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Monitoring IAQ and thermal comfort in a conservation area low energy retrofit

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Abstract

EnerPHit and low energy retrofitting projects are increasing in adoption to tackle greenhouse gas emissions target in the United Kingdom. While good energy reductions can be achieved, there is a growing concerned of overheating in these low energy projects with high levels of insulation and airtightness.

The aim of this study was to evaluate the thermal comfort and Indoor Air Quality (IAQ) of a low energy dwelling in London based on EnerPHit principles to reduce energy consumption.

This project concerns an 1860’s Victorian terrace house situated within a conservation area in Kentish Town North London. The design approach was to radically reduce its heating demand while using ecological materials that are moisture open. It was also important to hold onto the original features inside and out that define this house’s character.

The approach chosen to monitor IAQ and thermal comfort was based on monitoring the following indoor hygrothermal conditions: internal air temperature, relative humidity (RH) and CO_2 concentration. Sensors were placed in every room of the dwelling for temperature and relative humidity. CO_2 concentration was measured in the lounge and bedroom 2.

Low energy retrofits can be achieved in conservation areas but more importantly, indoor temperatures in the property can be maintain steadily between 19–20 degrees centigrade, while relative humidity will be comfortably in between the range of 40 % and 70 %, with CO_2 concentration levels well below the 1000 ppm readings as required for good air exchange and healthy IAQ.

Keywords: indoor air quality; EnerPHit; retrofit; temperature; relative humidity; CO_2 concentration

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1. Introduction

Historic buildings represent over 25 % of all building in Europe [1], creating a challenge to achieve the European targets of 20 % greenhouse gas emission reductions by 2020 in relation to 1990 levels [2]. In relation to the United Kingdom, the UK government adopted even more challenging targets agreeing a carbon emission reduction of 34 % by 2020 and 80 % by 2050 [3]. Considering that the domestic sector in the United Kingdom accounted for 27.7 % of the total energy consumption [4], retrofitting the domestic sector is a high priority and the proliferation of low energy retrofits projects and EnerPHit standard projects have increased in recent years.

The EnerPHit standard is based on the Passivhaus standard developed by the Passivhaus Institut for the application into retrofitting buildings. EnerPHit standard is based on a fabric first approach providing high levels of insulation and airtightness and the use of mechanical ventilation. To achieve EnerPHit standard, the annual heating demand must be under 25 kWh/m^2a^2, while the maximum airtightness is 1 ach and a limiting primary energy of 120 kWh/m^2a^2 [5]. Concerns regarding overheating of domestic properties following Passivhaus principles have been increasing in the United Kingdom [6].

The aim of this study was to evaluate the thermal comfort and Indoor Air Quality (IAQ) of a low energy dwelling in London based on EnerPHit principles to reduce energy consumption.

2. Case study description

This project concerns an 1860's Victorian terrace house situated within a conservation area in Kentish Town North London of around 120 m^2 treated floor area. Fig. 1(a) shows a view of the entrance to the property.

Our client's brief was to radically reduce its heating demand while using ecological materials that are moisture open. It was also important to hold onto the original features inside and outside that define this house's character.

The rear extension was found to be an amalgamation of several constructions and was in very poor condition. It was decided at feasibility stage to rebuild this completely using a timber structure and wood fibre insulation in order to maximise its efficiency thermally as well as architecturally. The windows of this new element are triple glazed and the cladding is timber.

The main house received loft insulation, blown cellulose 300 mm thick, and glass wool insulation within the suspended ground floor. In rooms where cornices had been removed, internal insulation was applied to the solid brick walls. This was 90 mm wood fibre within either a lime finish or a lining of battens and plaster board. The front room on ground and first floors had some fine decorative cornices and other important features that made thick internal wall insulation not possible. In these areas, 20 mm aerogel on 10 mm boards was fixed to internal walls.

Generally existing sash windows with fine frames and historic glass were preserved and double glazed secondary windows were installed, as shown in Fig. 1(b). Where the windows were in very poor condition, new double glazed airtight sashes were fitted.

The project followed EnerPHit principles with the following design parameters: Heating demand of 42 kWh/m^2a^2, with an airtightness of 2.1 ach and a design overheating frequency of 7.5 % according to EnerPHit design. A gas boiler provides space heating and domestic hot water.

(a) (b)

Fig. 1. (a) Front view of the property; (b) double glazed secondary window.

3. Research methods

The approach chosen to monitor IAQ and thermal comfort was based on monitoring the following indoor hygrothermal conditions: internal air temperature, relative humidity (RH) and CO_2 concentration. Sensors were placed in every room of the dwelling for temperature and relative humidity, as shown in Fig. 2, although sensors placed in bathroom and drying cover were not taken into consideration for this paper as their temperature and relative humidity will not be representative of the average values for the property and this would have affected the results due to the higher temperature and relative humidity readings, which are normal to happen in bathrooms.

The internal air temperature and relative humidity were monitored using a Perfect-Prime temperature and humidity data logger [7], with an accuracy of ±1 °C. Measurements were recorded at one hour interval, this was corroborate with a measurement every 15 minutes showing no statistical differences using the longer interval. At least two sensors containing temperature and relative humidity per floor were used to calculate the values of these variables for each floor are presented in Fig. 2, only the ground floor was using three sensor placed in the kitchen (extension), lounge and corridor.

CO_2 concentration was recorded using a Trotec BZ30 CO_2 air quality data logger [8], with an accuracy of 5 %. Measurements were recorded with a 15 minutes interval between readings. Two sensors were used for CO_2 concentration, one placed in the lounge in the ground floor and the other situated in bedroom 2 in the second floor.

The airtightness of the whole house was improved substantially from around 10 ach to 2.1 ach at 50 Pa. A centralised continuous extract fan was fitted, extracting from wet spaces, including bathrooms and drying cover. The fresh air intake was supplied by natural ventilation.

The study excluded the influence of air velocities due to having a draught free environment, achieved by the airtightness construction and careful design of centralised continuous extract system.

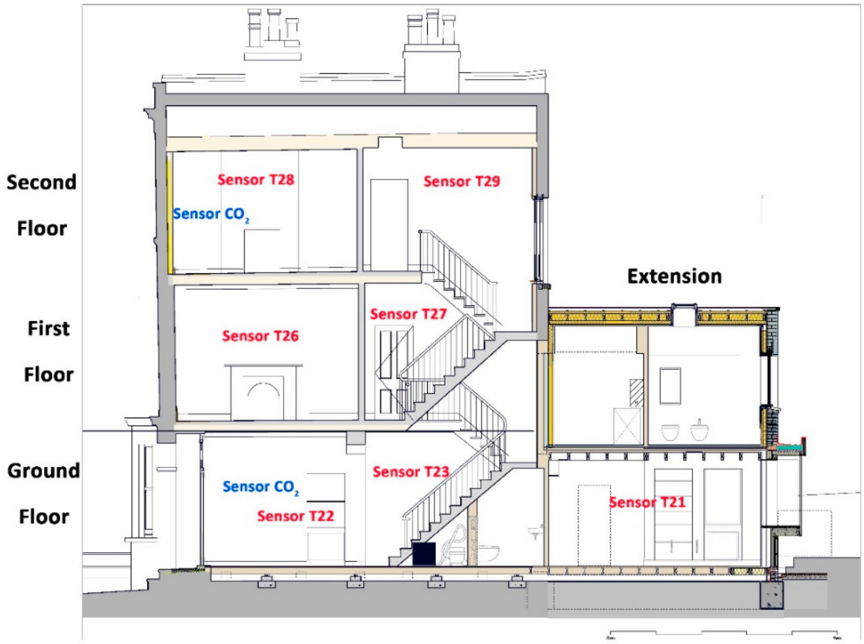


Fig. 2. Sensors location. Temperature and relative humidity in red and CO_2 in blue.

4. Findings

Following a trial and adaptation period for the monitoring approach, data was collected continuously from all sensors for the period between 1st August 2017 and 28th February 2018. Fig. 3 shows the data collected in the ground floor lounge for the monitoring period as an example and the outdoor conditions according to the closer meteorological weather station.

The monitored heating demand, as extrapolated from the eight monitored months, stands currently at 52.04 kWh/m^2a^2.

Regarding the data analysis for CO_2, temperature and relative humidity, the following process was applied:

- In terms of temperature and relative humidity, data was average for each floor in accordance to the sensor locations presented in Fig. 2;
- CO_2 data was taken directly from the lounge, in the ground floor, and bedroom 2, in the second floor;
- Frequency analysis was performed on all the data for a classification of temperatures in accordance to lower than 16 degrees, higher than 25 degrees and one degree increments between 16 and 25 degrees. As the data was collected during the end of the summer season and most of the winter season, our priority was to identify if the dwelling is keeping its temperature at around 19 degrees;
- Frequency analysis was performed on all the data for a classification of relative humidity in accordance to lower than 30 % RH, higher than 70 % RH and 10 % RH increments between 30 % and 70 % degrees. According to McMullan [9], relative humidity should be kept between 30 % and 70 % to achieve thermal comfort and avoid condensation risks;
- Frequency analysis was performed on all the data for a classification of CO_2 concentration in accordance to lower than 400 ppm, higher than 2000 ppm and 200 ppm increments between concentrations of 400 ppm and 2000 ppm. Typical indoor spaces with good air exchange should not exceed 1000 ppm CO_2 concentration [10];
- Frequency percentages were calculated and plotted into the graphs presented in Fig. 4.

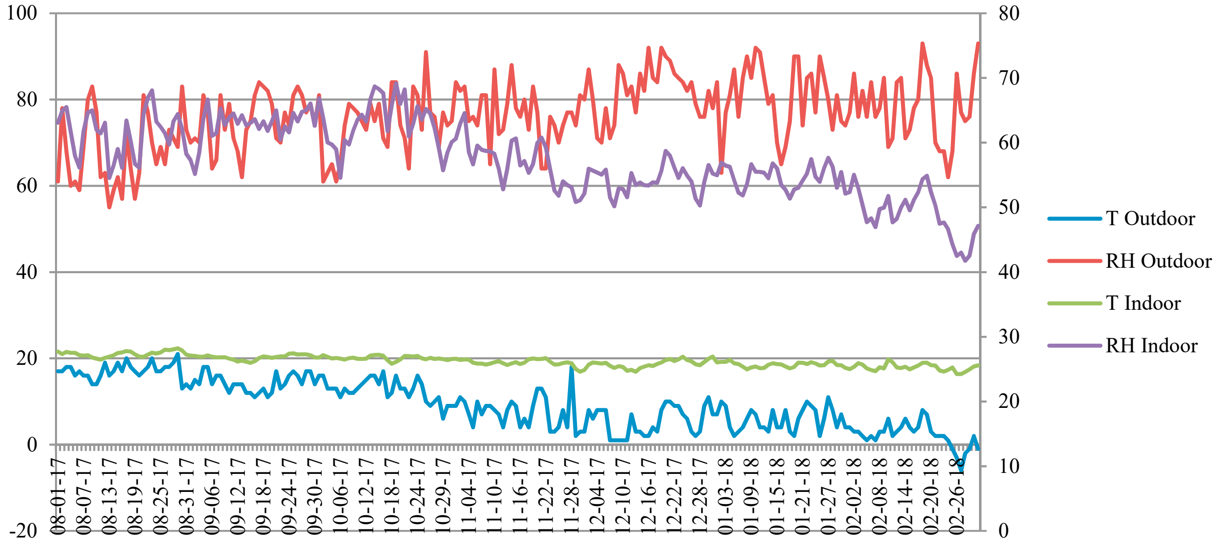
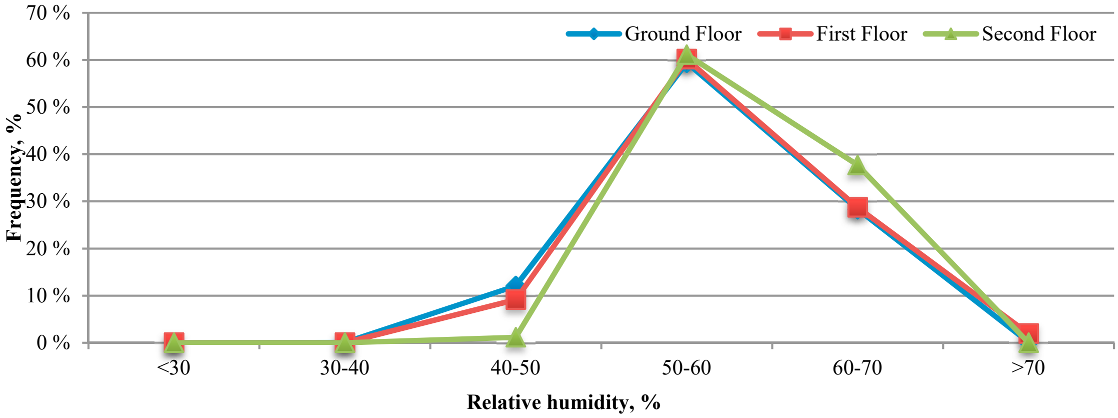
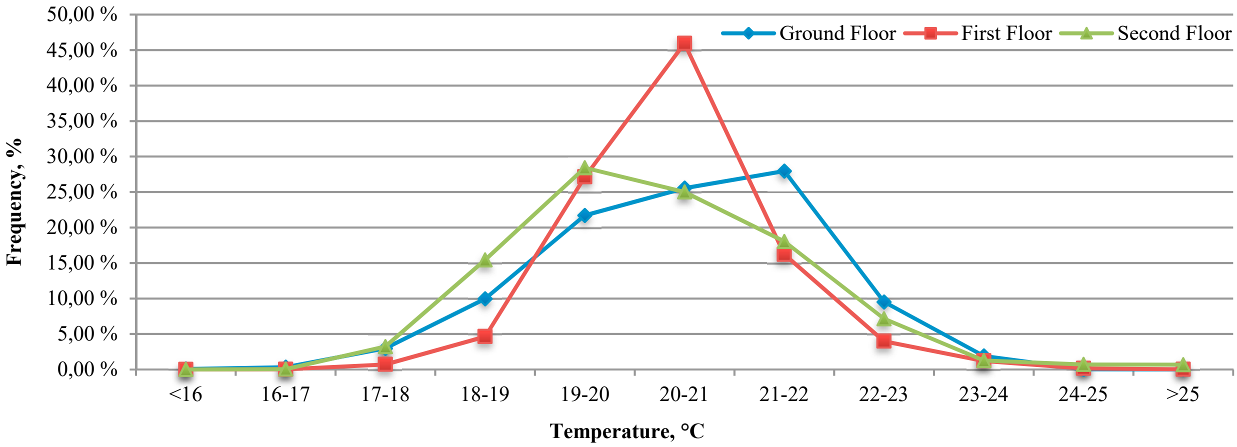


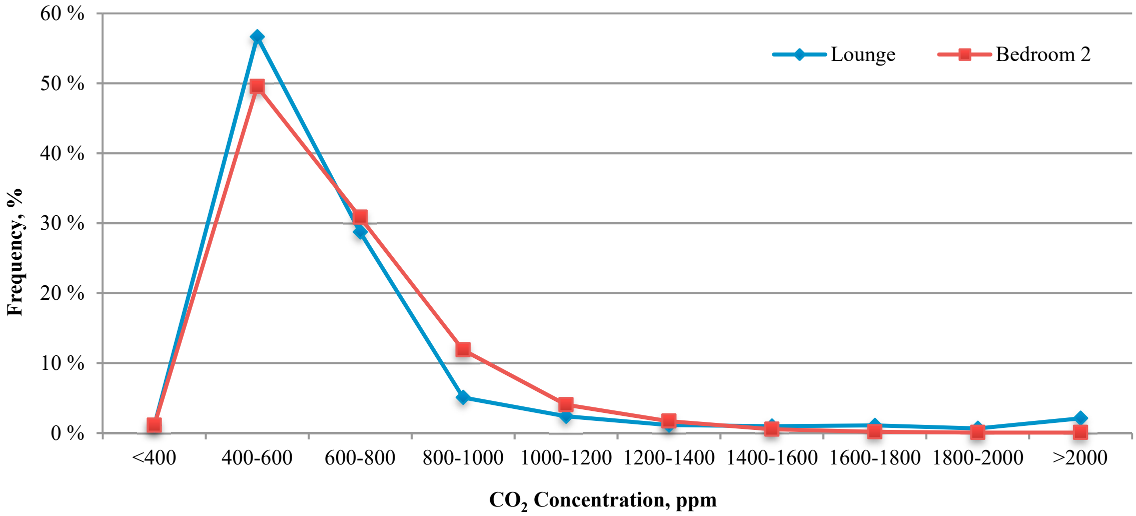
Fig. 3. Temperature and relative humidity in the lounge located in the ground floor and outdoor condition during the monitoring period.



(a)



(b)



(c)

Fig. 4. (a) Temperature frequency data; (b) relative humidity frequency data for all floors; (c) CO_2 concentration frequency for lounge and bedroom 2.

5. Discussion

Fig. 3 provides a graphical view showing how temperatures were kept quiet closely to the design temperature of 19 degrees centigrade and even during August and the end of the summer; temperatures were not higher than 23 degrees centigrade regardless of the outdoor temperatures. Relative humidity oscillates mostly between 50 % and 70 % but kept below 70 % values, avoiding any condensation issues associated with higher relative humidity. The heating effect on indoor relative humidity can be appreciated when the outdoor temperature starts to get colder in Fig. 3.

The performance gap for the heating demand between EnerPHit designed and monitored values is in the range of 19.29 %.

5.1. Internal air temperature

As it is shown in Fig. 4, temperatures are very well kept around the 19–21 degrees areas and very much spot on the mean values monitored in 290 households in Leicester [11], showing that the EnerPhit approach can achieve very good and stable temperature levels throughout the year. The following exceptions must be noted:

- Ground floor tends to be higher than any other floor probably due to the open plan distribution incorporating the kitchen and lounge. Taken into consideration the amount of glazing in the ground floor with the access to the garden, this will have an implication in heating a bit more the ground floor of the property;
- The first floor presents a very stable distribution of temperatures mostly between 19 and 22 degree centigrade, with the temperature stability being due to locating the main bedrooms in use in the house;
- The second floor shows a tendency to lower temperatures, which could be due to being the part of the house less in use during most of the day.

5.2. Relative humidity

All the floors are well kept between the comfort zones for relative humidity, as shown in Fig. 4, keeping the values between 30 % and 70 % relative humidity [9]. These values shown than the centralised continuous extract system is performing a good task in releasing to the outside any generation of relative humidity happening in wet spaces to maintain a control environment.

Two known special issues, which may have contributed to the relative humidity in the property, are:

- Drying out due to major flood within the dwelling caused by a burst pipe during the construction period. This caused saturation of a large part of the building fabric. While time was allowed for drying out, it is very likely this process has continued through the monitoring period;
- Remediation to floor due to rising damp from a neighbouring house leaky drains.

5.3. CO_2 concentration

CO_2 concentrations are shown in Fig. 4 and it is very encouraging that the dwelling is able to provide to occupants a healthy environment with CO_2 concentrations below 1000 ppm target [10] for over 91 % of the monitoring period in the lounge and over 93 % for bedroom 2. Such a healthy IAQ is the payback, which should be expected in low energy retrofits. In the case of the lounge in the ground floor, even the open plan configuration connecting to the kitchen is not compromising healthy CO_2 levels.

6. Conclusion

This study shows that low energy retrofit projects in conservation areas can achieve a healthy Indoor Air Quality and successful provision of thermal comfort for the occupants, during summer and winter season. It should be noted that the limitation of this study as only having one project monitored during the end of summer season and winter months and the ideal occupants' behaviour in terms of energy efficiency. Monitoring of the dwelling currently continues and further assessments regarding IAQ and thermal comfort will take place regarding the overheating aspects of thermal comfort in the summer months.

As reported by the authors [12] in a previous project, low energy retrofits can be achieved in conservation areas but more importantly, indoor temperatures in the property can be maintain steadily between 19–20 degrees centigrade, while relative humidity will be comfortably in between the range of 40 % and 70 %, with CO_2 concentration levels well below the 1000 ppm readings as required for good air exchange and healthy IAQ.

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