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# Evaluation of comfort conditions in airport terminal buildings

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ABSTRACT

This paper presents findings from extensive field surveys in three airport terminal buildings in the UK, where the indoor environmental conditions were seasonally monitored and simultaneous structured interviews were conducted with 3087 terminal users. Moving beyond the recent work which brought to light the significantly differentiated requirements for thermal comfort between passengers and staff, this paper expands on the investigation of thermal and lighting comfort needs for the entire spectrum of terminal users under the scope of energy conservation. The results demonstrate the influence of the thermal environment on overall comfort and reveal consistent discrepancies, up to 2.1 °C, between preferred and experienced thermal conditions. Outdoor temperature dictated the clothing levels worn indoors, where the preferred thermal state was other than neutral. Terminal users demonstrated high levels of thermal tolerance and wide acceptability temperature ranges, averaging 6.1 °C in summer and 6.7 °C in winter, which allow for heating energy savings through the fine-tuning of indoor temperature set-points. Lighting comprises an additional field for energy savings through the maximisation of natural light. Bright rather than dim conditions were preferred and a preference for more natural light was evident even in cases where this was deemed to be sufficient, while the preference for more daylight was found to be time-dependent suggesting a link with the human circadian rhythm. The findings from this study can inform strategies aimed at reducing energy use in airport terminals without compromising comfort conditions as well as the design and refurbishment of new and existing terminals respectively.

## 1. Introduction

Airport terminals are characterised by open and large spaces with non-uniform heat gains and often with extensive glazing areas aimed at providing natural light and aesthetically attractive facilities. Terminals comprise a particular type of building also from an operational perspective; accommodating a range of stakeholders and activities, terminals experience diverse and transient occupancy and long operational hours which in large airports can reach 24/7 all year round. Times of very low occupancy and times of peak occupancy can alternate several times a day while being also weather-dependent. As a result, HVAC systems use large amounts of energy that can be greater than 40% of the total electrical energy, with most of that being used by air conditioning systems, while with the exception of small systems (e.g. hot water) HVAC systems can also account for nearly all gas use at an airport [1].

While HVAC systems are most often among the highest energy end use together with lighting, outdoor temperature and daylighting are the main external influencers of energy demand patterns [2]. Reduction of the energy used for the regulation of the indoor thermal environment can be accomplished and maximised alongside other energy efficiency strategies through the optimisation of environmental controls, including adjustments of the indoor climatic set-points and of the respective heating and cooling dead bands in accordance to the outdoor weather conditions. The adoption of a broader range of indoor temperatures would yield less energy for heating, cooling and ventilation, but requires awareness and understanding of occupant comfort requirements to avoid jeopardising comfort.

Lighting also comprises a significant component for energy conservation in terminals. Beyond its general purpose in the indoor environment - of enabling occupant to work and move in safety, to perform tasks correctly and at an appropriate pace and of providing a pleasing appearance [3] - terminal lighting is also part of the establishment of character in the different areas of the building. Nowadays, airport design is increasingly making use of daylighting to improve the ambiance of the terminals and reduce lighting costs. Typical buildings that take advantage of daylight can save 40–60% of the energy used for lighting [4]. As the sunlight produces less heat per lumen of light than most electrical lighting, indirect daylighting may impose less demand on the cooling system. However, this requires a proper design to ensure that the cooling required to offset solar heat gains does not outweigh energy savings from lighting.

As a result of the extensive development of airport terminals across

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the globe, the last two decades have seen a worldwide inception of studies (e.g. Greece, UK, China, India) on the evaluation of indoor environmental conditions with implications for energy saving strategies. Balaras et al. took spot measurements of the thermal and lighting conditions in three Greek airports and revealed issues with temperature regulation and humidity controls as well as lack of lighting uniformity, insufficient lighting in certain areas of the buildings and excessive lighting in other as a result of poor solar control. Using a sample of 285 passengers and staff, the study found considerably different satisfaction levels between the two groups with all IEQ parameters. With respect to the thermal environment, for instance, the satisfaction range was 40–70% for employees and over 80% for passengers, similarly to lightings conditions which were satisfactory for about 30% of employees and 40–90% of passengers across the three terminals [5]. Environmental and subjective IEQ data were also collected in eight Chinese airports. The study reported thermal issues such as overcooling in summer and overheating in winter in certain buildings, however underperformance was considerably higher in terms of air quality and acoustics across the terminals surveyed [6]. Another study on IEQ investigated the effect of individual IEQ factors on passenger overall satisfaction using Kano's model [7]. Thermal comfort conditions were highlighted together with space layout as basic factors, indicating that their underperformance has a prominently negative effect on overall satisfaction. On the other hand, lighting conditions were highlighted alongside air quality and acoustic environment as proportional factors denoting that their under- and over-performance have approximately equal strength of influence on overall satisfaction [8].

Investigating thermal comfort conditions in Terminal 1 at Chengdu Shuangliu International Airport, China, Liu et al. undertook physical and subjective measurements over a period of two weeks in summer and winter. The neutral temperature was found at 21.4 °C in winter and 25.6 °C in summer for passengers and the respective comfort zones at 19.2–23.1 °C and 23.9–27.3 °C. The results from 569 questionnaires showed that 78.3% of passengers were generally satisfied with the thermal environment and 95.8% considered the thermal conditions acceptable, concluding that passengers' adaptive ability is very powerful [9]. Microclimatic and subjective data from 128 passengers and staff were also collected in Ahmedabad airport terminal, India, yielding a high comfortable temperature range in the air-conditioned part of the building, 24–32 °C [10]. On the contrary, a staff-oriented study in the departures lounge of Suvarnabhumi airport, Thailand, found employees slightly uncomfortable and dissatisfied with the thermal conditions as a result of overheating attributed to the large proportion of glazed roof in the air-conditioned lounge [11]. Another study in three airports in Brazil found the temperature below acceptable levels, which could result in thermal discomfort particularly in occasions of prolonged dwell times [12]. Research on thermal comfort conditions in other building types has highlighted the importance of the duration of exposure [13], demonstrating that discomfort is not viewed negatively if the exposure to it is short [14] or the subject anticipates it is temporary [15].

Thermal comfort criteria are currently provided by ASHRAE and CIBSE. Aiming for an 80% acceptability comfort zone, ASHRAE's design criteria recommend a temperature range of 23.0–26.0 °C and a RH range of 30–40% in winter and 40–55% in summer [16]. CIBSE details seasonal comfort criteria for five terminal areas based on clothing insulation levels and metabolic rate, allowing for varying temperature ranges in different facilities [3]. Recommended illuminance levels in EN 12464 range from 150 lux for general circulation areas (e.g. connecting areas, escalators and travellators) to 500 lux for task-performing areas such as information desks, check-in desks, costums and passport control desks [17].

Despite the wealth of research outputs on the evaluation of environmental comfort conditions in different operational contexts, field research in airport terminals is still in its infancy. Studies are relatively few, often restricted to a single terminal building or a very small number of terminal spaces and as a result findings have been largely fragmented (Table 1). Continuing form the initial assessment of comfort conditions in three airport terminals which revealed a consistent variation of comfort requirements between passengers and staff [18], this paper focusses on the investigation of the thermal and lighting comfort needs of the terminal population as a whole, as to enable designs and energy saving strategies that do not compromise comfort conditions. The study borrows from the methods and procedures of comfort studies in different operational contexts and employs extensive field surveys with a large population sample across the spaces of three airport terminal buildings.

## 2. Methods and data sources

Three major UK airport terminal buildings of different capacity and typology were surveyed in summer and winter in 2012–2013. The field surveys comprised week-long monitoring of the indoor microclimatic conditions and concurrent questionnaire-guided interviews with occupants throughout the terminal spaces.

### *2.1. Case study airport terminals*

The terminals surveyed are London City Airport (LCY), Manchester Terminal 1 (MAN T1) and Manchester Terminal 2 (MAN T2) (described in detail in Ref. [19]). LCY is a 2-storey compact terminal with total floor area of 10,000 $m^2$. The building employs the linear terminal concept and has relatively small spaces with little variance in size and design features. It is a business passenger-oriented terminal aiming for fast passenger processing that along its small size and short walking distances provides significantly shorter dwell times which can be down to 20 min from check-in to boarding. Nowadays, LCY serves over 4 million passengers a year and is ranked 14th among the busiest airports in the UK [20].

The significantly larger Manchester airport handles over 23 million passengers a year representing the 3rd busiest airport [20]. The passenger-related facilities in MAN T1 and MAN T2 utilise a total area of 43,499 $m^2$ and 26,063 $m^2$ offering an annual capacity of 11 and 8 million passengers respectively [21]. The 4-storey MAN T2 building is the newest (1993) among the terminals surveyed. It is a linear structure with gates spread across the two diametrically opposed piers spanning from the central building and features the most contemporary terminal design compared to its peers at Manchester airport. Most of its areas consist of large open-plan spaces with high floor-to-ceiling heights and extensive use of natural light through curtain walls and rooflights. On the other hand, MAN T1 is a 5-storey building with a finger and a satellite pier that has evolved through various expansion and overhaul schemes since its opening in 1962. Accordingly, many of its areas were developed years apart at varying standards resulting in a complex building which comprises an assortment of diverse design trends ranging from the old "boxed up" style to modern spaces.

All three terminals use mechanical ventilation systems. MAN T1 and MAN T2 employed a number of variable refrigerant volume (VRV) systems, fan coil unit systems and direct expansion (DX) systems in smaller areas aiming for a fixed temperature set-point of 21 °C throughout the year. The indoor environment in LCY was controlled by 13 air handling units aiming for the temperature set-points of 20 °C in winter and 23 °C in summer.

### *2.2. Field surveys*

The evaluation of comfort conditions required the investigation of the immediate microclimate occupants experience [22,23]. Thus, a transportable and easily dismountable microclimatic monitoring station conforming to ISO 7726 [24] was designed to enable movement between airside and landside areas. The station consisted of data logging system, a shielded temperature and humidity probe, an ultrasonic anemometer, a black globe thermometer, a lux sensor and a $CO_2$ sensor. The monitored parameters included dry bulb and black globe