Post occupancy evaluation of a sports pavilion within an educational establishment

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Post occupancy evaluation of a sports pavilion within an educational establishment

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SUMMARY
The focus of buildings performance is no longer merely the basic functions of providing shelter or safeguarding human lives and property. Concerns relating to indoor environment quality (IEQ) has increasingly been a topic of interest, mainly in terms of occupants' comfort and energy consumption. However, these concerns are not often assessed in educational buildings especially sports venues for reasons unknown. This study presents an evaluation of a sports pavilion at University of Reading. IEQ variables, energy consumption and occupancy patterns have been investigated through *in-situ* measurements which are analysed in comparison with existing benchmark and building energy simulation. The *in-situ* measurements reflect that the IEQ in the pavilion is considered to be generally satisfactory after comparison with benchmarks. The findings also show that the building has good air-tightness hence high-energy retention. The building was modelled using Integrated Environmental Solutions (IES), a building simulation software. The model verified against metered energy consumption showed a 1.6% deviation. The paper also discussed relevant recommendations to maintain good IEQ and energy efficiency.

KEYWORDS
Indoor environmental quality (IEQ), energy consumption, educational sports venue, building energy simulation

1 INTRODUCTION

It is reported that the final energy consumption for 28 member states in European Union was about 1.1 million ktoe, for which the building sector contributed 39% of its total. As a result, the building sector is fundamental to the wider energy consumption. UK's energy consumption was approximately 200 million tonnes (EUROSTAT, 2015). As of 2012 consumption values, it was estimated that among categories in the non-residential sector in UK, educational buildings contribute 15% to the total energy consumption whereas sports facilities contributed 11% (Laustsen *et al.*, 2011). In order to achieve energy consumption reduction in buildings and good indoor environment, building design and operation are regarded to be the most significant factors (Olesen, 2012). This implies the indivisible relationship between indoor environmental quality (IEQ) and energy consumption. Therefore, more and more people are interested in understanding the impact of IEQ in buildings. A lot of existing literature has discussed IEQ and energy efficiency for commercial and residential buildings with fixed operation hours (Ncube & Riffat, 2012; Pistore *et al.*, 2015) However, there is less research output on studies relevant to educational sports building with irregular operations hours and occupancy. Various parameters of IEQ and its relationship with energy consumption of an educational sports building are discussed.

IEQ is not only about thermal comfort but also different parameters like indoor air quality, visual comfort and acoustics comfort. All of these parameters interact with each other to influence the overall indoor comfort and building energy consumption (Catalina & Iordache, 2012). As IEQ directly affects energy consumption, it can be regarded as supplementary information on building energy performance evaluation (ISO 13790, 2008). Dascalaki et al. (2009) suggested that good IEQ can effectively enhance working conditions and reduce complaints from occupants. Wong et al. (2009) also emphasized the significant connection between respiratory health and environmental quality. When it comes to educational building, high environmental quality can significantly improve occupants' learning performance and a lot of previous studies had been undertaken to investigate their relationship in buildings at educational institutions of different tier including kindergarten, primary school, secondary school and university (Zaki et al., 2017). These studies were mainly based on classrooms with consistent occupancy patterns. However, a lot of educational buildings are of other uses with irregular occupancy patterns. These include sports buildings like gymnasiums and pavilions. The existing literatures for sports building, which mostly involve special operational profiles and requirements, are minimal (Tsoka, 2015).

According to Ward et al. (2008), the UK education and education-related services has one of the fastest-growing energy consumption trend, in which higher education (HE) institutes has a steady increase of students in the previous decade, resulting in a large expansion in its scale and scope. Hence, an increase in energy consumption and CO_2 emission is inevitable. Therefore, it is worth understanding the complicated relationship between IEQ and energy consumption in an educational sports building.

In today's design of buildings, energy use cannot be considered an isolation of their IEQ due to its constant interaction (Pistore et al., 2015). Thus, the initial design provides major implications for the energy demand of the building (Catalina & Iordache, 2012), which suggests that it is important to also consider energy consumption factors including IEQ during the design stage. The aim of this ongoing studies is to investigate (through *in-situ* experimental measurements and building simulation) design implications on energy trends and IEQ parameters of a sports venue.

2 METHODS

The case building for this study is the Sports Pavilion located at the Whiteknights Campus of University of Reading in South England. The building is a single-storey building constructed with dense blockwork wall with metallic panels as external cladding. The total floor area is approximately 671.5m^2. The two major methods used in the study include experimental measurements and building energy simulation. IEQ parameters (including VOC concentrations) and outdoor environment conditions were measured on site. These parameters were compared with existing benchmarks as discussed in CIBSE (2015), BSRIA (2011), HSE (2005) and BS EN 15251 (2007) to determine the operational limits in the pavilion. The simulated results from the building simulation model was verified with the actual annual energy consumption provided by the University.

2.1 Experimental Measurements

In-situ measurements were carried out over two seasons – May-June (Period 1) and October-December (Period 2) in order to understand how seasonal changes would influence the indoor environment of the Sports Pavilion. This reflected the air-tightness of the pavilion as well as the effectiveness of the heating system which started operating from late October.

The IEQ parameters were measured using various sensors: Temperature and relative humidity (RH) were measured internally and externally with Lascar USB Data Sensor at 5-minute intervals. The sensors were placed at a height of 1.8m from floor level to depict parsons standing height and to avoid unexpected influence caused by occupancy activities. Illuminance and noise levels were measured using a 4 in 1 multi-function environmental meter. Illuminance measurements (five datasets) were conducted from each measurement location in several rooms. Noise level were assessed in rooms along the A/C room to investigate the potential effect of noise pollution on the rooms nearby. HOBO Occupancy/Light data loggers were used to monitor occupancy patterns of each rooms. The logger was placed at a height of 1.8m in rooms and on the heavy traffic doors to ensure that the opening and closing of doors were recorded. This allowed for occupancy patterns to be detected. The CO_2 concentration was measured using the HOBO MX CO_2 Logger at 5-minute intervals. From the results, the ventilation rate were calculated using the decay method as discussed by Essah (2009). Three types of Volatile Organic Compounds (VOCs): – acetaldehyde, isobutylene and toluene and were measured using TSI Q-Trak 7575-X an Indoor Air Quality Monitor together with a 986 probe which also monitors VOCs. Each VOC was measured for 30 seconds in each location measured. All of the collected data was compared with existing benchmark and standards to determine IEQ of the Sports Pavilion. In this paper not all the results collated are presented. The locations of sensors are illustrated in Figure 1.

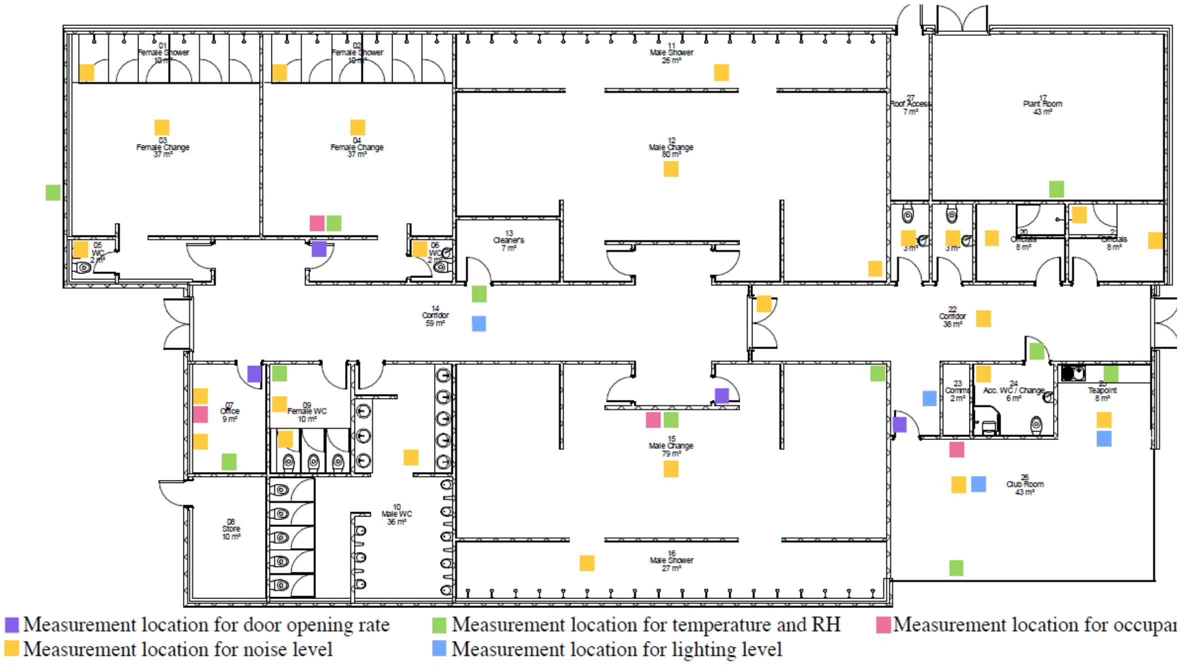
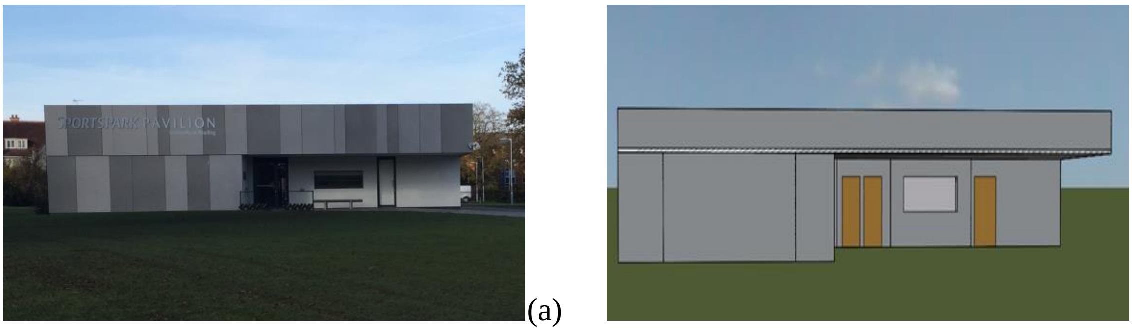


Figure 1. sensor installation location for respective measurements

2.2 Building Energy Simulations

The Virtual Environment of Integrated Environmental Solution (IES), a building energy simulation software was used for the building energy simulation. A detailed IES model was developed with Model-It (an IES interphase) with floor plans provided by University. The model evaluated the IEQ performance of the Sports Pavilion based on its location, orientation, building materials etc. *In-situ* measurement data were used to create heating, lighting and occupancy profiles. Energy consumption of a year in the Sports Pavilion was simulated. The simulated data was then compared with the actual energy consumption data provided by the university. Figure 2 shows photo of the Sports Pavilion and the IES model.



(a) (b)

Figure 2. (a) Photo of the Sports Pavilion (b) IES model of the Sports Pavilion

3 RESULTS AND DISCUSSION

3.1 Temperature and Relative Humidity (RH)

The measured results are compared with several benchmarks including CIBSE (2015), BSRIA (2011) and BS EN 15251 (2007) and the summary is as shown in Table 1. During Period 1, the outdoor temperature had considerable fluctuations. The indoor temperature followed the same trend but with less fluctuation. However, they were relatively similar between different rooms. This reflected the influence by the external environment on the indoor condition. As suggested in CIBSE (2015), thermal comfort is unacceptable by 80% of occupants when the indoor temperature exceeds 27˚C during summer. The indoor measured temperature could reach up to as high as 36.5 ˚C, which indicated the issue of overheating.

During Period 2, the indoor temperature had been maintained regardless of the fluctuation of outdoor temperature since the start of heating system operation. Regarding the average temperatures of each room, only the temperature of Female WC falls within the recommended range. All the other rooms were regarded to be 'uncomfortable' when comparing to the suggested range by different benchmark. The changing rooms showed greatest variation from the benchmark recommendations.

Similarly, the indoor RH was observed to be influenced by the external RH. The average indoor RH of all rooms were within the recommended range. However, the range suggested that they were not within the suggested range at all times.

Table 1. Range of measured values for temperature and RH

	Temperature (˚C)			**RH (%)**		
	Measured		**Benchmark**	**Measured**		**Benchmark**
	Outdoor	Indoor	Indoor	Outdoor	Indoor	Indoor
Period 1	75-40.0	16.5-36.5	21-26	0.0-100.0	29.0-79.5	40-70
Period 2	-2.0-27.5	11.0-27.0	19-24	40.5-97.0	17.0-89.0	40-70

Within the University, the major functions of the Sports Pavilion is to provide changing facilities, showers and a club room. With this in mind, the design of the Sports Pavilion has changing rooms and shower areas which occupy more than 50% of floor area.

The temperatures within the two changing rooms were similar during Period 1 (Figure 3a) ranging from 17˚C to 30˚C while during Period 2, it varied from 13˚C to 23˚C. The temperature values were deemed to be 'comfortable' for only 43.5% of time during Period 1. For 37.5% of time, the changing rooms was recorded to be colder than the recommended range and 19% of time were considered to be hotter. Approximately 10% of time temperature values exceeded 27˚C, which is regarded to be thermally unacceptable as suggested by CIBSE (2015). During

Period 2 (Figure 3b), the indoor temperatures in the changing rooms were regarded to be ‘uncomfortable’ for almost the entire measurement period. Temperatures in the male changing rooms did not comply with the recommended range during the whole period while the female changing rooms met the suggested value for only 0.8% of time. It implies that the heating system cannot effectively warm up the changing rooms to a ‘comfortable’ level.

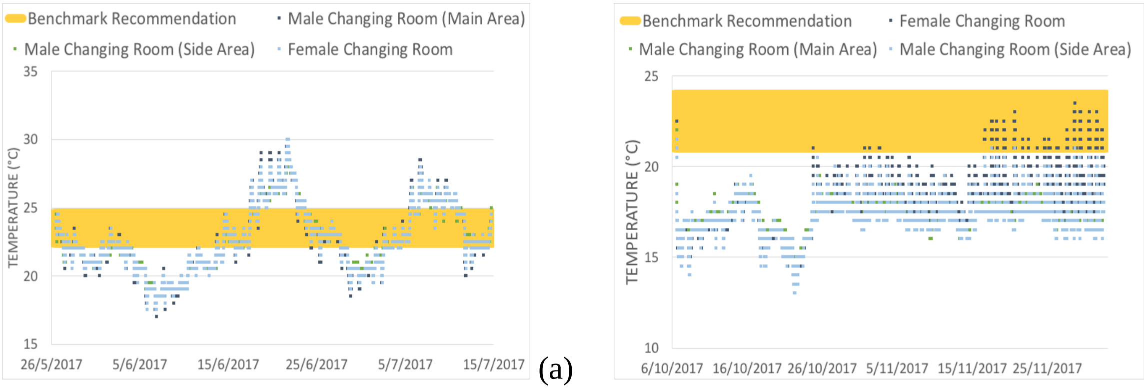


Figure 3. Measured temperature of changing rooms with benchmark recommendation (a) during Period 1 (summer) (b) during Period 2 (winter)

In terms of the RH, the changing rooms had values ranging from 34%-80% with an average of 53.5% during Period 1. Only 2.5% in the Male Changing Room and 2% in the Female Changing Room did not fall within the recommended range during this period. Therefore, the RH during Period 1 were generally deemed to be satisfactory. During Period 2, the RH varied from 23% to 89% with an average of 59.2%. The Male Changing Room had a comfortable RH level for 70% of time and 65% for Female Changing Room. The RH dropped since the heating system started operating. Before that, the RH for the changing rooms were out of the recommended range for 60% of time but only deemed ‘uncomfortable’13 % of the time when heating was on. This reflects the effectiveness of the heating system to maintain a constant indoor RH. This in effect demonstrates that, the RH condition in the changing rooms were generally satisfactory but heating is required to maintain an ideal indoor RH during winter.

3.2 Indoor Air Quality, Visual Comfort and Acoustic Comfort

The CO_2 concentration was measured during Period 2 and then compared with indoor recommended levels (BS EN 152521, 2007). The ventilation rate of the office was calculated using the decay method from the measured CO_2 concentration for over a month. However four periods are considered and analysed and presented in this paper (Figure 4 and Table 2). This implies a great air-tightness of the building. Using the relation by Essah (2009) in Equation 1, where $\boldsymbol{Q}$ (m^3/h) is the volume flow rate, $\boldsymbol{V}$ (m^3) is the volume and $\boldsymbol{t}$ (sec) is the time. From equation 1, the gradient (Q/V) is the air change rate per hour (ach).

$$lnC_t - lnC_o = -\frac{Q}{V}\, t \qquad (1)$$

In terms of volatile organic compounds (VOCs), acetaldehyde, toluene and isobutylene were measured within the building. It must be noted that only background VOCs within the environment were measured using the Q-Trak 7575-X From the result only traces in concentration levels of VOCs were found in most zones. Table 3 illustrates traces measured in the office and the male changing room. The VOCs concentration within the indoor environment was noted to be insignificant, hence on impact on occupants (HSE, 2005;OSHA, 1970) that would not impact the health of occupants.

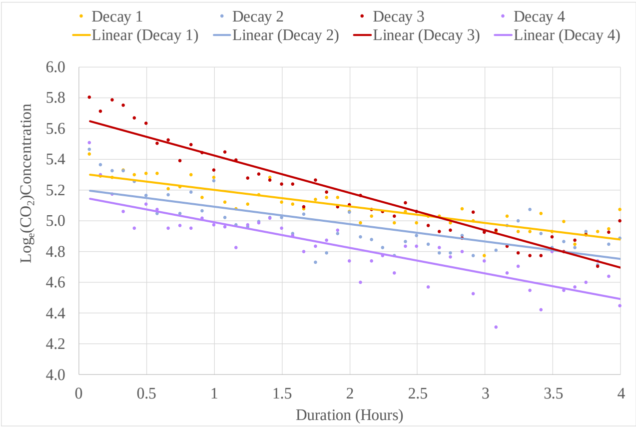


Figure 4. Decays of CO_2 concentration

Table 2. Average ventilation rate

Decay	$y = mx + c$	Q(m^3/h)
1	$y = -0.1079x + 5.3101$	2.43
2	$y = -0.1131x + 5.2053$	2.54
3	$y = -0.2433x + 5.6672$	5.47
4	$y = -0.1665x + 5.1584$	3.75

Table 3. Summary of measured VOCs and benchmark exposure limits

	Office		Right Male Changing Room		Benchmark
VOCs	Average (ppm)	Range(ppm)	Average (ppm)	Range(ppm)	(ppm)
Acetaldehyde	0.02	0.01 – 0.02	0.00	0.00 – 0.00	50 – 200
Toluene	0.03	0.02 – 0.04	0.00	0.00 – 0.00	50 – 200
Isobutylene	0.22	0.14 – 0.37	0.03	0.00 – 0.06	–

The illuminance varied throughout the building nevertheless measured values demonstrates general levels of acceptability in comparison to the benchmark requirements provided by CIBSE (2015), BSRIA (2011) and BS EN 12462-1 (2011) (Figure 5). The measured results showed that the roof lights and glazing had significant influence to the indoor illuminance due to the penetration of daylight, increasing the indoor illuminance by at least approximately 400-600 lux depending on location. When the rooms are supported by only artificial lightings, sufficient illuminance were generally provided. However, some zones within the building did not have adequate illuminance. This included the shower areas, corridor and washrooms. However, it is estimated that the occupants and the operation of the building would not be greatly impacted on since only a small area was affected. Therefore, the illuminance was considered to be within the acceptable range.

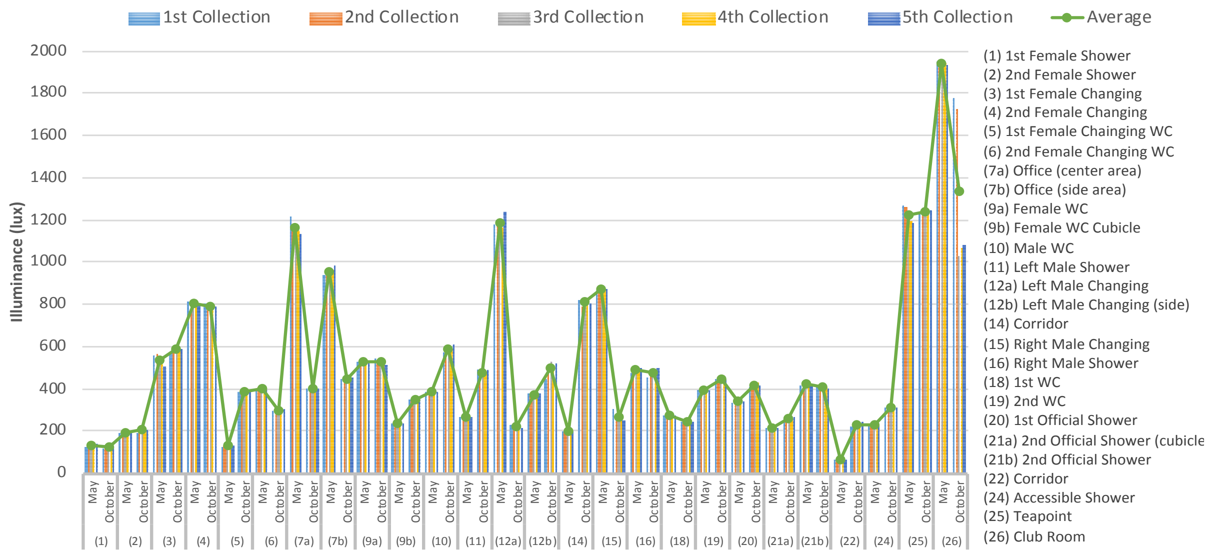


Figure 5. Average measured illuminance of different rooms during May and October

The noise level was measured in 4 locations near to the A/C room so as to investigate whether the operation of the A/C unit would cause noise pollution to the occupants. The average measured noise level was 32dB noted to be within the benchmark requirements as stipulated in BS EN 15251 (2007), CIBSE (2015) and the Department of Education (2015). However, an average of 50dB was recorded at the area right outside the A/C Room, notably this the measured value was still within the suggested range. However, the measurements were performed when the Sports Pavilion was not occupied. It could be estimated that if the Sports Pavilion is occupied, the noise level in this area would possibly exceed the recommended range. The noise level was broadly acceptable.

3.3 Building Energy Simulation

The collated energy consumption of the Sports Pavilion is as shown in Table 4.Though not illustrated the simulation showed similar trends and the total annual energy consumption was 154.6MWh ± 1.6% off the simulation results. The error presented can be attributed to the boundary conditions some of which were assumed due to the lack of experimental data. This included the lack of monitored foot-falls which was estimated based on booking records. The IES model would be used further to identify occupancy patterns and how it influences energy consumption and other IEQ parameters.

Table 4. Summary of simulated and actual natural gas, electricity and total energy consumption

	Natural Gas	**Electricity**	**Total Energy**
Simulated (MWh)	116.6	38.0	154.6
Actual (MWh)	122.8	29.4	152.1
Difference	6.22	8.6	2.5

5 CONCLUSIONS

This paper demonstrates a study which investigates IEQ majorly in terms of occupants' comfort and energy consumption in an educational sports building. The Sports Pavilion at University of Reading, which is an educational sports building with irregular occupancy patterns, was chosen to be the case building. By *in-situ* measurements and building energy simulation, parameters influencing IEQ had been identified and analysed. The results from the measurement have revealed a good air-tightness of the building. This contributes to overheating during summer and excessive RH in changing and showering areas. From the results, as with most buildings, the major improvement required to enhance the IEQ would be increasing the effectiveness of the heating system. This more so evident in the winter months.

The model simulated using the IES software provided findings which were observed to be within limits of error (due to boundary conditions) hence of a 1.6% deviation margin. The simulated model provided options to investigate the effect of varying parameters on energy consumption and IEQ parameters, some of which have been discussed in the context presented. Further studies are ongoing for detailed investigation on the complex relationship between energy consumption and IEQ.

6 REFERENCES

Barbhuiya, S. and Barbhuiya, S. 2013. *Building and Environment*, vol.68 p.1-11
British Standard Institution. 2007. *EN 15251* London; BSI
British Standard Institution. 2011. *EN 12464-1* London; BSI
BSRIA 2011 *Rule of Thumb: Guidelines for building services* (5ed.) BSRIA

Catalina, T. & Iordache, V. 2012. *Building and Environment*, vol.49 pp.129-140
CIBSE. 2015. *Environmental Design CIBSE Guide A*. Suffolk: The Lavenham Press Ltd.
Department for Education 2015. *Building Bulletin 93*
Dascalaki, E., Gaglia, A., Lagoudi, C. & Lagoudi A. 2009. *Energy Build*, vol. 41 pp. 551-560
Essah EA: 2009. *PhD Thesis*, Glasgow Caledonian University, Glasgow, UK.
EUROSTAT. 2015. *Energy, transport and* environment *indicators* (2015 ed.). Luxembourg:Publications Office of the European Union.
Health and Safety Executive. 2005. *EH40/2005 Workplace Exposure Limits*, 2ed. London: Crown Publishing Group
Laustsen, J., Ruyssevelt, P., Staniaszek, D., Strong, D. & Zinett, S. 2011. *Europe's Buildings Under the Microscope*. Brussels: Buildings Performance Institute Europe (BPIE).
Ncube, M. & Riffat, S. 2012. *Building and Environment* vol.53 p.26-33
Occupational Safety and Health Act. 1970.
Pistore, L., Cappelletti, F., Romagnoni P. & Zonta A. 2015. *Energy Procedia*, vol.82, p.519-525
Tsoka, S. 2015. *Energy Procedia*, vol.78, pp.2802-2807
University of Reading. 2014. *New Sports Pavilion for Whiteknights Campus – Have Your Say*. Available from: <https://www.reading.ac.uk/internal/staffportal/news/articles/spsn-557590.aspx> [26th Jan 2018]
Ward, I., Ogbonna, A. & Altan, H. 2008. *Energy Policy*, vol.38, no.8, pp.2939-2949
Wong, S., Lai, L., Ho, D., Chau, K., Lam, C. & Ng, C. 2009. *Habitat International*, vol. 33 pp. 463-471
Zaki, S., Damiati, S., Rijal, H., Hagishima, A. & Razak, A. 2017. *Building and Environment*, vol.122, pp. 294-306