ARIS
D 5.2 Evaluierungsbericht

Projekt Referenz	FFG Projekt Nr. 845143
Projekt Akronym	ARIS
Projekt Titel	Anwendung nichtlinearer Regelungstechnik und intelligenter Sensorik zur Effizienzsteigerung in Gebäuden
Programm	ENERGIE DER ZUKUNFT
Ausschreibung	SdZ 1. Ausschreibung

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1 Introduction

The present deliverable illustrates the results from the EnergyBase field test. The ventilation system that feeds fresh air into the seminar rooms from the Fachhochschule was actuated on the basis of a model based energy management. The goal was to improve the overall air quality while taking the energy consumption for the actuation of the whole process into further consideration. A survey was conducted to gather information from the students that were present in the seminar rooms that day.

2 HIL-Run ENERGYbase

On December 2, 2016 a field test has been performed in the ENERGYbase building. The goal of the test was to validate the behavior of developed components, and to test drive the predictive controller in the human-in-the-loop mode. The field test had to be operated partly manually, since a coupling of the controller with the supervisory control system proved unfeasible and would have required significant refurbishment of the ventilation system controller, which was not foreseen. The approach therefore was to let the controller run using the acquired data for volume flows, pressure and CO_2 levels and calculate the setpoints for the volume flows of the rooms. These volume flows then had to be entered manually into the supervisory control system.

In the test the building ventilation system model (pressure drop model), the predictive controller and the virtual occupancy sensor were validated. The experiment was performed between 8:00 and 16:00h, on a workday, when, based on the FH Technikum room scheduling, it was estimated that the space usage will be as usual for the duration of the experiment.

2.1 Data collection

All the data is collected in a database that was set up by partner AutomationX. The indoor parameters are directly recorded from the BACnet datapoints and provided to the controller. Furthermore they are stored in the database for further analysis.

2.2 Ventilation system model

The ventilation system of the building has been modeled as described in Deliverable 4.1 and 4.2 in the MATLAB-based system created by AIT. Also the CO_2 room models are provided in MATLAB, and the models are all executed in the same framework in which the controller operates.

2.3 Predictive optimization controller

Predictive optimization model is configured to maintain the CO_2 concentration below the set point. This is accomplished by actively balancing the system based on the current and forecasted CO_2 generation in rooms. CO_2 forecast is generated using the provided lecture schedules and norms for CO_2 emissions from people based on the activities they are performing. System is balanced in such a way as to have at least one variable air volume (VAV) controller fully open at all times.

Ideally, control parameters are VAV controller settings (volume of air in time unit for each of the rooms) and the main fan air pressure. In our experiment, the main fan pressure was considered fixed. However, one manual change has been made to the pressure when it seemed that the actual pressure at the time wasn't high enough to provide sufficient flow to the whole system.

2.4 Analysis

Figures 1 to 5 shows the combined graph with measured CO_2 value and CO_2 set point, required and provided fresh airflow volume on the left scale, and estimated, counted and occupancy information derived from the calendar on the right scale. Occupancy counting was done in discrete time intervals, so it was expected that it won't follow the actual occupancy closely. Required and provided airflow volumes were calculated for each room based on the readings of the room's VAV controller using the following formulas:

$$V_{needed} = Volumeflowcontrollersupexh/100 * VAV\_Configured\_setpoint\_value;$$

$$V_{provided} = EXHcontrolsignal/100 * VAV\_Nominal\_flow$$

Table 1 contains room-specific values used to calculate the needed and provided airflow into the rooms.

Table 1 Room-specific data for calculation of needed and provided airflow

Room number stored in DESIGO	Name of the room in FH	Diameter of the VAV (meters)	Nominal flow (m3/h)	Configured value for the setpoint (m3/h)
E1.04	Seminar 1	0,2	1357	1200
E1.11	IT Lab 1	0,2	1357	600
E1.12	IT Lab 2	0,2	1357	600
E1.13	Office	0,2	1357	600
E1.14	Lecture room 1	0,3	3567	1200
E1.15	Lecture room 2	0,3	3567	1200
E1.22	Office	0,3	3567	1200

From these graphs several conclusions can be drawn. In general, the comfort in the room is considered optimal if CO_2 concentration is kept under the set point most of the time. For two rooms (Room 11 Figure 2, Room 12 Figure 3) CO_2 concentrations were above the set point almost for the whole duration of the experiment. For other rooms, set point value was satisfied, except for the period between 13:00 and 15:00 where the value peaked and then plateaued at around 1000 ppm for all the rooms except for room 112 (Figure 3), where it didn't exceed 900, but where it was also above the set point most of the time.

On several graphs it looks like the local VAVs are being saturated (i.e. requesting locally defined maximal airflow), almost all the time, e.g. room 104. The actual data shows however that the reached value always falls short of configured maximums for VAVs. In case of Room 104, the configured maximum value is 1200m^3/h and the calculated value peaks at 600 m^3/h.

In comparison to room 104, the room 111 shows quite the same amount of desired fresh air (needed airflow) - Figure 2. Despite the fact that an equal number of people is detected by the occupancy estimator the amount of fresh air remains the same. Apparently the controller limits the amount of fresh air taking also the energy consumption into consideration. The following effect of a rising CO_2 concentration is hence clear. The actual value for CO_2 goes beyond the CO_2 set-point, however is accepted as such due to the constraints with regards to the energy consumption of the ventilation system fans.

Room 112 – see Figure 3 – shows a similar behavior compared to rooms 104 and 111. However, the weights of the controller regarding the energy consumption were higher to see the effect of the energy – efficient actuation (the needed airflow calculated by the controller is less than the one calculated for the rooms 104 and 111). Obviously the CO_2 concentration is higher though, however accepted this way at the cost of lower energy consumption. There is also a mismatch between the calculated air flow and the actual one. The reason for that behavior could be the mismatch in the settings of the VAV (internal) controller and the model used to calculate the desired air flow of the model based controller.

Room 114 shows an obvious behavior having only little need for fresh air as the estimation is calculating a count of 2 people – see Figure 4. The controller is reacting to that accordingly, however, the process reaction does not happen instantaneously such that the results are visible straight away. As the test run was abandoned at around 4 pm the reaction to the actuation is not visible in these results.

Room 115 shows equals behavior as room 114 – see Figure 5.

Figure 6 to Figure 8 show the cumulative needed, provided and needed/provided difference air flow respectively. Especially the graph showing the difference between required and provided is interesting as it shows how the difference gap develops over time. It is a good way to depict the overall fresh air needs for each room.

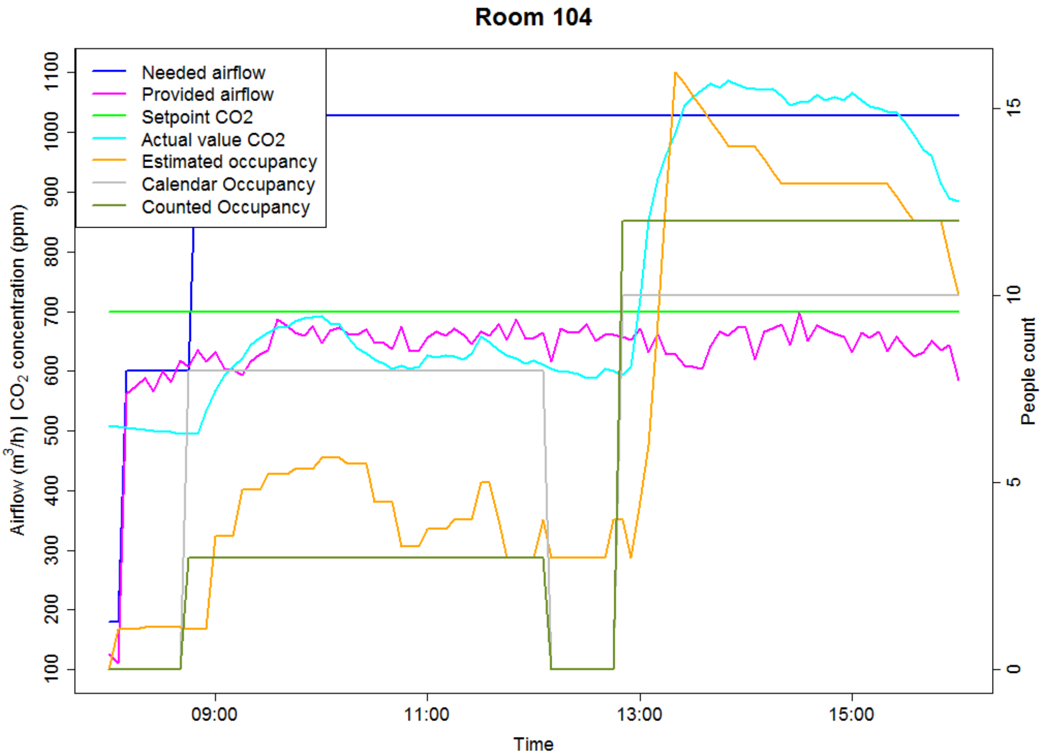

Figure 1 Airflow and CO_2 concentration (Room 104)

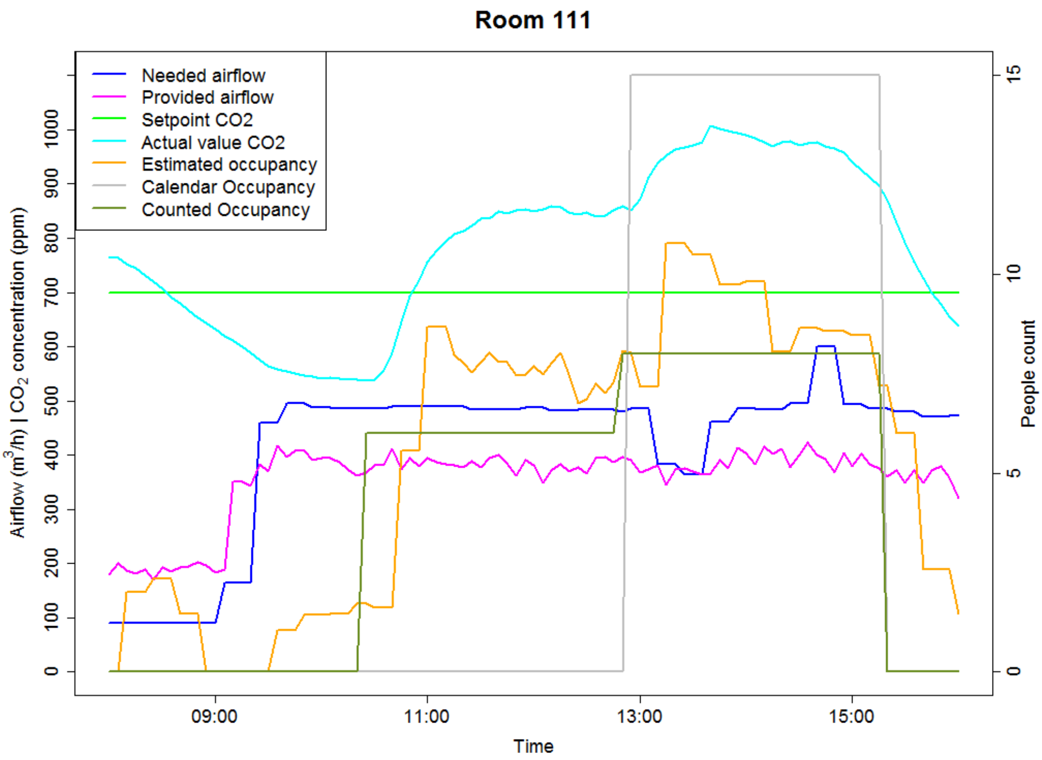

Figure 2 Airflow and CO_2 concentration (Room 111)

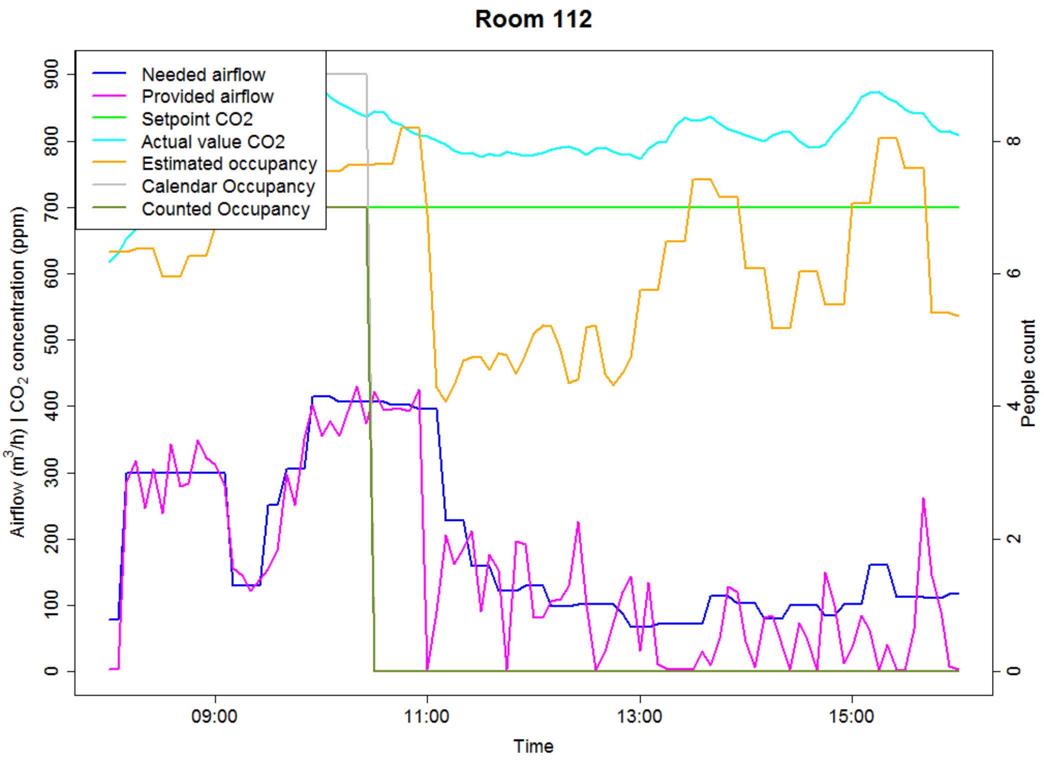

Figure 3 Airflow and CO_2 concentration (Room 112)

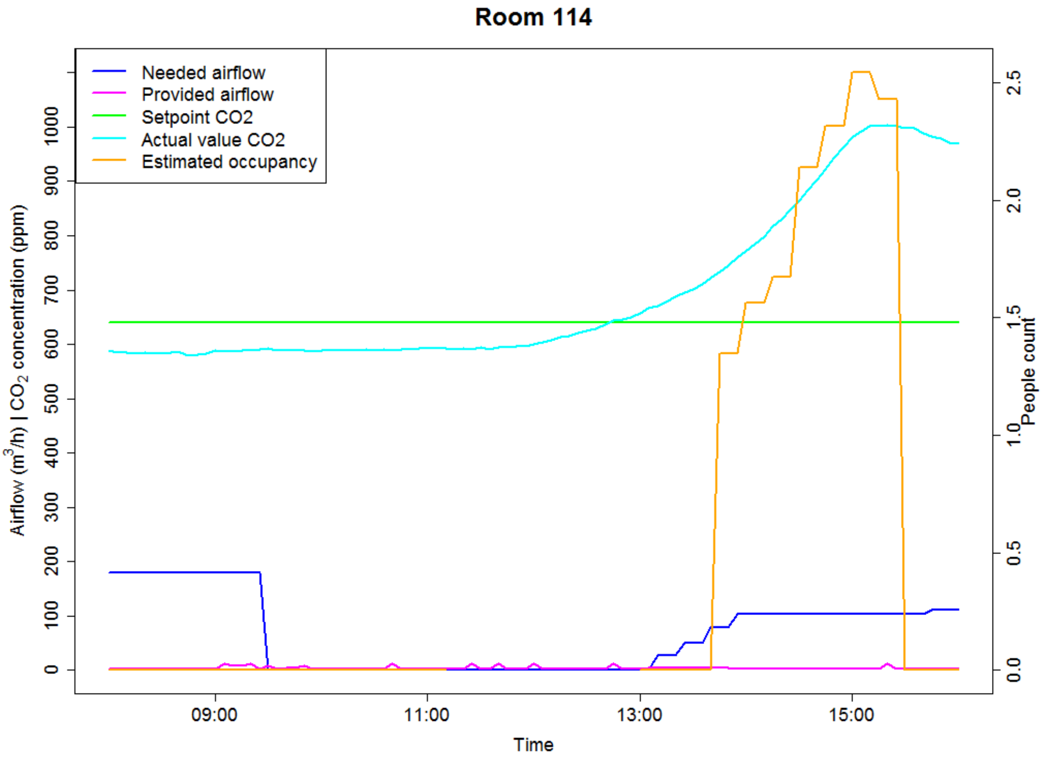

Figure 4 Airflow and CO_2 concentration (Room 114)

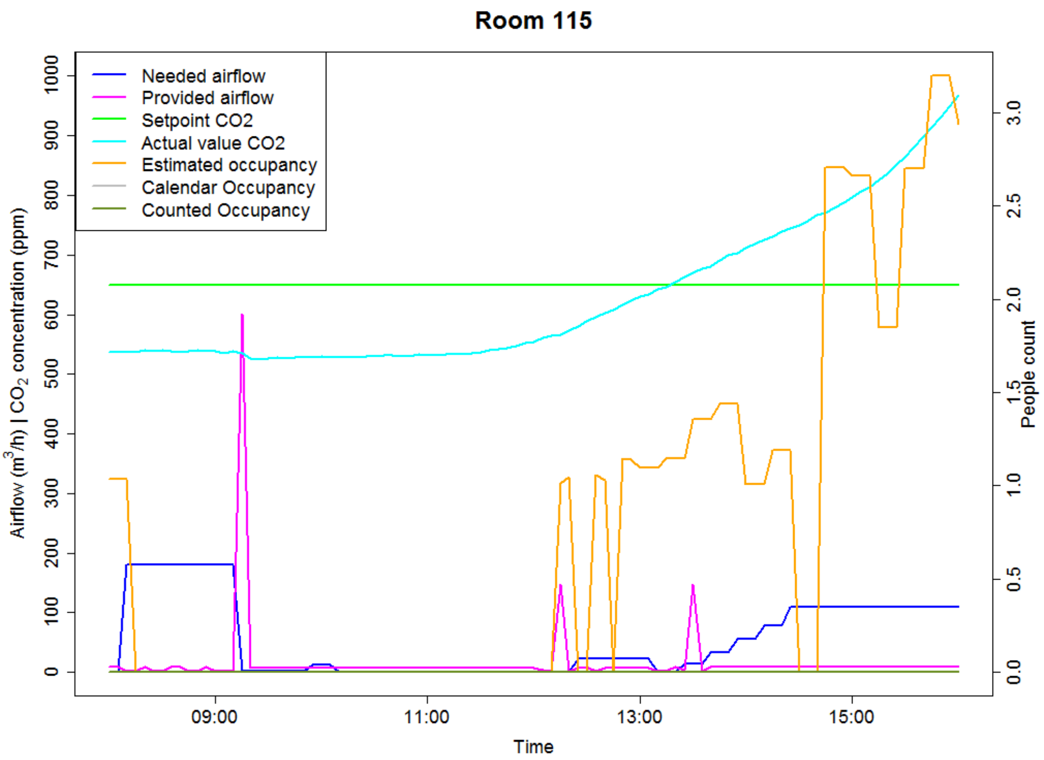

Figure 5 Airflow and CO_2 concentration (Room 115)

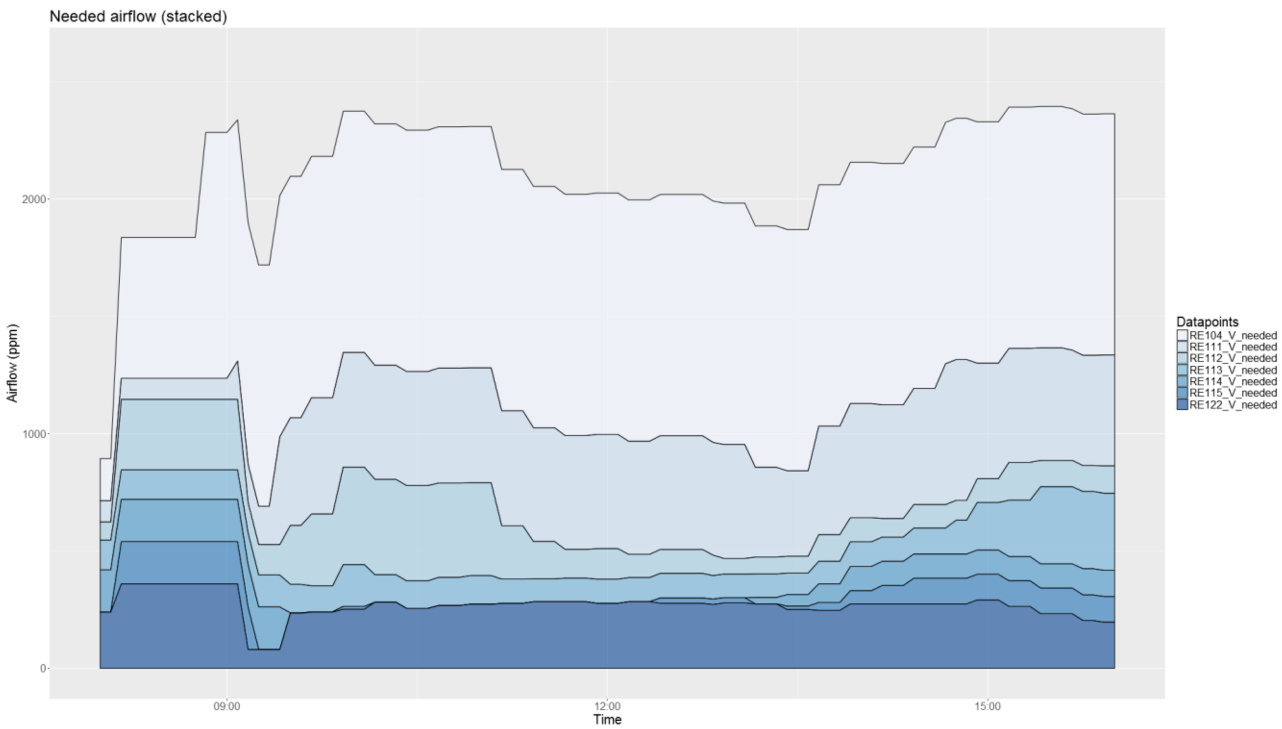

Figure 6 Cumulative needed airflow

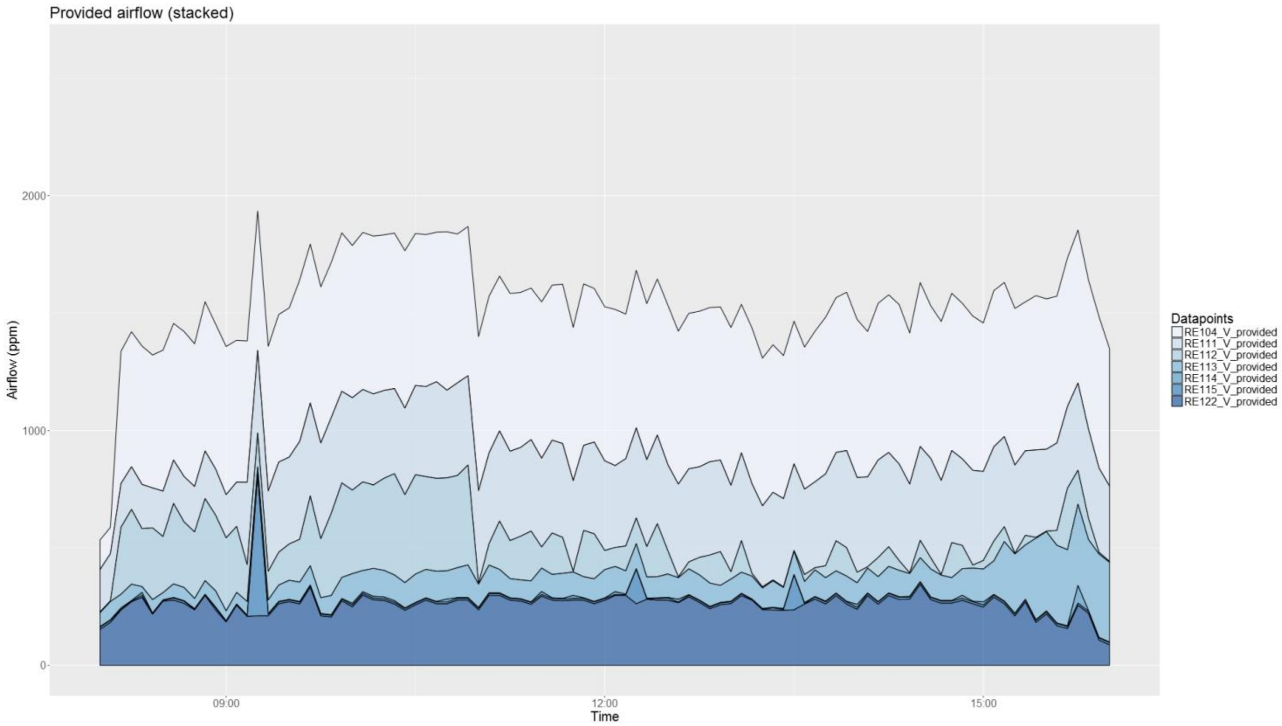

Figure 7 Cumulative provided airflows

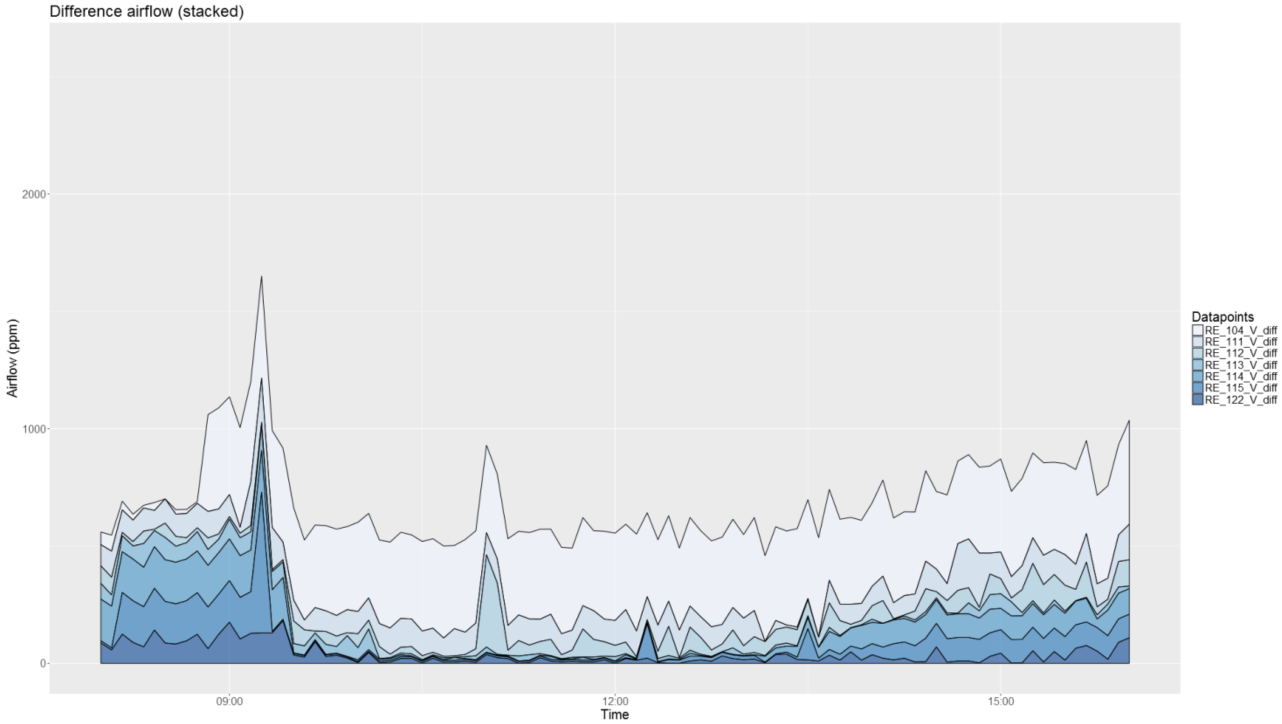

Figure 8 Cumulative difference between needed and provided airflows

3 E+E Office Building

In E+E building it was not possible to perform a test similar to the one in ENERGYbase building. Therefore only the data collection was performed and occupancy estimation was performed using the available data.

3.1 Heat Map Visualzations

Figure 9 - Figure 14 represent the collected available dataset for room 8244 (one of the five rooms for which the monitoring data was collected). Data is represented in the form of an hourly heat map. Data is completely collected for the period of 2 months and 10 days – between 1st of February and 11th of March. Collected datapoints include CO2 concentration, two temperature sensors for each room, provided airflow in cubic meters per hour, and calendar-based occupancy of each room. Estimated occupancy is then calculated using this data, and is represented here as well. It is clear from the graph that there is a strong correlation between airflow and estimated number of people, even in this coarse representation.

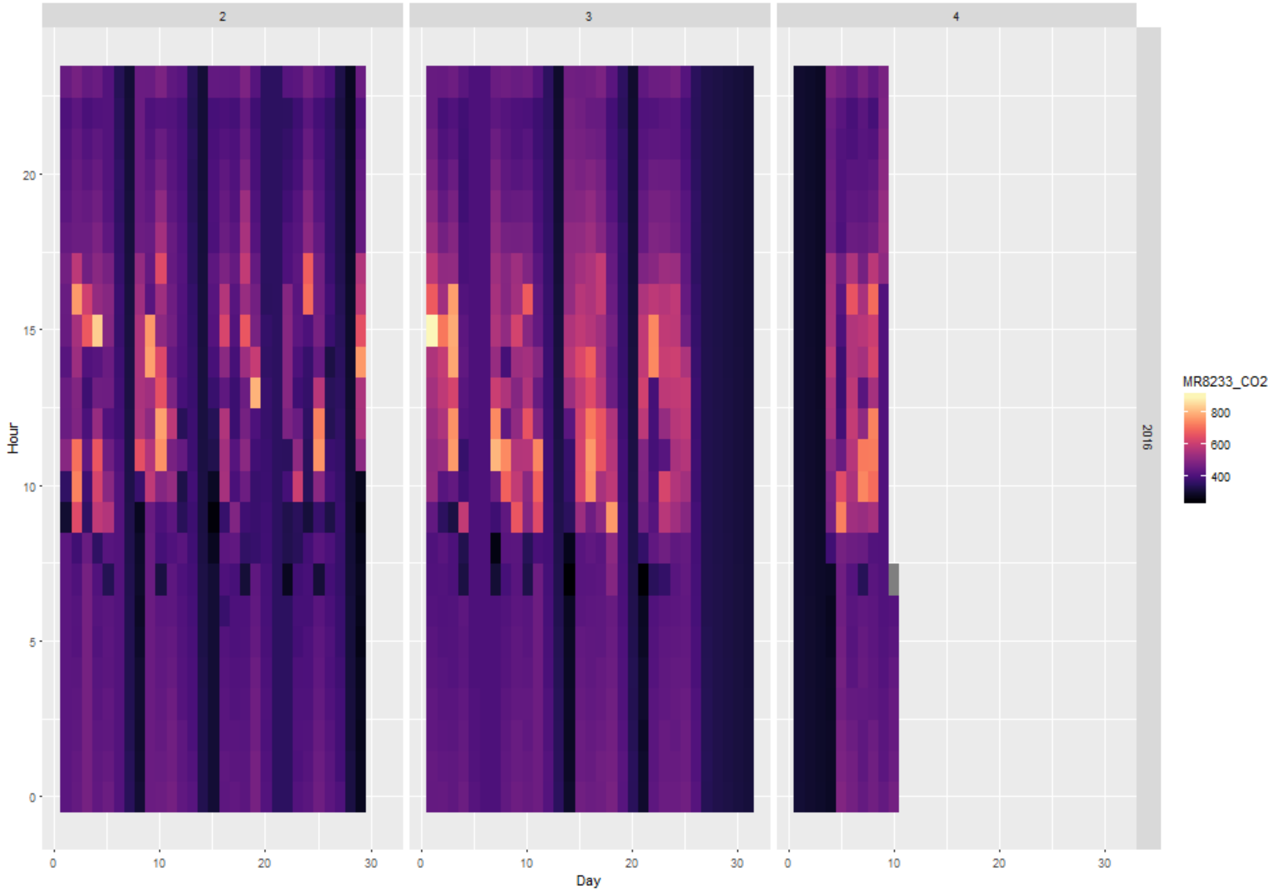

Figure 9 – CO_2 concentration heat map for room 8233

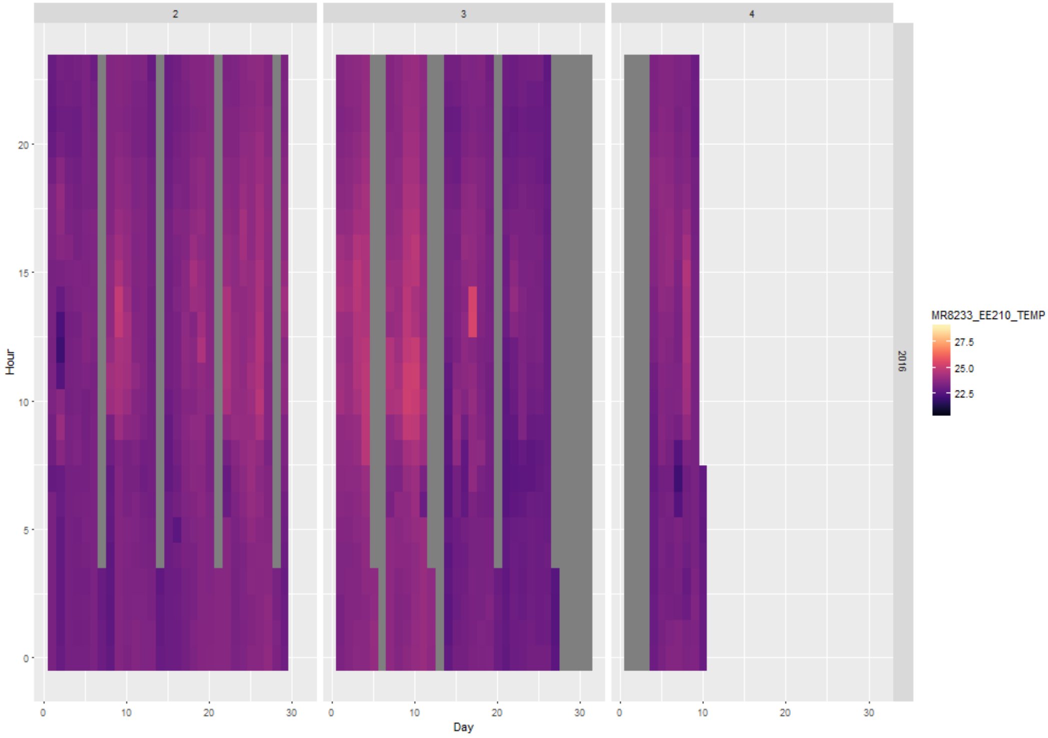

Figure 10 – Temperature heat map for room 8233

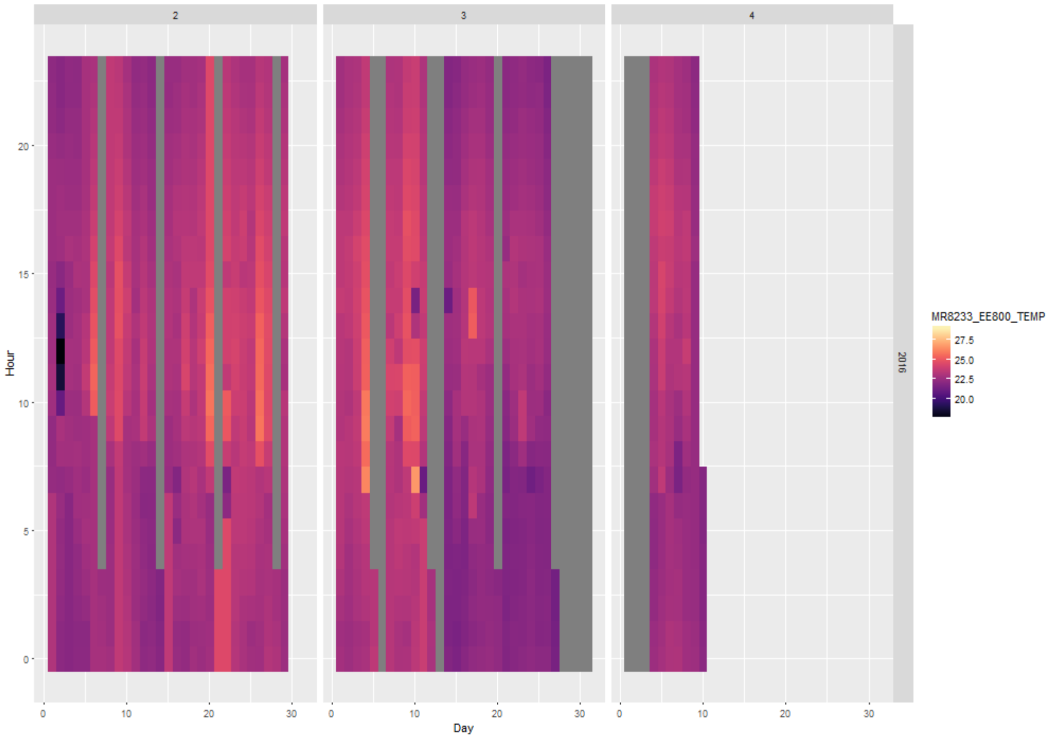

Figure 11 – Temperature heat map for room 8233

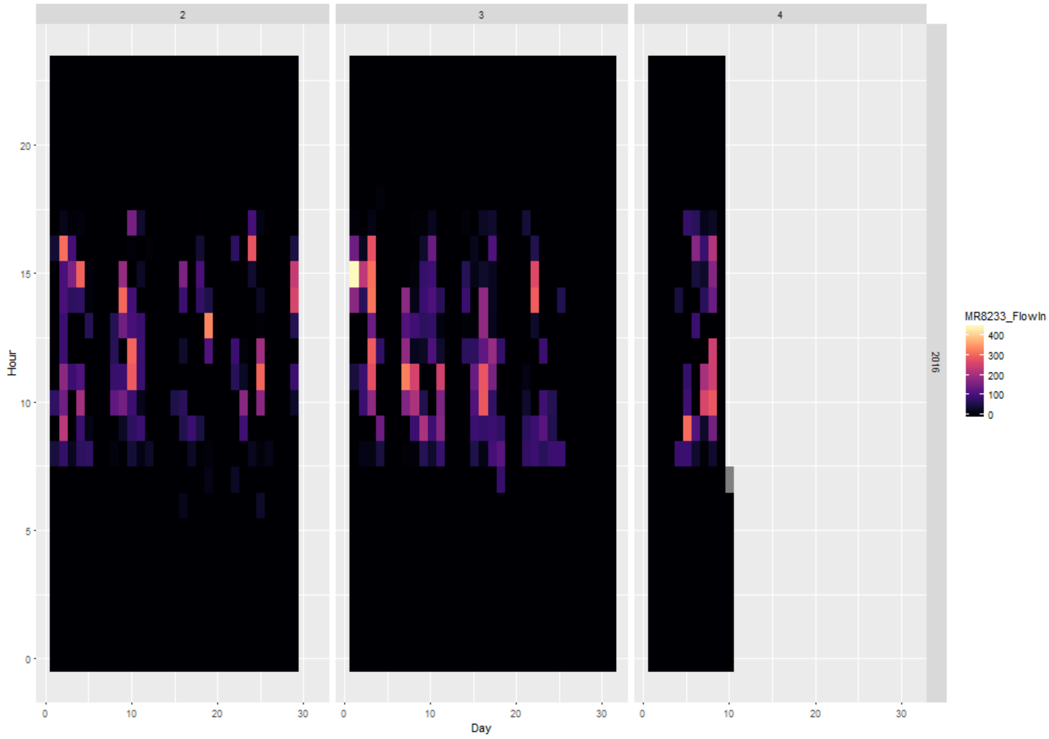

Figure 12 – Airflow heat map for room 8233

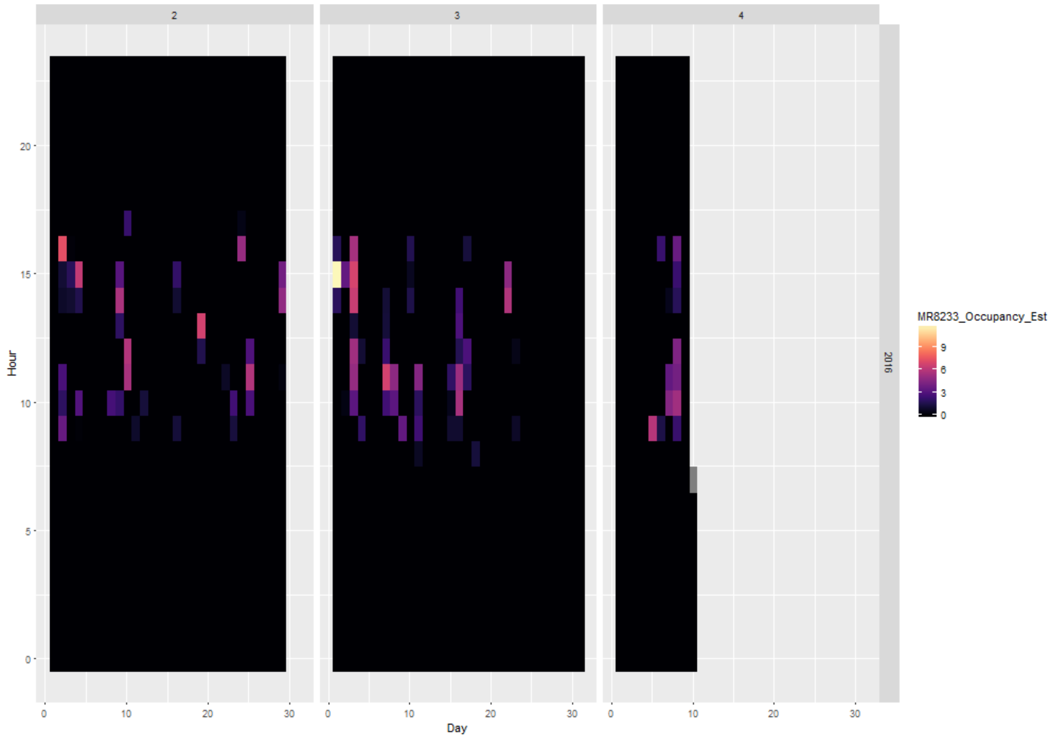

Figure 13 – Estimated occupancy heat map for room 8233

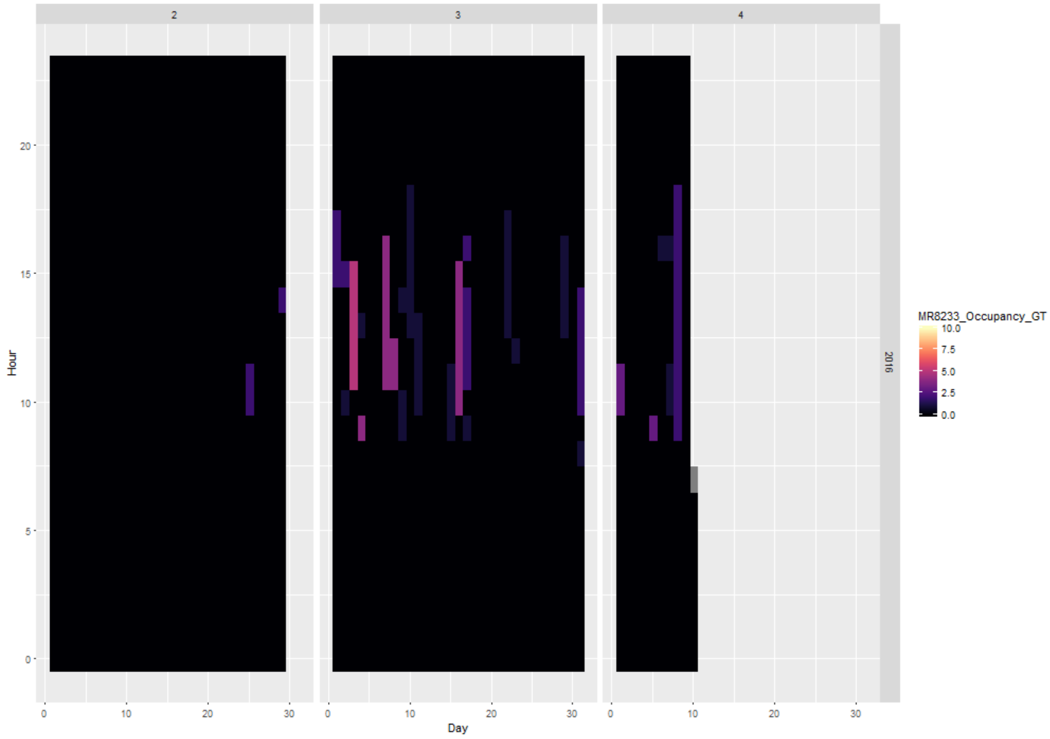

Figure 14 – Calendar occupancy heat map for room 8233

3.2 Occupancy Estimates

Additionally, Figure 15 - Figure 19 are combined graphs of provided airflows and CO_2 concentrations on the left scale, and calendar-based occupancy and estimated occupancy on the right scale. While the calendar-based occupancy time series is created from the room booking listing, it should not be considered a very precise measure of real occupancy. It is possible, and as can be seen from the graphs, quite usual, that people are present in the room even when there is no room booking in the system (Figure 16, around 9AM), or that number of people foreseen in the calendar differs significantly from the actual number of people (although we do not know the exact number of people, looking at Figure 15, the increased airflow, and CO_2 trend it seems that the number of people present is significantly more than 1). The system is coping well with the load. The CO_2 concentration is within the standard range, although the estimated occupancies are not exceeding 6 people, so it can be said that system was not exposed to high loads.

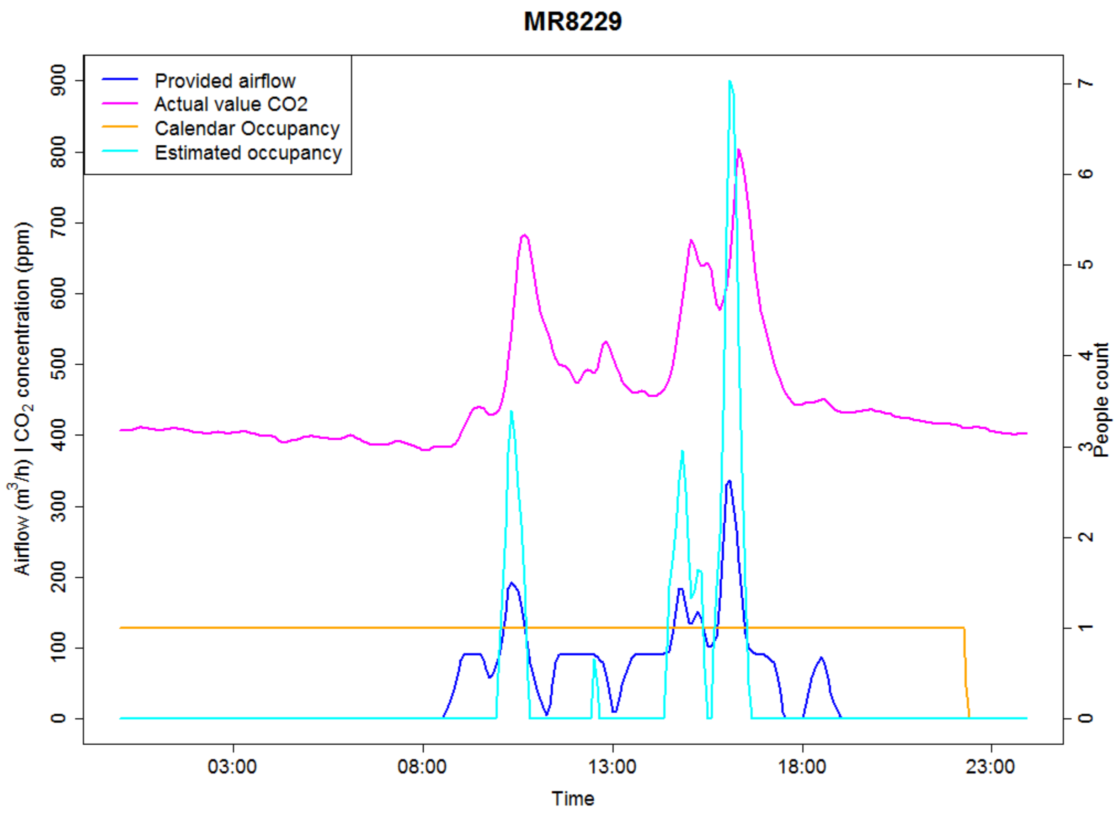

Figure 15 – Combined plot for room 8229

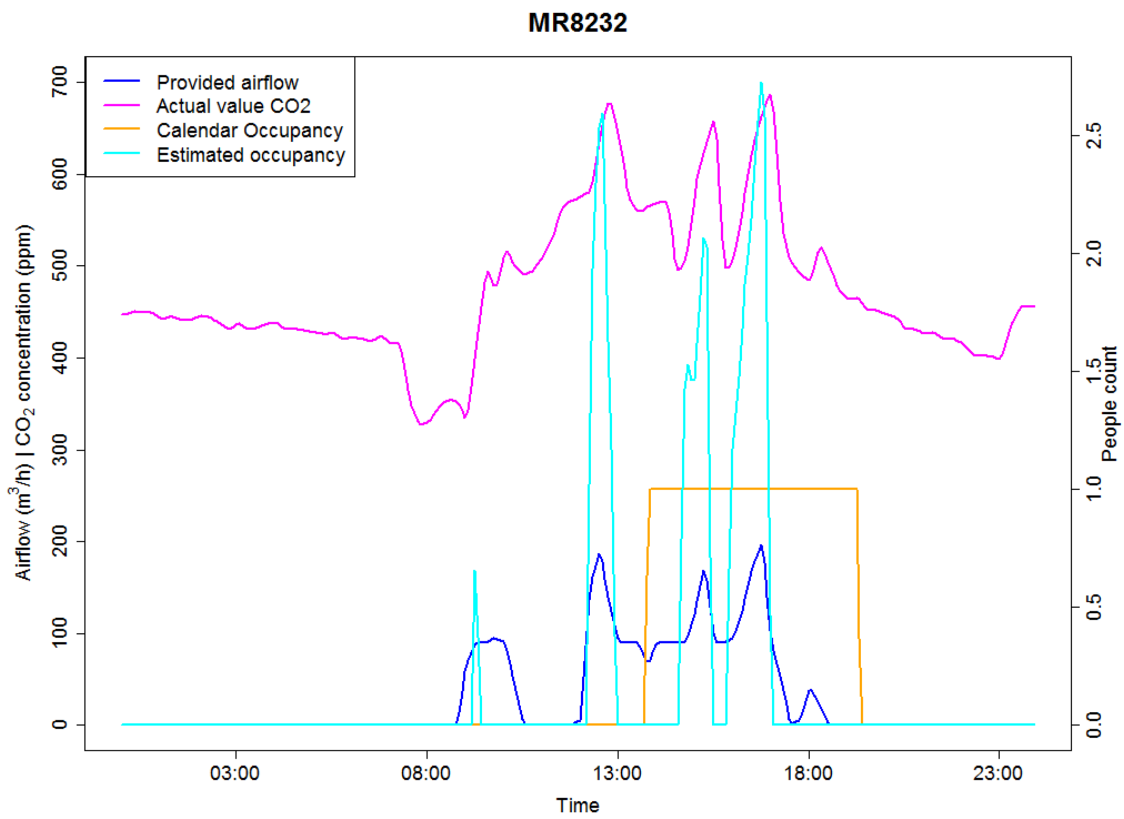

Figure 16 – Combined plot for room 8232

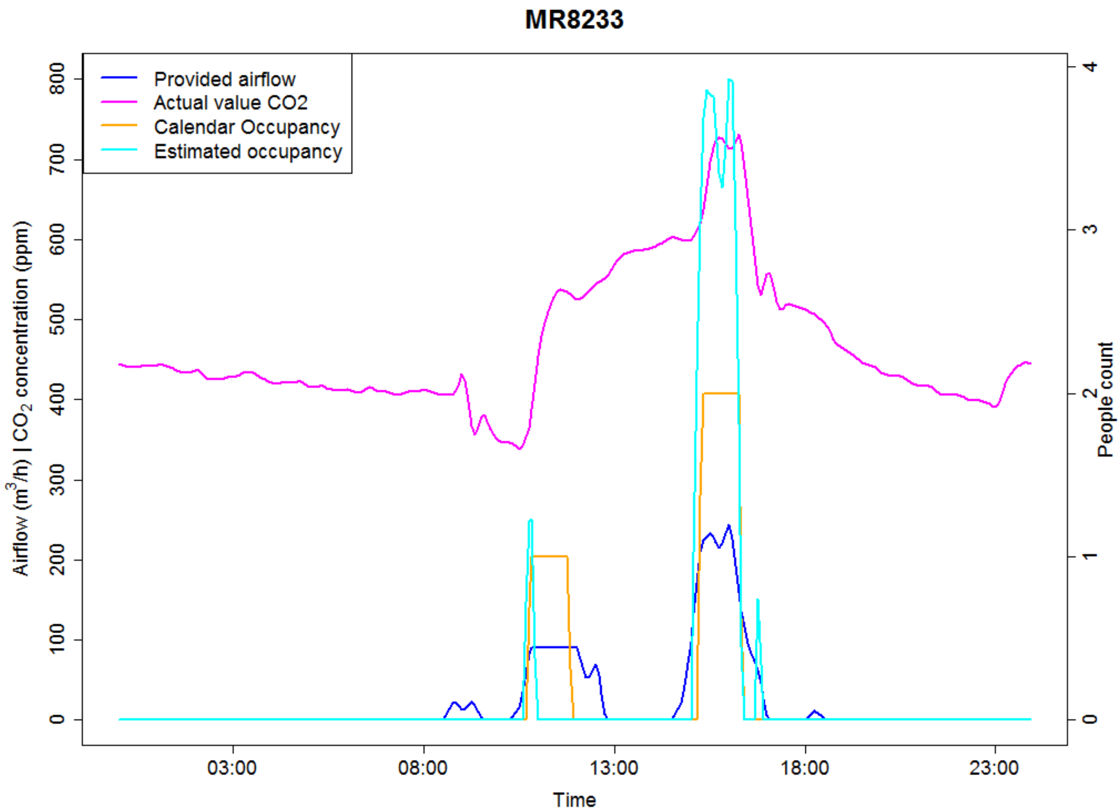

Figure 17 – Combined plot for room 8233

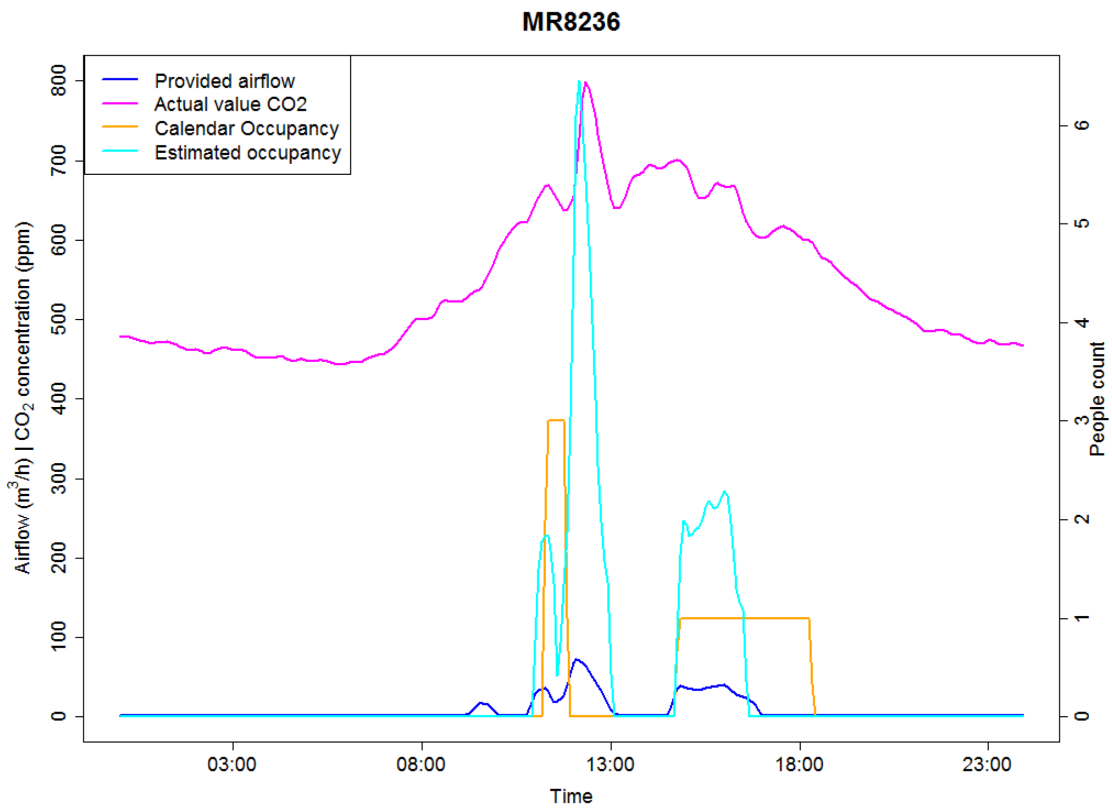

Figure 18 – Combined plot for room 8236

On Figure 19 it can be seen that, even though there is an announced occupancy, and an increase in CO_2 level (between 8:00-13:00), the airflow remains almost zero. The actual airflow is increased early in the morning, and later in the evening and during the night. Figure 20 shows that this was typical for ventilation in this room, especially during February.

CO_2 concentration is, however, still inside the allowed range. This indicates some problem in the system configuration or in the monitoring system.

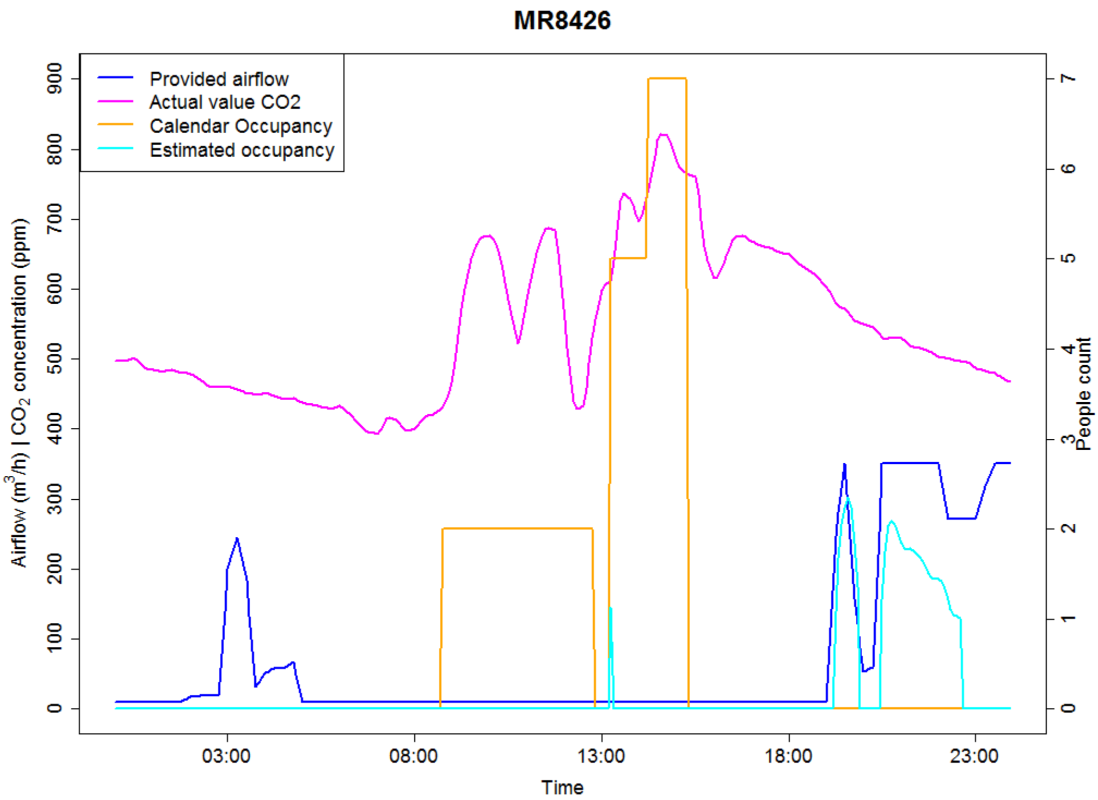

Figure 19 – Combined plot for room 8426

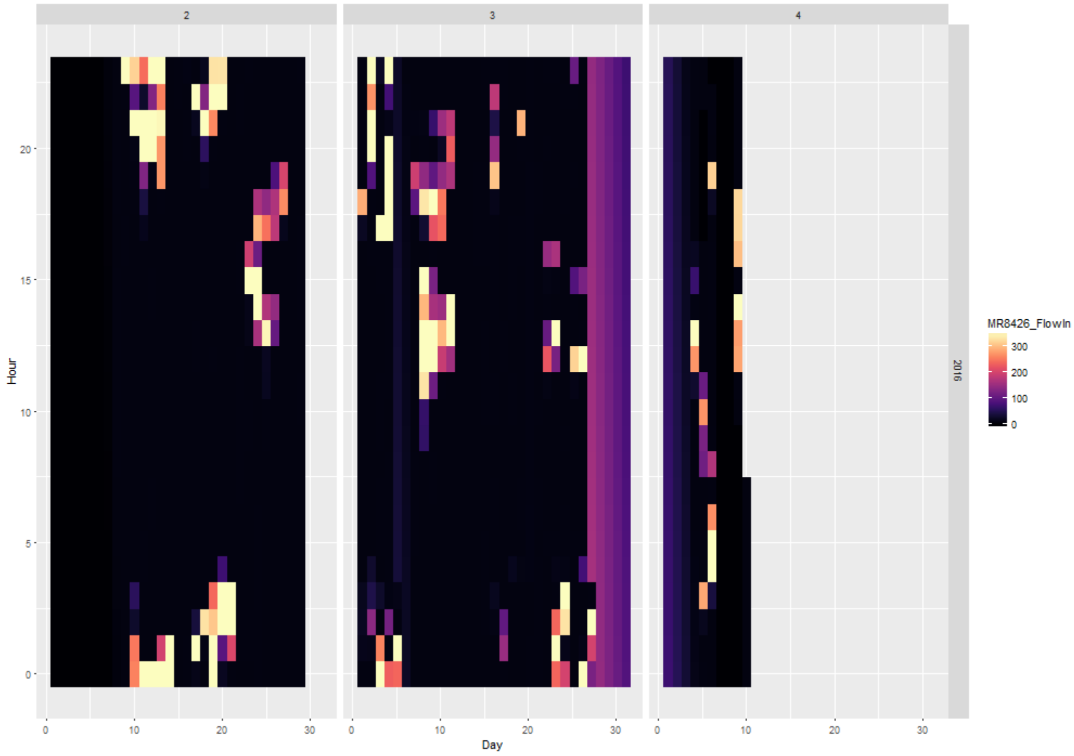

Figure 20 – Airflow heat map for room 8426 showing strange behavior

4 Conclusion

The upper graphs show good performance of the deployed model based controller for the EnergyBase building. Besides the possibility to actuate the VAV boxes according to the actual needs, which are apparently calculated upon the presence of people in the controlled rooms, there is also the option to take the energy efficiency into consideration. This is done by including weights into the control algorithms. Additional constraints in the control algorithms make sure that energy (electric) is not wasted. Naturally as the models used to run the controllers are fairly simplified, a tradeoff is made between control quality and computational power required to execute the algorithms.

Due to technical restrictions no tests were performed for the E+E building. Nevertheless, a detailed energy analysis was performed to find the required correlations between the required volume flows and the people count. The upper figures show a good description of the correlations, pointing out the necessity to improve current situation with the coordinated, model based control of the VAV box configuration for the fresh air supply of the offices in the E+E building.