due to the lack of occupancy (Figure 123). This is the reason why histogram of CO_2 occurrence shows almost unanimously about 70% of the CO_2 levels up to 600 ppm (Figure 124).

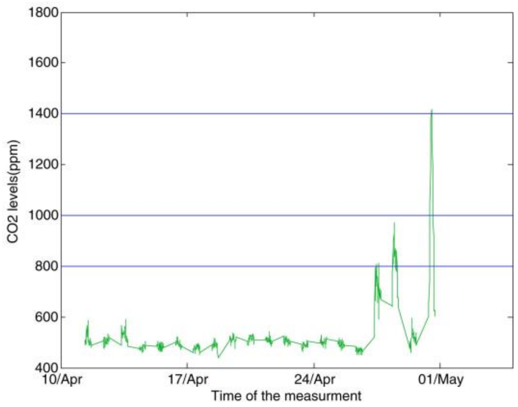


Figure 123. CO_2 levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours

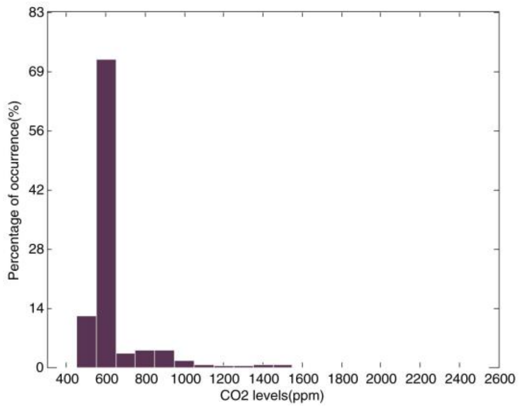


Figure 124. Histogram of CO_2 levels. R-ML2. Period 11.04.2016-01.05.2016, occupancy hours

Restaurant Area ML2. Period: 01.05.2016-31.06.2015

CO_2 levels were in average 626.95 ppm, while the minimum level was a bit higher than on the ML1, with 460 ppm (Table 17). Nonetheless, the air quality can be assessed as very good, describing the properly working mechanical ventilation. In this case, about 60% of the measurements belong to the IDA category 1 with levels up to 800 ppm, while about 30% belong to the IDA category 2 (Figure 125, Figure 126).

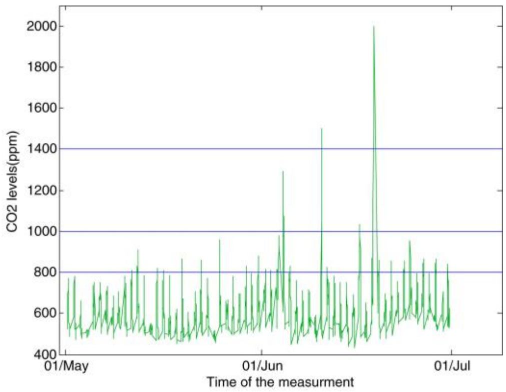


Figure 125. CO_2 levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours

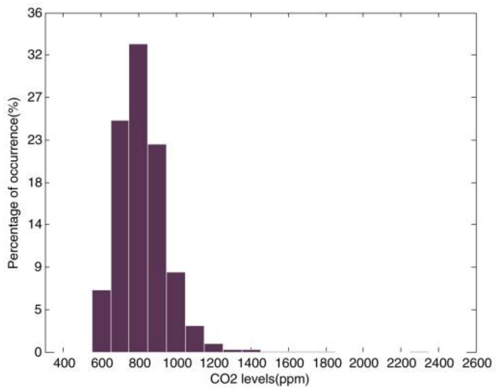


Figure 126. Histogram of CO_2 levels. R-ML2. Period 01.05.2016-31.06.2016, occupancy hours

Distribution of the CO_2 levels over EN 13779 categories of Indoor Air Quality in the Restaurant area

The final evaluation of the air quality within the Restaurant Area is illustrated in the Figure 127. The CO_2 levels of both measurement locations belong in more than 90% to the Indoor Air Quality (IDA) category 1 for the whole monitoring period (Figure 127). This result illustrates the effectiveness of the mechanical ventilation in this area.

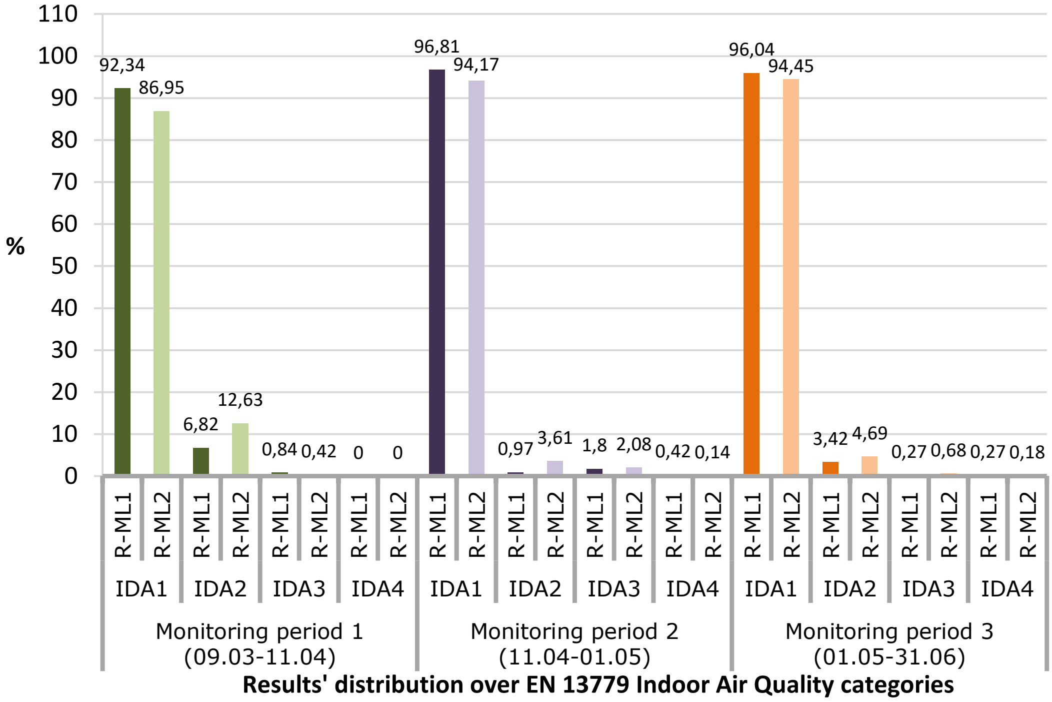


Figure 127. R-ML1 and R-ML2. Distribution of CO_2 levels over the EN 13779 categories of Indoor Air Quality (IDA)

Seminar Room

Seminar Room cannot be absolutely assessed through IDA categories, since both EN 15251 and EN 13779 refer to the mechanically ventilated spaces. This issue is already discussed in the Subchapter 2.2. The indoor air quality evaluation of this space was simply made consistent with the evaluation of the Restaurant Area, as explained in the Subchapter 3.3.2. The room is seldom occupied and it is not surprising that CO_2 levels are very low except for the peaks of occupancy when, if the window is not manually opened, CO_2 level tends to rise (Table 18).

Table 18. Seminar Room long term (09.03.2016-31.06.2016) minimum, maximum and average CO_2 levels during the occupancy hours

Device location	Period of time	Min CO_2 (ppm)	Max CO_2 (ppm)	Aver. CO_2 (ppm)
S-ML1	09.03-11.04	420	2515	562.44
	11.04-01.05	430	580	508.74
	01.05-31-06	420	1660	541.29

Seminar Room ML1. Period: 09.03.2016-11.04.2016

CO_2 levels from 9th of March until 11th of April (Figure 128) indicate that the space was three times fully or partially occupied. This is represented by the three peaks of CO_2 levels in March, with the maximum level of 2515 ppm (Table 18). Although about 90% of the CO_2 levels are under 600 ppm (Figure 129), this is not a reliable indicator of the room's air quality because it was only occupied when the peaks above 1000 ppm occurred. This leads to an issue of how safe is it to rely on users' actions in design of the building systems, particularly in non residential buildings. In these cases usually the appropriate training and informing of the employees is mandatory.

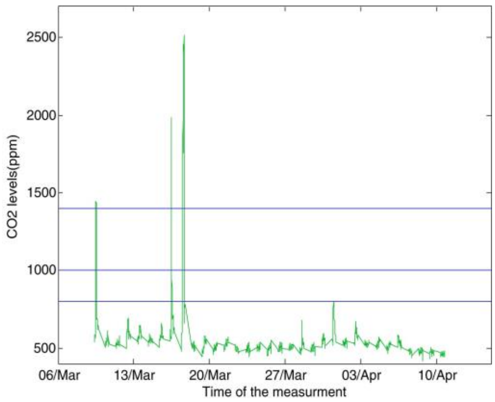


Figure 128. CO_2 levels. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

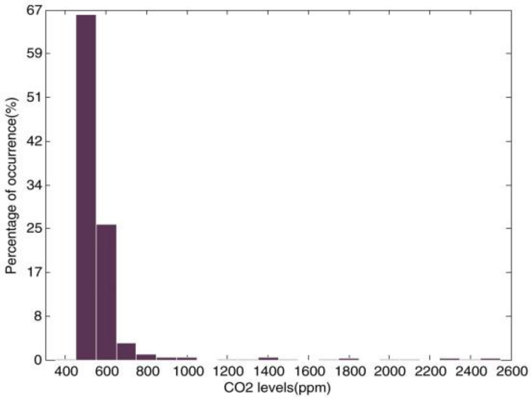


Figure 129. Histogram of CO_2 levels. S-ML1. Period 09.03.2016-11.04.2016, occupancy hours

Seminar Room ML1. Period: 11.04.2016-01.05.2016

Second monitoring period does not reveal any significant information on the air quality of the Seminar Room, since CO_2 levels are kept constant between values of 500 ppm and 600 ppm due to the lack of occupancy (Figure 130, Figure 131).

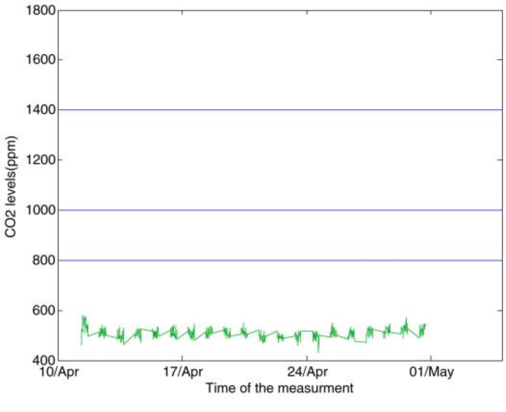


Figure 130. CO_2 levels. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

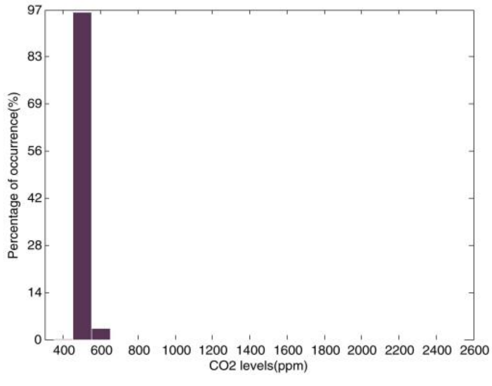


Figure 131. Histogram of CO_2 levels. S-ML1. Period 11.04.2016-01.05.2016, occupancy hours

Seminar Room ML1. Period: 01.05.2016-31.06.2016

Third monitoring period unfolds the similar results as the period 1. The occupied intervals show levels higher than the Pettenkofer's number, with 1100 ppm and 1660 ppm (Figure 132, Table 18), while 70% of the CO_2 levels are around 500 ppm (Figure 133).

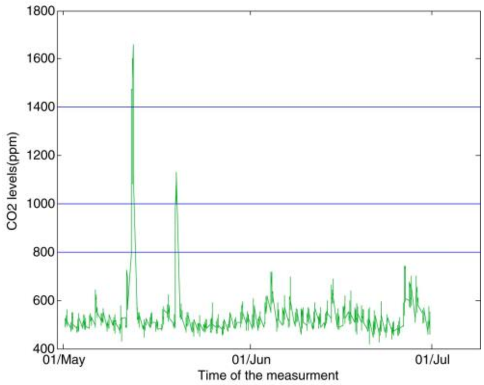


Figure 132. CO_2 levels. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

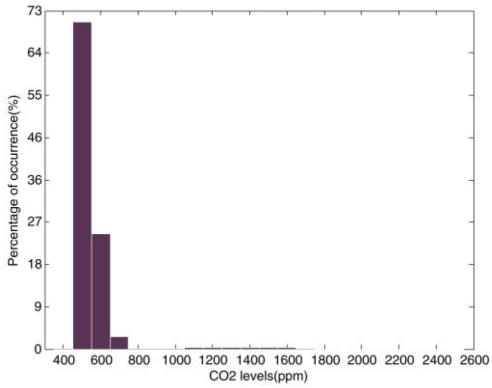


Figure 133. Histogram of CO_2 levels. S-ML1. Period 01.05.2016-31.06.2016, occupancy hours

Distribution of CO_2 levels over EN 13779 categories of Indoor Air Quality in the Seminar Room

Throughout the complete monitoring, CO_2 levels in Seminar Room belong above 90% to the best Indoor Air Quality category (Figure 134). However, reason in this case is not the good ventilation, but rather the fact that the room was not often in use. During the singular events when the room was occupied the bad IDA categories are present because the air quality is based on the natural ventilation from the users' manual operation. 1.68% of the CO_2 levels belong to the IDA category 4 during the monitoring period 1, while 1% belong to the IDA category 3 during the monitoring period 3 (Figure 134).

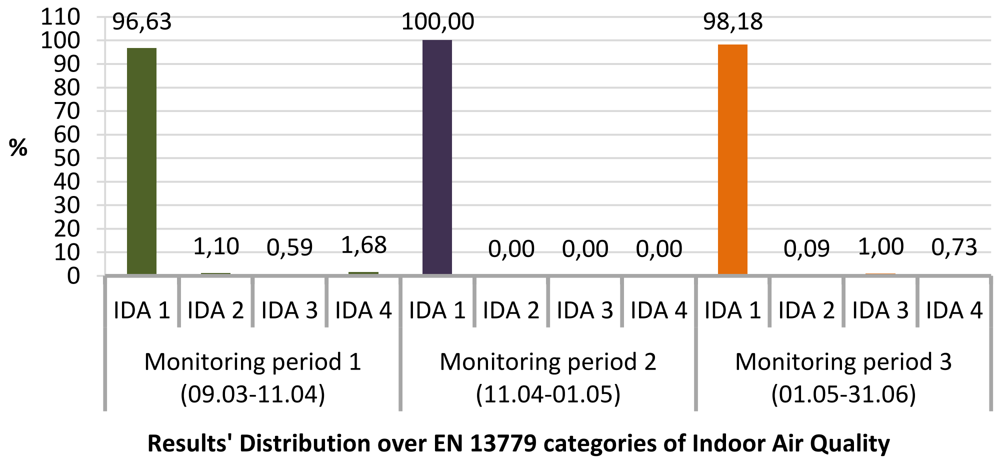


Figure 134. S-ML1. Distribution of CO_2 levels over the EN 13779 categories of Indoor Air Quality (IDA)

4.4 Electrical load management evaluation

The electrical load management is evaluated as explained in the Subchapter 3.3.2. The mutual relation between heating load management and thermal comfort will also be discussed. As previously described in Subchapter 3.2, Krippenstein's building systems are all operating on electricity. This indicates that the well managed electricity distribution from the distribution boards to the circuits is of crucial importance.

In the first part of this Subchapter, the total electric power and heating power use are presented for the period of the chosen three weeks (from 27th of January until 14th of February), in order to find the days with the highest heating loads and their corresponding relation to the total electrical loads.
Secondly, the current electrical load management is tested for the days with the highest heating loads. This is done by virtually testing its response to the theoretical higher loads in extreme weather conditions. After this, the direct influence of the load shedding to the thermal comfort is assessed. Finally, another approach of predictive load shedding is schematically suggested as an alternative to the current load management approach.

4.4.1 Total electric and heating power use through daily intervals

Since heating system of the Krippenstein station is operating with electricity, it is significant to assess its relation to the overall electricity feed, and other circuits fed from the same distribution board. Distribution board 1, NSHV 400 has a peak load at 400 kVA or 400 kW. Out of this, 50 kW are left as a maximum load of the heating S_B_1, which corresponds to the Seminar Room and Restaurant. The scheme of the electricity distribution is seen in the Figure 13. Except for the heating, same distribution board is feeding also lighting for the same areas, kitchen equipment and cable car Krippenstein III. Hence, the electrical loads of this Distribution board will be in continuation assessed.

In scenarios of cold winter conditions and morning opening hours when the whole building is heated after the night, the peak load could be theoretically reached. In this load shedding in active to prevent that no blackouts are occurring. This means that the number of the heaters requested by BMS, in order to reach the set point temperature, will be reduced. This could influence the room temperature, but presumably only when there are more hours in row where load balancing blocks the heating. Since the monitored winter, although with chosen coldest weeks, was not the most representative one in terms of low temperatures, the system was tested with the theoretical colder weather conditions using historical weather data. This will be further discussed in the following Subchapter. The load shedding also happens on a scale of the total power feed. The maximum of 400 kW could be theoretically reached on the extreme days with full heating load in combination with the power consuming cable car operation. In these scenarios, the uninterrupted operation of the cable car has the highest priority and the loads of other systems are shedded in order to prevent an electricity outage.

Firstly, the graphs of the total electric power and heating power are presented in order to understand better the pattern of the loads, their distribution and percentages within daily intervals during the three weeks.

In the first week (27th to 31st of January) the electrical power maximum load of about 90 kW is reached on the first day in the interval from 08:00 to 12:00 (Figure 135). However, on 27th and 28th of January the monitored data was not fully continuous during the night hours, so these results should be interpreted with caution. From the following days, the predicted pattern starts regularly showing with the peaks in the interval from 10:00 to 12:00 (Figure 135). When total power is compared to the heating power, the inversely proportional relation is seen between their loads. The maximum loads of total power are usually corresponding to the lower heating power. The higher total power means that, for instance, kitchen equipment is on and Restaurant is occupied. The internal loads coming from these factors raise the room temperature and there is no need for the high heating load. This usually happens on weekends, when many people are visiting Krippenstein.

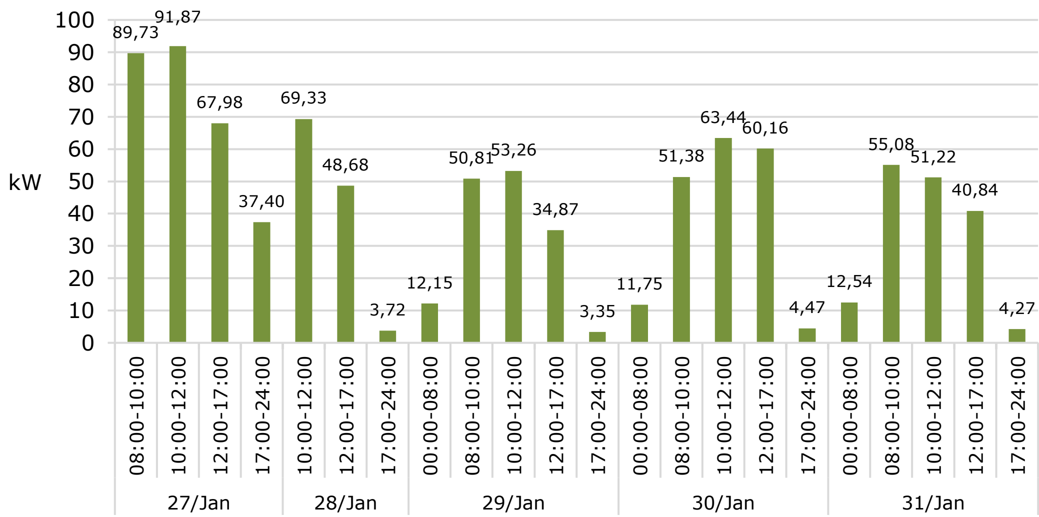


Figure 135. Average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 27.01.2016-31.01.2016

During the first week, the maximum load percentage of 22.97% was reached on 27th of January, as discussed (Figure 136). In the following days the maximum average loads were significantly lower, reaching about 13 to 15% of the maximum power load of 400 kW (Figure 136). As already stated, data from 27th and 28th of January should be treated with caution for its not ideal consistency.

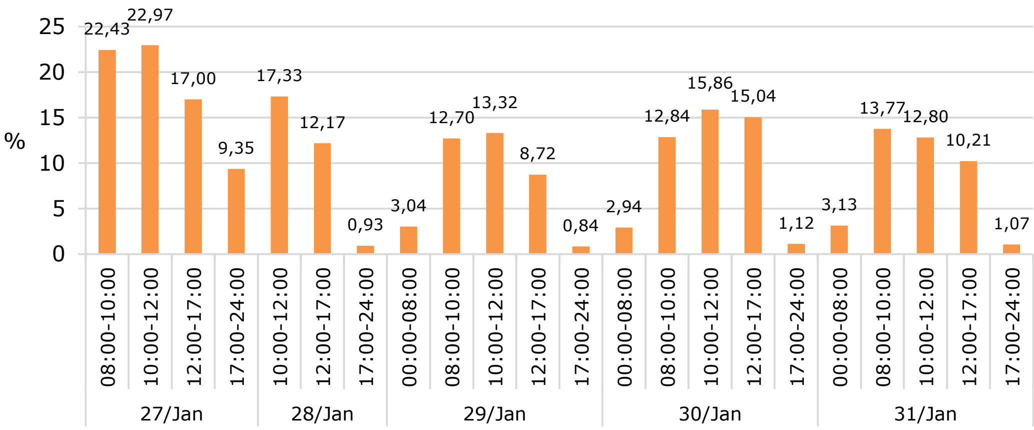


Figure 136. Percentage of the average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 27.01.2016-31.01.2016

As seen from the Figure 137, in the week from 1st until 7th of February, the pattern of loads during occupancy and non occupancy hours is clearly visible. As expected, the night hours from 17:00 to 08:00 tend to have low average power outputs. The power consumption is usually highest in the interval from 10:00 to 12:00 when most of the kitchen equipment and heating is on. From 12:00 to 17:00, power use is already reducing towards the night hours. The maximum average loads in this week are reached on 6th and 7th of February, which are weekend days, with peak load of 70.22 kW on February 7th (Figure 137).

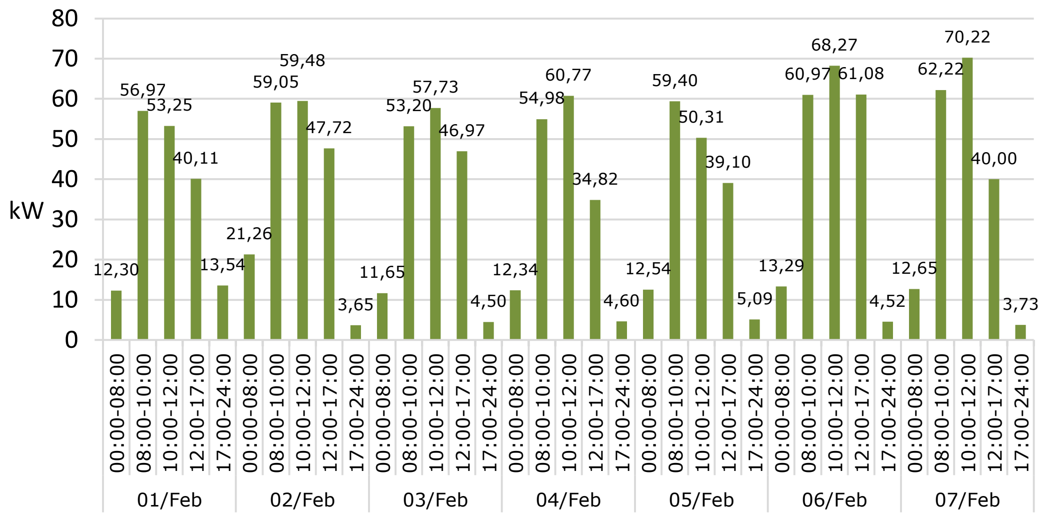


Figure 137. Average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 01.02.2016-07.02.2016

The maximum average load of this week, on 7th of February from 10:00 to 12:00, corresponds by percentage to 17.55 % of the maximum load allowed (Figure 138).

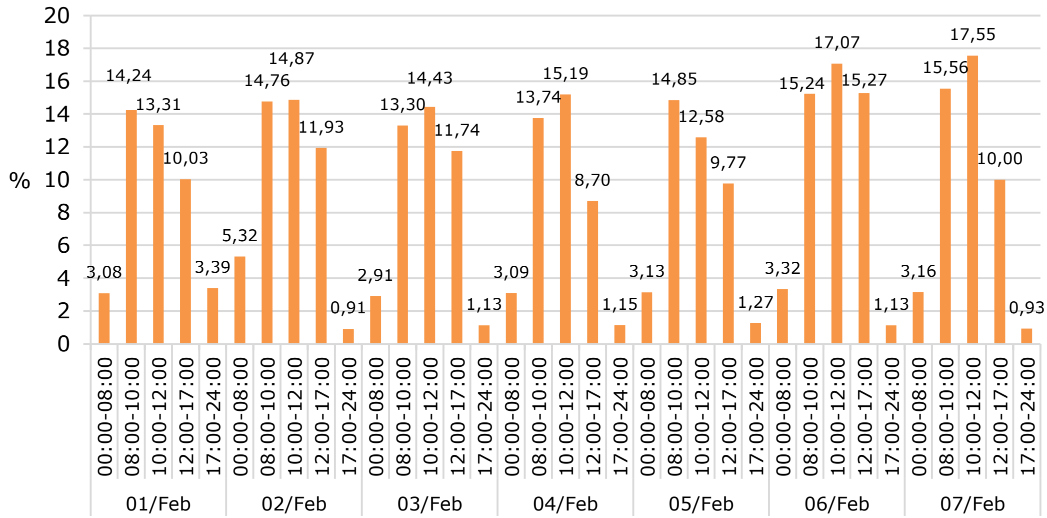


Figure 138. Percentage of the average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 01.02.2016-07.02.2016

In the third week there are few days with continuously high loads, with maximum peak of 72.42 kW on 12th of February from 10:00 to 12:00 (Figure 139). This corresponds to the percentage of 18.11% compared to the peak load of 400 kW (Figure 140). These days the lowest outside temperature was measured (Figure 141), so increased total loads are presumably also coming from the high heating loads.

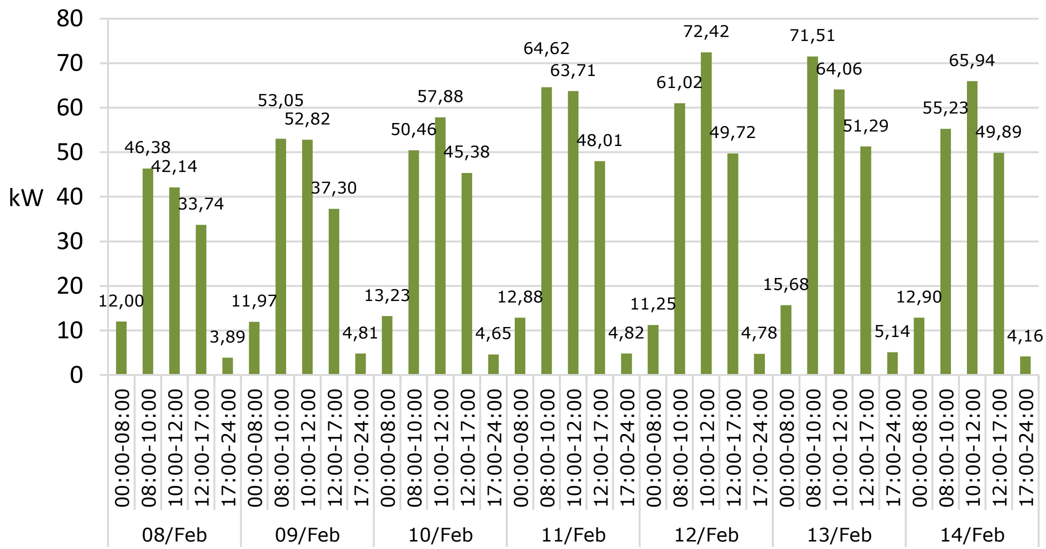


Figure 139. Average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 08.02.2016-14.02.2016

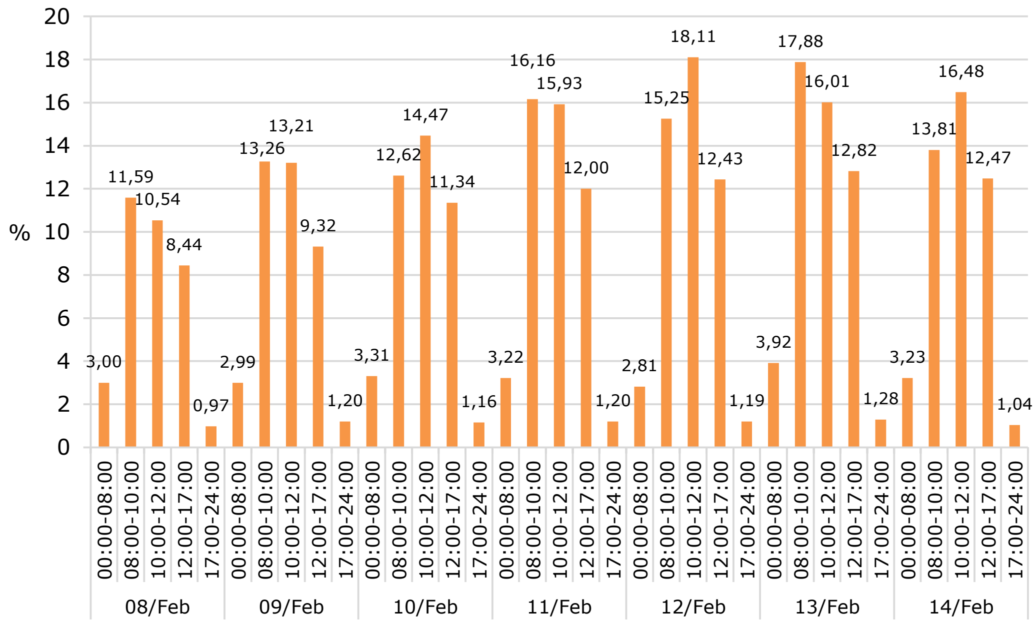


Figure 140. Percentage of the average total power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 08.02.2016-14.02.2016

Apart from the total electric power, heating power distribution is assessed through the same three weeks, in order to spot the days with the highest heating loads when the load shedding was expected. Out of 400 kW reserved for the total power, 50 kW peak load is maintained for the heating purpose. In order to comment on the heating loads, the histogram of the average daily outside air temperature is shown in Figure 141. Moreover, the corresponding daily heating degree days are shown in Figure 142. Heating degree days have, in assumption, the directly proportional relation to the energy invested for heating.

As proved by the graphs in continuation, the maximum heating loads happen mostly from 08:00 to 10:00 when all the heaters are turning on in order to warm up the building for the following operating hours. The potential for the predictive load management lays here. The peak loads might be avoided with the rescheduling of the heating loads and preheating of some of the rooms. This would have positive effects on balancing of the total loads and prevention of the electricity outage to the circuits.

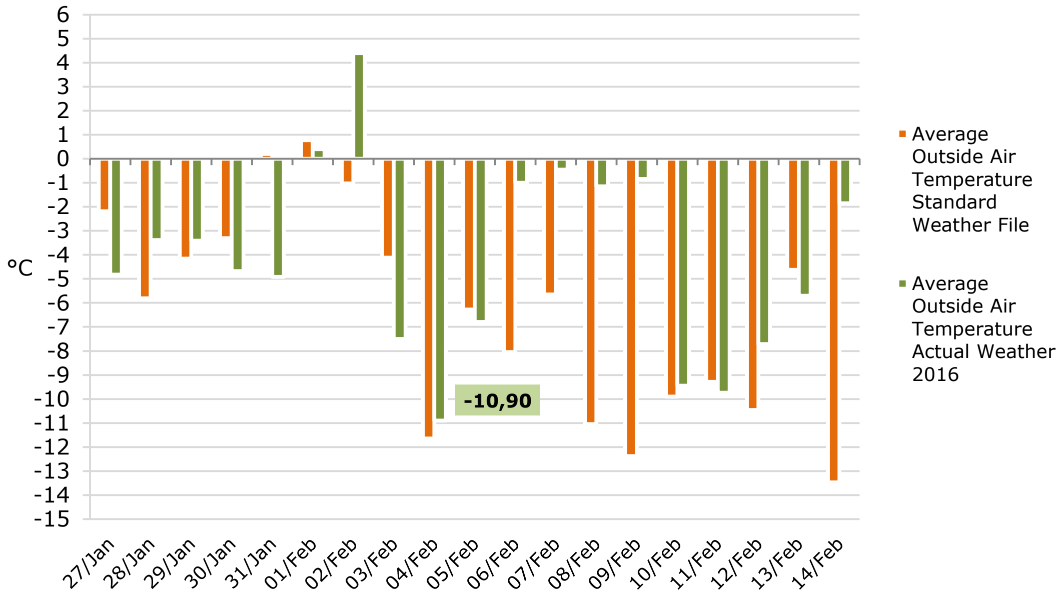


Figure 141. Average daily outside air temperature from the Standard Weather File and Actual Weather 2016 File. Period: 27.01-14.02

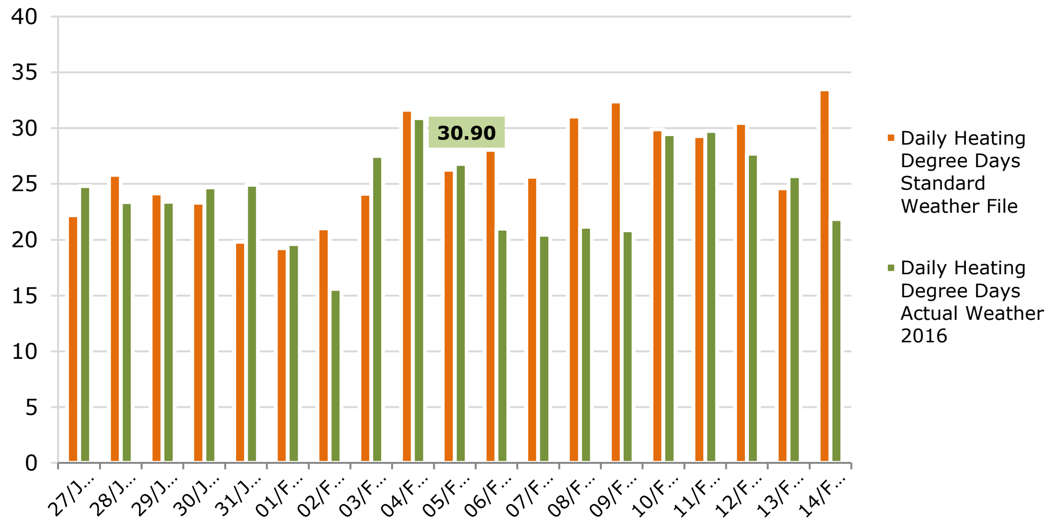


Figure 142. Daily heating degree days comparison between Standard Weather File and Actual Weather 2016 File. Period. 27.01-14.02

During the first week, the pattern of the interval loads is already shown well with the maximum loads from 08:00 to10:00. Similar to the total power graphs, first two days are not presented with full twenty four hours, as data was missing from the certain intervals. The maximum load is reached on 29th of January, with 35.96 kW (Figure 143), or 71.91% of the peak load of 50 kW (Figure 144).

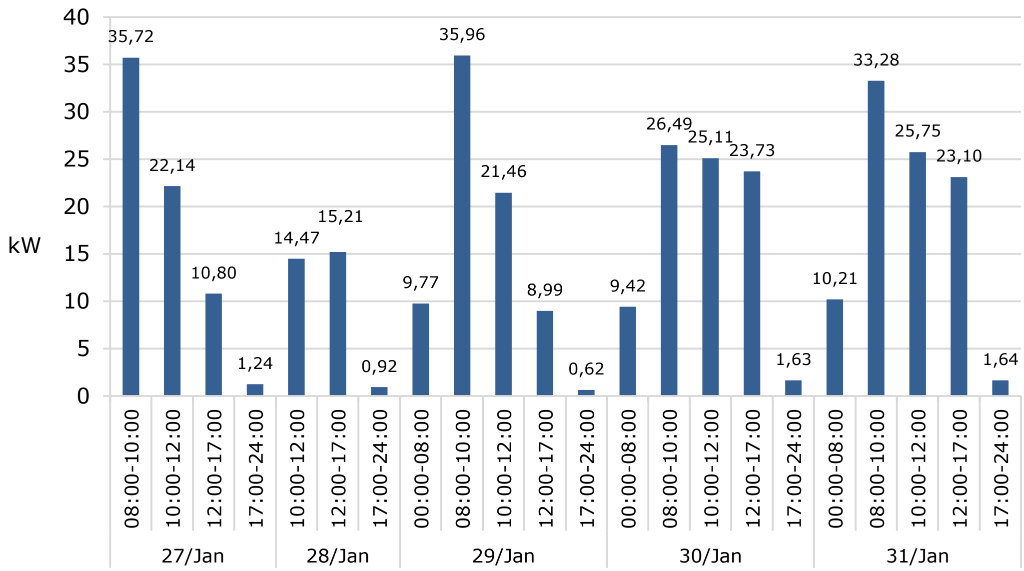


Figure 143. Average heating power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 27.01.2016-31.01.2016

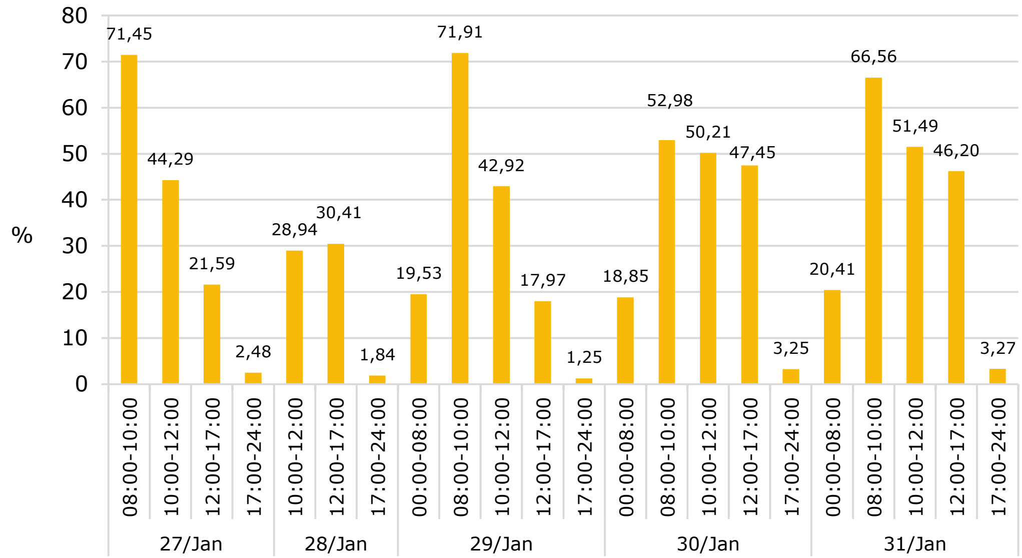


Figure 144. Percentage of the average heating power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 27.01.2016-31.01.2016

It is significant to highlight that loads shown in these graphs are averaged, and will have the mean value lower than the actual peak load in that interval. For this reason the additional graphs are presented in this section, with the hourly heating percentage (Figure 145) and the trend of heating percentage (Figure 146) in order to spot the maximum heating loads. In case of the first week, when comparing the Figure 144 and Figure 145, the maximum peak loads on 29th of January are not significantly different as they are averages from the two hour interval and one hour interval. However, the distinction is clearly shown in Figure 146 where on 29th of January few values in the highest load interval (from 08:00 to 10:00) are reaching close to 100%. The load of 100% will not be reached as this would mean the electrical power outage. In these scenarios, the load balancing unit reduces correspondingly the number of the turned on heaters in order to keep the load away from 100%.

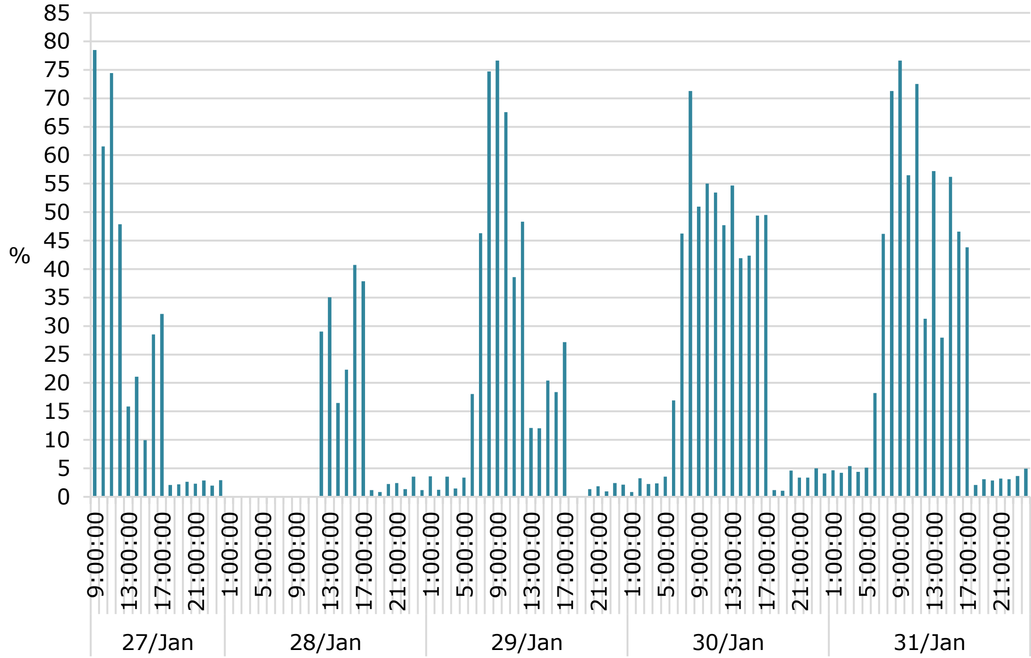


Figure 145. Hourly Percentage of the heating power used from the Distribution board 1, NSHV 400. Period 27.01.2016-31.01.2016

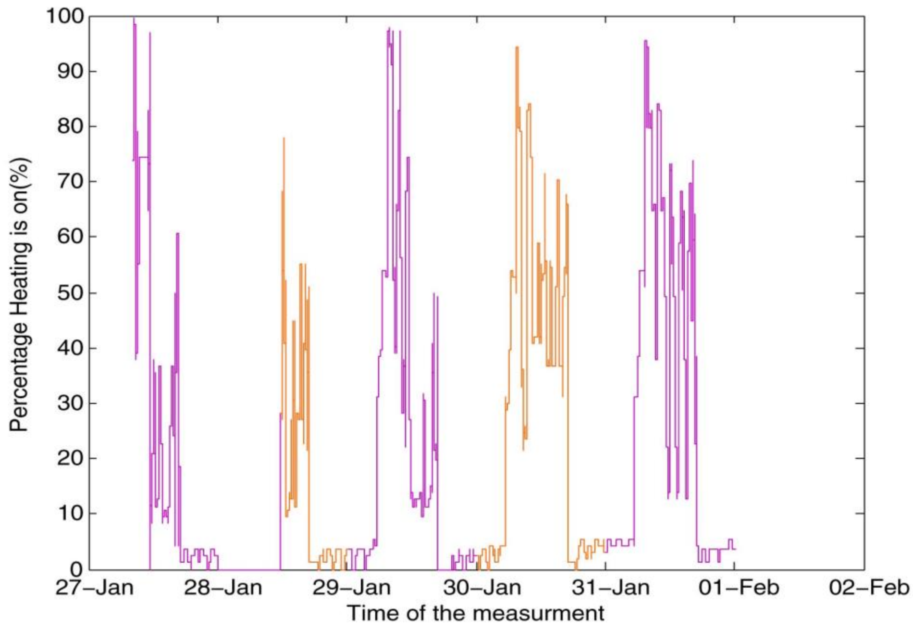


Figure 146. Trend of heating system operation percentages, representing the percentage of the heating system used from the Distribution board 1, NSHV 400. Period 27.01.2016-31.01.2016

In the second monitoring week, from 1st until 7th of February, the outside temperatures were not really low (Figure 141). This means that in average less heating was needed, especially on the weekend days when there were many internal loads, principally in the occupancy hours from 10:00 to 17:00. The coldest day of the week was 4th of February with an average daily temperature of -10.90 °C (Figure 141) and related heating degree days of 30.90 (Figure 142). On the following day the highest heating loads are noted after the previous cold night, with the peak of 39.52 kW in the morning interval from 08:00 to 10:00 (Figure 147). This correlates to the percentage of 79.04 % of heating maximum load (Figure 148). The 4th of February was a day with the lowest average daily temperature among the observed period of winter of 2016 and the coldest day of the whole that year. Hence, this temperature was further on used for the comparison of the heating degree days of coldest/extreme day of the Actual Weather 2016 and Standard Weather File.

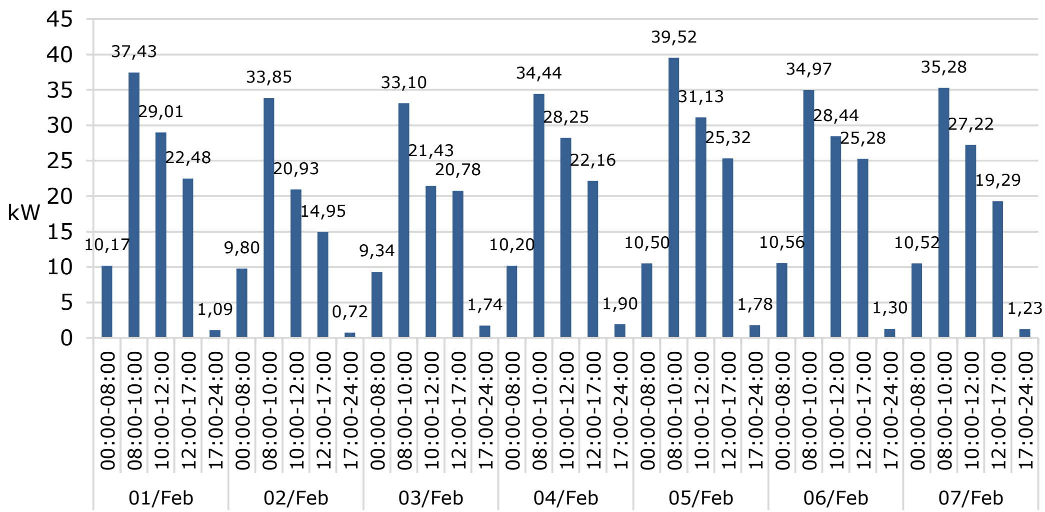


Figure 147. Average heating power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 01.02.2016-07.02.2016

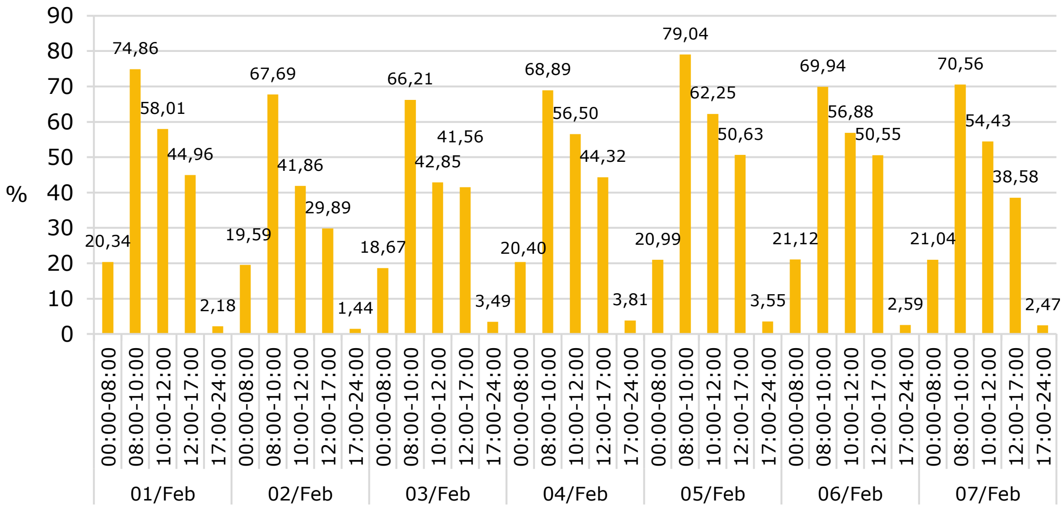


Figure 148. Percentage of the average heating power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 01.02.2016-07.02.2016

However, although the following two days of 6th and 7th of February bring the significantly higher daily temperatures (Figure 141), the heating loads of the morning interval do not change much from the peak day of 5th of February. This is probably because the outside temperatures are still low from the night hours in the morning interval from 08:00 to 10:00. On the other hand, in the following intervals the percentage of the turned on heating is lower than on the 5th of February (Figure 149). This is clearly visible in the trend of heating system percentages in the afternoon hours which are lowering gradually from 5th to 7th of February as the air temperatures rise (Figure 150).

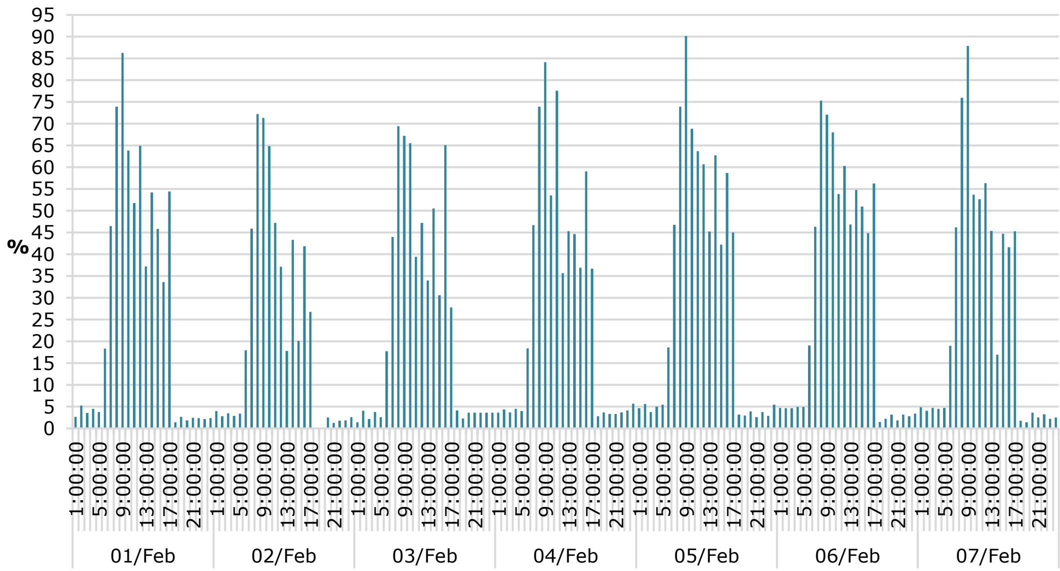


Figure 149. Hourly Percentage of the heating which is used from the Distribution board 1, NSHV 400. Period 01.02.2016-07.02.2016

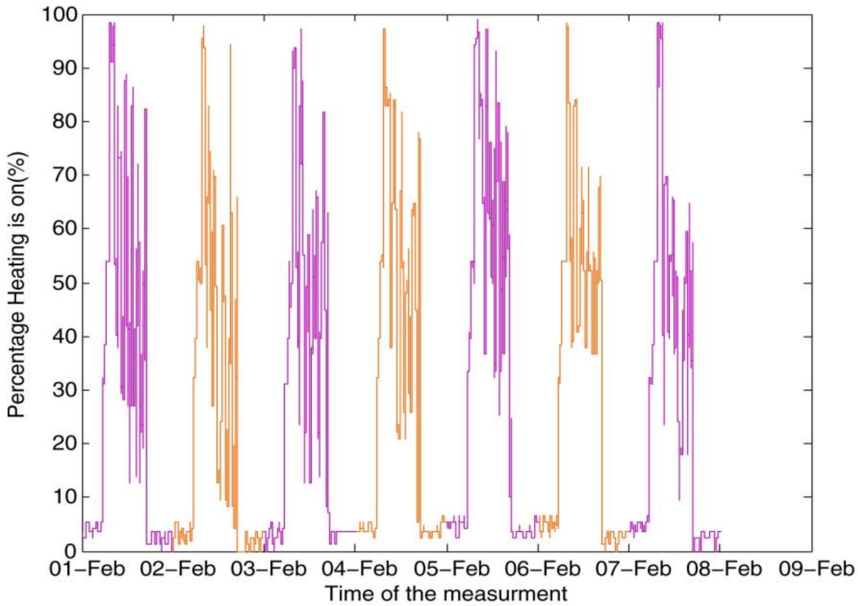


Figure 150. Trend of heating system operation percentages, representing the percentage of the heating system which is used from the Distribution board 1, NSHV 400. Period 01.02.2016-07.02.2016

In the third chosen week, the heating loads tend to be the highest among the three weeks for some days in row, precisely 10th, 11th, 12th and 13th of February (Figure 151). This corresponds logically to the low average temperatures in those days (Figure 141) and consequently to the highest total electrical power rate, as previously said. The peak heating power is measured on 11th of February, with 43.62 kW, in the well known interval from 08:00 to 10:00 (Figure 151). This value relates to the percentage of 87.25 % of the maximum 50 kW of the heating power (Figure 152).

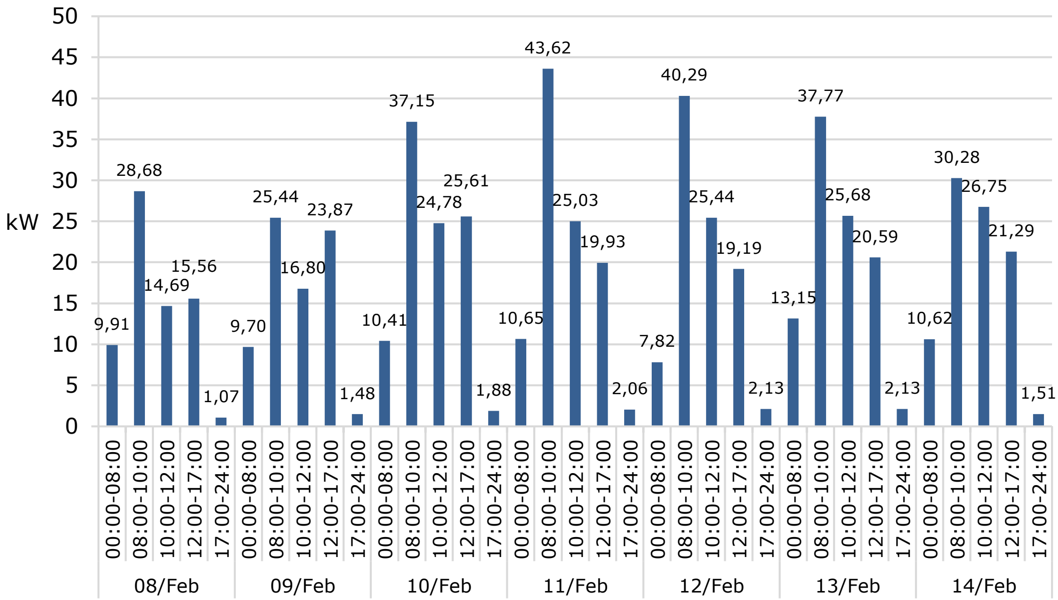


Figure 151. Average heating power used through daily time intervals from the Distribution board 1, NSHV 400. Period: 08.02.2016-14.02.2016

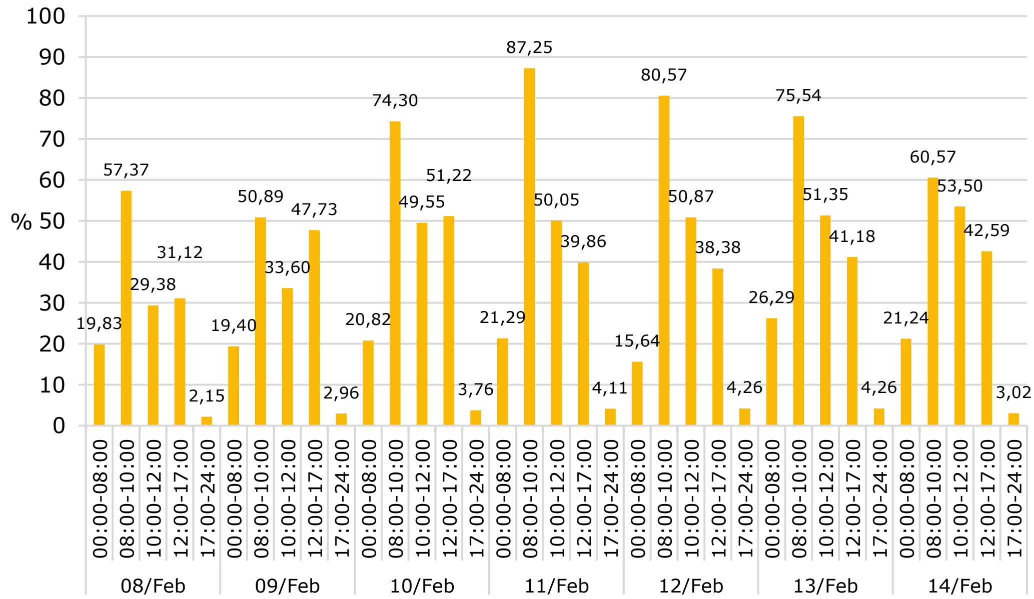


Figure 152. Percentage of the average heating power used used through daily time intervals from the Distribution board 1, NSHV 400. Period: 08.02.2016-14.02.2016

However, previously mentioned values are the averaged ones and do not represent perfectly the circumstances in given hour or moment, as Figure 153 and Figure 154 do. In the interval from 08:00 to 09:00 in the morning of 11th of February, the percentage of about 93% of heating was used in average (Figure 153). However, the trend of percentages in Figure 154 shows that the maximum percentages of heating are reached repeatedly during the morning hours on 10th, 11th, 12th and 13th of February, with approximately 98%. These are the intervals when the load shedding was applied in order to keep this percentage away from being the full 100%. In other words, the number of heaters is reduced by the load balancing unit in order to prevent the electricity outage. This also applies to the whole rooms depending of their place in the priority list for heating. Some of them stay without heating until loads are balanced again or shifted to the next time interval. In the circumstances of mild winter, this does not represent the real problem, as the comfort temperatures are still kept and always compensated. However, with the cold winter and few hours in row of the load shedding theoretically there might be some issues with temperatures lower than the comfort ones. This will be discussed in the continuation. The days chosen for the further evaluation because of the highest loads are 11th and 12th of February.

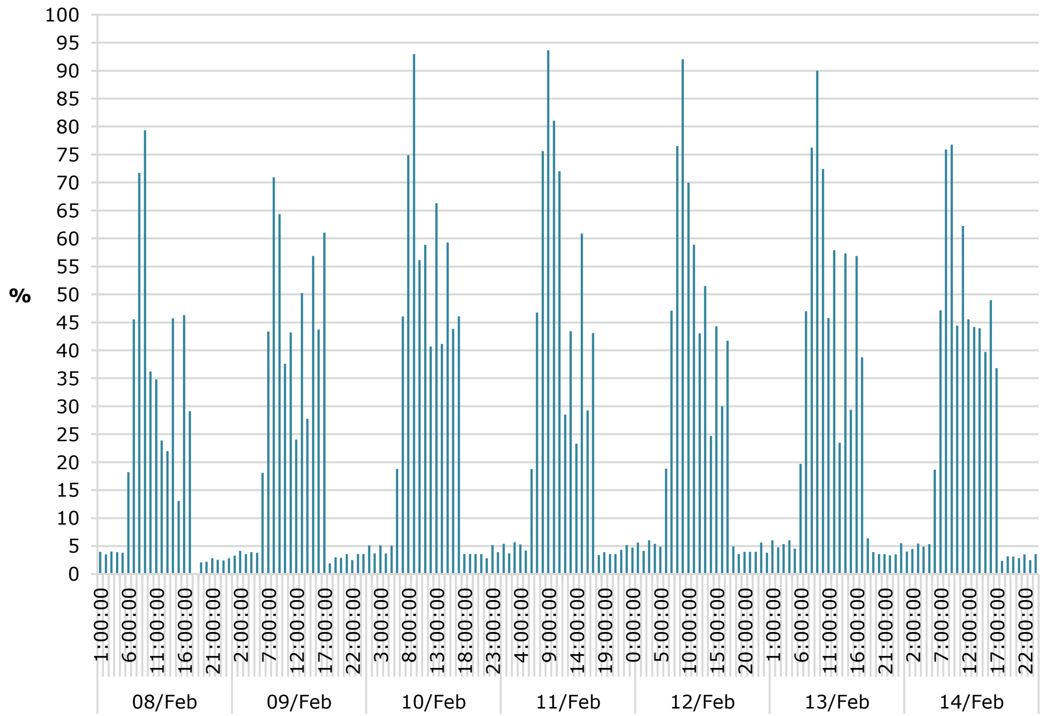


Figure 153. Hourly Percentage of the heating which is used from the Distribution board 1, NSHV 400. Period 08.02.2016-14.02.2016

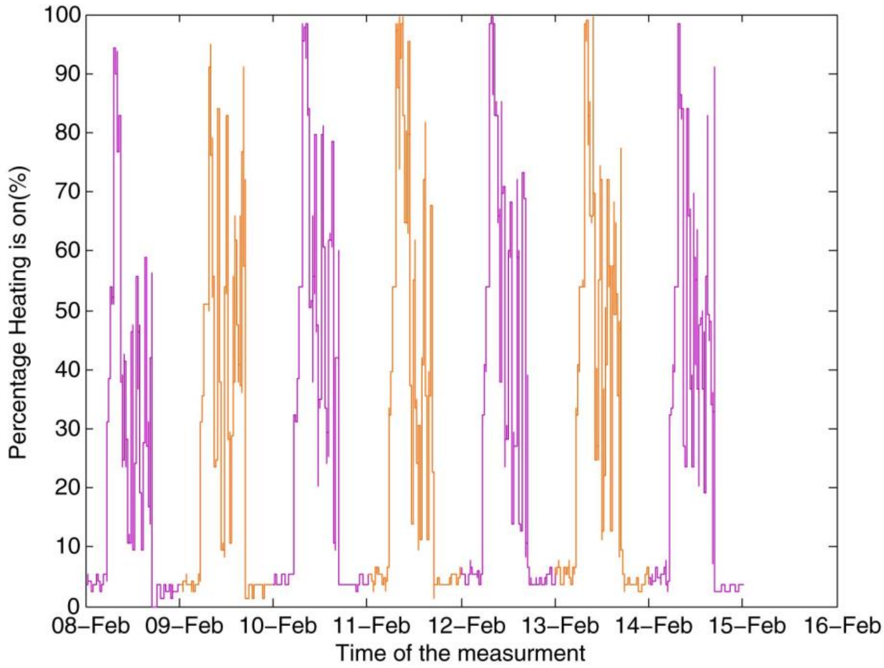


Figure 154. Trend of heating system operation percentages, representing the percentage of the heating system which is used from the Distribution board 1, NSHV 400. Period 08.02.2016-14.02.2016

4.4.2 Heating load management prediction for extreme temperatures

The days with the highest heating loads among the monitoring period are 11th and 12th of February, as stated in the previous Subchapter (Figure 151, Figure 152, Figure 153, Figure 154). During those days the morning intervals from 08:00 to 10:00 are facing in average 87.25% and 80.57% of the turned on heating. These percentages are high when taken into consideration that they are averaged over two hours, which means that peak loads close to 100% happen often as events within the interval. These days are chosen as specimens for the further assessment. The following evaluation is based on the claim that the monitored winter of 2016 was not the most representative one temperature-wise. The load management response to the extreme weather conditions will be evaluated.

From the comparison of average daily temperatures between Standard Weather file and Actual Weather 2016 file (Figure 141) and corresponding daily Heating Degree Days (Figure 142) may be perceived that in average winter of 2016 was milder than what was historically measured at that location. For a comparison between the actual and standard winter was taken the extreme day scenario with the lowest daily temperature for both winters (Table 19). Minimum daily temperature for Standard Weather File year was -14.85 °C, while for the winter of 2016 this temperature was -10.90 °C (Figure 141). The corresponding Heating Degree Days are 34.85 for the Standard extreme day and 30.90 for the Actual 2016 extreme day (Table 19). Number of Heating Degree Days for a building location is considered directly proportional to the amount of energy invested for heating of the building. Hence, the percentage difference between Heating Degree Days of two winters was taken as a percentage increasing the heating load in case of the extreme winter. This is the percentage of 11.33% (Table 19), which will be applied to the overall heating loads of 11th and 12th of February.

Table 19. Percentage comparison of the Heating Degree Days between coldest/extreme day of Actual Weather 2016 and Standard Weather File

Minimum mean daily temp. in a year in °C (Standard Weather File)	Minimum mean daily temp. in a year in °C (Actual Weather 2016 File)	Corresponding Daily Heating Degree Days for the year's coldest/extreme day (Standard Weather File)	Corresponding Daily Heating Degree Days for the year's coldest/extreme day (Actual Weather 2016 File)	Percentage of difference of HDD for the year's coldest/extreme day between Standard Weather and Actual Weather File (%)
-14.85	-10.90	34.85	30.90	**11.33**

To the existing percentage of heating power used on 11th of February (Figure 155), the additional percentage of 11.33% is applied for all the daily intervals. Figure 156 is schematically explaining how the current system of load management would work. After the elevation of the load for 11.33%, the interval from 08:00 to 09:00 is facing the average load higher than 100%. In order to prevent the electricity blackout, the load balancing unit is intentionally shutting of the heating to some rooms which are not highest at the priority list for heating. The load needed to reach the temperature set point is merely transferred to the next interval, meaning that the room in question will be heated later and with certain time delay. Thus, the heating percentage in the interval between 09:00 and 10:00 is now getting increased for estimated 11.33% plus additional 5.06% leftover from the previous interval (Figure 156), and is getting in total 97.32% (Figure 157).

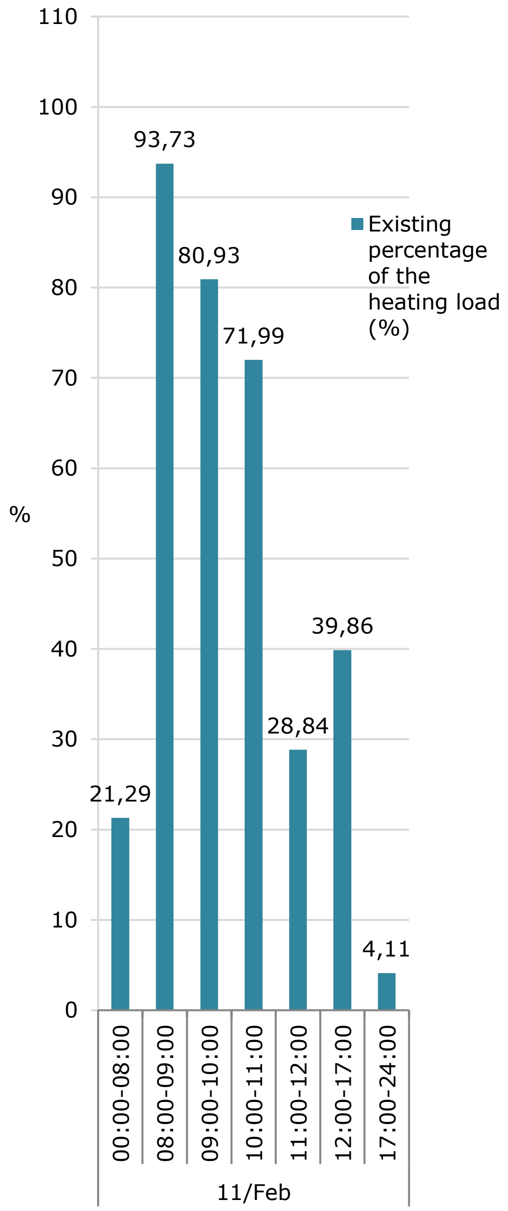


Figure 155. Existing percentage in year 2016 of the heating load from the Distribution board 1, NSHV 400 through daily intervals. Date: 11.02.2016.

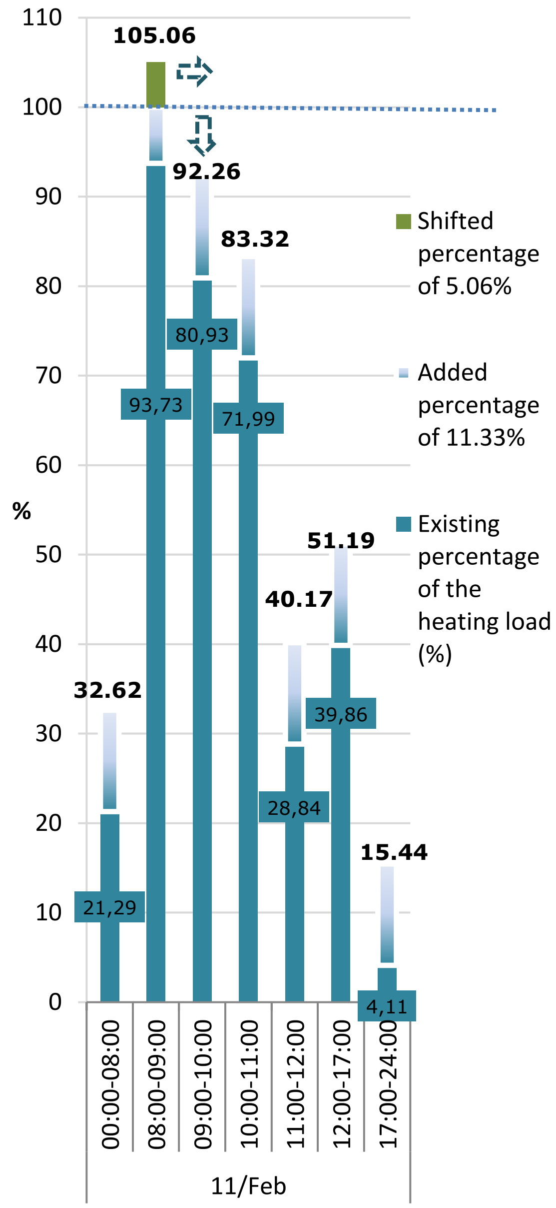


Figure 156. Increased existing percentage of the heating load through daily intervals for assumed 11.33% higher heating energy needed. Date: 11.02.2016.

The shifting of the load to the following interval for the period of one hour might be causing the certain drop of the temperature. In order to assess how big this drop is and if it affects the thermal comfort, the Figure 159 is presented. It represents the natural drop of the temperature in the Restaurant Area after the heating system is turned off after the operation hours. The biggest drop is happening in the first two hours, when the temperature falls for approximately 1.40 °C in the first hour and 0.60 °C in the second hour. Due to the good insulation of the building after the refurbishment and a strong thermal mass of the walls, the temperature drop slows down after the initial hours. Thus, if the heating operation is stopped for approximately two hours or more, it may be that the temperature is getting close to the uncomfortable 18 °C or less. This is a consequence of the load management approach applied currently as a system of load balancing. However, also in the theoretical extreme weather condition and an increased load of 11.33%, the delay in heating would be simply shifted to the following interval and would not last longer than one hour (Figure 157). This means that there would be no serious influences to the temperature drop and corresponding negative effects on the thermal comfort (Figure 159). Thus, the initial assumption of the issues related to the heating load and declining thermal comfort in extreme circumstances is not really valid. It might be stated that the heating system is well sized according to the building needs. This type of the load management is the easiest approach of simple load shifting which is not in any sense predictive or in reference to the outside temperature and can have as a theoretical consequence some intervals of the slight thermal discomfort. In Figure 158 is schematically represented an alternative to it.

The approach of predictive load shedding would work with preheating of the building during the night hours or early morning hours when loads are low. Instead of reaching the excessive load in the interval from 08:00 to 09:00, the building would be earlier preheated in accordance to the load predicted by the weather forecast. As building has a good thermal envelope to keep the heat, this method would prevent the uncomfortable drops of the indoor temperatures and the electricity peaks due to heating. This would, in final effect, also lower the electricity cost, as suggested in the chapter of Background.

Dynamic load balancing happens during the intervals with the highest heating loads, and this is represented in Figure 160 illustrating the initial 15 minutes of the interval from 08:00 o'clock. For almost the whole length of 15 minutes, the BMS was requesting 17 heaters in order to reach the determinate set point in the rooms, but, as may be seen, load balancing unit was allowing the maximum of 16 heaters to be turned on, in order to prevent reaching the peak load. This histogram represents in a descriptive way the operation of the Krippenstein's load management system in a short term interval, but also applies to the general long term load balancing.

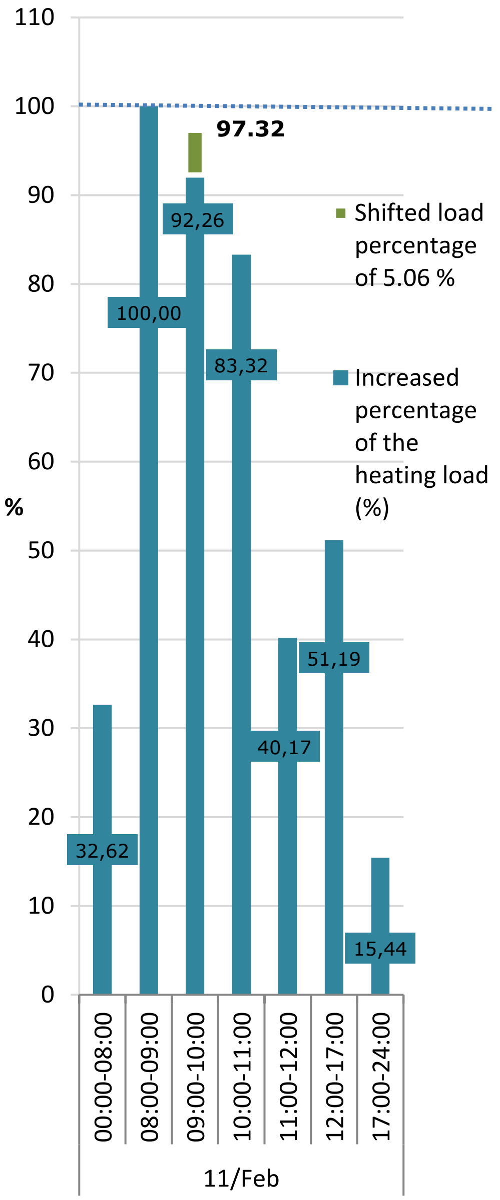


Figure 157. Increased existing percentage of the heating load after shifting the assumed additional 11.33% load from full load interval to the following one. Date: 11.02.2016.

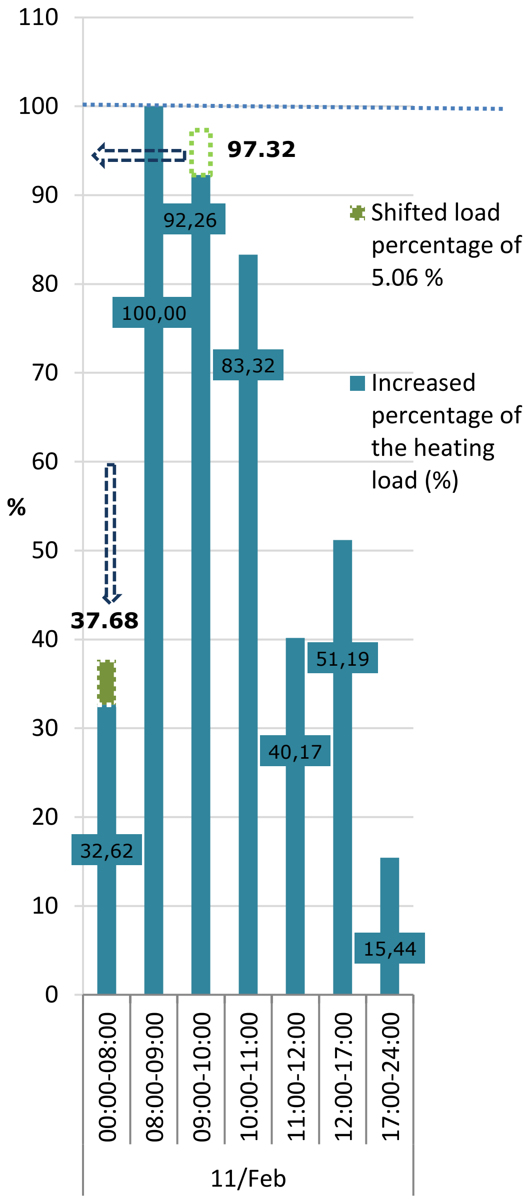


Figure 158. Increased existing percentage of the heating load with suggestion of shifting the assumed additional 11.33% load from full load interval to the previous one. Date: 11.02.2016.

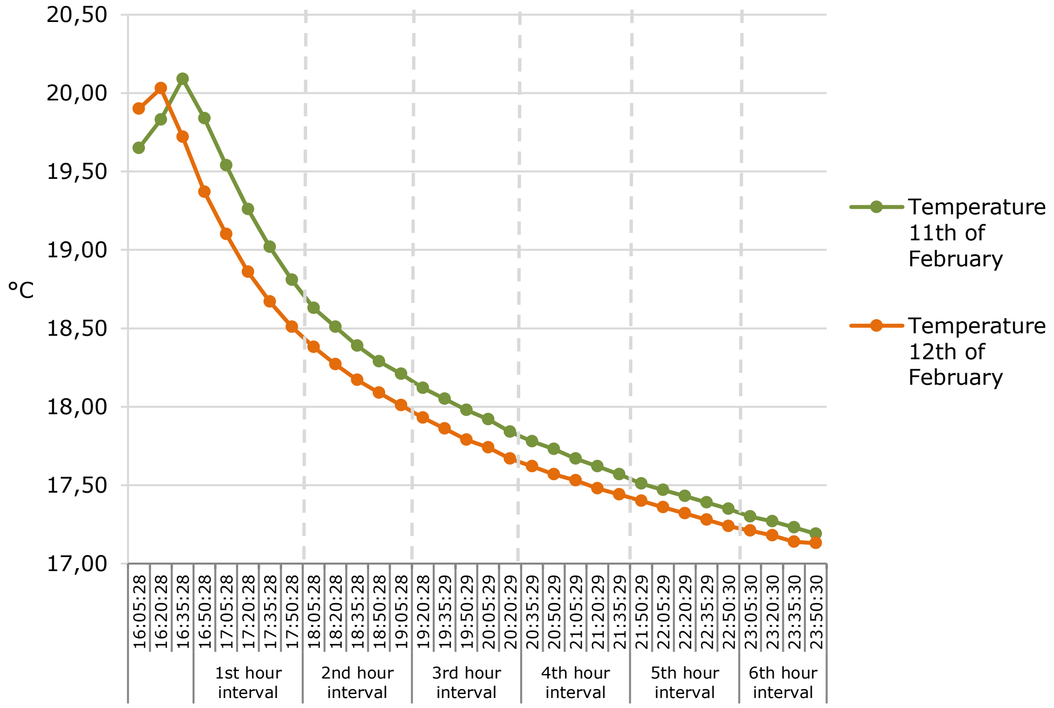


Figure 159. Trend of indoor temperature drop after turning off of the heating system at the Restaurant area for the days of 11th and 12th of February for the interval from 16:00-24:00 o'clock

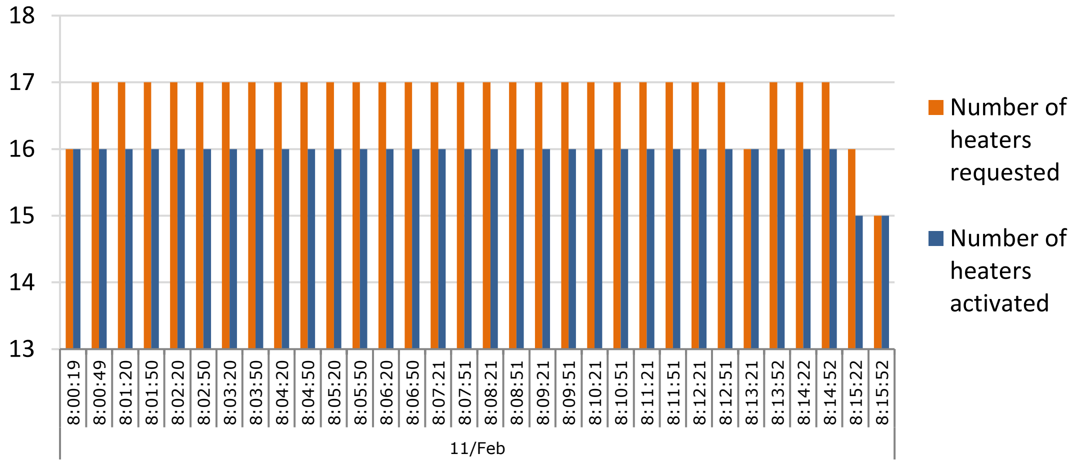


Figure 160. Number of heaters requested by BMS and corresponding number of heaters activated by load balancing unit from 08:00-08:15 o'clock. Date:11.02.2016

What was previously said for 11th of February, applies really well for 12th of February too, as a day with second highest loads within the chosen period. The existing loads presented in Figure 161, are increased for the additional 11.33% to simulate an extremely cold winter day from the historic weather data. In the current load management system, the load leftover of 3.29% outside the limit of

100% would be shifted from the peak interval to the following hour in order to prevent the electricity outage (Figure 162).

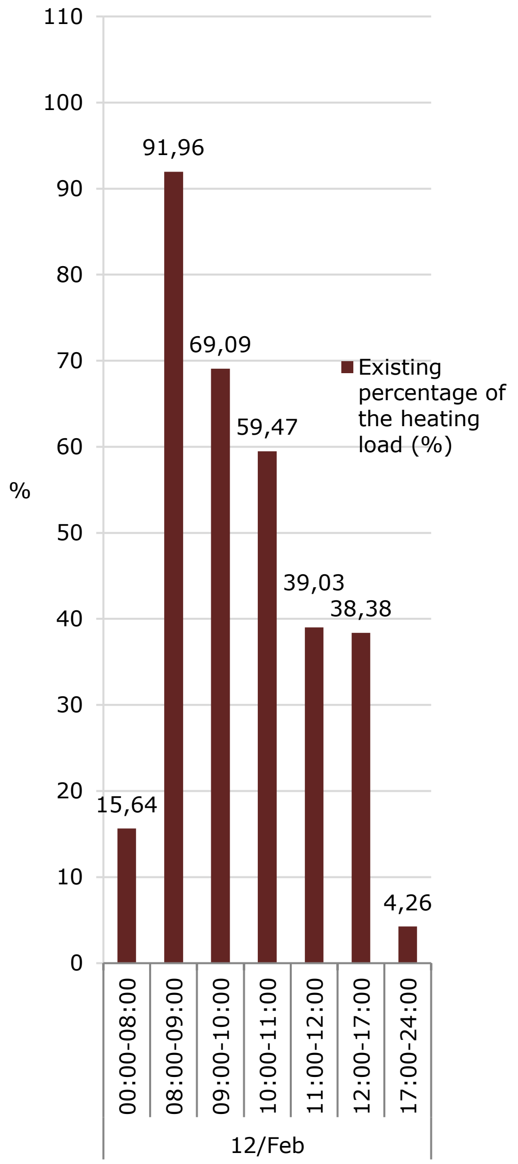


Figure 161. Existing percentage in year 2016 of the heating load from the Distribution board 1, NSHV 400 through daily intervals. Date: 12.02.2016.

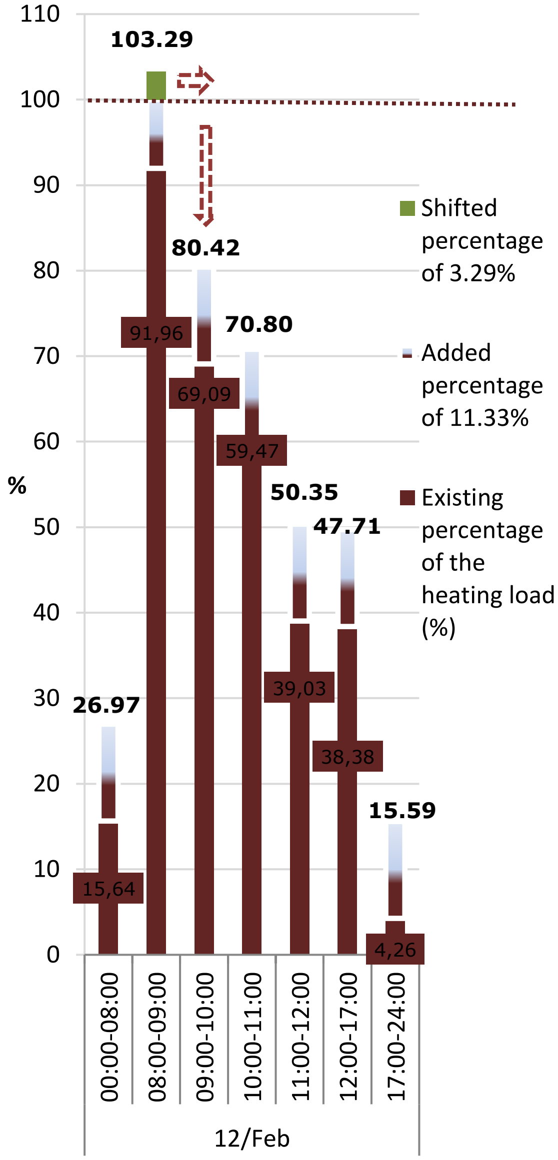


Figure 162. Increased existing percentage of the heating load through daily intervals for assumed 11.33% higher heating energy needed. Date: 12.02.2016.

As a consequence, high loads of 83.81% would be reached also in the interval from 09:00 to 10:00 (Figure 163). Also in this case, the formerly mentioned drop of temperature due to the turned off heaters (Figure 159) would not really affect the thermal comfort, as it would not last longer than one hour. Again, an alternative solution in the extreme scenarios would be the predictive approach with well planned preheating schedules when high loads are expected due to the low outside temperature (Figure 164).

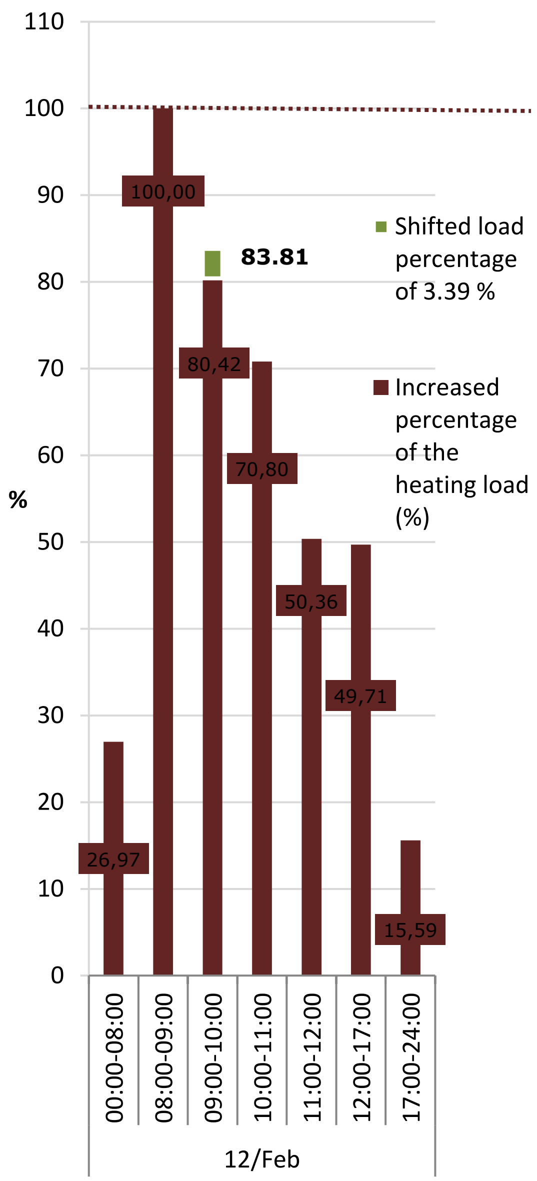


Figure 163. Increased existing percentage of the heating load after shifting the assumed additional 11.33% load from full load interval to the following one. Date: 12.02.2016.

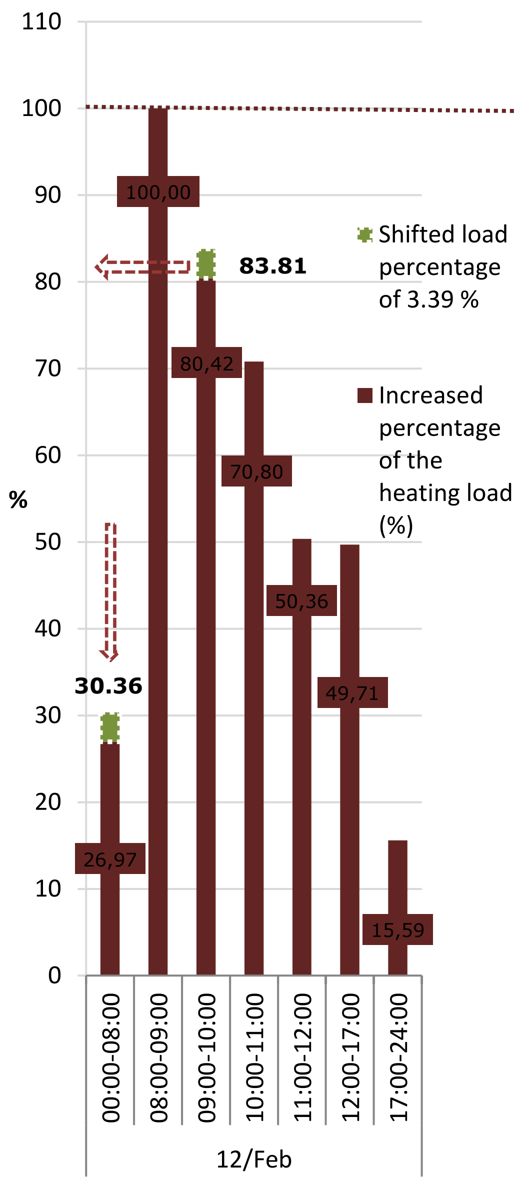


Figure 164. Increased existing percentage of the heating load with suggestion of shifting the assumed additional 11.33% load from full load interval to the previous one. Date: 12.02.2016.

The averaged loads represented in the graphs above do not fully show a constant load balancing happening with the high loads, but this may be seen from Figure 165. During the 15 minute interval represented in histogram, load balancing unit is very dynamically, with a minute time step, regulating the number of the heaters to keep the load under 100%. From the 16 requested heaters, 15 of them were regularly activated during this interval on 12th of February.

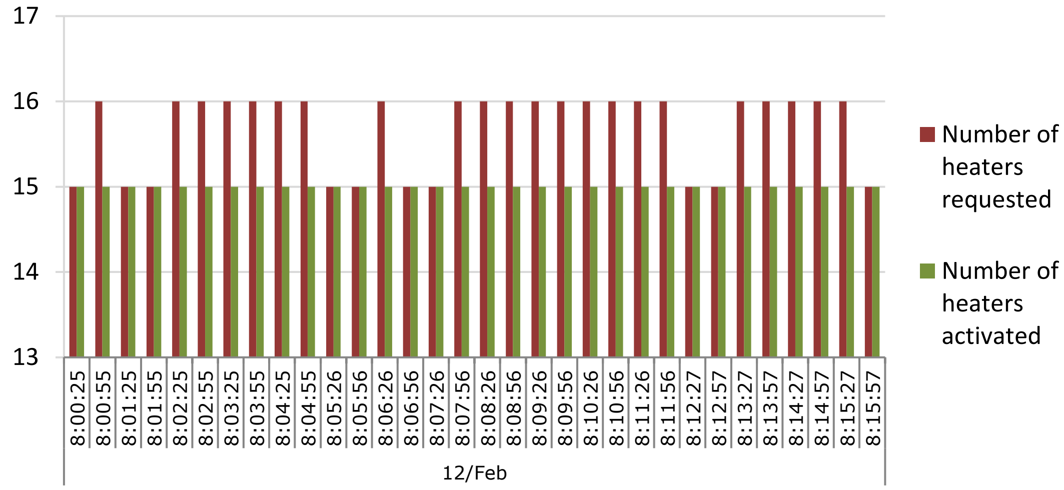


Figure 165. Number of heaters requested by BMS and corresponding number of heaters activated by load balancing unit from 08:00-08:15 o'clock. Date:12.02.2016

5 CONCLUSION

This study evaluated the performance of the retrofitted Krippenstein Mountain Station in the areas of thermal comfort, air quality and electrical load management. In case of the first two areas the recommendations from the standards (ISO 7730 and EN 13779) were fulfilled and adequate comfort levels were reached. The results for the electric load management system showed that the current electric heating system and load shedding approach could fulfil the building needs without negative effects on the thermal comfort.

It could be clearly stated that the building can provide satisfactory levels of the thermal comfort and that the new electrical heating system together with the improved building envelope fulfil the expectations. The regularly operated and conditioned Restaurant Area provided the conditions with good PMV and PPD values. Both general thermal comfort and local discomfort parameters showed values within the highest rated A and B categories of thermal environment according to ISO 7730. In addition, the results of the Seminar Room showed thermally comfortable conditions when the room was heated for events.

The indoor air quality evaluation is performed based on CO_2 measurement and EN 13779 categories of indoor air quality (IDA). Almost 100% of the CO_2 measurements fall into the best indoor air quality category (IDA 1).

Finally, the last part of the research provided an insight into the electrical load management and heating system performance. The two coldest days of the observed period, 11^{th} and 12^{th} of February of 2016, when the highest heating loads are measured, show no weaknesses in the load management approach. That is, thermal comfort is fully reached even in the coldest days by the heating system operation. Moreover, even when an increased load is introduced in the calculations for the extreme weather conditions, the current load management system still provides acceptable thermal comfort. This is illustrating the good performance of the heating system and that the assigned maximum electrical loads are not causing any problematic issues in real operation. However, it might be given a suggestion for the slightly modified load balancing approach, as a potentially more efficient alternative to the existing one. The predictive load management would work on the reconfiguration of the load schedules in advance by preheating in the intervals of the low heating loads, in correspondence to predicted weather related factors. This approach would bring the benefits of reduced peak loads and could also influence the final costs of the electricity used for heating.

6 INDEX

6.1 List of Figures

6.2 List of Tables

6.3 List of Equations

7 LITERATURE

ASHRAE, 2013. ANSI/ASHRAE Standard 55 *Thermal Environmental Conditions for Human Occupancy.*

CEN, 2006. *EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings-addressing indoor air quality, thermal environement, lighting and acoustics.*

CEN, 2007. *EN 13779 Ventilation for non residential buildings- Performance requirements for ventilation and room-conditioning systems.*

Cheng,Y., Gao, N., Niu, J., 2011. *Thermal comfort models: A review and nummerical investigation.* Building and Environment 47, pp. 13-22.

Dachstein Salzkammergut, 2016. Annal. 2016. *http://www.dachstein-salzkammergut.com/winter/dachstein-krippenstein/dachstein-krippenstein/*.

De Gids, W.F., Wouters, P., 2010. *VIP 33: CO_2 as indicator for the indoor air quality-General principles.* AIVC VIP 33, pp. 1-4.

Djongyang, N., Tchinda R., Njomo D., 2010. *Thermal comfort: A review paper.* Renewable and Sustainable Energy Reviews 14, pp. 2626-2640.

EASME, 2016. Annal 2016. *https://ec.europa.eu/easme/sites/easme-site/files/practical_approaches_to_the_buildings_renov_challenge.pdf.*

Fanger, P.O., 1970., *Thermal Comfort : analysis and applications in environmental engineering.* Copenhagen: Danish Technical Press.

Feuerriegel, S., Neumann, D., 2016. *Integration scenarios of Demand Response into electricity markets: Load shifting, financial savings and policy implications.* Energy Policy 96, pp. 231–240.

Google Maps, 2016. Annal 2016. *https://www.google.at/maps*.

Hauer I., Wolter M., Stötzer M., Richter M., Styczynski Z.A., 2015. *A probabilistic load shedding concept considering highly volatile local generation.* Electrical Power and Energy Systems 67, pp. 478–487.

Hensen, J.L.M., 1991. *On the thermal interaction of building structure and heating and ventilation system.* PhD dissertation: Eindhoven University of Technology.

ISO, 2005. ISO 7730 *Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.*

Kim, K., Nam, H., Cho, Y., 2014. *Estimation of the inconvenience cost of a rolling blackout in the residential sector: The case of South Korea.* Energy Policy 76, pp. 76–86.

Maqbool, S.D., Ahamed, T.I., Al-Ammar, E., Malik, N.H., 2011. *Demand response in Saudi Arabia.* In: Proceedings of the 2nd International Conference, Electric Power and Energy Conversion Systems (EPECS 2011), pp. 15-17 November, 2011, UAE.

Mein Bezirk, 2015. Annal 2015. *http://www.meinbezirk.at/salzkammergut/ wirtschaft/ zweihoechstes-restaurant-in-ooe-wird-am-krippenstein wiedereroeffnet-d1247922.html.*

Oliviera, C.A.,Orosa J.A., 2010. *A new thermal comfort approach comparing adaptive and PMV models.* Renewable Energy 36, pp. 951-956.

Parsons, K.C., Olesen, B.W., 2002. *Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730.* Energy and Buildings 34, pp. 537-548.

Rozali, N.E.M., Wan Alwi, S.R., Manan, Z.A., Klemes, J.J., 2015. *Peak-off-peak load shifting for hybrid power systems based on Power Pinch Analysis.* Energy 90, pp. 128-136.

Tourismusverband Inneres Salzkammergut, 2015. Annal 2015. *http://dachstein.salzkammergut.at/uploads/tx_ooeneucat/GVZ-komplett-2015-17_01.pdf*.

Zdraveski, V., Todorovski, M., Kocarev, L., 2015. *Dynamic intelligent load balancing in power distribution networks.* Electrical Power and Energy Systems 73, pp. 157–162.