

Evaluation of Indoor Environment System Performance for Airport Buildings

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Abstract: Airport terminals are energy intensive buildings. They are mostly thought to operate on a 24/7 scale and so indoor environment systems run on full schedules and do not have fine control based on detailed passenger flow information. While this assumption of round-the-clock operation may be true for the public areas of the airport building and so opportunity for complete shut-down of HVAC and lighting systems are limited especially in a busy airport terminals, there are many passenger exclusive area within the airport in which occupancy varies strictly with flight schedules. This paper presents the results of indoor environment measurement and flight schedules to identify such opportunities and to implement energy conservation measure in the passenger exclusive areas of the airport building. It also uses building simulation to assess the benefits of such energy saving interventions in terms of comfort, energy and carbon emission savings.

Keywords: Airport Terminal Building, Energy Conservation in Airport Terminal, Flight Schedule, Thermal Comfort

1. Introduction

Airports are major magnets of economic growth and development and because only about 5% of the population of the world has ever flown (2), it is an area with huge capacity for further growth. However, like all human activities, airports have great impact on the environment. These impacts includes water and air pollution, waste generation, noise pollution, extensive use of land resources and in direct relation to this paper, the use of fossil energy which has been identified as a major culprit for climate change (3-5).

Every year about 200 million people transit through UK's airports (6) which has resulted in demands for huge amount of energy and created an equally huge amount of carbon emission. A large airport can consume more energy than a city of 50,000 households; for example, in 2008, UK's largest airport, Heathrow Airport, consumed over 1000 GWh of energy (7) compared to an average of about 20 MWh (8) for UK's dwellings. Therefore, any little energy saving effort in the way airport terminals are built and operated can have tremendous impact.

It was surprising that given the stated importance and uniqueness of the airport terminal buildings, published studies on airport built environment energy performances are

quite few. Galliers and Booth in a publication by Building Services Research and Information Association (BSRIA) carried out a physical and public's perception survey of some six public transport buildings including an airport terminal. The conclusion was that *public transport buildings have a fair way to go in order to provide the ideal environment for the travelling public* (9). Balaras *et al* (2003) analysed, some specific measures aimed at reducing energy use without compromising comfort in Hellenic airports using thermal simulations and collected site data. By exploring various design options, it was concluded that that potential energy savings of 15-35% exist (10). Babu (2008) proffer design alternatives by varying building fabrics and HVAC configuration for Ahmedabad Airport terminal (11). Liu *et al* (2009) used CFD thermal simulations, indoor environment monitoring and thermal comfort surveys based on the PMV at Chengdu Shuangliu International Airport. The result of the study shows that 95.8% of the passengers were satisfied with their thermal environment (12). Griffith *et al* (2003) actually used the earliest form of EnergyPlus (Version 1.0.3) to study the influence of advanced building technologies such as optimised envelope systems and schedules for a proposed Air Rescue and Fire Fighting Administration Building at Teterboro airport and found that the results obtained compare

well with those obtained using DOE-2.1E (13).

This paper discusses the indoor environment systems' comfort performance of a UK airport terminal and compares it with the standard comfort requirement for such spaces using Chartered Institute of Building Services Engineers (CIBSE) standards for indoor temperature, relative humidity and lighting levels (14) and Occupational Safety and Health Administration (OSHA) for indoor CO₂ Level (15). It also analyses the flight schedules to identify the Opportunities for implementing energy conservation strategy such as setbacks and switch offs.

2. Material and Methods

The methods comprise indoor environment system's monitoring and measurement for summer and winter to establish performance characteristics, analysis of flight schedules in summer and winter to identify opportunity for energy conservation measures and airport building computer modelling and simulation to gauge the savings in energy and carbon emission and comfort performance of a propose

energy conservation measures.

2.1. Indoor Environment Monitoring

An indoor site monitoring was conducted for winter period from 26th October to the 2nd November and for summer period 22nd August to 29th August. This site monitoring involves mounting HOBO U12 Data logger and CO₂ sensors for a week to measure temperature, relative humidity, lighting levels and CO₂ levels in four separate areas of the airport.

The places monitored include Baggage Reclaim area, a Duty-Free shop, a Departure Gate, and the Arrival Hall. The reason for the choice of these places was to focus on the airside of the terminal where passenger occupancy varies directly with flight schedules as against the landside where the structure occupancy pattern is complex and difficult to predict. Some pictures of these places are shown in Figure 1A-D; the positions of the sensors are indicated with a red arrow. The more expensive CO₂ sensors have to be hidden from view in some places since the airport is a public place.

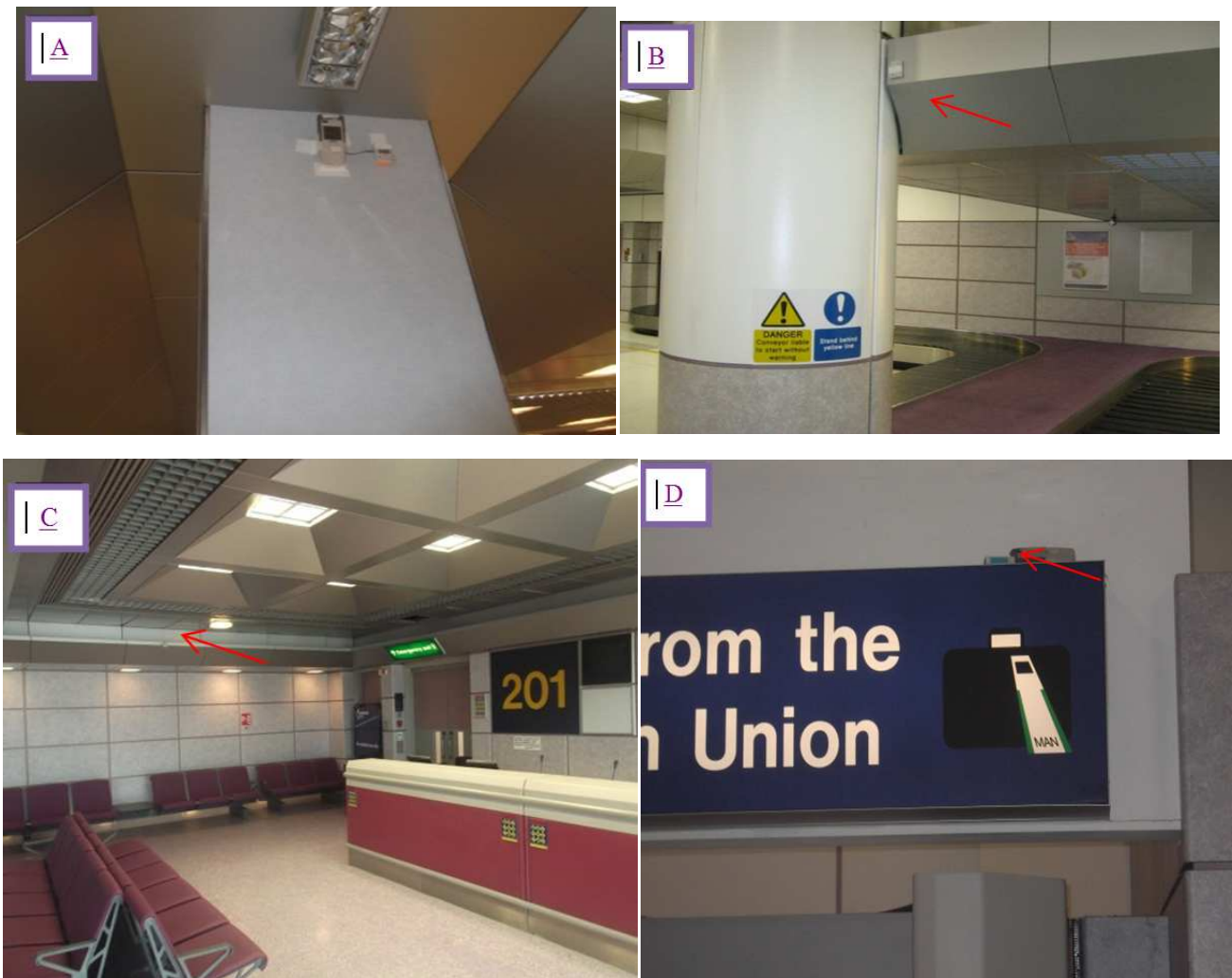


Figure 1. (A) Passport Control (B) Departure Gate (C) Baggage Reclaim (D) Arrival Hall

The indoor temperatures of the spaces were monitored and the external temperature collected from the archives of (16). External temperature influence solar heat gains, temperature of ventilation air and the convective and conductive heat exchange across the building fabrics. Therefore, when external temperature profile is compared with the indoor temperature profile it could provide clue of heating or cooling requirement to achieve the indoor comfort. It can also indicate opportunities available from the external environment to meet indoor thermal requirement either purely through passive means and/or together with active means.

2.2. Collection and Analysis of Flight Schedules

The summer and winter week's flight schedule was used for examining arriving and departing flight pattern. This was uploaded from the Chroma suite (the airport information management system) one week in advance. The average flight punctuality in UK airports is about 80 % with a maximum delay time of about 10 minutes. The data collected in advance is valid.

2.3. Modelling Of Building Geometry and HVAC Systems

The case study airport is the busiest airport in the UK outside London with an annual turnover of 21 million air passengers transiting through and about 16,250 employees on site (23). It has two runways operated in two ways depending on the wind directions. Terminal 2 was recently refurbished

making it a suitable candidate for low energy refurbishing study. This terminal was constructed in 1992 on the North-West part of the airport site. It is made up of five-floor central building covering a gross floor area of about 18,000 m² and has two piers of four floor levels measuring about 5,400 m² spanning to the left and right direction of the central building. The ground and the first floor contain the arrivals hall, the third floor, the departure halls, and the fourth floor is made up of lounges, offices and the control room on the central building it mainly housed the plant rooms on the piers. The fifth floor is mainly plant rooms. So the airport building's function is already well segregated.

The terminal's hot water is served by gas boilers located in the central and eastside of the terminal. There are external air-cooled chillers located on steelwork frames in the main plant rooms. The air handling units comprises of Inlet damper, mixing box, HPHW Frost Coil, Panel Filter, Bag Filter, Carbon Filter, Cooling Coil, HPHW Re-heat Coil, Supply Fan, Extract Fan. This airport is mainly an air conditioned building. The building has no lighting control. However, the luminaires was upgraded, and the introduction of lighting control is being considered.

The first step in building modelling in DesignBuilder is in the definition of location and choice of weather data to match the location. Weather data was the hourly ASHRAE International Weather for Energy Calculation (IWEC) GBR MN6 data based on thirty years average in EnergyPlus Weather format.

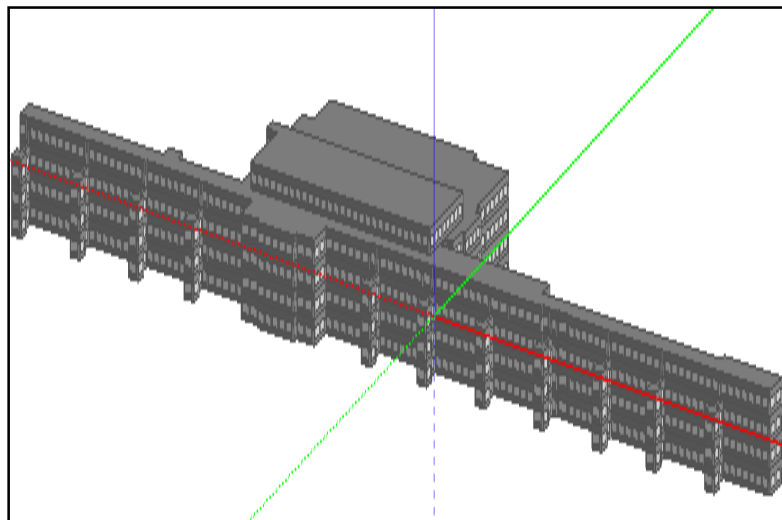


Figure 2. Thermal Model of Terminal Two

The building geometry was modelled by importing the 2D AutoCAD drawings of the building using the dxf import facility. The model was assembled by positioning blocks in the 3D space to define the external walls based on the CAD drawings. Figure 2 shows the resultant 3D geometric form of the building.

Thermal zones (internal partition walls) were defined based on the functions of the space and type of the HVAC system in the indoor space for each of the floors according to

the description obtained from Jacobs Engineering's HVAC system physical survey report and CAD drawings of terminal 2.

For this case study, there are twenty-two thermal zones in the building. However, these zones are further sub-grouped into six zone groups according to the HVAC system type. In EnergyPlus, A "zone" is different from a geometric form; it is an air volume of uniform temperature and all the heat transfer and heat storage surfaces surrounding or internal to the air

volume. The building model was zoned according to passenger flow such that the areas accessible to the public were separated from the areas that were restricted to only passengers and staff. Occupancy in the restricted areas such as the Check-in, Customs, Security, passport control and baggage reclaim areas can easily be linked to arriving/departing passenger planes. However, in the public spaces such as the booking hall, some retail areas and some offices, the flow of people needs to be estimated and therefore more complicated to control.

The building façade data, lighting and opening types was chosen from the template to satisfy the Part L Building Regulation for commercial buildings in England and Wales (1990-1994) since according to the report; the building was constructed in 1992 since the details of the airport building material was not available.

The HVAC modelling was done using the recently approved Version 3 which allows access to a wide range of EnergyPlus HVAC systems component through an easy to use diagrammatic interface and satisfied compliance rating for LEED, BREEAM and Green Star. The HVAC system's specification was also based on the airport's HVAC system

survey report.

The HVAC model includes the boilers, chillers, condenser, air handling units (AHU) and the zone groups as described previously. The activity template was based on the BRE National Calculation method specifications for passenger terminal spaces contained in the DesignBuilder activity templates. This template covers occupancy profiles, internal gain data, equipment usage and plant schedules, design indoor temperature, illuminance levels and ventilation rates per person. To create the base case scenario, occupancy schedules, internal gain data and setpoints were adjusted to simulate the as measured scenario.

For the energy saving scenario, compact schedules interface was utilised to supply CIBSE thermal setpoints, lighting setpoints and air flow rates which varies with the passenger flow data. Since Terminal 2 is a jet only terminal with low cost, charter and long haul carriers. Smallest regular aircraft type is the B737-300 with 148 seats and the largest is Virgin's B747-400 with around 500 seats. This information was used to estimate the passenger number per given flight time. The flight arrival and departure data were gathered from airport's information desk.

Table 1. Summary of Parameters Used In Base and Test Case

Parameters	Base Case	Energy Case
External walls	0.45 U (W/m ² K)	0.45 U (W/m ² K)
Ground floor	0.20 U (W/m ² K)	0.20 U (W/m ² K)
Flat roof	0.35 U (W/m ² K)	0.35 U (W/m ² K)
Windows, Doors and Roof light	3.00 U (W/m ² K)	3.00 U (W/m ² K)
Occupancy	Full schedules	Varies as flight schedules but within aircraft size range
Environment Setpoints	As measured	Based on comfort standards

The summary of parameters used in base and test case was provided in Table 1.

The summer and winter week simulation dates presented in figures were chosen to reflect the monitoring period

The output of the simulation was the total electricity and gas usage in kWh combined to give the total energy usage in kWh, total carbon dioxide emission in kg of CO₂ and Fanger PMV rating.

3. Results and Discussions

3.1. Winter Case

The outside temperature varies from about 2°C on the night of the 28th to the highest day temperature of about 16°C on the 30th and 31st.

The results for indoor temperature for the monitored spaces are as shown in Figure 3A and this shows that indoor temperature range for Arrival Hall (21 – 22.5°C), Departure Gate (22 – 23°C), Duty-Free Shop (24 – 26°C) and Baggage Reclaim (20 – 22.5 °C) throughout the week. However, the CIBSE recommended temperature for arrival hall, Departure Gate, Duty-free shop is 19 – 21°C and 12 – 19°C for baggage

reclaim area.

Also, Figure 3B shows the relative humidity profile for the same spaces. The range of values for Arrival Hall, Baggage Reclaim, Departure Gate and Duty-Free Shop is 36-55%, 38-60%, 32-55% and 28-46% respectively as against the 40-70% as the CIBSE recommended values for all kinds indoor spaces. CIBSE Guide A state that a relative humidity lower than 30% is acceptable where risk of static electricity is low and above 70% where risk of microbial growth is minimal as such it is not uncommon to see practitioners quoting 20 - 80% as the acceptable range for comfort. Additionally and more important to the passenger exclusive areas of the airport, the standard stipulates that lower relative humidity is acceptable in areas of short occupancy. In this context, therefore, the relative humidity values recorded for all the indoor space except the Duty-Free Shop are acceptable. In the shops, attendants remain in the space for a long duration of time, so while it may not matter to the passenger, 28% relative humidity may be not be acceptable to the staff. However, this level was only reached briefly on a Friday afternoon, otherwise, the range has been within acceptable level for the rest of the times.

By plotting the measured indoor temperature and relative

humidity represented by the yellow shade and the CIBSE recommended setpoints for the same variables depicted with the blue shade on the psychrometric chart shown in Figure 4; it can be seen that the indoor environments are warmer than

they should be compared to the standard requirements for such places. However, the relative humidity in all monitored spaces is within the acceptable limits (20-80%).

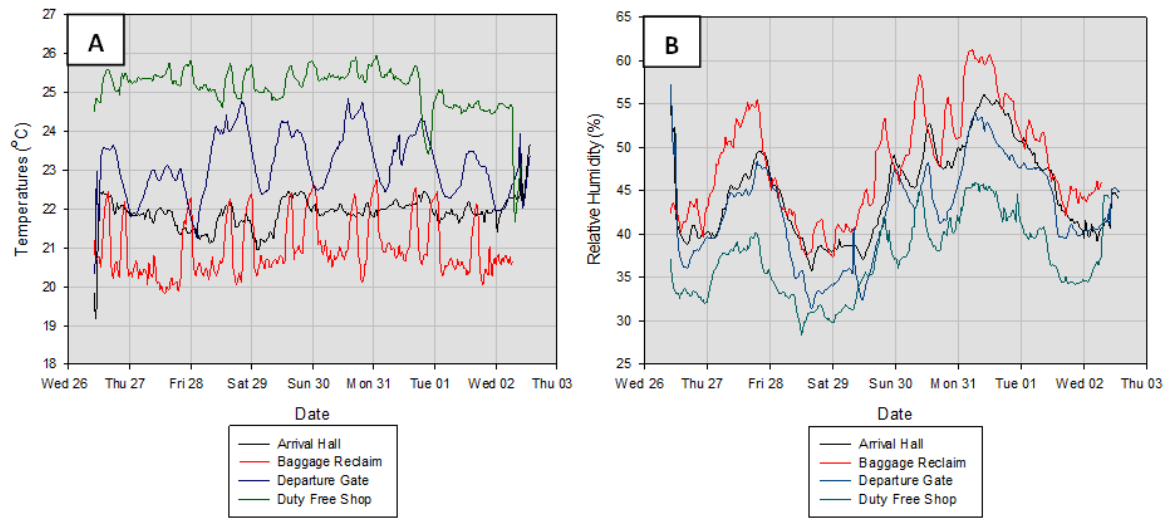


Figure 3. (A) Indoor Temperature Profile (B) Indoor RH Profile

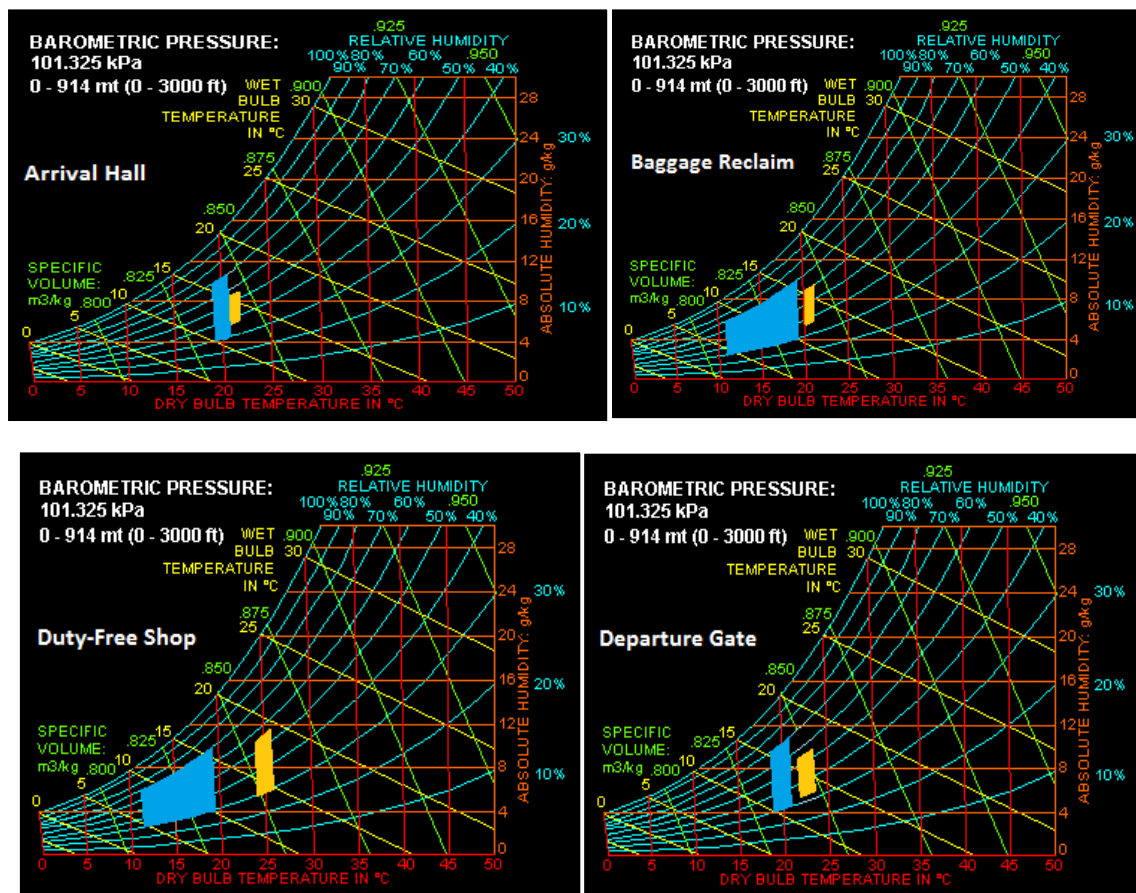


Figure 4. Measured vs. Recommended Comfort Variables

3.1.1. Indoor CO₂ Levels

CO₂ is an indicator of the amount of fresh air injected into a space to dilute pollutants and provides oxygen necessary for respiration. So, elevated CO₂ is a likely indicator of the

presence of other air pollutants and a pointer to inadequate ventilation. Although, ANSI/ASHRAE Standard 62-2007 (a very conservative standard for transient spaces) specified that an indoor concentration of not more than 700 ppm above the

outdoor concentration will satisfy majority (80%) of building occupants and the National Institute for Occupational Safety and Health (NIOSH) recommends that a concentration of over 1000 ppm was a marker for inadequate ventilation. European standards however limit carbon dioxide to 3500 ppm and Occupational Safety and Health Administration (OSHA) limits carbon dioxide concentration in the workplace to 5,000 ppm for prolonged periods, and 35,000 ppm for 15 minutes (15).

The CO₂ Levels recorded in all the places monitored was less than 900 ppm during peak occupancy. Comparing this with the OSHA standards quoted above, the inference is that these spaces may have been over ventilated.

3.1.2. Indoor Illuminance Levels

As can be seen from Figure 5, the indoor illuminance level

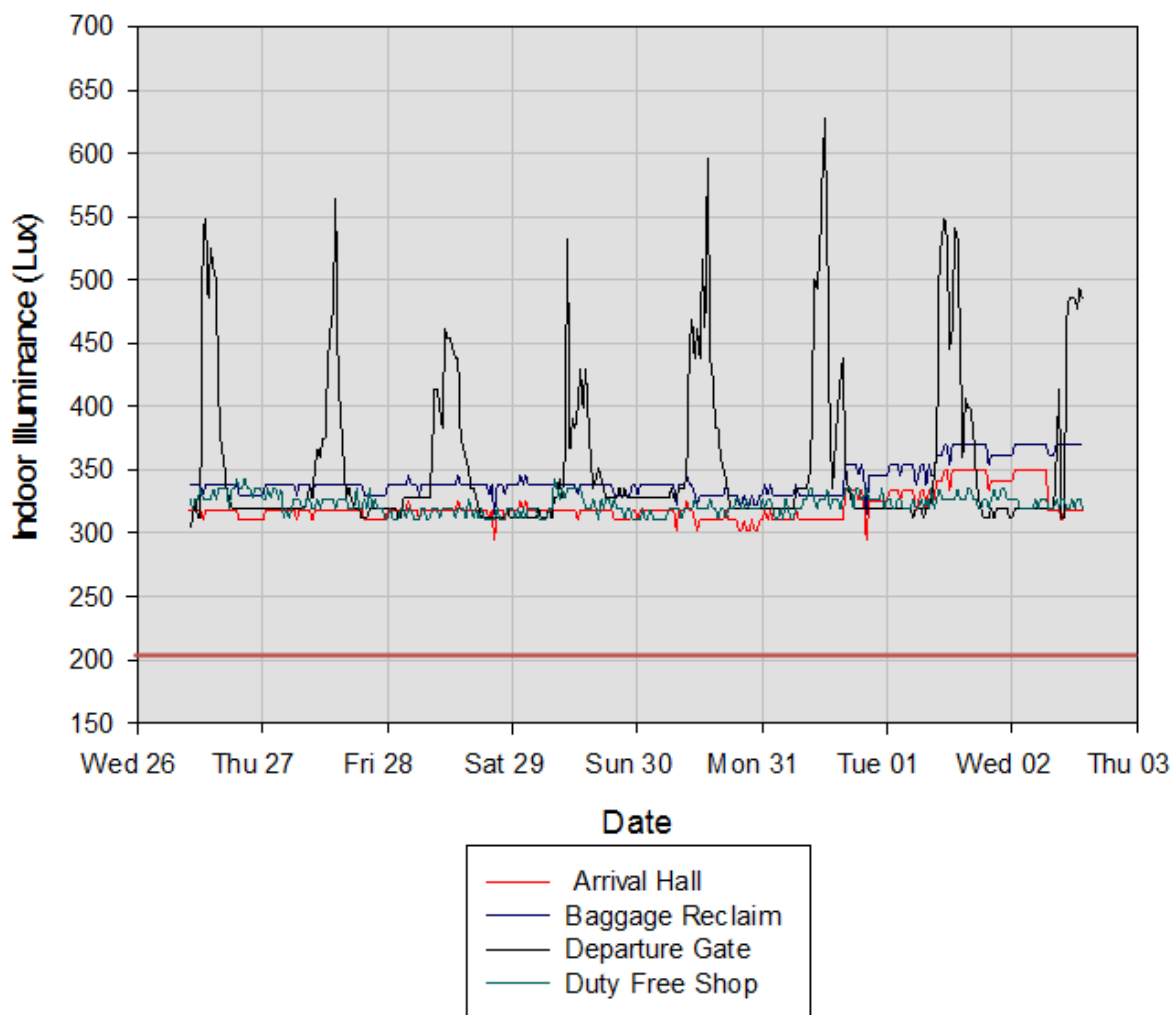


Figure 5. Indoor Illuminance

The environmental performance for winter, have clearly shown that the lighting, temperature and ventilation setpoints has exceeded the recommended CIBSE and OSHA values. These excess values have led to substantial loss in energy. It can be seen from the temperature profile that there was no indication of setback operation in the space during

for Arrival Hall, Baggage Reclaim, Departure Gate and Duty-Free Shop is 250-400 Lux, 310-370 Lux, 320-600 Lux and over 310 Lux respectively. These levels are higher than the recommended 200 lux (the brown line in Figure 5) for these spaces. The indoor illuminance level depends on whether the space in question is exposed to direct daylight and that is the reasons for the high illuminance spikes during the day time in the Departure Gate Area. This area is suitable for Daylighting control. During site assessment tour, it was observed that almost all the artificial lights were on even in spaces where the daylight illuminance was very high such as the Departure Gates and Departure Concourses generally. The new lighting system installed after the monitoring period, now has the capability of maximising the daylighting in terminals.

unoccupied times. The setback temperature during unoccupied hours will be dictated by the external temperature and occupancy. Although relative humidity level was not controlled as part of the airport's HVAC control strategy, the level recorded was about right for comfort in all the spaces monitored except for a short period in the shop.

3.2. Summer Case

External and indoor temperature were measured. The external temperature ranges from 11°C for some nights to 19°C on some days.

3.2.1. Indoor Thermal Comfort Variables

This indoor temperature profile in Figure 6A showed a week-long temperature ranges of 22-25°C for Arrival Hall, 24-26.5°C for Baggage Reclaim, 22-23°C for Departure Gate, 22-23.5°C Duty-Free as against the CIBSE recommended range of 21-25°C for all spaces. There was no adjustment of setpoints during unoccupied hours to reduce energy consumption in the airport terminal. So although, the recommended setpoints is the same for all the spaces, recorded temperature shows considerable variation with the Baggage Reclaim area; a deep plan space with no opening to the outside, was much warmer. However, the Departure Gate, the only space with an external wall had the lowest temperature.

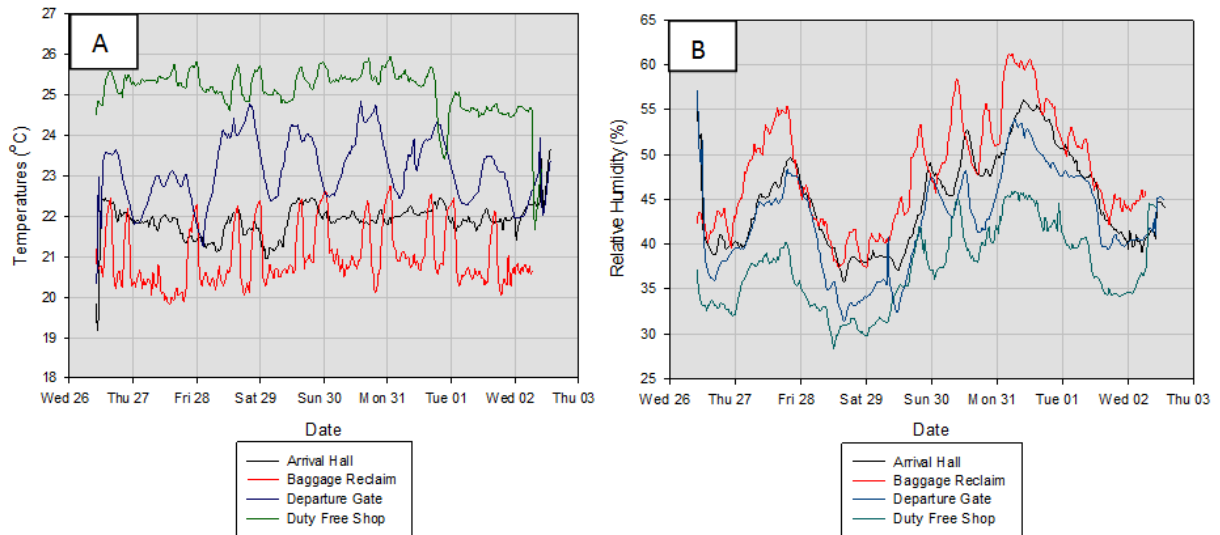


Figure 6. Summer Indoor Temperature & RH

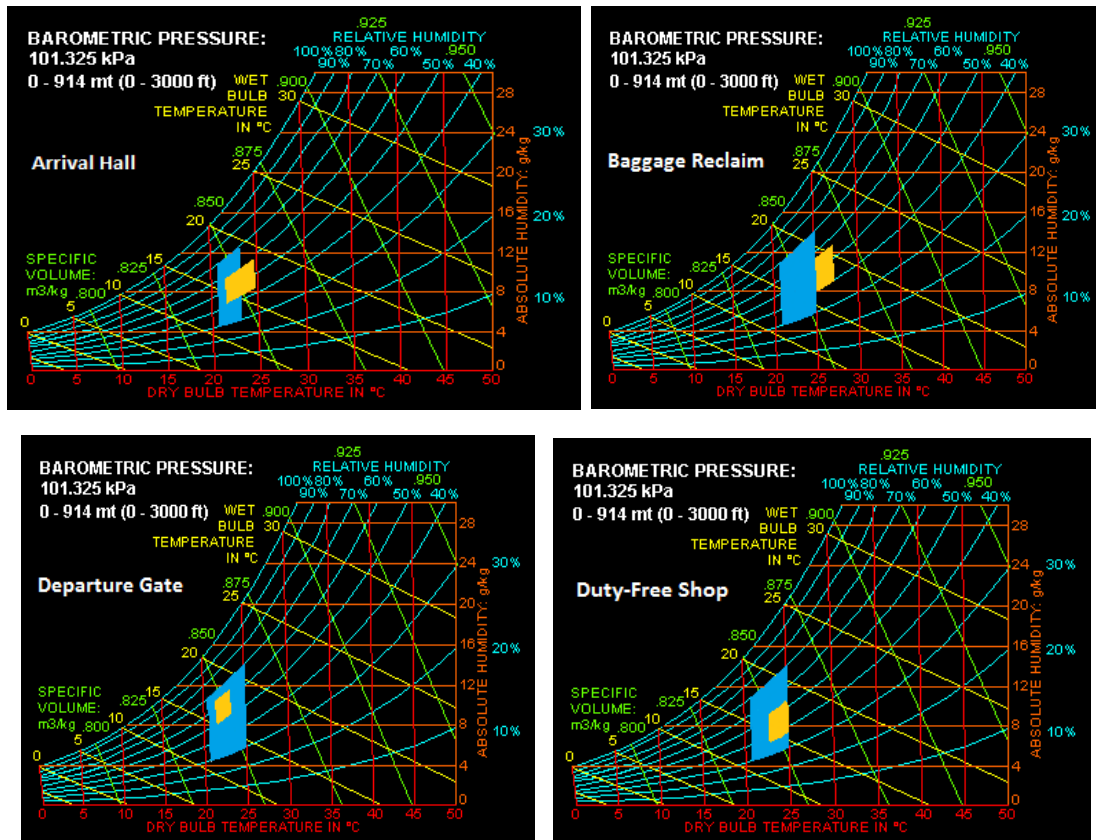


Figure 7. Measured vs. Recommended Comfort Variables

Similarly, the indoor relative humidity value for the indoor places shows considerable variation (Figure 6B). For example, the range of values measured for the Arrival Hall, Baggage Reclaim, Departure Gate and the Duty-Free Shop was 43-58%, 37-53%, 46-65% and 37-53% respectively. However, the range in all the spaces monitored was within the acceptable level for comfort.

By juxtaposing the plotted measured indoor relative humidity and temperature (Yellow shade) with the acceptable values (Blue shade) for these variables on the psychrometric chart as shown in Figure 7, it can be seen also that the indoor spaces are warmer than they should be. Space temperature control for comfort usually has a dead-band (interval between higher and lower comfort setpoint) of several degrees for most indoor spaces. (17,18) investigates the effect of control deadband on acceptability of indoor space and energy consumption. The result showed that the tightly air-temperature-controlled space (dead-band 2) does not provide higher acceptability for occupants in comparison with non-tightly air-temperature-controlled spaces (deadband 4 and deadband 6). In fact in a recent revision, ASHRAE Standard 90.1 (2010) recommends a deadband of at least 5 (19). The indoor data collected for both winter and summer operation show that the HVAC is applying tight control (small area covered by yellow compare to the large area covered by the blue shade) of the variables compare to what is acceptable. Although, this is typical of many air conditioned space, it results in high energy cost (18,20).

3.2.2. Indoor CO₂ Levels

The measured CO₂ at peak occupancy is about 1150 ppm. While this does not satisfy the requirement set by ASHRAE Standard 62 and NIOSH recommendations of about 400 ppm, it still appears over-ventilated by European and OSHA Standards for transient occupancy.

3.2.3. Indoor Illuminance Levels

Also, the indoor illuminance values in Figure 8 shows a range of over 250 Lux for Arrival Hall, 300 lux for Baggage Reclaim, 250 Lux for the Departure Gate and 280 lux for Duty-Free shop. However the recommended illuminance for most of these spaces is 200 Lux (Brown line in Figure 7) for most of these spaces. The difference in the illuminance level between winter (2011) and summer periods especially in arrival and departure areas are due to upgrade of the terminals luminaires from the metal Halides to TiLite High Bay. According to the installer company, Philips, this has already resulted in about 50% energy savings but the fact that these high illuminance levels were sustained throughout the experimental week shows that there is still room for more energy saving through adjusting artificial lighting according to the occupancy pattern and daylighting (20). The monitored results from the Departure gate which mainly uses daylighting show an average daylight level of 240 lux to a daily peak of 300-1000 lux. This is more than sufficient for the requirement of this space, so, incorporating a Daylighting control in this area and similar areas within the terminals will lead to additional energy savings.

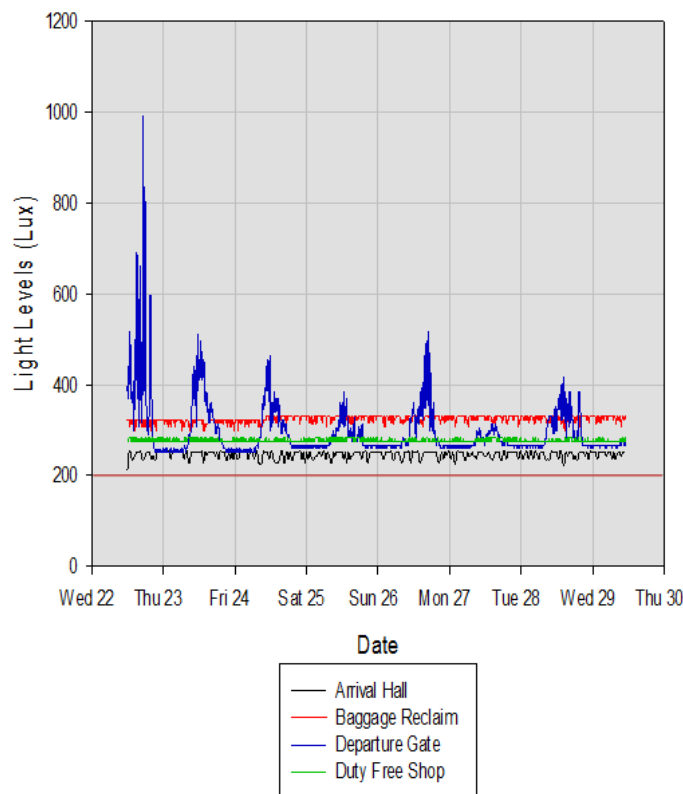


Figure 8. Summer Indoor Illuminance

From the summer and winter results it is clear that there are opportunities for reducing energy consumption within the airport terminal building. The monitoring results have demonstrated the potential of energy saving through appropriate set points for indoor air quality, thermal and visual comfort according to the occupancy pattern. Relative humidity level was generally within acceptable range; therefore this has been excluded from this study.

4. Flight Time Interval

4.1. Winter Arrival & Departure Times and Intervals between Flights

Figure 9A below shows plane arrival times plotted against the time-interval between two consecutive arrivals for the period 27th October to 3rd (7 days) November. ICAO recommended duration for arriving passenger moving from disembarkation to baggage collection was one hour, as shown

by the blue line in the figure. Aggregating the hours above the blue line, up to 50 hours per week was available for implementing energy saving strategies.

A recent survey (21) conducted in seven major UK airports (Manchester, Heathrow, Stansted, Gatwick, Luton, Edinburgh, Inverness) by Civil Aviation Authority (CAA) in 2009 shows that normal processing time for most passengers in these airports is even less than the provisions in the standard. It is 45 minutes for arrival and 1 hour for departure processing in most airports (1).

Figure 9B also shows plane departure times plotted against the time-interval between any two consecutive departures for 7 days. By using the 1 hour ICAO recommendation for the duration from presentation of passengers at first processing point to the scheduled time of flight departure; Up to 52 hours interval is available in the week for implementing energy conservation measures.

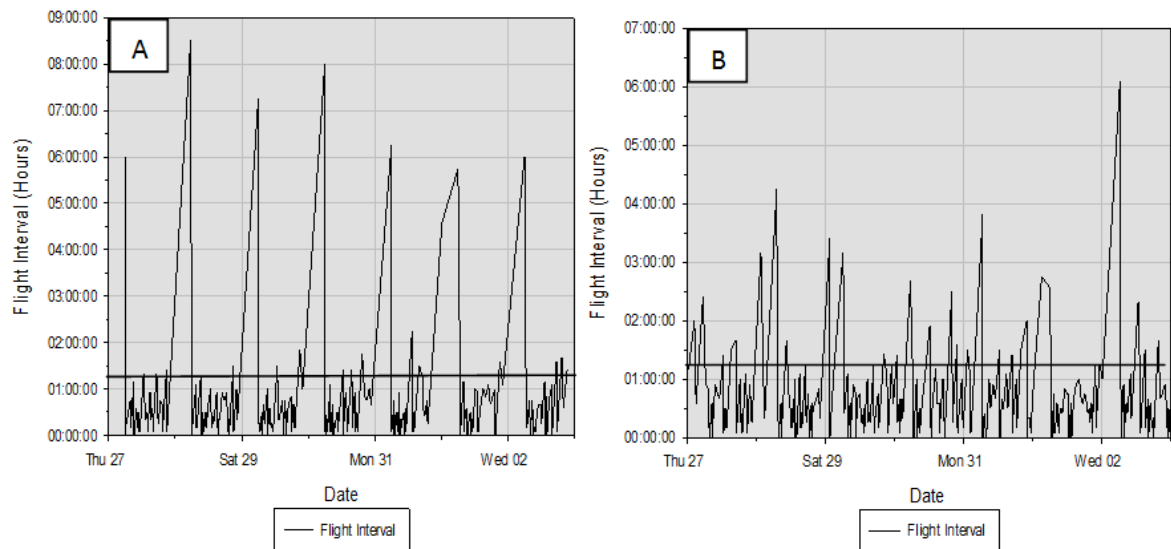


Figure 9. (A) Plane Arrival's; (B) Departure's Time Versus Arrival's Time Intervals

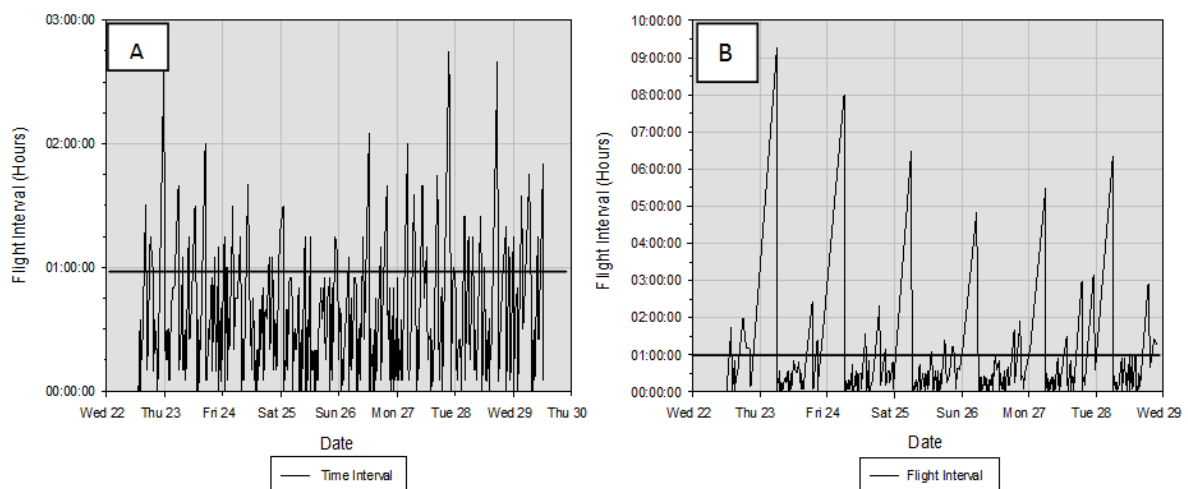


Figure 10. Plane Arrival's Time Versus Arrival's Time Intervals

4.2. Summer Arrival & Departure Times and Intervals between Flights

Similarly, Figure 10A below shows plane arrival time-interval between two consecutive arrivals for the period 22nd to 29th August. Based on the one hour clearing time, Up to 21 hours opportunity exist for the week under review to switch to energy saving mode.

Figure 10B shows departures for the period 22nd to 29th August and has Up to 50.667 hours' opportunity existed for energy conservation.

Table 2. Setback Opportunities in 7 Days Monitoring

Spaces	Winter (Hours)	Summer (Hours)
Arrival	39.05	21.50
Departure	52.00	50.67

From the winter and summer arrival and departure schedules and as summarised in Table 1, it can be seen that there are more flights in summer time than in winter period (less time interval between flights for the same number of days) and also there are more arriving than departing flights in both seasons.

A close look at the histograms in Figure 11 showing the distribution of the interval duration for the week under review, It can be seen that 75% of the time intervals is in the range of over 1 hour duration in the Winter Arrival, about 82% of the time for the Winter Departure and about 85% of the time for Summer Departure. This shows that the time available to implement energy conservation measure for duration above one hour has greater availability. The distribution in summer arrival however shows that this is a particularly busy period for the airport and so the intervals are tighter and the duration shorter (0-1 forms 70% of the range). The entire distribution shows that there are more arrivals than departure flights for both winter and summer.

What was demonstrated in this work was a week review for an airport. If all these energy conservation opportunities are extrapolated across the whole airport terminals and for a whole year, the energy saving is very significant.

This results shows the need to develop an airport environment management system capable of providing the required comfort setpoint during occupancy and implementing energy conservation measure during unoccupancy by taking into account passenger flow pattern and external (22).

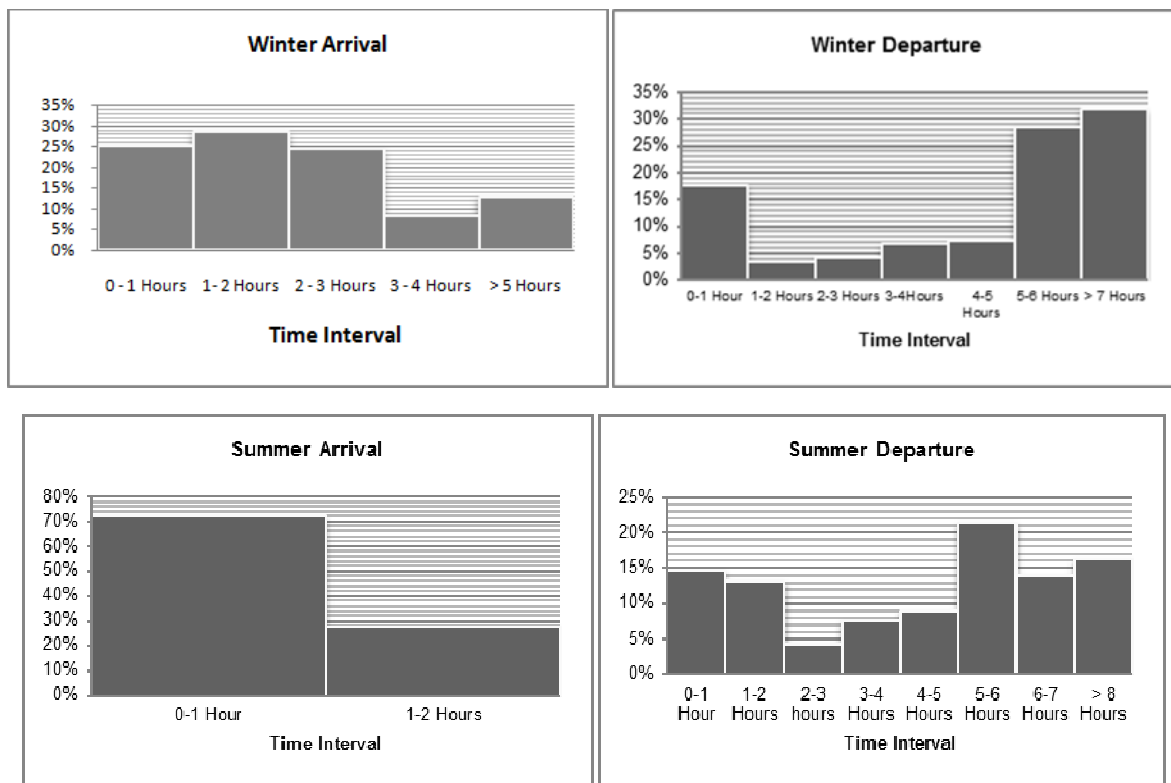


Figure 11. Distribution of Flight Interval

5. Building Simulation Results

From Figure 12 it can be seen that the energy savings of 21 to 27% was achieved for the summer case 40 to 50%

recorded for the winter time. The main reason for less energy saving during summer period is that there are more flights during summer with fewer intervals between the flights

Energy savings for both summer and winter cases are due

to:

(1) reducing the high indoor setpoints since the external temperature for both winter and summer for the period under review was less than 19 degrees, comfort setpoints can be achieved almost passively.

(2) by scheduling the system to implement setback during passenger un-occupied period in the passenger exclusive area.

Also, based on Fanger's 7 point thermal sensation scale in winter, the base case generally showed a warm environment

and the energy case edged the scale towards the neutral point. Similarly in the summer case, the energy case also edges the scale father away from warm towards the neutral position. These clearly indicate that by implementing energy conservation measures, the indoor environment of the airport terminal has been made more comfortable. So these energy savings has been achieved with increase in comfort of the passengers.

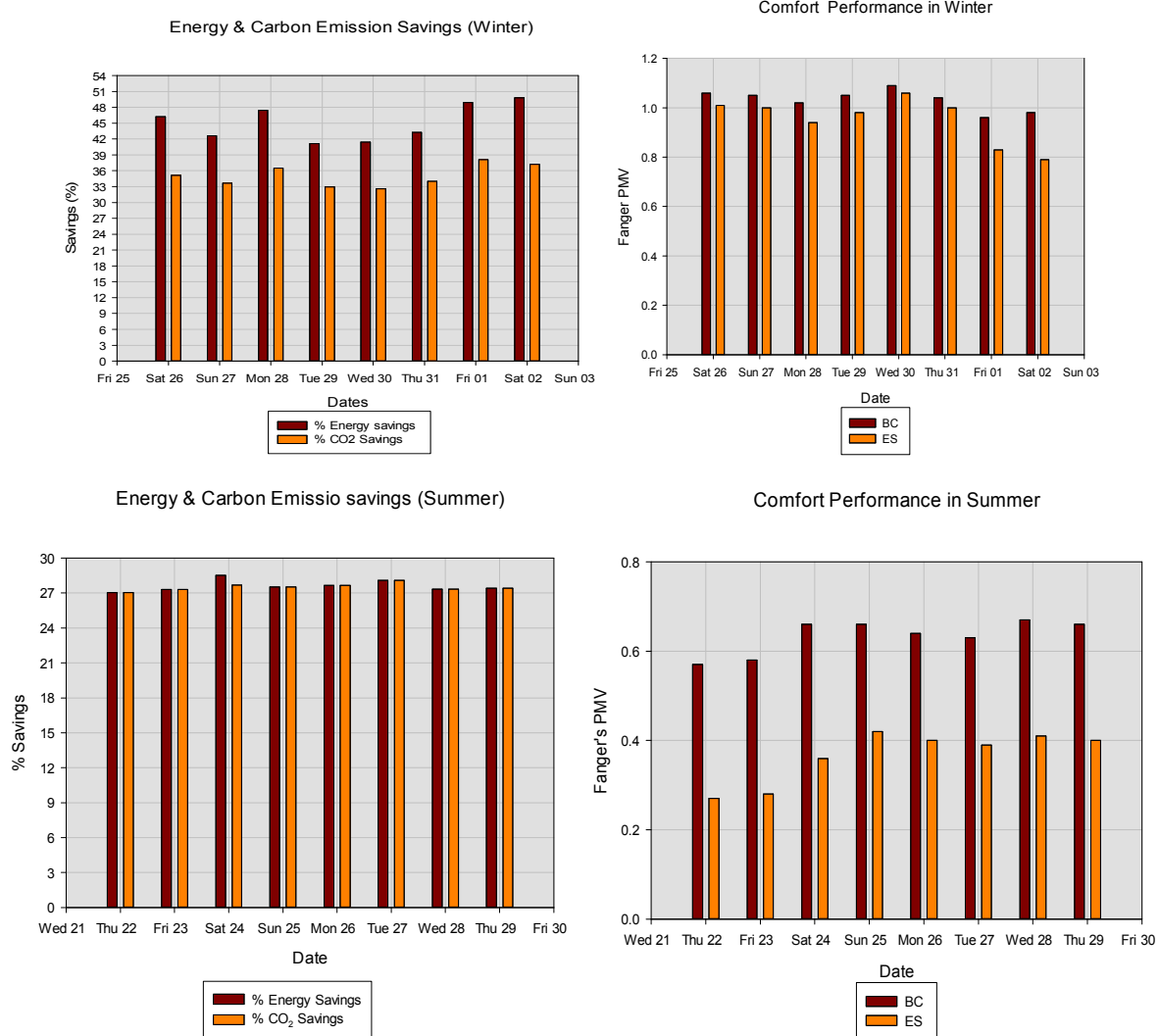


Figure 12. Energy, CO₂ emission and Comfort Rating from Energy Conservation

6. Conclusions

This paper presented the analysis of the primary data collected for both the arrival and departure indoor spaces of a UK airport during winter and summer scenarios. From the comfort variables analysed, it can be seen that the indoor spaces temperature, lighting and ventilation rates were higher than the recommended values. However, relative humidity satisfies the comfort level though it was not being controlled. Tight deadband were also noticed in the control of temperature; a situation that will lead to higher energy consumption. Also, analysis of the flight schedules showed

that there are sufficient opportunities to implement energy conservation measures especially in the passenger exclusive spaces. This Paper considers varying indoor environment comfort set points according to passenger flow through the airport and this would lead to energy saving of 20-25% while considerably improving thermal comfort of the passengers.

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References

- [1] ICAO. International Standards and Recommended Practice, Annex 9 to the convention of International Civil Aviation Organization -Facilitation. 2005; Available at: <http://dcaa.trafikstyrelsen.dk:8000/icaodocs/Annex%209%20-%20Facilitation/Facilitation.pdf>. Accessed 11/2014.
- [2] Worldwatch Institute. VITAL FACTS: Selected facts and story ideas from Vital Signs 2006-2007 | Worldwatch Institute. 2007; Available at: <http://www.worldwatch.org/vital-facts-selected-facts-and-story-ideas-vital-signs-2006-2007>. Accessed 5/20/2013, 2013.
- [3] Turnbull D, Bevan J. The impact of airport de-icing on a river: The case of the Ouseburn, Newcastle upon Tyne. *Environmental pollution* 1995;88(3):321-332.
- [4] Moussiopoulos N, Sahm P, Karatzas K, Papalexioiu S, Karagiannidis A. Assessing the impact of the new Athens airport to urban air quality with contemporary air pollution models. *Atmos Environ* 1997;31(10):1497-1511.
- [5] Unal A, Hu Y, Chang ME, Talat Odman M, Russell AG. Airport related emissions and impacts on air quality: Application to the Atlanta International Airport. *Atmosphere Environ* 2005;39(32):5787-5798.
- [6] Aviation Foundation. Fast Facts. 2013; Available at: <http://www.aviationfoundation.org.uk/Fast-Facts/>. Accessed 5/20/2013, 2013.
- [7] Heathrow. Sustainability performance summary: Toward a sustainable Heathrow. 2010; Available at: <http://www.refworks.com/refworks2/?r=references|MainLayout:init#>. Accessed 12, 2012.
- [8] OFGEM. Typical Domestic Energy Consumption Figures. 2011; Available at: <http://www.ofgem.gov.uk/Media/FactSheets/Documents1/domestic%20energy%20consump%20fig%20FS.pdf>. Accessed 12/24, 2012.
- [9] Galliers S, Booth W. Quality Environments for Public Transport Buildings: Comparisons of Public Perceptions of the Environment and Physical Measuring of the Environment. CIBSE Publications 1996.
- [10] Balaras C, Dascalaki E, Gaglia A, Droutsas K. Energy conservation potential, HVAC installations and operational issues in Hellenic airports. *Energy Build* 2003;35(11):1105-1120.
- [11] Babu AD. A Low Energy Passenger Terminal Building for Ahmedabad 'Building Envelop as an Environment Regulator'. 25th Conference on Passive and Low Energy Architecture, Dublin 2008.
- [12] Liu J, Yu N, Lei B, Rong X, Yang L. Research on Indoor Environment for the Terminal 1 of Chengdu Shuangliu International Airport. 2009.
- [13] Griffith B, Pless S, Talbert B, Deru M, Torcellini P. Energy design analysis and evaluation of a proposed air rescue and firefighting administration building for Teterboro airport. : National Renewable Energy Laboratory Golden, CO; 2003.
- [14] CIBSE. Guide A: Environmental design. London: Chartered Institution of Building Services Engineers 2006.
- [15] OSHA, Occupational Health and Safety Administration 1990. Carbon Dioxide In Workplace Atmospheres. 1990; Available at: <https://www.osha.gov/dts/sltc/methods/inorganic/id172/id172.html>.
- [16] Freemeteo. Hourly weather history of Manchester Airport. 2013; Available at: <http://freemeteo.com/default.asp?pid=20&gid=2643743&la=1&sid=33340&lc=1>.
- [17] Arens E, Humphreys MA, de Dear R, Zhang H. Are 'class A' temperature requirements realistic or desirable? *Build Environ* 2010 1;45(1):4-10.
- [18] Hoyt T, Lee KH, Zhang H, Arens E, Webster T. Energy savings from extended air temperature setpoints and reductions in room air mixing. 2009.
- [19] ANSI/ASHRAE/IES Standard 90.1 (2010). Energy Standard for Buildings Except Low-Rise Residential Buildings. I-P Edition, 2010; Available at: https://www.google.co.uk/search?q=ASHRAE+90.1+%282010%29+&ie=utf-8&oe=utf-8&rls=org.mozilla:en-US:official&client=firefox-a&gws_rd=cr&ei=lqMIUvmfLeiJ0AXUuoCQAQ.
- [20] Philips. Case Study Manchester Terminal 2. 2012; Available at: http://www.lighting.philips.co.uk/pwc_li/gb_en/projects/Assets/projects/Manchester_Airport_T2/Case_study_Manchester_Terminal_2.pdf. Accessed 4/15/2013, 2013.
- [21] DfT. Air passenger experience: Results from CAA survey module (2009). 2010; Available at: <https://www.gov.uk/government/publications/air-passenger-experience-results-from-caa-survey-module-2009>.
- [22] Supervisory Control of Indoor Environment Systems to Minimise the Carbon Footprint of Airport Terminal Buildings—A Review. Sustainability in Energy and Buildings: Proceedings of the 3rd International Conference on Sustainability in Energy and Buildings (SEB'11): Springer; 2012.
- [23] Knowles M. Lighting and Lighting Controls - Manchester Airport Case Study. North-West Energy Forum 2006.