MASTERARBEIT

MONITORING AND EVALUATION OF A PROTOTYPE BUILDING IN TROPICAL CLIMATE REGARDING THERMAL COMFORT

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ABSTRACT

A large percentage of the energy consumption occurs in the building sector, especially for heating and cooling. According to the overall goal to decrease the cooling demand in tropical climate, a radical new approach for sustainable architecture is being realized in the Philippines on Palawan near Puerto Princesa City within the EU switchasia project Zero Carbon Resorts (ZCR). This prototype building combines vernacular building elements and indigenous materials with a contemporary architecture and up to date technologies for zero energy buildings. But for a further distribution the functionality of the concept has to be proven and that thermal comfort in a resort cottage made of local renewable resources in tropical climate can be achieved due to design features and natural ventilation without the use of air conditioning units.

Within this work a comprehensive monitoring of the local outdoor climate and the indoor environment was carried out, subdivided in a long time monitoring with special focus on the air temperature and the relative humidity and a short time monitoring using the PMV/PPD method for the evaluation of thermal comfort at selected positions.

In a first step the indoor conditions of each room were compared with the local outdoor climate, showing that the correlation is dependent on the design of the building, the position of the rooms and the different implemented passive cooling strategies, while also distinctions between different types of sensors and their varying positions within each room were explored. In the second part the PMV/PPD method, based on the standards of ASHRAE and DIN EN ISO 7730, was adapted for the evaluation of thermal comfort in natural ventilated buildings. In addition, the measured values were then also applied to modified psychrometric charts for the use in tropical climate.

The results are showing that, considering the circumstances of this extreme hot and humid climate at the project location, acceptable indoor conditions can be achieved by the implemented design features of this sustainable building.

Keywords

Indoor climate, Measurement, PMV/PPD, Philippines, Sustainable building

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CONTENTS

1 INTRODUCTION

1.1 Overview

According to the overall objective of the EU switchasia project Zero Carbon Resorts (ZCR) a radical new approach for sustainable architecture is being realized in the Philippines on Palawan near Puerto Princesa City, in order to meet modern comfort demands and high user expectations with the lowest possible environmental footprint (Wimmer et al, 2014). This prototype building combines vernacular architecture elements and indigenous materials with a contemporary architecture and up to date technologies for zero energy buildings.

Within this work a comprehensive monitoring of the indoor environment and the local outdoor climate was carried out to state that thermal comfort in tropical climate can be achieved by this new design approach.

In the first chapter the motivation and the background information, especially regarding the standards for thermal comfort and the necessary adaptions for measurements in tropical climate, are provided, while chapter 2 is describing the applied methods to achieve the objective of this thesis. Additional to the hypothesis, the project site is delineated and the monitoring system described in detail, subdivided in the categories outdoor climate - monitoring, indoor climate - long-time monitoring and thermal comfort - short-time monitoring. In chapter 3 the results of the accomplished monitoring are presented. Starting with the outdoor climate and a comparison for each room with focus on the air temperature and the relative humidity, the results for the thermal comfort with PMV/PPD are displayed in the second part in addition with the application of a psychrometric chart for tropical climates.

1.2 Motivation

A relatively large percentage of energy and resource consumption occurs in the building sector (Directive 2010/31/EU). This concerns the production of building materials, the construction of buildings and also the energy consumption during the use phase caused by the users. Energy for space heating and increasingly for space cooling is needed especially for buildings of low energetic standards.

While extensive research has been carried out in recent years about passive house design in cold climates, and the heating demand can now be reduced strikingly, far less was done or is documented and available for tropical climates. In contrary building models of developing countries are being widely adopted with little regard to tropical climate, but because of reasons as status symbols. The results are predictable, enclosed buildings with glass windows that results in very high indoor temperatures in summer (Mahdavi et al., 1996). To counteract this, air conditioning units are required to make this glass box comfortable, which then again increase dramatically the energy consumption.

New appropriate design concepts for tropical climates are therefore required and have to be proven as functional to decrease the energy demand for cooling in the long view.

1.3 Background

The thermal comfort equation invented by P.O. Fanger (Fanger, 1970), which combines the effects of the parameters metabolic rate, clothing value, air temperature, mean radiant temperature, air velocity and relative humidity, was used as basis for the monitoring and analysis of this prototype building in agreement with the definitions of the ASHRAE Handbook (ASHRAE, 2005) and the DIN EN ISO 7730 standard (DIN EN ISO 7730, 2006; DIN EN ISO 7730-1, 2007).

1.3.1 Thermal comfort

The standards of the ASHRAE Handbook as well of DIN EN ISO 7730 are describing the relation between the human sensation of heat and the degree of uncomfortableness with the ambient conditions. Through which an analytical evaluation and interpretation of thermal comfort is possible, by use of the calculation of PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) along with the criteria of the local surrounding.

The calculation is based on the thermal interaction of the human body with its environment (see Figure 1) and the human ability of thermoregulation.

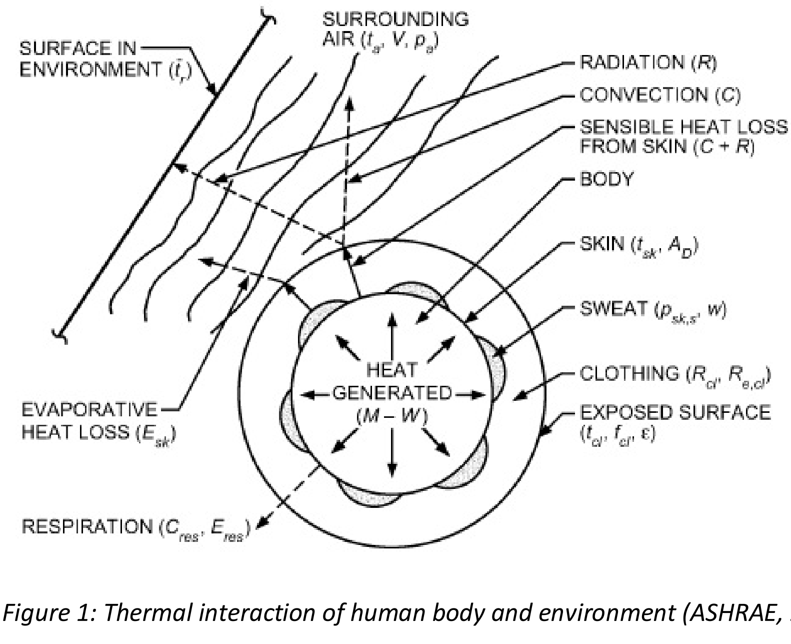

Figure 1: Thermal interaction of human body and environment (ASHRAE, 2005)

Depending on the internal body temperature and the condition of the surrounding the human body automatically starts to regulate the body temperature to its set point.

An important influencing factor therefore is the metabolic rate, the generated internal heat depending on the activity of the body. This is in general resulting in overheating and therefore sweating occurs to cool down the body temperature. But in the case of a too low body temperature this can also result in shivering to heat up the body. Thus, the set point for the regulation is not fixed, for example through repeated intermittent exposure to heat the set point for the activation of the sweating system can be increased. This should therefore be taken into account for the analysis in hot climates.

The sensation of the human body can therefore be also different. In case of the contact with a medium of a constant temperature, the person can feel pleasant or not depending if the person´s body is overheated or cooled.

This thermal interaction between the human body and the environment can be expressed with the energy balance:

$$M - W = q_{sk} + q_{res} + S = (C + R + E_{sk}) + (C_{res} + E_{res}) + (S_{sk} + S_{cr}) \quad (1)$$

M = rate of metabolic heat production, W/m2
W = rate of mechanical work accomplished, W/m2
qsk = total rate of heat loss from skin, W/m2
qres = total rate of heat loss through respiration, W/m2
C + R = sensible heat loss from skin, W/m2
Esk = total rate of evaporative heat loss from skin, W/m2
Cres = rate of convective heat loss from respiration, W/m2
Eres = rate of evaporative heat loss from respiration, W/m2
Ssk = rate of heat storage in skin compartment, W/m2
Scr = rate of heat storage in core compartment, W/m2
(ASHRAE, 2005; Fanger, 1970)

Local discomfort

Thermal comfort or actual thermal discomfort can also be a matter of unwanted heating or cooling of the human body by the local surrounding, even if the room climate is within the target comfort zone for thermally neutral sensation. Like a person who feels in general thermally neutral, but because of a non-uniform cause like a too strong and cold breeze of an open window or a hot plate in the room, which influences maybe only a part of the body, the person feels still uncomfortable. The most frequent factors therefore are asymmetric radiation of hot and cold surfaces, draft, vertical air temperature difference and warm or cold floors.

Asymmetric radiation

Asymmetric or non-uniform radiation in a space can result in discomfort. The main reasons for this effect are walls without insulation, cold windows, insufficient installed heating panels on the wall and hot or cold appliances within the room. But in resident buildings as well as in offices it was observed that especially cold windows and improperly installed heating panels in the ceiling are the most common causes for asymmetric radiation. Especially warm ceilings and cold walls are sensed as very unpleasant.

Vertical air temperature difference

A high vertical air temperature difference between the head and the ankle can also lead to a reduced thermal comfort. Since in most buildings the air temperature normally increases with the height, warm discomfort in the area of the head and cold discomfort around the ankles can arise. Decaying temperatures are in contrary less recognized and a greater difference is tolerated.

Draft

Draft is in an unwanted cooling of the human body by air movement, and if sensed a higher air temperature is in general requested, because of heat loss by convection. There is no minimum air velocity required to reach the comfort zone, but according to DIN EN ISO 7730 a higher air velocity can be used to compensate the thermal sensation of a higher temperature. The temperature set point can therefore be above the actual legitimate 26 °C to achieve thermal comfort, assumed the air velocity can be increased. Additionally it was also discovered by Fanger that the turbulence intensity is affecting the draft sensation. Due to decreased turbulence intensity, the air velocity can be increased to cause the same effect.

Floor temperatures

Independent of the effect on the mean radiant temperature of a room a floor can also create a local discomfort, if its temperature is too high or too low. The biggest influencing factor, if not an active heating or cooling is installed in the floor, is of course the construction of the building itself like the position of the room, which can be above a basement or another room, with contact to the earth or alternatively the structure of the building element. For people with normal indoor footwear the optimum temperature was observed at 25 °C for conditioned buildings in moderate climate, but for locations, where people are bare feet, the material of the floor is important as well. For wooden floors and similar a temperature range with a higher upper temperature limit was discovered.

It is obvious that thermal comfort cannot be defined by the temperature alone, as it is widely managed in the region of the surveyed building through the digital control display of AC-units. In fact it is actually influenced by a number of factors and of course it is also a subjective sensation. But it is possible to predict the thermal comfort of an indoor climate with the PMV and PPD invented by Fanger.

PMV

The PMV (Predicted Mean Vote) itself is actually an index for the evaluation of thermal comfort for a group of people in the same climate on a 7 point scale (see Table 1) on the base of the energy balance.

Table 1: Thermal sensation scale

+ 3	hot
+ 2	warm
+ 1	slightly warm
0	neutral
- 1	slightly cool
- 2	cool
- 3	cold

The PMV is applicable for combinations with different a metabolic rate, clothing factor, air temperature, air velocity, mean radiant temperature and air humidity, while t_{cl} and h_c can be solved iterative.

PPD

The PPD (Predicted Percentage of Dissatisfied) is in contrary a quantitative evaluation about the number of dissatisfied persons in percentage of the analyzed climate according to the thermal sensation scale and can be determined after the calculation of the PMV.

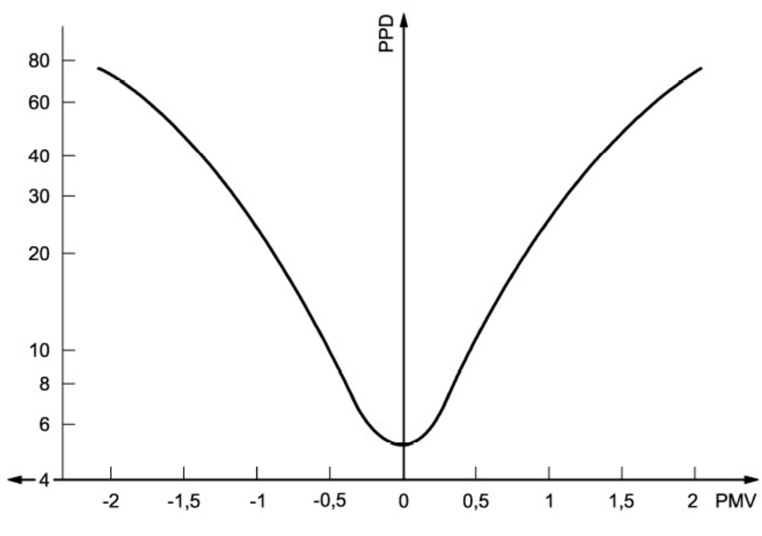

Figure 2: PPD as function of PMV (DIN EN ISO 7730, 2006, Fanger, 1970)

1.3.2 Thermal comfort for natural ventilated buildings in tropical climate

Reduced metabolic rate

Since the PMV model was first hand developed and validated for buildings with HVAC systems in cold, temperate and warm climates, and persons, which are you used to live and work in hot climates, can also adopt easier a higher work performance in warm surroundings than persons, which are used to cooler climates, according to Fanger (Fanger et al., 2002) an adaption of the model for the application in hot climates, and especially for natural ventilated buildings, is necessary.

This was also verified by the use of field studies, which are showing that for these conditions a higher thermal sensation was predicted than actually sensed by the buildings´s occupants. The cause for this is that people unconsciously tend to slow down their activity in hot surroundings. To compensate this effect a reduced metabolic rate by 6.7 % per unit of the thermal sensation scale, if higher than neutral, should be used for the calculation of the PMV.

Expectancy factor *e*

Additional to the observation that people, depending on the type of building in which they are living or working most time of the year, air-conditioned or naturally ventilated, have a different expectation regarding the homogeneity of cool indoor temperatures. In cases when the condition is deviating from thermal comfort, this is then sensed much more critical by persons used to air-conditioned spaces than by persons used to naturally ventilated buildings, in which, because of building openings, the local daily and seasonal conditions of the outdoor climate are much more reflected. As a result, their tolerance is covering a wider range of temperatures than accepted for conditioned spaces (De Dear et al., 2002).

This effect on the thermal sensation can be expressed with the expectancy factor *e* (Fanger et al., 2002), which has to be multiplied with the calculated PMV for adapting the thermal comfort calculation to naturally ventilated buildings in hot climates.

The expectancy factor *e* itself is estimated by two parameters, the duration of the hot period over the year and the comparability of naturally ventilated buildings with the amount of air-conditioned buildings in the target area.

Table 2: Expectancy factors

Warm periods	**Expectancy factor *e* category**	**Location**	**Subdivision of the category**
Occurring briefly during the summer season	0.9-1.0	In regions where air-conditioned buildings are common	upper value
Summer season	0.7-0.9	In regions with some air-conditioned buildings	medium value
All seasons	0.5-0.7	In regions with few air-conditioned buildings	lower value

As shown in Table 2 the *e* factor can be in the range between a minimum 0.5 and a maximum 1 for air-conditioned buildings in moderate climate. As an effect of the adaption also a higher upper temperature limit is adjusted with $e < 1$.

2 METHOD

2.1 Overview

This chapter is describing the methods applied to achieve the objective of this thesis. Therefore the hypothesis was defined to clarify the purpose of this project work (chapter 2.2) and the design of the building object as well as its location and climate is delineated (chapter 2.3).

In the second part of this chapter the monitoring system is described in detail, subdivided in the categories outdoor climate-monitoring (chapter 2.4), indoor climate-long time monitoring (chapter 2.5) and thermal comfort-short time monitoring (chapter 2.6).

In total the monitoring system of this building consists of one weather station for the data record of 6 different parameters of the outdoor climate, 2 different types of permanent installed sensors at 11 different positions for measuring the air temperature and the relative humidity as well as a mobile measurement kit for the evaluation of the thermal comfort. The general monitoring period of this work is for the outdoor climate and the long time monitoring of the indoor climate from the beginning of April to mid-June, while the short time monitoring was conducted on selected days between mid-May and mid-June.

2.2 Hypothesis

Thermal comfort in a resort cottage made of local renewable resources in tropical climate can be achieved due to design features and natural ventilation without the use of air conditioning units.

2.3 Zero Carbon Resort Cottage

The overall objective of this prototype building is to demonstrate an innovative building concept that significantly reduces CO_2 emissions over the whole life cycle with a minimum of grey energy. Therefore, this building was designed by combining vernacular building materials and skills with modern architecture based on an analysis of traditional buildings and a number of passive cooling principles to achieve an optimal performance of the building.

Figure 3: Prototype building

2.3.1 Location and climate

The Zero Carbon Resort Cottage is located in Irawan, an outer district of Puerto Princesa on Palawan, in the south west of the Philippines. The exact coordinates of the building are latitude at 9.787070°, longitude at 118.678940° and an altitude of 26 m.

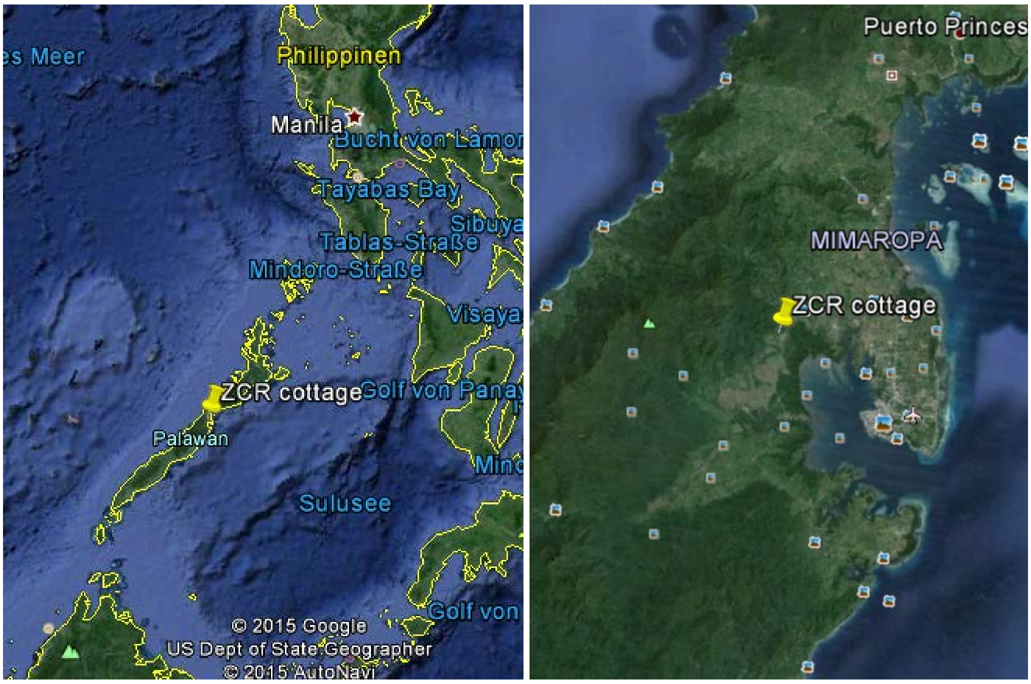

Figure 4: Location of the Zero Carbon Resort Cottage (google earth)

With average monthly air temperatures between 27.2 and 28.8 °C (see Figure 5) and average monthly rel. humidities between 77 to 84 % Puerto Princesa has a tropical climate with a dry and a wet season.

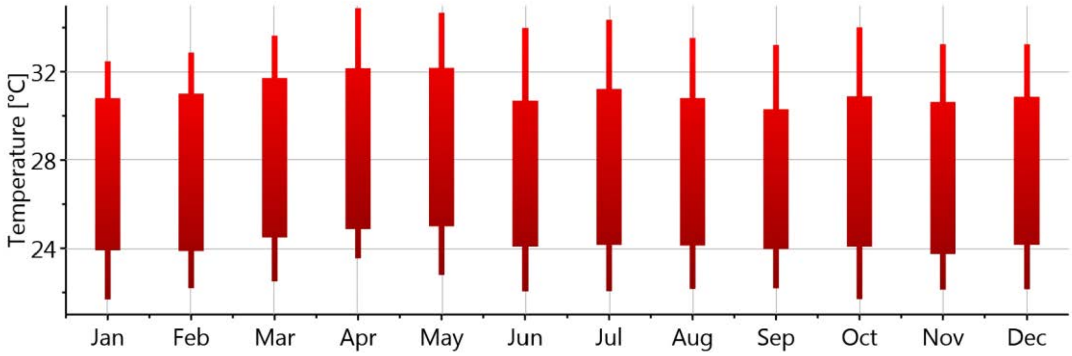

Figure 5: Average monthly temperatures for Puerto Princesa (Meteonorm, 2015)

According to the map of world climates by Rudloff (Rudloff, 1981), Palawan itself is categorized as Aw, which means tropical summer rain. The dry season in Puerto Princesa and Palawan is starting in November and ending in June, while the wet season is then starting at the end of June and lasting till October. The precipitation can then easily differ from less than 50 mm in average to beyond than 200 mm. But with the shift of the seasons also the wind direction is changing from northeast in the dry season to south west in the wet season.

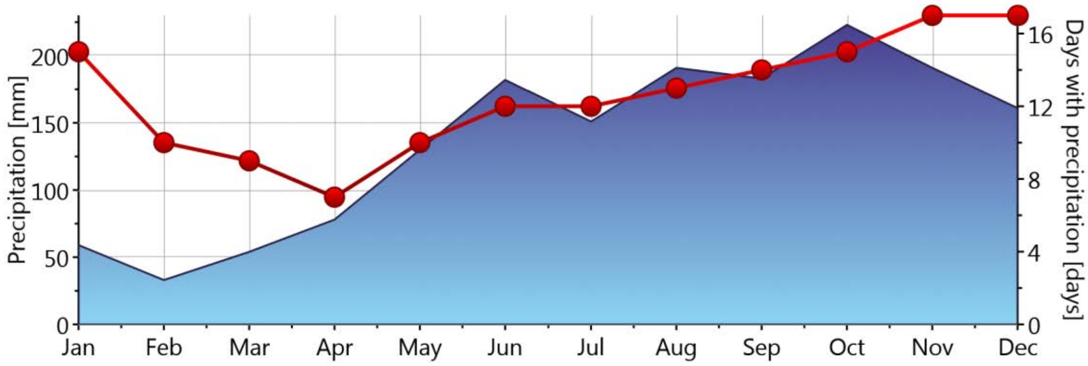

Figure 6: Average precipitation for Puerto Princesa (Meteonorm, 2015)

The complete climate data of the Meteonorm database for Puerto Princesa is displayed in the appendix Meteonorm climate date.

2.3.2 Design strategies

The cottage itself is a lightweight construction with a total functional area of 114.42 m². As main construction material locally available bamboo is used in different forms and applications, but also other traditional building materials like rattan or anahaw leaves in combination with bamboo split shingles for the butterfly shaped roof. In fact, several key innovations based on the passive cooling principles were implemented together with an off-grid energy system using photovoltaic panels and a solar water heater, tubular solar lighting devices, an indirect solar cooker as well as a rain water collection and waste water treatment system.

One passive cooling principle is of course the shading. As you can see in Figure 3, the building was designed with an overhanging roof to all directions as protection against overheating by direct solar radiation through transparent surfaces.

A second implemented principle is the natural ventilation. Operable openings like windows, slats or doors were installed at several strategic positions on all sides of the building to control the air flow. Therefore also the orientation of the building is important, not only because of the suns course, but also because of the changing wind direction in dry and wet season (see chapter 2.3.1). Big building openings are needed at the east side in the dry season, when the wind is coming from north east, while shutters are more appropriate at the southwest corner of the building. A detailed list of all operable building openings is provided in chapter 2.6.6 Influencing parameters.

Figure 7: Shutters at the southwest corner; big openings at the building´s east side

Additional to that, the cottage was constructed on stilts, which is another important design feature. With the entire building area raised from the ground, perfect conditions for natural ventilation are given. Therefore point foundations were used, which can be connected to the bamboo sticks of the support structure due to special steel joints (Figure 8, left). Whereby a ventilated floor plate made of renewable resources could have been used. To maximize the effect, the floor plate was designed with several ventilation slots at selected positions along the centre wall and the exterior walls of the main room and the bedroom. Figure 8 is showing a thermographic photo of the ventilation slots in the evening after sunset, when cooler outdoor air is flowing in the building.

Figure 8: Point foundations with steel joints; thermographic photo of ventilation slots

Another benefit of this foundation is that the amount of concrete was drastically minimized compared to a conventional baseplate, same as the sealed surface of the building site, which is good for the microclimate.

Another passive cooling principle used for the building design is the use of thermal mass. In this case in the shape of a massive rammed earth wall in the centre of the building. Its properties allow acting as temperature controller especially for the peak temperatures during the day.

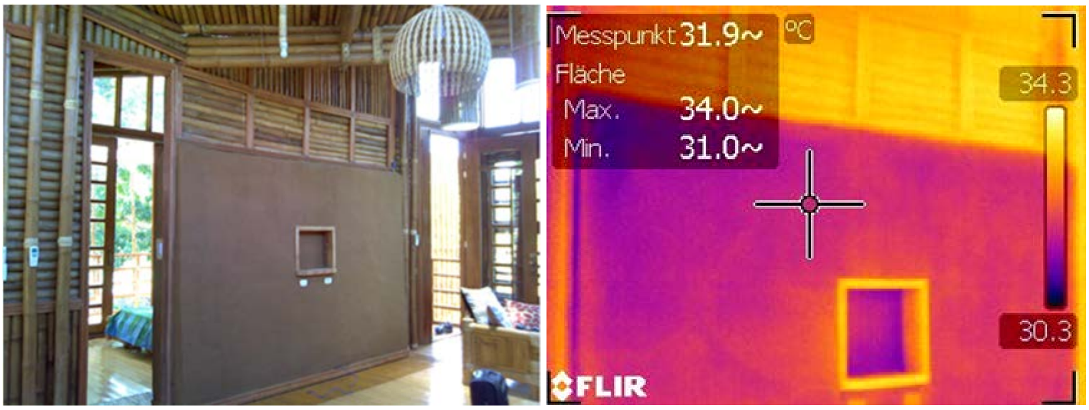

Figure 9: Centre wall as thermal mass; thermographic photo showing lower peak temperatures

The ventilation slots situated in front of the centre wall are supporting to cool down the thermal mass at night, but also the wind direction was considered. Newly installed breezeways with creeping plants should channel the cool air into the building and maximize the effect. These breezeways are located at the northeast and southwest corner according to the main wind directions to have a cooling influence all year around.

A last principle to mention is the design of the roof. It is a layered structure with anahaw leaves, which is a common round-leaf palm, a laminated aluminum foil for reflecting the solar radiation and tadtad split shingles on top. This combination minimizes the surface temperature of the ceiling drastically and increases therefore the thermal comfort inside the building.

Figure 10: New roof design using modern and vernacular building materials

2.4 Outdoor climate – monitoring

For the monitoring of the local climate and in further consequence for the comparison of the outdoor climate with the indoor climate to evaluate the effectiveness of the implemented design strategies a weather station was set up on the roof of the building.

2.4.1 Type and position of the weather station

A weather station from Aeron (Aeron, 2013) is used, which has integrated sensors from Davis Instruments for measuring all important climate data including air temperature (thermistor, -40 to 65 °C), rel. humidity (film capacitor element, 1 to 100 %), wind direction (wind vane and potentiometer, 0° to 360°) and wind speed (solid state magnetic sensor, 3 to 282 km/h), the amount of rain (tipping bucket) as well as the global radiation, the sum of both direct and diffuse components of solar irradiance (solar pyranometer). The weather station is powered by a 5W PV solar panel and has integrated batteries for energy storage.

Figure 11: Weather station on the roof of the building

2.4.2 Collection of data

All sensors of the weather station are collecting data synchronized with an interval of 10 minutes, which is then stored on a mini SD-card on-site. A manual readout of the data is possible for example via CVS export in excel.

For future monitoring and a more simple readout out the weather station should be connected to the monitoring server (see chapter 2.5.3), which is possible via a direct rs232 connection or through log-in to a remote Aeron server via GPRS internet connection.

2.5 Indoor climate – long time monitoring

A first approach to analyse the thermal comfort of the building´s indoor climate is done with 2 different sets of permanent installed sensors for measuring the temperature and the relative humidity of the air. Whereby possible incidents of local discomfort according to ASHRAE and DIN EN ISO 7730 should be detected as well as a correlation between the indoor and outdoor conditions, by using also the data of the weather station, should be specified. The types and positions of the sensors for measuring the indoor condition of the building are described in detail in the following subchapters.

2.5.1 Temperature and relative humidity – SHT75

Type of sensor

The Sensirion SHT75 sensor (Sensirion, 2008) is a combined humidity (0 to 100 %) and temperature (-40 to 123.8 °C) sensor with a high long term accuracy of ±3 % for the rel. humidity and ±0.4 °C for the temperature with a digital interface. While a capacitive sensor element is used for the rel. humidity a band-gab sensor measures the temperature.

Additional also the temperatures for the dew point can be displayed out. These are not directly measured, but derived from the air temperature and rel. humidity values. Calculations are possible for temperature between -40 and 50 °C.

Figure 12: Sensirion SHT75 sensor mounted on the wall

Position of sensors

The sensors are installed in all 3 rooms. They are positioned in the main room at the north wall to the bathroom (HS2) and under the ceiling (HS4), in the bedroom at the west wall to the bathroom (HS3) and in the bathroom at the north wall to outside (HS1) as shown in Figure 13. At the positions HS1, HS2 and HS3 always 2 sensors were installed, one in a height of 10 cm above the floor (in the area of the ankle) and one in a height of 160 cm above the floor (in the area of the head) to measure not only the air temperature and the rel. humidity in the room, but also to analyze the vertical air temperature difference within the rooms. Although the sensors were not at all positions installed with an enclosed white box, there was no perceptible effect on the sensors by solar radiation.

Table 3: List of Sensirion SHT75

Sensor	Controller	Location	Position	Parameter
HS1_1	C1	Bathroom	10 cm above floor; north wall to outside; 12 cm to corner	Temperature Humidity Dew point
HS1_2	C1	Bathroom	160 cm above floor; north wall to outside; 12 cm to corner	Temperature Humidity Dew point
HS2_1	C3	Main room	10 cm above floor; north wall to bathroom; 10 cm to corner	Temperature Humidity Dew point
HS2_2	C3	Main room	160 cm above floor; north wall to bathroom; 10 cm to corner	Temperature Humidity Dew point
HS3_1	C4	Bedroom	10 cm above floor; west wall to bathroom; 20 cm to end of block wall	Temperature Humidity Dew point
HS3_2	C4	Bedroom	160 cm above floor; west wall to bathroom; 20 cm to end of block wall	Temperature Humidity Dew point
HS4	C4	Main room	410 cm above floor; under ceiling; 40 cm northwest of the fan	Temperature Humidity Dew point

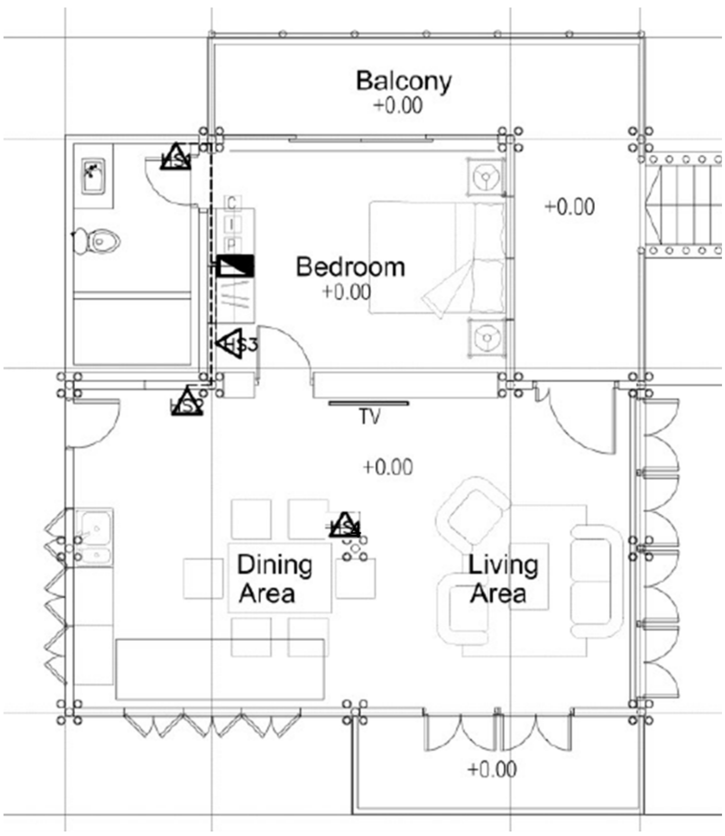

Figure 13: Positions of SHT75 sensors in the building

2.5.2 Temperature and relative humidity – AM2303

Type of sensor

Additional to the SHT75 sensors 4 wireless AM2303 sensors by Aosong (Guangzhou) Electronics Co. were installed, which are measuring the rel. humidity (0 to 100 %) with a polymer humidity capacitor element and the temperature (-40 to 125 °C) using a DT18B20 element for detection with a digital output (Aosong). The accuracy for this sensor is ±5 % for the rel. humidity and ±0.2 °C for the temperature.

Figure 14: AM2303 temperature and rel. humidity sensors

Position of sensors

The wirless AM2303 sensors for measuring the air temperature and rel. humidity were placed in all 3 rooms, in the bathroom at the east wall to the bedroom (RA1), in the bedroom at the west wall to the bathroom (RA2) and in the main room under the ceiling (RA3) and in front of the rammed earth wall (RA4). The sensors were placed at different heights between 120 to 200 cm and under the ceiling (see Table 4 and Figure 15).

Table 4: List of AM2303

Sensor	Controller	Location	Position	Parameter
RA1	-	Bathroom	200 cm above floor; east wall to bedroom; 45 cm to door	Temperature Humidity
RA2	-	Bedroom	140 cm above floor; west wall to bathroom; 5 cm to end of block wall	Temperature Humidity
RA3	-	Main room	380 cm above floor; under ceiling; 40 cm south to door	Temperature Humidity
RA4	-	Main room	120 cm above floor; centre of clay wall	Temperature Humidity

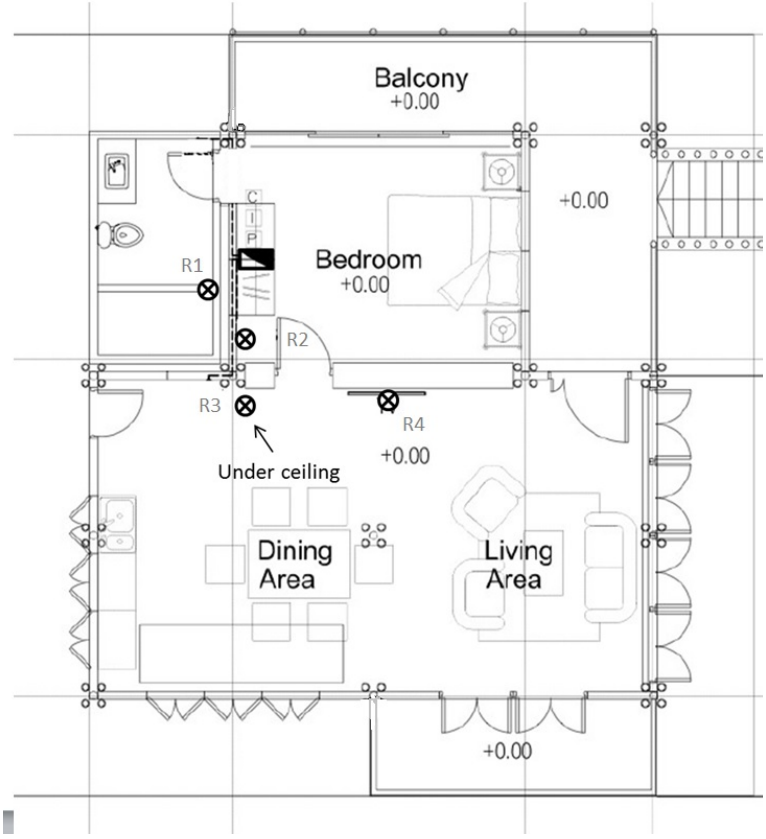

Figure 15: Positions of AM2303 sensors in the building

2.5.3 Collection of data

For the operation of the SHT75 and the AM2303 sensors as well as for an automatic storage of the measured data a monitoring server was set up.

This server is a standard linux server on a standard raspberry pi embedded platform, which is connected to 5 sensor controllers allocated in the building. The monitoring server is receiving data from the sensors every 5 minutes. After storage the data of all sensors is accessible via the server website for a further analysis.

2.6 Thermal comfort – short time monitoring

Thermal comfort cannot be defined by the temperature alone, in fact it is being influenced by a number of factors and it is also a subjective sensation as already described in chapter 1.3.1. The thermal comfort of an indoor climate can be evaluated with the PMV (Predicted Mean Vote) and the PPD (Predicted Percent of Dissatisfied).

The first 2 parameters, clothing factor and metabolic rate, are iterative and can be chosen according to the standards, ASHRAE or DIN EN ISO 7730, where defined values can be found for different pieces of clothing as well as for the metabolic rate, depending on the assumed activity and clothing. The other 4 parameters, air temperature, relative humidity, mean radiant temperature and air velocity, for defining the room climate have to be measured.

The set up for this thermal comfort measurement is described in the following subchapters.

2.6.1 Type of sensors

For the monitoring of the other 4 parameters a measurement kit like the one from Ahlborn in the following picture is needed. It includes a combined temperature and humidity sensor, a globe bulb thermometer and an omnidirectional thermo-anemometer (Ahlborn, 2013).

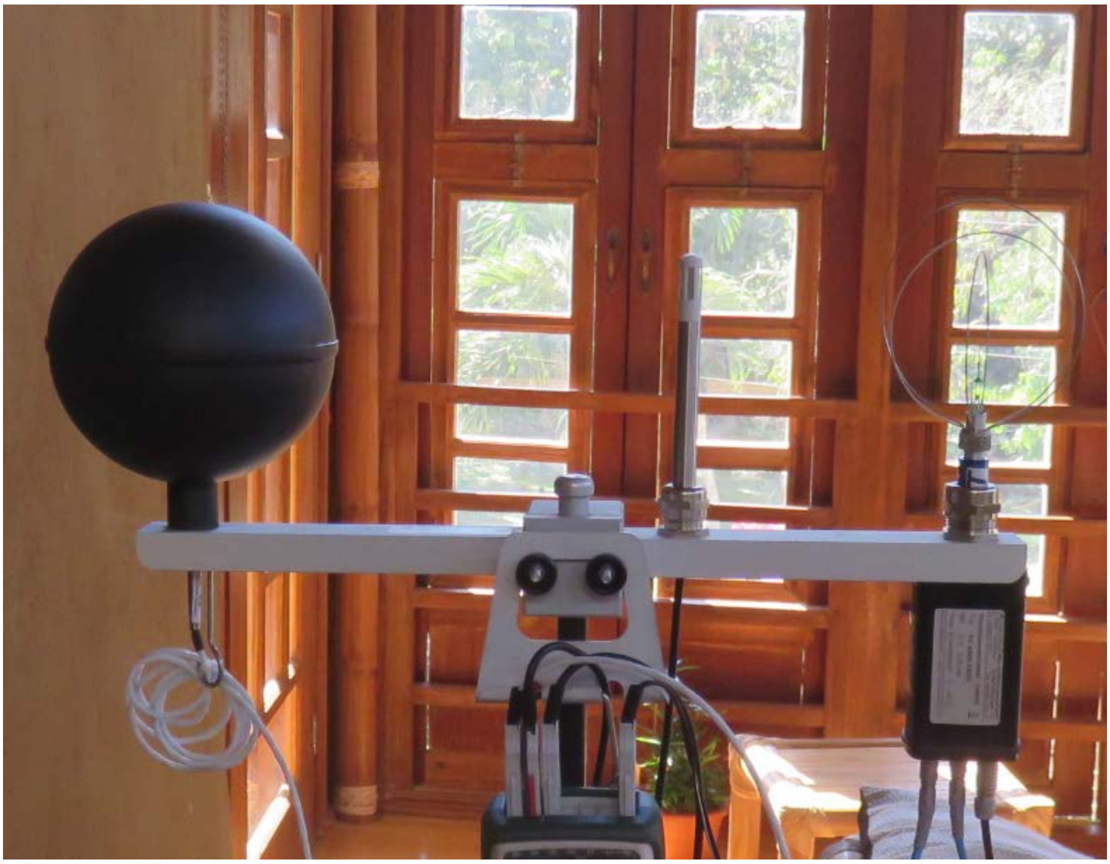

Figure 16: Measurement-kit for the monitoring of the indoor environment

Air temperature/relative humidity – FHAD4641

The FHAD4641 is a combined sensor by Ahlborn for determining the air temperature and the relative humidity using a capacitive sensor element. The accuracy is ±0.3 K at 25 °C and ±0.4 K for the temperature range between 10 and 40 °C, while it is up to ±1.8 % for the relative humidity between 10 and 90 %. Additional also the air pressure (700 to 1100 mbar; accuracy ±2.5 mbar for temperatures between 0 to 65 °C) can be measured as well as the dew point calculated.

Mean radiant temperature

For the determination of the mean radiant temperature the FPA805GTS globe bulb thermometer is used. This is consisting of 2 parts, a black body in shape of a sphere and a temperature sensor positioned in its centre, to get an average value of the radiant temperature of the local surrounding (-40 to 200 °C). The sphere is made of copper and has a diameter of 150 mm.

Air velocity

For the measurement of the air velocity, the last parameter for the calculation of the thermal comfort, the omnidirectional thermo-anemometer FVA605TA5O by Ahlborn is used. This has a miniature thermistor and a precision resistor for the detection of the airflow velocity for a range between 0.15 and 5.00 m/s.

2.6.2 Position of sensors

For the prediction of thermal comfort in an indoor space the sensors should be positioned as close as possible to the most used spot in the room like a working place in an office, because this is of course the place at which the ambient conditions have the biggest or longest effect on the occupants. But during the measurement the set-up should not be close to the occupants, because the emitted temperature of the human body will distort the measured mean radiant temperature significantly. Same counts for the exposure to direct solar radiation.

Under consideration of these principles 5 positions in the building for the prediction of thermal comfort were selected. Three of them are located in the main room, one in the bedroom and one in the bathroom.

Figure 17: Test set-up in the couch area of the main room

Figure 18: Test set-up in the bathroom and in the bedroom

The chosen positions in the living room are covering the main sectors for the indoor activity, the couch area, the dining and the centre of the room in front of the rammed earth wall, where most people are passing through. The detailed information of all positions is displayed in the following Table 5 and Figure 19.

Table 5: List of measurement points for thermal comfort prediction

Point	Location	Position
TC1	Bathroom	Centre, 160cm above floor
TC2	Bedroom	Bedhead next to the rammed earth wall, 100 cm above floor
TC3	Main room	Dining area, 120 cm above floor
TC4	Main room	Couch area, 100 cm above floor
TC5	Main room	Centre, 160 cm above floor

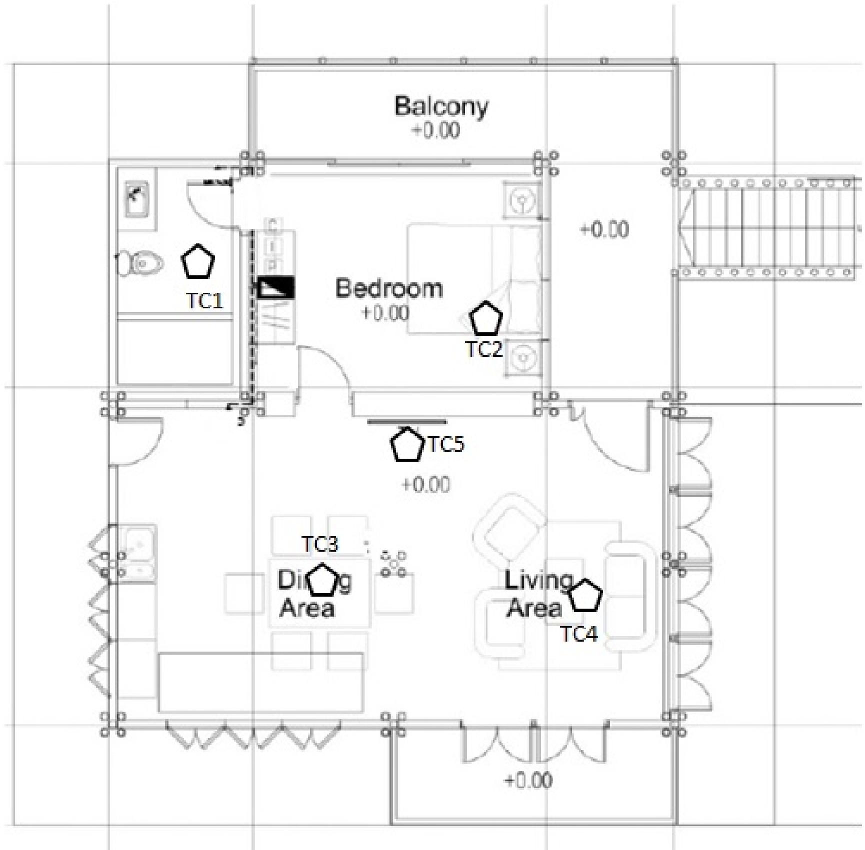

Figure 19: Sensor positions for thermal comfort prediction

2.6.3 Metabolic rate

The first iterative parameter, the metabolic rate is an important influencing factor for the thermal comfort as described in the background chapter Thermal comfort.

Depending on the activity level of the human body also the generated internal heat is variing. Therefor a different factor for the metabolic rate for each sensor position (see Figure 19) was chosen from ASHRAE (ASHRAE, 2005) depending on the assumed activities sleeping (bedroom), sitting (main room) or standing (bathroom, main room). No heavy work was considered for this maesurement, since the buildings primary functionality is a resort cottage in which the occupants are staying for relaxation and recovery.

Table 6: Selected values for metabolic rates

Point	Location	Position	Met (ASHRAE)	Activity
TC1	Bathroom	Centre	1.2	Standing relaxed
TC2	Bedroom	Bedhead	0.7	Sleeping
TC3	Main room	Dining area	1.0	Seated, quiet
TC4	Main room	Couch area	0.8	Seated, reclining
TC5	Main room	Centre	1.2	Standing relaxed

But according to Fanger these values for the metabolic rate have to be adapted for thermal comfort predictions in natural ventilated buildings in tropical climate (Fanger et al., 2002). For measured PMV values above thermal neutrality (PMV > 0) the metabolic rate has to be reduced by 6.7 % per unit of the thermal sensation scale (see also chapter 1.3.2), in order to recalculate the PMV and PPD values.

2.6.4 Clothing factor

The second iterative parameter is the clothing factor. Same as the metabolic rate it is also an important influencing factor, since clothing is insulation for the human body and therefore influencing the prior mentioned energy balance between persons and the ambient surrounding.

In accordance with the metabolic rates for the assumed activities and of course adjusted to the local climate, different sets of clothing were defined and the associated clothing factors selected from the DIN EN ISO 7730 standard (DIN EN ISO 7730, 2006). For the positions TC1 in the bathroom and TC2 in the bedroom different sets were defined for day and night times. For the points in the main room the same clothing was used for the whole day. But the major modifications for the clothing factors were caused by addition of furniture, which is essential since the activities for TC2 and TC4 are in a reclining position and for TC3 in a sitting position.

The factor for the wood chair (0.01 clo) in the dining area as well as for the armchair (0.15 clo) in the couch area can be extracted from the DIN EN ISO 7730 or from ASHRAE since these standards were mainly developed for workplaces during daytime in which selected office furniture is included.

In contrary these standards are not directly applicable for sleeping environments, because bedding systems are thus excluded. For the prediction of the thermal comfort in the bedroom the developed factors for commonly used bedding system in the subtropics by Lin and Deng were used instead (Lin et al., 2006; Lin et al., 2007). In one scenario just a mattress with a sheet was added to the set light summer cloth 1 for daytime measurements, while in a second one a blanket with a 59.1 % cover of the human body was added together with short sleeping cloth for measurements during the night.

In addition some scenarios were recalculated afterwards with a higher clo of 0.5 for a more formal dress at the positions in the main room and with a lower clo of 1.01 for the position TC2 in the bedroom. The detailed applied clothing factors in this study are displayed in the following table.

Table 7: Clothing factors for defined activities and positions

Set	Clothing	clo	Point (time)
Underwear (UW)	Panties, bra	0.03	TC1 (morning)
Light summer cloth 1 (LSC1)	Shorts, t-shirt, underwear	0.18	TC1 (forenoon-night) TC5 (day/night)
Light summer cloth 2 (LSC2)	Shorts, t-shirt, underwear, simple wood chair	0.19	TC3 (day/night)
Light summer cloth 3 (LSC3)	Shorts, t-shirt, underwear, armchair	0.33	TC4 (day/night)
Sleepwear 1 (SW1)	Shorts, t-shirt, underwear, mattress, sheet	1.16	TC2 (day)
Sleepwear 2 (SW2)	Half-slip sleepwear, mattress, sheet, blanket (cover 59.1%)	1.76	TC2 (night)
Sleepwear 3 (SW3)	Underwear, mattress, sheet	1.01	TC2 (day/night)
Formal wear (FW)	Shirt with short sleeves, light pants, underwear, socks, shoes	0.5	TC3 (day/night) TC4 (day/night) TC5 (day/night)

2.6.5 Expectancy factor *e*

For the use of the PMV/PPD model for the evaluation of the thermal comfort in the prototype building the expectancy factor *e* has to be included in the calculation, because of a higher acceptance regarding deviating conditions from thermal comfort by occupants of naturally ventilated buildings in hot climates (see chapter 1.3.2). The expectancy factor is defined by 2 parameters according to the table of classifications by Fanger (see Table 2).

With a hot climate throughout the whole year and a comparatively low amount of air-conditioned buildings in the outer suburbs of Puerto Princesa an expectancy factor of 0.6 for the building site was selected. This is the same value defined for Bangkok, which has a similar climate but definitely a higher amount of air-conditioned buildings, so that 0.6 can be used as a worse case benchmark or for future thermal comfort predictions in case the number of HVAC is also increasing in the project area.

2.6.6 Influencing parameters

Except for the basic principles of the setup like distance to human bodies and no exposure to direct solar radiation, the settings of all operable building openings and mechanical cooling devices were recorded during the measurement, which are, according to Zhang (Zhang et al., 2010), beside the clothing adjustment the most often used behaviours for controlling the indoor environment of naturally ventilated buildings in hot and humid regions towards thermal comfort.

A complete list of all recorded parameters and the possible settings, which were adjusted during the measurement to achieve thermal comfort, as well as the exact positions are displayed in the following Table 8 and Figure 20.

Table 8: List of influencing parameters – building openings and fans

Point	Parameter	Position	Setting
DI1	Interior door	Bathroom/bedroom	Open/closed
DI2	Interior door	Bedroom/main room	Open/closed
DN1	Door to outdoor	North wall of bedroom, balcony	Open/half open/closed
DN2	Door to outdoor	North wall of main room, main entrance	Open/closed
DS1	Door to outdoor	South wall of main room, balcony	Open/half open/closed
DW1	Door to outdoor	West wall of main room, back entrance	Open/closed
F1	Fan	Bedroom	On/off
F2	Fan	Main room	On/off
WE1	Window	East wall of main room	Open/tilted/closed
WE2	Window	East wall of main room	Open/tilted/closed
WE3	Window	East wall of main room	Open/tilted/closed
WE4	Window	East wall of main room	Open/tilted/closed
WS1	Window	South wall of main room	Tilted/closed
WS2	Window	South wall of main room	Tilted/closed
WS3	Window	South wall of main room	Tilted/closed
WW1	Window	West wall of main room	Tilted/closed
WW2	Window	West wall of main room	Tilted/closed
WW3	Window	West wall of main room	Tilted/closed

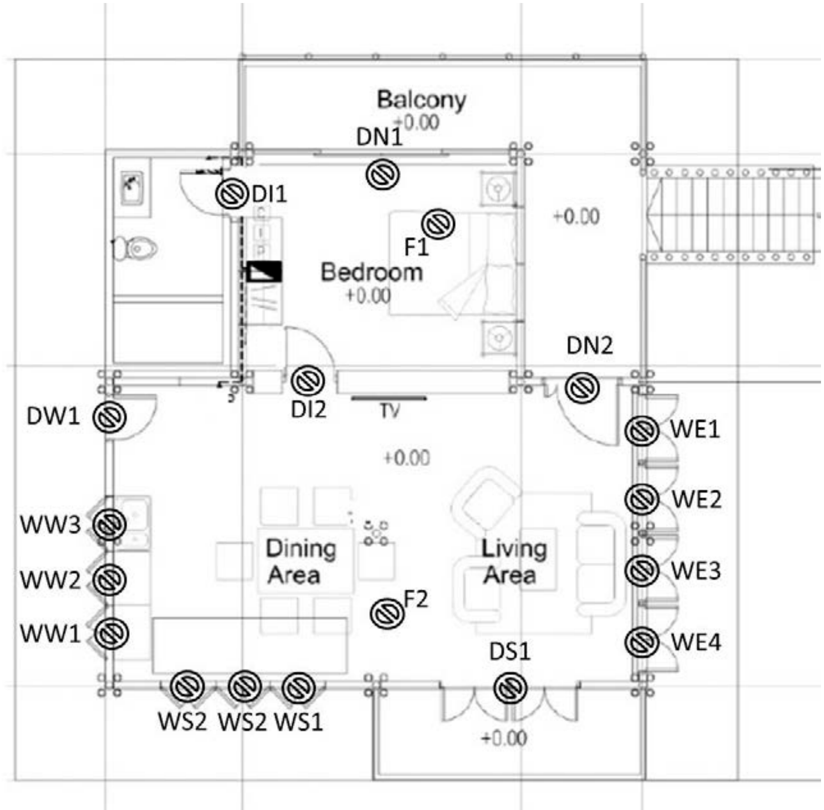

Figure 20: Influencing parameters – building openings and fans

Further influencing parameters, which are strongly connected to the user behaviour of the occupants, like the shower in the bathroom or the cooking area in the main room were not used during the measurement and therefore excluded in this study.

2.6.7 Collection of data

For the operation of the measurement kit (see chapter 2.6.1) the data logger ALMEMO 2590-4AS by Ahlborn was used together with the AMR WinControl software for thermal comfort prediction. Thereby not only the measured data for air temperature, rel. humidity, mean radiant temperature and air velocity can be stored in the data logger as well as directly on a connected laptop for an export as CSV, but also the PMV/PPD calculation for the thermal comfort can be executed online. Even if the calculation has to be modified afterwards, because of the necessary adaptions for thermal comfort calculation in tropical climates (see chapter 1.3.2), for which the software was not invented first hand, the tendencies of the online result can be used for operating the controllable influencing parameters towards a thermally neutral indoor climate.

For the measurement and therefore also for the prediction of thermal comfort a frequency of 1 second was selected, because of the high reflection of the local climate conditions due to the many building opening in naturally ventilated buildings. Thereby it is possible to analyse the immediate effect of sudden changes in weather like a rain shower, but also day and night tendencies via mean values in case of longer measurement periods or repeated data records in short intervals during the day.

2.6.8 Comfort zones

In addition to the evaluation of the thermal comfort with PMV and PPD the data of the measurements should be applied for comfort zones, in which 80 % of sedentary or slightly active people are sensing the environment as thermally acceptable. These zones are outlining the correlation between thermal comfort and the main parameters temperature and humidity. The comfort zones described in the ASHRAE standard were developed for moderate climates, in which also the rel. humidity should not exceed 60 % at the warm site to prevent warm discomfort, and are therefore not applicable for the naturally ventilated target building in this hot and humid climate.

The thermal comfort zone needs to be adapted since these necessary neutrality temperatures are hardly to experience in tropical climates. A common strategy in the concerned regions is to counteract this fact by increasing the indoor air velocity through natural or mechanical ventilation. Based on the research by Dear and Brager (De Dear et al., 2002) that the air velocity is assumed as less than 0.25 m/s, the comfort zone can be extended by increasing the air velocity. An adapted model for the location of Colombo in Sri Lanka, which has a similar but not that extreme climate like the project location, was designed thru expanding the thermal comfort zone by a quantity equal to an average air velocity of 6V-V² (Halwatura, 2014).

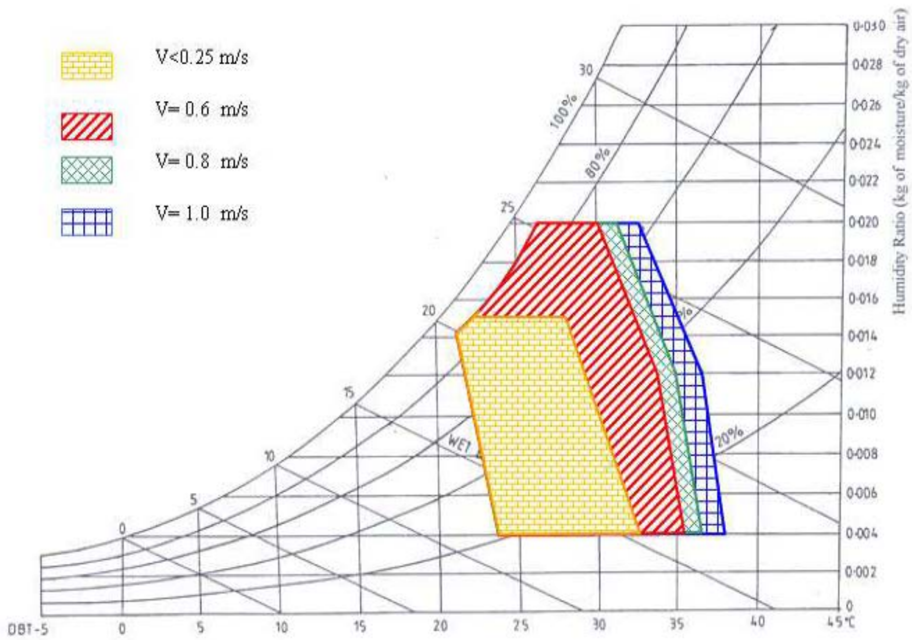

Figure 21: Modified comfort zone for the tropical location of Colombo, Sri Lanka (Halwatura, 2014)

3 RESULTS AND DISCUSSION

3.1 Overview

In this chapter the results of the accomplished monitoring are displayed. Starting with the outdoor climate and a comparison with the available climate data of Meteonorm for the total measurement period (chapter 3.2), each room is then analyzed in more detail regarding air temperature and relative humidity (chapter 3.3). In a first step the correlation of the rooms to the local outdoor climate are investigated, while in a second step the differences between the two sensor types and their varying positions within each room are explored. In the second part of this chapter the results of the short time monitoring, the evaluation of the thermal comfort with PMV/PPD, for selected locations in the building are displayed (chapter 3.4), whereas in addition these measured values are then applied to modified psychrometric charts for the use in tropical climate (chapter 3.5).

3.2 Outdoor climate

The local outdoor climate of the ZCR cottage was monitored with an Aeron weather station, as described in chapter 2.4, in the general measurement period of this project from the 1st of April till the 15th of June 2015. The data, measured with an interval of 10 minutes, was then summarized in a next step for a general overview of the weather conditions at the time of the survey and for a comparison with the average values of the Meteonorm data set from the closest available location (Meteonorm, 2015). The data shown in the following table is comparing the monthly average values (except for the June values of the ZCR Cottage, which are representing the period from 1st to 15th of June only) for air temperature, rel. humidity, wind direction and wind speed of the ZCR cottage and the Puerto Princesa AFB, which is approximately 6 km apart in the southeast (see also appendix Meteonorm climate date).

Table 9: Average monthly climate data for period of measurement

Period of measurement	Data set	Air temperature [°C]	Rel. humidity [%]	Wind direction [deg]	Wind speed [m/s]
April (01.04-30.04)	Meteonorm ZCR cottage	28.8 27.9	77 79	75 140	2.5 1.6
May (01.05-31.05)	Meteonorm ZCR cottage	28.5 28.1	80 81	75 157	2.3 1.1
June (01.06-15.06)	Meteonorm ZCR cottage	27.7 28.2	82 81	224 150	2 0.94

The average air temperatures in this period are quite similar with values between 27.7 and 28.8 °C and a maximum standard derivation in April of 0.45 °C. According to the Meteonorm data set the minimum and maximum air temperatures are in June with approximately 22.0 °C and 34.0 °C, in contrary the coolest value measured at the project location was with 20.65 °C at the 3rd of April at 5 a.m. while the highest temperature was observed at the 1st of May at 1 p.m. (see also Table 10).

Table 10: Minimum and maximum air temperatures

Period of measurement	**Data set**	**Minimum air temperature [°C]**	**Maximum air temperature [°C]**
April (01.04-30.04)	Meteonorm ZCR cottage	*approx. 23.5* *20.6*	*approx. 33.5* *36.3*
May (01.05-31.05)	Meteonorm ZCR cottage	*approx. 23.0* *21.8*	*approx. 33.0* *37.2*
June (01.06-15.06)	Meteonorm ZCR cottage	*approx. 22.0* *22.6*	*approx. 34.0* *36.2*

Same counts for the relative humidity with values between 77 and 81 % and a maximum standard derivation of 1 % in April.

In general the measured values for air temperature and relative humidity are reflecting the climate data of Meteonorm. While the temperature is slightly lower and the air humidity slightly higher in April and May, it is opposite for June, but this is referable to the approaching rainy season, which was only partly measured in June, whereas the constant lower values for the wind velocity are depending on the location. Situated behind the Puerto Bay and surrounded by the forest, the ZCR cottage is much more protected than the Puerto Princesa AFB, which is located at an open field close to the sea.

In contrary the average monthly values for the wind direction and the wind speed are divergent in the observed period. While the wind speed at the cottage is showing a constant difference of approximately 50 % less with average velocities between 0.9 and 2.5 m/s and standard derivations between 0.45 m/s (April) and 0.6 m/s (May), the measured wind directions are reflecting an aberration for the time and location with average values of 140, 157 and 150 ° since the wind is coming in general in the whole area during dry season from north east and in the rainy season, which is from June to October, from south west (see chapter 2.3.1).

The varying numbers for the wind direction in contrary are quite unusual. Therefore additional data from a location about 25 km north east of the cottage at Honda Bay was used for reference. The data was retrieved from windguru.cz, a platform mainly used for sailing sports, where it is possible to check the weather forecast as well as the history (Windguru, 2015). This history in the last years is in general showing the same wind directions for this time of the year as the Meteonorm data set, that the wind is usually turning from north east to south east end of May, but for the period of the measurement from 1st of April till 15th of June 2015 the wind direction is similar to the measured data at the cottage. At that location the wind was as well already turning to south east in the second half of March, whereby for all data sets the wind was then turning to south west in the middle of June. That means the wind direction was showing an anomaly during the period of the measurement.

In the following table also the precipitation is displayed, the monthly amount of rain as well as the number of raining days. April was a relatively dry month with less than 9 mm in total, whereas the measured data in May is showing similar numbers like the average values from Meteonorm. June in this case is because of the shorter monitoring time and the approaching rainy season not comparable.

Table 11: Monthly data for precipitation

Period of measurement	Data set	precipitation [mm]	days with precipitation
April (01.04-30.04)	Meteonorm ZCR cottage	Average sum approx. 75 8.87	8 5(4*)
May (01.05-31.05)	Meteonorm ZCR cottage	Average sum approx. 125 111.13	11 12(4*)
June (01.06-15.06)	Meteonorm ZCR cottage	Average sum approx. 175 26	13 4(2*)

*Days with raining time less than 10 minutes and total precipitation of less than 1 mm

3.3 Air temperature and relative humidity

In a next step the monitoring data for the air temperature and the relative humidity of the local outdoor climate was compared with the measured data of the long-time indoor monitoring. The monitoring period for the SHT75 and AM2303 sensors is the same as for the weather station. Starting at the 1st of April and ending at the 15th of June.

For the evaluation of the long-time monitoring data it has to be taken into account that the measured values of the sensors for the outdoor and indoor climate are saved in different data formats. While for example the date and time of the outdoor climate is given in a text string in different cells, the one of the indoor climate is given in the Unix Time Stamp for which additionally also the time difference of +8 hours in summer time and +9 hours in winter time has to be considered, because the monitoring software was originally programmed for applications in the coordinated universal time zone UTC±0.

It is important to mention that for the long-time monitoring in general no record of the influencing parameters like window openings etc. was done, except for the days in which also the short-time monitoring was executed (see chapter 2.6.6). In these other days there is no record of the buildings occupants and therefore also no monitoring if these parameters were changed to optimise the thermal comfort in the building, because this has to be done by the buildings occupants. Other groups of persons, which had randomly access to the building in this monitoring period and might have changed the influencing parameters in that time, were security guards (in general twice a day), cleaning staff, craftsmen for further optimisation of the building and visitors. During the monitoring process it was also observed that the data record of single sensors failed randomly. This was not a big issue for the data collection itself, because it could be fixed just by resetting the monitoring server, but as a result the collected data is not gapless.

For a first overview about the functionality of the building and the general indoor conditions, the air temperature and the relative humidity of each room is compared with the outdoor air temperature and rel. humidity on a weekly base (see Figure 22 and Figure 23).

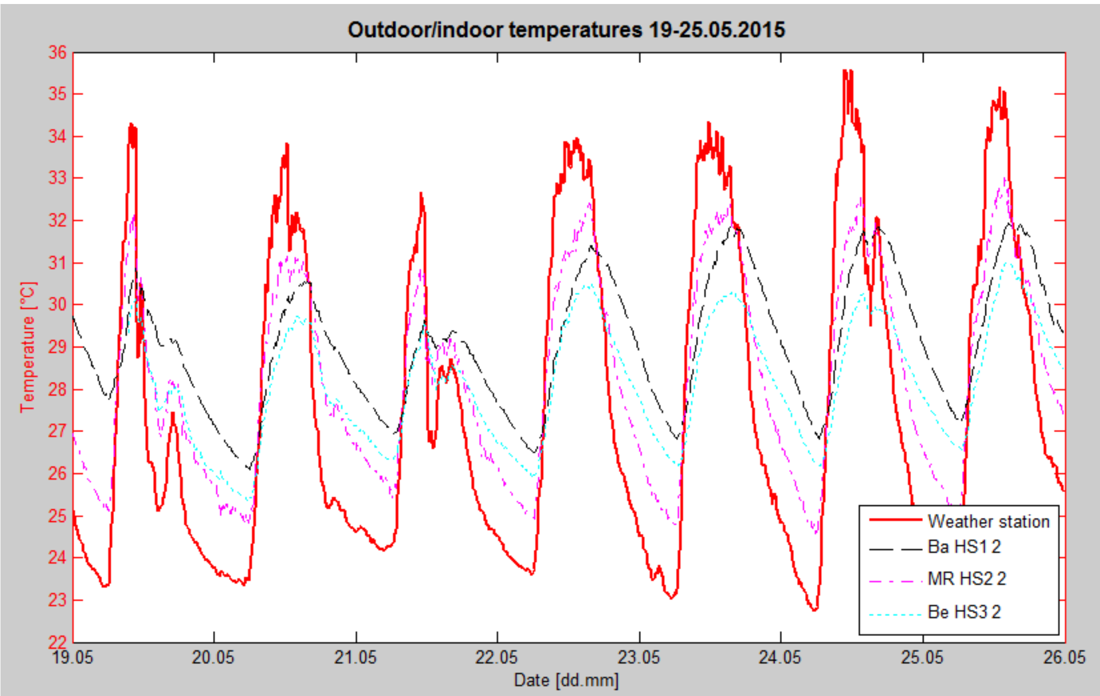

Figure 22: Weekly outdoor and indoor air temperatures, 19-25.06.2015

The selected week from the 19th till the 25th of May in the middle of the monitoring period is reflecting typical weather conditions for a hot and humid climate at this location. The outdoor conditions are quite constant with minimum temperatures of around 23 °C at night and maximum temperatures of up to almost 36 °C at midday.

Scattered showers during the day are also apparent in the figure like at the 21st of May, when the temperature is decreasing. The air temperatures of the different rooms are of course dependant on the outdoor climate, since it is a natural ventilated building, but in correlation with the design of the building, the position of the rooms and the different passive cooling strategies, they are more constant and are showing a less extreme variation.

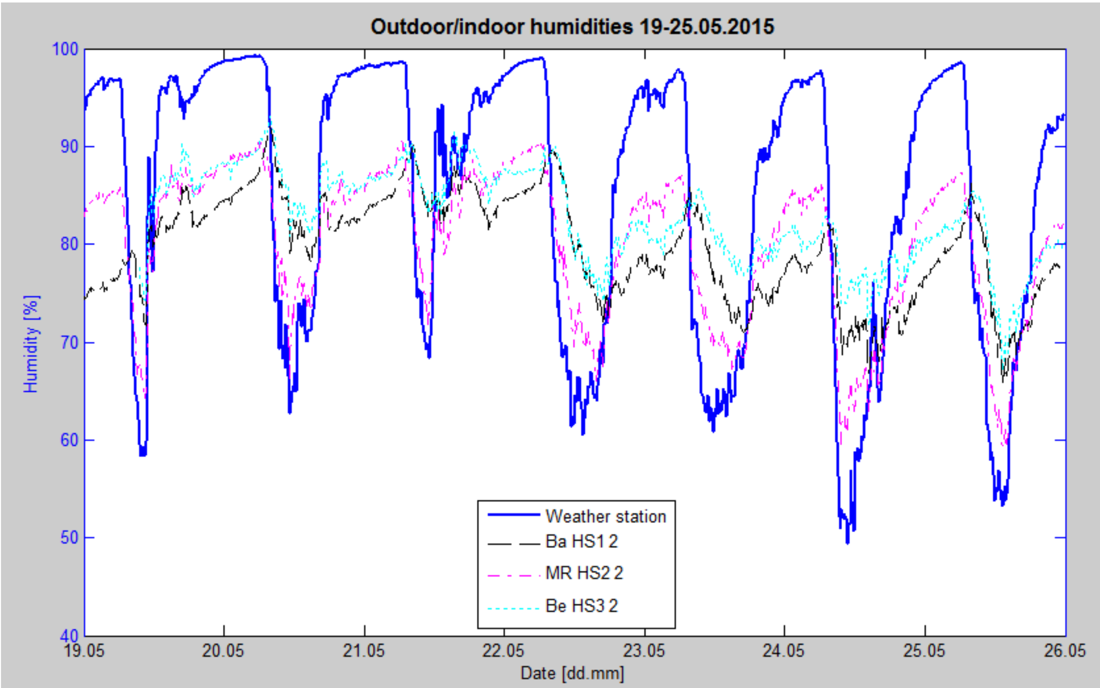

Figure 23: Weekly outdoor and indoor relative humidities, 19-25.06.2015

The graph for the relative humidity is illustrating a similar behaviour. While the outdoor air is very humid during night times with peaks of more than 95 %, the humidity is significantly dropping down at day times. Accordingly to the chart for the air temperatures, also the rain periods during the day are clearly visible in this figure, when the humidity is increasing. See also Figure 47 and Figure 48 in appendix for an additional weekly comparison at the end of the monitoring period from 8th to 14th of June. For the comparison of the outdoor and indoor environment regarding air temperatures and relative humidity the data of the SHT75 sensors at the positions HS1_2, HS2_2 and HS3_2 at a height of 160 cm above the floor was used.

A more detailed evaluation for the bathroom, the bedroom and the main room and their dependence to the outdoor climate as well as a comparison of the different sensor types within the same room including an analysis of the vertical air temperature difference is described also on a daily base in the following subchapters. Representative examples for each room were selected for days when also the short time monitoring was done, because for these days also the controllable influencing parameters were recorded in detail.

3.3.1 Bathroom

Outdoor-indoor climate

In this subchapter a comparison of the bathroom with the local outdoor climate concerning air temperature and rel. humidity is done. The Table 12 and Table 13 are showing the monthly mean, maximum and minimum values for the air temperature and the relative humidity between the outdoor and the indoor environment, while Table 14 is displaying the absolute differences for both parameters.

Table 12: Outdoor-indoor temperatures, bathroom HS1_2

Period	Mean value outdoor air temp. [°C]	Mean value air temp. HS1_2 [°C]	Maximum outdoor air temp. [°C]	Maximum air temp. HS1_2 [°C]	Minimum outdoor air temp. [°C]	Minimum air temp. HS1_2 [°C]
April	27.95	29.47	36.27	32.97	20.66	25.91
May	28.12	29.69	37.20	33.70	21.82	26.04
June	28.25	29.98	36.15	33.90	22.64	25.87
Total	**28.08**	**29.66**	**37.20**	**33.90**	**20.66**	**25.87**

Table 13: Outdoor-indoor rel. humidities, bathroom HS1_2

Period	Mean value outdoor rel. hum. [%]	Mean value rel. hum. HS1_2 [%]	Maximum outdoor rel. hum. [%]	Maximum rel. hum. HS1_2 [%]	Minimum outdoor rel. hum. [%]	Minimum rel. hum. HS1_2 [%]
April	78.81	72.92	99.27	90.16	35.63	50.20
May	81.28	75.43	99.27	92.01	34.10	48.52
June	81.48	75.11	99.51	90.04	45.38	59.56
Total	**80.35**	**74.35**	**99.51**	**92.01**	**34.1**	**48.52**

The tables are showing a constant tendency for the measurement period with slightly increasing values from April until June. The temperatures in the bathroom are varying between 25.87 and 33.90 °C, while the rel. humidity is in the range of 34.1 and 92.01 %. The biggest differences to the outdoor climate are at the 3rd of April with 5.92 °C at 3 a.m. and 26.59 % at 4.10 a.m.

Table 14: Outdoor-indoor temperature and rel. humidity differences, bathroom HS1_2

Period	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
April	3.02	5.92	12.64	26.59
May	3.17	5.60	13.24	24.70
June	3.08	5.89	12.84	25.40
Total	**3.09**	**5.92**	**12.92**	**26.59**

For a direct comparison of the outdoor climate with the conditions in the bathroom on a daily base the 10th of June was selected. This day was starting very sunny with a few clouds only, but later in the afternoon it got very cloudy. The humidity was then increasing and the temperature dropping down. There was no rain at the project location, but in the area. At sunset it was cooling down again, while the humidity was increasing.

See also Figure 49 to Figure 51 in appendix for a comparison of the 28th of May as well as of 11th and 12th of June.

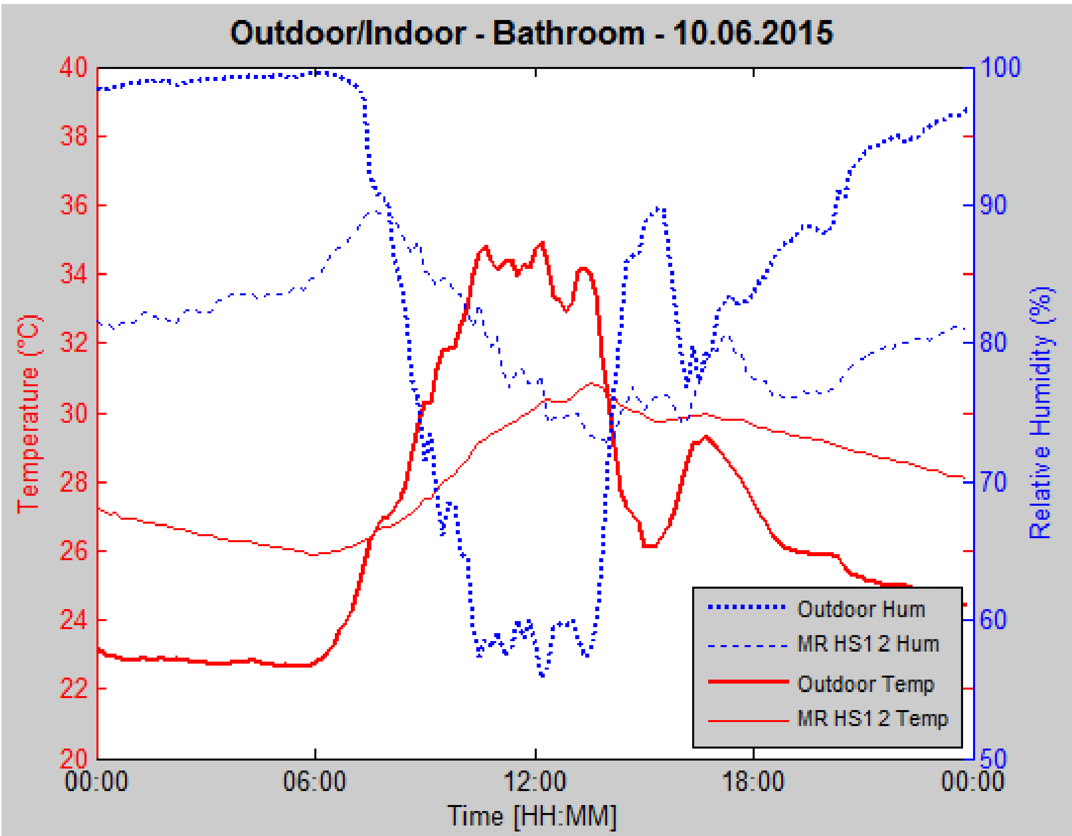

Figure 24: Air temperature and humidity for bathroom (SHT75) and outdoor, 10.06.2015

All in all, the bathroom has because of its orientation to the northwest, the smallest number of building openings and the highest amount of thermal mass comparable constant indoor conditions. The bathroom is with its massive wall elements to all sites the warmest room in the building during night. Therefore also the biggest air temperature differences between the bathroom and the local outdoor environment are at night, when the outdoor air temperatures are dropping fast. Because of the same reason also the lowest rel. humidity in the building during night is in the bathroom. In return the temperatures are increasing in general slowly during day with its peak in the afternoon when the sun is hitting the bathroom wall to the west.

Comparison of sensor types and positions

In the following subchapter the 2 sensor types at the different positions within the bathroom are set in comparison to each other. Therefore also the mean as well as the maximum and minimum values for the air temperature and the rel. humidity for the total measurement period are summarized in the following Table 15.

Table 15: Temperatures and rel. humidities, bathroom

Sensor	Mean value air temperature [°C]	Maximum air temperature [°C]	Minimum air temperature [°C]	Mean value rel. humidity [%]	Maximum rel. humidity [%]	Minimum rel. humidity [%]
HS1_1	29.95	33.24	26.84	71.92	85.31	54.19
HS1_2	29.66	33.90	25.87	74.35	92.01	48.52
RA1	29.41	34.10	25.50	66.55	96.50	38.70

In Table 16, which is showing the absolute differences for the bathroom, a maximum vertical air temperature difference of 2.75 between HS1_1 and HS1_2 is given. In fact this value was measured at midday of the 16th of April, which is the only day with a difference of more than 2 °C. Since there is no abnormality for the local climate and all other days are within a maximum variation of 1.66 °C, it is assumed that the sensors were influenced by an incident in the building. This is actually confirmed by the same abnormal difference of 3.12 °C between HS1_1 and RA1 at the same day. The second biggest difference is 2.04 °C at midday of the 6th of April. The differences for the rel. humidity are in accordance with the temperature and also dependant on the location and different height of 160 and 200 cm above the floor (see also chapters 2.5.1 and 2.5.2).

Table 16: Temperature and rel. humidity differences, bathroom

Sensors	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
HS1_1_HS1_2	0.64	2.75	3.14	8.92
HS1_2_RA1	0.37	1.46	8.01	18.39
HS1_1_RA1	0.90	3.12	6.22	19.33

It is also visible in the direct comparison for the day of the 10th of June (Figure 25) that the biggest differences are in general at midday during the hottest period of the day or because of a sudden change in the weather.

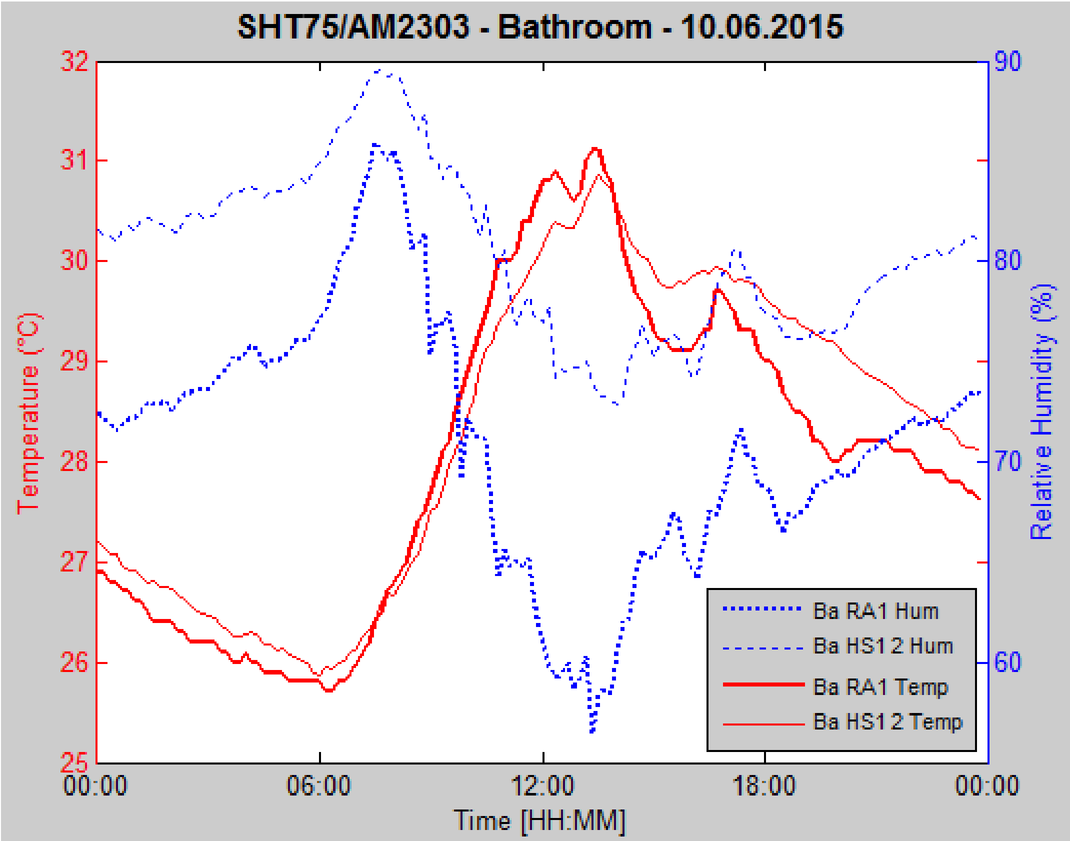

Figure 25: Air temperature and humidity, bathroom, AM2303 und SHT75, 10.06.2015

The direct comparison of the HS1_1 and HS1_2 (Figure 26) is showing a similar constant tendency with respect to the positions of the sensors and the different horizontal and vertical distances to each other. Solely a higher sensation for the upper and lower values of the rel. humidity for the AM2303 sensor was recognized.

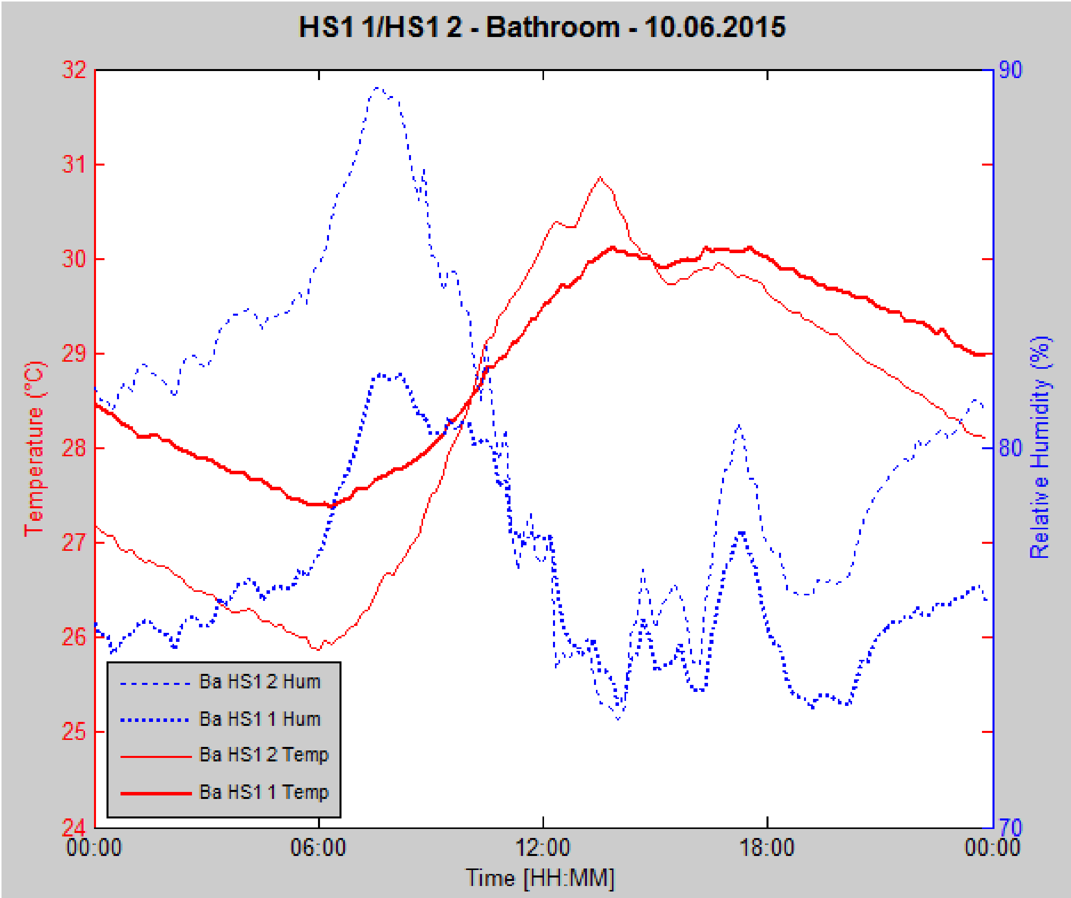

Figure 26: Air temperature and rel. humidity difference SHT sensors HS1_1 and HS1_2, 10.06.2015

3.3.2 Bedroom

Outdoor-indoor climate

The comparison of the condition in the bedroom with the outdoor climate is showing a similar tendency like the bathroom, but while the temperature in the bedroom is with a mean of 28.34 °C for the total period minimal lower, the rel. humidity is with 78.59 % in contrary slightly higher. The monthly means as well as the maximum and minimum values for the air temperature and relative humidity are summarized in following Table 17 and Table 18.

Table 17: Outdoor-indoor temperatures, bedroom HS3_2

Period	Mean value outdoor air temp. [°C]	Mean value air temp. HS3_2 [°C]	Maximum outdoor air temp. [°C]	Maximum air temp. HS3_2 [°C]	Minimum outdoor air temp. [°C]	Minimum air temp. HS3_2 [°C]
April	27.95	28.37	36.27	31.76	20.66	24.95
May	28.12	28.26	37.20	31.35	21.82	25.34
June	28.25	28.34	36.15	31.79	22.64	25.60
Total	**28.08**	**28.34**	**37.20**	**31.79**	**20.66**	**24.95**

Table 18: Outdoor-indoor rel. humidities, bedroom HS3_2

Period	Mean value outdoor rel. hum. [%]	Mean value rel. hum. HS3_2 [%]	Maximum outdoor rel. hum. [%]	Maximum rel. hum. HS3_2 [%]	Minimum outdoor rel. hum. [%]	Minimum rel. hum. HS3_2 [%]
April	78.81	76.64	99.27	91.04	35.63	62.06
May	81.28	81.92	99.27	93.01	34.10	67.10
June	81.48	81.01	99.51	91.41	45.38	62.84
Total	**80.35**	**78.59**	**99.51**	**93.01**	**34.1**	**62.06**

The maximum air temperature difference between the bedroom and the local environment is 6.57 °C at the 25th of May at 10.50 a.m. and the biggest rel. humidity difference is at the 14th of April at 08.40 in the morning (see Table 19).

Table 19: Outdoor-indoor temperature and rel. humidity differences, bedroom HS3_2

Period	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
April	2.38	6.47	10.68	26.61
May	2.58	6.57	11.60	25.43
June	2.50	6.43	11.53	26.31
Total	**2.45**	**6.57**	**11.04**	**26.61**

For a more detailed illustration for the bedroom the night from the 11th to 12th of June was selected. The curves for the air temperature and the rel. humidity at this night are reflecting typical conditions. The outdoor temperature is decreasing drastically after sunset and then levelling off, whereas the indoor temperature is declining continuous. The outdoor humidity is in contrary increasing exponential towards 100 % humidity until sunrise, while the humidity in the room is raising constant. See also Figure 52 in appendix for a comparison of the 9th and 10th of June.

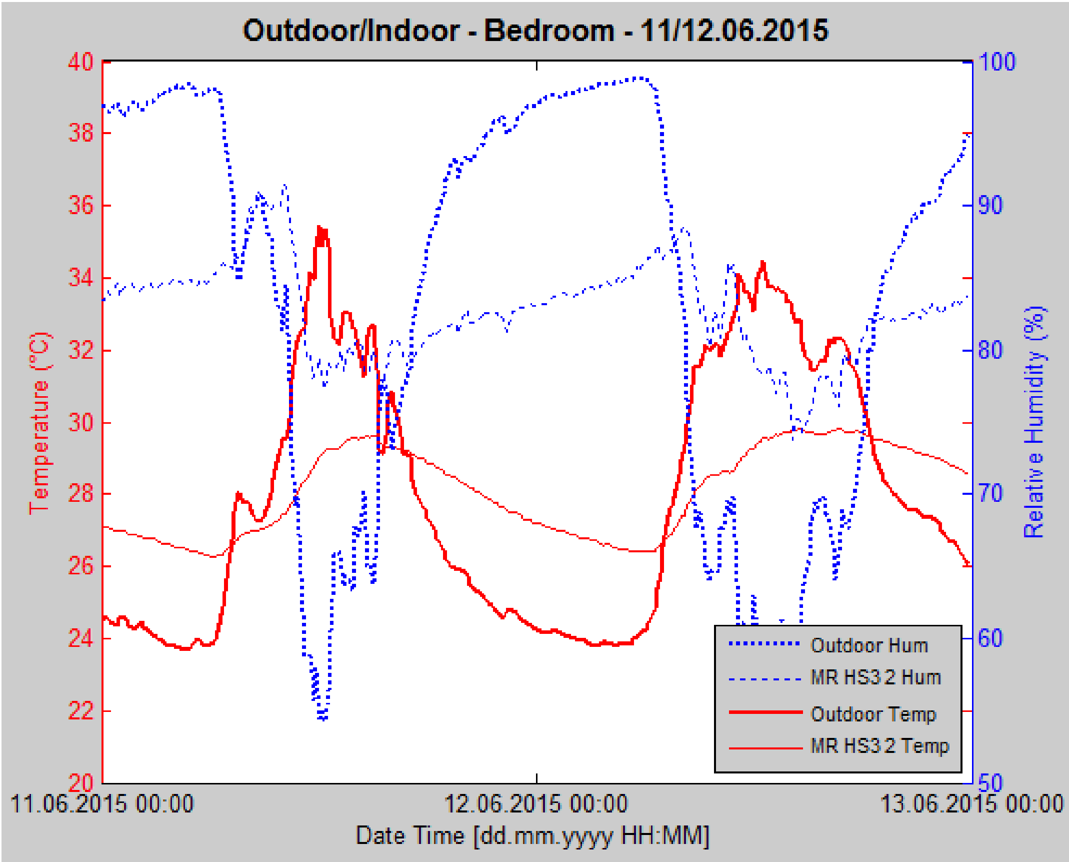

Figure 27: Air temperature and humidity for bedroom (SHT75) and outdoor, 11 and 12.06.2015

Summarizing, the bedroom has the highest variation to the outdoor air temperature because of the massive wall elements to the south and west as well as the room´s orientation to the north, especially at forenoon when the outdoor air temperature is increasing. The bedroom is therefore in total the coolest room in the building. The difference of the relative humidity is similar to the one of the bathroom but in general slightly higher with its biggest difference in the morning after sunrise when the outdoor humidity is dropping drastically.

Comparison of sensor types and positions

The Table 20 and Table 21 are providing an overview for the comparison of the different sensors installed in the bedroom regarding the mean, maximum and minimum values for the air temperature and rel. humidity for the total measurement period as well as the absolute differences.

Table 20: Temperatures and rel. humidities, bedroom

Sensor	Mean value air temperature [°C]	Maximum air temperature [°C]	Minimum air temperature [°C]	Mean value rel. humidity [%]	Maximum rel. humidity [%]	Minimum rel. humidity [%]
HS3_1	28.73	32.88	24.65	75.67	91.36	57.68
HS3_2	28.34	31.79	24.95	78.59	93.01	62.06
RA2	29.33	33.00	25.50	74.61	93.20	48.10

Table 21: Temperature and rel. humidity differences, bedroom

Sensors	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
HS3_1_HS3_2	0.44	6.22	2.94	20.65
HS3_2_RA2	0.80	4.25	3.05	13.00
HS3_1_RA2	0.44	3.11	1.16	12.06

The tables are revealing two abnormities. The first one is that the mean and maximum temperatures of the HS3_1 and RA2 sensors are higher than the ones from the HS3_2 sensor, which was with 160 cm above the floor installed at the highest position in the bedroom (see also chapters 2.5.1 and 2.5.2).

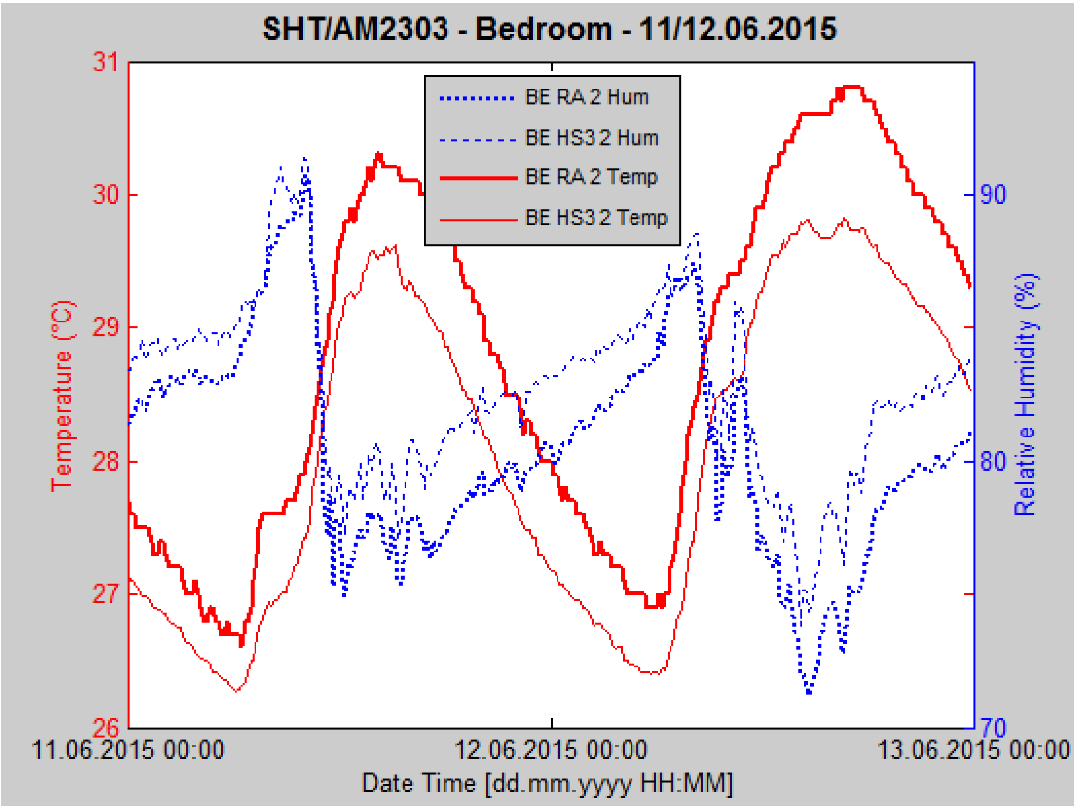

Figure 28: Air temperature and humidity, bedroom, AM2303 und SHT75, 11/12.06.2015

This is because these sensors are slightly affected by the warm exhaust air of the PV inverter, which was installed in the lower part of the wall next to them. The HS3_1 is affected most and has therefore a comparable high temperature. RA2 is affected less by the PV inverter, but has, because of higher position, still a higher temperature than HS3_1 (see also Figure 28 and Figure 29 for direct comparisons).

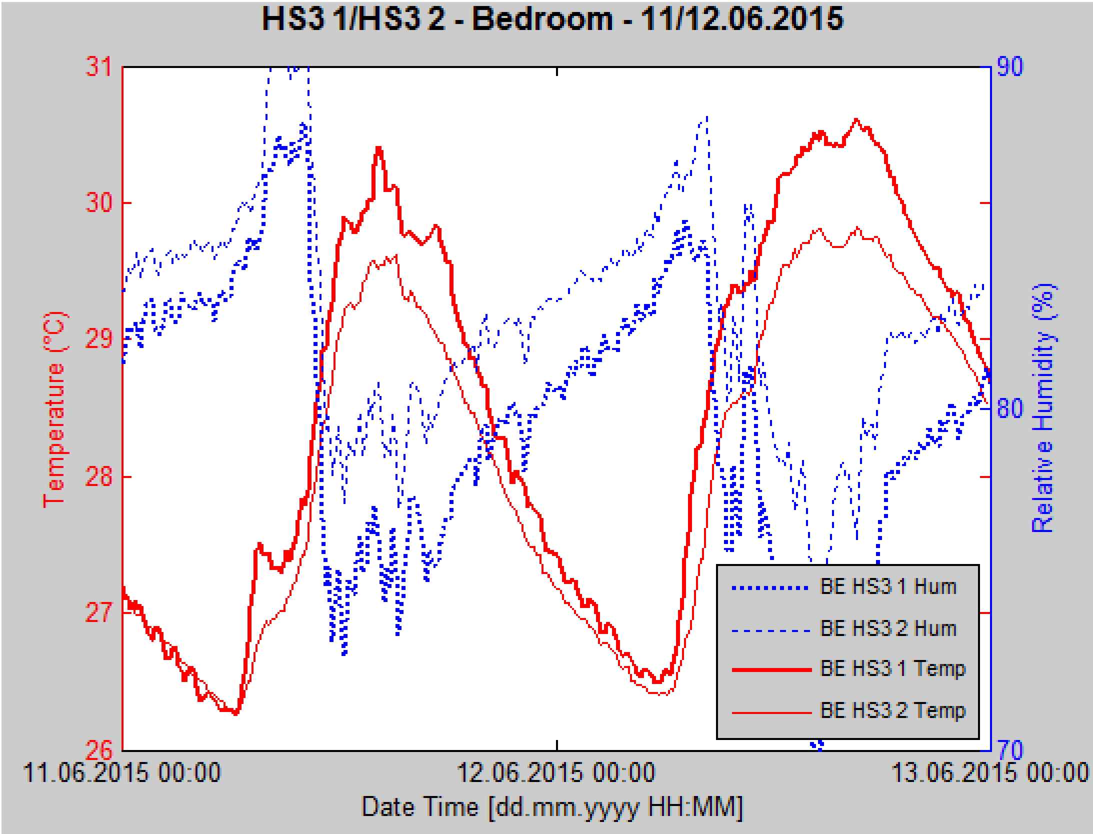

Figure 29: Air temperature and rel. humidity difference SHT sensors HS3_1 and HS3_2, 11/12.06.2015

The second abnormity is the high maximum air temperature difference, which is referable to short exposures to direct sunlight, especially for HS3_1, in the morning between 7.30 and 7.40 at the beginning of the measurement period in April. This is explaining the much bigger difference between HS3_1 and HS3_2 especially when the door to the north is already open at that early time of the day in addition to the temperature increase for HS3_1, because of the PV inverter. The situation is the same for RA2 but the interference is less extreme because of the higher position of the sensor, and therefore also the difference between RA2 and HS3_2 is smaller. The difference between RA2 und HS3_1 is in comparison the smallest, because both sensors are affected by the sun at the same time of the day. Even if RA2 is closer to HS3_2 than to HS3_1, the temperature difference is bigger because HS3_2 is in accordance with its higher position not affected by the sun. This interference is slowly decreasing until end of April with the change of the sun path.

Same as for the air temperature also the measurement for rel. humidity is influenced by the exposure of the sensor to direct sunlight. These short time variations are showing an identical tendency. The maximum difference of 20.65 % rel. humidity between HS3_2 and HS3_1 is also in the morning from 7.30 to 7.40 a.m. At the same time the difference between HS3_2 and RA2 is 13 % rel. humidity because of the higher position of the sensor compared to the HS3_1, while the difference between RA2 and HS3_1 is the smallest. The selected figures above are not showing the effect of the second abnormity, since this behaviour is only occurring at the minority of days of the total measurement period.

3.3.3 Main room

Outdoor-indoor climate

The comparison of the condition in the main room with the outdoor climate is revealing a smaller variance by contrast with the bedroom and the bathroom. Table 22 and Table 23 are also showing that the main room has with temperatures between 23.46 and 34.94 °C and rel. humidities in the range from 40.12 to 93.14 % more extreme conditions.

Table 22: Outdoor-indoor temperatures, main room HS2_2

Period	Mean value outdoor air temp. [°C]	Mean value air temp. HS2_2 [°C]	Maximum outdoor air temp. [°C]	Maximum air temp. HS2_2 [°C]	Minimum outdoor air temp. [°C]	Minimum air temp. HS2_2 [°C]
April	27.95	28.66	36.27	33.84	20.66	24.06
May	28.12	28.74	37.20	34.94	21.82	23.46
June	28.25	29.01	36.15	34.40	22.64	24.42
Total	**28.08**	**28.76**	**37.20**	**34.94**	**20.66**	**23.46**

Table 23: Outdoor-indoor rel. humidities, main room HS2_2

Period	Mean value outdoor rel. hum. [%]	Mean value rel. hum. HS2_2 [%]	Maximum outdoor rel. hum. [%]	Maximum rel. hum. HS2_2 [%]	Minimum outdoor rel. hum. [%]	Minimum rel. hum. HS2_2 [%]
April	78.81	73.08	99.27	90.21	35.63	41.88
May	81.28	76.31	99.27	93.14	34.10	40.12
June	81.48	75.79	99.51	89.45	45.38	52.98
Total	**80.35**	**74.90**	**99.51**	**93.14**	**34.1**	**40.12**

The maximum differences for the air temperature with 4.67 °C at the 26th of April at 7.40 a.m. and the rel. humidity with 23.37 % in the night of the 3rd of April at 4 a.m. are in contradiction rather small.

Table 24: Outdoor-indoor temperature and rel. humidity differences, main room HS2_2

Period	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
April	1.65	4.67	8.53	23.37
May	1.60	4.38	8.02	18.49
June	1.65	3.76	8.51	16.70
Total	**1.63**	**4.67**	**8.32**	**23.37**

The following illustrations for the selected days of the 19th and 29th of May are reflecting typical conditions for a rainy day (Figure 30) and for a sunny day (Figure 31).

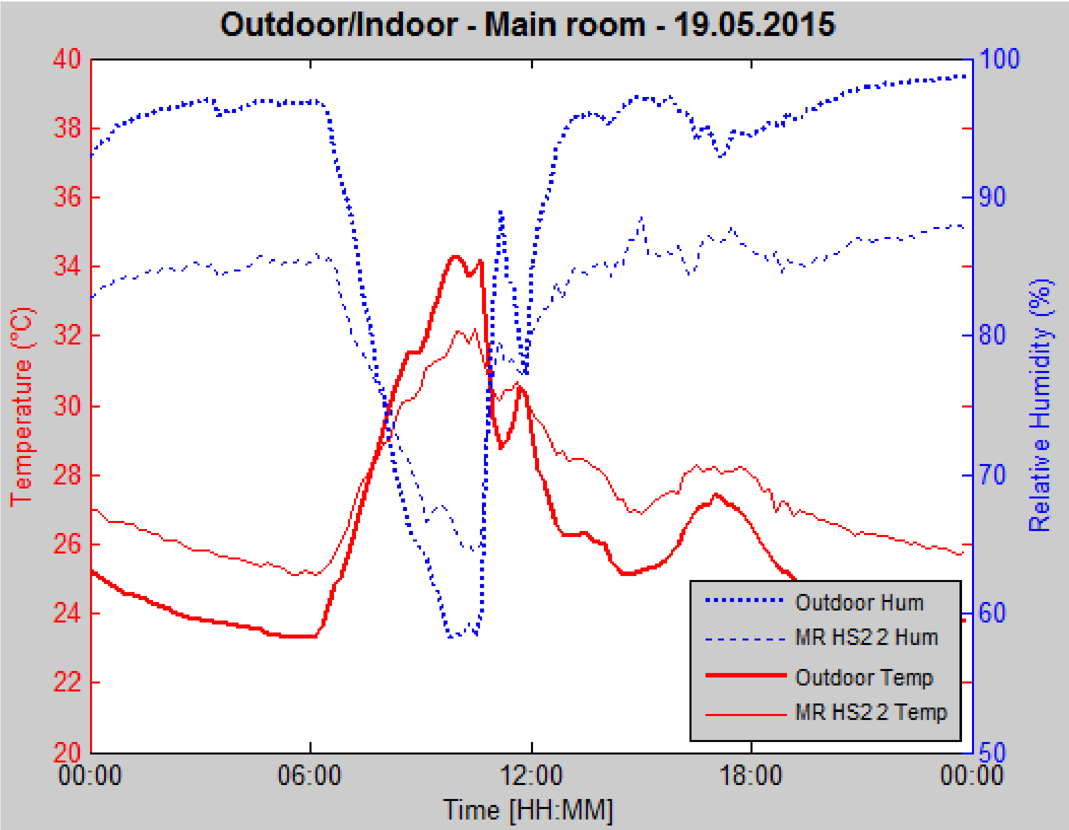

Figure 30: Air temperature and humidity, main room (SHT75) and outdoor, 19.05.2015

In general the temperatures are always decreasing during night until sunrise, while the humidity is increasing exponential. In case of the 19th of May clouds were forming in the local area at forenoon and it also started to rain, a first shower of rain at around 10.50 a.m. and a prolonged period of heavy rain from midday until evening. The outdoor humidity was then already increasing significantly above 90 % and the indoor humidity above 80 %. At the same time the temperatures were dropping down.

In contrary to the 29th of May, when the outdoor air temperature is reaching the maximum in the midday heat and then slowly decreasing, while the indoor air temperature is increasing constantly during the day until the temperature level of the already decreasing outdoor temperature is reached and then starting to descend. The humidity is showing a mirror-inverted behaviour for this weather condition. See also Figure 53 to Figure 57 in appendix for outdoor-indoor comparisons at the 21st, 22nd and 25th of May as well as at the 5th and 8th of June 2015.

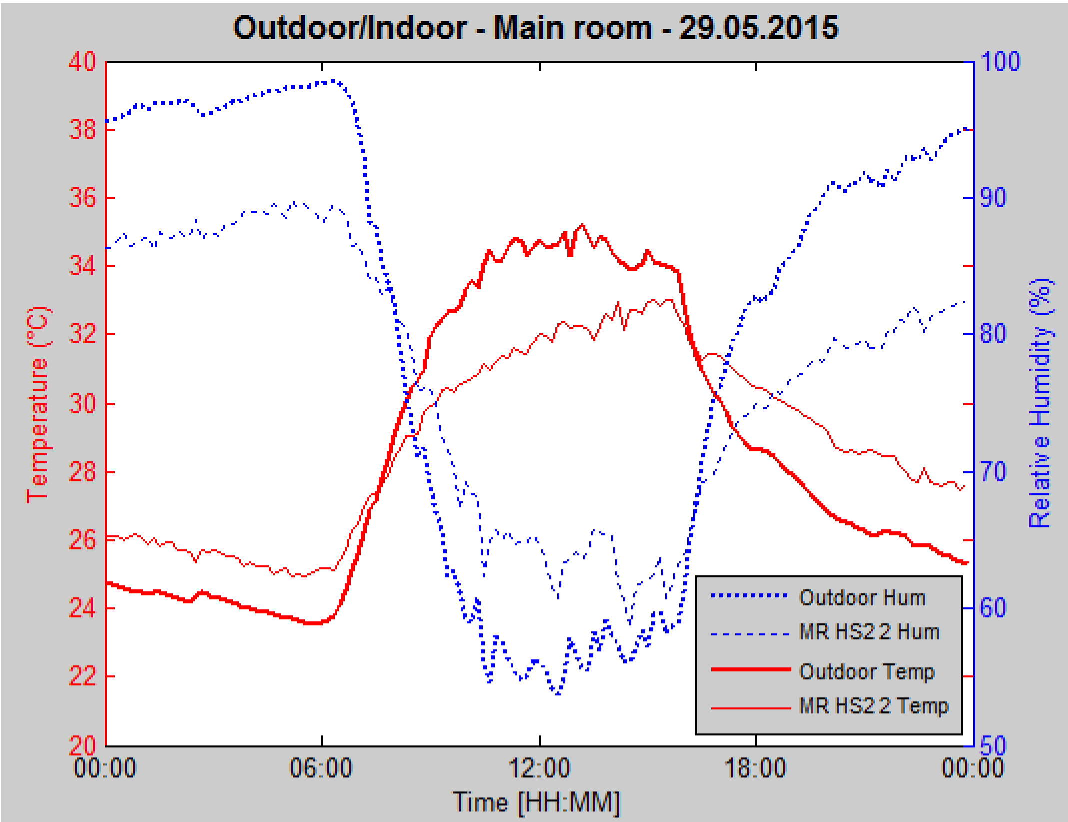

Figure 31: Air temperature and humidity, main room (SHT75) and outdoor, 29.05.2015

In summary, it can be stated that the condition in the main room has the highest dependency to the outdoor environment, influenced by the room´s orientation to the south, the highest number of operable building openings and the smallest amount of massive wall elements compared to the size of the room. Therefore the room is showing the smallest difference to the outdoor climate for both parameters. It is the hottest room in the building during the day with the lowest relative humidity and the coolest one during the night. The maximum air temperature difference is in general in the morning after sunrise, when the temperature of the outdoor air is increasing faster than the one of the main room, because of the room´s position. Conversely the biggest relative humidity differences are at night, because the outdoor humidity is also increasing faster than the indoor humidity.

Comparison of sensor types and positions

The measurement results of the 5 sensors installed at the different positions in the main room of the cottage (see chapter 2.5.1 and 2.5.2) are summarized in the following Table 25 and Table 26.

Table 25: Temperatures and rel. humidities, main room

Sensor	Mean value air temperature [°C]	Maximum air temperature [°C]	Minimum air temperature [°C]	Mean value rel. humidity [%]	Maximum rel. humidity [%]	Minimum rel. humidity [%]
HS2_1	28.57	33.50	24.06	75.40	90.12	44.31
HS2_2	28.76	34.94	23.46	74.90	93.14	40.12
HS4	29.27	35.91	22.94	72.68	89.75	50.58
RA3	30.42	38.10	23.70	60.64	85.90	31.20
RA4	29.59	32.80	25.90	72.37	89.00	54.50

Table 26: Temperature and rel. humidity differences, main room

Sensors	Absolute mean value difference [°C]	Absolute min/max difference [°C]	Absolute mean value difference [%]	Absolute min/max difference [%]
HS2_1_HS2_2	0.87	2.78	3.69	12.10
HS2_2_HS4	0.82	3.10	3.47	9.87
HS2_2_RA3	1.74	5.58	14.35	27.98
HS2_2_RA4	1.44	3.73	7.59	29.68
HS2_1_RA4	1.08	2.74	5.35	25.59
HS4_RA3	0.85	4.83	10.52	29.03

The results are displaying quite big differences. Especially sensor RA3 is showing with a mean of 30.42 °C and a maximum of 38.1 °C very high temperatures and with a minimum of 31.2 % rel. humidity also comparable low relative humidities because of its position under the ceiling at a height of 380 cm above the floor close to the water harvesting duct made of metal, which is the hottest area in the building.

Very interesting are also the values of the sensor RA4, also shown in comparison to the sensor HS2_2 in Figure 32. The sensor was placed close to the massive rammed earth wall, which main component is clay. The graph is illustrating clearly the functionality of this passive cooling element. The curves for the air temperature in the area of the wall element as well as for the relative humidity are both less extreme and more constant, because of the mass and the moisture compensating ability of the material.

The biggest variations between RA4 and HA2_2 are therefore at times with the most extreme condition, in general at cool and very humid periods during the night or at hot and dry periods during the day. See also Figure 58 to Figure 61 for the days of the 3rd of April as well as for the 8th, 9th and 10th of June.

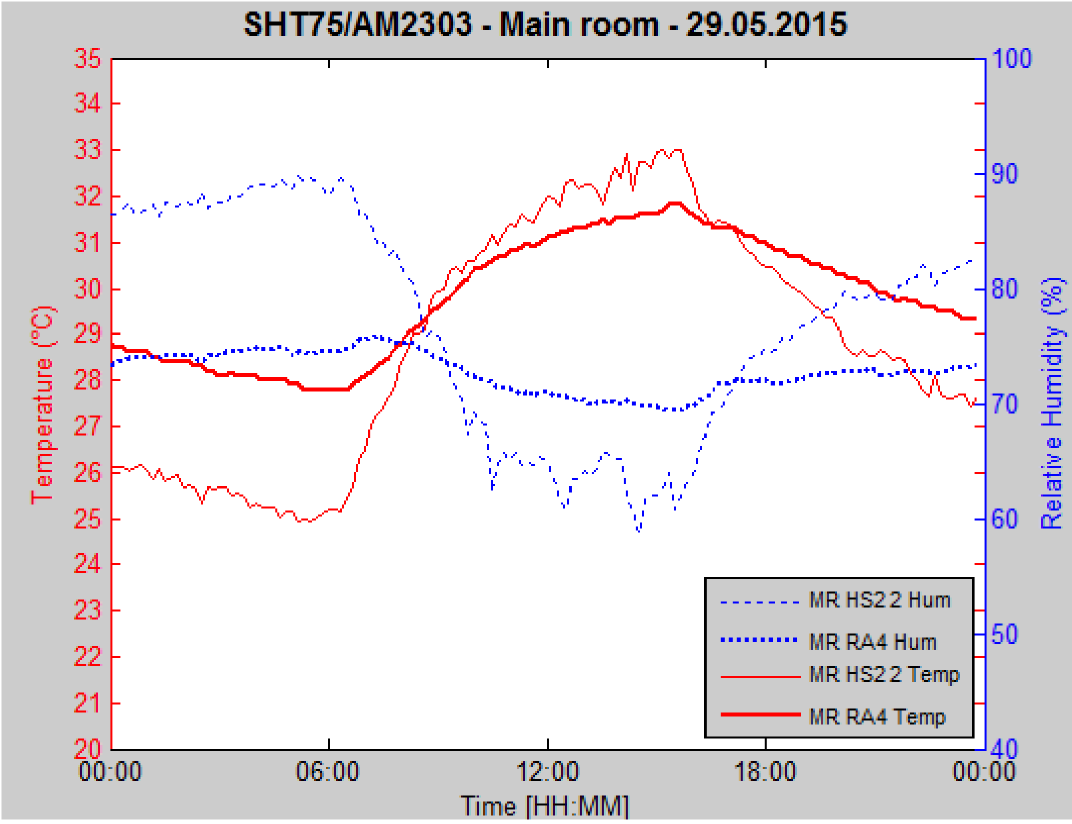

Figure 32: Air temperature and humidity, main room, AM2303 und SHT75, 29.05.2015

The comparison of the HS2_1 with the HS2_2 sensor in the main room is showing a similar and constant variation like in the bathroom, but with a slightly higher difference because of the higher interference of the outdoor climate, which is also reflected in the following Figure 33.

A further comparison with the HS4 sensor is also showing a normal vertical air temperature difference considering the height of 410 cm above the floor; even it is not placed at the same location but in the centre of the room.

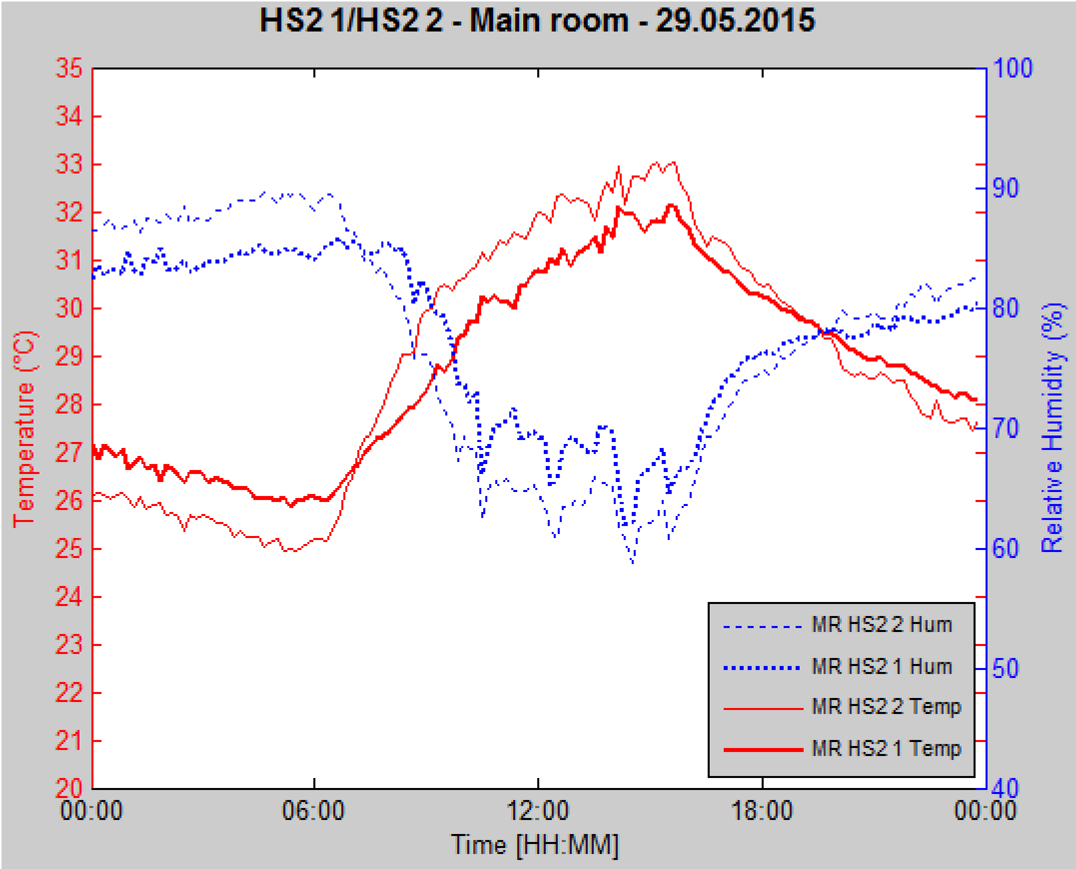

Figure 33: Air temperature and rel. humidity difference SHT sensors HS2_1 and HS2_2, 29.05.2015

3.4 Thermal comfort - PMV/PPD

In this chapter the results of the thermal comfort evaluation with PMV/PPD are displayed according to the collection of data in chapter 2.6.7 and the described necessary adaptions for natural ventilated buildings in tropical climate in chapter 1.3.2.

For showing not only the functionality for a specific defined condition, but also for the buildings design in general, the measurement periods were either extended or repeated within a short timespan over the day. A mean value with an interval of 10 minutes of the adapted measured data was then calculated to display the day and night tendencies for the thermal comfort evaluation at each position. The table below is giving an overview about the measurements described in detail in the following subchapters, while additional days are displayed in the appendix chapter Evaluation of the thermal comfort.

Table 27: Overview PMV/PPD measurements

Point	Date	Clothing set	Activity
TC1	28.05.2015	Underwear/Light summer cloth 1	Standing relaxed
TC2	11/12.06.2015	Sleepwear 1/Sleepwear 2	Sleeping
TC3	26.05.2015	Light summer cloth 2	Seated, quiet
TC4	25.05.2015	Light summer cloth 3	Seated, reclining
TC5	29.05.2015	Light summer cloth 1	Standing relaxed

For every measurement the iterative factors, the influencing parameters and the results for PMV and PPD are described in following subchapters, while the measured data of the mean values is displayed in the attachment.

3.4.1 Bathroom

For the position TC1 in the bathroom the thermal comfort evaluation was done at 4 different days. At the 28th of May a long time measurement from morning to afternoon was carried out, while at the other days additional short time measurements in the morning, at midday and in evening were carried out (See also appendix Evaluation of the thermal comfort for the days of the 10th, 11th and 12th of June).

The 28th of May was a mainly sunny day with some clouds especially around 10.00 a.m. and 01.30 p.m. At midday the temperatures were rising up to almost 36 °C. The rel. humidity was between 51 and 65 % during the measurement, while the wind was reaching a maximum speed of 2.01 m/s (see also Figure 49 in the appendix).

The evaluation of the thermal comfort for the position TC1 was done that day with 2 different clothing factors. In the morning hours the clothing set Underwear with 0.03 clo was selected for using the bathroom after waking up, while for the rest of the measurement the set Light summer cloth 1 with 0.18 clo was chosen with a more appropriate value during the day. The metabolic rate of 1.2 was adapted according to Fanger (see section 2.6.3).

Table 28: Iterative factors, bathroom TC1, 28.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
09:50	UW	Standing relaxed	Adapted*	0.6
10:52	LSC1	Standing relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

The settings of the door to the bedroom as well as of the doors to the bordering area were not changed during the period of the measurement (see Table 29).

Table 29: Influencing parameters, bathroom TC1, 28.05.2015

Time	DI1	DI2	DN1
09:50	open	open	half open
10:52	open	open	half open

The Figure 34 is displaying totally acceptable results regarding the thermal comfort in the bathroom at that day with a minimum PMV of 0.74 and a PPD of 16.64 % in the morning and with slightly increasing values over the day till a PMV of 1.36 and a PPD of 43.47 % at 15.15 p.m. Also the data for the measured parameters of the mean radiant temperature (29.84-32.15 °C), air temperatures (30.34-32.67 °C), air velocity (0.03-0.18 m/s) and rel. humidity

(60.76-70.67 %) is quite constant. See also Table 51: Bathroom, 28.05.2015, measured values for the thermal comfort evaluation in appendix for more information about the results in detail.

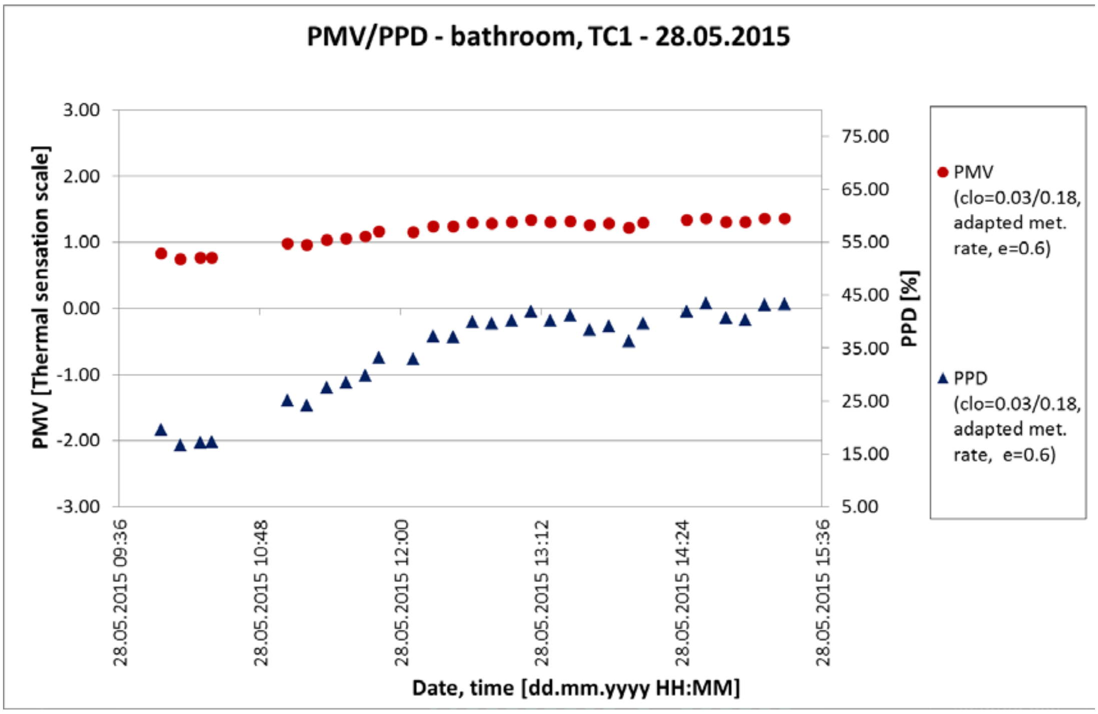

Figure 34: PMV/PPD, bathroom TC1, 28.05.2015

The following picture Figure 35 is showing a comparison of recalculated PMV variations for that period using the same indoor environment parameters. The results are illustrating that the calculation for the PMV without any adaptions for measurements of naturally ventilated buildings in tropical (see section 1.3.2) is revealing the highest values followed by the calculation with an adapted metabolic rate. Due to a further reduction of the expectancy factor to 0.5 maximum PMV values of 0.69 with the set UW and 1.13 with the set LSC1 can be achieved for the different measurement periods (see also Table 31).

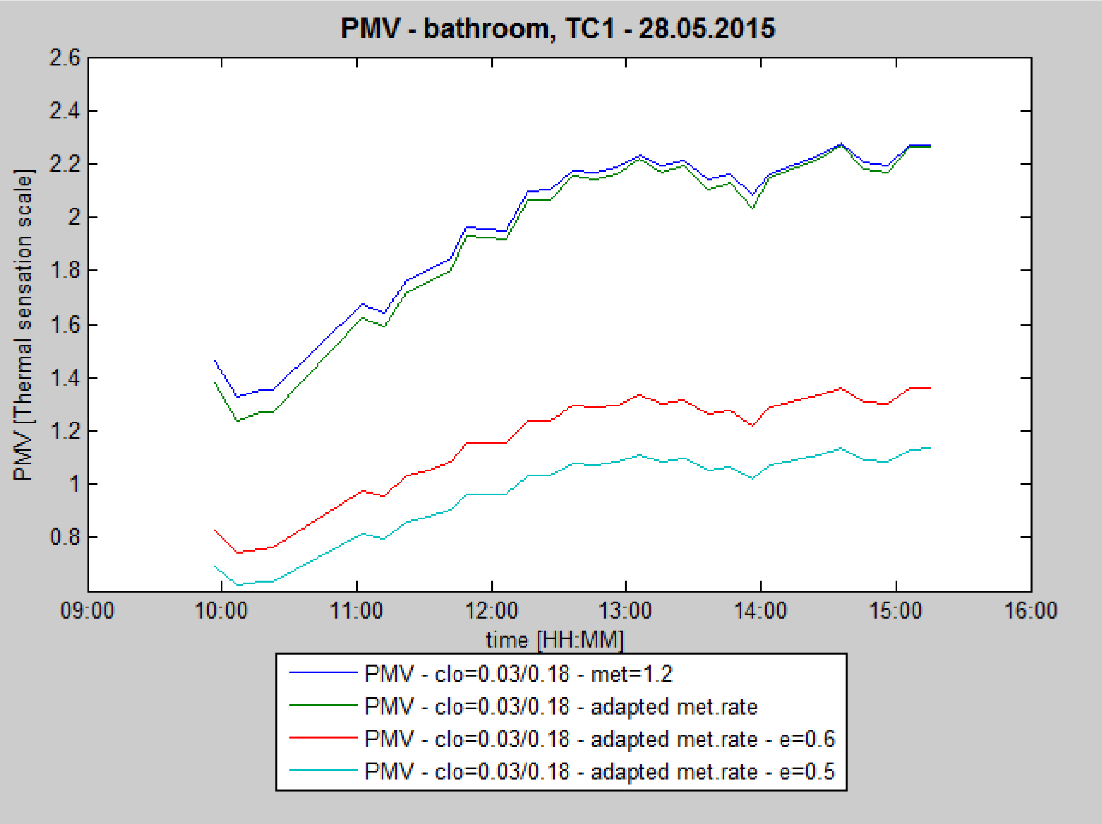

Figure 35: PMV variations for the bathroom, TC1, 28.05.2015

The results for PMV and PPD for the measured days as well as the variations with the different clothing factors, metabolic rates and expectancy factors of the bathroom are summarized in the following Table 30: PMV/PPD results for the bathroom and Table 31: PMV variations for the bathroom together with the parameters for the indoor climate.

The results are quite constant in comparison to the measurements for the activities at the other positions, affected mainly by the high amount of massive building elements as well as by the orientation of the room. The effect of the natural ventilation has in reverse only a minor influence on the results, since there is only one small window to the outside, but the thermal comfort could be increased towards neutrality by installing a mechanical ventilation device in the bathroom.

Table 30: PMV/PPD results for the bathroom

Day, time [dd.mm, HH:MM]	Set	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max	PPD (adapted met. rate, *e*=0.6) - **mean**; min;max	Air temp. - **mean**; min;max [°C]	Radiant temp. - **mean**; min;max [°C]	Air velocity - **mean**; min;max [m/s]	Rel. humidity - **mean**; min;max [°C]
28.05, 09:57-10:23	UW	**0.77** 0.74 0.83	**17.63** 16.64 19.50	**30.53** 30.34 30.68	**29.94** 29.84 30.05	**0.06** 0.03 0.10	**69.20** 67.92 70.67
28.05, 10:52-15:16	LSC1	**1.23** 0.95 1.36	**36.99** 24.20 43.47	**32.13** 30.85 32.67	**31.56** 30.31 32.15	**0.13** 0.08 0.13	**63.84** 60.76 63.84
10.06, 08:59-09:24	UW	**0.50** 0.43 0.59	**10.25** 8.81 12.19	**29.24** 28.92 29.57	**28.72** 28.54 28.96	**0.03** 0.02 0.06	**76.02** 75.22 77.20
11.06, 19:34-19:47	LSC1	**0.52** 0.46 0.57	**10.60** 9.42 11.82	**28.52** 28.49 28.59	**28.49** 28.48 28.49	**0.10** 0.07 0.14	**80.05** 79.93 80.29
12.06, 08:55-09:17	UW	**0.54** 0.52 0.55	**11.09** 10.67 11.43	**29.33** 29.29 29.41	**28.95** 28.90 29.06	**0.01** 0.01 0.02	**76.96** 76.77 77.18
12.06, 11:37-12:10	LSC1	**0.96** 0.90 1.04	**24.36** 22.11 27.88	**30.43** 30.26 30.61	**30.09** 29.87 30.49	**0.02** 0.01 0.02	**73.02** 72.09 73.54

Table 31: PMV variations for the bathroom

Day, time [dd.mm, HH:MM]	Set	PMV (1.2 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.5) - **mean**; min;max
28.05, 09:57-10:23	UW	**1.37** 1.33 1.46	**1.29** 1.24 1.38	**0.64** 0.62 0.69
28.05, 10:52-15:16	LSC1	**2.08** 1.64 2.28	**2.05** 1.59 2.27	**1.03** 0.79 1.13
10.06, 08:59-09:24	UW	**0.87** 0.76 1.00	**0.83** 0.71 0.98	**0.41** 0.36 0.49
11.06, 19:34-19:47	LSC1	**0.90** 0.79 0.97	**0.86** 0.77 0.95	**0.43** 0.38 0.48
12.06, 08:55-09:17	UW	**0.95** 0.93 0.97	**0.90** 0.87 0.92	**0.45** 0.43 0.46
12.06, 11:37-12:10	LSC1	**1.64** 1.57 1.76	**1.59** 1.50 1.74	**0.80** 0.75 0.87

3.4.2 Bedroom

The evaluation of the thermal comfort at the position TC2 in the bedroom was done at 2 days overnight from the 9th to the 10th as well as from the 11th to the 12th of June (see also appendix: Evaluation of the thermal comfort). For both dates the measurements were started in the afternoon and conducted until the late evening before midnight and then again in the early hours of the next morning to get also a tendency for the whole night.

The 11th of June was a comparable clear and sunny day in the morning with some clouds arising at the beginning of the measurement and temperatures of around 30 °C. At night the temperatures were then dropping down to a minimum of 23.80 °C and the humidity was increasing up to more than 95 %, even it was not raining. In the morning of the 12th of June it was sunny again with cloudy intervals and temperatures of more than 34 °C and a rel. humidity of less than 60 % (see also Figure 28). The maximum wind speed in that time was 1.2 m/s.

The measurement for the thermal comfort was also done with 2 different clothing factors, same as for the bathroom. In the afternoon of the 11th and the forenoon of the 12th the set Sleepwear 1 including a mattress and a sheet was selected for the simulation of a nap during the day, while for the time at night the set Sleepwear 2 including a bed with a cover was selected. A big difference for TC2 compared to all other positions is that a constant metabolic rate of 0.7 was used instead of a reduced one according to the adaption for thermal comfort calculations in tropical climate, because in a sleeping state it is already at the lowest point (see Table 32: Iterative factors, bedroom TC2, 11.06.2015 and 12.06.2015).

Table 32: Iterative factors, bedroom TC2, 11.06.2015 and 12.06.2015

Date, time	Set of clothing	Activity	Metabolic rate [met]	Exp. factor *e*
11.06.2015, 16:36	SW1	Sleeping	0.7	0.6
11.06.2015, 19:52	SW2	Sleeping	0.7	0.6
12.06.2015, 09:26	SW1	Sleeping	0.7	0.6

The door at the north side of the building was half open during the day and closed overnight from evening to morning; while the interior doors to the bordering rooms were open all the time. The fan under the ceiling was only switched on for a short period after closing the door DN1 for the night.

Table 33: Influencing parameters, bedroom TC2, 11.06.2015 and 12.06.2015

Date, time	DN1	DI1	DI2	F1
11.06.2015, 16:36	half open	open	open	off
11.06.2015, 18:07	closed	open	open	on
11.06.2015, 19:52	closed	open	open	off
12.06.2015, 09:26	half open	open	open	off

The values illustrated in the following graph (PMV/PPD, bedroom TC2, 11.06.2015 and 12.06.2015) are predicting a pleasant thermal comfort in the bedroom during the measurement. Especially the results during the day at the 11th are with an average PMV value of 0.50 and a PPD value of 10.76 % close to thermal neutrality. The measured values during the cooler night are showing in general the same tendency with average values for PMV of 0.61 and 12.95 % for PPD because of the different clothing sets, but with an increase for the time after sunrise with average values of 0.95 and 24.58 %. The evaluation of the thermal comfort for the day of the 12th of June is then showing results in the slightly warmer range of the thermal sensation scale, because of the more extreme outdoor conditions. In the time period of the measurement the mean radiant temperature was varying between 26.76 and 31.39 °C, the air temperature between 26.80 and 31.78 °C and the rel. humidity between 68.34 and 84.59 %, while there was only a comparable low air speed in the room with values between 0.01 and 0.21 m/s except for the time of the early evening when the fan was switched on. See also Table 56: Bedroom, 11.06.2015 and 12.06.2015, measured values for the thermal comfort evaluation in appendix.

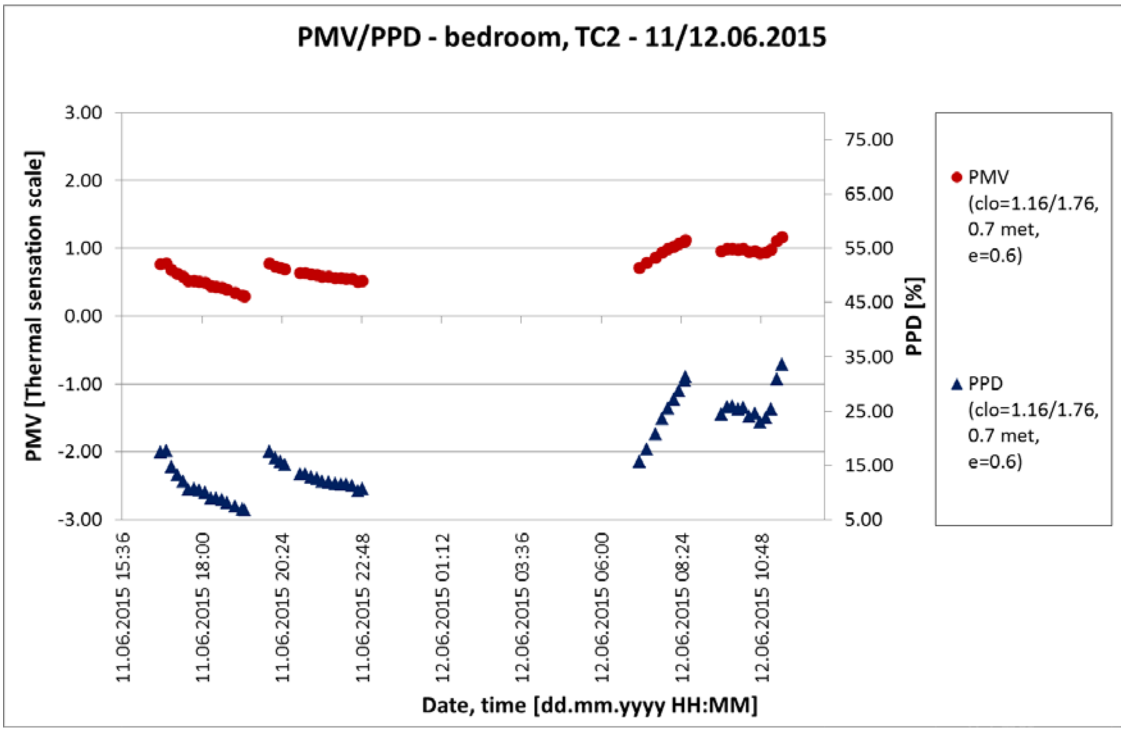

Figure 36: PMV/PPD, bedroom TC2, 11.06.2015 and 12.06.2015

The following chart (PMV variations for the bedroom, TC2, 11/12.06.2015) is displaying the comparison of the recalculated results using different values for the clothing and expectancy factor. Same as for the bathroom, the highest values were calculated for the standard PMV (set SW1/SW2), followed by the adaptions caused by the influence of the expectancy factor. An exception in this case is the recalculated PMV with the adjusted clothing factor of 1.01 (set SW3), while achieving results during the day, which are only slightly lower than of the standard PMV, a thermal comfort close to neutrality can be achieved even without the adaption of the expectancy factor (see also Table 35).

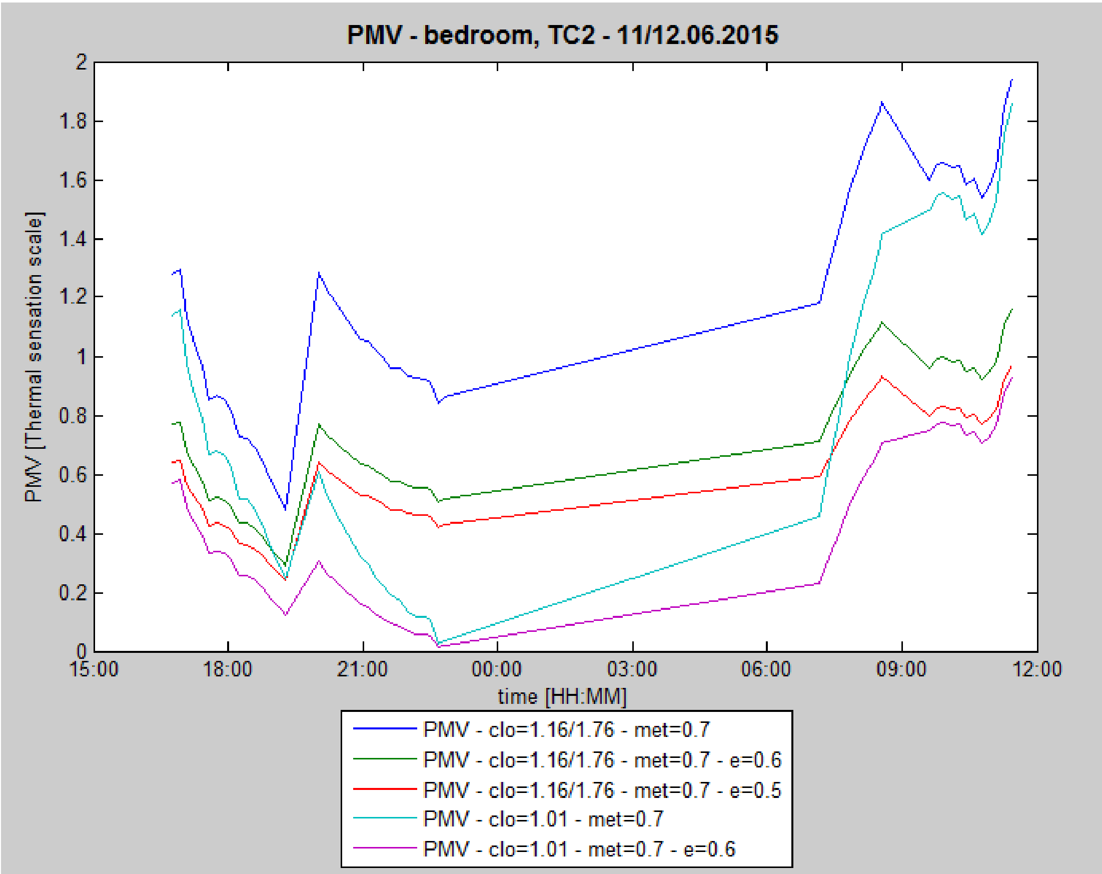

Figure 37: PMV variations for the bedroom, TC2, 11/12.06.2015

The Table 34 and the Table 35 below are summarizing the PMV and PPD results for the bedroom all together with the parameters for the indoor conditions as well as the results for the PMV variations. The results are showing that the type of the bedding system and the percentage of the cover are influential for achieving a thermal comfort. Especially during the night the thermal comfort in the bedroom can be controlled by the choice of the bedding, while during the day a thermal comfort can be achieved by the support of the fan.

Table 34: PMV/PPD results for the bedroom

Day, Time [dd.mm, HH:MM]	Set	PMV (0.7 met, *e*=0.6) - **mean**; min;max	PPD (0.7 met, *e*=0.6) - **mean**; min;max	Air temp. - **mean**; min;max [°C]	Radiant temp. - **mean**; min;max [°C]	Air velocity - **mean**; min;max [m/s]	Rel. humidity - **mean**; min;max [°C]
09.06, 15:33-19:49	SW1	**0.39** 0.19 0.55	**8.38** 5.72 11.36	**27.81** 26.93 28.52	**27.79** 26.98 28.51	**0.05** 0.02 0.09	**83.19** 80.40 85.02
09.06, 19:55-22:39	SW2	**0.42** 0.34 0.53	**8.67** 7.41 10.79	**26.29** 25.97 26.85	**26.31** 25.98 26.85	**0.06** 0.03 0.09	**84.59** 83.46 85.73
10.06, 06:22-08:38	SW2	**0.56** 0.20 0.84	**12.66** 5.87 20.00	**27.06** 25.10 28.85	**27.01** 25.13 28.73	**0.04** 0.02 0.07	**83.86** 76.75 87.58
11.06, 16:36-19.16	SW1	**0.50** 0.29 0.78	**10.76** 6.72 17.67	**29.06** 28.39 29.89	**28.87** 28.15 29.85	**0.25** 0.07 0.37	**78.38** 74.68 80.70
11.06, 19:52-22:50	SW2	**0.61** 0.50 0.77	**12.95** 10.29 17.49	**27.32** 26.80 28.11	**27.31** 28.22 26.76	**0.05** 0.03 0.08	**83.33** 81.84 84.49
12.06, 07:09-08:32	SW2	**0.95** 0.71 1.12	**24.58** 15.59 31.33	**29.22** 27.82 30.30	**29.07** 27.63 30.06	**0.02** 0.01 0.04	**80.37** 75.68 84.59
12.06, 09:26-11:26	SW1	**1.00** 0.92 1.17	**26.01** 22.98 33.60	**30.91** 30.47 31.78	**30.61** 30.31 31.39	**0.08** 0.06 0.12	**72.51** 68.34 77.71

Table 35: PMV variations for the bedroom

Day, Time [dd.mm, HH:MM]	Set	PMV (0.7 met) - **mean**; min;max	PMV (0.7 met, *e*=0.5) - **mean**; min;max	Set	PMV (0.7 met) - **mean**; min;max	PMV (0.7 met, *e*=0.6) - **mean**; min;max
09.06, 15:33-19:49	SW1	**0.65** 0.31 0.92	**0.32** 0.16 0.46	SW3	**0.46** 0.11 0.75	**0.23** 0.05 0.38
09.06, 19:55-22:39	SW2	**0.69** 0.57 0.88	**0.35** 0.28 0.44	SW3	**-0.19** -0.35 0.06	**-0.09** -0.18 0.03
10.06, 06:22-08:38	SW2	**0.94** 0.34 1.41	**0.47** 0.17 0.70	SW3	**0.14** -0.66 0.82	**0.07** -0.33 0.41
11.06, 16:36-19.16	SW1	**0.84** 0.48 1.29	**0.42** 0.24 0.65	SW3	**0.65** 0.24 1.16	**0.32** 0.12 0.58
11.06, 19:52-22:50	SW2	**1.02** 0.84 1.28	**0.51** 0.42 0.64	SW3	**0.25** 0.02 0.61	**0.13** 0.01 0.30
12.06, 07:09-08:32	SW2	**1.59** 1.18 1.86)	**0.80** 0.59 0.93	SW3	**1.03** 0.46 1.41	**0.51** 0.23 0.71
12.06, 09:26-11:26	SW1	**1.66** 1.54 1.94	**0.83** 0.77 0.97	SW3	**1.55** 1.41 1.86	**0.78** 0.71 0.93

3.4.3 Main room - Dining Area

The prediction of the thermal comfort in the main room was executed at the three most used positions in this room. Starting with TC3 for the dining area, the monitoring was carried out at four different days. The results of the measurement for the 26th of May are described in detail in this subchapter, while the days of the 19th, 21st and 22nd of May are displayed in the appendix: Evaluation of the thermal comfort.

The 26th of May was a sunny day without precipitation but with some cloudy intervals later on, at which the air temperature was increasing to a maximum of almost 35 °C. The rel. humidity was in the range from 56 to 75 % during the time of the measurement and with an average of 1.04 m/s and a maximum of 3.82 m/s it was quite windy.

The prediction of thermal comfort at the dining area TC3 was done with a clothing factor of 0.19, which includes the set Light summer cloth 1 as well as the impact of a wooden chair.

Table 36: Iterative factors, dining area TC3, 26.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
09:27	LSC2	Seated, quiet	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

The building openings of the main room were operated in dependency to the outdoor climate with the goal to achieve a thermal comfort as close as possible to thermal neutrality. The openings to the east were therefore in general closed in the morning and forenoon; the openings to the south were closed during midday, while the openings to the west were closed from around half past two until sunset according to the path of the sun to prevent a heating-up of the room. On the other hand, doors and windows opposite to each other were opened at the same time to let a breeze flowing through the building according to the passive cooling principles (see Table 37 and Table 38). Additional the fan was switched on because of the high outdoor temperatures during the time of the measurement.

Table 37: Influencing parameters, dining area TC3, 26.05.2015, doors and fan

Time	DN2	DW1	DI2/DN1	DS1	F2
09:27	closed	open	open/open	half open	on
10:05	closed	open	open/open	half open	on
11:36	closed	open	open/open	half open	on
12:11	closed	open	open/open	closed	on
13:05	closed	open	open/open	closed	on
14:37	closed	closed	open/open	half open	on

Table 38: Influencing parameters, dining area TC3, 26.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
09:27	closed	closed	closed	closed	tilted	tilted	tilted	tilted	tilted	tilted
10:05	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
11:36	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted
12:11	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
13:05	tilted	tilted	tilted	tilted	closed	closed	closed	tilted	tilted	tilted
14:37	tilted	tilted	tilted	tilted	tilted	tilted	tilted	closed	closed	closed

The Figure 38 below is displaying acceptable results regarding thermal comfort for the dining area of the main room at the 26th of May with values for PMV between 0.45 and 1.64 considering an average outdoor air temperature of 33.23 °C for the time of the measurement. The results are showing a thermal comfort close to neutrality in the morning and especially in the afternoon as well as in the evening, while the critical time is the very hot period in the middle of the day. The short increase of the PMV and therefore also of the PPD in the afternoon is explained by the missing shading device for the backdoor (DW1) of the building. The measured parameters are varying between 31.05 and 33.93 °C for the mean radiant temperature, 31.25 and 33.91 °C for the air temperature, 0.67 and 1.00 m/s for the air velocity at the location TC3 as well as between 58.55 and 70.87 % for the rel. humidity. See also Table 60: Dining area, 26.05.2015, measured values for the thermal comfort evaluation in appendix for more information about the results in detail.

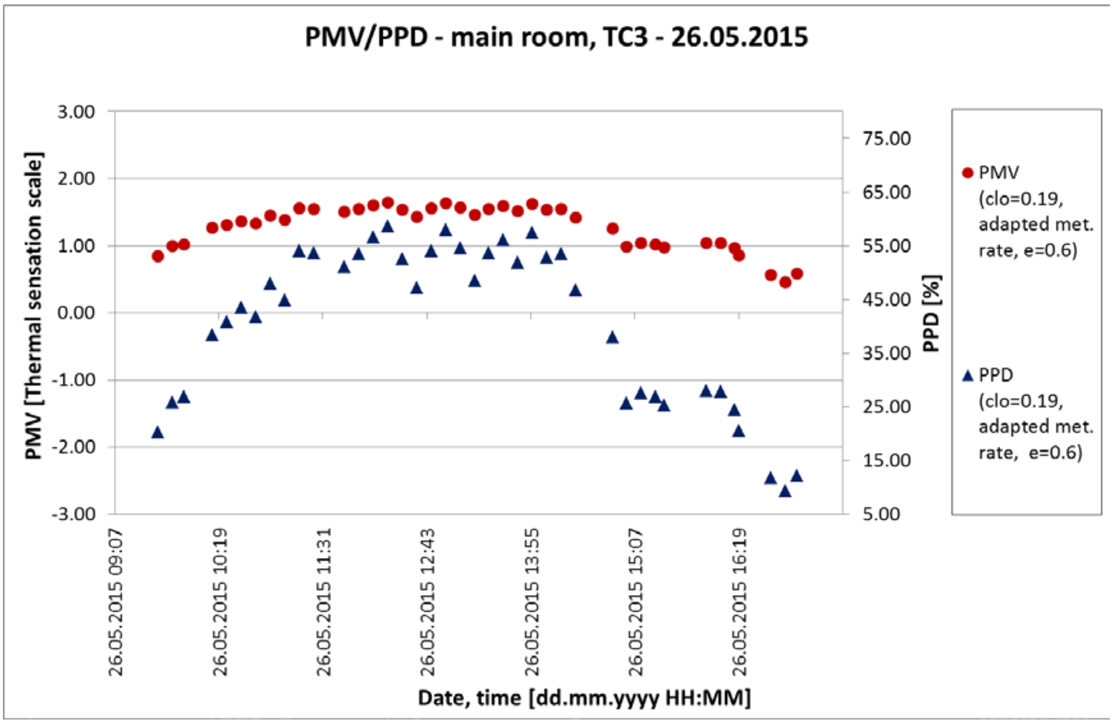

Figure 38: PMV/PPD, dining area TC3, 26.05.2015

The Figure 39 below is illustrating the different recalculated PMV variations for the dining area at the 26th of May using different iterative parameters. Additional to the calculations without the adaptions for predictions in tropical climates and with a further reduced expectancy factor, the comparison was also done with a higher clothing factor of 0.5 clo for the set FW, simulating formal apparel. This last one without any adaptions is showing the highest PMV results, followed by the variations without the addition of an expectancy factor. The curves with the lower values were caused by the expectancy factor accordingly (see also Table 40).

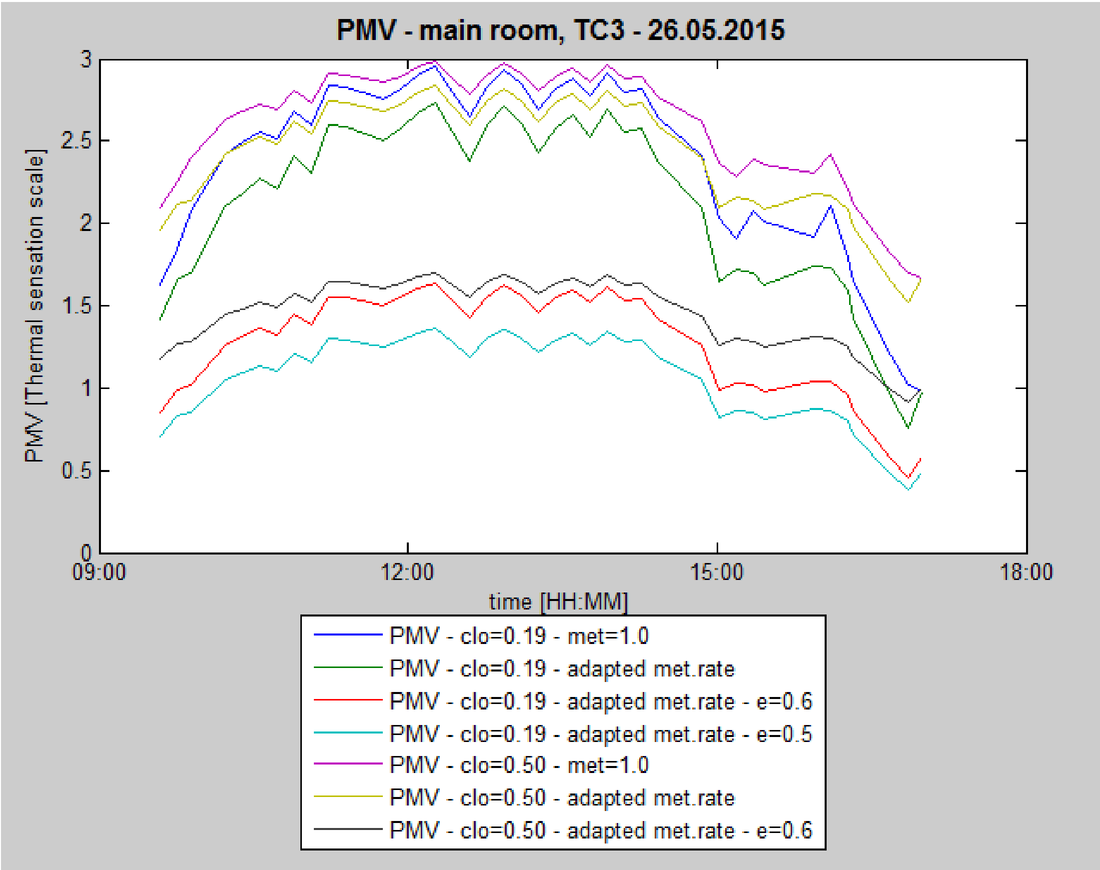

Figure 39: PMV variations for the dining area, TC3, 26.05.2015

The results for PMV and their variations as well as the values of the indoor conditions during the times of the measurements are summarized in the following Table 39 and Table 40.

The values are clarifying the higher dependency of the main room to the outdoor climate. While at cooler days with a very high humidity even outcomes in the cool area of the thermal sensation scale were obtained, a higher air velocity is needed to provide an acceptable thermal comfort for hot and dry periods. Due to the supporting use of the fan located above the dining area, an average indoor air velocity close to the average wind velocity can be provided to achieve a PMV (LSC2, adapted met. rate, e=0.6) of less than 1.64 even at most extreme outdoor conditions.

Table 39: PMV/PPD results for the dining area in the main room

Day, Time [dd.mm, HH:MM]	Set	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max	PPD (adapted met. rate, *e*=0.6) - **mean**; min;max	Air temp. - **mean**; min;max [°C]	Radiant temp. - **mean**; min;max [°C]	Air velocity - **mean**; min;max [m/s]	Rel. humidity - **mean**; min;max [°C]
19.05, 12:05-17:30	LSC2	**0.16** -0.06 0.39	**5.94** 5.00 8.17	**28.14** 27.01 29.74	**28.23** 27.16 30.04	**0.09** 0.04 0.18	**85.10** 80.73 87.30
21.05, 10:37-16:25	LSC2	**0.20** -0.42 0.95	**8.72** 5.01 23.95	**29.97** 28.61 32.15	**29.99** 28.63 32.19	**0.62** 0.48 0.89	**78.30** 68.65 83.97
22.05, 09:33-18:08	LSC2	**0.94** 0.14 1.21	**25.17** 5.43 35.57	**32.22** 30.22 32.89	**32.24** 30.08 32.93	**0.66** 0.51 0.89	**68.04** 64.46 71.59
26.05, 09:27-16:59	LSC2	**1.28** 0.45 1.64	**40.51** 9.32 58.55	**33.17** 31.25 33.91	**33.12** 31.05 33.93	**0.85** 0.76 1.00	**61.79** 58.55 70.87

Table 40: PMV variations for the dining area in the main room

Day, time [dd.mm, HH:MM]	Set	PMV (1.0 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.5) - **mean**; min;max	Set	PMV (1.0 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max
19.05, 12:05-17:30	LSC2	**0.42** -0.10 0.98	**0.27** -0.10 0.65	**0.13** -0.05 0.33	FW	**1.02** 0.59 1.51	**0.90** 0.53 1.26	**0.54** 0.32 0.75
21.05, 10:37-16:25	LSC2	**0.38** -0.69 1.77	**0.34** -0.69 1.58	**0.17** -0.35 0.79	FW	**1.22** 0.48 2.21	**1.19** 0.48 2.08	**0.71** 0.29 1.25
22.05, 09:33-18:08	LSC2	**1.82** 0.24 2.32	**1.57** 0.24 2.01	**0.88** 0.12 1.01	FW	**2.22** 1.15 2.56	**2.05** 1.15 2.56	**1.23** 0.69 1.40
26.05, 09:27-16:59	LSC2	**2.52** 1.12 3.08	**2.13** 0.76 2.73	**1.06** 0.38 1.37	FW	**2.61** 1.67 2.98	**2.43** 1.53 2.84	**1.46** 0.92 1.70

3.4.4 Main room - Couch Area

The couch area TC4 is the second position in the main room, located in the eastern part. For this position the thermal comfort prediction was done at 2 different days, the 25th of May as well as at the 8th of June (see also appendix: Evaluation of the thermal comfort).

The 25th of May was a comparable hot and sunny day with temperatures of more than 35 °C during the measurement, while the rel. humidity was dropping down from 98 % before sunrise to 53 % around midday and then rising again in the second half of the day before reaching values of more than 90 % at 8.30 p.m. (see also Figure 55). There was no precipitation that day, but with an average of 1.06 m/s it was constantly windy.

The measurement for the prediction of the thermal comfort for the location of the couch area was carried out with one clothing factor of 0.33, similar to the measurement for the dining area, using light summer clothing but with an armchair in addition instead of a wooden chair. The metabolic rate of 0.8 (seated, reclining) was adapted according to Fanger (see chapter 2.6.3).

Table 41: Iterative factors, couch area TC4, 25.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
10:50	LSC3	Seated, reclining	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

The influencing parameters, especially the operable building openings, were controlled according to the same principle as for the dining area and in dependency to the outdoor climate with the difference that the fan is out of reach to affect the couch area and was therefore switched off from the beginning until the end of the measurement (see Table 42 and Table 43).

Table 42: Influencing parameters, couch area TC4, 25.05.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
10:50	open	open	open	half open	off
11:36	closed	open	open	half open	off
13:00	closed	open	open	closed	off
15:48	closed	closed	open	closed	off

Table 43: Influencing parameters, couch area TC4, 25.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
10:50	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
11:36	open	open	open	open	open	tilted	tilted	tilted	tilted	tilted
13:00	open	open	open	open	open	closed	closed	closed	tilted	tilted
15:48	open	open	open	open	tilted	tilted	tilted	closed	closed	closed

The values illustrated in the chart (PMV/PPD, main room TC4, 25.05.2015) below are predicting the thermal comfort for the couch area at the 25th of May. The results with an average of 1.14 for PMV and 34.45 % for PPD are similar to the ones of the dining area at the 26th of May as well as the tendency over the day. In the time period of the measurement the mean radiant temperature was fluctuating between 30.86 and 34.29 °C, the air temperature between 30.81 and 34.614 °C and the rel. humidity between 54.52 and 72.50 %, while the air velocity was varying between 0.17 and 0.45 m/s at the position TC4. See also Table 61: Couch area, 25.05.2015, measured values for the thermal comfort evaluation in appendix.

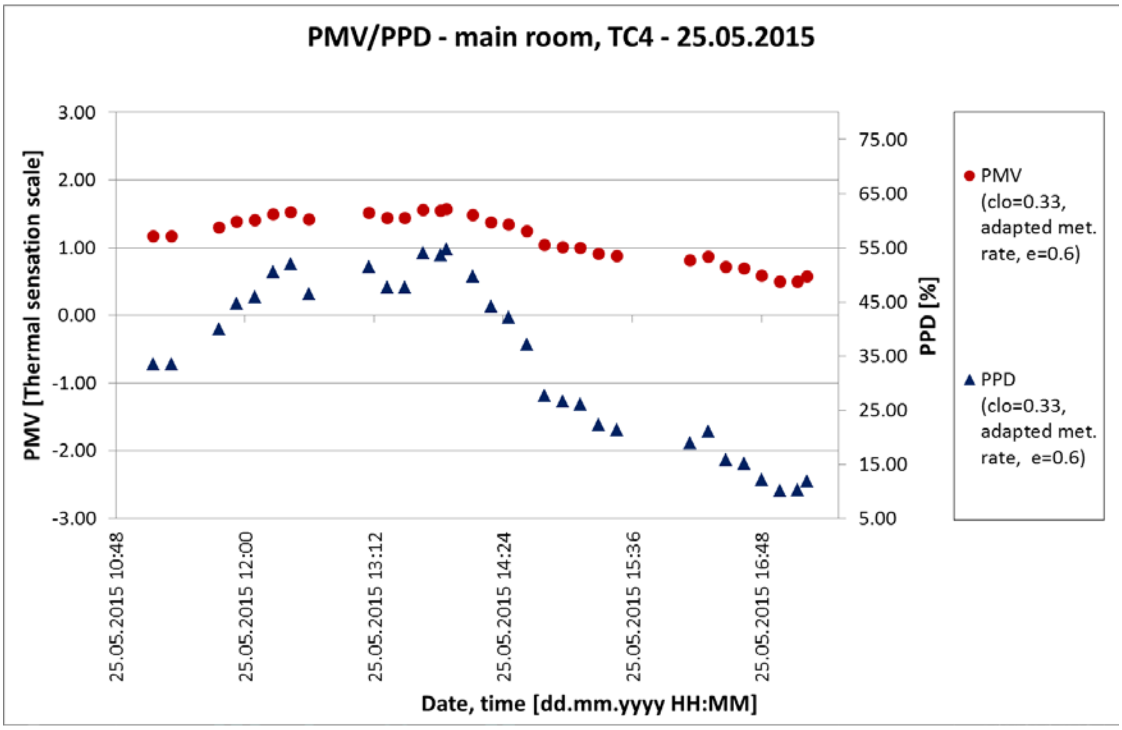

Figure 40: PMV/PPD, main room TC4, 25.05.2015

The comparison of the results with the PMV variations for the standard calculation and with the adaptions regarding the metabolic rate and the expectancy factor for the clothing factors 0.33 (LSC3) and 0.5 (FW) at that day (see the following Figure 41) is showing the same tendencies as for the dining area at the 26th of May (see also Table 45).

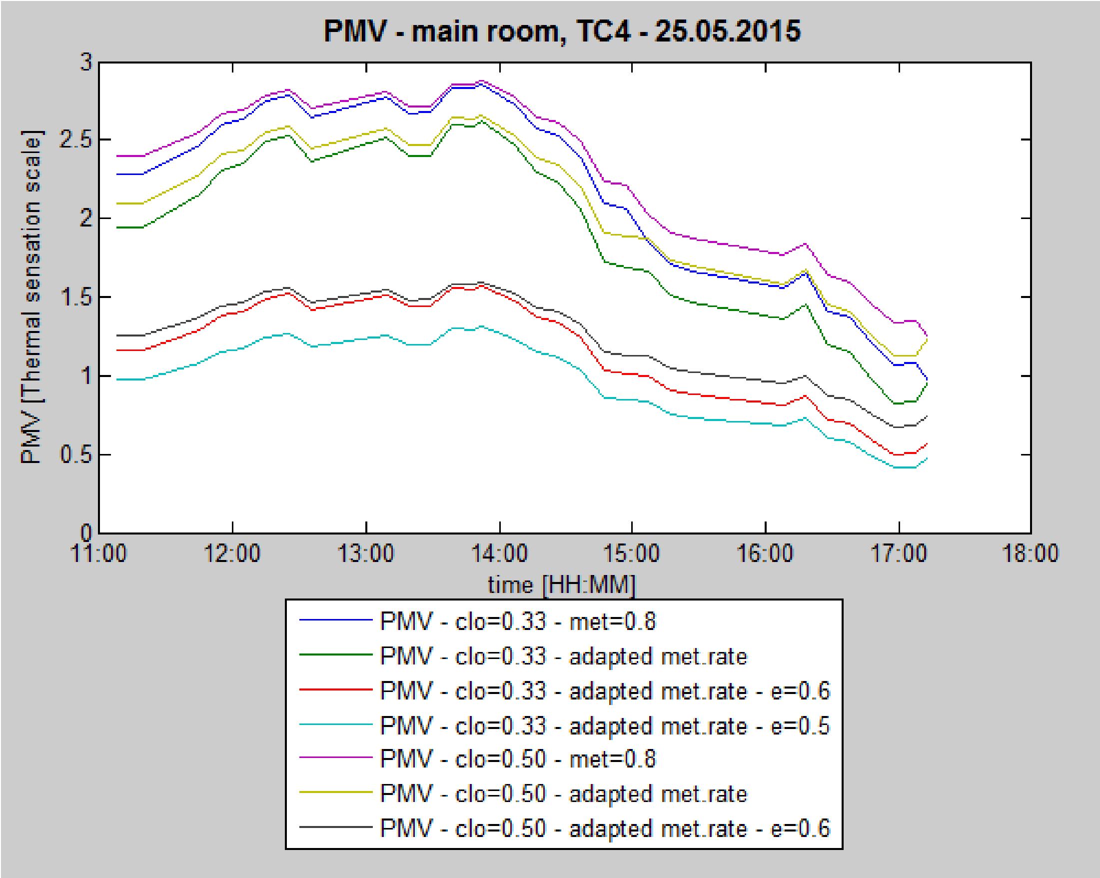

Figure 41: PMV variations for the couch area, TC4, 25.05.2015

The Table 44 and the Table 45 below are summarizing the PMV and PPD results and the variations for the bedroom of the examined days together with the measured parameters of the indoor conditions.

Even the average values are showing acceptable values for a thermal comfort in the couch area, considering the extreme outdoor conditions at these days; some results tend to rise towards the warmer area on the thermal sensation scale. These peaks are partly caused by the very low air velocity at the position, since there is no supporting ventilation device for equalizing calm periods.

Table 44: PMV/PPD results for the couch area in the main room

Day, time [dd.mm, HH:MM]	Set	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max	PPD (adapted met. rate, *e*=0.6) - **mean**; min;max	Air temp. - **mean**; min;max [°C]	Radiant temp. - **mean**; min;max [°C]	Air velocity - **mean**; min;max [m/s]	Rel. humidity - **mean**; min;max [°C]
25.05, 10:50- 17.13	LSC3	**1.14** 0.49 1.57	**34.45** 10.10 54.69	**32.98** 30.81 34.14	**33.08** 30.86 34.29	**0.33** 0.17 0.45	**61.88** 54.52 72.55
08.06, 10:09- 17:22	LSC3	**1.53** 0.92 2.08	**53.11** 22.76 80.26	**34.05** 32.16 35.32	**34.36** 32.39 35.64	**0.35** 0.20 0.61	**55.32** 48.70 63.98

Table 45: PMV variations for the couch area in the main room

Day, time [dd.mm, HH:MM]	Set	PMV (0.8 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.5) - **mean**; min;max	Set	PMV (0.8 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max
25.05, 10:50-17.13	LSC3	**2.16** 0.96 2.85	**1.90** 0.82 2.62	**0.95** 0.41 1.31	FW	**2.28** 1.25 2.87	**2.06** 1.13 2.66	**1.23** 0.68 1.60
08.06, 10:09-17:22	LSC3	**2.84** 1.72 3.67	**2.56** 1.53 3.47	**1.28** 0.67 1.73	FW	**2.85** 1.89 3.56	**2.60** 1.73 3.36	**1.56** 1.04 2.01

3.4.5 Main room - Centre

The third examined position in the main room is the centre, for which the thermal comfort calculation with PMV/PPD was done at the 29th of May, as described below, and at the 5th of June (see appendix: Evaluation of the thermal comfort).

The 29th of May was a very hot and sunny day with only a few clouds arising in the late afternoon. It was not raining in the local area and the maximum wind speed during the measurement was 2.42 m/s. After sunrise the outdoor temperature was increasing constantly until more than 35 °C and then declining again after midday to 25 °C at midnight. The outdoor rel. humidity on the other side was decreasing from more than 90 % in the night to a minimum of 53 % in the middle of the day (see also Figure 31).

The thermal comfort prediction for the centre of the main room at the position TC5 was done with the clothing factor of the set Light summer cloth 1, without the addition of any furniture since a standing position is assumed for this location (see Table 46).

Table 46: Iterative factors, centre TC5, 29.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
09:36	LSC1	Standing relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Since the 29th of May was similar to the 25th and 26th of May a dry and hot day without rain, the building openings were controlled according to the described principle for the dining and couch areas (see chapters 3.4.3 and 3.4.4), while the fan was only switched on at midday (see Table 47 and Table 48).

Table 47: Influencing parameters, centre TC5, 29.05.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
09:36	closed	open	open	half open	off
11:48	closed	open	open	closed	on
14:26	closed	closed	open	half open	on

Table 48: Influencing parameters, centre TC5, 29.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
09:36	closed	closed	closed	closed	tilted	tilted	tilted	tilted	tilted	tilted
11:48	open	open	open	open	closed	closed	closed	tilted	tilted	tilted
14:26	open	open	open	open	tilted	tilted	tilted	closed	closed	closed

The following chart (PMV/PPD, main room TC5, 29.05.2015) is exemplifying the results for the thermal comfort prediction in the centre of the main room at the 29th of May. The thermal comfort is with an average PMV of 1.59 and a maximum of 1.77 at the edge of the acceptance, considering even the very hot outdoor climate with an average of 34.1 °C during the measurement. The measured parameters for the indoor conditions are fluctuating between 32.15 and 33.83 °C for the mean radiant temperature, 32.21 and 33.86 °C for the air temperature, 0.19 and 0.38 m/s for the air velocity at this position as well as between 55.94 and 63.85 % for the rel. humidity. See also Table 63: Centre, 29.05.2015, measured values for the thermal comfort evaluation in appendix for more detailed information about the measurement results.

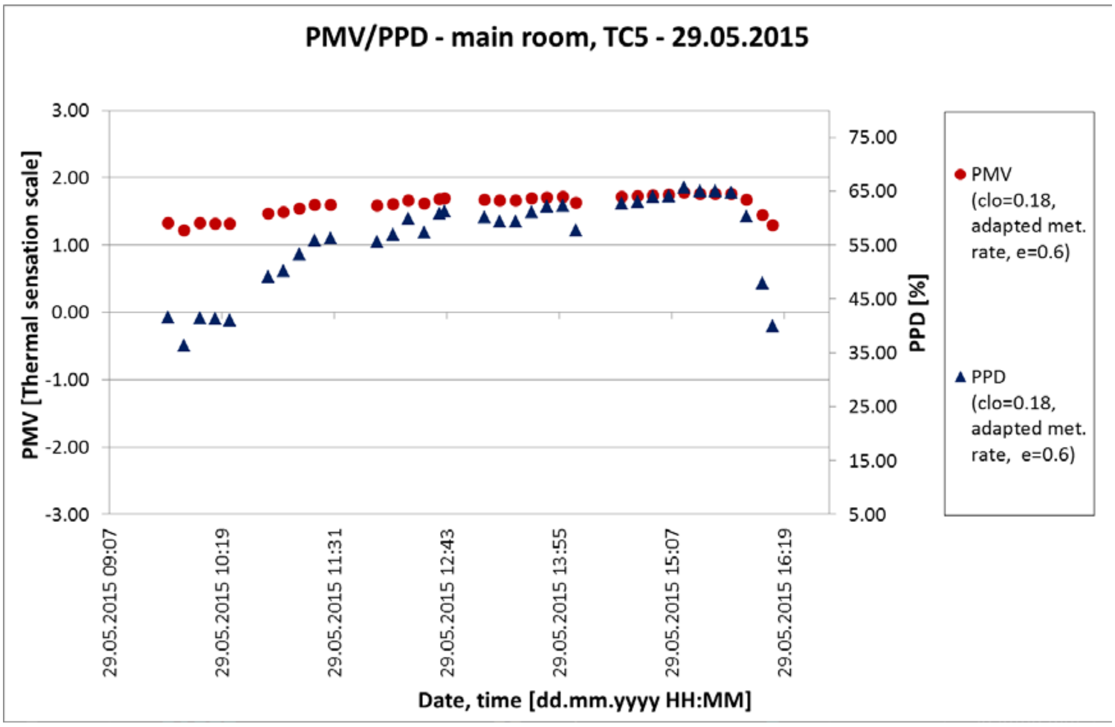

Figure 42: PMV/PPD, main room TC5, 29.05.2015

The chart PMV variations for the centre of the main room, TC5, 29.05.2015 is displaying the comparison of the calculations with the same variations like for the dining and couch area, based on the thermal comfort evaluation using the clothing factor of the set LSC1 for the position TC5 (see also Table 50).

The curves of the PMV variations for the centre of the main room are showing a different behaviour in the upper range of the thermal sensation scale compared to the positions TC3 and TC4. First, in contradiction to the other positions, the PMV results for the calculation with the adapted metabolic rates (no multiplication with an expectancy factor) are showing higher values than the standard calculations for LSC1 and FW. Second, the calculation with the adapted metabolic rate for the set LSC1 is showing higher values than the standard calculation for the set UW, which has a higher clothing factor. This behaviour is caused by the interaction of the human ability of thermoregulation in combination with the clothing (see section 1.3.1) at these extreme indoor conditions with almost no air movement at this position.

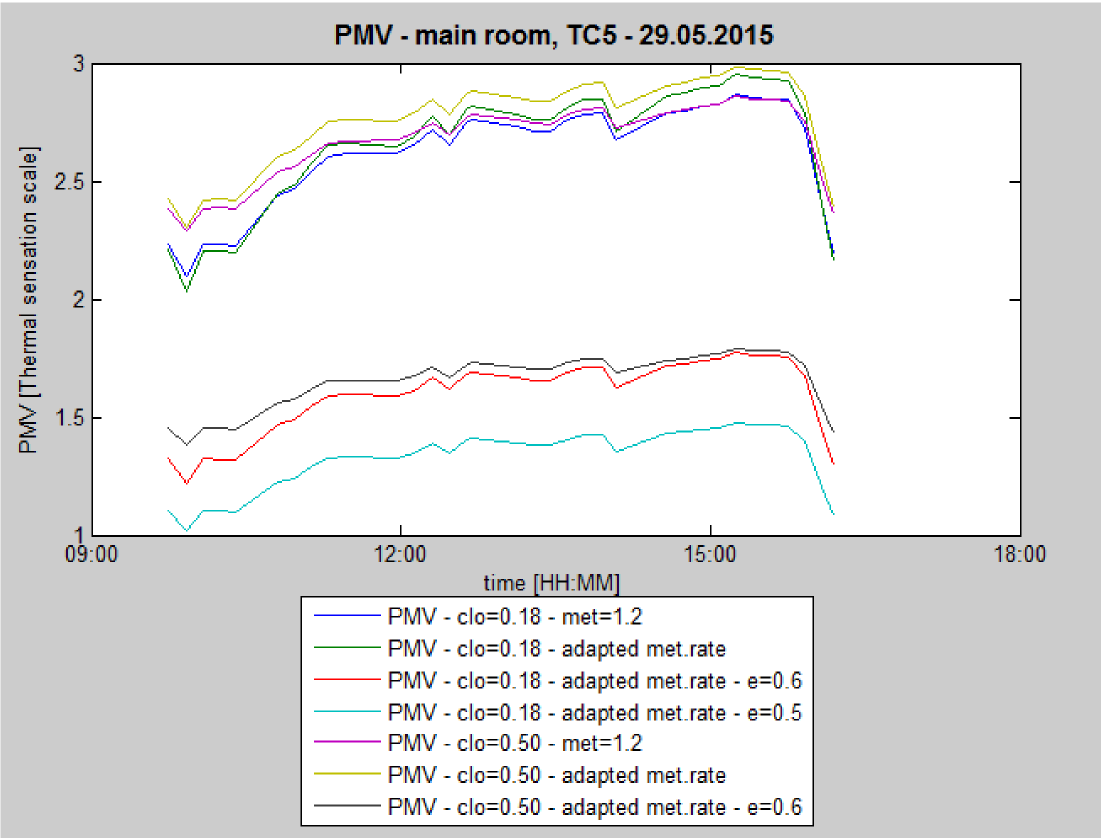

Figure 43: PMV variations for the centre of the main room, TC5, 29.05.2015

The Table 49 and the Table 50 below are summarizing the PMV and PPD results for the position TC5 in the main room, the PMV variations as well as the parameters for the indoor conditions. The results are clarifying again, similar to the couch area, the importance for the need of an additional ventilation device especially for calm periods, since the maximum air velocity at this position was measured with 0.3 m/s. In addition to a fan, also shades for the backdoor of the building (DW1) to the west are needed to prevent the main room of heating-up in the afternoon.

Table 49: PMV/PPD results for the centre of the main room

Day, time [dd.mm, HH:MM]	Set	PMV (adapted met. rate, *e*=0.6) - **mean**; min;max	PPD (adapted met. rate, *e*=0.6) - **mean**; min;max	Air temp. - **mean**; min;max [°C]	Radiant temp. - **mean**; min;max [°C]	Air velocity - **mean**; min;max [m/s]	Rel. humidity - **mean**; min;max [°C]
29.05, 09:36-16.12	LSC1	**1.59** 1.22 1.77	**55.96** 36.24 65.64	**33.34** 32.21 33.86	**33.22** 32.15 33.83	**0.28** 0.19 0.38	**59.85** 55.94 63.85
05.06, 09:58-15:57	LSC1	**1.73** 1.51 1.90	**63.39** 51.47 71.99	**33.85** 33.15 34.43	**33.80** 32.98 34.34	**0.28** 0.15 0.38	**55.77** 52.77 61.79

Table 50: PMV variations for the centre of the main room

Day, Time [dd.mm, HH:MM]	Set	PMV (1.2 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.5) - **mean**; min;max	Set	PMV (1.2 met) - **mean**; min;max	PMV (adapted met. rate) - **mean**; min;max	PMV (adapted met. rate, *e*=0.6) - **mean;** min;max
29.05, 09:36-16.12	LSC1	**2.62** 2.09 2.87	**2.65** 2.03 2.65	**1.33** 1.02 1.48	FW	**2.67** 2.29 2.86	**2.76** 2.31 2.98	**1.66** 1.38 1.79
05.06, 09:58-15:57	LSC1	**2.83** 2.50 3.10	**2.89** 2.52 3.16	**1.44** 1.26 1.58	FW	**2.82** 2.59 3.02	**2.92** 2.66 2.92	**1.75** 1.59 1.87

3.5 Thermal comfort zones

In addition to the evaluation of the thermal comfort with PMV/PPD thermal comfort zones for each room of the prototype building are constructed by using the designed zone model described in section 2.6.8 for the location of Colombo in Sri Lanka and the measured data of the short-time monitoring.

According to the executed measurement for the thermal comfort prediction the data is covering times for each room, when they are in general in use. Meaning the psychometric charts for the bathroom (Figure 44) and for the main room (Figure 46) are showing values for times between morning and evening, while the one for the bedroom (Figure 45) is displaying values for day and night times.

The graph (Psychometric chart for the bathroom) is showing that the measured values are in general in the area of the expanded comfort zone for the tropical climate of Colombo. 41.9 % of the values are in the area of the red zone, while 19.4 % are in the green and 35.5 % are in blue one with temperatures between 28.39 and 32.67 °C, rel. humidities between 54.43 and 80.29 %, and correlating humidity ratios in the range from 0.01672 to 0.02013 kg_w/kg_{da}.

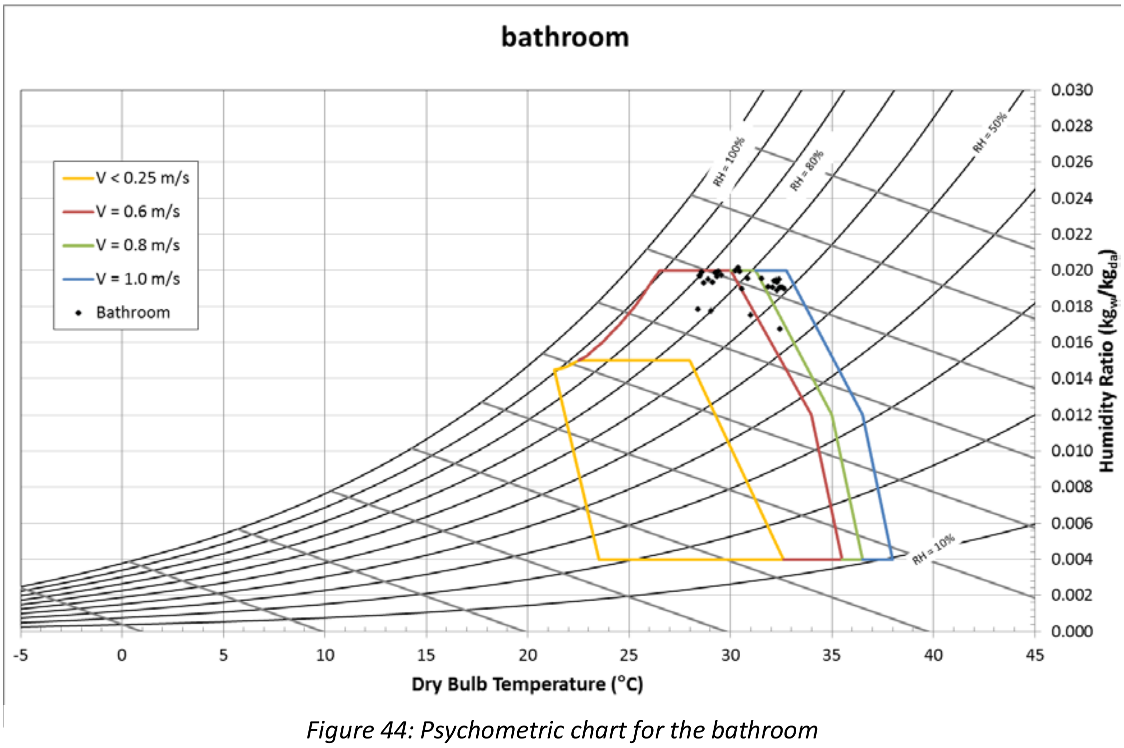

Figure 44: Psychometric chart for the bathroom

Most of the values for the bedroom are also within the expanded thermal comfort zones. The distribution of the results is displayed in the following figure (Psychometric chart for the bedroom). With an air velocity of maximum 0.6 m/s in the room a thermal comfort for 75.6 % of the measured cases can be achieved, while for 6.7 % a velocity of maximum 0.8 as well as 1 m/s is necessary. The temperatures for the conditions in the bedroom are in the range between 26.84 and 33.13 °C, while the rel. humidity is varying between 56.87 and 84.59 %. The correlating humidity ratio is showing values from 0.01706 and 0.02011 kg_w/kg_{da}.

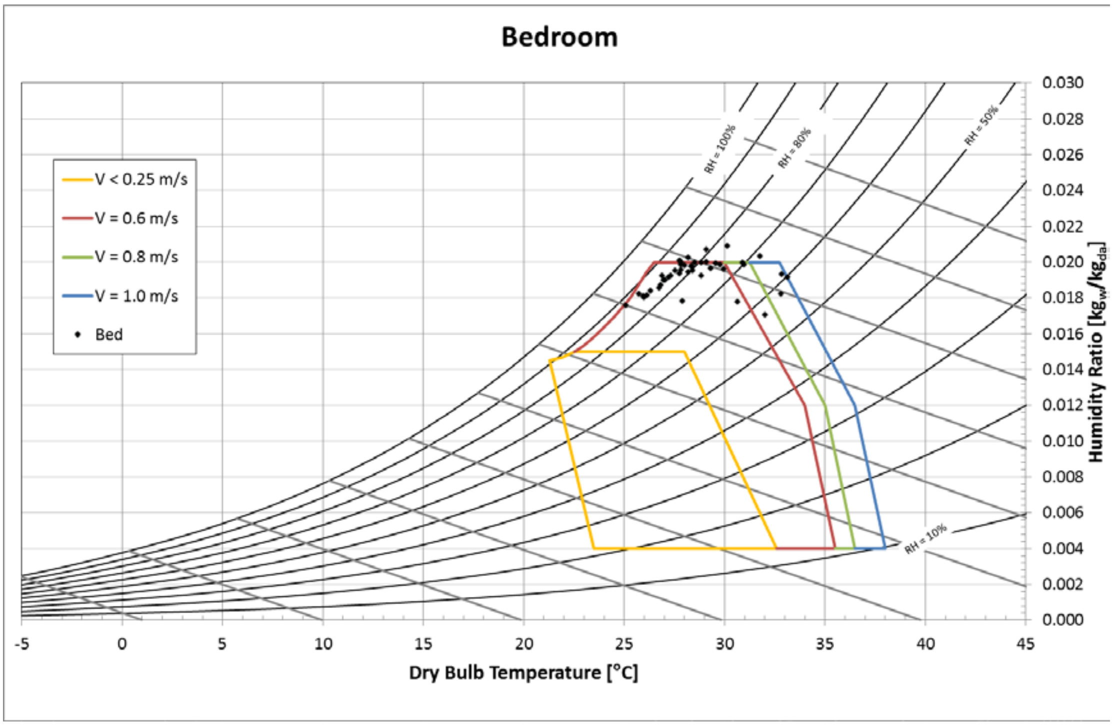

Figure 45: Psychometric chart for the bedroom

In the graph (Psychometric chart for the main room) below the conditions for the 3 measurement points in the main room are displayed.

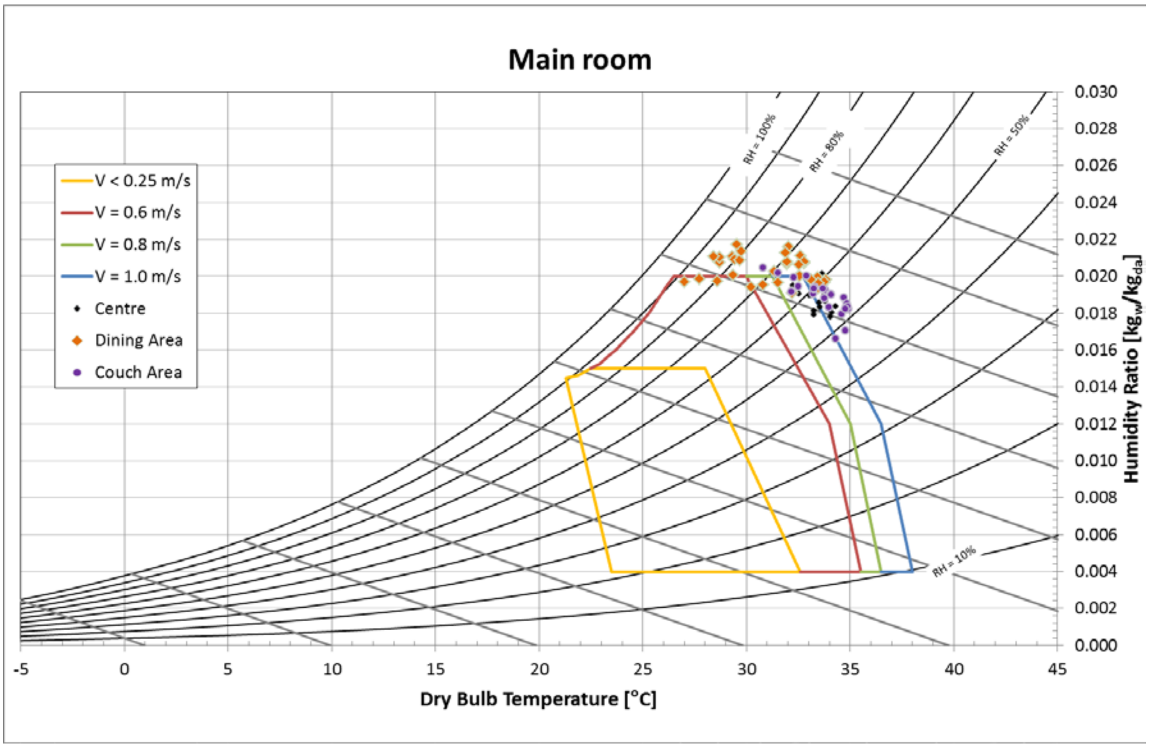

Figure 46: Psychometric chart for the main room

In this case the temperatures are in a higher range between 28.61 and 34.93 °C, while also the values for the rel. humidity are differing slightly more in the range between 51.53 and

87.13 % compared to the other rooms. The correlating humidity ratio is therefore showing values from 0.01662 to 0.02159 kg_w/kg_{da}. Accordingly only 6.3 % of the surveyed cases are in the red zone, 2.5 % in the green zone and 20.3 % are in the blue zone. The majority with 70.9 % is situated outside along the border of the expanded comfort zone.

Concerning the results it is to mention that these thermal comfort models are designed with a constant clo of 0.5 in contrary to the executed thermal comfort prediction in chapter 3.4. That means, depending on the clothing factor, the temperature borders of the comfort zones are to adjust by 0.6 K for each clo in both directions. Also the different activity at each location should be considered, especially for the bedroom with the activity sleeping. This lower metabolic rate has a contrary affect to the higher clothing factor, caused by the addition of the furniture.

Anyway with this analysis method and these comfort zones designed for the tropical climate of Colombo the indoor conditions of the bathroom during the day and the conditions of the bedroom are to a great extend close to the borders but within the comfort zone windows. Thermal comfort can be achieved in these rooms to a greater part even for this more extreme climate on Palawan, if the necessary ventilation can be provided as already described in the chapters 3.4.1 to 3.4.5. The main room is with its design and orientation more dependant to the outdoor climate, which is with an annual average of 27.7 °C and 81 % rel. humidity more extreme compared to Colombo with 26.9 °C and 79.8 %. The conditions of the main room are therefore by contrast only partly within the expanded comfort zones, but for the better part a little outside of this defined area for thermal comfort.

4 CONCLUSION

The overall purpose of this research was to examine that thermal comfort in a prototype resort cottage made of local renewable resources in the Philippines can be achieved without the installation and use of air conditioning units to decrease the energy demand in tropical climates.

The thesis focused on two methods, the comparison of the outdoor and indoor climate, and the evaluation of thermal comfort with PMV/PPD.

The main two parameters targeting for the comparison of the outdoor and indoor conditions are the air temperature and the relative humidity. All three rooms are showing an obvious dependency to the local climate. Influenced by the south orientation, the highest number of operable building openings and the smallest amount of massive building elements the main room is showing the highest dependency and smallest difference to the outdoor climate for both parameters. The indoor conditions of the north oriented bedroom and of the northwest oriented bathroom have in contrary the same difference tendency, but the temperature level is in the bathroom slightly higher, caused by containing the biggest quantity of massive building elements and the smallest number of building openings. In contrary the rel. humidity is higher in the bedroom.

The evaluation of the thermal comfort with PMV/PPD, after adaption for the use in tropical climate, is showing that a thermal sensation close to neutral can be achieved especially for raining days and during the night in the different areas of the building by choosing appropriate clothing for the local climate and with an expedient control of the buildings influencing parameters. Hot periods during the day are more critical and are illustrating the importance of a mechanical ventilation system for calm times.

The monitoring was executed at sunny days with hot and dry periods as well as at rainy days with cooler but more humid conditions. Therefore the results can be used paradigmatically for the whole year, because of the constant conditions of the dry and the rainy season.

The study is showing that a thermal comfort for conditioned buildings as defined in the standards cannot be accomplished with the implemented design features for this natural ventilated building, but considering the circumstances of this extreme hot and humid climate at the project location a totally acceptable thermal comfort can be achieved for the building, especially if you take the almost daily brown- and blackouts into account.

Overall, a sustainable and environment-friendly building concept with a very low energy demand suitable for tropical climates was developed.

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APPENDIX

Meteonorm climate date

Soeren_Thesis

Location name

9.78
Latitude [°N]

118.68
Longitude [°E]

26
Altitude [m a.s.l.]

V, 2
Climate region

Standard
Radiation model

Standard
Temperature model

Perez
Tilt radiation model

2000–2009
Temperature period

1991–2010
Radiation period

Additional information

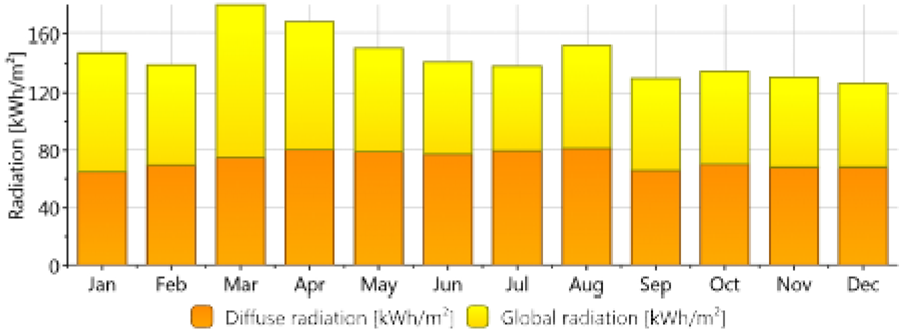
Uncertainty of yearly values: Gh = 5%, Bn = 9%, Ta = 0.5 °C
Trend of Gh / decade: 8.5%
Variability of Gh / year: 9.1%
Radiation interpolation locations: Satellite data
Temperature interpolation locations: PUERTO PRINCESA AFB (6 km)

Month	G_Gh	G_Bn	G_Dh	Lg	Ld	N	Ta	Td
	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[W/m2]	[octas]	[°C]	[°C]
January	198	173	87	22107	11794	5	27.2	23.2
February	207	156	104	23088	14126	5	27.3	23.1
March	242	195	101	27032	13616	4	28.0	23.7
April	233	172	111	26248	15161	5	28.8	24.4
May	203	144	106	22950	14314	5	28.5	24.6
June	196	127	107	22238	13898	6	27.7	24.4
July	186	117	107	21076	13636	6	27.6	24.3
August	205	139	109	23207	14504	5	27.4	24.2
September	180	128	92	20484	11938	5	27.4	24.2
October	181	128	94	20573	12070	5	27.4	24.4
November	181	130	95	20483	12658	6	27.5	24.3
December	170	120	92	19111	11934	6	27.4	24.0
Year	199	144	100	22383	13304	5	27.7	24.1

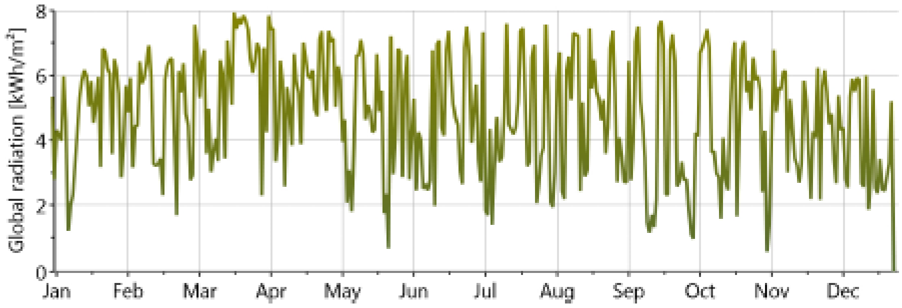
Month	RH	p	DD	FF
	[%]	[hPa]	[deg]	[m/s]
January	79	1010	49	3.7
February	78	1010	64	3.5
March	78	1010	73	2.9
April	77	1010	75	2.5
May	80	1010	75	2.3
June	82	1010	224	2.0
July	82	1010	233	2.1
August	83	1010	233	2.1
September	83	1010	236	2.1
October	84	1010	251	2.2
November	83	1010	75	2.6
December	82	1010	67	3.4
Year	81	1010	78	2.6

Gh: Mean irradiance of global radiation horizontal
Bn: Irradiance of beam
Dh: Mean irradiance of diffuse radiation horizontal
N: Cloud cover fraction
Lg: Global luminance
Ta: Air temperature
RH: Relative humidity
Td: Dewpoint temperature
DD: Wind direction
FF: Wind speed
p: Air pressure

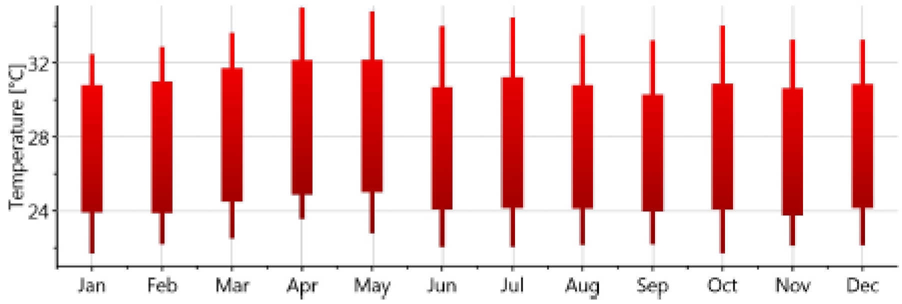
Monthly radiation



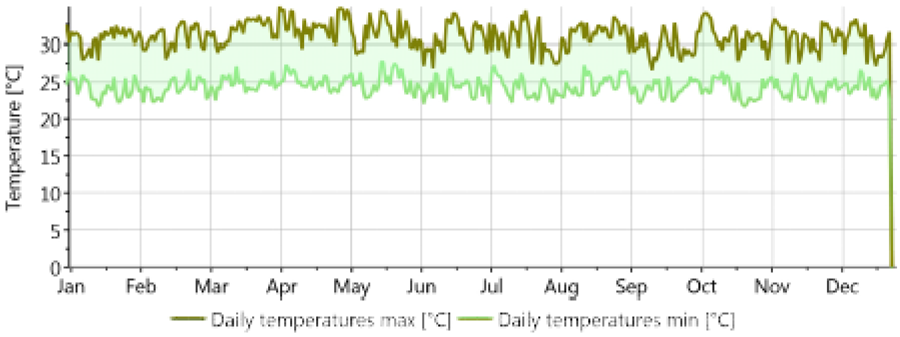
Daily global radiation



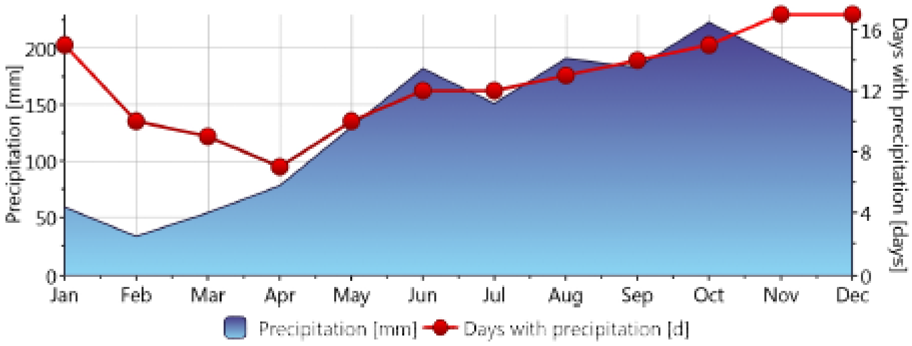
Monthly temperature



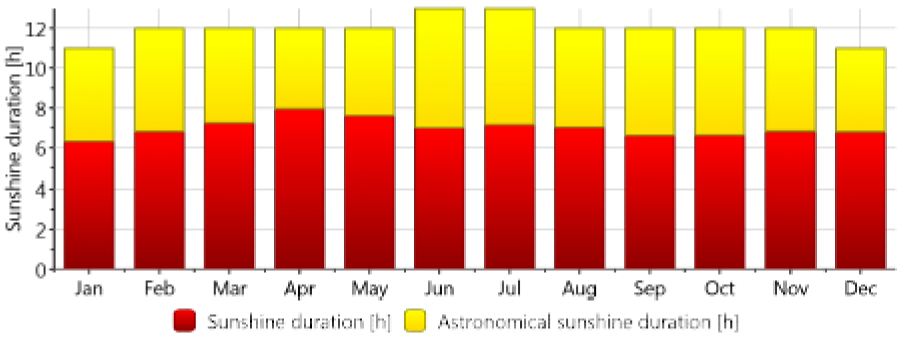
Daily temperature



Precipitation



Sunshine duration



Weekly outdoor and indoor conditions

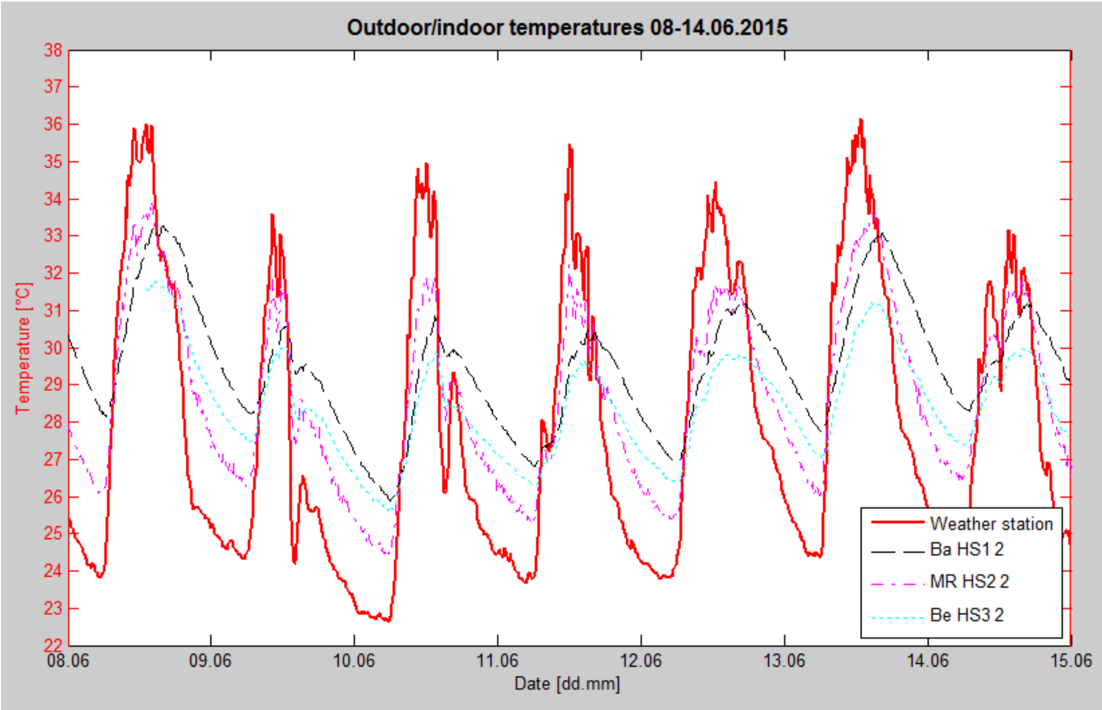


Figure 47: Weekly outdoor and indoor air temperatures, 08-14.06.2015

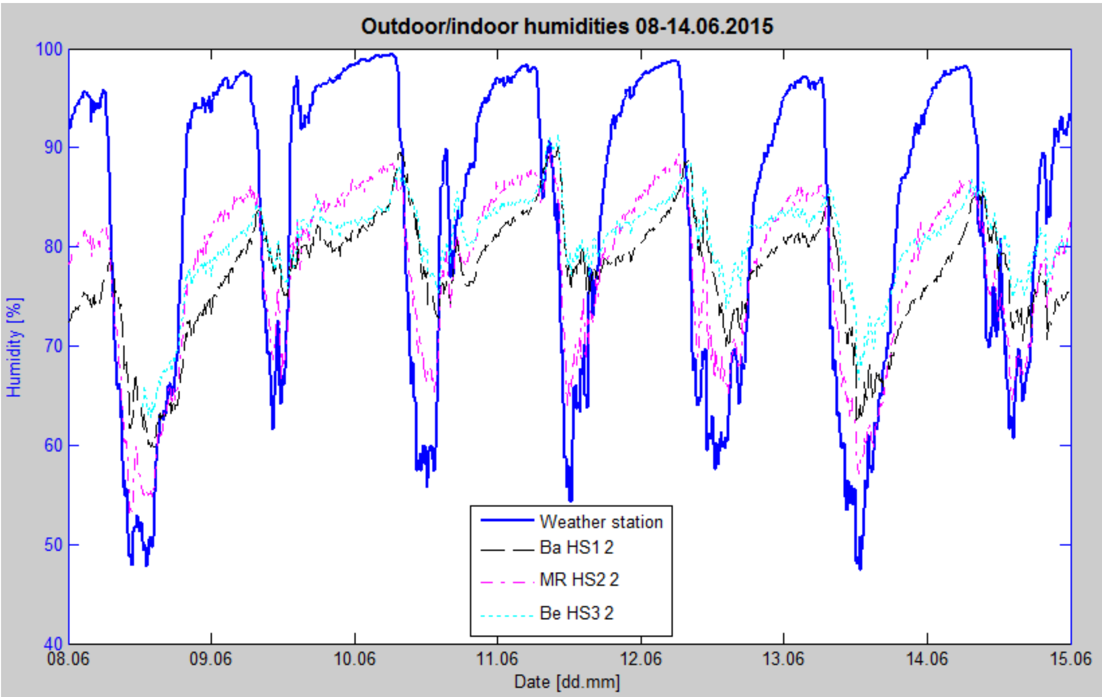


Figure 48: Weekly outdoor and indoor relative humidities, 08-14.06.2015

Daily outdoor and indoor conditions – SHT75/Weather station

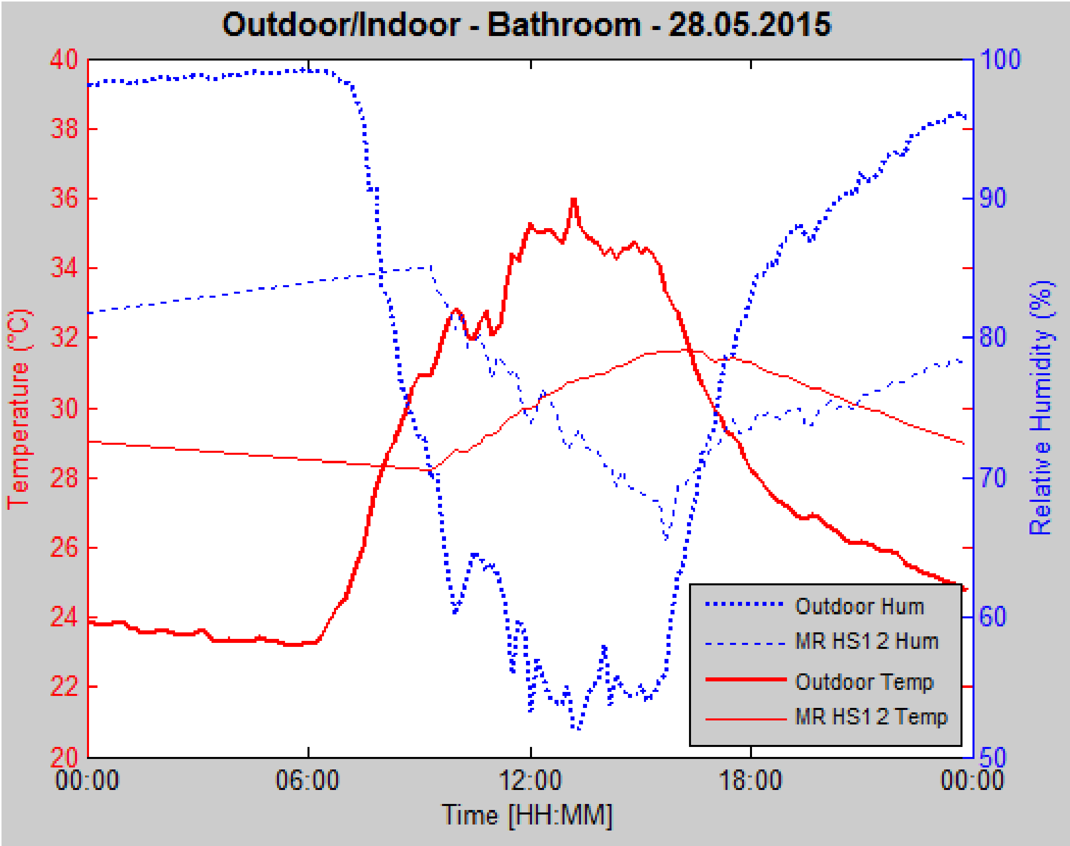


Figure 49: Air temperature and humidity, bathroom (SHT75) and outdoor, 28.05.2015

Remark: Failure of sensor HS1_2 in the morning; reset of monitoring server at 9.20 a.m.

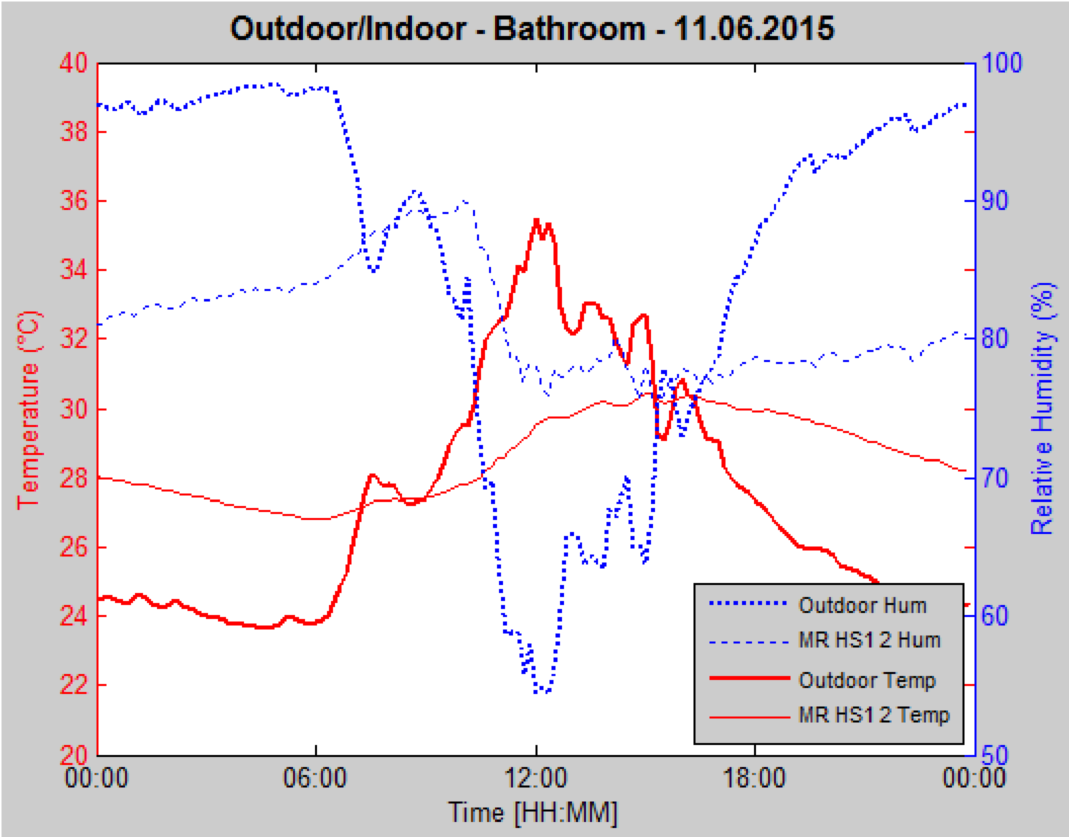


Figure 50: Air temperature and humidity, bathroom (SHT75) and outdoor, 11.06.2015

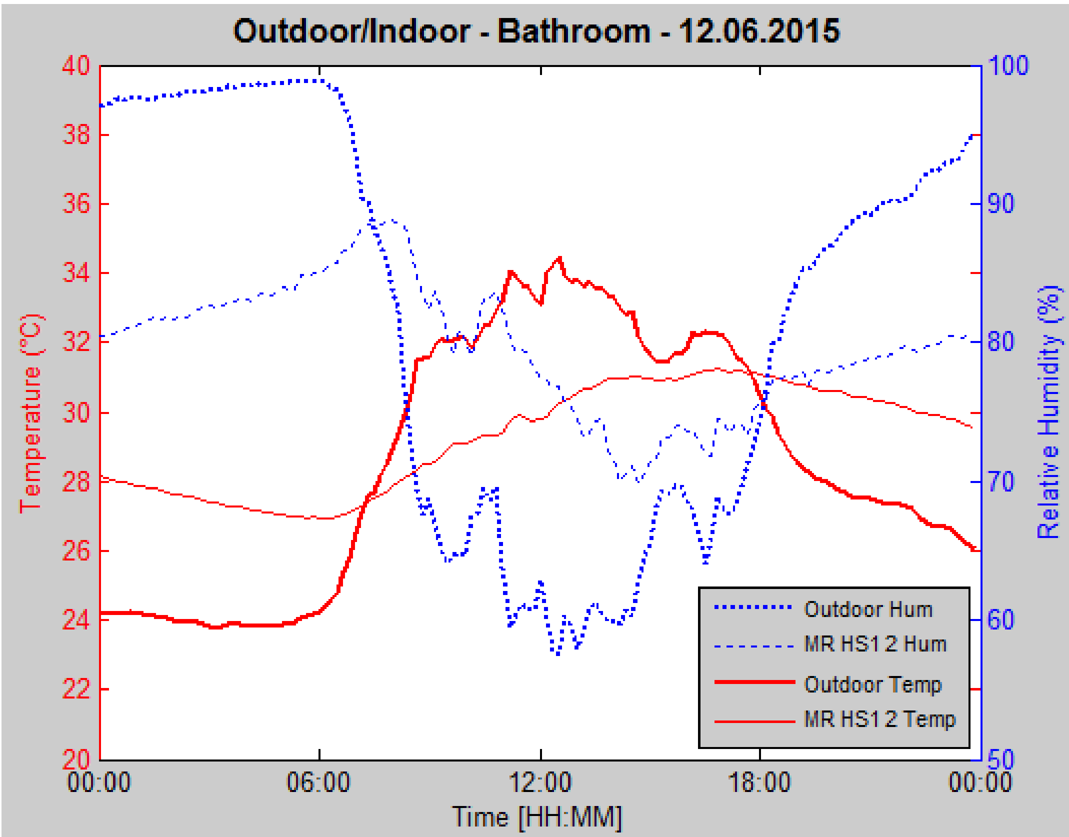


Figure 51: Air temperature and humidity, bathroom (SHT75) and outdoor, 12.06.2015

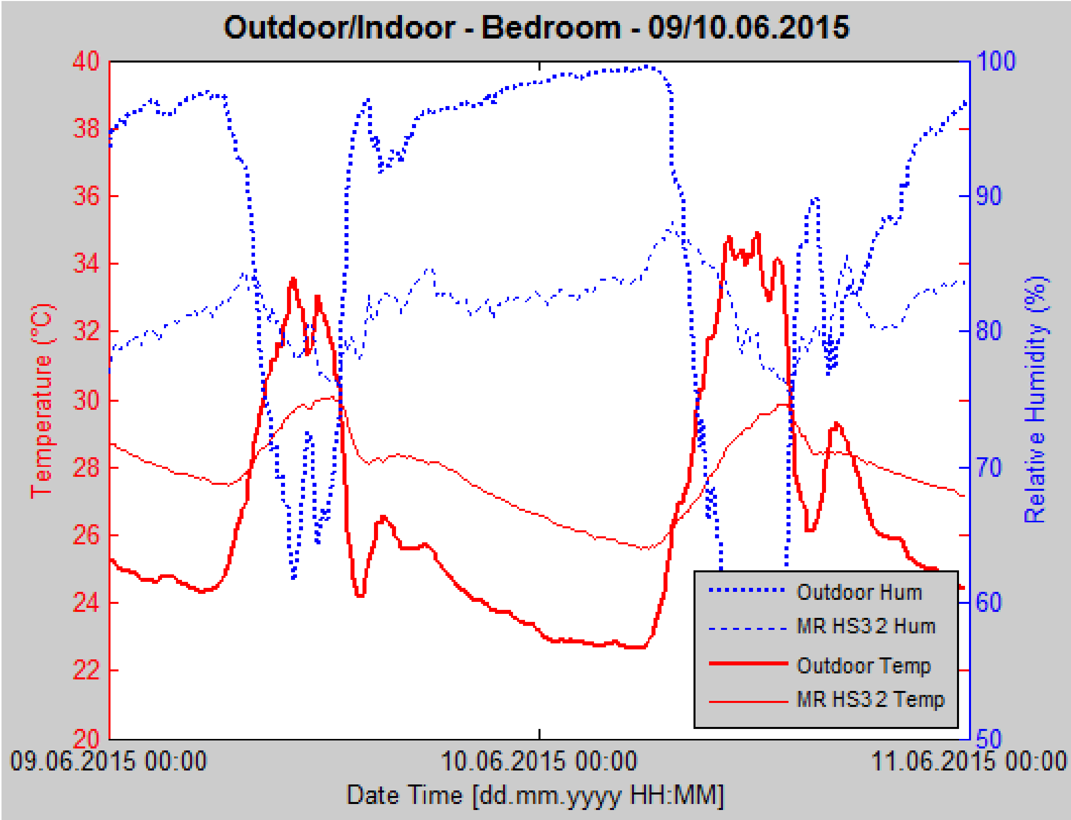


Figure 52: Air temperature and humidity, bedroom (SHT75) and outdoor, 09 and 10.06.2015

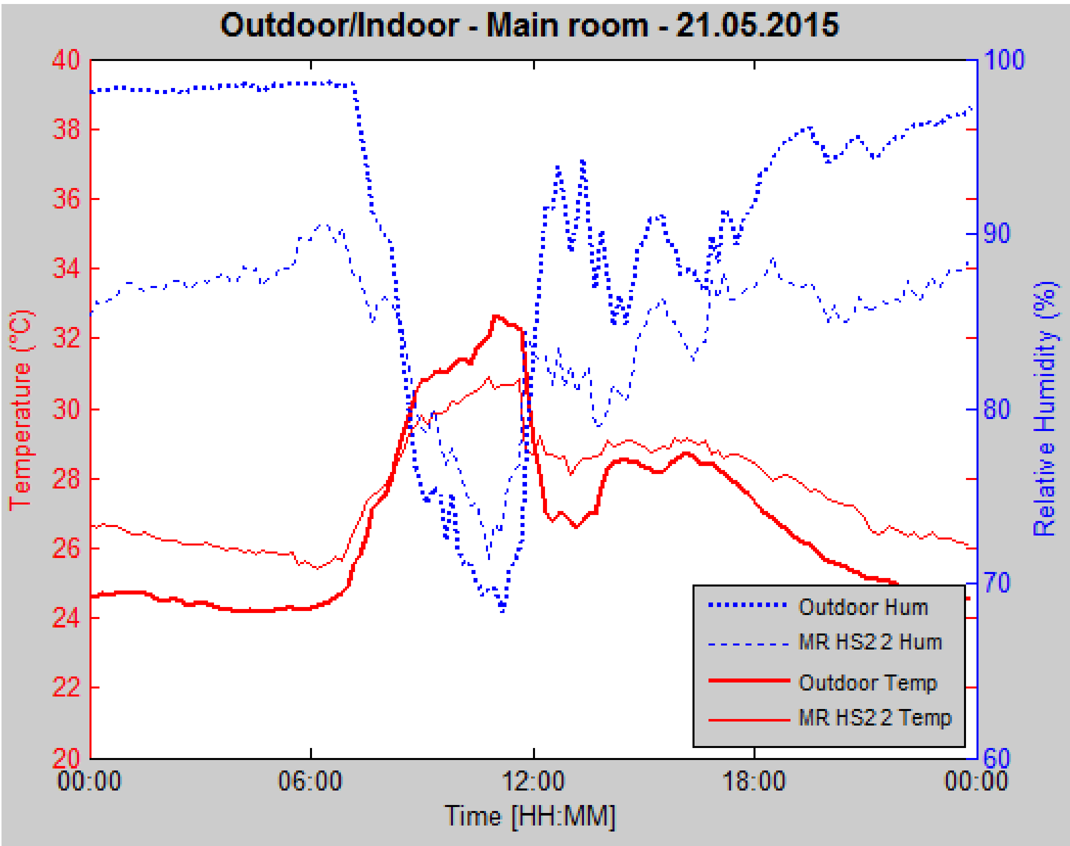


Figure 53: Air temperature and humidity, main room (SHT75) and outdoor, 21.05.2015

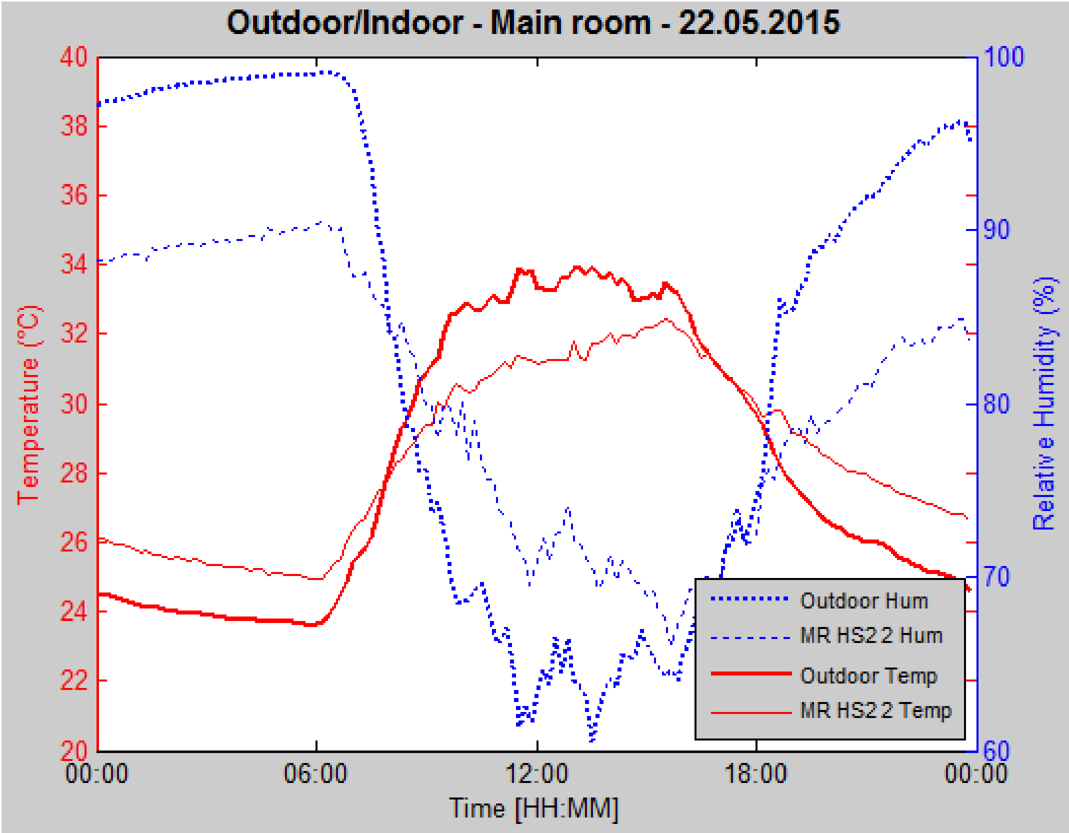


Figure 54: Air temperature and humidity, main room (SHT75) and outdoor, 22.05.2015

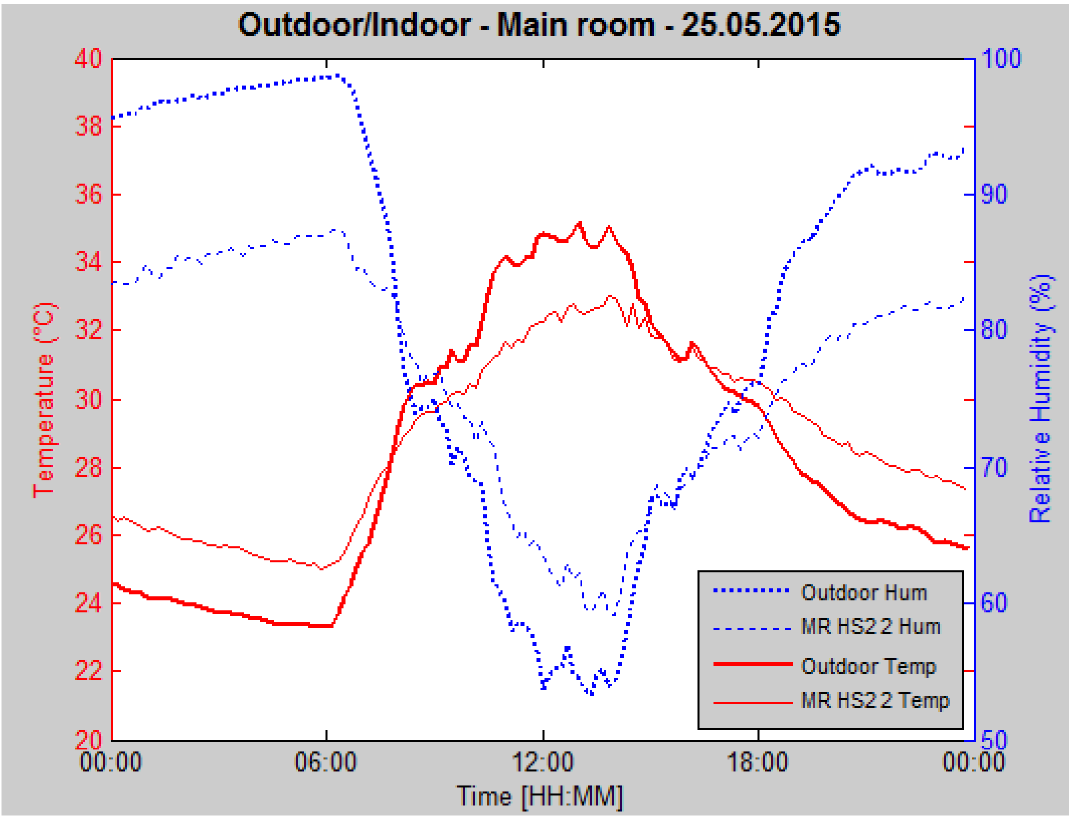


Figure 55: Air temperature and humidity, main room (SHT75) and outdoor, 25.05.2015

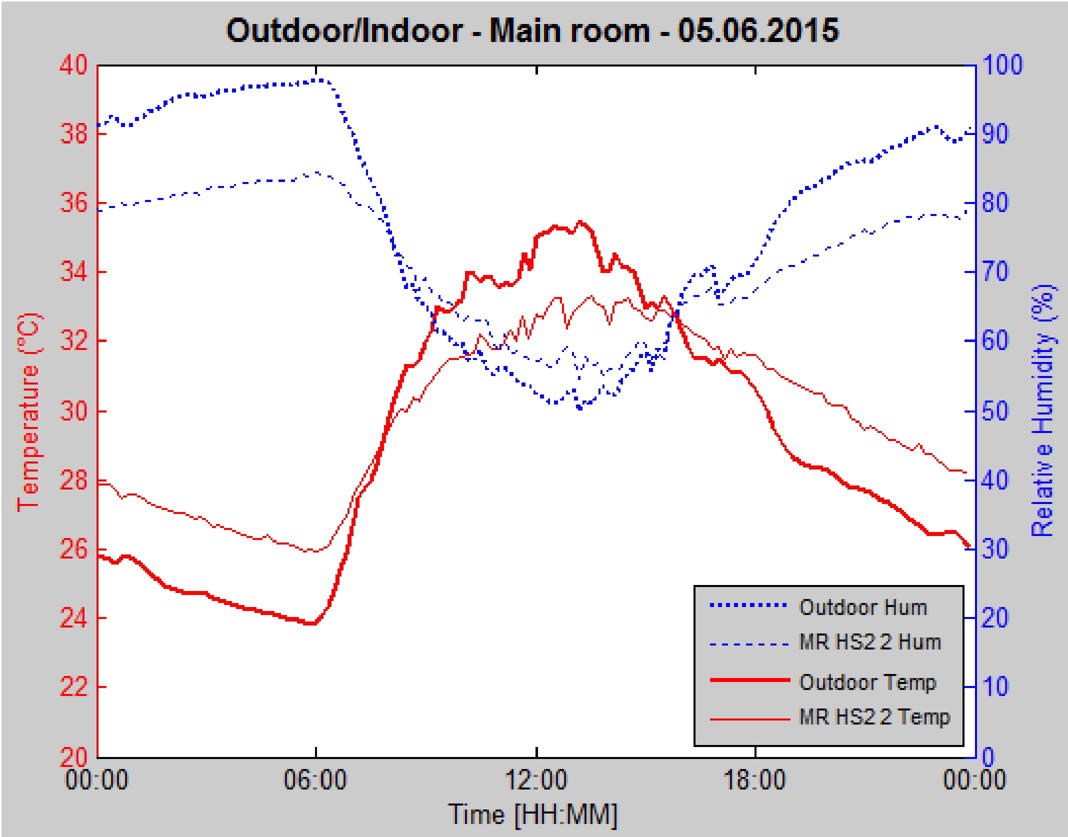


Figure 56: Air temperature and humidity, main room (SHT75) and outdoor, 05.06.2015

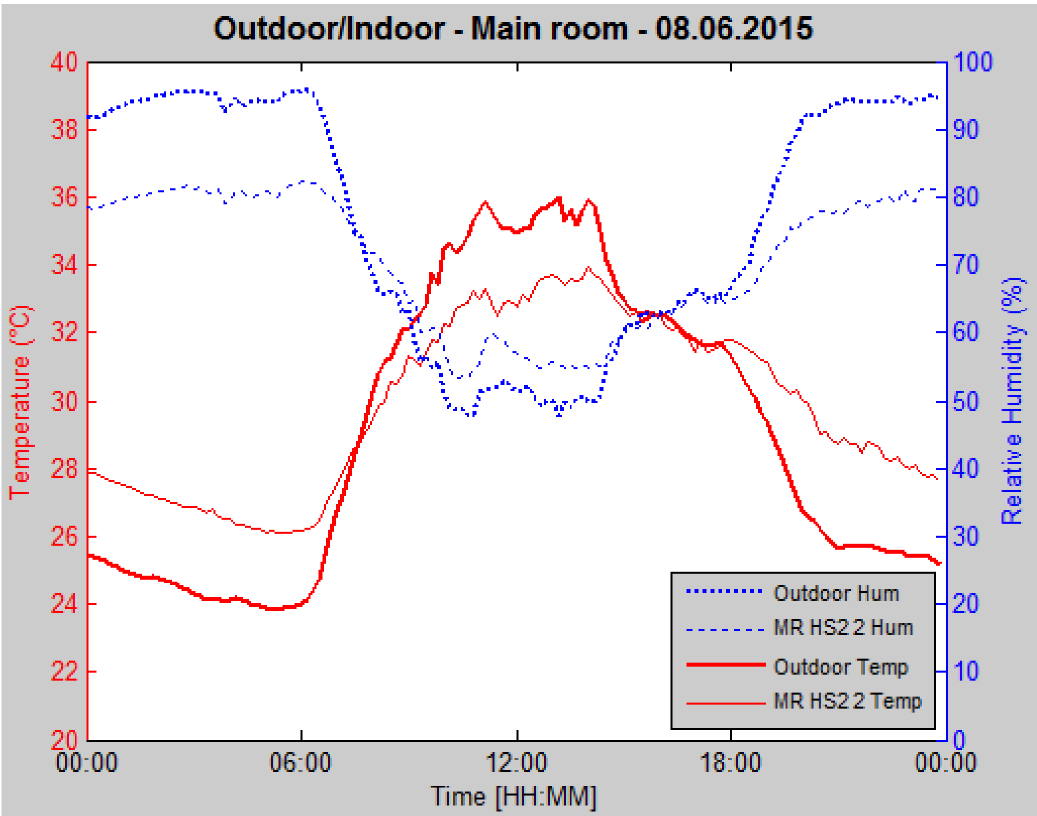


Figure 57: Air temperature and humidity, main room (SHT75) and outdoor, 08.06.2015

Daily indoor conditions – AM2303/SHT75

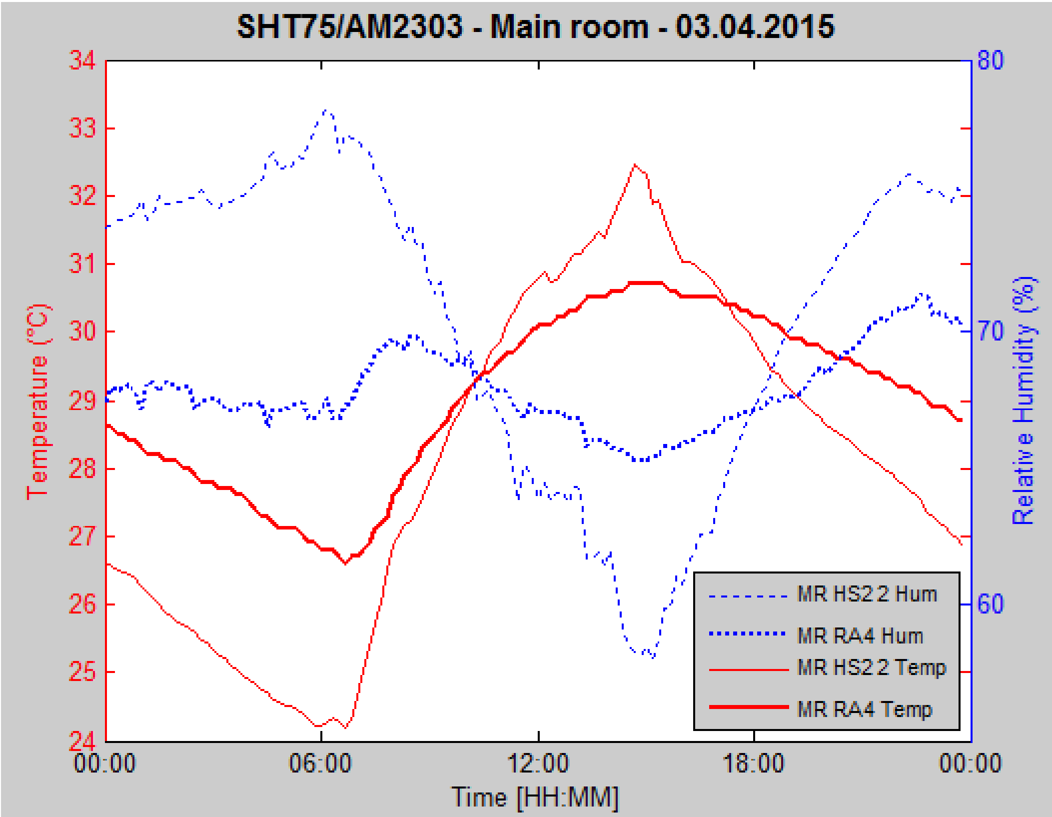


Figure 58: Air temperature and humidity, main room, AM2303 und SHT75, 03.04.2015

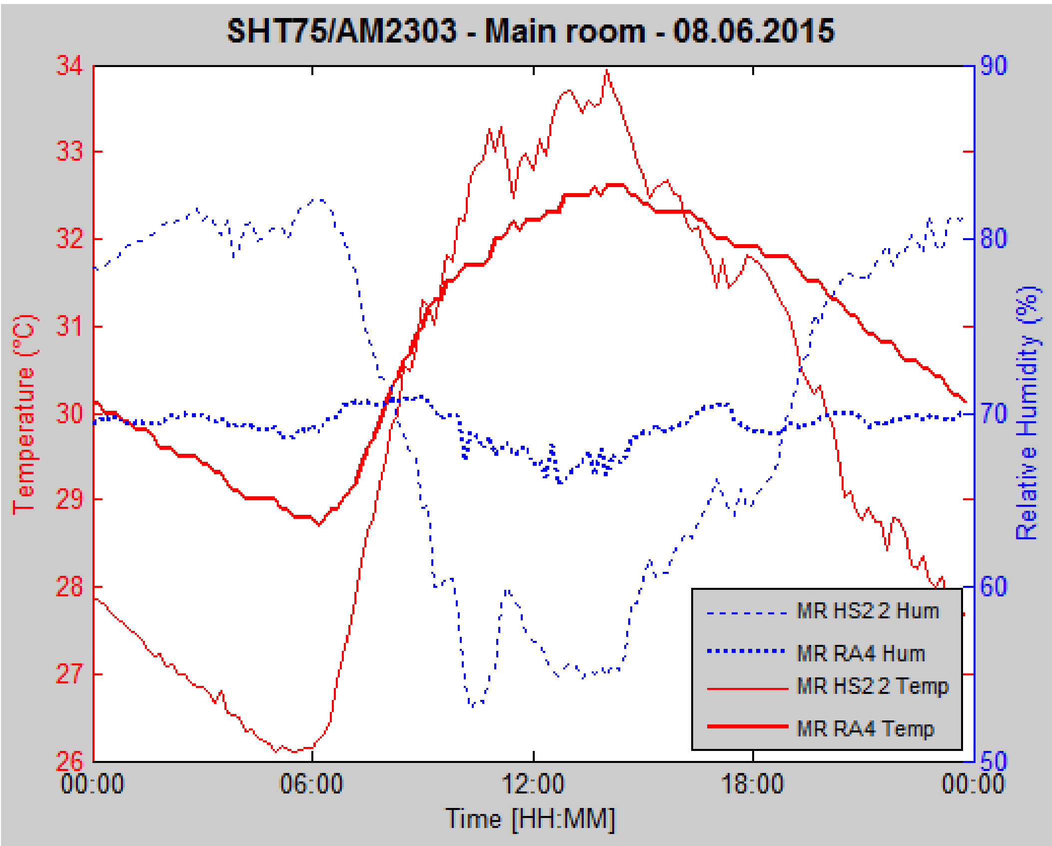


Figure 59: Air temperature and humidity, main room, AM2303 und SHT75, 08.06.2015

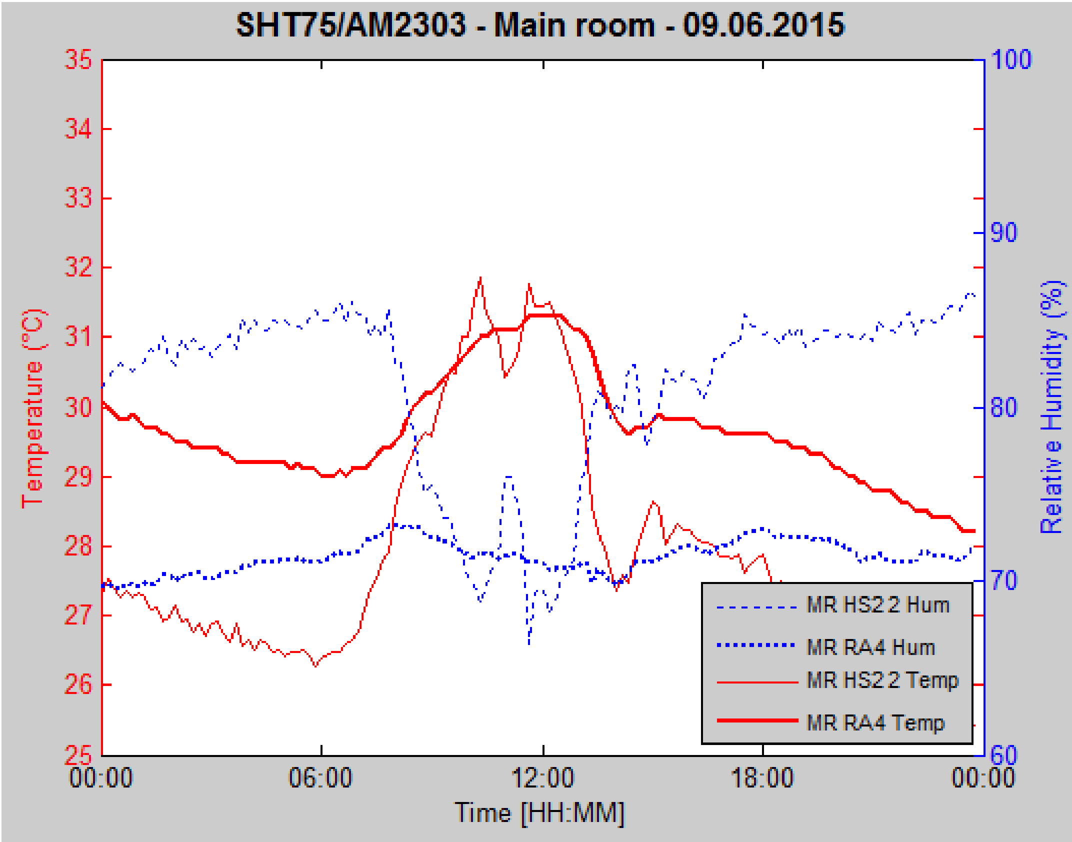


Figure 60: Air temperature and humidity, main room, AM2303 und SHT75, 09.06.2015

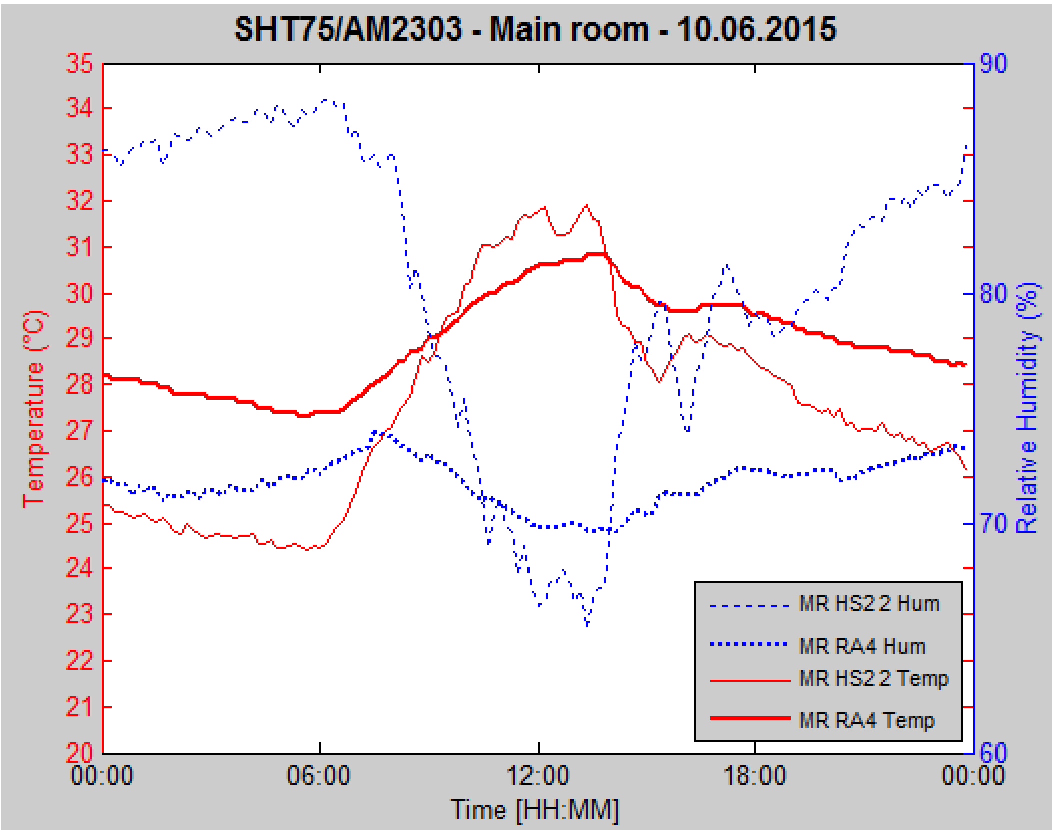


Figure 61: Air temperature and humidity, main room, AM2303 und SHT75, 10.06.2015

Measured values for the thermal comfort evaluation

Table 51: Bathroom, 28.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.03/0.18, adapted met. rate, e=0.6)	PPD (clo=0.03/0.18, adapted met. rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
28.05.2015 09:57	0.83	19.50	29.99	30.68	0.05	69.95
28.05.2015 10:07	0.74	16.64	30.05	30.58	0.10	68.26
28.05.2015 10:17	0.76	17.17	29.86	30.34	0.04	70.67
28.05.2015 10:23	0.76	17.20	29.84	30.47	0.03	67.92
28.05.2015 11:02	0.98	25.09	30.31	30.85	0.08	67.83
28.05.2015 11:12	0.95	24.20	30.33	31.03	0.12	68.10
28.05.2015 11:22	1.03	27.47	30.62	31.44	0.13	66.65
28.05.2015 11:32	1.05	28.42	30.86	31.55	0.16	66.49
28.05.2015 11:42	1.08	29.74	30.95	31.62	0.14	65.27
28.05.2015 11:49	1.16	33.21	31.19	31.94	0.15	65.50
28.05.2015 12:06	1.15	32.90	31.26	31.87	0.14	63.90
28.05.2015 12:16	1.24	37.22	31.40	32.14	0.09	64.74
28.05.2015 12:26	1.24	37.09	31.58	32.16	0.13	64.98
28.05.2015 12:36	1.29	39.93	31.60	32.26	0.08	64.67
28.05.2015 12:46	1.29	39.59	31.70	32.29	0.10	63.57
28.05.2015 12:56	1.30	40.16	31.80	32.42	0.12	62.42
28.05.2015 13:06	1.33	41.89	31.91	32.51	0.12	62.94
28.05.2015 13:16	1.30	40.24	31.93	32.43	0.16	63.21
28.05.2015 13:26	1.32	41.13	31.89	32.42	0.12	63.27
28.05.2015 13:36	1.26	38.41	31.83	32.31	0.16	63.08
28.05.2015 13:46	1.28	39.09	31.82	32.34	0.15	63.54
28.05.2015 13:56	1.22	36.27	31.73	32.15	0.17	63.88
28.05.2015 14:04	1.29	39.69	31.69	32.19	0.08	63.63
28.05.2015 14:26	1.33	41.88	32.03	32.55	0.14	61.36
28.05.2015 14:36	1.36	43.47	32.10	32.64	0.14	62.10
28.05.2015 14:46	1.31	40.71	32.08	32.51	0.18	61.11
28.05.2015 14:56	1.30	40.30	32.02	32.46	0.17	61.69
28.05.2015 15:06	1.36	43.21	32.11	32.60	0.13	61.44
28.05.2015 15:16	1.36	43.31	32.15	32.67	0.15	60.76

Table 52: Bathroom, 10.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.03/0.18, adapted met. Rate, e=0.6)	PPD (clo=0.03/0.18, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
10.06.2015 08:59	0.43	8.81	28.54	28.92	0.02	77.20
10.06.2015 09:09	0.45	9.28	28.61	29.12	0.06	75.75
10.06.2015 09:19	0.52	10.73	28.76	29.36	0.02	75.90
10.06.2015 09:24	0.59	12.19	28.96	29.57	0.04	75.22

Table 53: Bathroom, 11.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.18, adapted met. rate, e=0.6)	PPD (clo=0.18, adapted met. rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
11.06.2015 19:34	0.46	9.42	28.48	28.59	0.14	80.29
11.06.2015 19:44	0.52	10.56	28.49	28.49	0.09	79.93
11.06.2015 19:47	0.57	11.82	28.49	28.50	0.07	79.93

Table 54: Bathroom, 12.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.03/0.18, adapted met. Rate, e=0.6)	PPD (clo=0.03/0.18, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
12.06.2015 08:55	0.55	11.40	29.06	29.30	0.01	77.18
12.06.2015 09:05	0.52	10.67	28.90	29.29	0.02	76.96
12.06.2015 09:15	0.53	10.87	28.90	29.31	0.02	76.92
12.06.2015 09:17	0.55	11.43	28.95	29.41	0.01	76.77
12.06.2015 11:46	1.04	27.88	30.49	30.61	0.02	73.54
12.06.2015 11:56	0.94	23.75	30.03	30.38	0.02	73.26
12.06.2015 12:06	0.90	22.11	29.87	30.26	0.02	73.20
12.06.2015 12:10	0.94	23.68	29.97	30.48	0.01	72.09

Table 55: Bedroom, 09.06.2015 and 10.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=1.16/1.76, 0.7 met, e=0.6)	PPD (clo=1.16/1.76, 0.7 met, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
09.06.2015 15:42	0.55	11.36	28.51	28.52	0.02	80.88
09.06.2015 15:52	0.53	10.83	28.40	28.41	0.05	81.31
09.06.2015 16:02	0.52	10.68	28.34	28.40	0.03	81.46
09.06.2015 16:12	0.51	10.40	28.32	28.36	0.04	80.87
09.06.2015 16:22	0.48	9.90	28.25	28.26	0.04	80.58
09.06.2015 16:32	0.47	9.55	28.19	28.19	0.03	80.40
09.06.2015 16:42	0.46	9.51	28.13	28.15	0.03	81.58
09.06.2015 16:52	0.45	9.20	28.04	28.04	0.03	82.63
09.06.2015 17:02	0.44	9.00	27.99	28.00	0.03	82.67
09.06.2015 17:12	0.43	8.78	27.93	27.91	0.06	83.57
09.06.2015 17:22	0.41	8.54	27.85	27.84	0.06	84.15
09.06.2015 17:32	0.42	8.66	27.84	27.87	0.02	84.52
09.06.2015 17:42	0.41	8.46	27.84	27.86	0.07	84.72
09.06.2015 17:52	0.40	8.31	27.76	27.76	0.06	85.02
09.06.2015 18:02	0.40	8.41	27.75	27.81	0.04	84.99
09.06.2015 18:12	0.38	8.05	27.76	27.84	0.08	84.94
09.06.2015 18:22	0.40	8.27	27.75	27.82	0.03	83.78
09.06.2015 18:32	0.38	7.93	27.69	27.73	0.04	83.58
09.06.2015 18:42	0.35	7.60	27.60	27.62	0.04	83.97
09.06.2015 18:52	0.33	7.27	27.51	27.54	0.06	83.79
09.06.2015 19:02	0.26	6.39	27.39	27.38	0.09	84.03
09.06.2015 19:12	0.27	6.50	27.30	27.32	0.07	83.73
09.06.2015 19:22	0.26	6.38	27.23	27.23	0.06	83.88
09.06.2015 19:32	0.24	6.16	27.15	27.15	0.06	83.70
09.06.2015 19:42	0.21	5.95	27.06	27.04	0.06	84.04
09.06.2015 19:49	0.19	5.72	26.98	26.93	0.07	84.09
09.06.2015 20:09	0.53	10.79	26.85	26.85	0.06	83.98
09.06.2015 20:24	0.49	9.93	26.77	26.77	0.08	83.46
09.06.2015 20:39	0.45	9.25	26.64	26.63	0.09	83.68
09.06.2015 20:55	0.47	9.55	26.54	26.52	0.06	84.30
09.06.2015 21:10	0.43	8.79	26.40	26.33	0.07	84.78
09.06.2015 21:22	0.43	8.87	26.33	26.32	0.05	84.82
09.06.2015 21:32	0.42	8.63	26.30	26.29	0.06	83.64
09.06.2015 21:42	0.38	8.08	26.23	26.21	0.08	84.31
09.06.2015 21:52	0.40	8.26	26.16	26.13	0.06	84.71
09.06.2015 22:02	0.39	8.12	26.11	26.08	0.05	85.09
09.06.2015 22:12	0.34	7.41	26.05	26.00	0.09	84.89
09.06.2015 22:22	0.37	7.90	25.99	26.01	0.03	85.46
09.06.2015 22:32	0.38	7.93	26.00	26.00	0.06	85.73
09.06.2015 22:39	0.37	7.82	25.98	25.97	0.06	85.43
10.06.2015 06:22	0.20	5.87	25.13	25.10	0.07	87.41
10.06.2015 06:32	0.24	6.20	25.20	25.28	0.03	87.58
10.06.2015 06:42	0.28	6.60	25.43	25.46	0.03	87.34
10.06.2015 06:52	0.33	7.27	25.68	25.76	0.03	86.99
10.06.2015 07:02	0.39	8.25	26.01	26.11	0.02	86.64
10.06.2015 07:10	0.45	9.15	26.27	26.39	0.02	86.31
10.06.2015 07:22	0.55	11.40	26.87	26.92	0.03	85.83
10.06.2015 07:32	0.62	13.14	27.29	27.30	0.06	85.26
10.06.2015 07:42	0.67	14.52	27.56	27.57	0.03	84.33
10.06.2015 07:52	0.71	15.61	27.81	27.85	0.02	82.41
10.06.2015 08:02	0.75	16.72	28.02	28.03	0.04	82.10
10.06.2015 08:12	0.77	17.62	28.17	28.21	0.04	81.50
10.06.2015 08:22	0.80	18.41	28.35	28.43	0.04	79.54
10.06.2015 08:32	0.82	19.21	28.56	28.68	0.06	77.97
10.06.2015 08:38	0.84	20.00	28.73	28.85	0.06	76.75

Table 56: Bedroom, 11.06.2015 and 12.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=1.16/1.76, 0.7 met, e=0.6)	PPD (clo=1.16/1.76, 0.7 met, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
11.06.2015 16:45	0.77	17.45	29.85	29.89	0.12	75.02
11.06.2015 16:55	0.78	17.67	29.66	29.80	0.07	74.68
11.06.2015 17:05	0.68	14.68	29.49	29.55	0.14	76.37
11.06.2015 17:15	0.62	13.17	29.36	29.58	0.22	75.87
11.06.2015 17:25	0.58	12.01	29.19	29.28	0.20	77.16
11.06.2015 17:35	0.51	10.48	28.88	29.02	0.21	78.53
11.06.2015 17:45	0.52	10.64	28.82	29.11	0.21	78.28
11.06.2015 17:55	0.51	10.44	28.83	29.01	0.21	79.01
11.06.2015 18:05	0.49	10.00	28.72	28.93	0.21	79.39
11.06.2015 18:15	0.44	8.96	28.66	28.89	0.31	79.55
11.06.2015 18:25	0.43	8.93	28.65	28.91	0.32	79.43
11.06.2015 18:35	0.41	8.58	28.62	28.86	0.34	79.31
11.06.2015 18:45	0.39	8.16	28.53	28.73	0.33	79.80
11.06.2015 18:59	0.34	7.40	28.37	28.55	0.35	80.29
11.06.2015 19:13	0.30	6.92	28.20	28.42	0.35	80.66
11.06.2015 19:16	0.29	6.72	28.15	28.39	0.37	80.70
11.06.2015 20:02	0.77	17.49	28.22	28.11	0.03	81.84
11.06.2015 20:12	0.74	16.38	27.96	27.95	0.03	82.50
11.06.2015 20:22	0.71	15.69	27.83	27.86	0.03	82.36
11.06.2015 20:30	0.69	15.05	27.74	27.78	0.05	81.95
11.06.2015 20:57	0.63	13.41	27.48	27.52	0.07	82.79
11.06.2015 21:07	0.63	13.34	27.39	27.41	0.05	83.24
11.06.2015 21:17	0.61	12.82	27.30	27.26	0.05	83.83
11.06.2015 21:27	0.60	12.50	27.22	27.24	0.06	83.77
11.06.2015 21:37	0.58	11.95	27.16	27.16	0.07	84.05
11.06.2015 21:49	0.58	11.94	27.10	27.11	0.06	83.95
11.06.2015 22:01	0.56	11.56	27.02	27.00	0.05	84.12
11.06.2015 22:11	0.56	11.45	26.96	26.98	0.03	84.29
11.06.2015 22:21	0.55	11.41	26.96	27.05	0.03	83.04
11.06.2015 22:31	0.55	11.27	26.94	27.01	0.05	83.22
11.06.2015 22:41	0.50	10.29	26.85	26.84	0.08	83.85
11.06.2015 22:50	0.52	10.62	26.76	26.80	0.05	84.49
12.06.2015 07:09	0.71	15.59	27.63	27.82	0.04	84.59
12.06.2015 07:22	0.78	17.96	28.09	28.22	0.01	83.38
12.06.2015 07:37	0.86	20.71	28.56	28.65	0.01	82.17
12.06.2015 07:50	0.94	23.66	29.02	29.10	0.01	80.96
12.06.2015 08:00	0.99	25.52	29.27	29.34	0.02	80.56
12.06.2015 08:10	1.02	27.17	29.47	29.58	0.03	79.93
12.06.2015 08:20	1.06	28.75	29.65	29.82	0.02	79.18
12.06.2015 08:30	1.10	30.57	29.92	30.16	0.02	76.88
12.06.2015 08:32	1.12	31.33	30.06	30.30	0.03	75.68
12.06.2015 09:36	0.96	24.43	30.35	31.04	0.06	68.45
12.06.2015 09:46	0.99	25.72	30.68	30.98	0.08	69.84
12.06.2015 09:56	1.00	25.91	30.56	30.74	0.06	73.22
12.06.2015 10:06	0.98	25.40	30.57	30.87	0.06	70.20
12.06.2015 10:16	0.99	25.66	30.62	30.91	0.07	70.57
12.06.2015 10:26	0.95	23.98	30.53	30.67	0.12	74.17
12.06.2015 10:36	0.96	24.52	30.35	30.48	0.08	77.56
12.06.2015 10:46	0.92	22.98	30.31	30.47	0.12	77.07
12.06.2015 10:56	0.94	23.69	30.35	30.52	0.12	77.71
12.06.2015 11:06	0.98	25.42	30.47	30.85	0.08	73.29
12.06.2015 11:16	1.11	30.82	31.10	31.61	0.11	69.73
12.06.2015 11:26	1.17	33.60	31.39	31.78	0.07	68.34

Table 57: Dining area, 19.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.19, adapted met. Rate, e=0.6)	PPD (clo=0.19, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
19.05.2015 12:26	0.39	8.17	30.04	29.74	0.18	80.73
19.05.2015 12:36	0.28	6.61	29.62	29.32	0.16	81.32
19.05.2015 12:50	0.16	5.52	28.90	28.74	0.12	83.17
19.05.2015 13:00	0.24	6.19	28.80	28.70	0.13	83.02
19.05.2015 13:10	0.20	5.85	28.63	28.57	0.13	84.65
19.05.2015 13:20	0.32	7.15	28.57	28.51	0.07	85.30
19.05.2015 13:30	0.30	6.88	28.58	28.55	0.09	84.59
19.05.2015 13:42	0.30	6.88	28.52	28.46	0.08	84.60
19.05.2015 13:52	0.26	6.42	28.39	28.34	0.07	84.83
19.05.2015 14:02	0.12	5.30	28.21	28.08	0.10	85.83
19.05.2015 14:12	-0.02	5.01	27.94	27.74	0.11	84.19
19.05.2015 14:22	-0.12	5.29	27.64	27.39	0.11	85.00
19.05.2015 14:33	-0.02	5.01	27.32	27.19	0.10	85.99
19.05.2015 14:43	-0.01	5.00	27.21	27.13	0.07	86.60
19.05.2015 14:53	-0.06	5.08	27.16	27.01	0.10	87.13
19.05.2015 15:03	0.00	5.00	27.21	27.17	0.08	87.30
19.05.2015 15:13	0.02	5.01	27.28	27.24	0.07	86.88
19.05.2015 15:23	0.04	5.04	27.33	27.36	0.07	86.01
19.05.2015 15:41	0.08	5.13	27.52	27.57	0.06	85.60
19.05.2015 15:51	0.11	5.26	27.64	27.65	0.07	85.74
19.05.2015 16:39	0.33	7.30	28.77	28.71	0.04	84.14
19.05.2015 16:49	0.29	6.78	28.64	28.52	0.07	86.43
19.05.2015 16:59	0.26	6.36	28.57	28.50	0.09	86.66
19.05.2015 17:09	0.21	5.90	28.53	28.49	0.10	85.23
19.05.2015 17:20	0.22	6.01	28.45	28.42	0.09	85.93
19.05.2015 17:30	0.24	6.21	28.43	28.44	0.04	85.66

Table 58: Dining area, 21.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.19, adapted met. Rate, e=0.6)	PPD (clo=0.19, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
21.05.2015 10:48	0.82	19.16	31.91	31.96	0.78	68.65
21.05.2015 10:58	0.91	22.62	32.11	32.15	0.80	69.24
21.05.2015 11:08	0.93	23.20	32.19	32.12	0.75	69.26
21.05.2015 11:12	0.81	18.78	32.05	31.96	0.89	69.03
21.05.2015 11:32	0.85	20.07	31.96	31.93	0.75	71.14
21.05.2015 11:42	0.95	23.95	32.06	32.11	0.71	72.72
21.05.2015 11:52	0.61	12.86	31.73	31.28	0.74	74.09
21.05.2015 12:26	-0.04	5.03	29.56	29.44	0.69	80.14
21.05.2015 12:36	-0.08	5.14	29.43	29.34	0.68	79.43
21.05.2015 12:46	-0.04	5.04	29.35	29.35	0.63	80.83
21.05.2015 12:56	-0.19	5.74	29.14	29.09	0.67	79.42
21.05.2015 13:01	-0.26	6.43	28.93	28.92	0.66	79.08
21.05.2015 13:13	-0.42	8.60	28.63	28.61	0.69	79.63
21.05.2015 13:23	-0.15	5.46	28.97	29.00	0.56	79.95
21.05.2015 13:33	-0.15	5.45	29.09	28.97	0.57	80.56
21.05.2015 13:43	-0.11	5.23	29.21	29.14	0.58	77.97
21.05.2015 13:53	-0.02	5.01	29.43	29.35	0.58	77.39
21.05.2015 14:01	0.08	5.13	29.57	29.57	0.56	77.83
21.05.2015 14:14	0.09	5.17	29.63	29.54	0.55	78.64
21.05.2015 14:24	0.10	5.20	29.59	29.55	0.54	78.89
21.05.2015 14:34	0.09	5.17	29.64	29.67	0.61	78.94
21.05.2015 14:44	0.14	5.43	29.69	29.73	0.57	79.28
21.05.2015 14:54	0.18	5.70	29.69	29.66	0.51	81.54
21.05.2015 15:04	0.16	5.55	29.65	29.67	0.54	82.10
21.05.2015 15:14	0.12	5.30	29.52	29.44	0.50	83.40
21.05.2015 15:24	0.08	5.15	29.42	29.38	0.51	83.85
21.05.2015 15:34	0.14	5.39	29.45	29.49	0.49	83.97
21.05.2015 15:44	0.16	5.54	29.50	29.56	0.48	82.56
21.05.2015 15:54	0.18	5.64	29.62	29.76	0.56	82.88
21.05.2015 15:57	0.23	6.11	29.72	29.85	0.53	82.20
21.05.2015 16:15	0.14	5.42	29.69	29.85	0.64	80.50
21.05.2015 16:25	0.15	5.45	29.66	29.75	0.58	80.47

Table 59: Dining area, 22.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.19, adapted met. Rate, e=0.6)	PPD (clo=0.19, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
22.05.2015 09:42	0.84	19.92	31.74	31.86	0.64	72.59
22.05.2015 09:52	0.92	22.73	32.02	32.03	0.67	71.36
22.05.2015 10:02	0.85	20.34	31.91	31.86	0.66	72.04
22.05.2015 10:12	0.86	20.57	31.87	31.87	0.63	71.71
22.05.2015 10:22	0.86	20.77	31.86	31.89	0.63	71.74
22.05.2015 10:25	0.87	20.94	31.92	31.90	0.63	70.86
22.05.2015 10:43	0.98	25.18	32.32	32.45	0.60	69.15
22.05.2015 10:53	1.01	26.74	32.51	32.50	0.64	69.54
22.05.2015 11:03	1.06	28.69	32.42	32.32	0.64	68.93
22.05.2015 11:13	1.09	30.13	32.38	32.42	0.62	68.75
22.05.2015 11:23	1.05	28.29	32.60	32.61	0.64	67.54
22.05.2015 11:48	1.18	34.15	32.90	32.84	0.57	65.23
22.05.2015 11:58	1.01	26.44	32.71	32.53	0.65	64.46
22.05.2015 12:08	1.02	26.95	32.57	32.59	0.65	65.72
22.05.2015 12:18	1.04	27.79	32.60	32.60	0.64	66.65
22.05.2015 12:28	1.01	26.64	32.59	32.55	0.66	66.55
22.05.2015 12:38	1.14	32.46	32.73	32.80	0.63	67.57
22.05.2015 13:03	1.15	32.65	32.75	32.79	0.62	67.78
22.05.2015 13:13	1.17	34.01	32.86	32.80	0.57	67.14
22.05.2015 13:23	1.10	30.68	32.74	32.70	0.61	66.51
22.05.2015 13:33	1.19	34.62	32.86	32.89	0.61	66.23
22.05.2015 13:43	1.14	32.58	32.85	32.79	0.61	65.62
22.05.2015 13:46	1.16	33.29	32.82	32.80	0.58	66.46
22.05.2015 13:59	1.19	34.60	32.89	32.87	0.60	66.18
22.05.2015 14:09	1.17	33.69	32.91	32.81	0.62	66.70
22.05.2015 14:14	1.13	31.76	32.83	32.73	0.60	66.07
22.05.2015 14:30	1.21	35.57	32.93	32.81	0.51	67.14
22.05.2015 14:40	1.17	34.00	32.88	32.77	0.53	66.58
22.05.2015 14:50	1.13	32.06	32.79	32.70	0.53	66.22
22.05.2015 15:00	1.17	33.95	32.89	32.77	0.52	65.95
22.05.2015 16:15	1.04	27.70	32.89	32.53	0.70	66.40
22.05.2015 16:24	0.97	24.98	32.38	32.24	0.77	66.95
22.05.2015 16:47	0.79	18.18	31.92	31.92	0.79	67.08
22.05.2015 16:57	0.64	13.63	31.64	31.62	0.77	65.58
22.05.2015 17:04	0.57	11.77	31.44	31.52	0.83	67.05
22.05.2015 17:31	0.50	10.23	30.88	31.00	0.84	71.39
22.05.2015 17:41	0.42	8.64	30.72	30.82	0.84	71.14
22.05.2015 17:45	0.37	7.78	30.63	30.79	0.89	69.48
22.05.2015 17:58	0.26	6.36	30.41	30.48	0.85	70.40
22.05.2015 18:08	0.14	5.43	30.08	30.22	0.83	71.29

Table 60: Dining area, 26.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.19, adapted met. Rate, e=0.6)	PPD (clo=0.19, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
26.05.2015 09:36	0.85	20.19	32.18	32.23	1.00	62.65
26.05.2015 09:46	0.99	25.82	32.25	32.55	0.96	63.05
26.05.2015 09:54	1.02	26.88	32.56	32.80	0.87	62.82
26.05.2015 10:14	1.26	38.35	33.14	33.23	0.89	61.66
26.05.2015 10:24	1.31	40.82	33.18	33.36	0.93	61.10
26.05.2015 10:34	1.36	43.49	33.26	33.44	0.87	61.07
26.05.2015 10:44	1.33	41.65	33.31	33.34	0.86	60.67
26.05.2015 10:54	1.44	47.89	33.40	33.62	0.90	60.24
26.05.2015 11:04	1.39	44.76	33.39	33.49	0.85	59.21
26.05.2015 11:14	1.56	54.00	33.61	33.83	0.87	59.66
26.05.2015 11:24	1.55	53.66	33.65	33.80	0.87	59.65
26.05.2015 11:46	1.50	51.08	33.58	33.69	0.82	59.96
26.05.2015 11:56	1.55	53.52	33.72	33.77	0.81	59.10
26.05.2015 12:06	1.60	56.50	33.79	33.87	0.79	59.50
26.05.2015 12:16	1.64	58.55	33.92	33.91	0.76	59.59
26.05.2015 12:26	1.53	52.56	33.73	33.69	0.81	60.37
26.05.2015 12:36	1.43	47.09	33.52	33.52	0.81	60.05
26.05.2015 12:46	1.56	54.02	33.63	33.82	0.80	59.35
26.05.2015 12:56	1.63	57.93	33.93	33.91	0.81	58.55
26.05.2015 13:06	1.57	54.51	33.78	33.80	0.83	58.98
26.05.2015 13:16	1.46	48.49	33.60	33.57	0.81	59.46
26.05.2015 13:26	1.55	53.55	33.70	33.77	0.78	59.23
26.05.2015 13:36	1.59	56.06	33.81	33.84	0.79	59.56
26.05.2015 13:46	1.52	51.83	33.74	33.67	0.80	59.53
26.05.2015 13:56	1.62	57.31	33.78	33.90	0.77	59.87
26.05.2015 14:06	1.53	52.73	33.81	33.67	0.77	59.86
26.05.2015 14:16	1.55	53.41	33.78	33.72	0.79	59.81
26.05.2015 14:26	1.42	46.66	33.56	33.47	0.76	59.97
26.05.2015 14:51	1.25	37.95	33.30	33.10	0.78	61.83
26.05.2015 15:01	0.99	25.63	32.81	32.55	0.79	64.30
26.05.2015 15:11	1.03	27.59	32.46	32.48	0.84	64.80
26.05.2015 15:21	1.02	26.81	32.64	32.69	0.80	64.44
26.05.2015 15:27	0.98	25.21	32.67	32.57	0.78	64.34
26.05.2015 15:56	1.04	27.93	32.58	32.54	0.97	64.41
26.05.2015 16:06	1.04	27.77	32.84	32.74	0.89	63.71
26.05.2015 16:16	0.96	24.40	32.46	32.34	0.94	64.73
26.05.2015 16:19	0.86	20.57	32.15	32.18	0.98	66.21
26.05.2015 16:41	0.57	11.74	31.48	31.57	0.92	67.77
26.05.2015 16:51	0.45	9.32	31.17	31.34	0.92	69.71
26.05.2015 16:59	0.58	12.16	31.05	31.25	0.89	70.87

Table 61: Couch area, 25.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.33, adapted met. rate, e=0.6)	PPD (clo=0.33, adapted met. rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
25.05.2015 11:08	1.16	33.53	33.29	33.24	0.36	61.74
25.05.2015 11:19	1.16	33.51	33.35	33.31	0.40	59.81
25.05.2015 11:45	1.29	39.98	33.70	33.53	0.42	59.90
25.05.2015 11:55	1.38	44.65	33.87	33.75	0.44	58.98
25.05.2015 12:05	1.41	45.95	33.94	33.80	0.39	57.84
25.05.2015 12:15	1.49	50.53	34.07	33.99	0.34	57.23
25.05.2015 12:25	1.52	51.97	34.21	34.04	0.38	56.50
25.05.2015 12:35	1.42	46.44	34.05	33.84	0.45	56.71
25.05.2015 13:09	1.51	51.41	34.17	34.04	0.40	56.43
25.05.2015 13:19	1.44	47.71	34.07	33.92	0.33	54.52
25.05.2015 13:29	1.44	47.61	34.04	33.97	0.42	54.58
25.05.2015 13:39	1.56	54.02	34.22	34.14	0.31	56.12
25.05.2015 13:49	1.55	53.54	34.29	34.08	0.34	56.21
25.05.2015 13:52	1.57	54.69	34.27	34.14	0.30	56.30
25.05.2015 14:07	1.48	49.72	34.19	33.92	0.38	56.59
25.05.2015 14:17	1.37	44.15	33.88	33.69	0.36	58.39
25.05.2015 14:27	1.34	42.14	33.71	33.60	0.37	60.38
25.05.2015 14:37	1.24	37.16	33.58	33.35	0.40	61.69
25.05.2015 14:47	1.04	27.65	33.05	32.88	0.33	63.22
25.05.2015 14:57	1.01	26.55	32.96	32.89	0.37	63.53
25.05.2015 15:07	1.00	26.09	32.66	32.45	0.32	65.77
25.05.2015 15:17	0.91	22.31	32.39	32.32	0.35	66.02
25.05.2015 15:27	0.88	21.28	32.27	32.27	0.32	65.18
25.05.2015 16:08	0.81	18.92	31.92	31.98	0.23	66.66
25.05.2015 16:18	0.87	21.00	32.08	32.06	0.22	66.98
25.05.2015 16:28	0.72	15.81	31.69	31.61	0.21	68.72
25.05.2015 16:38	0.69	15.07	31.45	31.51	0.17	68.74
25.05.2015 16:48	0.59	12.18	31.25	31.24	0.19	70.19
25.05.2015 16:58	0.49	10.10	31.05	31.09	0.21	70.34
25.05.2015 17:08	0.50	10.28	30.94	31.05	0.18	70.58
25.05.2015 17:13	0.58	11.93	30.86	30.81	0.20	72.55

Table 62: Couch area, 08.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.33, adapted met. Rate, e=0.6)	PPD (clo=0.33, adapted met. Rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
08.06.2015 10:18	1.63	58.08	34.77	34.32	0.42	50.22
08.06.2015 10:28	1.52	52.02	34.58	34.18	0.61	49.07
08.06.2015 10:38	1.64	58.68	34.74	34.68	0.40	48.97
08.06.2015 10:48	1.72	63.08	34.98	34.79	0.45	48.70
08.06.2015 10:57	1.94	73.83	35.31	35.16	0.40	50.09
08.06.2015 11:14	1.96	75.06	35.34	35.06	0.40	54.28
08.06.2015 11:24	1.84	68.90	35.26	34.74	0.44	54.60
08.06.2015 11:34	1.76	65.10	35.00	34.70	0.46	53.85
08.06.2015 11:44	1.66	59.46	34.85	34.48	0.40	53.94
08.06.2015 11:54	1.69	61.40	34.81	34.62	0.38	53.41
08.06.2015 11:58	1.75	64.42	34.97	34.70	0.35	53.25
08.06.2015 12:15	1.83	68.40	35.14	34.85	0.41	52.55
08.06.2015 12:25	1.74	63.76	35.04	34.65	0.45	52.76
08.06.2015 12:35	1.83	68.68	35.08	34.93	0.44	51.53
08.06.2015 12:45	1.95	74.65	35.38	35.16	0.37	50.63
08.06.2015 12:55	2.08	80.26	35.64	35.32	0.45	51.34
08.06.2015 13:20	1.71	62.55	35.06	34.61	0.37	51.64
08.06.2015 13:25	1.66	59.83	34.81	34.60	0.52	51.96
08.06.2015 13:43	1.94	73.89	35.48	35.05	0.42	50.60
08.06.2015 13:53	1.87	70.35	35.33	34.88	0.39	51.96
08.06.2015 14:03	1.92	72.85	35.37	35.02	0.37	51.59
08.06.2015 14:13	1.86	69.87	35.35	34.84	0.33	52.08
08.06.2015 14:23	1.80	67.21	35.21	34.77	0.27	51.97
08.06.2015 14:26	1.62	57.29	34.87	34.35	0.25	52.74
08.06.2015 14:43	1.44	47.59	34.34	33.76	0.45	56.64
08.06.2015 14:53	1.17	34.01	33.59	33.22	0.34	57.93
08.06.2015 15:13	1.12	31.39	33.27	33.04	0.26	59.99
08.06.2015 15:23	1.21	35.94	33.40	33.23	0.20	59.09
08.06.2015 15:33	1.31	41.04	33.65	33.46	0.21	58.89
08.06.2015 15:43	1.30	40.33	33.77	33.37	0.25	59.23
08.06.2015 15:53	1.26	38.29	33.65	33.25	0.23	59.86
08.06.2015 16:03	1.14	32.60	33.30	33.00	0.22	60.98
08.06.2015 16:13	1.05	28.11	33.13	32.82	0.26	61.44
08.06.2015 16:33	1.06	28.65	32.87	32.60	0.29	62.58
08.06.2015 16:43	1.03	27.23	32.78	32.51	0.28	62.77
08.06.2015 16:53	0.97	24.74	32.61	32.38	0.28	63.22
08.06.2015 17:03	0.95	24.12	32.53	32.30	0.26	63.98
08.06.2015 17:13	0.97	24.75	32.47	32.30	0.22	63.94
08.06.2015 17:22	0.92	22.76	32.39	32.16	0.21	63.08

Table 63: Centre, 29.05.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.18, adapted met. rate, e=0.6)	PPD (clo=0.18, adapted met. rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
29.05.2015 09:45	1.33	41.60	32.18	32.48	0.19	63.00
29.05.2015 09:55	1.22	36.24	32.15	32.21	0.28	62.48
29.05.2015 10:05	1.32	41.42	32.24	32.52	0.21	61.66
29.05.2015 10:15	1.32	41.34	32.32	32.55	0.25	61.42
29.05.2015 10:24	1.32	41.08	32.30	32.51	0.24	61.70
29.05.2015 10:48	1.47	49.15	32.84	33.03	0.28	59.43
29.05.2015 10:58	1.49	50.21	32.85	33.07	0.26	60.03
29.05.2015 11:08	1.54	53.25	32.97	33.25	0.22	59.21
29.05.2015 11:18	1.59	55.83	33.05	33.39	0.20	59.86
29.05.2015 11:28	1.60	56.21	33.17	33.38	0.22	59.38
29.05.2015 11:58	1.59	55.57	33.23	33.40	0.37	59.12
29.05.2015 12:08	1.61	56.97	33.27	33.49	0.37	58.97
29.05.2015 12:18	1.67	59.90	33.38	33.66	0.29	58.07
29.05.2015 12:28	1.62	57.29	33.40	33.50	0.33	56.70
29.05.2015 12:38	1.68	60.86	33.50	33.72	0.33	56.94
29.05.2015 12:41	1.69	61.26	33.52	33.70	0.38	58.50
29.05.2015 13:07	1.67	60.15	33.50	33.60	0.34	58.87
29.05.2015 13:17	1.66	59.35	33.45	33.54	0.33	59.49
29.05.2015 13:27	1.66	59.41	33.46	33.54	0.29	58.91
29.05.2015 13:37	1.69	61.12	33.47	33.64	0.35	60.56
29.05.2015 13:47	1.71	62.16	33.57	33.65	0.33	60.86
29.05.2015 13:57	1.71	62.27	33.56	33.62	0.34	62.25
29.05.2015 14:05	1.63	57.79	33.43	33.37	0.37	61.90
29.05.2015 14:35	1.72	62.74	33.62	33.82	0.23	55.94
29.05.2015 14:45	1.72	63.01	33.68	33.75	0.24	57.41
29.05.2015 14:55	1.74	63.87	33.71	33.76	0.23	58.58
29.05.2015 15:05	1.74	64.05	33.70	33.76	0.24	59.26
29.05.2015 15:15	1.77	65.64	33.75	33.86	0.26	59.71
29.05.2015 15:25	1.76	65.04	33.77	33.76	0.23	60.33
29.05.2015 15:35	1.76	65.00	33.77	33.81	0.22	58.91
29.05.2015 15:45	1.76	64.70	33.83	33.74	0.27	59.38
29.05.2015 15:55	1.67	60.27	33.56	33.47	0.24	60.26
29.05.2015 16:05	1.44	47.85	32.87	32.73	0.23	61.99
29.05.2015 16:12	1.29	39.99	32.36	32.24	0.22	63.85

Table 64: Centre, 05.06.2015, measured values for the thermal comfort evaluation

date:time	PMV (clo=0.18, adapted met. rate, e=0.6)	PPD (clo=0.18, adapted met. rate, e=0.6)	Mean radiant temperature [°C]	Air temperature [°C]	Air velocity [m/s]	Relative humidity [%]
05.06.2015 10:07	1.51	51.47	32.98	33.15	0.28	59.16
05.06.2015 10:17	1.64	58.78	33.33	33.58	0.29	58.53
05.06.2015 10:27	1.63	58.12	33.44	33.46	0.28	58.29
05.06.2015 10:37	1.64	58.75	33.42	33.50	0.30	59.32
05.06.2015 10:41	1.61	56.97	33.36	33.40	0.33	59.55
05.06.2015 10:59	1.53	52.68	33.27	33.26	0.38	56.19
05.06.2015 11:09	1.57	54.87	33.25	33.38	0.31	56.72
05.06.2015 11:19	1.56	54.27	33.31	33.33	0.35	56.51
05.06.2015 11:29	1.61	56.89	33.30	33.56	0.34	55.81
05.06.2015 11:39	1.66	59.84	33.52	33.70	0.34	54.91
05.06.2015 11:49	1.75	64.18	33.81	33.92	0.35	53.89
05.06.2015 12:10	1.85	69.80	34.15	34.39	0.29	53.91
05.06.2015 12:20	1.85	69.49	34.19	34.34	0.33	53.64
05.06.2015 12:30	1.85	69.44	34.24	34.31	0.30	53.72
05.06.2015 12:40	1.86	69.87	34.22	34.34	0.32	54.05
05.06.2015 12:50	1.90	71.99	34.34	34.43	0.32	54.35
05.06.2015 13:00	1.88	71.09	34.31	34.35	0.37	54.73
05.06.2015 13:10	1.84	68.96	34.19	34.30	0.29	53.81
05.06.2015 13:20	1.87	70.45	34.32	34.36	0.29	53.35
05.06.2015 13:30	1.88	71.18	34.34	34.39	0.28	53.94
05.06.2015 13:40	1.83	68.37	34.25	34.21	0.35	53.82
05.06.2015 13:50	1.83	68.71	34.15	34.13	0.28	53.25
05.06.2015 14:00	1.82	68.10	34.11	34.11	0.26	53.04
05.06.2015 14:10	1.80	67.18	34.07	34.06	0.28	52.77
05.06.2015 14:20	1.83	68.44	34.13	34.14	0.21	52.99
05.06.2015 14:30	1.85	69.82	34.26	34.34	0.18	54.31
05.06.2015 14:40	1.85	69.37	34.29	34.22	0.20	55.44
05.06.2015 14:50	1.75	64.62	33.87	33.76	0.18	57.12
05.06.2015 14:56	1.66	59.73	33.61	33.46	0.21	57.76
05.06.2015 15:16	1.57	54.65	33.43	33.25	0.26	55.61
05.06.2015 15:26	1.63	57.71	33.33	33.45	0.15	56.75
05.06.2015 15:37	1.68	60.78	33.56	33.63	0.18	56.47
05.06.2015 15:47	1.65	59.00	33.43	33.39	0.20	60.67
05.06.2015 15:57	1.66	59.68	33.43	33.40	0.19	61.79

Evaluation of the thermal comfort

Bathroom 10.06.2015

Table 65: Iterative factors, bathroom TC1, 10.06.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
08:50	UW	Standing relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 66: Influencing parameters, bathroom TC1, 10.06.2015

Time	DI1	DI2	DN1
08:50	open	closed	open

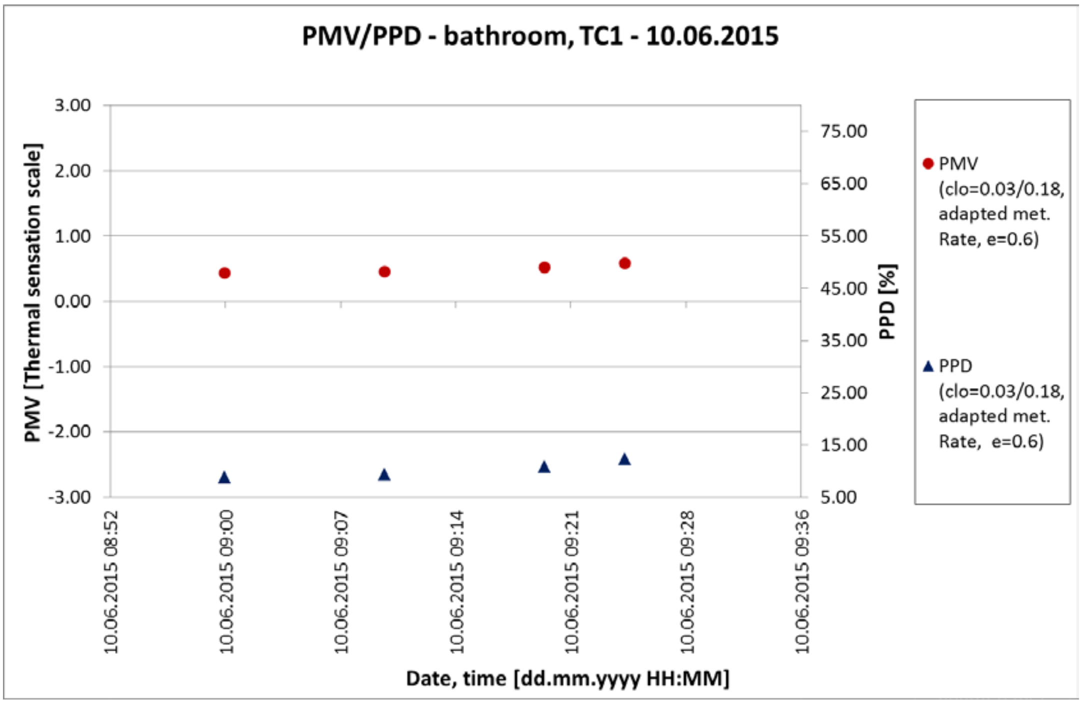


Figure 62: PMV/PPD, bathroom TC1, 10.06.2015

Remark: See also Table 51: Bathroom, 28.05.2015, measured values for the thermal comfort evaluation.

Bathroom 11.06.2015

Table 67: Iterative factors, bathroom TC1, 11.06.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
19:25	LSC1	Standing relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 68: Influencing parameters, bathroom TC1, 11.06.2015

Time	DI1	DI2	DN1
08:50	open	closed	open

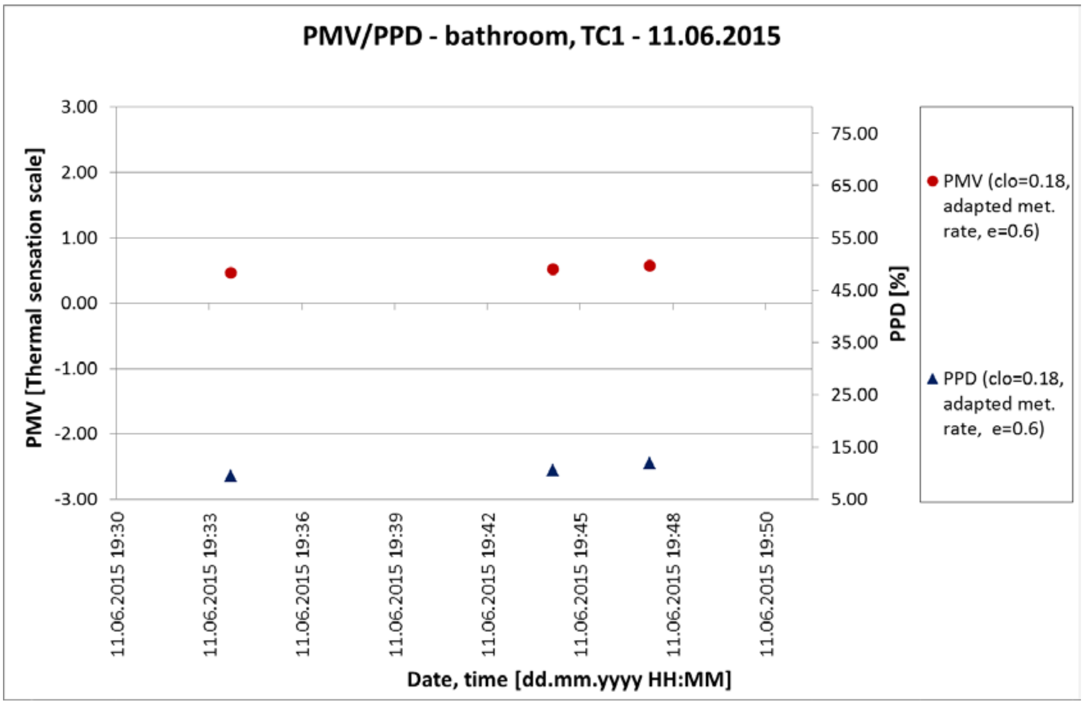


Figure 63: PMV/PPD, bathroom TC1, 11.06.2015

Remark: See also Table 52: Bathroom, 10.06.2015, measured values for the thermal comfort evaluation.

Bathroom 12.06.2015

Table 69: Iterative factors, bathroom TC1, 12.06.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
08:45	UW	Standing relaxed	Adapted*	0.6
11:37	LSC1	Standing relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 70: Influencing parameter, bathroom TC1, 12.06.2015

Time	DI1	DI2	DN1
08:45	closed	half open	open

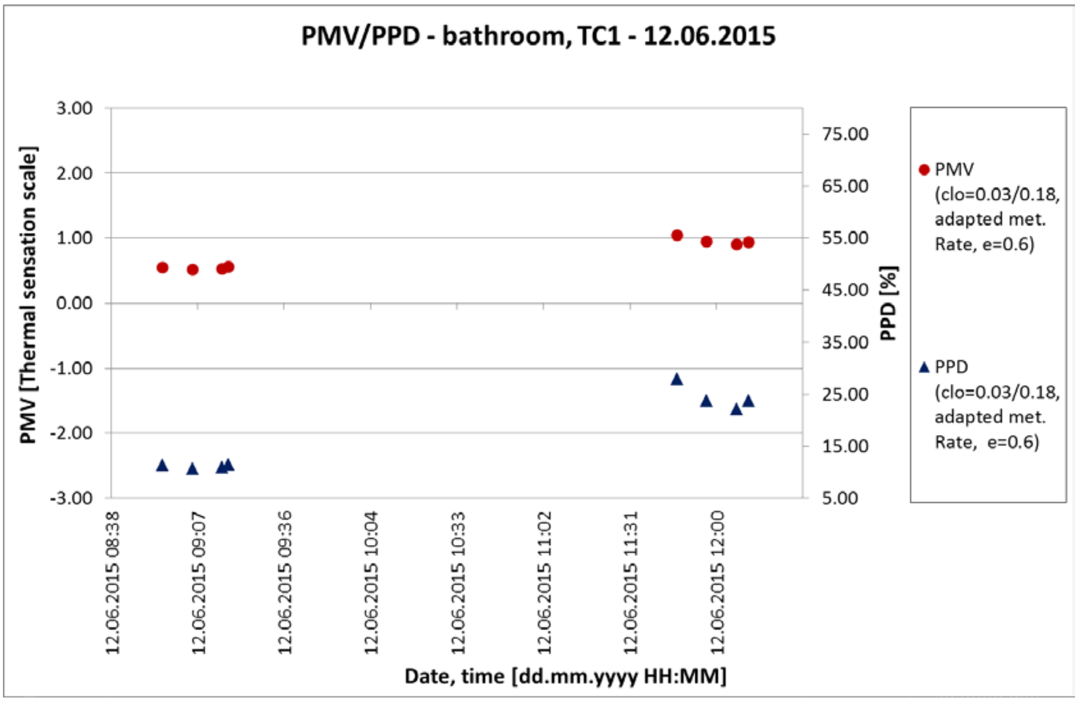


Figure 64: PMV/PPD, bathroom TC1, 12.06.2015

Remark: Clo=0.03 in the morning and clo=0.18 during the day. See also Table 53: Bathroom, 11.06.2015, measured values for the thermal comfort evaluation.

Bedroom 09.06.2015 to 10.06.2015

Table 71: Iterative factors, bedroom TC2, 09.06.2015 and 10.06.2015

Date, time	Set of clothing	Activity	Metabolic rate [met]	Exp. factor *e*
09.06.2015, 15:33	SW1	Sleeping	0.7	0.6
09.06.2015, 19:55	SW2	Sleeping	0.7	0.6

Table 72: Influencing parameters, bedroom TC2, 09.06.2015 and 10.06.2015

Date, time	DN1	DI1	DI2	F1
09.06.2015, 15:33	closed	open	open	off

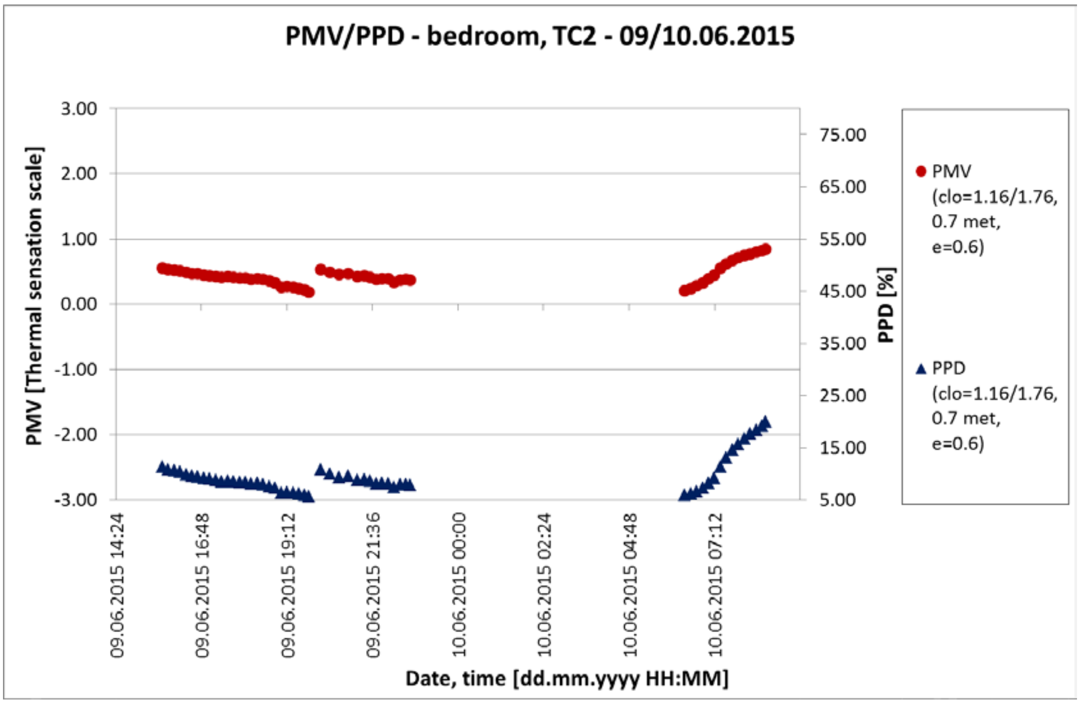


Figure 65: PMV/PPD, bedroom TC2, 09.06.2015 and 10.06.2015

Remark: Clo=1.16 during day and clo=1.76 at night (no furniture). See also Table 55: Bedroom, 09.06.2015 and 10.06.2015, measured values for the thermal comfort evaluation in appendix.

Dining Area 19.05.2015

Table 73: Iterative factors, dining area TC3, 19.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
12:05	LSC2	Seated, quiet	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 74: Influencing parameters, dining area TC3, 19.05.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
12:05	closed	closed	open	closed	on

Table 75: Influencing parameters, dining area TC3, 19.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
12:05	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
13:10	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted

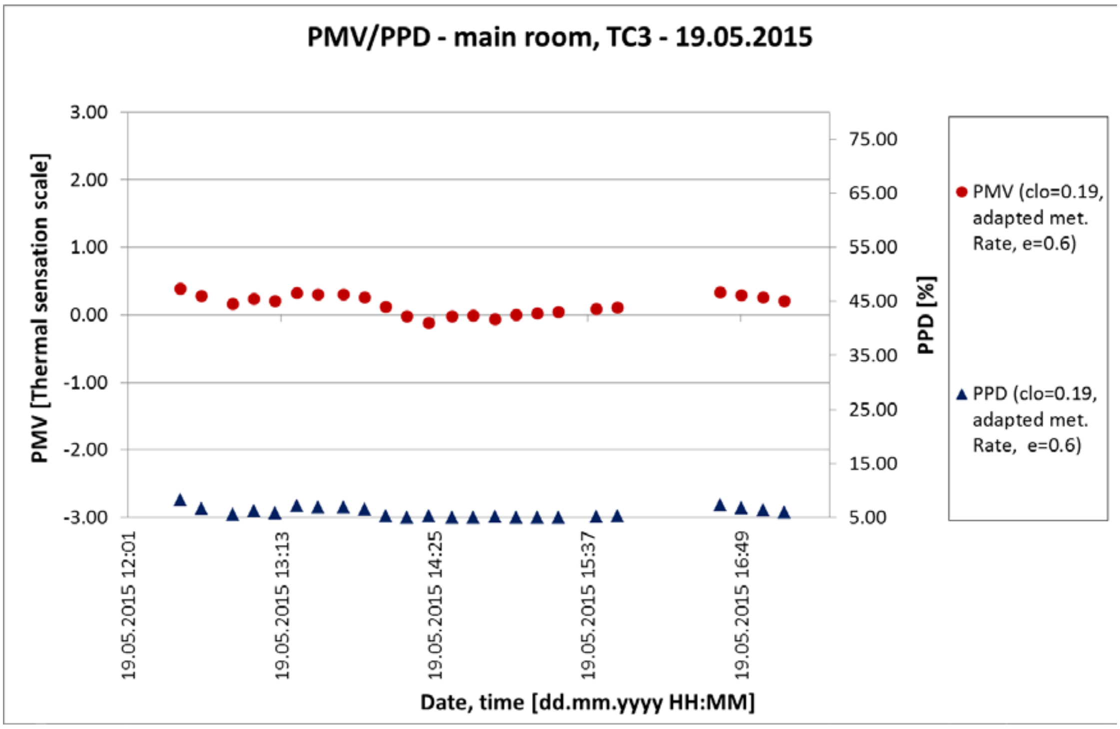


Figure 66: PMV/PPD, dining area TC3, 19.05.2015

Remark: Clo = 0.19; almost no change in influencing parameters because of rain (stop and go during day). See also Table 57: Dining area, 19.05.2015, measured values for the thermal comfort evaluation.

Dining Area 21.05.2015

Table 76: Iterative factors, dining area TC3, 21.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
10:37	LSC2	Seated, quiet	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 77: Influencing parameters, dining area TC3, 21.05.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
10:37	closed	open	open	open	on
10:49	closed	open	open	open	on
10:56	closed	open	open	closed	on
11:05	closed	open	open	closed	on
12:18	closed	closed	open	closed	on

Table 78: Influencing parameters, dining area TC3, 21.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
10:37	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
10:49	open	open	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
10:56	open	open	tilted	tilted	tilted	tilted	tilted	tilted	tilted	tilted
11:05	open	open	open	open	closed	closed	closed	tilted	tilted	tilted
12:18	tilted	tilted	tilted	tilted	closed	closed	closed	tilted	tilted	tilted

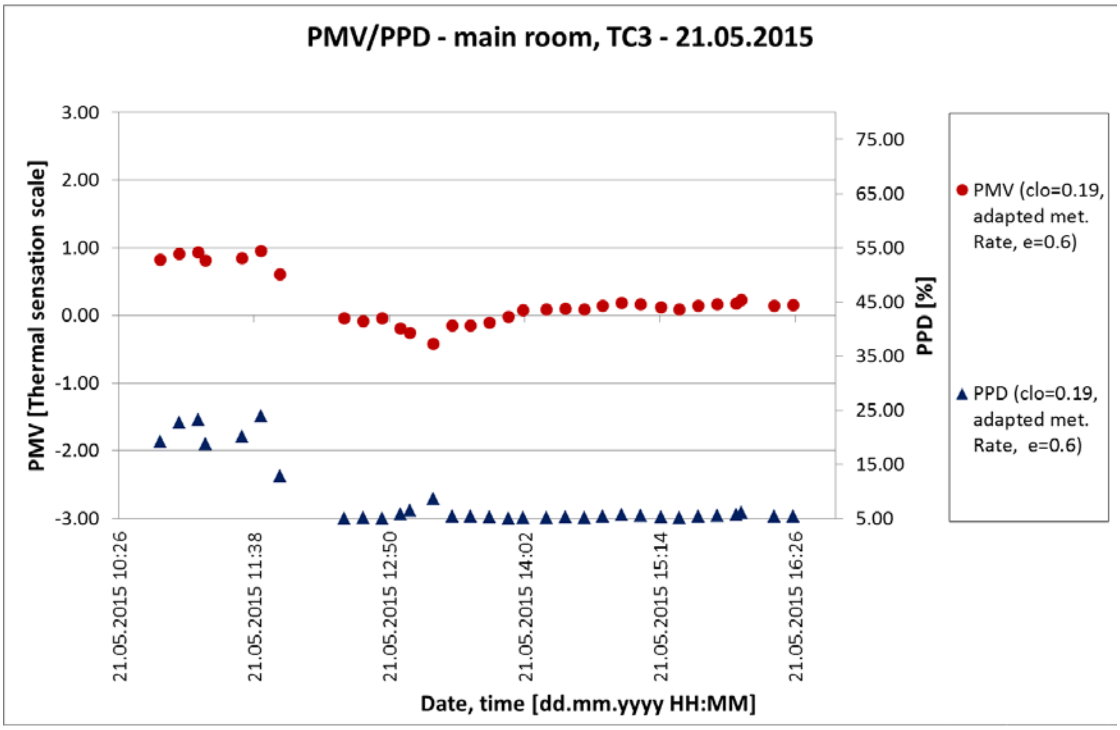


Figure 67: PMV/PPD, dining area TC3, 21.05.2015

Remark: Clo = 0.19; almost no change in influencing parameters because of rain (stop and go during day). See also Table 59: Dining area, 22.05.2015, measured values for the thermal comfort evaluation in appendix.

Dining Area 22.05.2015

Table 79: Iterative factors, dining area TC3, 22.05.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
09:33	LSC2	Seated, quiet	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 80: Influencing parameters, dining area TC3, 22.05.2015, doors and fan

Time	DN2	DW1	DI2/DN1	DS1	F2
09:33	closed	open	open/open	half open	on
10:33	closed	open	open/open	half open	on
11:39	closed	open	open/open	half open	on
14:20	closed	open	open/open	half open	on
14:30	closed	closed	open/open	half open	on
14:50	closed	open	open/open	half open	on
15:20	closed	closed	open/open	half open	on
17:20	closed	open	open/open	half open	on

Table 81: Influencing parameters, dining area TC3, 22.05.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
09:33	closed	closed	closed	closed	tilted	tilted	tilted	tilted	tilted	tilted
10:33	open	open	open	open	closed	closed	closed	tilted	tilted	tilted
11:39	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted
14:20	open	open	open	open	tilted	tilted	tilted	closed	closed	closed
14:30	open	open	open	open	tilted	tilted	tilted	closed	closed	closed
14:50	open	open	open	open	tilted	tilted	tilted	closed	closed	closed
15:20	open	open	open	open	tilted	tilted	tilted	closed	closed	closed
17:20	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted

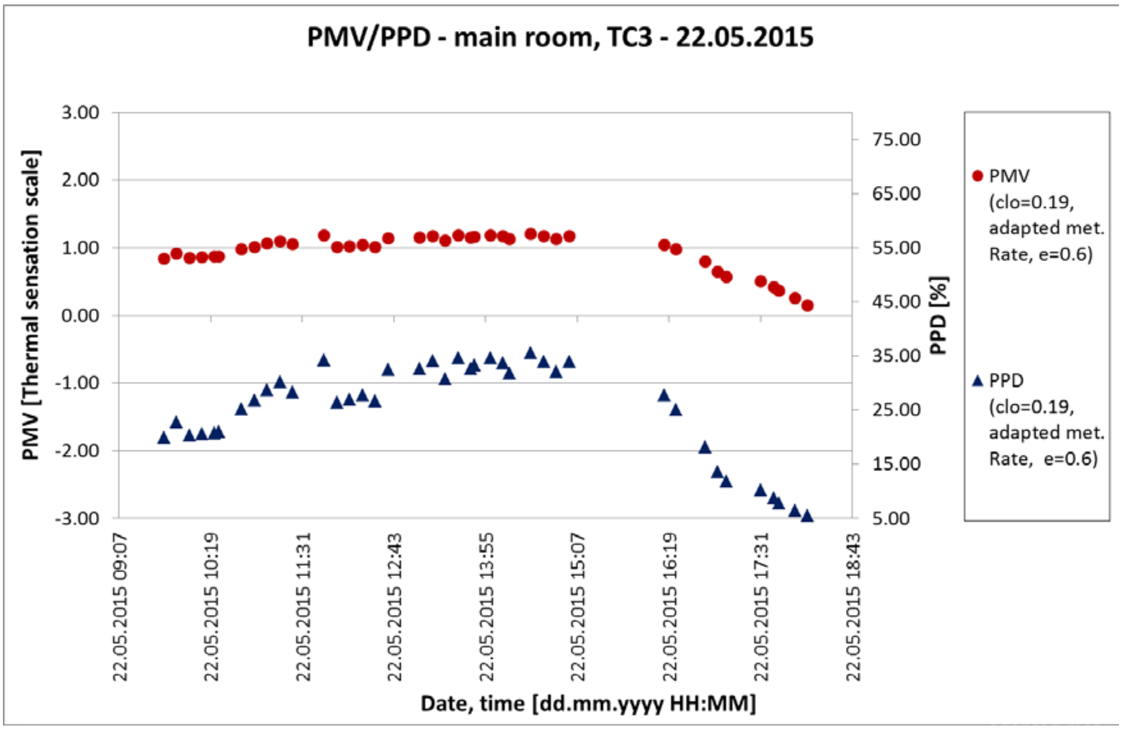


Figure 68: PMV/PPD, dining area TC3, 22.05.2015

Remark: Clo = 0.19; See also Table 59: Dining area, 22.05.2015, measured values for the thermal comfort evaluation.

Couch Area 08.06.2015

Table 82: Iterative factors, couch area TC4, 08.06.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
10:09	LSC3	Seated, reclining	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 83: Influencing parameters, couch area TC4, 08.06.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
10:09	open	open	open	open	on
13:33	open	closed	open	open	on
16:24	open	open	open	open	on

Table 84: Influencing parameters, couch area TC4, 08.06.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
10:09	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted
13:33	open	open	open	open	tilted	tilted	tilted	closed	closed	closed
16:24	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted

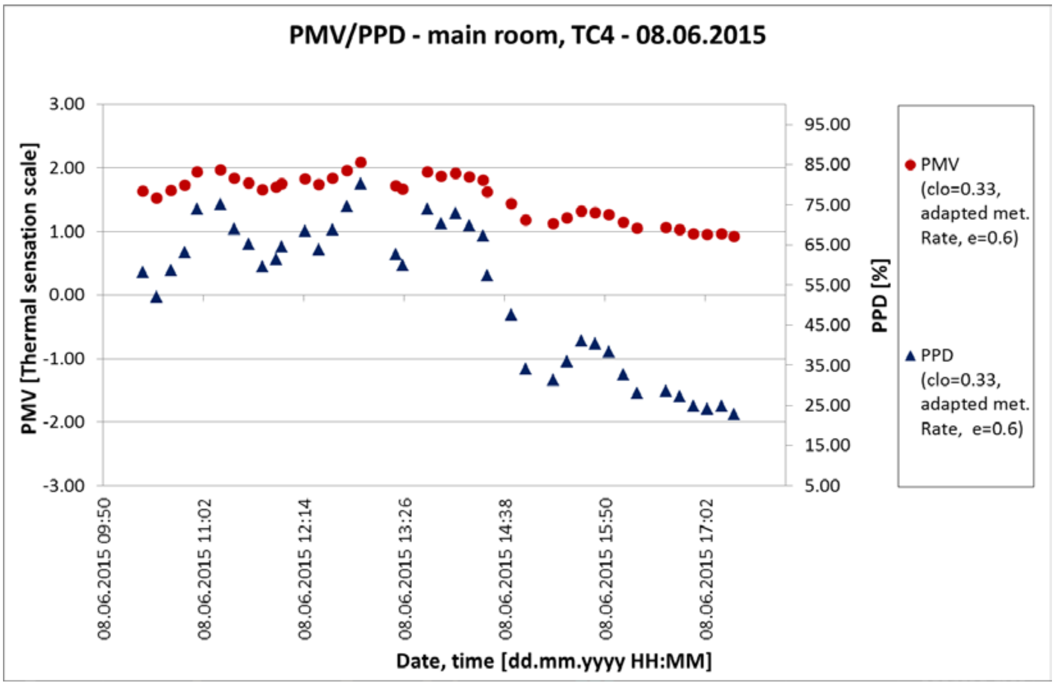


Figure 69: PMV/PPD, main room TC4, 08.06.2015

Remark: Clo=0.33 (armchair). See also Table 62: Couch area, 08.06.2015, measured values for the thermal comfort evaluation in appendix.

Centre 05.06.2015

Table 85: Iterative factors, centre TC5, 05.06.2015

Time	Set of clothing	Activity	Metabolic rate	Exp. factor *e*
09:58	LSC1	Standing, relaxed	Adapted*	0.6

*reduced by 6.7 % per unit on the thermal sensation scale

Table 86: Influencing parameters, centre TC5, 05.06.2015, doors and fan

Time	DN2	DW1	DI2	DS1	F2
09:58	closed	open	open	half open	on
10:50	closed	open	open	closed	on
14:13	closed	closed	open	half open	on

Table 87: Influencing parameters, centre TC5, 05.06.2015, windows

Time	WE1	WE2	WE3	WE4	WS1	WS2	WS3	WW1	WW2	WW3
09:58	open	open	open	open	tilted	tilted	tilted	tilted	tilted	tilted
10:50	open	open	open	open	closed	closed	closed	tilted	tilted	tilted
14:13	open	open	open	open	tilted	tilted	tilted	closed	closed	closed

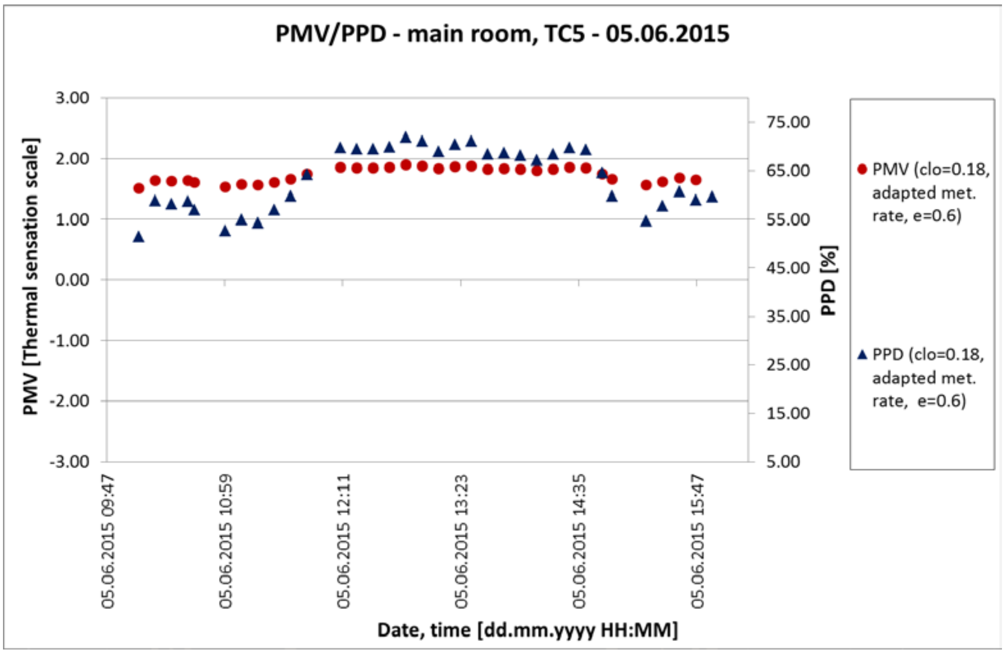


Figure 70: PMV/PPD, main room TC5, 05.06.2015

Remark: Clo=0.18. See also Table 64: Centre, 05.06.2015, measured values for the thermal comfort evaluation in appendix.