Aalborg Universitet

Bolig 2020 med godt indeklima og høj brugerkomfort – Målerapport 5

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Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Loukou, E., Heiselberg, P. K., & Jensen, R. L. (2018). Bolig 2020 med godt indeklima og høj brugerkomfort – Målerapport 5. Department of Civil Engineering, Aalborg University. DCE Technical Reports No. 259

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DEPARTMENT OF CIVIL ENGINEERING
AALBORG UNIVERSITY

Bolig 2020 med godt indeklima og høj brugerkomfort – Målerapport 5

Evangelia Loukou
Per Kvols Heiselberg
Rasmus Lund Jensen

ISSN 1901-726X
DCE Technical Report No. 259

Aalborg University
Department of Civil Engineering
Architectural Engineering

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by

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Rasmus Lund Jensen

December 2018

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Published 2018 by
Aalborg University
Department of Civil Engineering
Thomas Manns Vej 23
DK-9220 Aalborg Øst, Denmark

Printed in Aalborg at Aalborg University

ISSN 1901-726X
DCE Technical Report No. 259

1. Introduction

The purpose of this report is to register the operation and performance of the project building Bolig 2020 for the period of 3 months from September to November. The building is located in Kildebjerg Søvej 32, Ry.

The aim is the long-term assessment of the indoor environmental quality and energy use of the dwelling. Additionally, the data is examined in order to verify that the systems' and equipment's performance matches their intended operation.

The evaluation of the performance of Bolig 2020 case study is based on a combination of standards and measured data.

The data registration is taking place every 5 minutes, approximately, in all rooms of the dwelling. The registered parameters are the following:

Parameters	**Comments**
Cold water consumption [m^3]	Total amount of water consumption for cold and hot water
Hot water consumption [m^3]	
Energy consumption:	
District heating [MWh]	
Floor heating pump [kWh]	
Nilan system [kWh]	Energy consumption for ventilation and production of sanitary hot water
Control system [kWh]	
Kitchen stove [kWh]	Energy consumption for the operation of 2 ovens and the cooking plate
Refrigerator [kWh]	Energy consumption for the refrigerator, wine cooler and exhaust hood
Quooker [kWh]	
Dish washer [kWh]	
Dryer [kWh]	
Washing machine [kWh]	
Other consumption [kWh]	Includes everything else

Temperature [°C], CO_2 level [ppm], Relative humidity level [%] and Damper opening [min/ max]:
Room 1
Room 2
Room 3
Master Bedroom
Living Room
Kitchen/ Dining Room

Temperature [°C], Relative humidity level [%] and Damper opening [min/ max]:
Utility Room
Bathroom 1 (Master Bedroom)
Bathroom 2 (Corridor)

Temperature [°C] and Damper opening [min/ max]:
Wardrobe closet

For the compact unit:
Outdoor air temperature [°C]
Return air temperature [°C] and relative humidity [%]
Hot water temperature [°C]
Supply air temperature [°C]
Heat pump temperature [°C]
Ventilation speed [steps]

In the end of November, more parameters' registration was activated. These are the following:

External solar shading, skylight and window activation [0/1] (Automatically & Manually):
Solar shading 1: Master Bedroom – East
Solar shading 2: Master Bedroom – South
Solar shading 3: Living Room – South
Solar shading 4: Living Room – West
Skylight 1: Corridor
Skylight 2: Kitchen
Window: Room 1
Window: Room 3
Window: Kitchen/ Dining Room
Window: Living Room
Window: Master Bedroom

Floor heating actuators for each room [0/1]:
Living Room
Master Bedroom
Wardrobe closet
Bathroom 1 (Master Bedroom)
Kitchen/ Dining Room
Corridor
Room 1
Room 2
Room 3
Bathroom 2 (Corridor)
Utility Room

Supply and return air:
Flow [m^3/h]
Temperature [°C]

Water consumption:
Energy consumption for hot water production [kWh]
Hot water flow [l/h]
Hot water temperature (T1) [°C]
Cold water temperature (T2) [°C]

This report includes the registered period between the beginnings of September to the end of November. The data is presented both on a monthly level and for the entire period of the 3 months. The indoor environment evaluation is realized on a room basis, while the examined rooms are the most used ones, master bedroom, living room, kitchen and bathroom.

Each chapter addresses one of the examined parameters, including graphs for each examined month, as well as for the entire period (September, October and November). In the Annex are included more relevant graphs which are not in the report.

On the 26th of October, there are some missing information; the data registration starts at 17:10. The percentage of time in each category has been calculated ignoring the missing values. The graphs presented in the Annex are also missing the values for that part of the day, so the existing data is connected with a straight line.

2. Energy Consumption

2.1 Energy consumption for ventilation and DHW

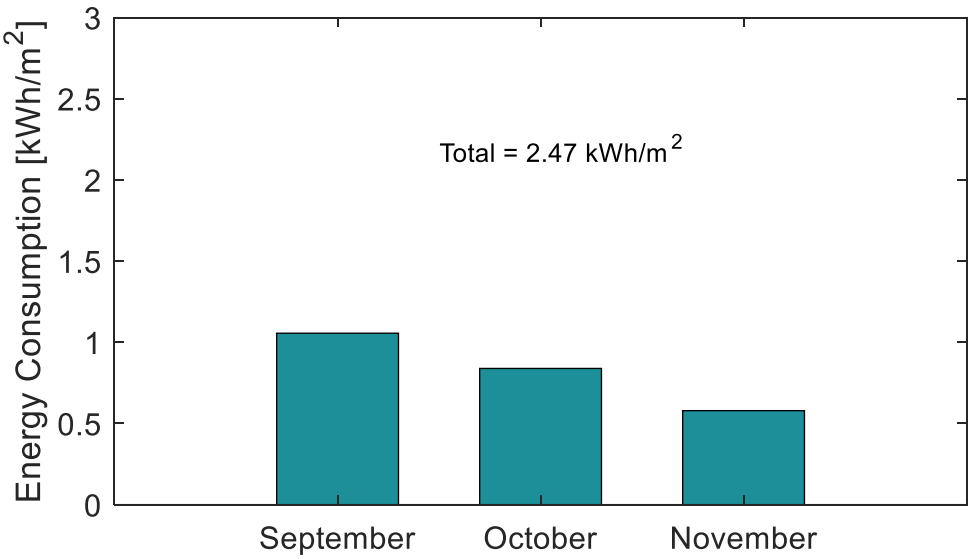

Figure 1: Energy consumption for ventilation and domestic hot water [kWh/m²]

The sanitary hot water is produced by the compact ventilation system through the recovered energy from the exhaust air. If the demand is particularly large, an electrical backup supplements the production of hot water.

2.2 Energy consumption for heating

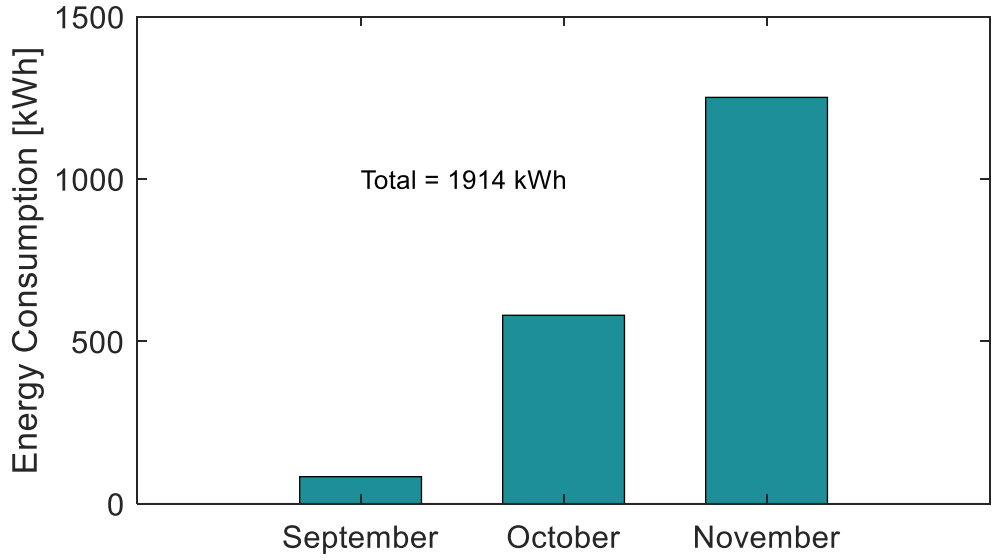

Figure 2: Energy consumption for heating [kWh]

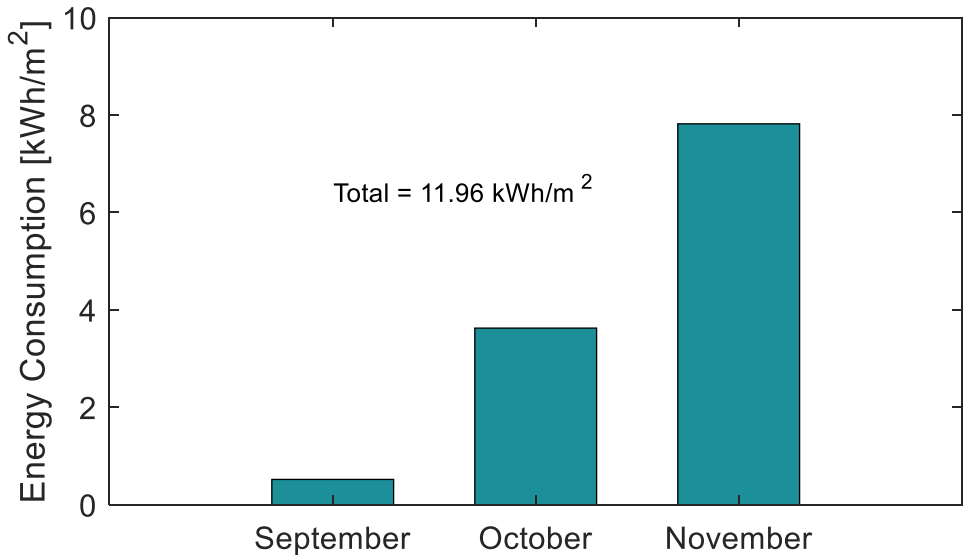

Figure 3: Energy consumption for heating [kWh/m^2]

Figures 2 and 3 illustrate the energy consumption for heating, given in [kWh] and [kWh/m^2], respectively. The values are taken from the data registered for "District Heating".

2.3 Electricity consumption

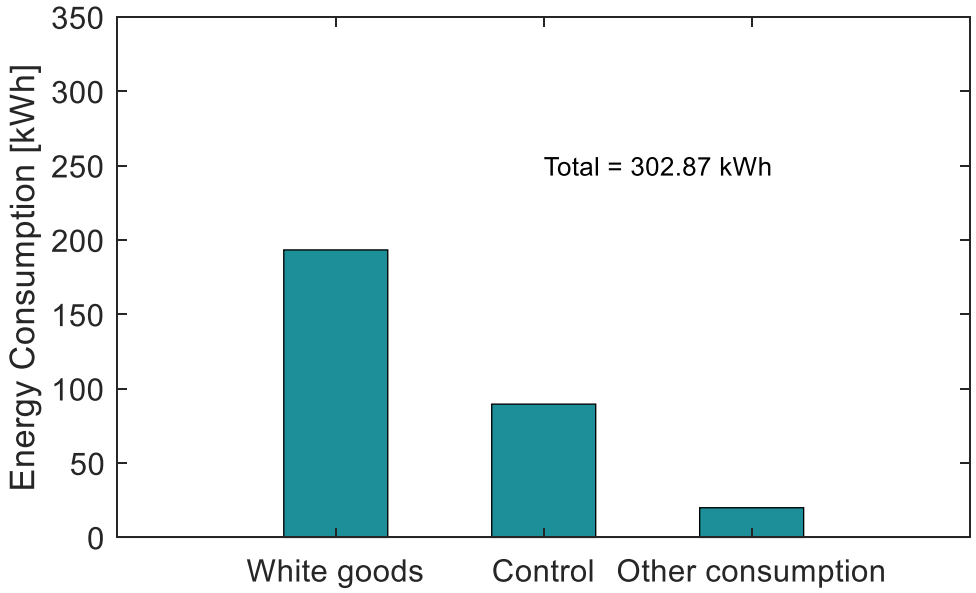

Figure 4: Consumption of electricity during 3 months period time (September, October, November) [kWh]

The energy consumption of white goods includes the kitchen stove, the refrigerator, the Quooker (for production of boiling water), the dishwasher, the dryer and the washing machine. The second column refers to the control of all systems, sensors etc., while the third column includes all the rest.

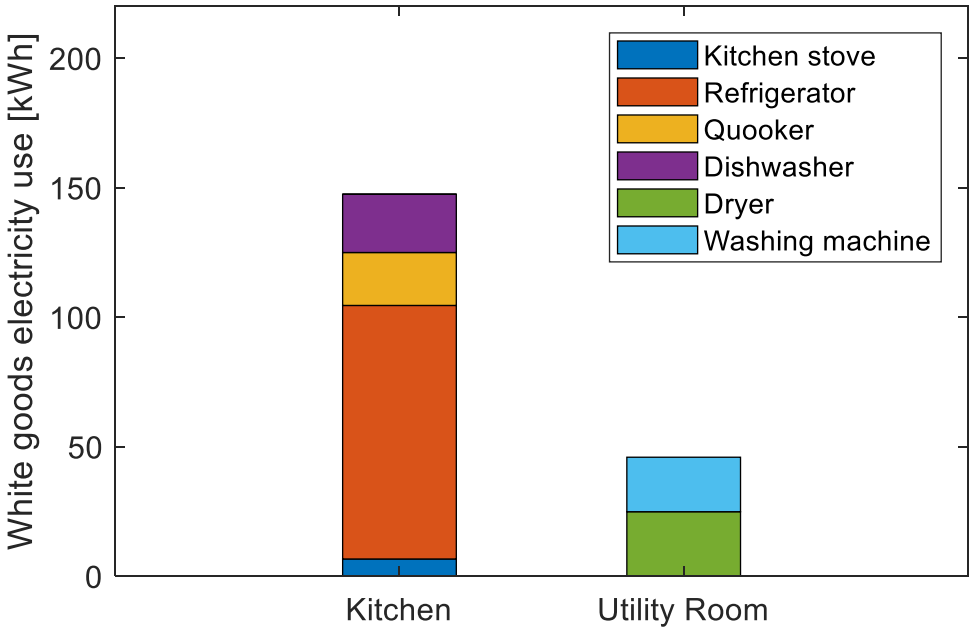

Figure 5: Consumption of electricity of white goods, on room level during 3 months period time (September, October, November) [kWh]

Figure 5 gives the energy consumption for all registered appliances divided in room level.

2.4 Water consumption

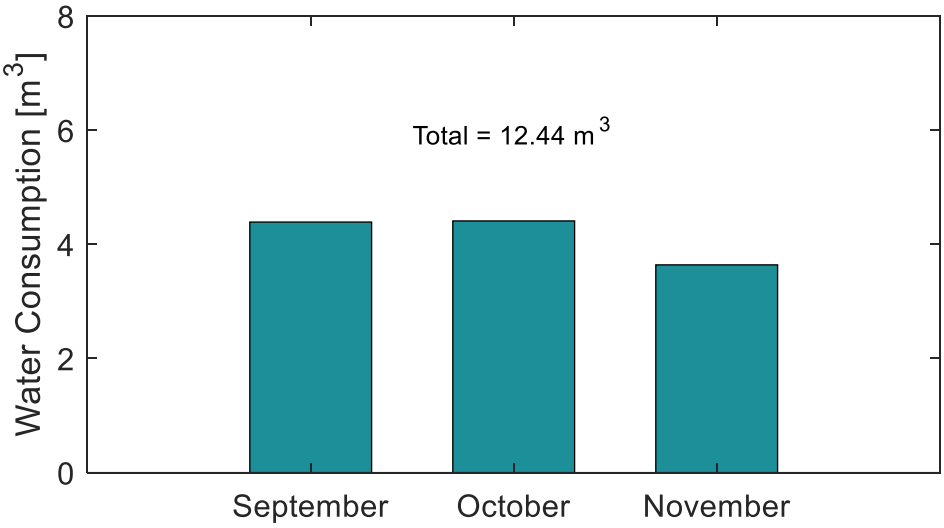

Figure 6: Water consumption [m^3]

In Figure 6 is presented the total water consumption for both cold and hot water. Due to changes in the data registration, the hot water consumption is unknown.

3. Indoor Environment

For the indoor environmental quality is evaluated the thermal and atmospheric indoor climate. More specifically, the examined parameters are the room temperature [°C], CO_2 level [ppm] and relative humidity level [%]. The rooms are examined on a daily level (24 hours), as well as for their expected occupied period. The time from 7:00 to 17:00 is counted as unoccupied, taking into consideration that the occupants are away from home during this period. The following table sums up the corresponding periods for each type of room.

	Scenario 1	Scenario 2
Living Room	24 h	Day: 17 - 23
Kitchen	24 h	Day: 17 - 23
Master bedroom	24 h	Night: 23 - 7

3.1 Thermal indoor environment

The thermal criteria are assessed according to the comfort categories given by the standards DS/EN 15251. The following table shows the temperature ranges for the three categories, assuming an activity level of 1.2 met (sedentary activity). September and October are calculated for the summer comfort range, while for November are assumed winter conditions.

Activity level [met]		1.2		
Category		I	II	III
Operative temperature [°C]	Summer	24.5 ± 1.0	24.5 ± 1.5	24.5 ± 2.5
	Winter	22.0 ± 1.0	22.0 ± 2.0	22.0 ± 3.0

The recommended criteria for acceptable deviations for the thermal environment, for Category II, are presented in the following table.

		Max. deviation	
	Criteria	Monthly	Yearly
General Assessment	Class II	3 & 5 %	3 & 5 %
Overheating	25 °C	10 %	10 %
	27 °C	-	100 h
	28 °C	-	25 h
Under heating	20 °C	-	100 h
	19 °C	-	25 h

The distribution of hours in each of the three categories is given in percentages, in form of bar charts, specifying whether the room temperature lies on the low or high part of the scale, for summer and winter period, respectively.

IV-	III-	II-	I	II+	III+	IV+
t < 22	22 ≤ t < 23	23 ≤ t < 23.5	23.5 ≤ t ≤ 25.5	25.5 < t ≤ 26	26 < t ≤ 27	27 < t
t < 19	19 ≤ t < 20	20 ≤ t < 21	21 ≤ t ≤ 23	23 < t ≤ 24	24 < t ≤ 25	25 < t

3.1.1 September

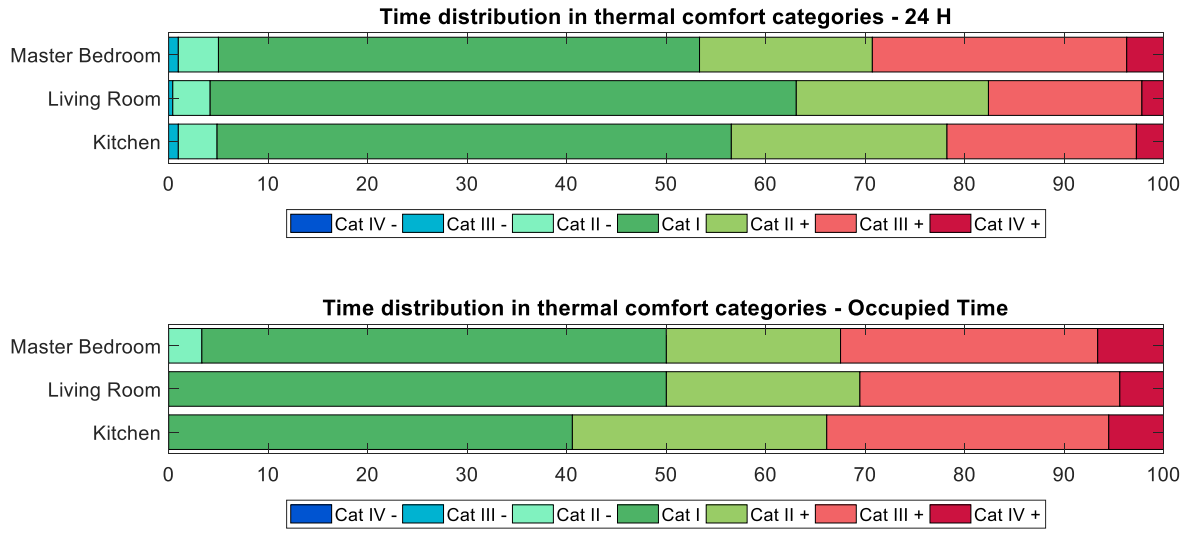

Figure 7: Percentage of time in each Category for tempeature during September

3.1.2 October

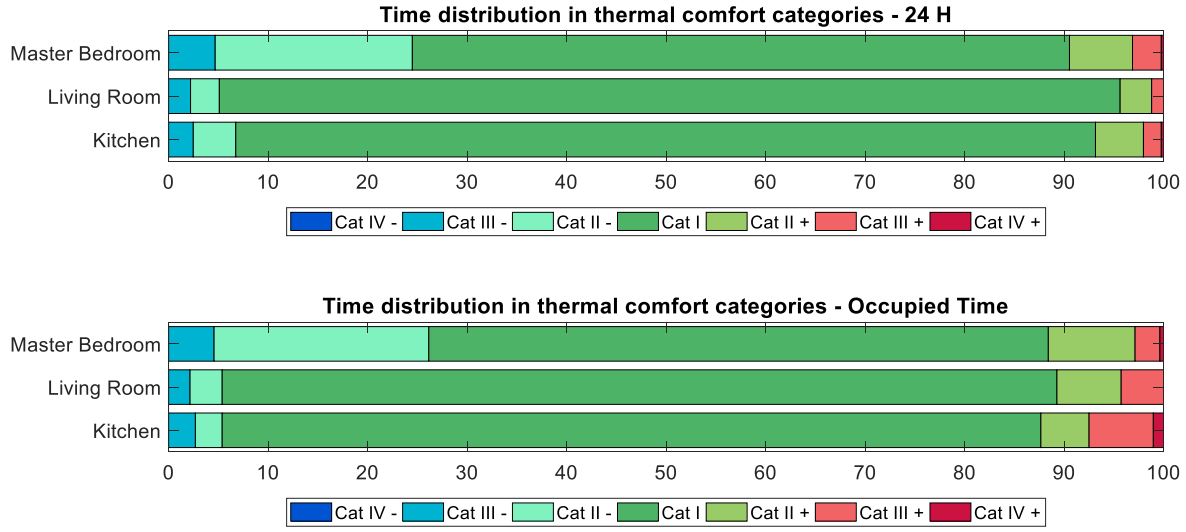

Figure 8: Percentage of time in each Category for tempeature during October

3.1.3 November

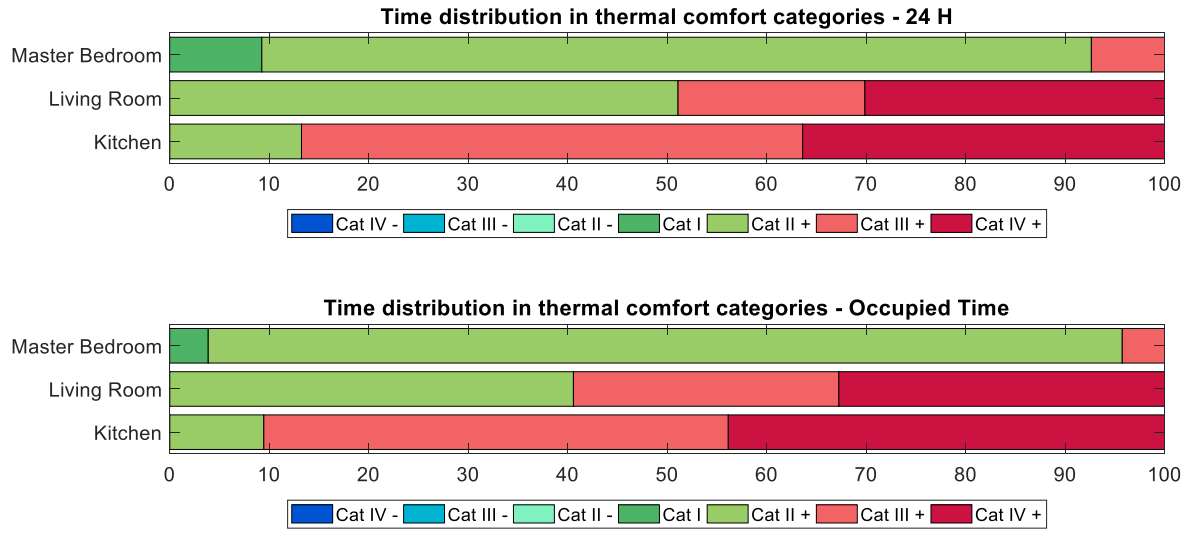

Figure 9: Percentage of time in each Category for tempeature during November

3.1.4 Entire period (September, October, November)

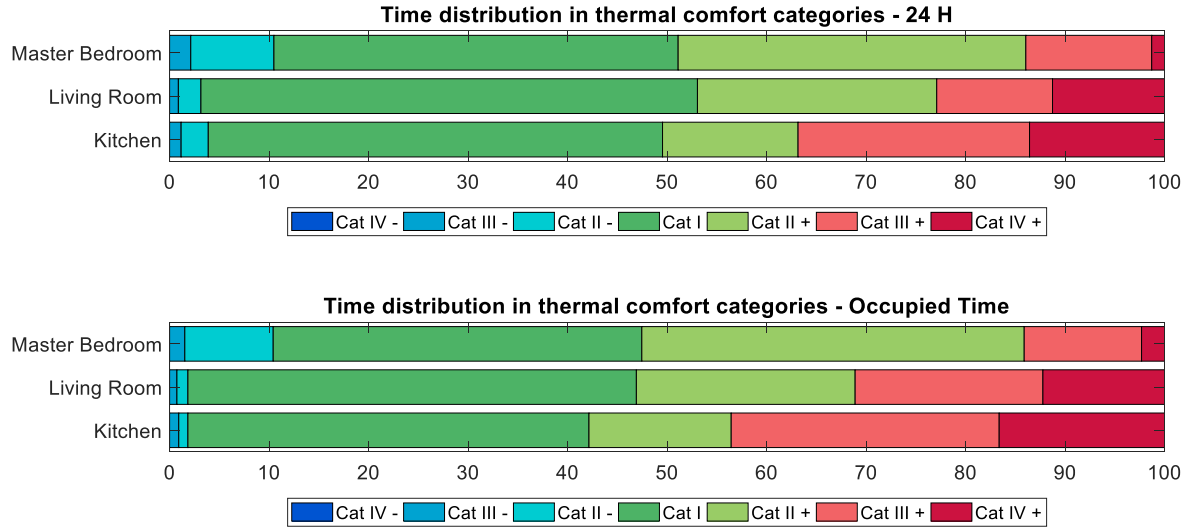

Figure 10: Percentage of time in each Category for tempeature during 3 months period time (September, October, November)

3.1.5 Thermal comfort and window activation

The following graphs are presenting the last days of November (22nd to 30th), when window activation is being registered. The graphs are on room level and they show if thermal comfort is achieved, in relation to window opening. It is considered that comfort conditions are met when the criteria for Category II are fulfilled. The activation of windows can be realized either automatically or manually. For the kitchen/ dining room, the skylight is also taken into consideration, apart from the window.

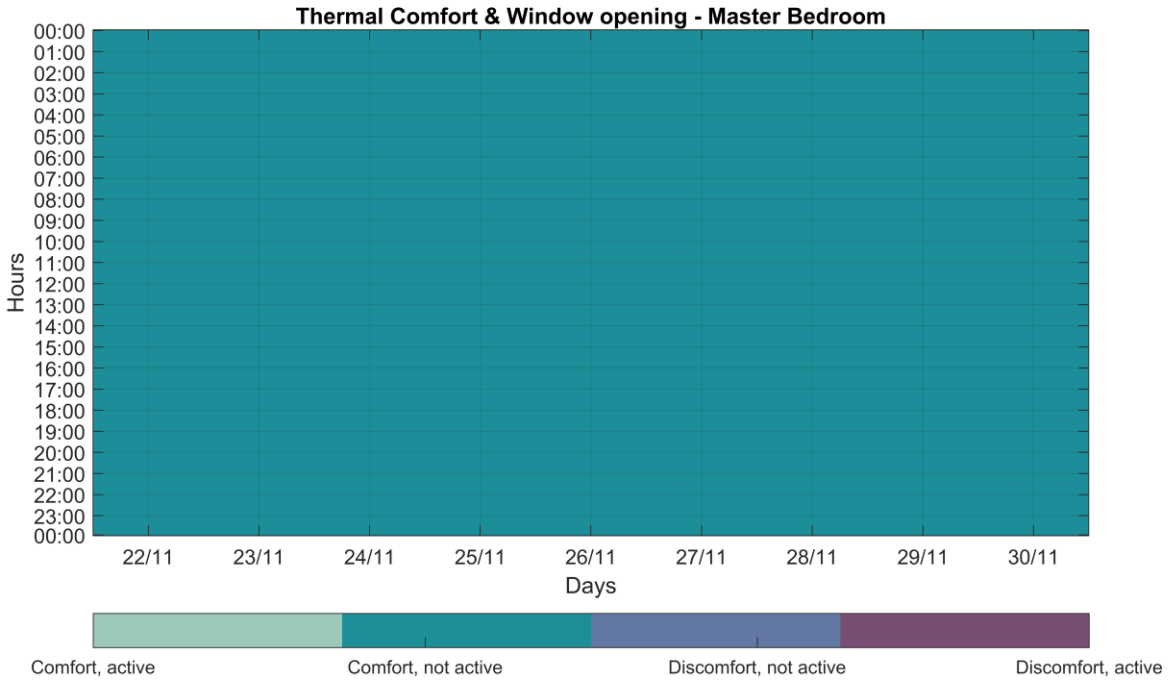

Figure 11: Thermal comfort in relation to window opening – Master bedroom (22 – 30 November)

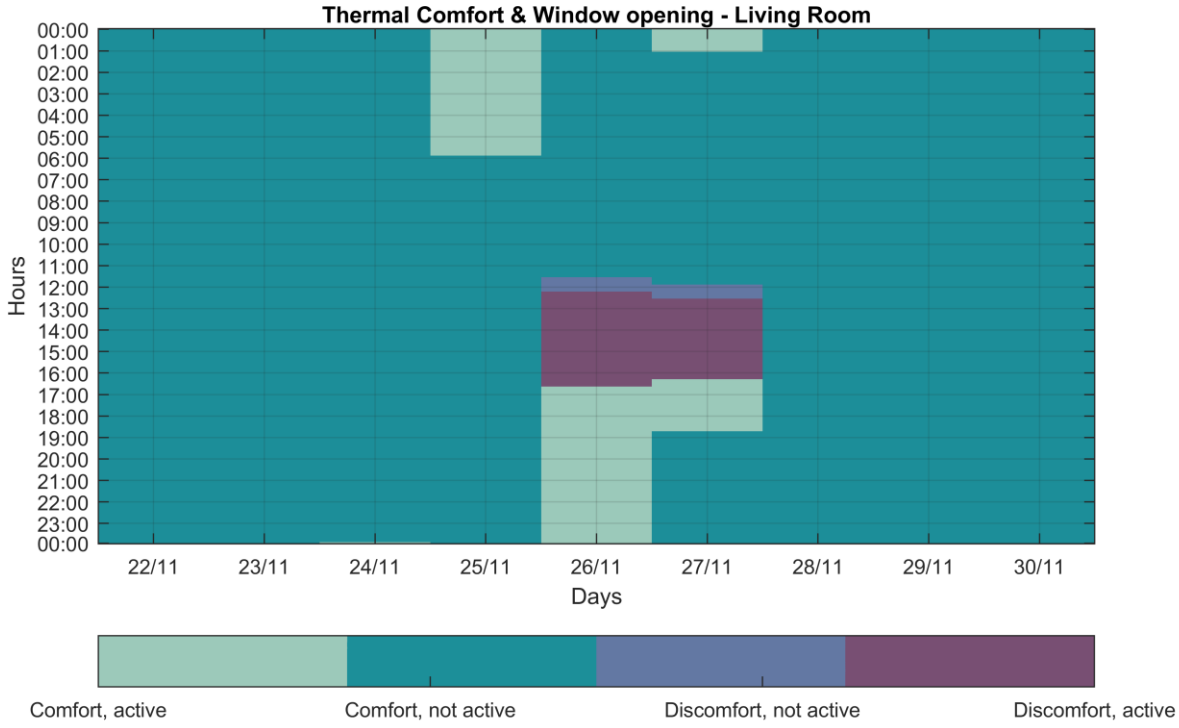

Figure 12: Thermal comfort in relation to window opening – Living room (22 – 30 November)

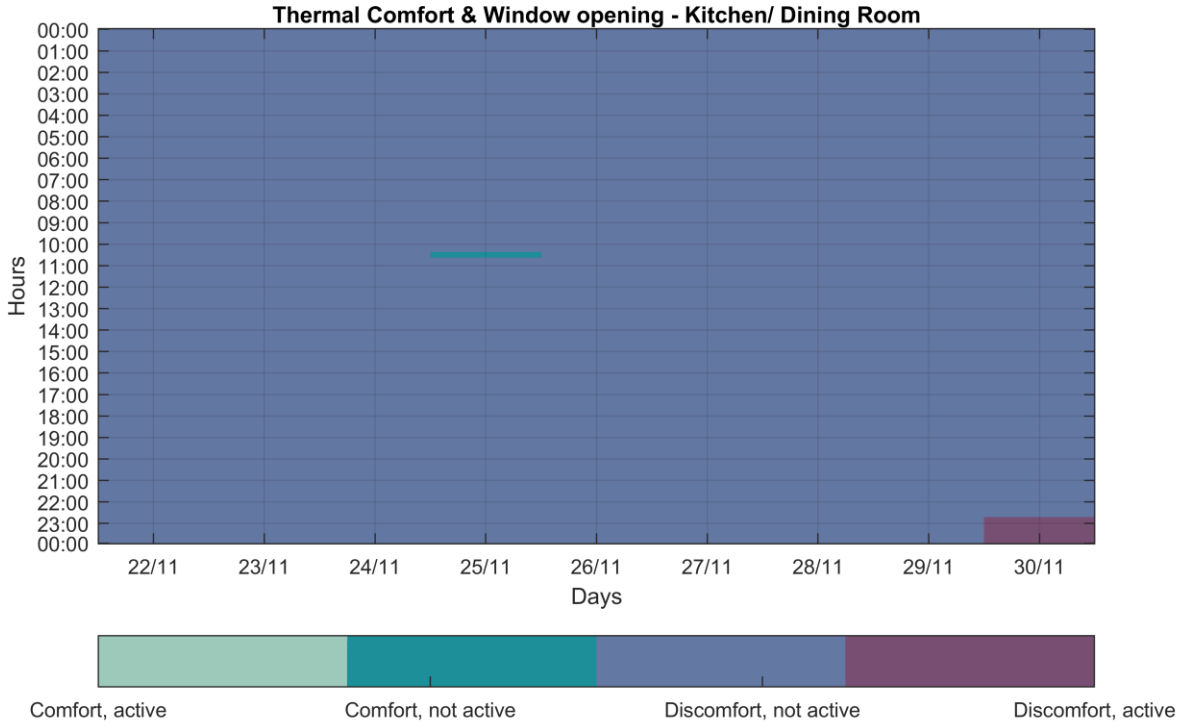

Figure 13: Thermal comfort in relation to window opening – Kitchen/ Dining room (22 – 30 November)

3.2 Atmospheric indoor environment

The indoor air quality is also assessed based on the comfort categories suggested by the standards DS/EN 15251. On the following tables are given the acceptable ranges for CO_2 level and relative humidity, respectively.

Category	Corresponding CO_2 above outdoors level [ppm]
I	350
II	500
III	800
IV	> 800

Category	Design relative humidity for dehumidification [%]	Design relative humidity for humidification [%]
I	50	30
II	60	25
III	70	20
IV	>70	<20

The outdoor CO_2 level is taken as a standard value of 400 ppm and not as the minimum registered value by the sensors in each room. This was decided based on the observation that occasionally some of the sensors would register some unrealistically small values. Actions have been taken in order to verify the proper operation of the sensors and eventually to calibrate or replace them. Therefore, it should be kept in mind that there is some uncertainty concerning the presented results for the CO_2 level.

Next table shows the recommended criteria for acceptable deviations for the atmospheric environment, for Category II.

		Max. deviation
	Criteria	Monthly
CO_2	Category II	3 & 5 %
	Category II	8 h in a row
Relative Humidity	Category II	3 & 5 %
	Category II	24 h in a row
	RH< 45%	-
	RH> 75%	1%

3.2.1 September

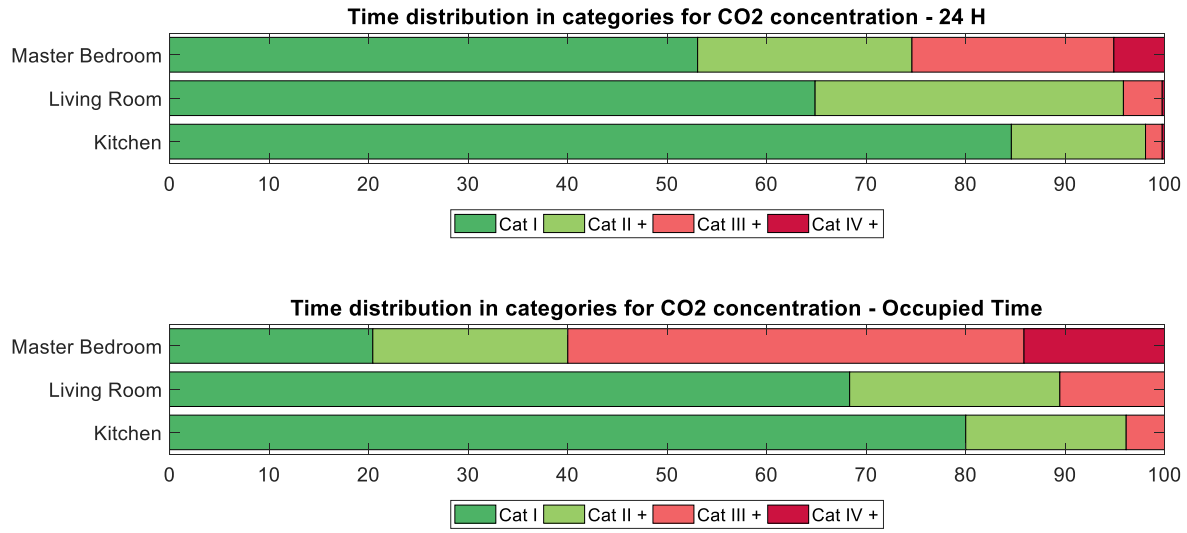

Figure 14: Percentage of time in each Category for CO_2 level during September

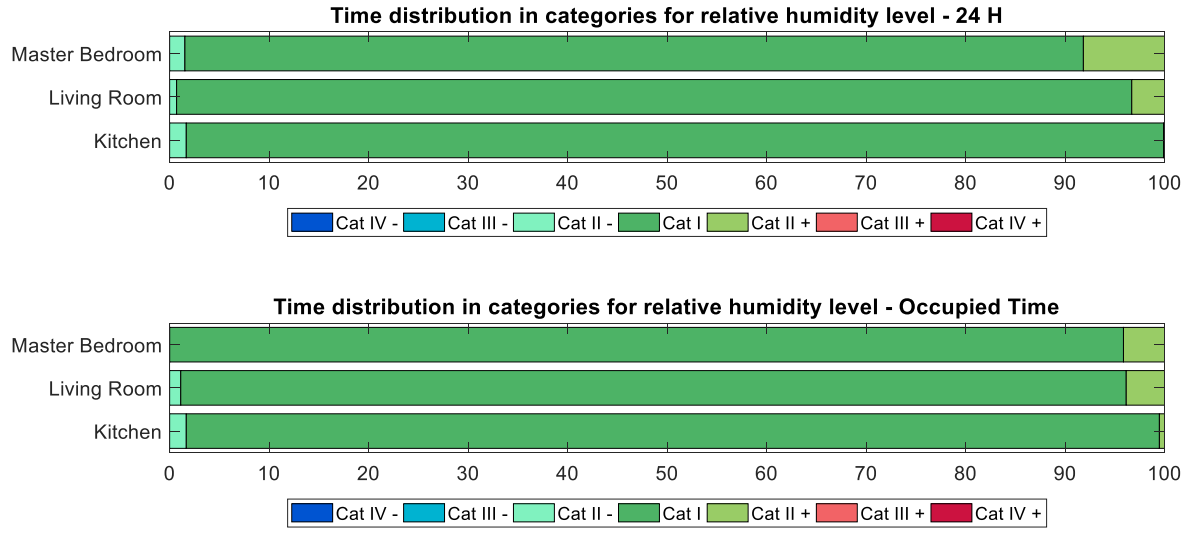

Figure 15: Percentage of time in each Category for relative humidity during September

3.2.2 October

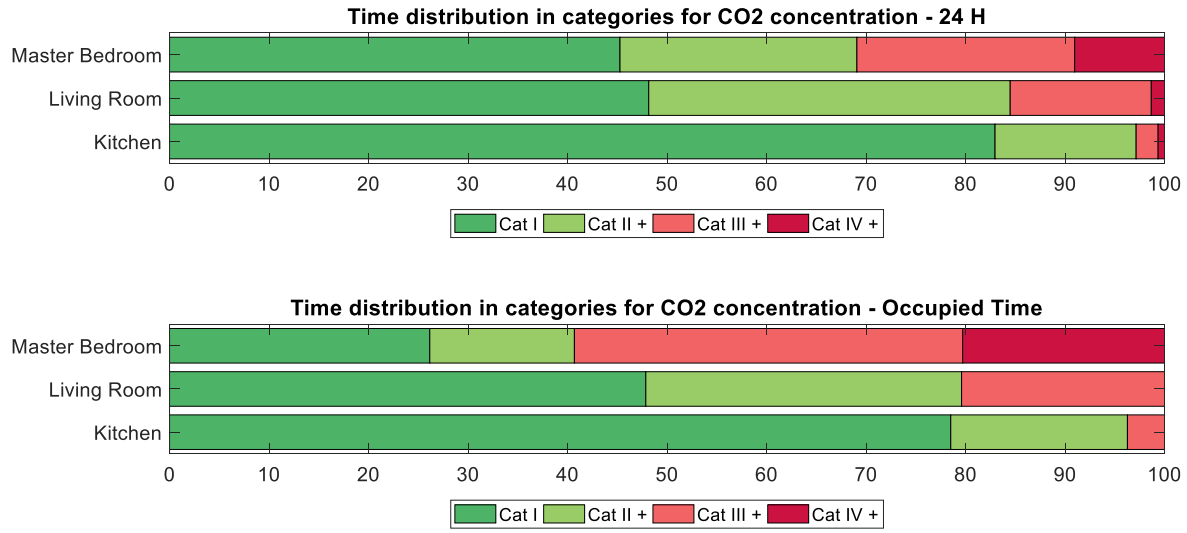

Figure 16: Percentage of time in each Category for CO_2 level during October

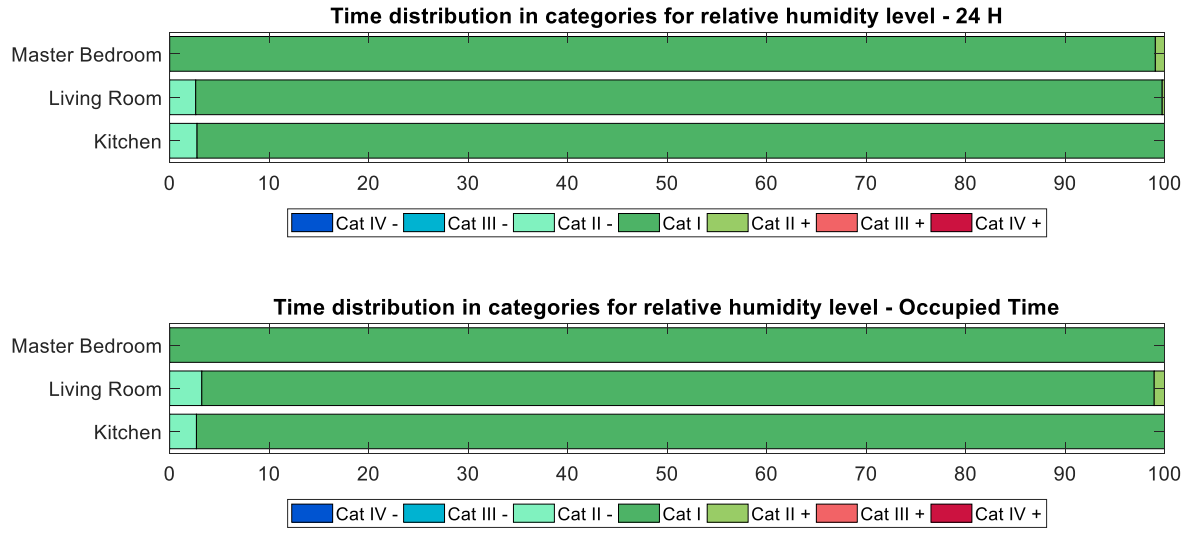

Figure 17: Percentage of time in each Category for relative humidity during October

3.2.3 November

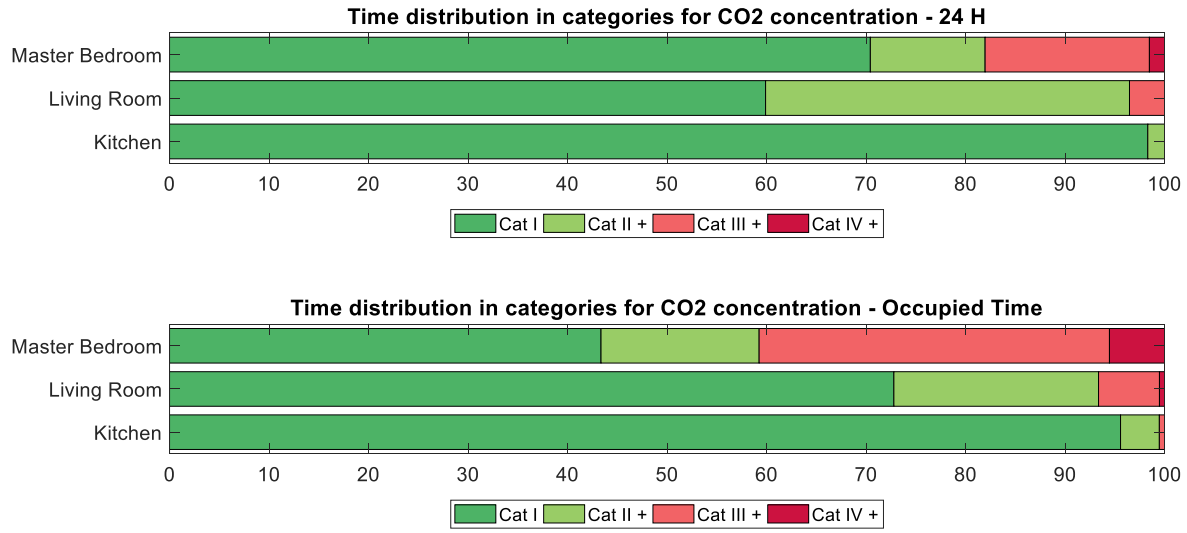

Figure 18: Percentage of time in each Category for CO_2 level during November

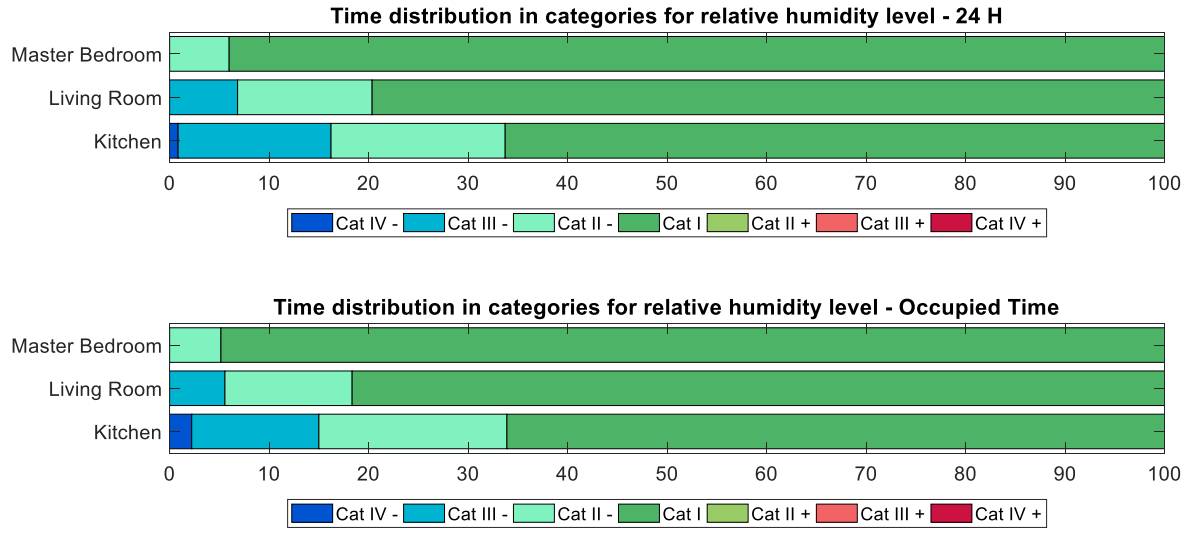

Figure 19: Percentage of time in each Category for relative humidity during November

3.2.4 Entire period (September, October, November)

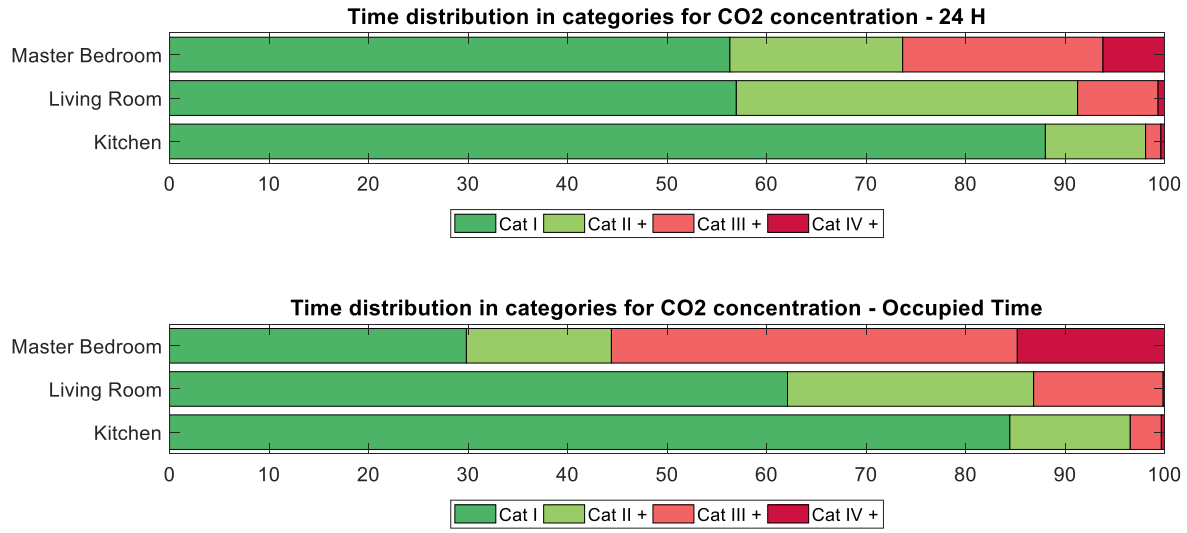

Figure 20: Percentage of time in each Category for CO_2 level during 3 months period time (September, October, November)

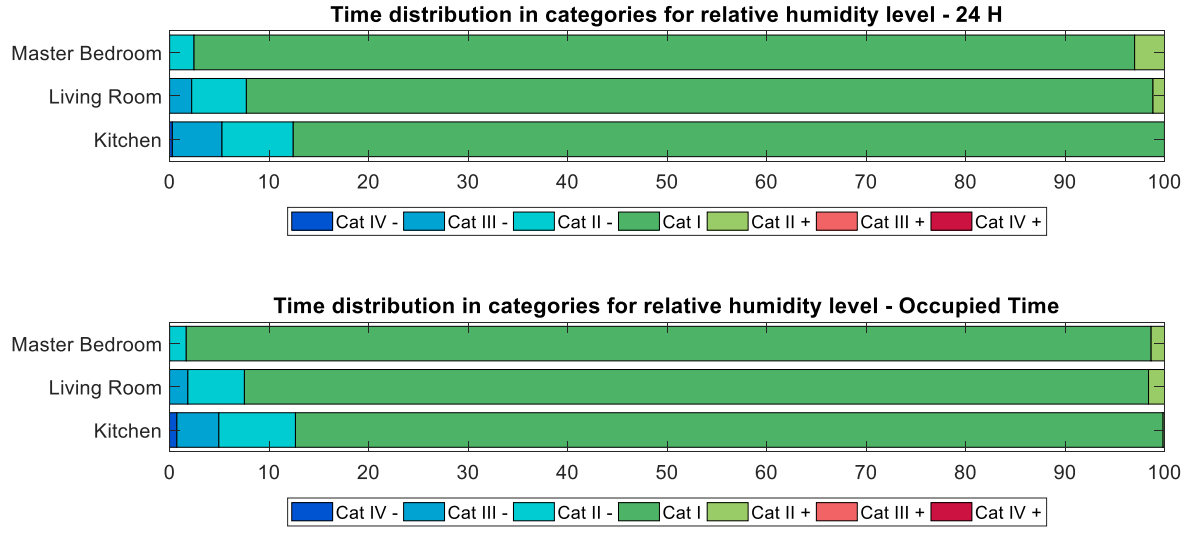

Figure 21: Percentage of time in each Category for relative humidity during 3 months period time (September, October, November)

3.2.5 Indoor air quality and window activation

The following graphs visualize the quality of indoor air, in relation to window opening. Like thermal comfort, it is considered that the conditions for good indoor air quality are met when the criteria for Category II are fulfilled. However, only relative humidity level is taken into account. The activation of windows can be realized either automatically or manually. For the kitchen/ dining room, the opening of the skylight is also taken into consideration, apart from the window.

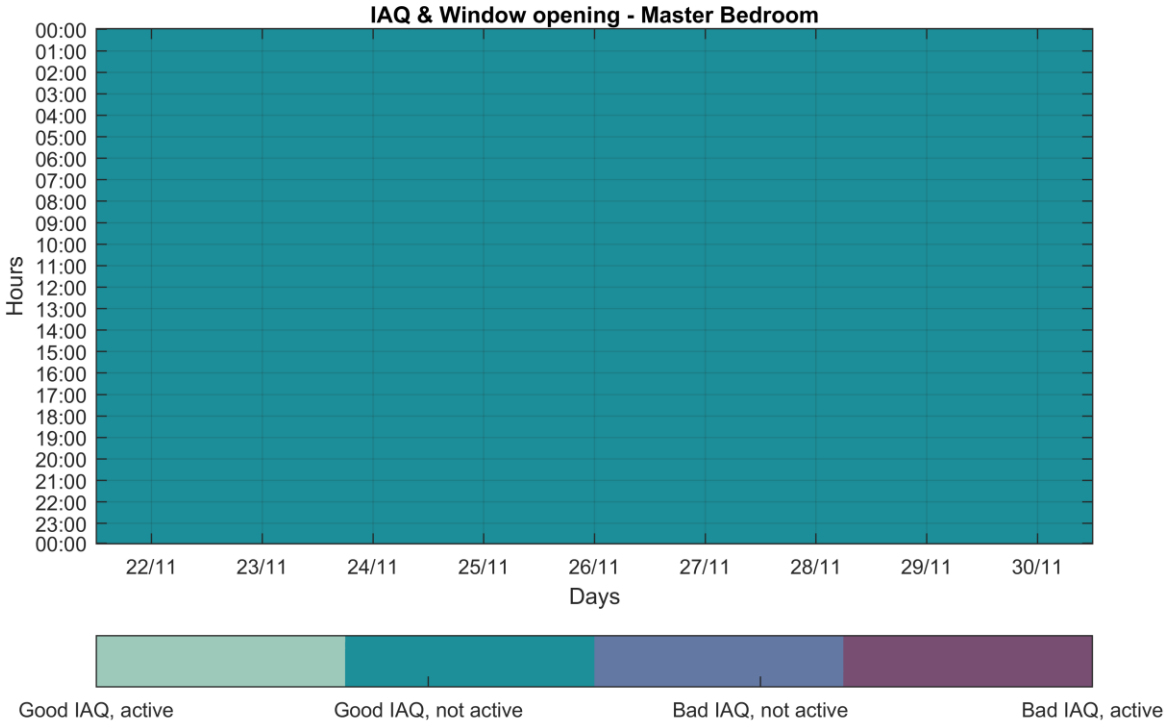

Figure 22: Indoor air quality in relation to window opening – Master bedroom (22 – 30 November)

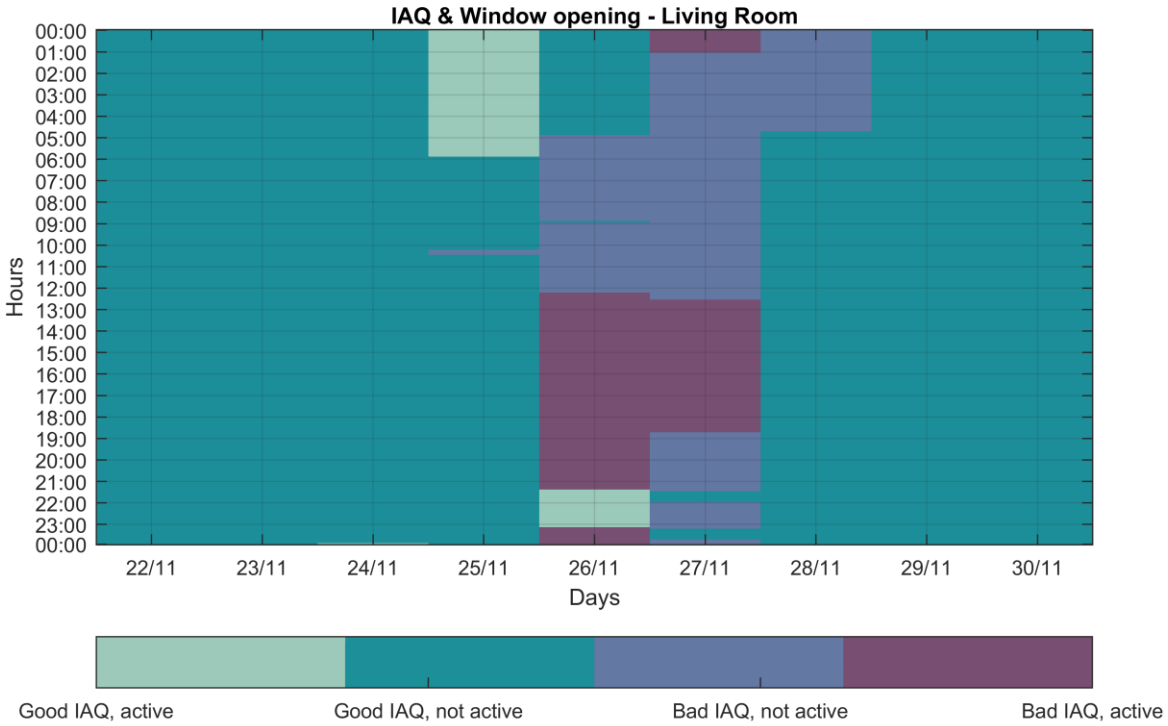

Figure 23: Indoor air quality in relation to window opening – Living room (22 – 30 November)

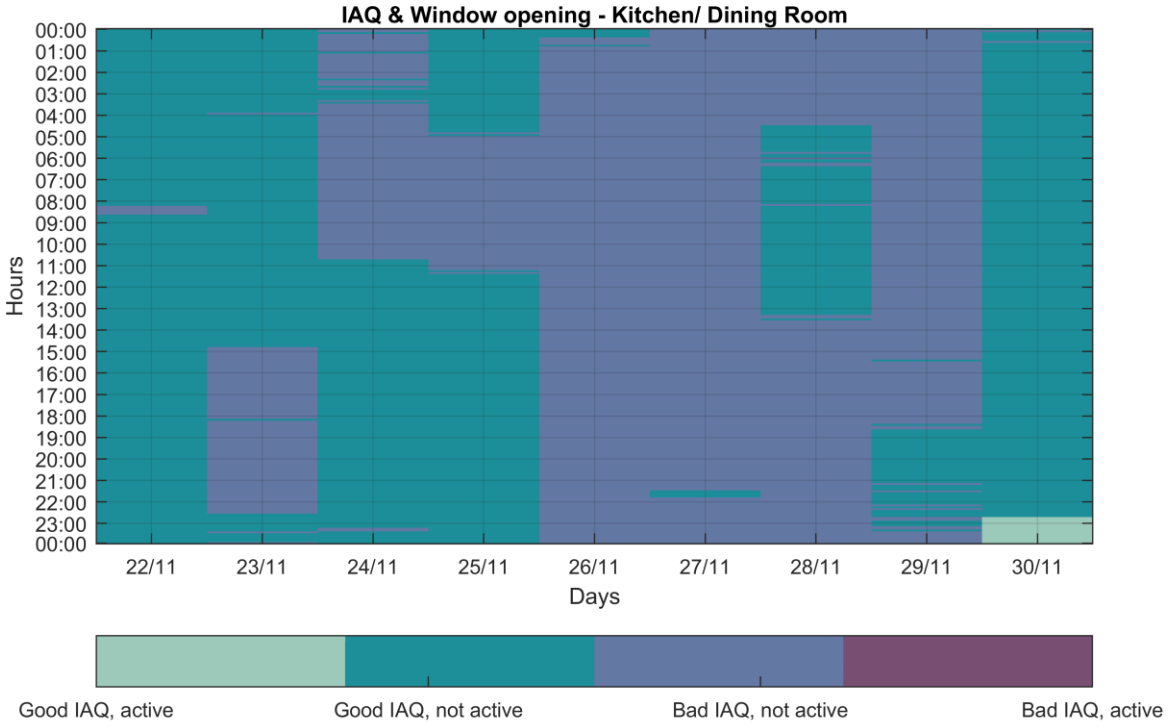

Figure 24: Indoor air quality in relation to window opening – Kitchen/ Dining room (22 – 30 November)

4. Ventilation Air Flow Rate

The following graphs describe the ventilation airflow rate during the month of November.

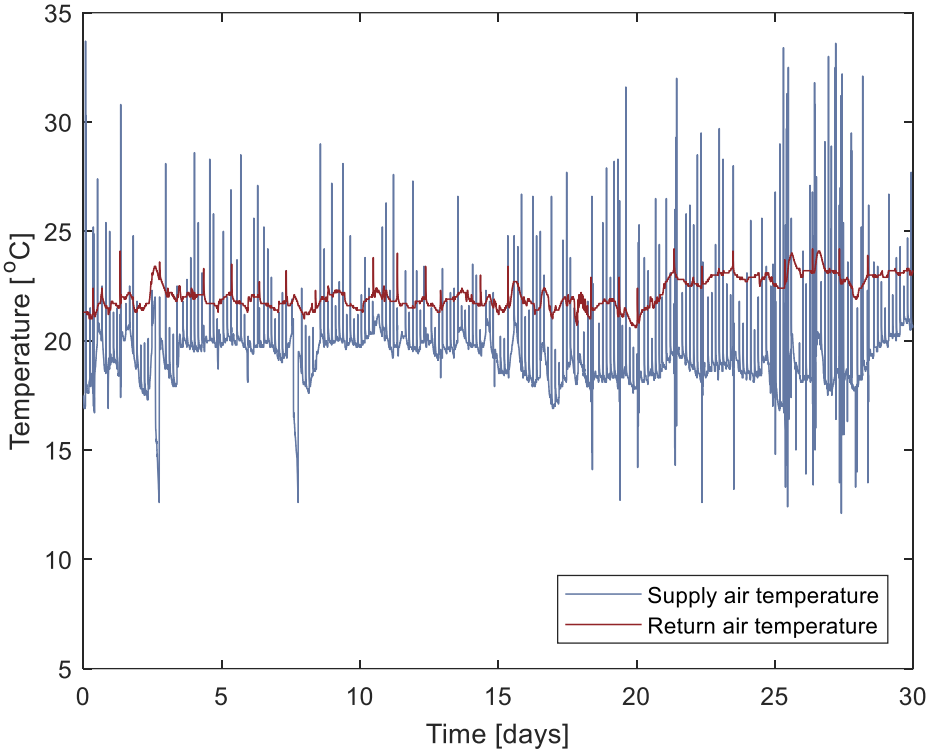

Figure 24: Inlet and outlet air temperature (November)

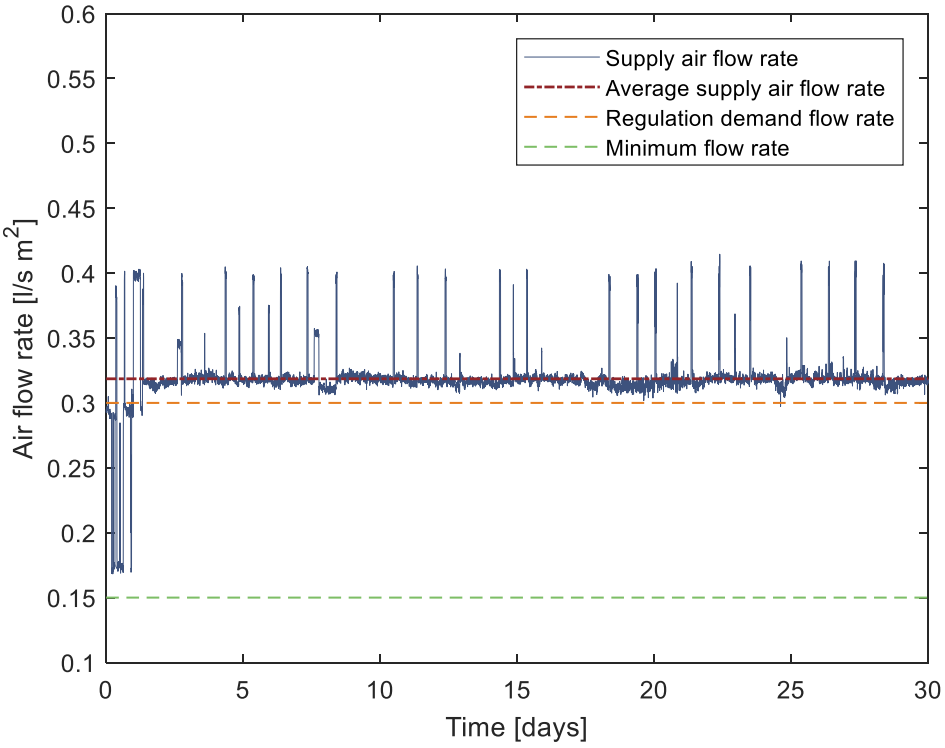

Figure 25: Inlet air flow rate (November)

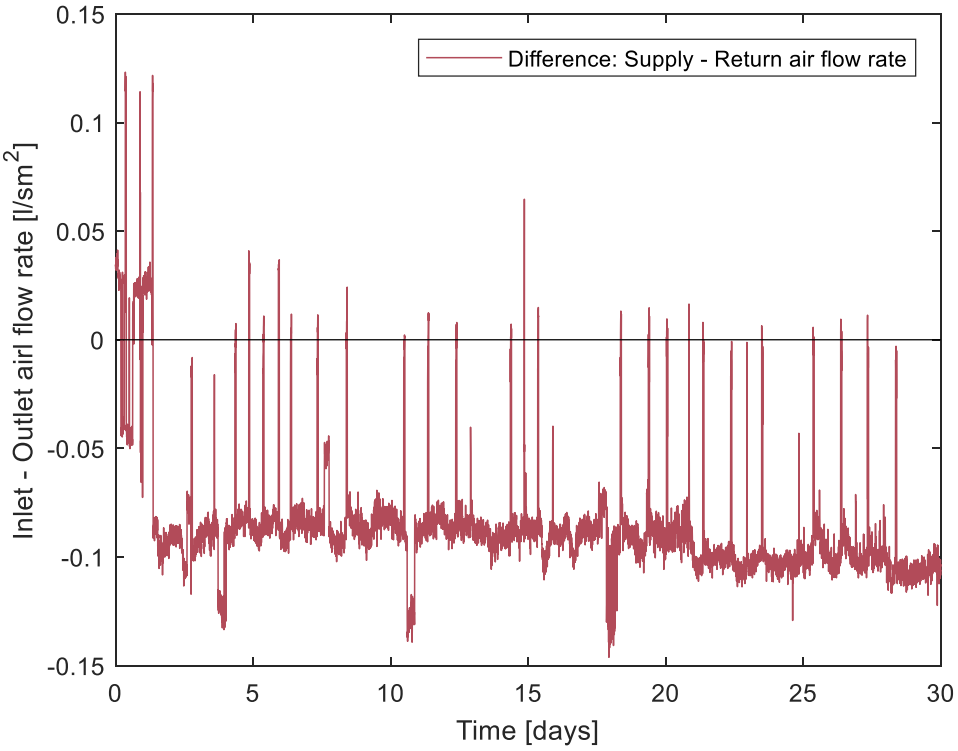

Figure 26: Difference between the inlet and outlet air flow rate (November)

5. Difference between building sensors and IC-meters

During the data analysis, it was observed a deviation of the registered values from what it would be expected. For this reason, additional sensors (IC-meters) were installed right beside the building sensors, in order to verify the accuracy of the data. The following graphs present the difference between the two recordings. Additionally, thermal and atmospheric comfort is recalculated using the values from the IC-meters, in order to visualize the sensors' impact on the comfort categories. The graphs are given for November, as a representative month.

The examined rooms are the living room and kitchen. The recordings for the master bedroom were not complete for an entire month, and so they are not presented.

5.1 Thermal indoor environment

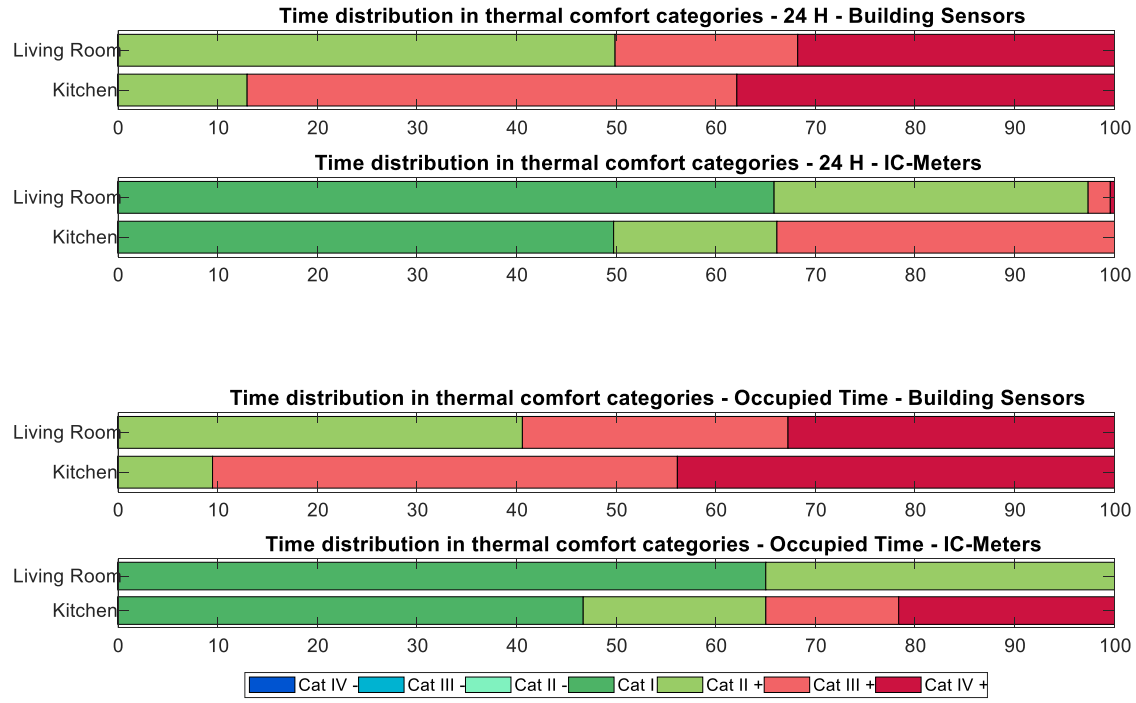

Figure 27: Percentage of time in each Category for tempeature, during November. Difference between sensors.

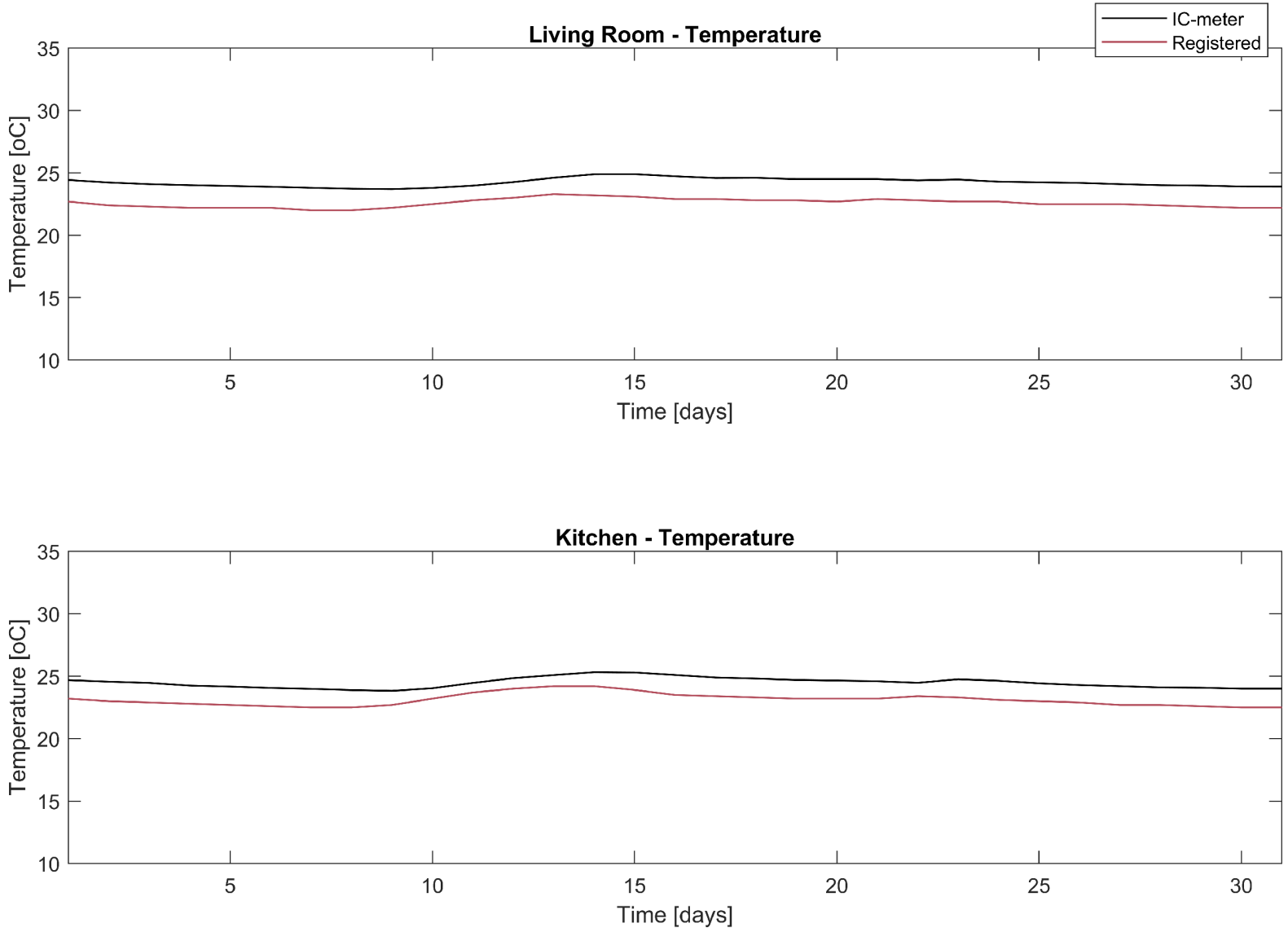

Figure 28: Registered temperature by different sensors during November

5.2 Atmospheric indoor environment

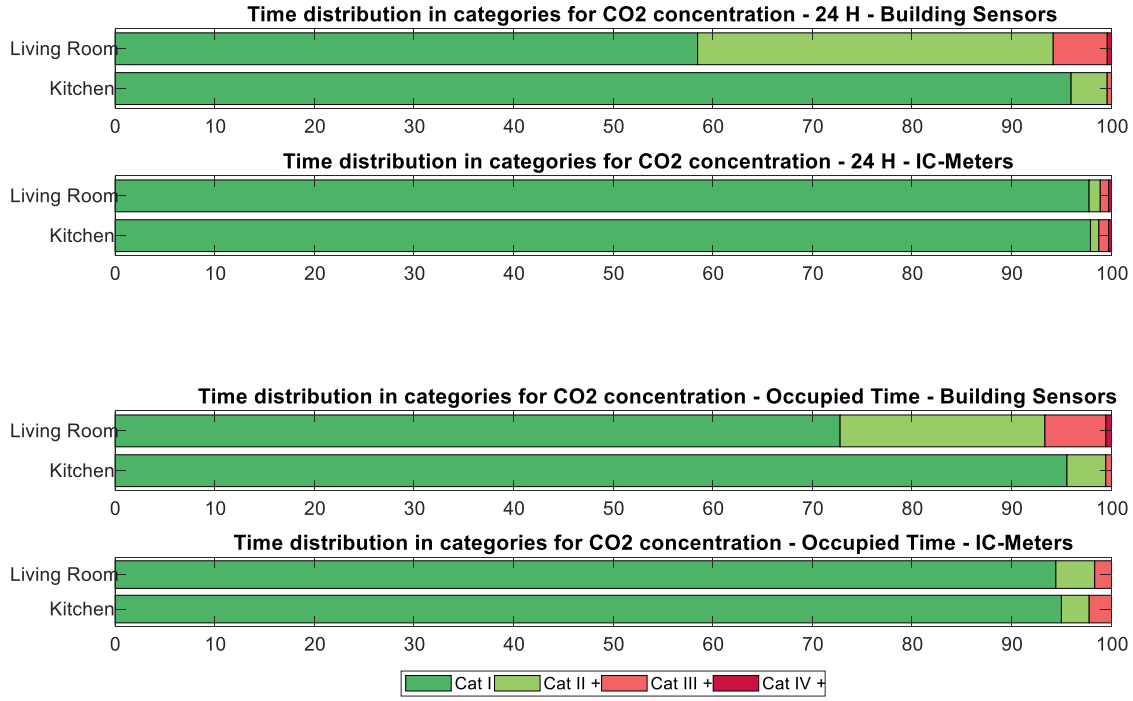

Figure 29: Percentage of time in each Category for CO_2 level, during November. Difference between sensors.

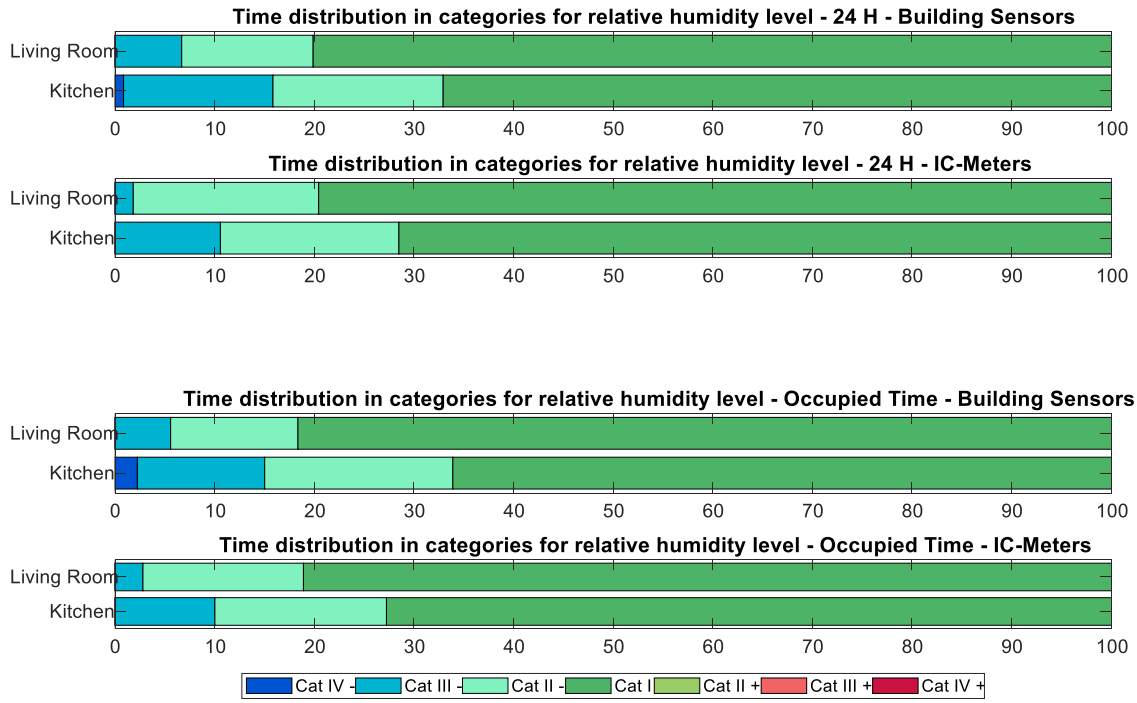

Figure 30: Percentage of time in each Category for relative humidity, during November. Difference between sensors.

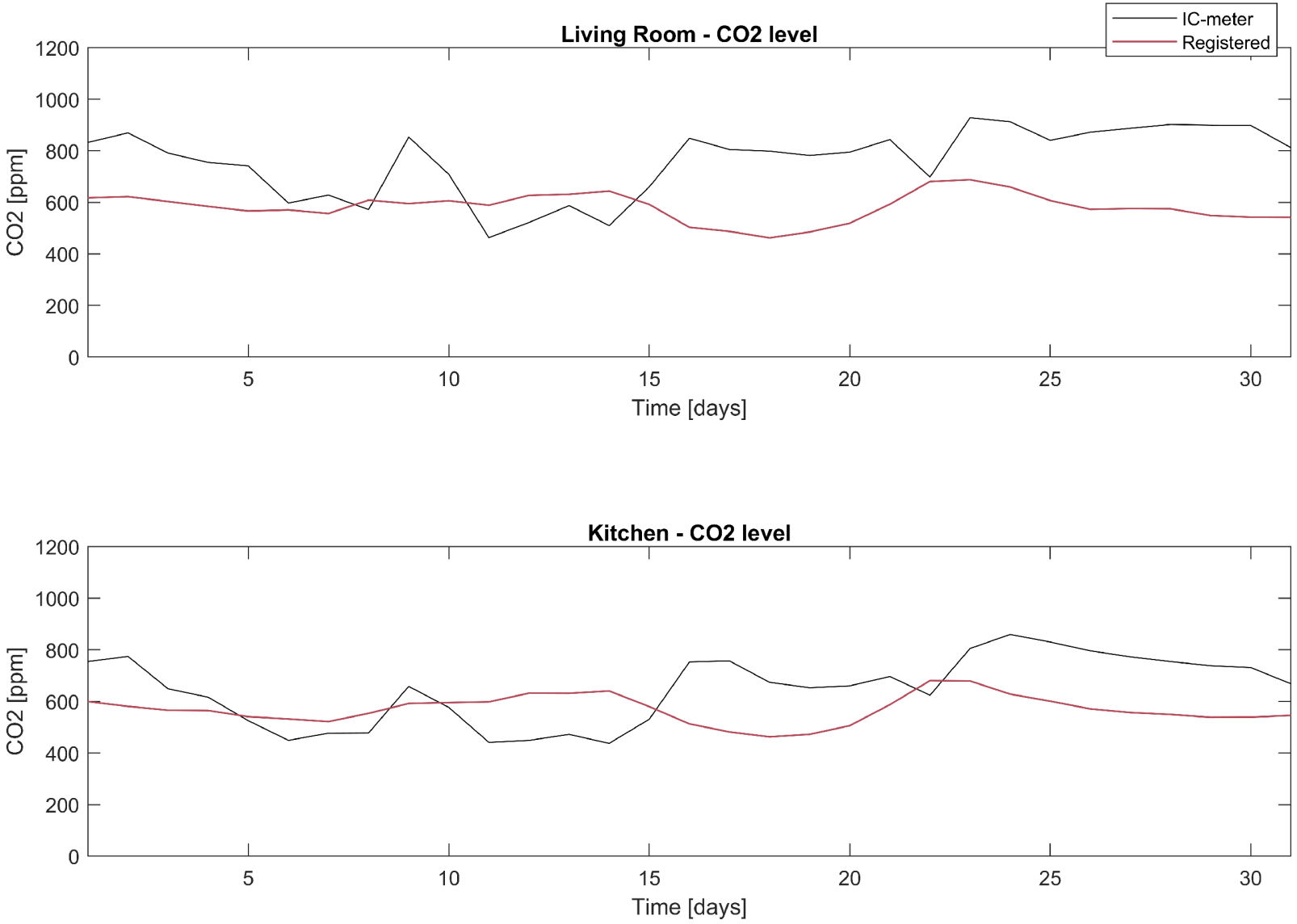

Figure 31: Registered CO_2 level by different sensors during November

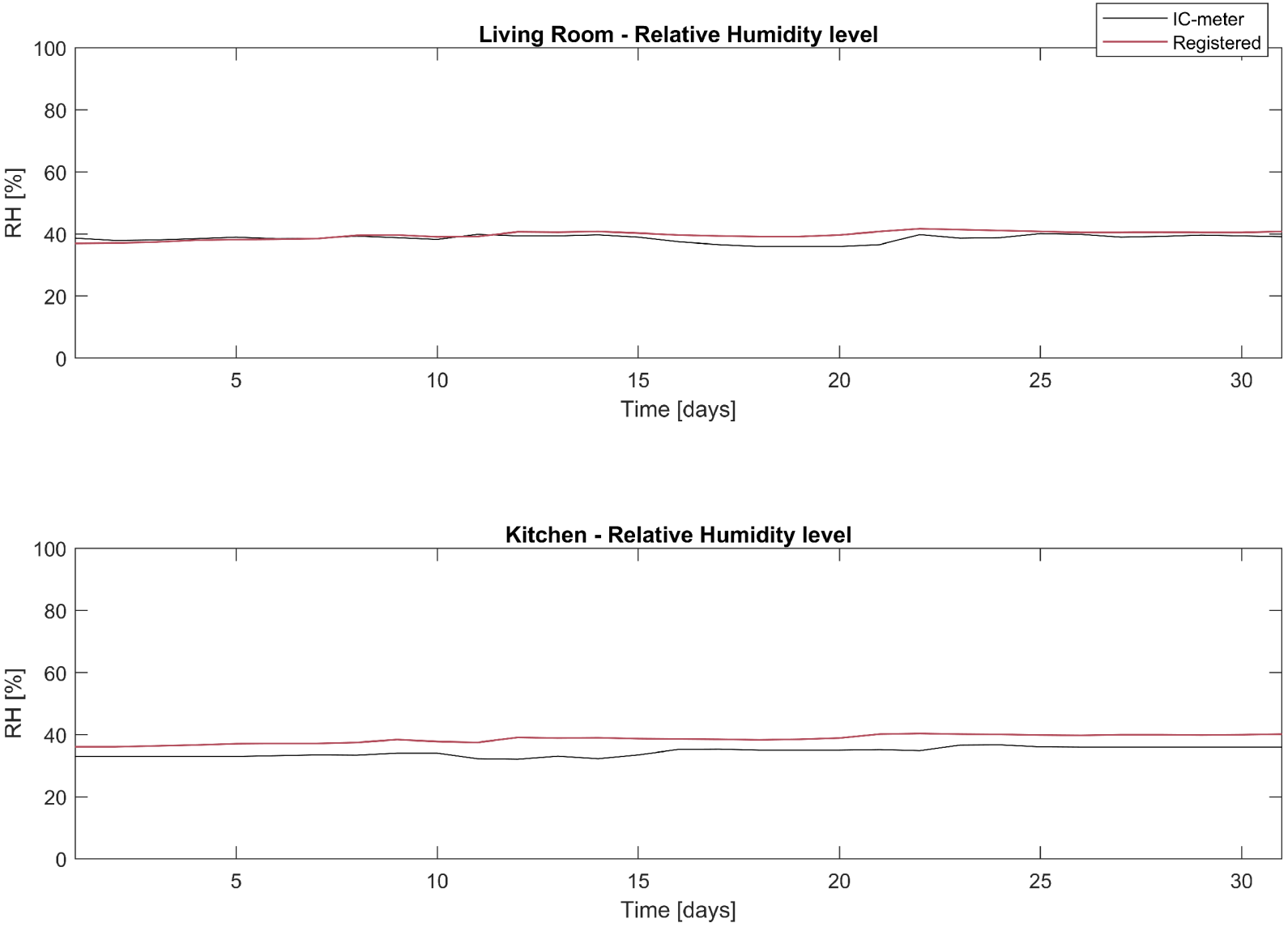

Figure 32: Registered relative humidity by different sensors during November

6. Annex

6.1 September

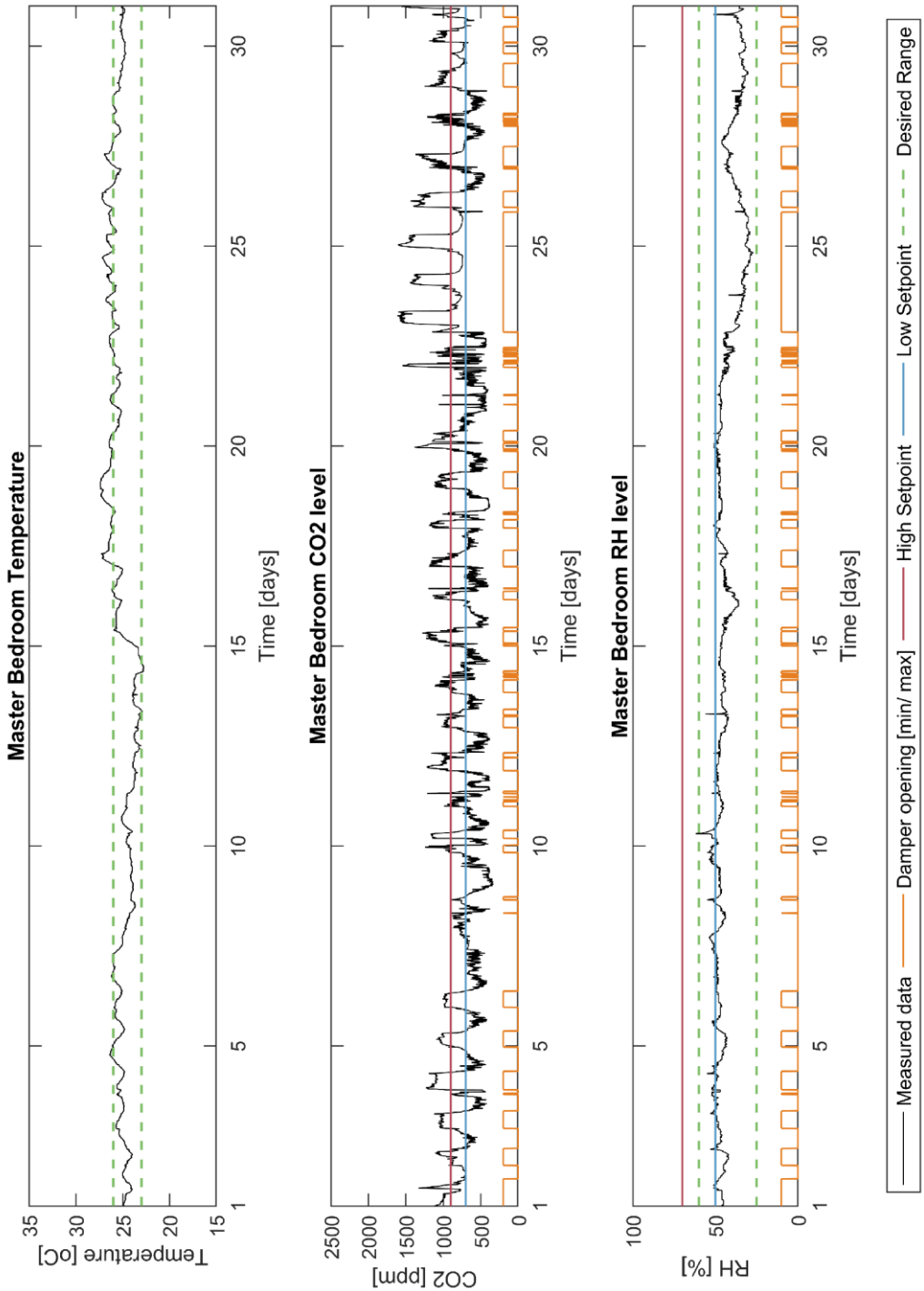

Figure 33: Graphs for temperature, CO2 level and relative humidity during the month of September – Master Bedroom

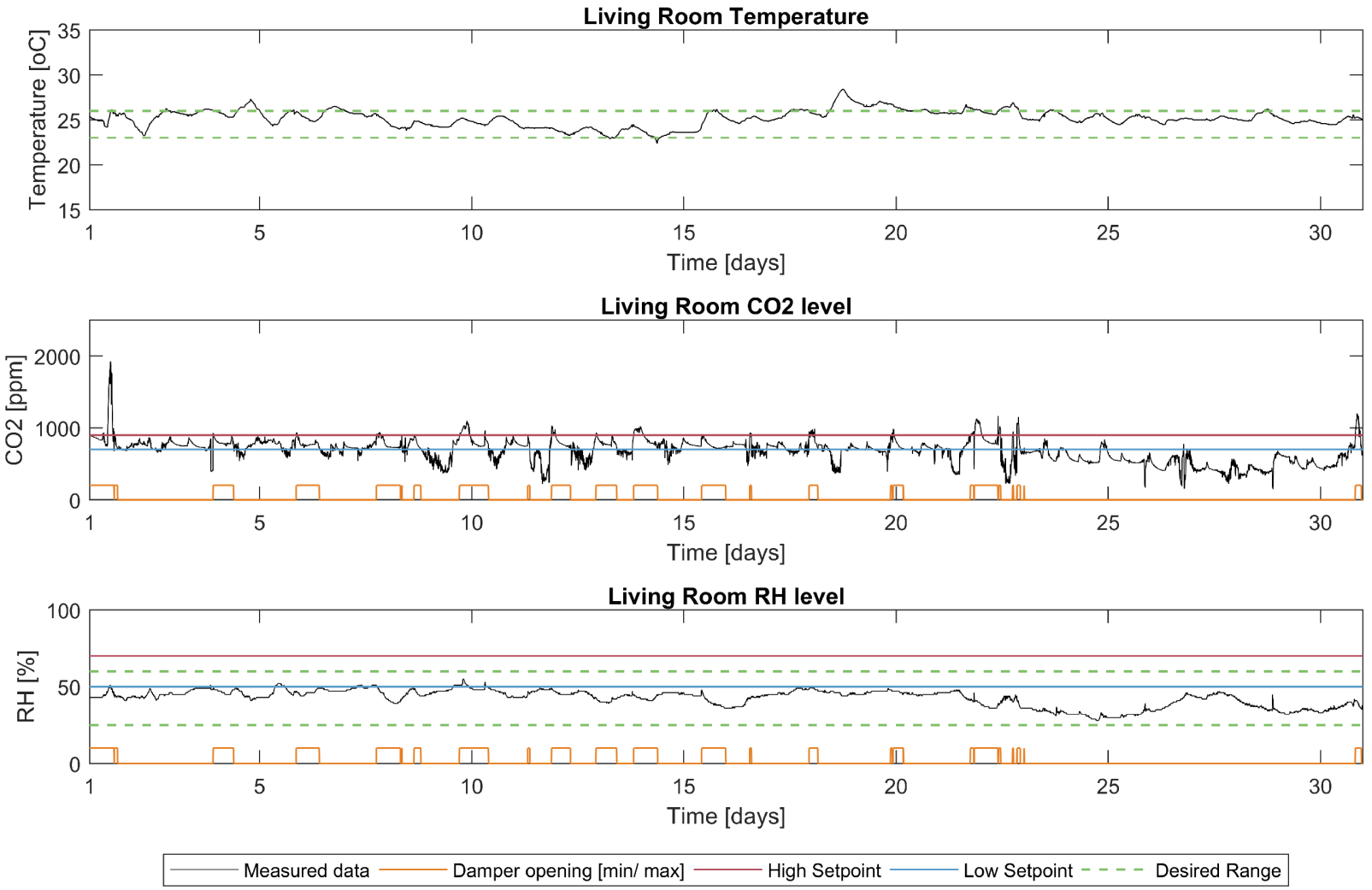

Figure 34: Graphs for temperature, CO_2 level and relative humidity during the month of September – Living Room

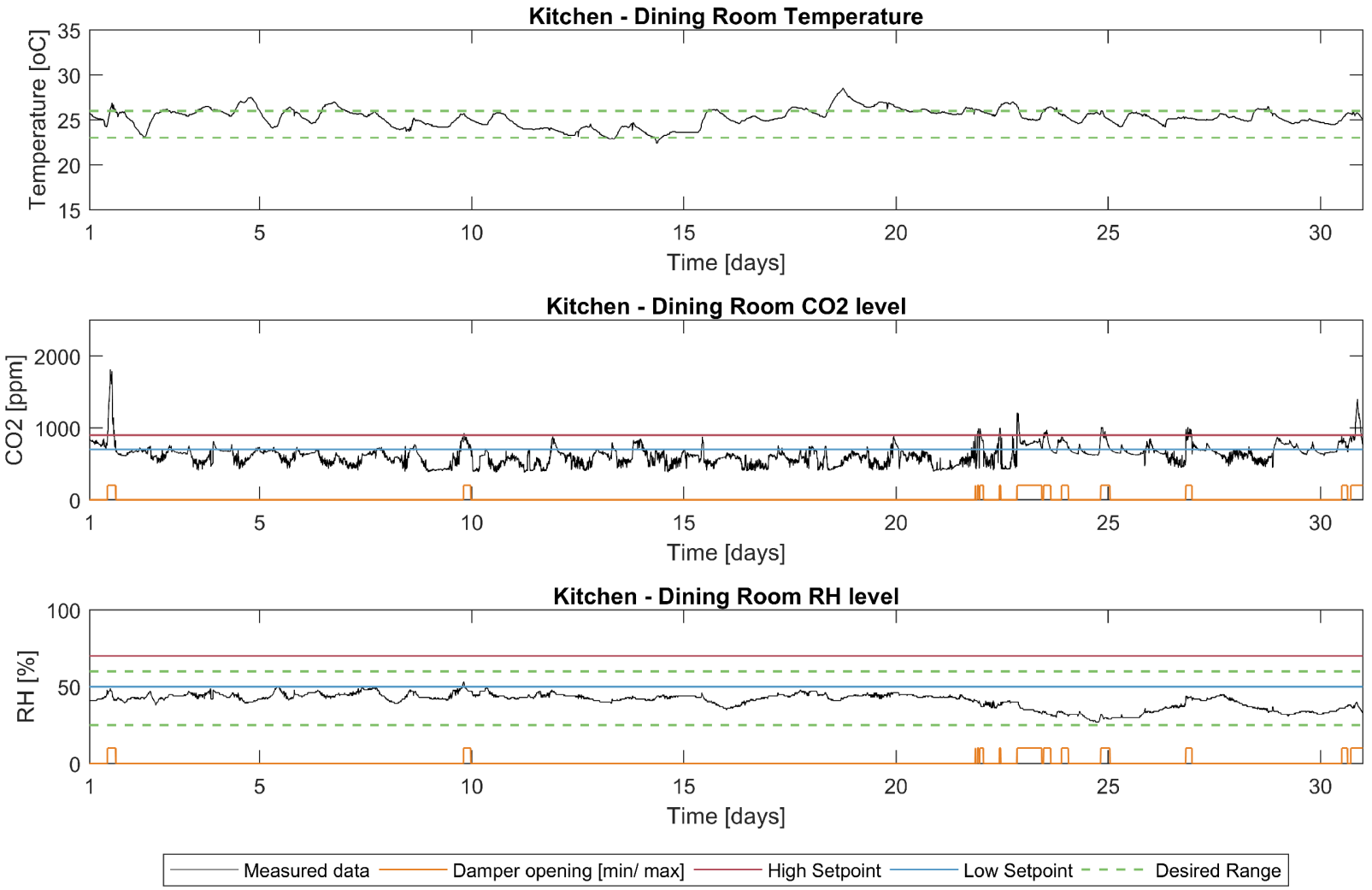

Figure 35: Graphs for temperature, CO_2 level and relative humidity during the month of September – Kitchen/ Dining Room

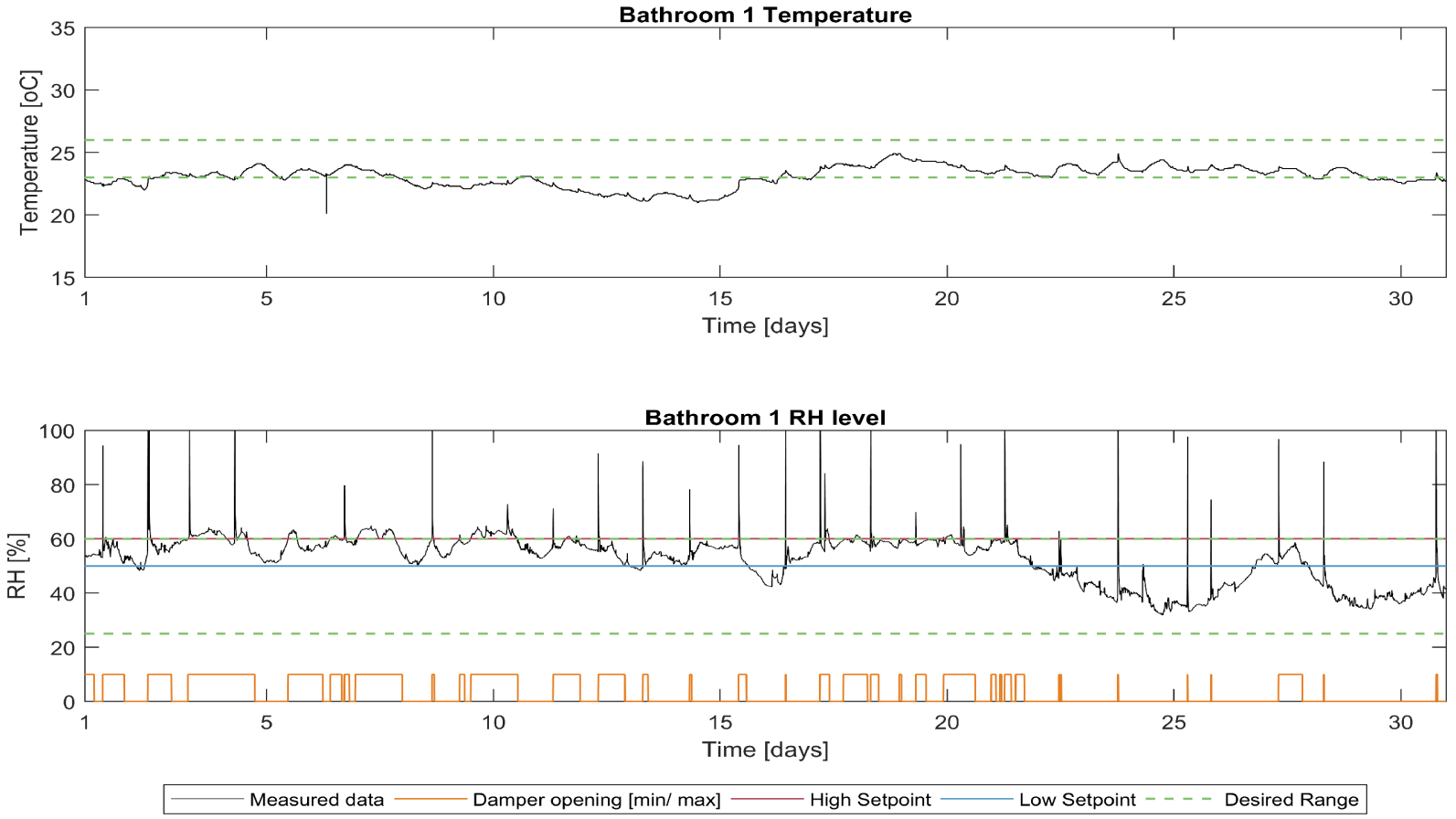

Figure 36: Graphs for temperature, CO_2 level and relative humidity during the month of September – Bathroom 1

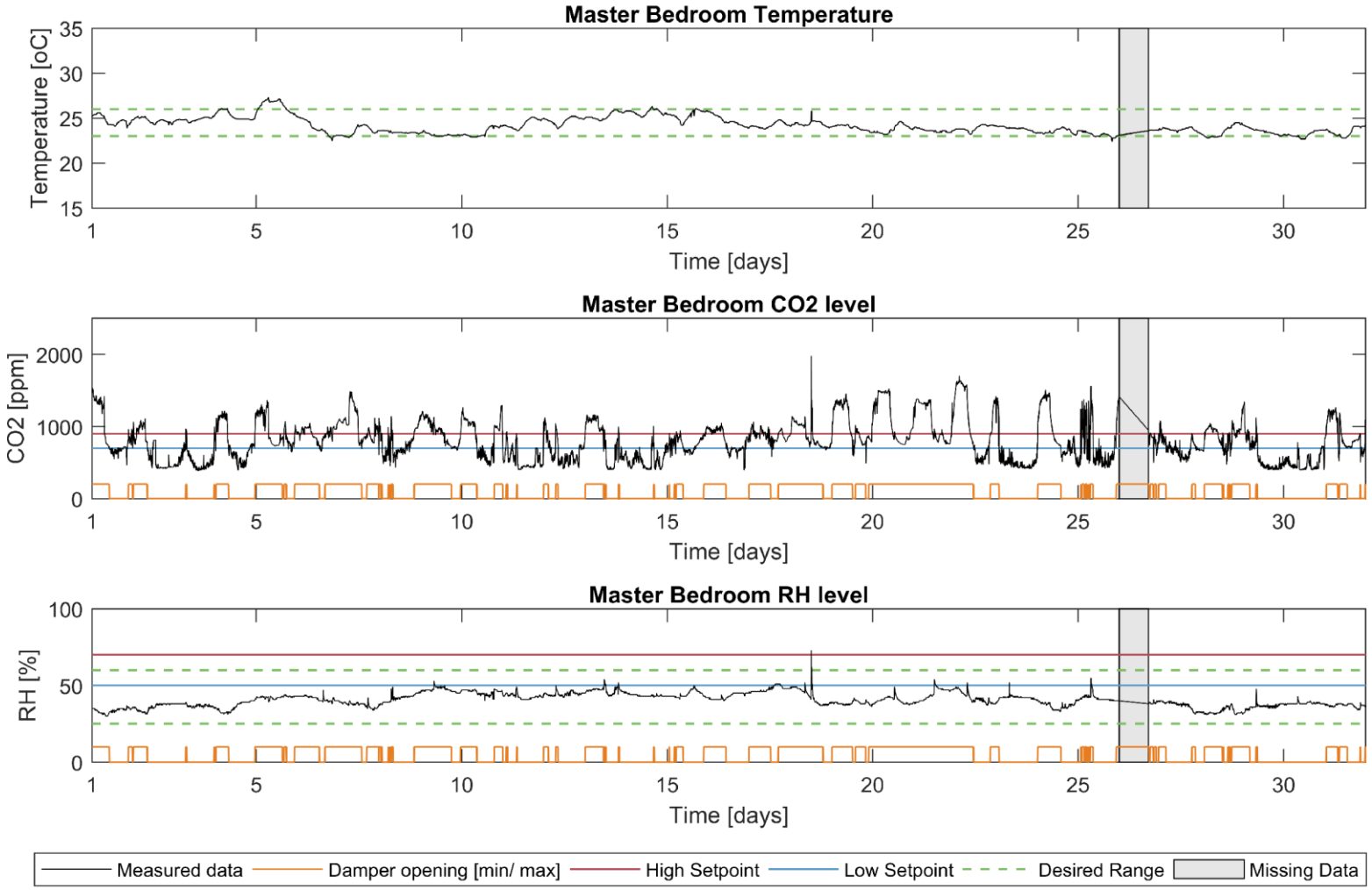

Figure 37: Graphs for temperature, CO_2 level and relative humidity during the month of October – Master Bedroom

6.2 October

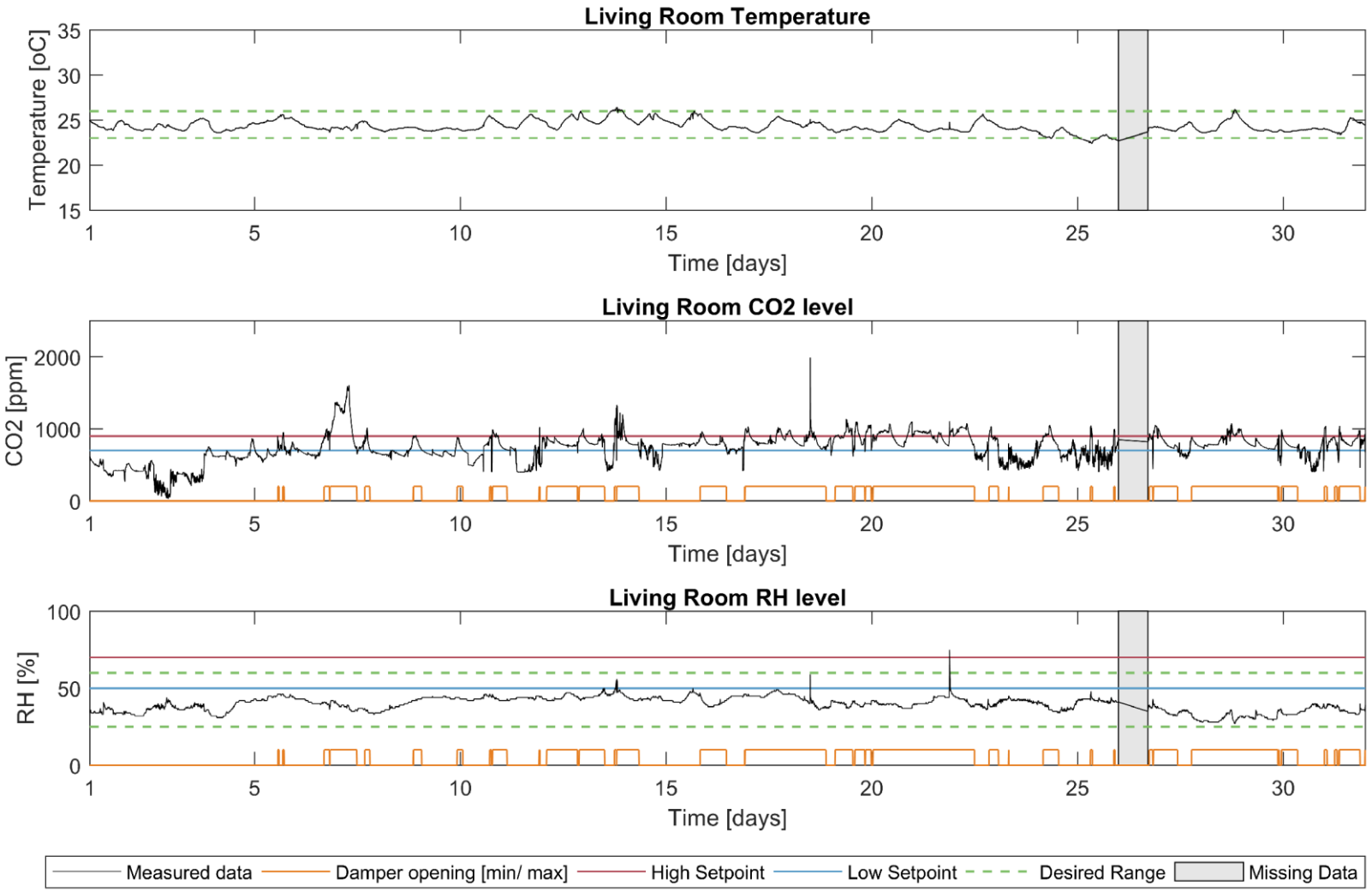

Figure 38: Graphs for temperature, CO_2 level and relative humidity during the month of October – Living Room

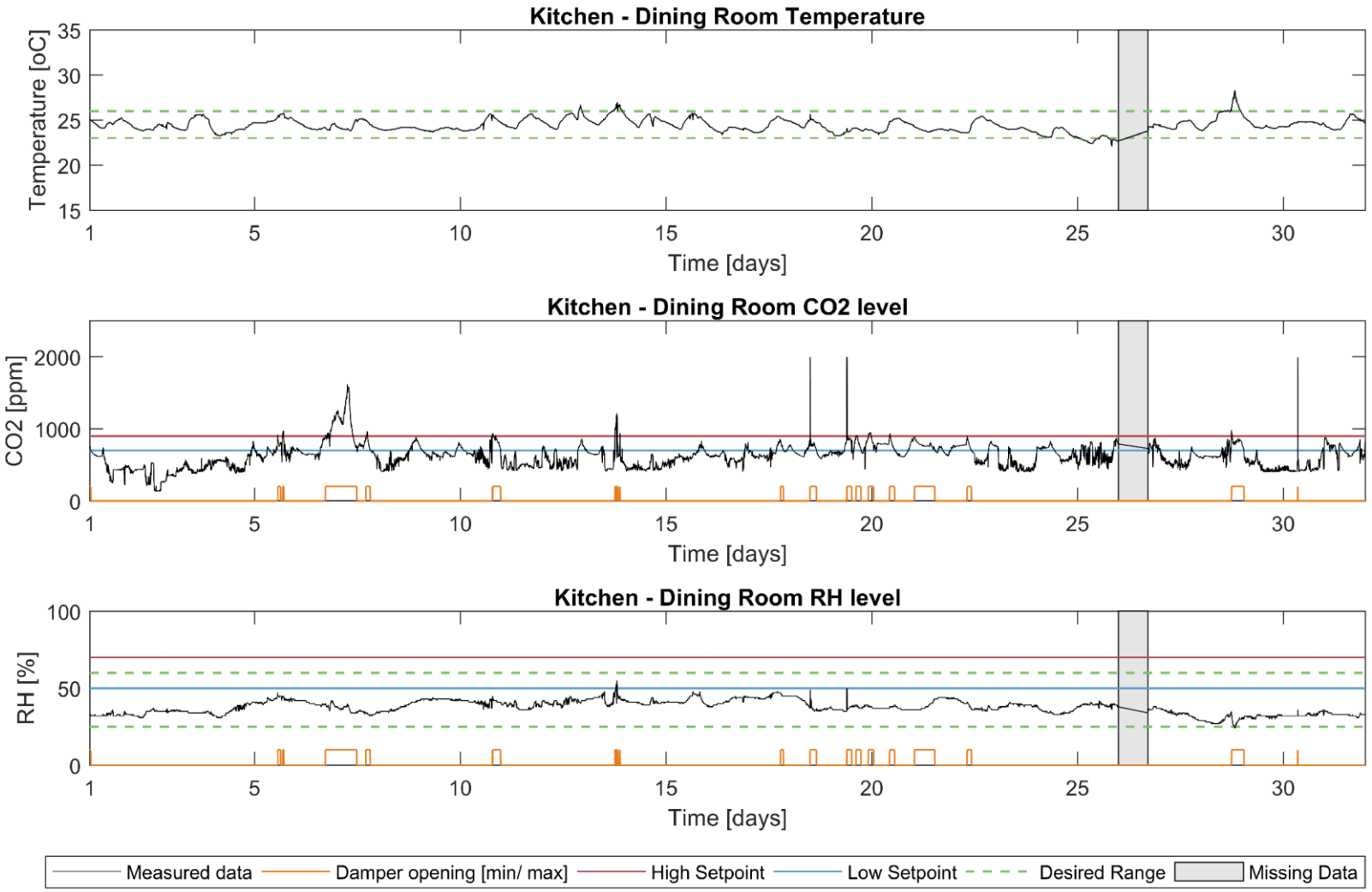

Figure 39: Graphs for temperature, CO_2 level and relative humidity during the month of October – Kitchen/ Dining Room

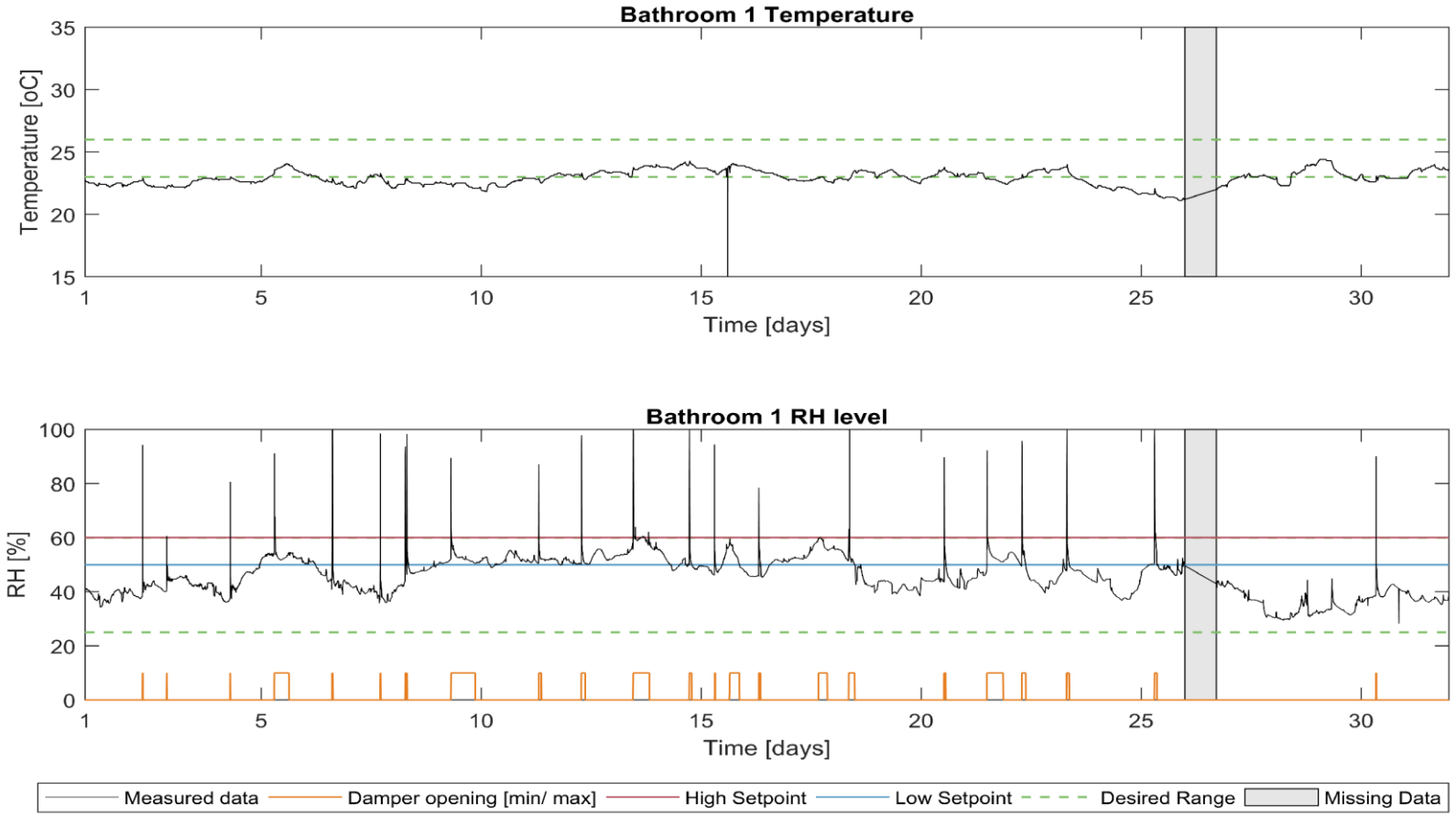

Figure 40: Graphs for temperature, CO_2 level and relative humidity during the month of October – Bathroom 1

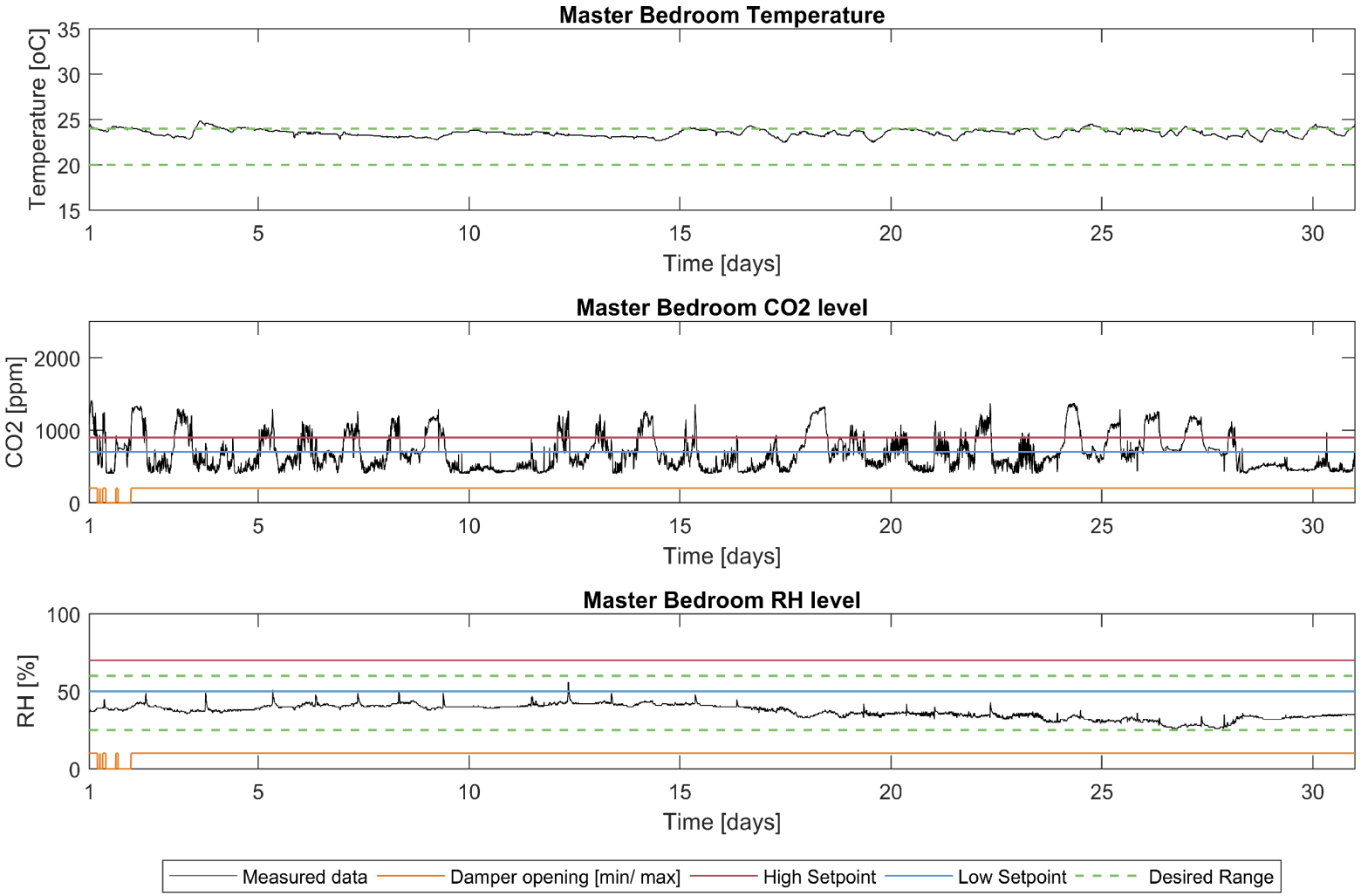

Figure 41: Graphs for temperature, CO_2 level and relative humidity during the month of November – Master Bedroom

6.3 November

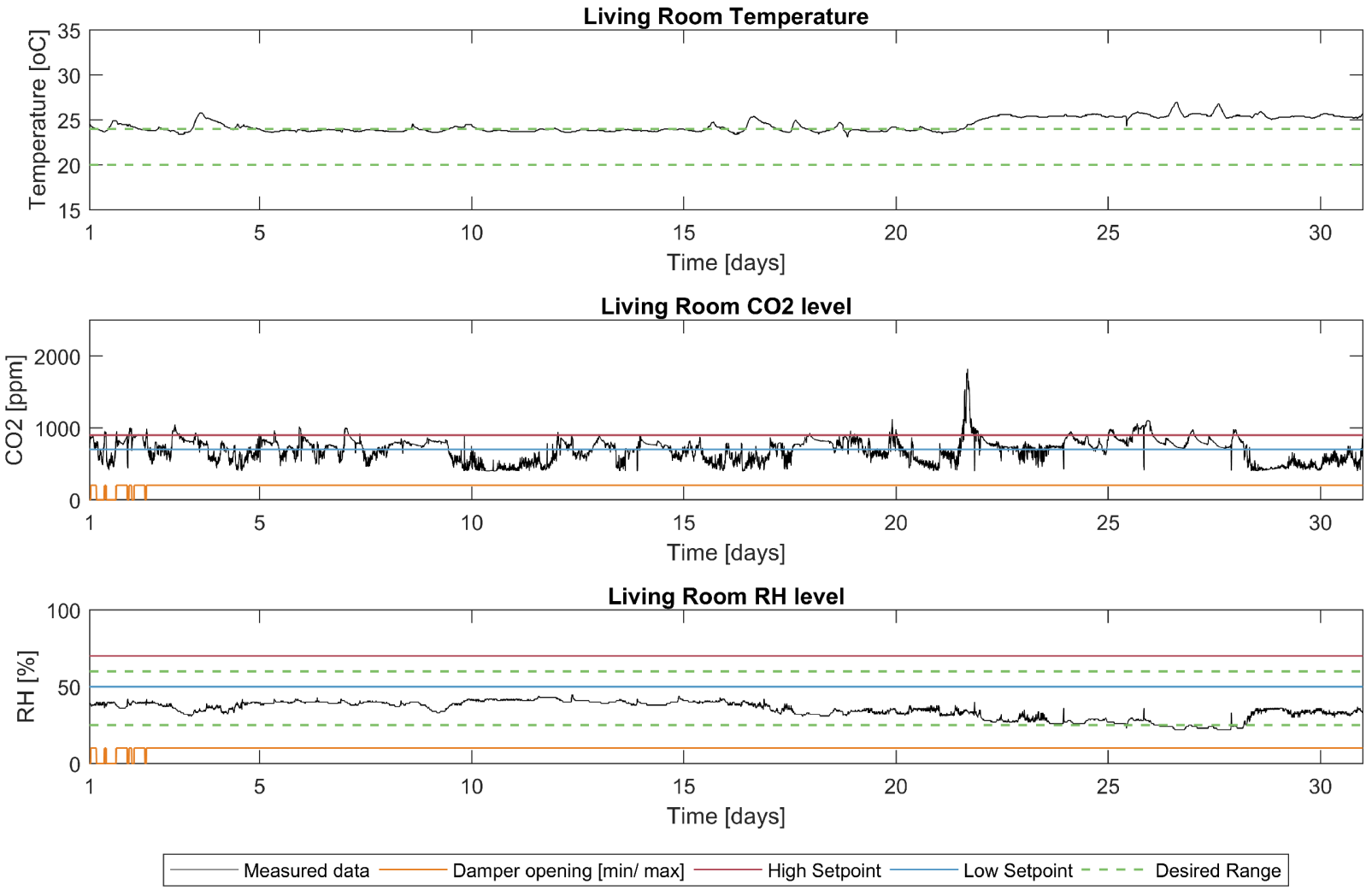

Figure 42: Graphs for temperature, CO_2 level and relative humidity during the month of November – Living Room

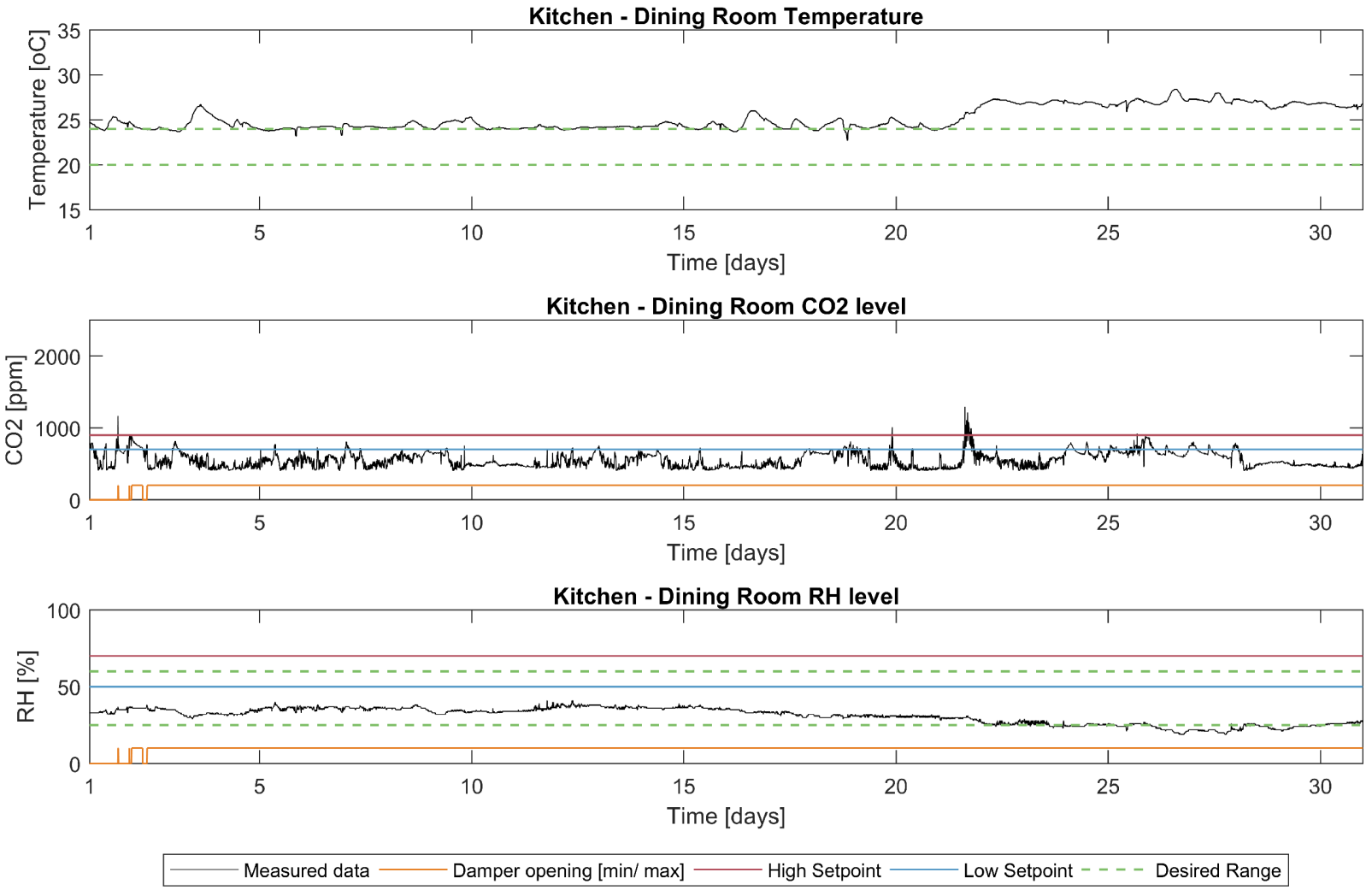

Figure 43: Graphs for temperature, CO_2 level and relative humidity during the month of November – Kitchen/ Dining Room

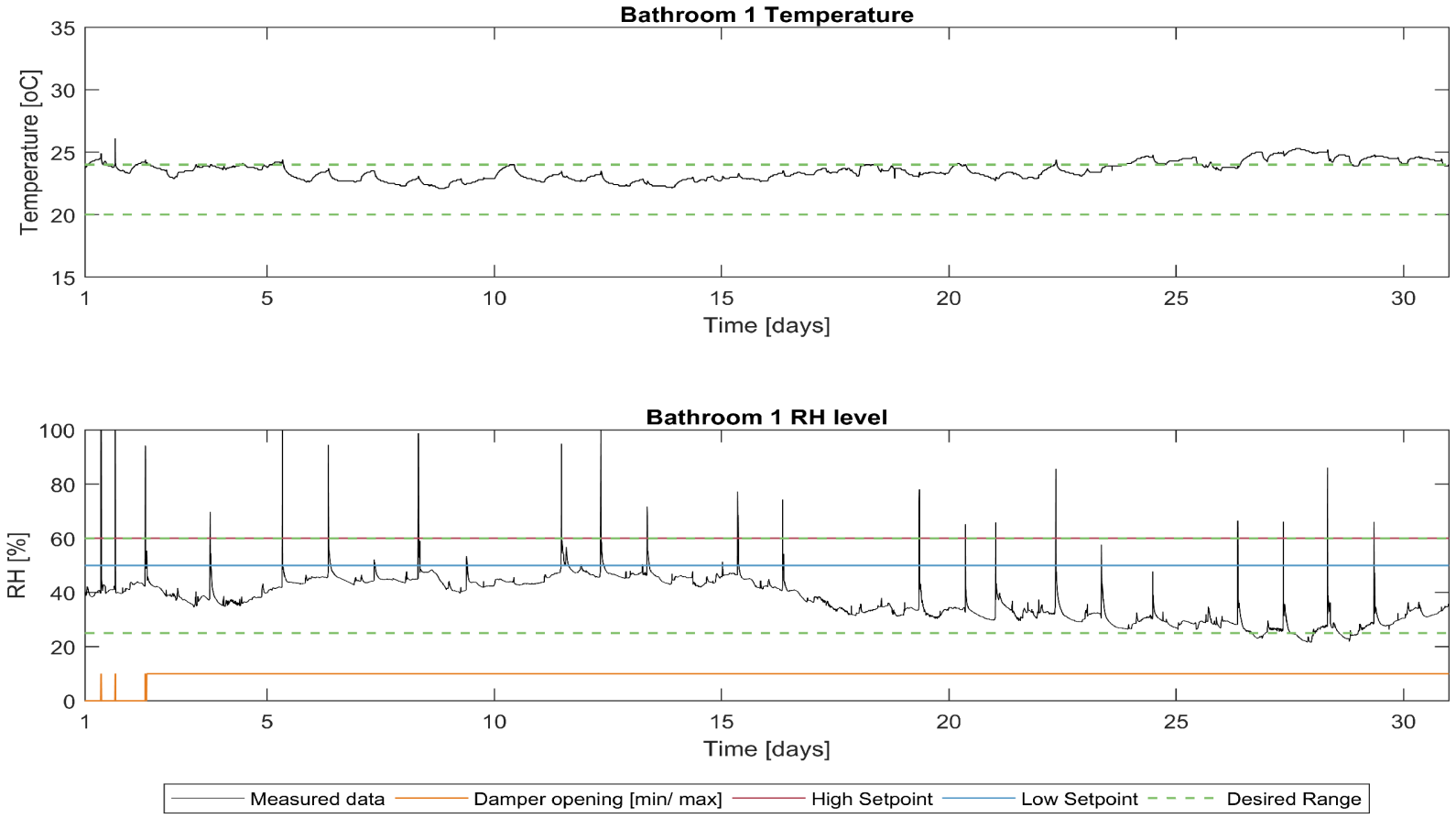

Figure 44: Graphs for temperature, CO_2 level and relative humidity during the month of November – Bathroom 1

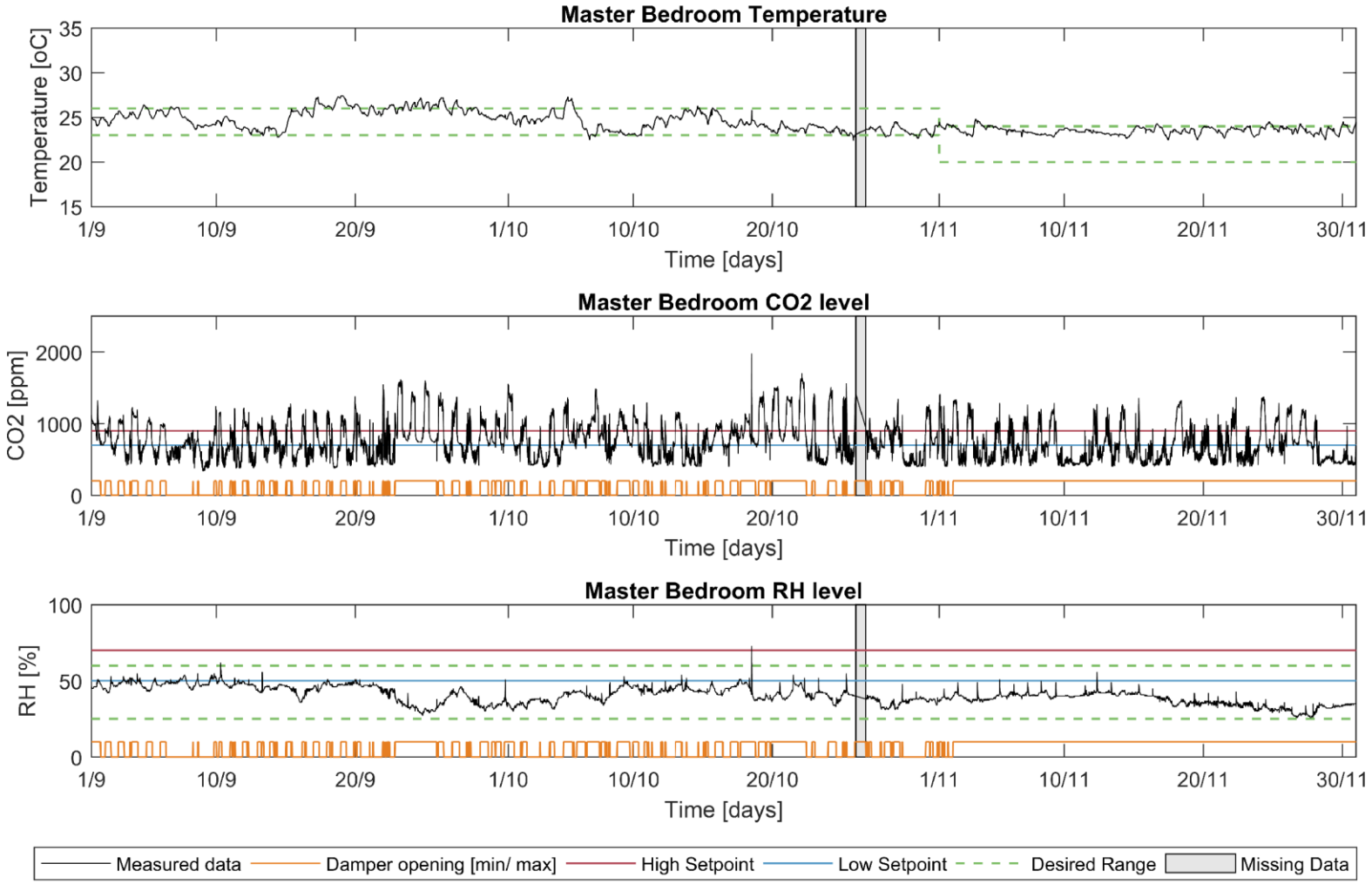

Figure 45: Graphs for temperature, CO_2 level and relative humidity during the 3 months period (September, October, November) – Master Bedroom

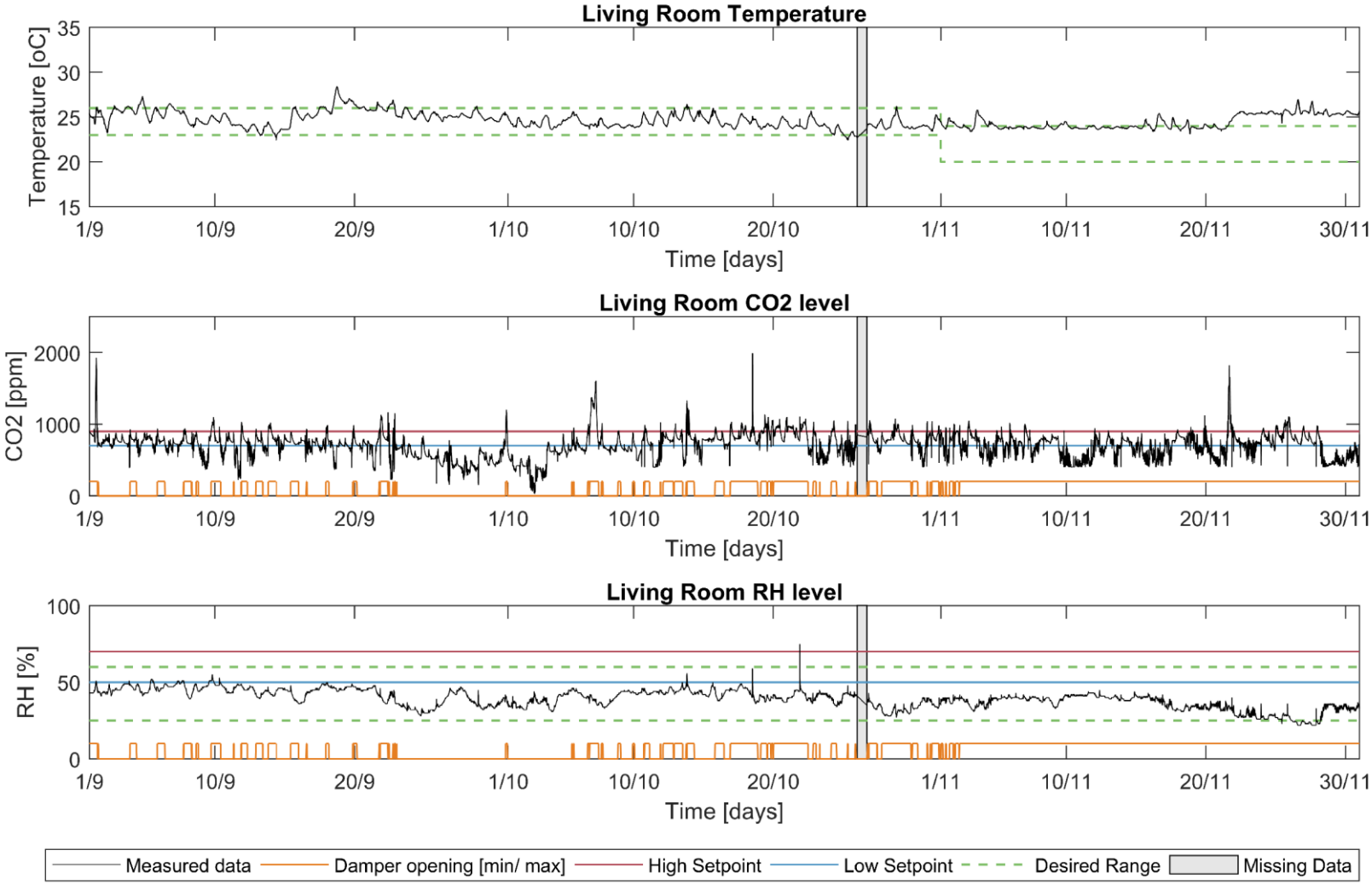

Figure 46: Graphs for temperature, CO_2 level and relative humidity during the 3 months period (September, October, November) – Living Room

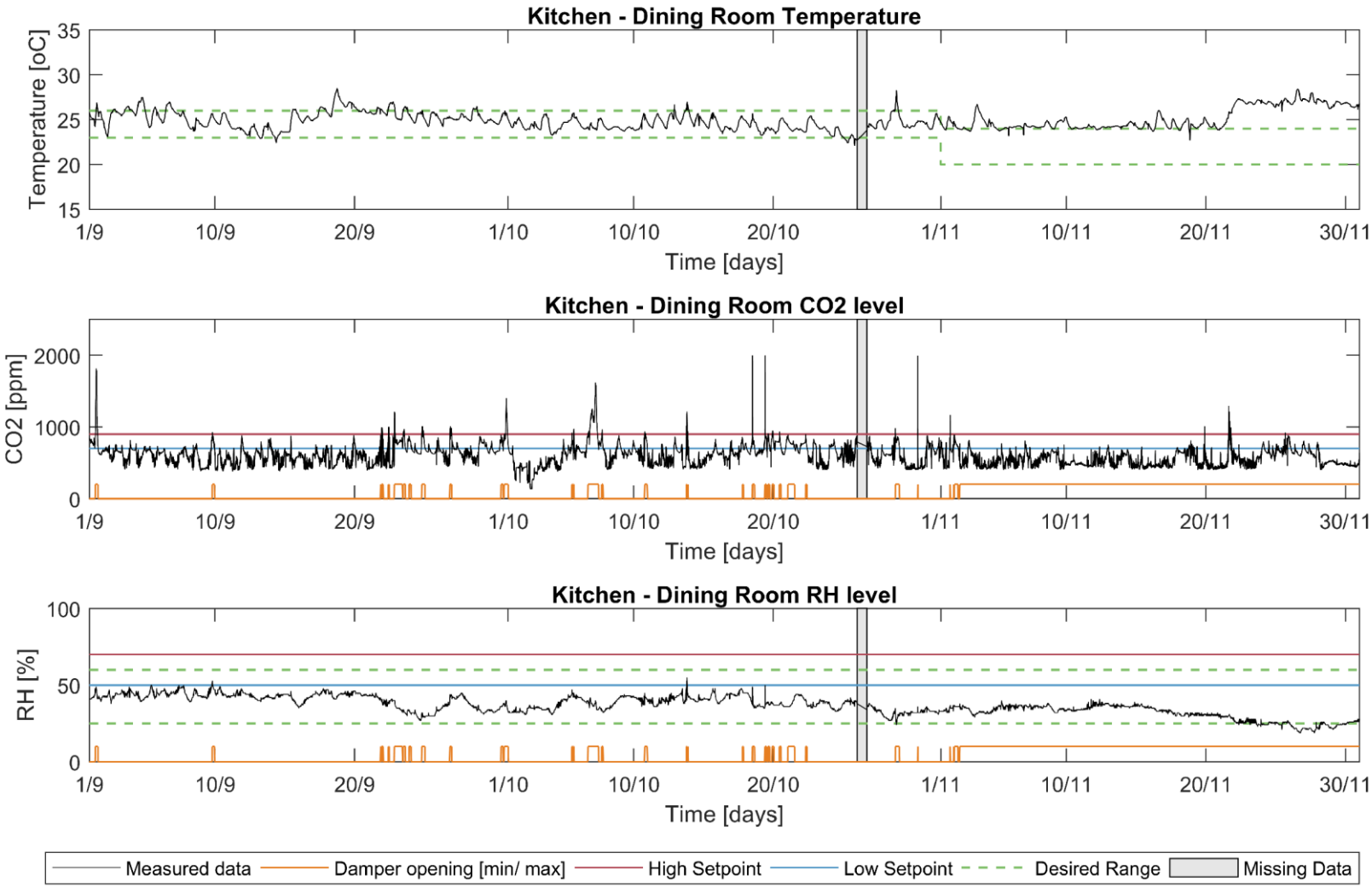

Figure 47: Graphs for temperature, CO_2 level and relative humidity during the 3 months period (September, October, November) – Kitchen/ Dining Room

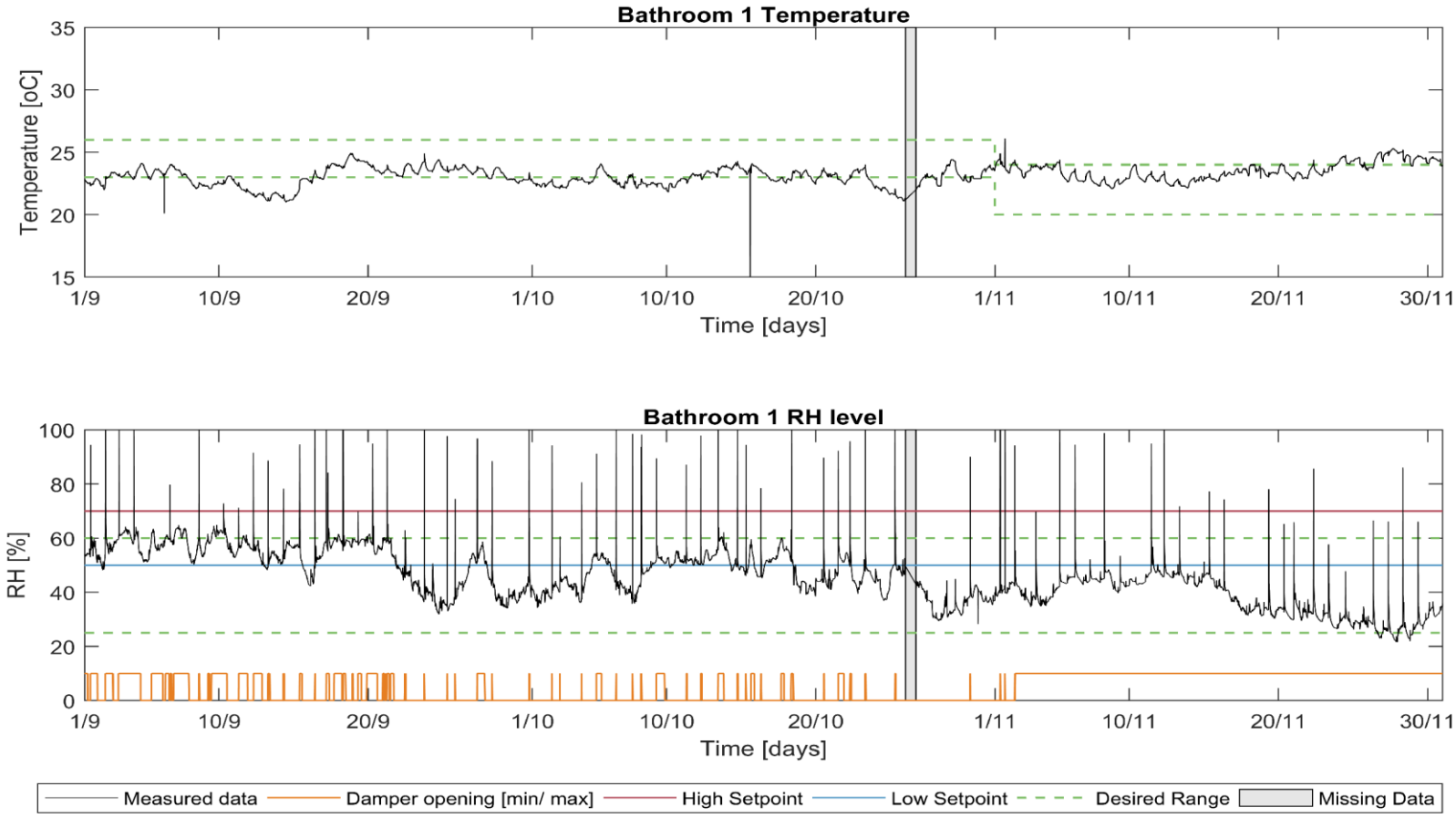

Figure 48: Graphs for temperature, CO_2 level and relative humidity during the 3 months period (September, October, November) – Bathroom 1

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DCE Technical Report No. 259