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The Indoor Air Quality in a Shared Students Kitchen: Pre and Post refurbishment Measurements

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Abstract
Indoor air quality and wellbeing are basic features in buildings' design criteria. Human behaviour and activities can be very unpredictable to intercept with the appropriate action by the buildings technical systems. This is especially true in shared accommodation in zones such as kitchens. In this study, a shared kitchen in a students' building was monitored to plan refurbishment. That included the particulate matter; CO_2; CH_2O; VOC; and air temperature and humidity. The same quantities were measured post-refurbishment using same device deployed at same location. The refurbishment included replacement of gas cookers by modern electrical cookers; appliances replacement with highest available energy class; kitchen furniture and visual quality; and greenery houseplant ventilator. The results show a comparison and analyses of the measured quantities pre and post refurbishment.

Keywords Indoor Air Quality; Kitchen pollutants; Kitchen Ventilation; Monitoring

1.0 Introduction
The best mitigation method for airborne pollutants is to remove the pollutant source. However, cooking is a common household activity where source removal is often impossible (1). According to the UK Building Regulations Part F (2), kitchen intermittent ventilation rates are 30 l/s extracted adjacent to hob or 60 l/s from elsewhere. This can be reduced to 13 l/s for a continuous mode of ventilation. Kitchen pollutants are typically combustion products when gas cookers are used. These include complete combustion products such as: carbon dioxide (CO_2); water vapour; and nitrogen oxides (e.g. NO_2). The incomplete combustion products, the more hazardous pollutants, are carbon monoxide (CO) and formaldehyde (CH_2O). The particulate matter (PM) in the air are also resultant of the kitchen activities especially cooking. As stipulated, the sizes are of particular importance in the impact on human health, most commonly $PM_{2.5}$ (Diameter up to 2.5 µm); and PM_{10} (Diameter up to 10 µm). Additionally, the Volatile Organic Compounds (VOCs) are also common domestic pollutants that are emitted from household cleaning products and construction materials. Methods are needed to assess the impact of cooking, smoking and domestic activities as well as ventilation behaviour in order to fully understand the impact of energy efficiency refurbishment (3).

Saha et al. (4) carried out air quality measurements in different hostels' kitchens to investigate the spread of pollutants. They showed that the pollutants spread around the cooker range hood, particularly in the breathing zone of the cook. Singer et al. (5) conducted measurements of combustion pollutants from gas cookers in 9 homes. This included CO_2; CO; NO; NO_2; and particulate matter. They stated that awareness of natural gas cookers as source of pollutants need to be increased. In addition, further recommendations were given for range hood sizing that a minimum of 95 l/s airflow need to be included in buildings standards. Furthermore, they stated that the hood dimensions need to fully cover the cooktop front burners, and to encourage the cooking on the cooktop back burners. Zhou et al. (6) studied pollutants generated from cooking using experimental and numerical techniques. This was for a case study in a residence applying the so-called push-pull ventilation in the cooking area. This ventilation is by supplying air from slots around the gas stove to create air curtain and allow the range hood to effectively pull/exhaust the cooking fumes. They measured and simulated, subject to that system, the CO_2 concentration in the breathing zone of the occupant carrying out the cooking activity. Silva et al. (7) investigated in two stages the IAQ of two blocks of flats, post refurbishment. The first stage was using a questionnaire and the second by measurements of CO_2 concentration. The questionnaire was related to the Sick Building Syndrome (SBS), thermal comfort, and sensation of pollutants by odour, and noise level associated with the ventilation system. The study showed that 64% of occupants confirmed SBS symptoms that disappeared once they leave the buildings. Further, 88% of respondents stated that they typically open the windows especially after cooking. Gubb et al. (8) studied the use of houseplants species to improve the IAQ by assimilating CO_2 and increasing the RH%. These two quantities create human health issues when increased and decreased, respectively. The results showed that most of the investigated species had little potential to reduce CO_2 concentration under the typical indoor lighting levels. The best CO_2 assimilating plants also found to be the best in raising the RH%. The final conclusion from that study was that increasing the indoor light to 300 μmol/m^2s has a significant impact on houseplant assimilation of CO_2 and increase of RH%. Turner et al. (9) introduced a combined energy and IAQ assessment of benefit. They concisely defined the commissioning process of a new or a retrofit system with a three principal elements: metrics; diagnostics; and norms. They manifested that, for buildings there are two broad performance metrics of interest such as energy use and IAQ. The diagnostics can be in form of short-term measurements or more complex measurements of suite of indoor concentrations of pollutants. Whilst a metric quantified by diagnostics does not indicate good or bad, the norms defined by standards will refer to the expected level of performance. The method for the combined assessment consisted of modelling the energy and airflows; determining indoor pollutants' concentration; and finally monetization of energy and IAQ benefits and costs. This was using a measure for overall disease burden for a person breathing pollutants to estimate costs due to IAQ. This is the so-called disability-adjustment-life-years (DALY) per person per year. The metric was the net present value of combined energy and IAQ benefits to occupiers and against commissioning costs decision.

In this study, a shared kitchen in a students' accommodation building was surveyed and monitored to evaluate the IAQ. This was carried out for several months pre and post the refurbishment interventions. The monitored quantities included particulate matter and CO_2 plus other indoor pollutants. The same quantities were also measured post-refurbishment using the same device deployed exactly at the same location. The pre and post refurbishment monitoring is aimed at planning, evaluating potential refurbishment measures and finally quantifying their real impact. This experimental setup is a part of larger setup that involved refurbishment measures for whole building. The refurbishment interventions, for the kitchen, included replacement of gas cookers (which represents an elimination of pollutant source) by highest energy-class electrical cookers; appliances replacement with highest available energy-class; kitchen furniture and visual quality by proper LED lighting; and a houseplant unit with a circulation fan. The study approach is focused on energy-efficiency and IAQ metrics, carrying out diagnostics and comparing results against the standard norms. The following sections present the details of the methods with description of the case study and experimental setup, and finally show the monitoring results with analysis and discussion.

2.0 Materials and Methods

2.1 Case study

This study is part of the ReCO2ST H2020 EU project (10). ReCO2ST is an Innovation Action project to develop a residential retrofit assessment platform and demonstrations for near zero energy building criterion (NZEB) and reduction in CO_2 emissions with optimum cost, health, comfort and environmental quality. The project aims to develop a comprehensive, accurate and accessible refurbishment assessment process, to design a method for accurate refurbishment planning, reducing the time, cost and complexity of the process and to deploy an integrated Retrofit-Kit that will achieve NZEB refurbishment in a wide variety of refurbishment scenarios and occupant behaviours. ReCO2ST has four demonstration buildings in Denmark, Switzerland, Spain and the UK.

The UK building is a student accommodation building at the campus of the Brunel University London. This is a closed University campus where the building is isolated from vehicle traffic and surrounded by pedestrian walkway with bushes and other natural greenery in landscape. During the refurbishment, the building had container offices, materials handling and disposals located at the front of the east façade; and minor excavation work was carried out in front of the north façade.

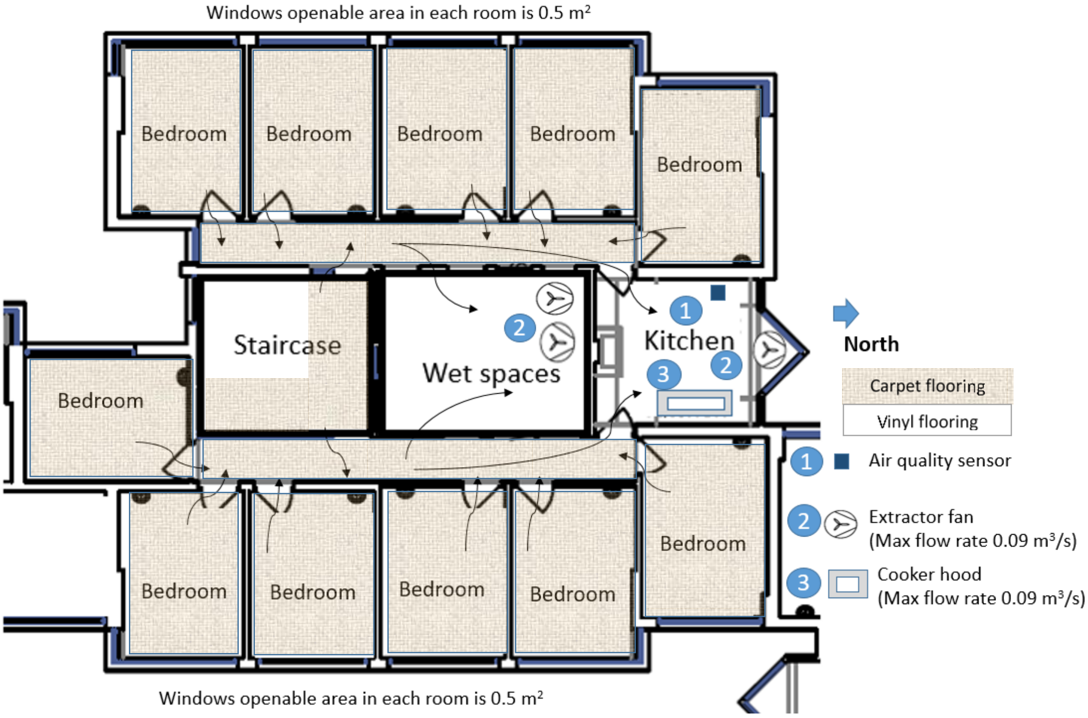

Figure 1 Layout of students' rooms and communal spaces including kitchen

The student accommodation building is a 1960 cavity wall construction with a history of moderate refurbishments. The building is continuously maintained and cleaned by the facilities management according to a regular daily schedule. The ReCO2ST team had the building continuously monitored since November 2018 till current time, and the decided refurbishment interventions were implemented during summer 2019. This included a shared kitchen, the focus of this study, which was fully refurbished to enhance the IAQ. The kitchen is a 14 m^2 floor area shared between eleven students and was equipped with: two double ovens/gas cookers; range hood and window-mounted fan extractor; and two under-table fridges plus other typical kitchen appliances. The sharing pattern is determined by the students themselves, where mostly only 3 students could fit in the kitchen at the same time. Figure 1 shows the floor layout of rooms and kitchen. The figure also illustrate the ventilation scheme which relies on natural ventilation by window/door openings at the bedrooms, wind pressure and the negative pressure created by the exhaust fans at the kitchen and the wet-spaces. The rooms are heated using a hydronic system with central heating gas boiler (located at the basement) that also provides the domestic hot water.

2.2 Monitoring

A range of sensors were deployed around the building to investigate pre and post refurbishment performance. The kitchen was equipped with an off-the-shelf monitor that measures 9 different quantities and instantaneously upload data to a server for live viewing and data logging. The data logging interval was set to 10 min. This setup has started since November 2018 and continues to collect post-refurbishment data. The measured data included the following quantities with the tabulated sensor specifications as shown in Table1.

Measured quantity	Sensor specifications
CO_2 (PPM)	Range: 0-3000ppm; resolution: 1ppm; max consistency error: ±50ppm+5%
CH_2O (mg/m³)	Range:0-1 mg/m³; resolution: 0.001 mg/m³; error: <5%
VOC (PPM)	Range: 0.01-10ppm
Particulate Matter: PM_1, $PM_{2.5}$, PM_{10} (µg/m³)	Range: 0-500 µg/m³; resolution: 0.001 µg/m³; max consistency error: ±10% @100-500 µg/m³
Temperature (°C)	Range: 0-99°C; resolution 0.1°C; max error: ±0.5°C
Humidity, RH (%)	Range: 0-99 %RH ; resolution 0.1 %RH; max error: ±2%RH

Table 1 Measured quantities and sensor specifications

2.3 Refurbishment Planning and execution

The kitchen refurbishment plan was based on eliminating the main pollutants source such as the gas cookers; enhancing the visual quality and kitchen environment by lighting and matching colours; adding houseplants to help to reduce the concentration of pollutants; and changing the intermittent ventilation by the window-mounted extractor fan to a continuous ventilation. The latter could not be implemented due to the tight work schedule. Most of appliances were replaced with an equivalent like-to-like in size and dimension, yet with a higher or at least the same energy class. The significant decision was about the replacement of gas cookers that needed electric board connections and electric wiring for the new 2 x 9 kW electric cookers. The used houseplant unit is accommodated in a transparent enclosure equipped with a small fan to circulate air through the plants, and is also equipped with a dedicated LED light. The unit (according to the supplier) would contribute to reduction in air temperature by 2°C; PM by 18%; and VOCs by 40%, whilst it is expected to evaporate 1 kg/day of moisture to the room air.

2.2 Data analysis

The data from the server were collected, on regular basis, and tabulated by Brunel's researchers. The server also allowed visualisation of data and quick checks for any possibly needed interventions. The collected data was cleaned, filtered and averaged (or summed) for the desired intervals. Python statistical and data analysis packages (11) were used to deduce indicators from the pre and post refurbishment measurements.

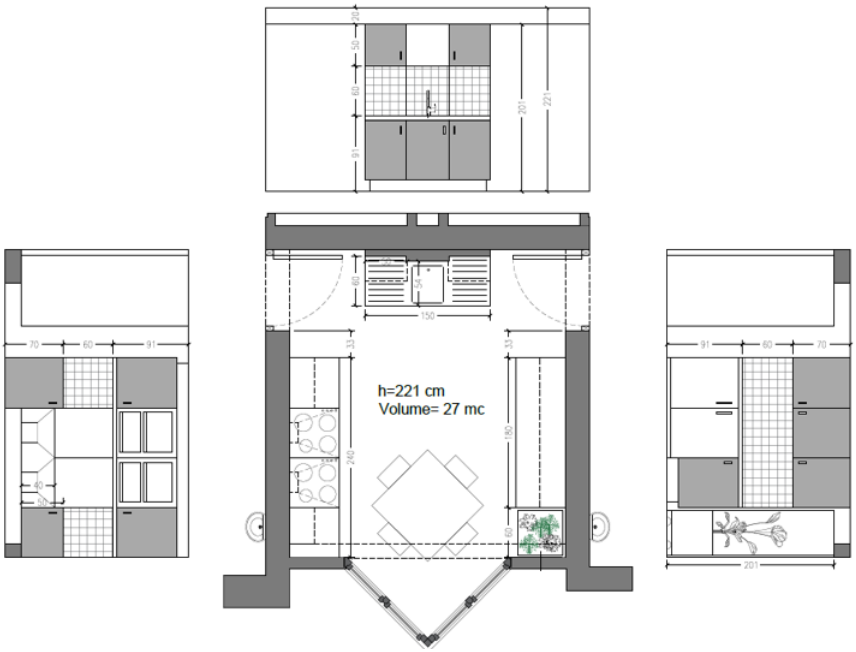

Figure 2 Kitchen Layout after refurbishment

3.0 Results and Discussion

The measured data count since November was 49,111 data records for all measured quantities. This included the pre-refurbishment measurement period from November 2018 to June 2019, whilst the post-refurbishment measurement has only started near to the end of September 2019 and ongoing. The data records were treated to fill any missing data and resample to different intervals. There were only few instances of missing data with the 10 min logging interval. Period masks were then used to create two different samples from 24/11/2018 to 31/01/2019; and from 24/11/2019 to 31/01/2020 (excluding in-between semesters holiday's period), where these periods represent pre and post refurbishment periods, respectively. The use of same period per year is to roughly assume that the students may have had a similar behaviour over same periods and also in relation to the seasonal weather. The two sample counts were about 1600 records of hourly data.

Quantity	**Pre-Refurbishment**				**Post-Refurbishment**			
	Mean	SD	Min	Max	Mean	SD	Min	Max
CO_2 (PPM)	642	383	403	4476	448	81	403	1146
CH_2O (mg/m³)	0.03	0.06	0.00	0.58	0.02	0.12	0.00	3.08
VOC (PPM)	0.58	1.53	0.00	20.8	0.16	0.6	0.00	9.1
PM_1 (µg/m³)	11.1	19.0	0.00	244	10.6	14.7	0.00	138
$PM_{2.5}$ (µg/m³)	18.3	39	0.00	556	17.7	28.7	0.00	355
PM_{10} (µg/m³)	21.8	51	0.00	780	21.7	39	0.00	561
Temperature (°C)	20.9	1.6	16.9	27.5	19.6	1.5	14.9	26.2
Humidity (%)	41.1	6.5	26.3	72.8	44.5	5.4	28	62.3

Table 2 – Sample hourly data stats for pre and post refurbishment

Table 2 shows statistics driven from these two samples. As can be seen, the refurbishment impact is especially clear with the reduction of CO2 level mainly due to the replacement of gas cookers. Other quantities such as the particulate matter and VOC have slightly decreased according to these two samples. This slight decrease can be due to the refurbishment process with new materials, and also by differences in the students' behaviour. Figure 3 shows example of 3 measured quantities from the two data samples but based on the 10 min interval. This includes the CO_2 depicted by the blue-dash-line curve with the axis numeric values on the right. As can be seen, the level of CO_2 varies between 400 PPM (outdoor concentration) to slightly under 3500 and 1000 for the pre and post refurbishment samples, respectively. The formaldehyde (CH_2O), is depicted with the grey-line curve on the left axis with values converted from mg/m³ to µg/m³. The levels of the two samples and also shown on the figure were almost in similar level for both pre and post refurbishment. Although, there is no gas combustion anymore post refurbishment, this can be related to different cooking behaviour and other possible activities. The particulate matter, represented in this figure by the $PM_{2.5}$, is depicted by the red-dotted-line curve with values on the left axis. As can be seen, the particulate matter varies from 0 to under 1000 µg/m³, with very minor change with the post-refurbishment data. The particulate matter levels post-refurbishment as mentioned above can be due to differences in occupants' behaviour. The measured quantities over the two periods also indicate late night occupancy/cooking at the kitchen zone with no clear relation to weekdays or weekends. This is the case as would be expected with the college age students.

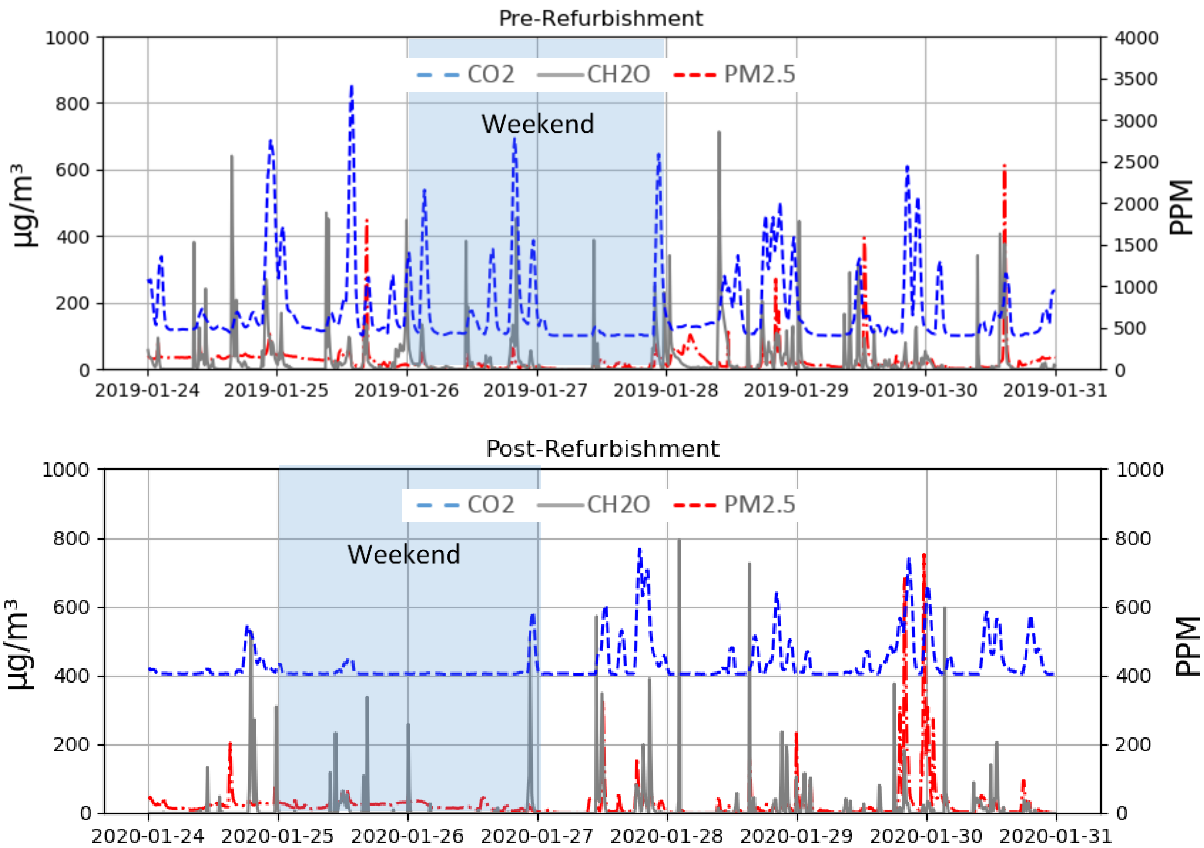

Figure 3 Example pollutants concentration for a week period

Figure 4 and 5 show histograms of the two data samples (hourly means) obtained with automatic class intervals (aka. bins). These figures typically show the values (x-axis) and their frequencies (y-axis) to manifest the distribution of the numeric data. The scale of the histogram axes are indicative, especially for the values on the x-axis. Therefore, for the visibility of the figures only manual scaling was applied to the y-axis to match the scale of pre and post refurbishment figures. The figures show all measured quantities including the different particulate matters levels (µg/m³); VOC and CO_2 (PPM); CH_2O (mg/m³); and air temperature (°C) and humidity (%). The sub-figures on the left are for the pre-refurbishment period, whilst the sub figures on the right are for the post-refurbishment. This completes the descriptive statistics of the data with the aid of Table 2 and visualisation of Figure 3.

Table 3 compares the pre and post refurbishment data to general thresholds values stipulated in different guidelines related to buildings and public health (2,12–14). The two data sets were resampled to obtain 8h, 24h and 30min means over a duration.

Quantity	**Pre-Refurb.**		**Post-Refurb.**		**Threshold**		**Ref.**
	Mean	**SD**	**Mean**	**SD**	**Limit**	**Duration**	
CO_2 (PPM)	693	230	461	62	5000 PPM	8h mean	(14)
CH_2O (mg/m³)	0.034	0.07	0.031	0.144	100 µg/m³	30min mean	(13)
CH_2O (mg/m³)	0.034	0.034	0.031	0.104	2500 µg/m³	8h mean	(14)
VOC (PPM)	0.58	0.85	0.22	0.45	300 µg/m³	8h mean	(2)
PM_1 (µg/m³)	10.9	8.0	9.6	7.2	No stated limits		
$PM_{2.5}$ (µg/m³)	18	14	12	3	25 µg /m³	24h mean	(13)
PM_{10} (µg/m³)	21	17	20	16	50 µg /m³	24h mean	(13)

Table 3 Resampled data indicators in relation to general thresholds fulfilment

As can be seen in Table 3, all of pre and post refurbishment data fulfilled the thresholds. CO_2 threshold was set to 5000ppm to indicate impact on occupants rather than the limit adopted as an indicator for adequate ventilation; however data show that CO2 is lower than 1000ppm too. CH_2O threshold of 100 µg/m³ is set to prevent sensory irritation and this is the reason for the short duration interval of 30min.

Finally it should be noted that, whilst for this research purpose the highest quality IAQ off-the-shelf monitor was used in these measurements, the accuracy and consistency of these available pollutants monitors is undergoing investigations by many field researchers e.g. (15). These devices are very useful for such field deployment in occupied buildings to measure relative impact; however, further verifications are needed for any absolute analysis in regards to IAQ refurbishment measures.

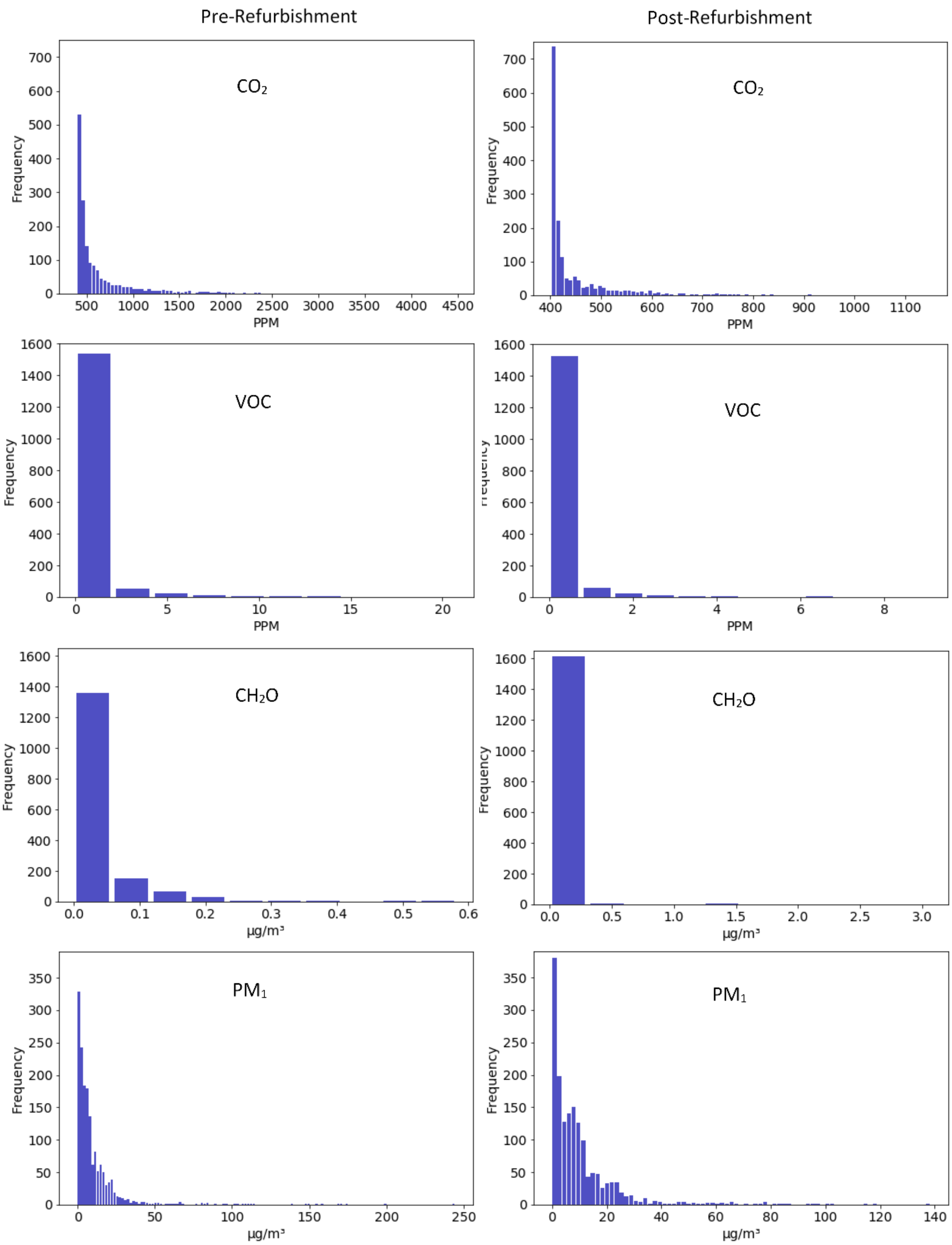

Figure 4 Histograms of measured quantities to indicate values/frequencies

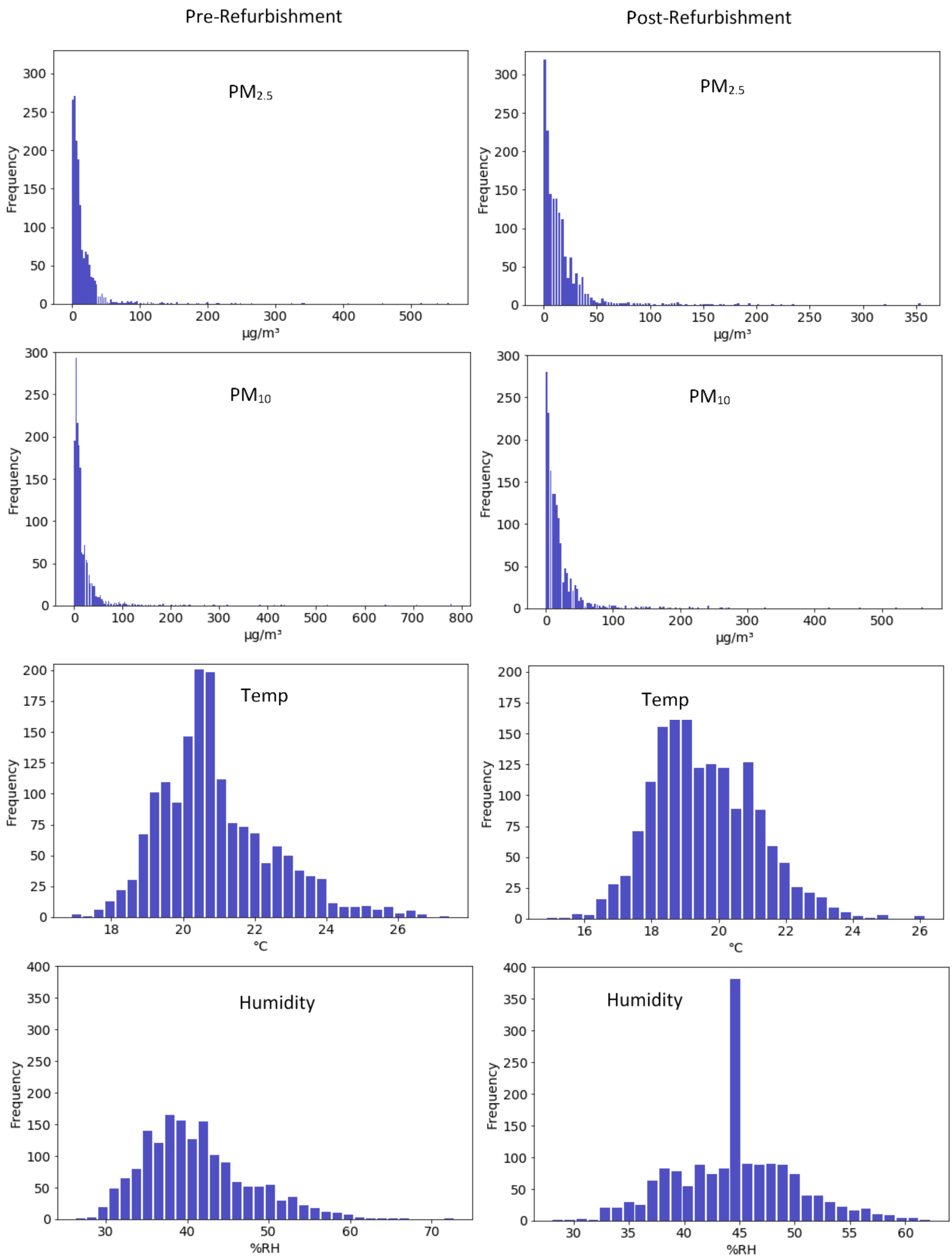

Figure 5 Histograms of measured quantities to indicate values/frequencies

4.0 Conclusions

This study introduced an example of research work that is conducted within the EU ReCO2ST project and aiming at introducing optimum energy and cost efficient solutions with the fulfilment of IEQ constraints, for the refurbishment of residential buildings. This paper reported on the special case of the indoor air quality monitoring in a shared students' kitchen for the London demo-site. Generally, the study approach focused on energy-efficiency and IAQ metrics, carried out diagnostics and compared results against the standard norms. The diagnostics included pre and post refurbishment measurements of particulate matter; CO_2; CH_2O; VOC; and air temperature and humidity. The measured data was resampled to provide descriptive statistics and manifest the impact of the refurbishment decisions. The replacement of the gas cookers by electrical cooker reduced the hourly mean of CO_2 level by nearly 30% and the max instantaneous value by more than 2000 PPM. The particulate matter and VOC levels have slightly decreased post refurbishment, whilst the CH_2O almost remained at the same level. This could be explained by differences in the occupants' behaviour; however, these results indicate favourable impact of the refurbishment measures. The pre and post refurbishment data was also examined against general recognised thresholds from guidelines related to buildings and public health. This analysis showed that pre and post refurbishment values fulfil the thresholds. The critical values were the formaldhyde CH_2O concentration that remained nearly at same pre-refurbishment level even though the gas cookers were eliminated. Future work will continue the analysis of the post-refurbishment data to evaluate the impact of the refurbishment based on a larger data sample and by monetization of energy and IAQ benefits and costs.

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