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Room-based Indoor Environment Measurements and Occupancy Ground Truth Datasets from Five Residential Apartments in a Nordic Climate

Andersen, Kamilla Heimar; Marszal-Pomianowska, Anna; Knudsen, Henrik N.; Johra, Hicham; Melgaard, Simon Pommerencke; Dahl, Marc Zein; Hundevad, Patrick Andersen; Heiselberg, Per Kvols

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DEPARTMENT OF THE BUILT ENVIRONMENT
AALBORG UNIVERSITY

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Aalborg University
Department of the Built Environment
Division of Sustainability, Energy & Indoor Environment

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by

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September 2023

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Introduction

This document consists of the description of the developed and curated datasets of 1) Indoor Environmental Quality (IEQ) and collection of occupancy ground truth (1-week data) and 2) long-term monitoring of IEQ in rooms in apartments in a low-energy multi-story residential building (8 months, February 2023 to August 2023).

The datasets with all the parameters can be found at the following GitHub repository [1].

The SATO Project

The Horizon2020 "SATO" (Self-Assessment Towards Optimization of Building Energy) project will implement a cloud-based platform to perform self-assessment and optimize energy-consuming devices in a building. This platform uses an artificial intelligence approach combined with 3D BIM-based visualization to provide an accurate vision of the real-life energy performance of buildings and appliances. See more information about the project here [2].

The authors gratefully acknowledge the support from the European Commission through the research project "Self-Assessment Towards Optimization of Building Energy" (SATO) Grant agreement number: 957128.

Datasets

Dataset 1

The curated IEQ dataset with occupancy ground truth consists of data from 30.01.2023 to 06.02.2023. The resolution of the data is 15 minutes and has the following parameters included:

1. Date and time [DD:MM:YY HH:mm]
2. Indoor CO_2 concentration [ppm]
3. Indoor air temperature [°C]
4. Indoor relative humidity [%]
5. Room type [string]
6. Room type [integer]
7. Categorical room types encoded as one-hot [0 / 1]
8. Room number [integer]
9. Apartment number [integer]
10. Floor area [m^2]
11. Ground truth occupancy [0 / 1]
12. Window opening ground truth [0 / 1]
13. Cycled encoded date: day_sin and day_cos [-1 - 1]
14. Cycled encoded hour: hour_sin and hour_cos [-1 - 1]
15. Day of the year [30-36]
16. Day label [0-111] (all rooms are vertically concatenated, 7 days x 16 rooms = 112 days)
17. Hour of the year [0-23]
18. Day of the week [1-7]

Dataset 2

The curated IEQ dataset consists of data from 01.02.2023 to 01.09.2023. The resolution of the data is 15 minutes and has the following parameters included:

1. Date and time [DD:MM:YY HH:mm:SS]
2. Indoor CO_2 concentration [ppm]
3. Indoor air temperature [°C]
4. Indoor relative humidity [%]
5. Room type [string]
6. Room type [integer]
7. Room number [integer]
8. Apartment number [integer]
9. Floor area [m^2]

This dataset will be available from October 2023 at GitHub: [1].

Key elements of the case study

More in-depth description of the case study can be seen in [3, 4].

- A multi-story residential building erected in 1949/50 and renovated to a low-energy building in 2012/2013
- Situated in the Northern Denmark region
- Have of five staircases, each consists of three to six apartments, 24 apartments in total
- This study consists of five apartments from the same staircase
    - Apartments on the left side are 72 m^2 (two-bedrooms, three apartments in total)
    - Apartments on the right side are 55 m^2 (one-bedroom, two apartments in total)
    - In total, 16 rooms are studied
    - Room types: Bedrooms, kitchen, living room and kitchen / living room
- Air Handling Unit (AHU) that provides a consistent ventilation rate of approximately 20 m^3/h
    - Supply vents are located in both the bedrooms and living areas, while exhaust vents can be found in the kitchens and bathrooms

Figure 1 shows the floor plan of the case study [3].

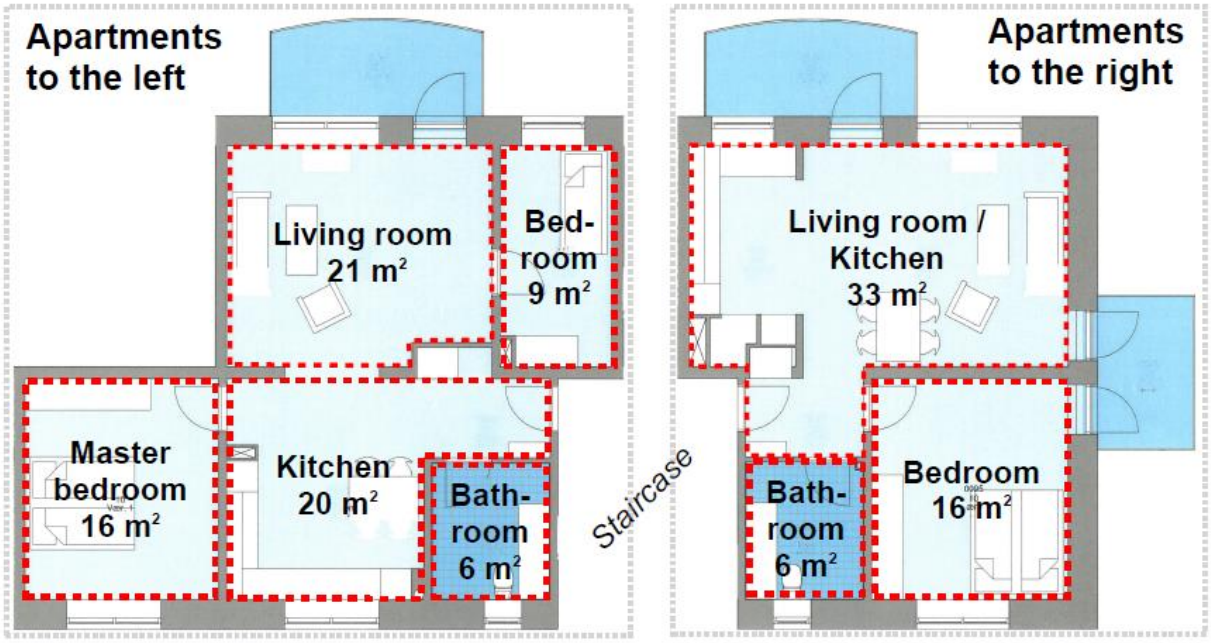

Figure 1: Floor plan of case study.

See Table 1 for information regarding apartment number, occupants, room number and room type [4].

Table 1: Apartment, number of occupants, animals, gender, occupation, and room number and type.

Apartment	Number of occupants	Room numbers and room type in parenthesis
Apartment 1 (55 m^2)	1	1 (bedroom) and 2 (living room/kitchen)
Apartment 2 (72 m^2)	1	3 (bedroom), 4 (kitchen), 5 (living room) and 6 (office)
Apartment 3 (55 m^2)	1	7 (bedroom) and 8 (living room/kitchen)
Apartment 4 (72 m^2)	2	9 (bedroom), 10 (kitchen), 11 (living room) and 12 (office)
Apartment 5 (72 m^2)	1	13 (bedroom), 14 (kitchen), 15 (living room) and 16 (office)

Specifications of IEQ sensors

The IEQ sensors are developed by the Danish company, Xtellio [5].

The specifications of the IEQ sensors [6] are presented in Table 2.

Table 2: IEQ sensor specifications at default conditions of 25 °C, 50 % relative humidity, ambient pressure 1013 mbar [6].

Parameter	Measuring range	Conditions	Uncertainty
Air temperature	-10 °C – 60 °C	15 °C – 35 °C -10 °C – 60 °C	± 0.8 °C ± 1.5 °C
Relative humidity	0 – 100 %	15 °C – 35 °C, 20 % – 65 % -10 °C – 60 °C, 0 % – 100 %	± 6 % ± 9 %
CO_2 concentration	0 – 5000 ppm	400 – 5000 ppm	± (40 ppm + 5 %)

The installed IEQ sensors are battery-driven and can be seen in Figure 2.

Figure 2: The IEQ sensors are enumerated to keep track of placement in each room.

The IEQ data collection is performed via a REST API to the Xtellio database.

IEQ sensor calibration procedure

Before installation of the IEQ sensors, they were calibrated according to available sensor calibration procedures and associated equipment in the laboratory at Aalborg University.

An outdoor air CO_2 concentration reference test was conducted with IC meter sensors, which can be seen in Figure 3 below. The specifications of the IC-meter sensors can be seen here: [7].The white sensors are the IC-meters and the black sensors are the Xtellio sensors. All the sensors were placed outside for five hours.

Figure 3: The IEQ sensors (black sensors) were tested and compared against IC meters (white sensors) under different conditions.

Individual calibration curves (ax + b) and additional offsets (c) were added to each sensor for CO_2 concentration. The additional offsets were added as the sensors did measure adequately below the current atmospheric CO_2 concentration [8, 9]. Only individual calibration curves (ax + b) for indoor air temperature and relative humidity were added. Equation 1 shows the definition of the individual calibration curve and the offset for the CO_2 concentration.

$$(ax + b) + c \qquad \text{(Equation 1)}$$

a = slope of the regression

x = independent variable, measured data point

b = offset

c = additional offset

For the indoor air temperature and relative humidity, only individual calibration curves were added to the sensor data and can be seen in Equation 2.

$$ax + b \qquad \text{(Equation 2)}$$

All the calibration measurements were made in an environmental chamber, as shown in Figure 4. The environmental chamber is from Vötsch, model type VCL 7010. This was performed to have control of the measurement environment by programming the chamber to desired environmental conditions.

Figure 4: IEQ sensors (black sensors) and IC meters (white sensors) placed in the environmental chamber.

- The CO_2 concentration calibration was performed with 1000 ppm, 1700 ppm and 2500 ppm
- The air temperature calibration consisted of the following process
    - Relative humidity was set to 70 %

    - The chamber was set to reach the following temperatures in °C: 10, 15, 18, 20, 22, 25, 30, 35
    - After the chamber had reached the target temperature, it was set to hold these conditions for 60 minutes.
- The relative humidity calibration was performed with the following process:
    - The environmental chamber temperature was set to 23 °C
    - The chamber was set to reach the following relative humidity in %: 20, 30, 40, 50, 60, 70
    - After the chamber had reached the target relative humidity, it was set to hold these conditions for 60 minutes.

Placement of the IEQ sensors

The IEQ sensors were installed in each apartment in mid-January 2023. There were two approaches for installing the IEQ sensors, which can be seen in Figure 5. The figure to the left is the IEQ sensor installed under the existing thermostat setpoint controller in each room (except the kitchen and bathroom), whereas the figure to the right is the sensors placed at a desired place in each room in each apartment. All the IEQ sensors were placed at a height of approximately 1.8 meters above the floor.

Figure 5: Installation of the IEQ sensors.

Figure 6 shows the placement of the IEQ sensors (red dots) and the heating- and cooling thermostat setpoint controller (black rectangle) in both apartment types (apartments to the left and right).

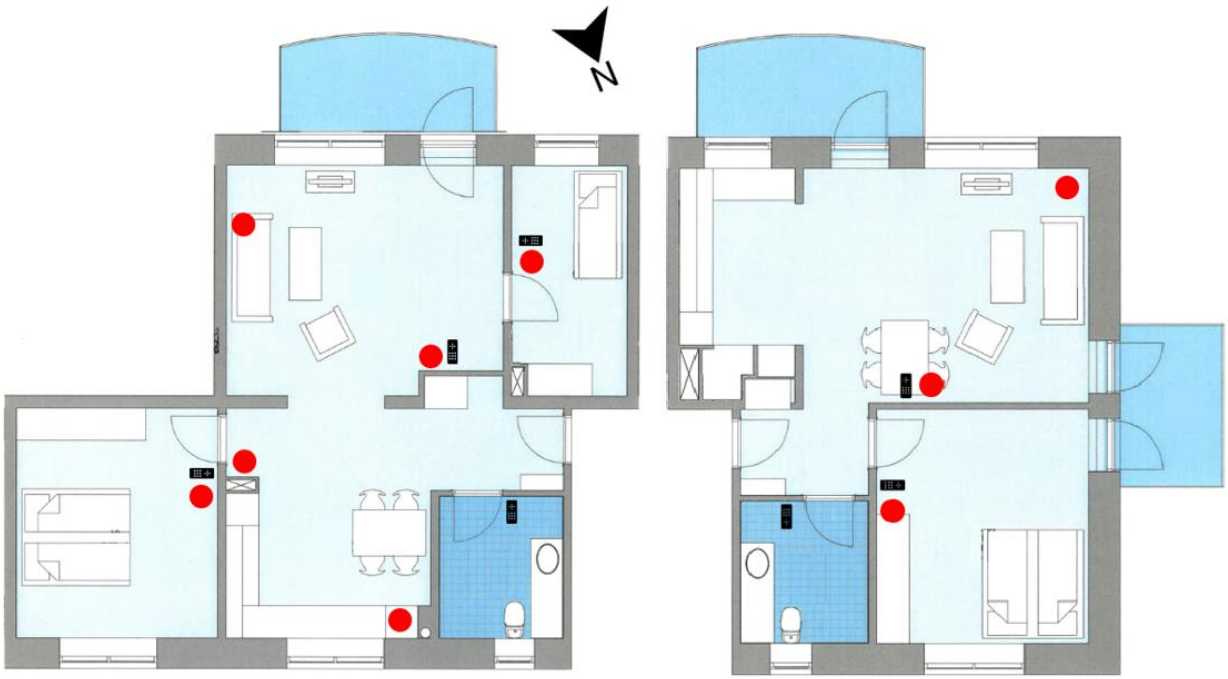

Figure 6: The red dots represent the approximate placement of the IEQ sensor in the apartments to the left (figure to the left) and right (figure to the right) apartments. The black rectangle represents the heating- and cooling thermostat setpoint controller.

Collection of ground truth

The collection of occupancy ground truth was performed with a logbook the recruited occupants filled out over 7 days, with 15. Minutes resolution from 30.01.2023 to 05.02.2023. One sheet per day, in each room was filled out. The occupancy ground truth survey was created to account for multiple purposes, as shown in Figure 7.

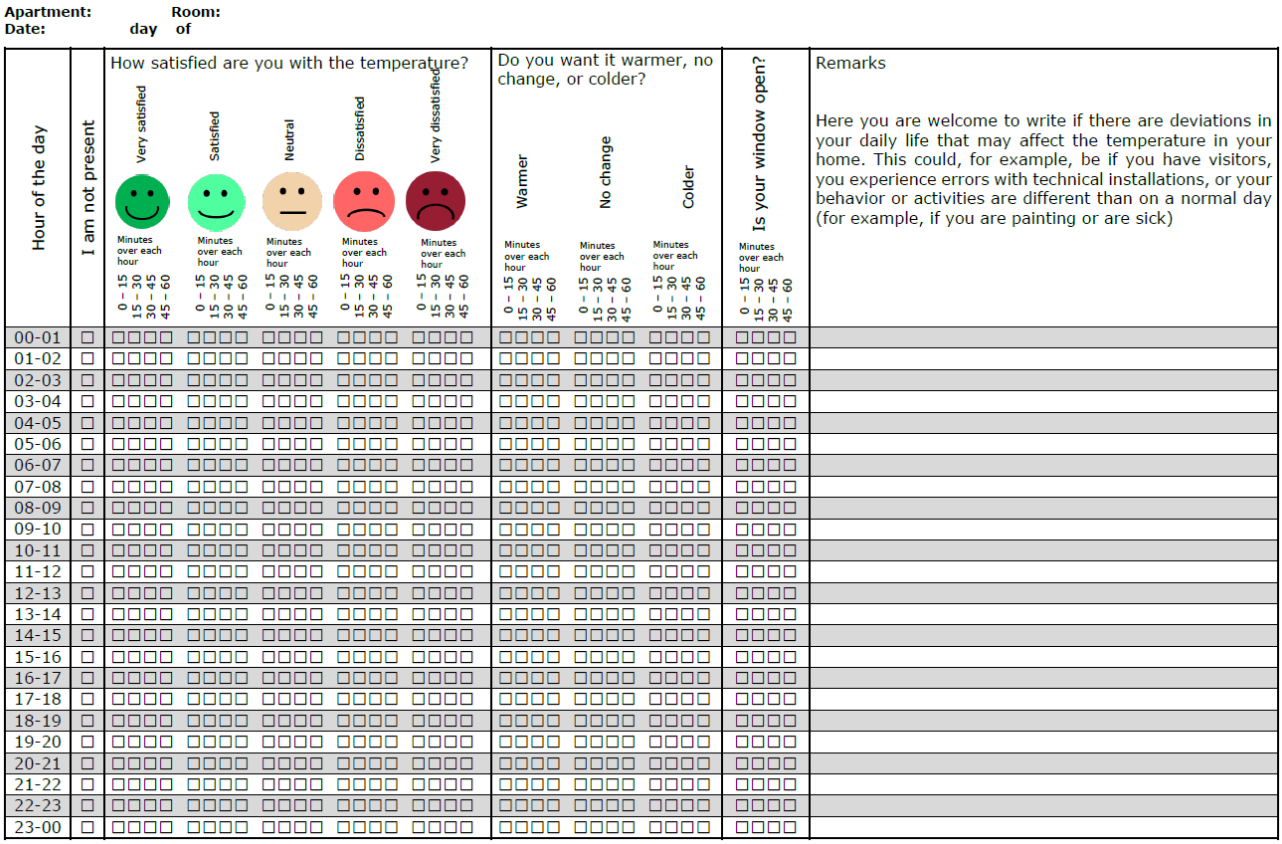

Figure 7: Survey sheet for collecting occupant ground truth. One survey sheet was to be filled out daily per room (out of seven days).

The survey consisted of the following questions and tick boxes to be filled out from the left to the right:

1. Hour of the day (0-23)
2. *"I am not present."*
3. "*How satisfied are you with the temperature*?"

This question was to be filled out when the occupants were present and is interpreted as *reported occupancy ground truth* (0 or 1, absence or presence). The occupant temperature satisfaction interpretation is not used in this study.

4. "*Do you want it warmer, no change or colder*?"

The answer from this question is also not used in this study.

5. *"Is your window open?"*
6. *Occupant feedback*

Lastly, there is a column consisting of occupant feedback. Such as if any anomalies were happening that day, if they were sick, or if they discovered anything faulty in the apartment. The surveys were printed as A3 papers and handed to the occupants before the ground truth collection date started. A full survey version can be found at the following GitHub repository: [1].

Dataset 1 overview: IEQ data

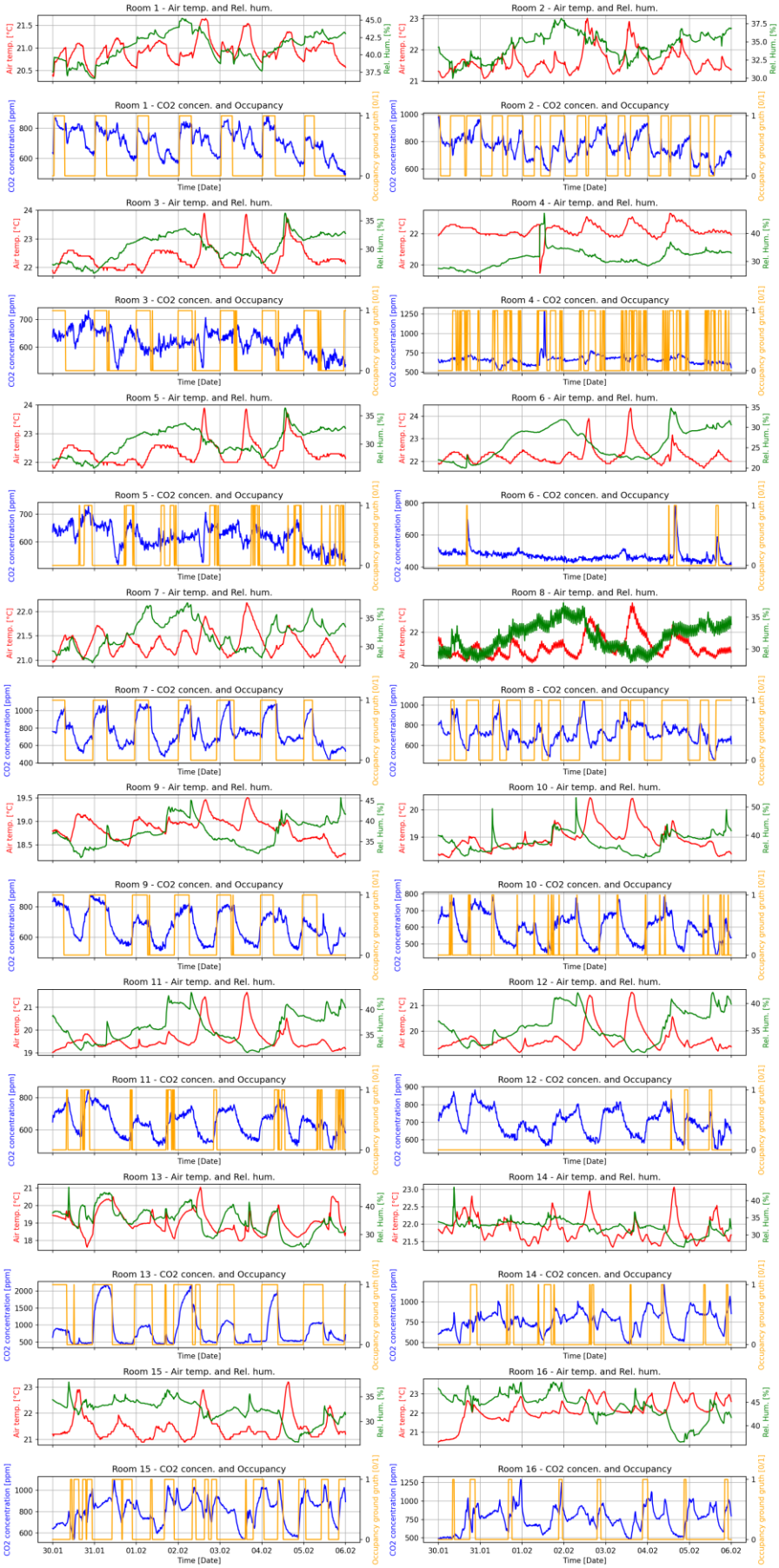

Figure 8: Measured indoor environment quality data and reported ground truth for each room in all the apartments.

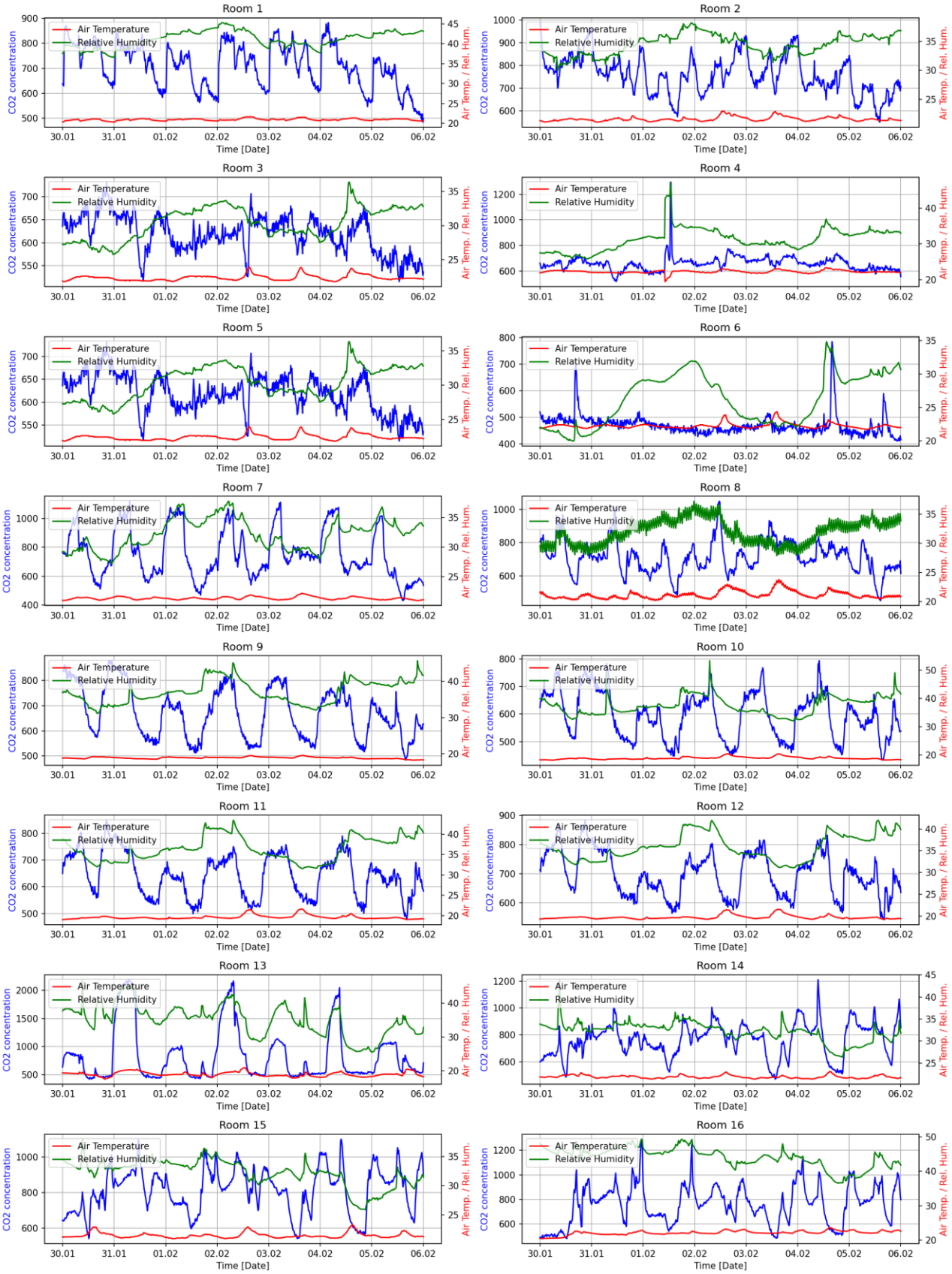

Figure 9: Measured indoor environment quality data for each room in all the apartments.

Dataset 1 overview: Reported occupancy ground truth

Figure 10 shows the data points representing the presence and absence of the reported ground truth data from each room, in each apartment. There are 673 data points in each room (one data point is equal to 15 minutes).

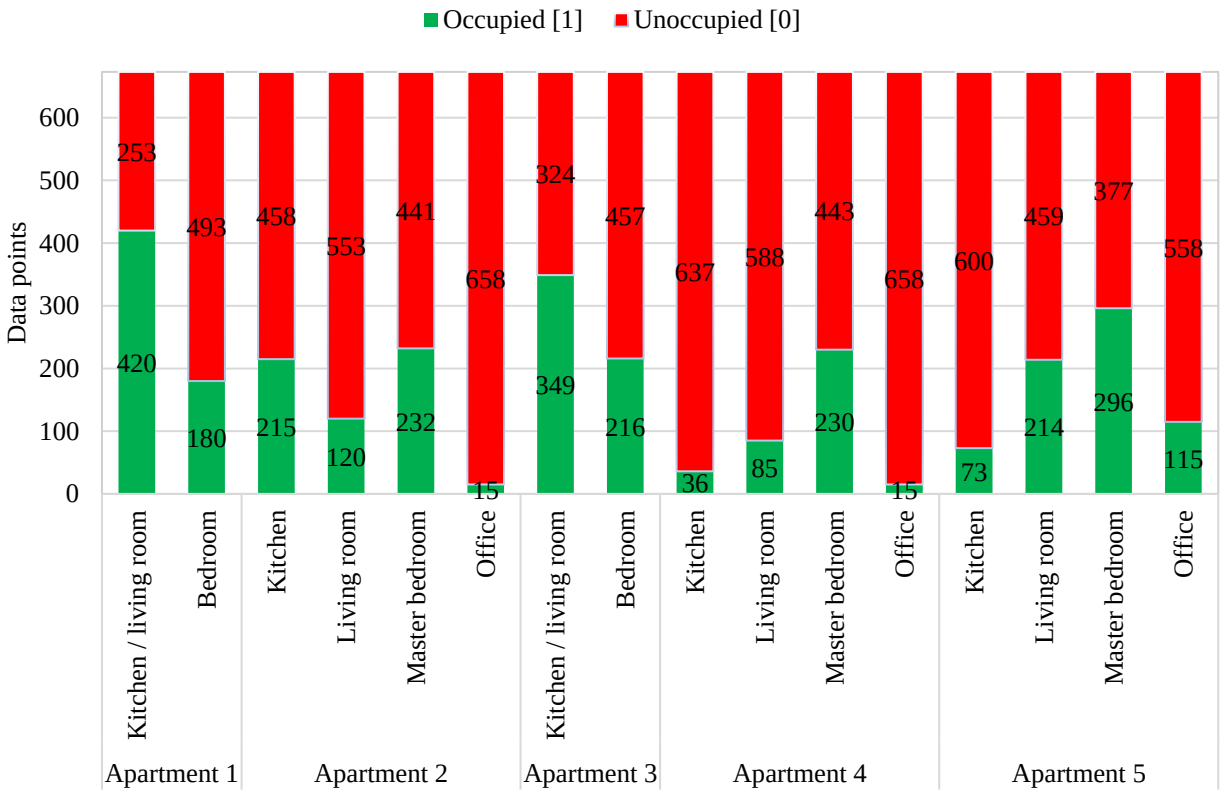

Figure 10: Representation of the number of data points for presence and absence for each room in each apartment, 15-minute resolution (per data point).

Correlation of IEQ sensor measurements and occupancy (Dataset 1)

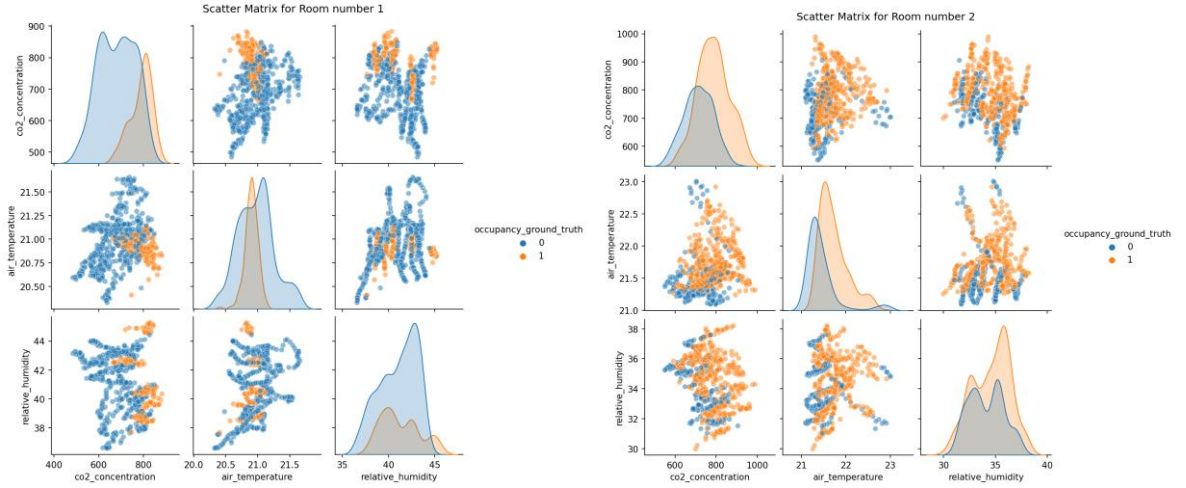

Figure 11: Apartment number 1.

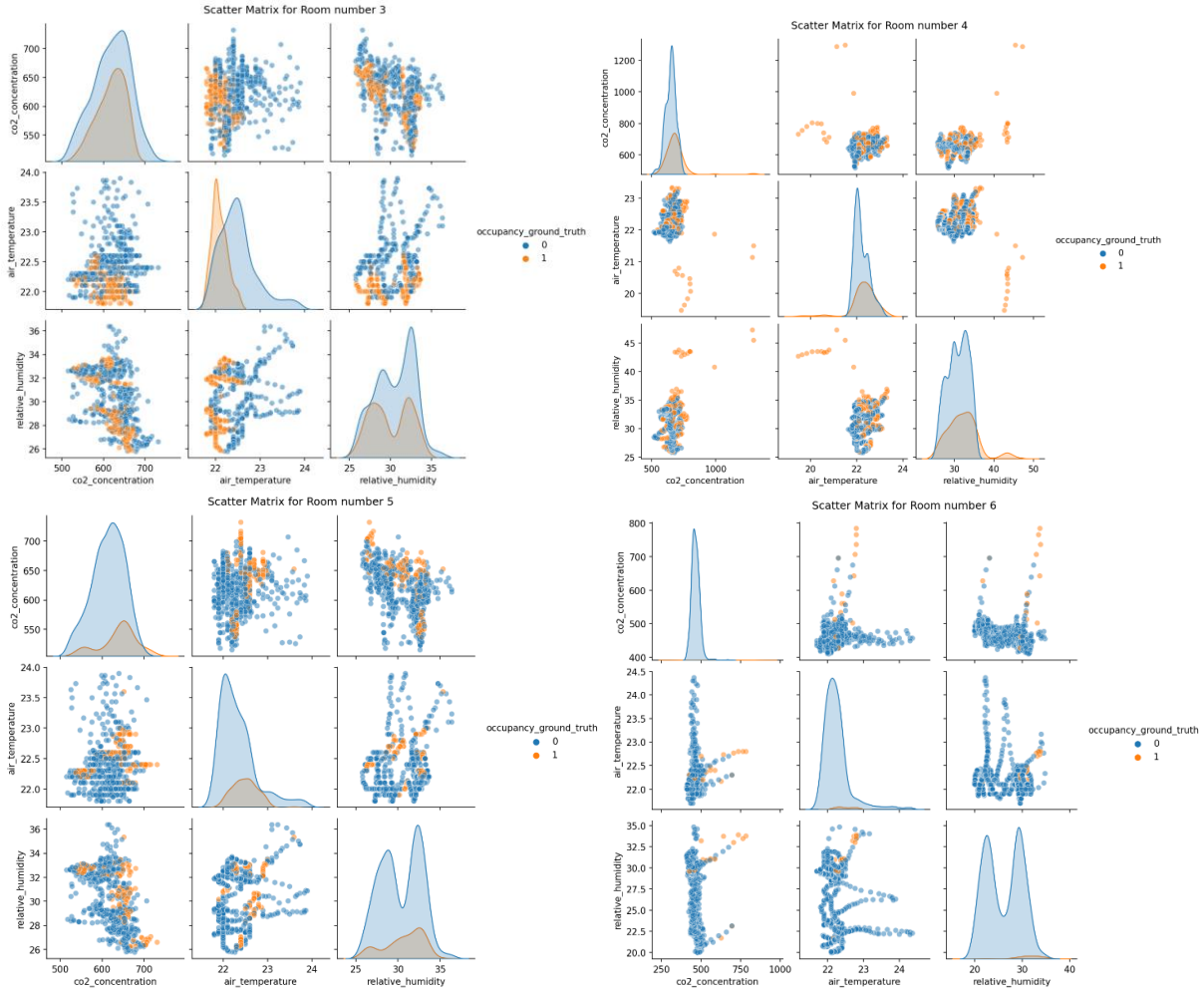

Figure 12: Apartment number 2.

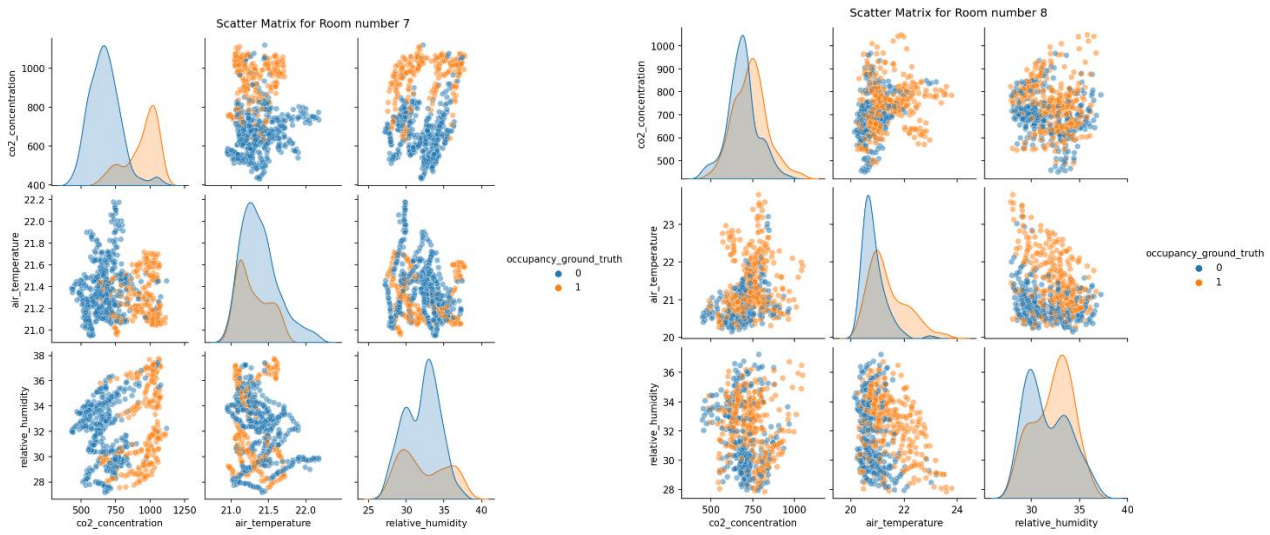

Figure 13: Apartment number 3.

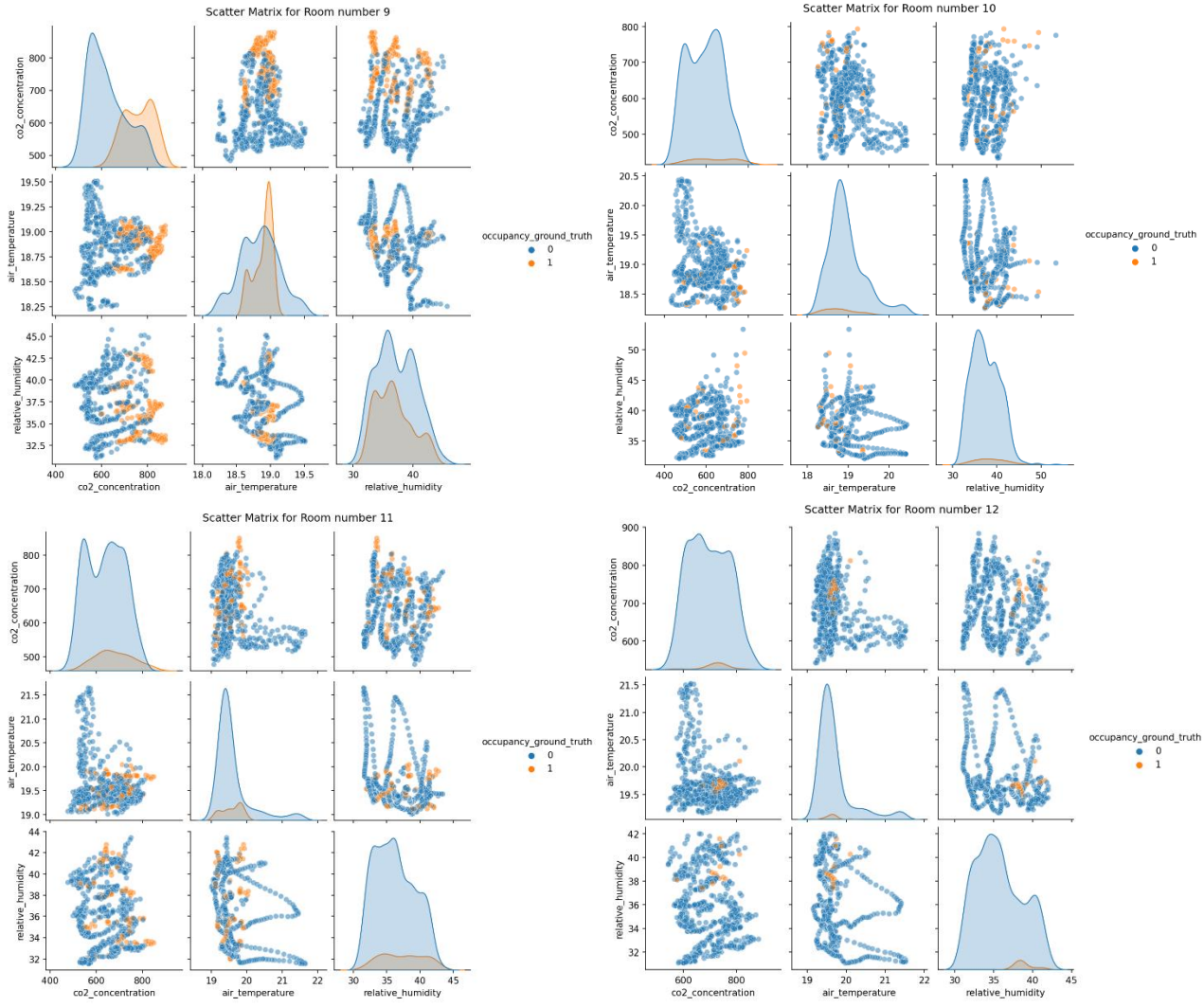

Figure 14: Apartment number 4.

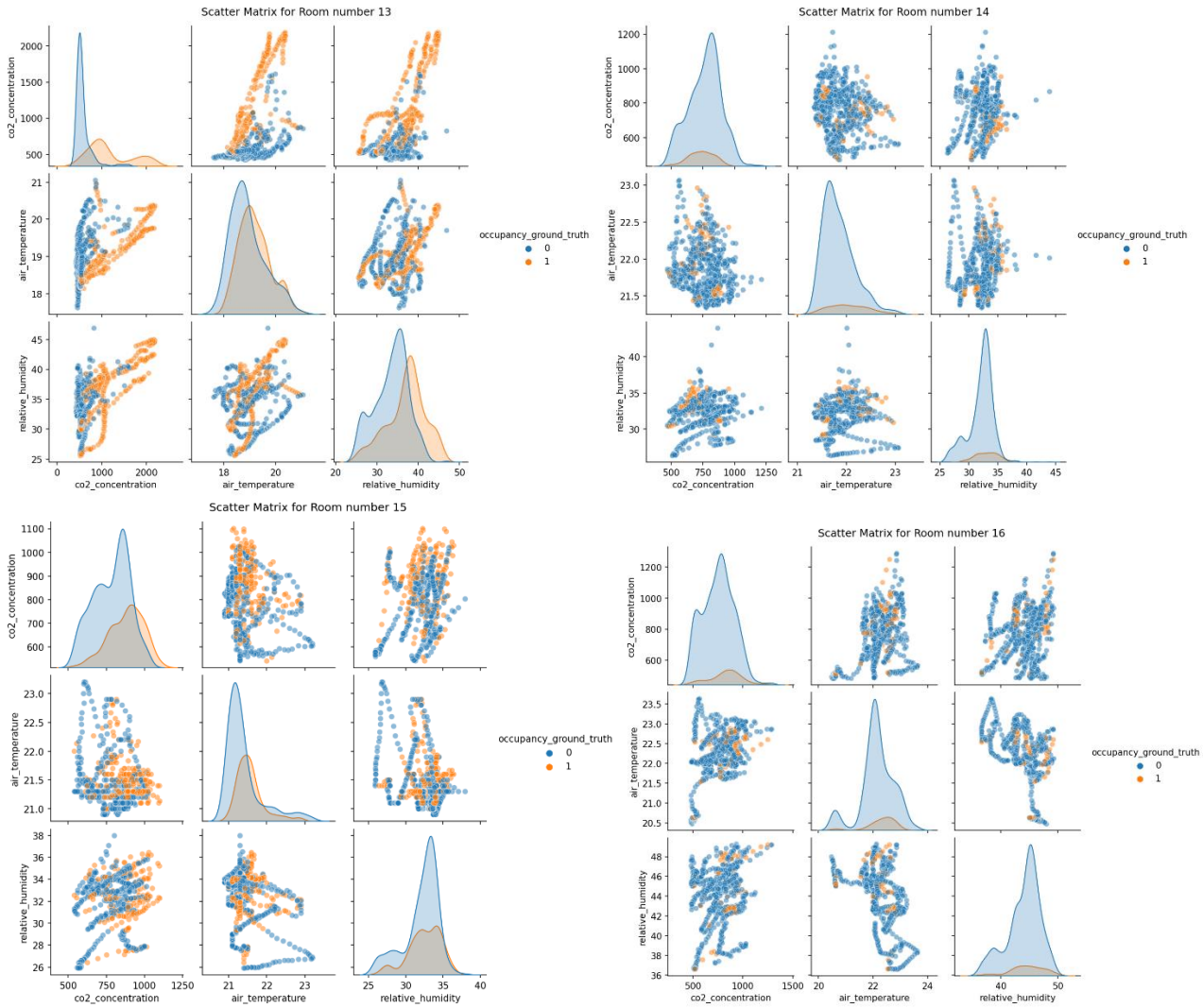

Figure 15: Apartment number 5.

Reported occupancy ground truth and measured CO_2 concentration sorted based on apartment (Dataset 1)

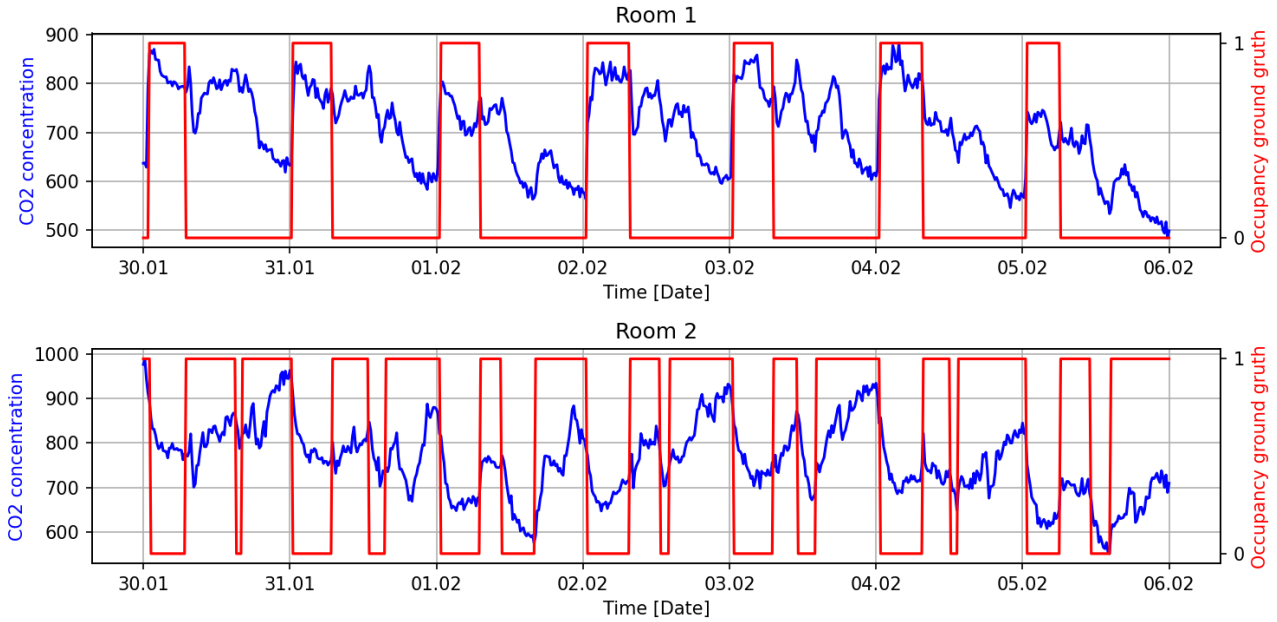

Figure 16: Apartment number 1.

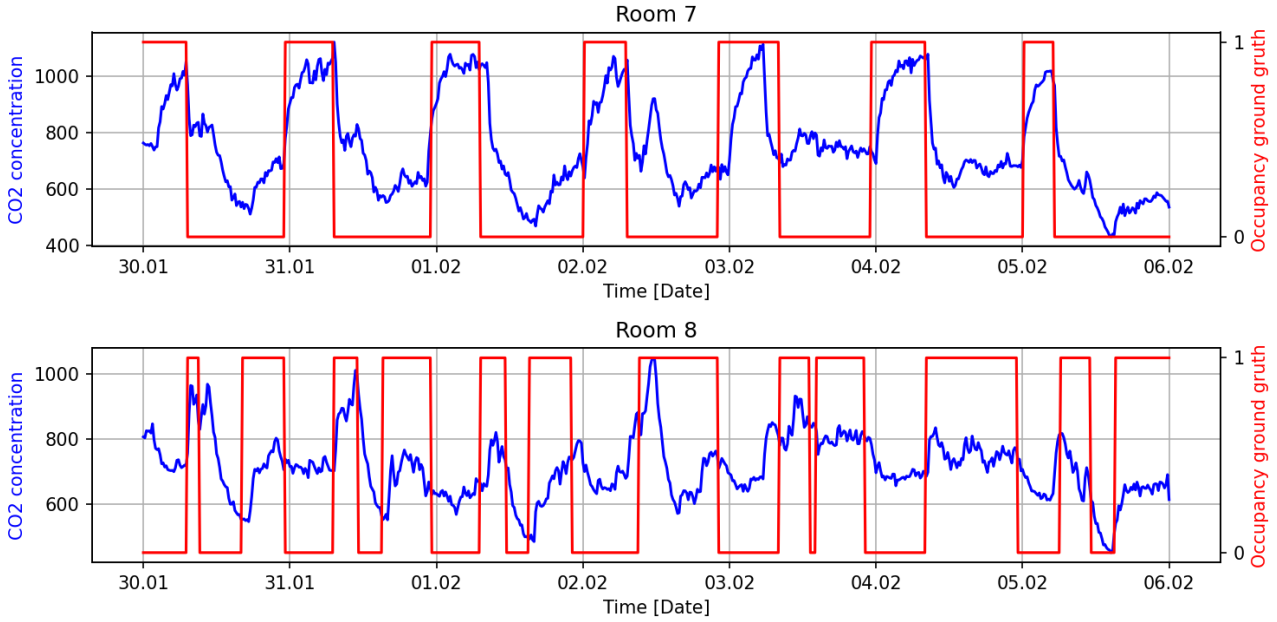

Figure 17: Apartment number 3.

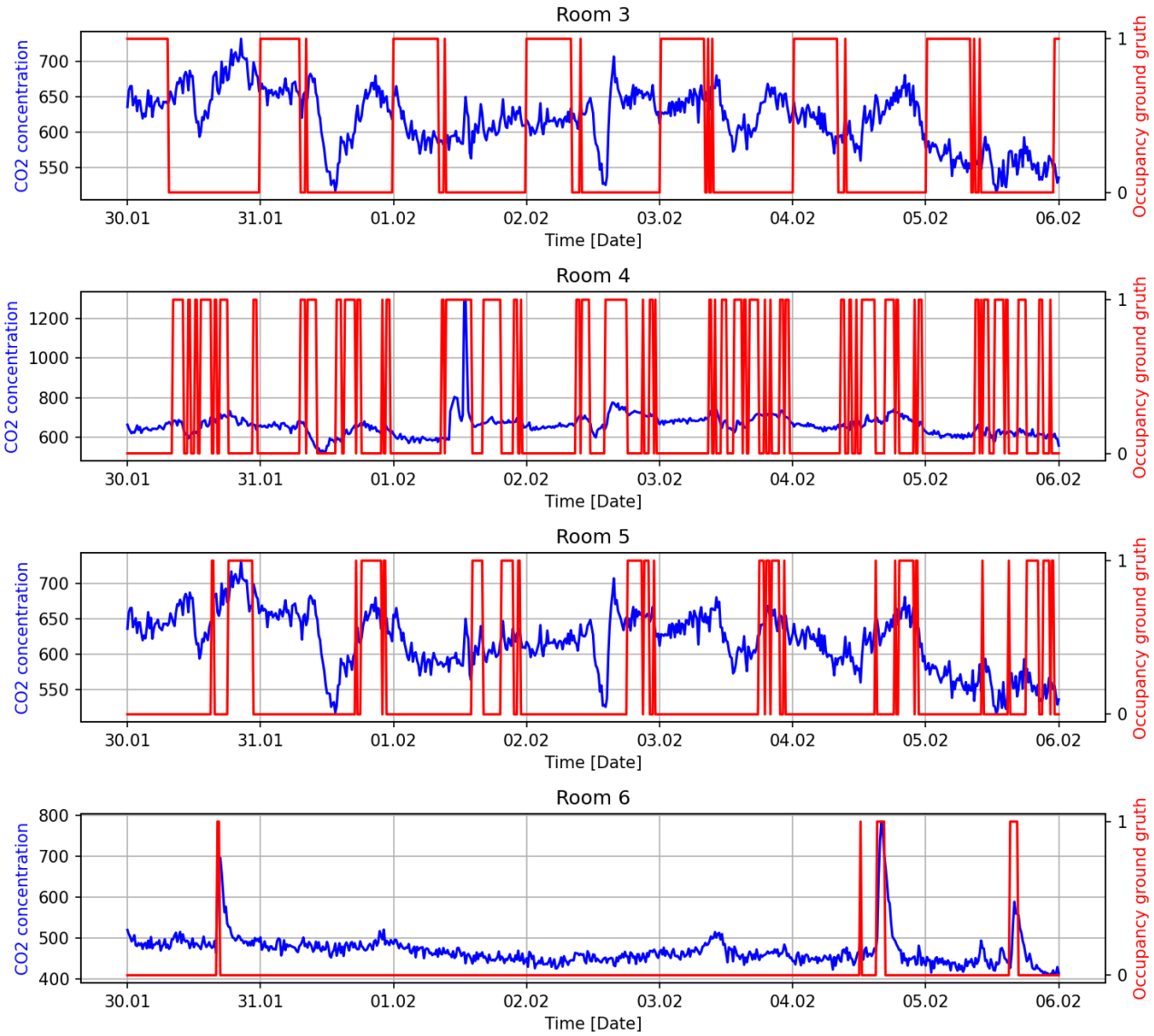

Figure 18: Apartment number 2.

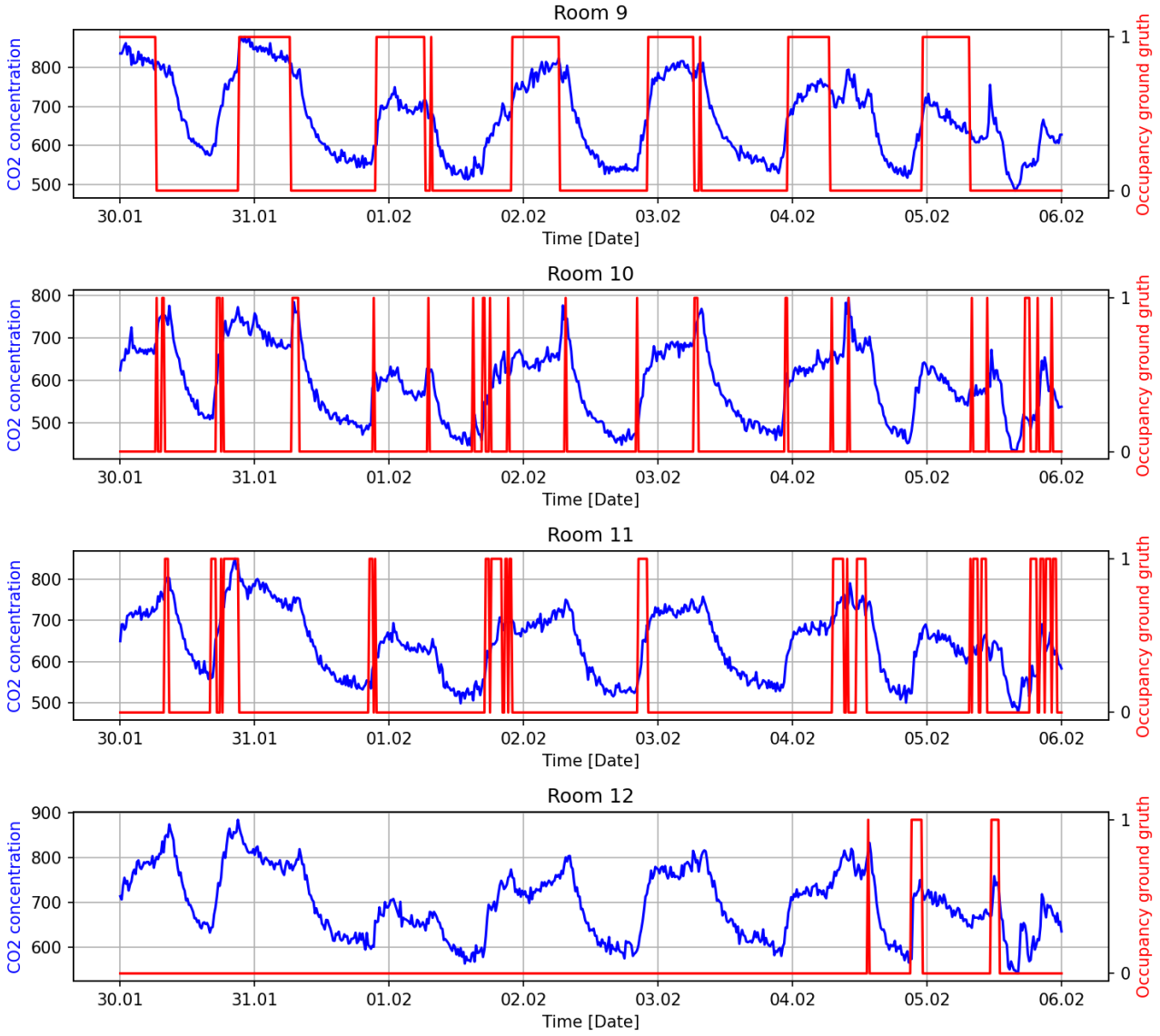

Figure 19: Apartment number 4.

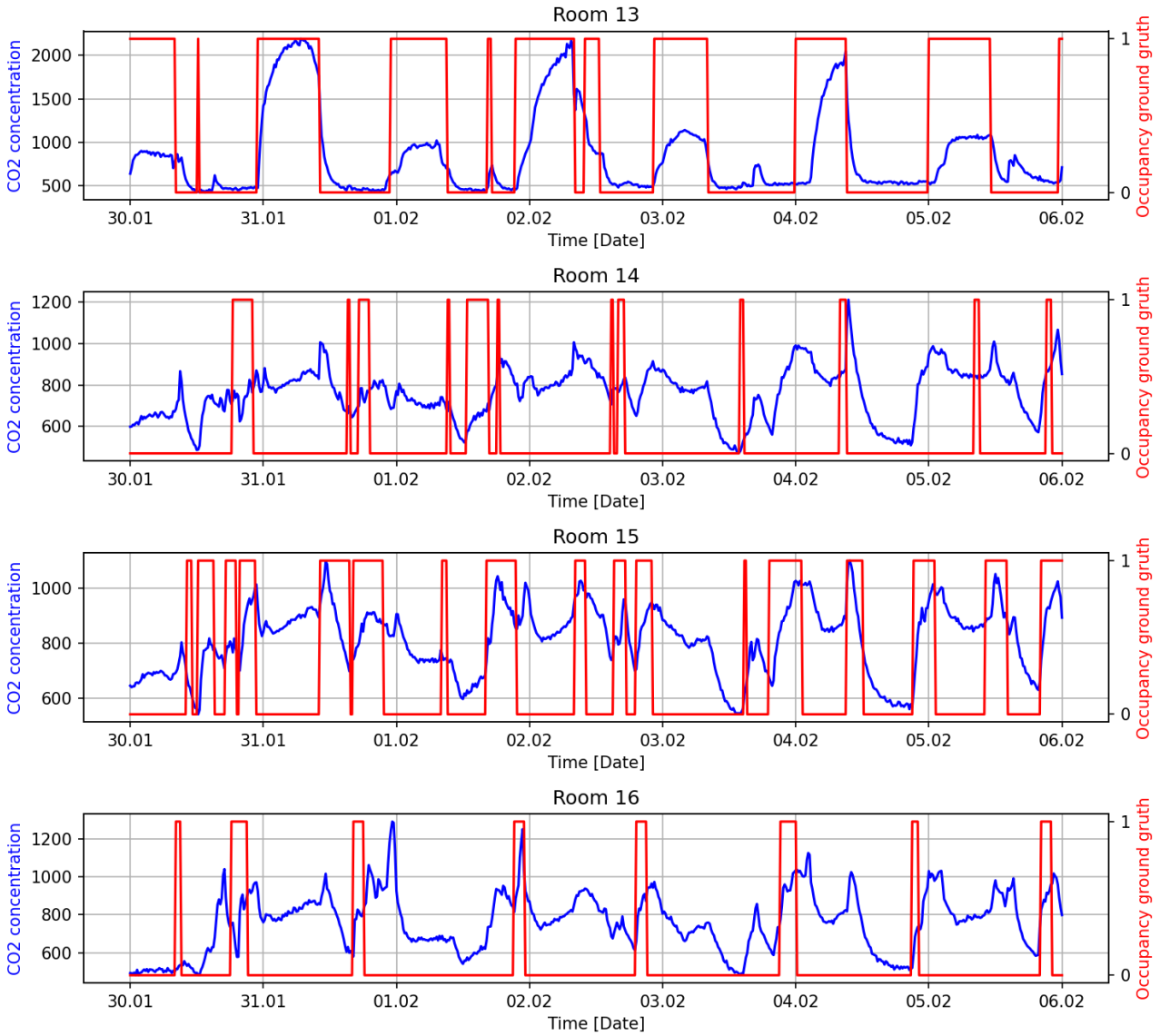

Figure 20: Apartment number 5.

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