Article:

Vargas, G., Lawrence, R. orcid.org/0000-0001-9518-6693 and Stevenson, F. (2017) The role of lobbies: short-term thermal transitions. Building Research & Information, 45. ISSN 0961-3218

https://doi.org/10.1080/09613218.2017.1304095

The role of lobbies: short-term thermal transitions

Gloria Vargas, Ranald Lawrence and Fionn Stevenson

Sheffield School of Architecture, The University of Sheffield, UK

Abstract

Maintaining comfort levels while reducing energy demand in buildings in the face of climate change is a key challenge in temperate zones. Creating transitional spaces and thermal variation in buildings may offer a way forward. This paper is a study of seasonal short-term thermal transitions in the lobby areas of three higher education buildings in Sheffield, UK involving 1,749 participants, thermal comfort questionnaires and simultaneous climatic measurements. New patterns of thermal transitions were identified, which significantly modified seasonal subject's thermal perception, and their reactions to temperature changes. Results suggest that it could be possible to positively alter people's thermal perception in the short and long term through the judicious use of lobby spaces. This could help to reverse the negative effects of air conditioning in people's thermal perception and aid energy saving. This work also provides a reflection on the purpose of transitional spaces in historical buildings and how the implementation of HVAC technologies has reduced the environmental diversity and the key role that transitional spaces play in providing thermal comfort in contemporary architectural design.

Keywords: *adaptive comfort, educational buildings, thermal history, transitional spaces*

Introduction

It is possible that all commercial buildings in the UK will be air conditioned by 2050 (Walker, Shove & Brown 2014). The rapid rise of AC installations in climates where they are not necessarily required will dramatically increase energy consumption, given that energy consumption from HVAC systems can exceed 50% of the total energy use of some buildings (Chua et al. 2013). Different studies show an increase of 10-15% in energy use per every 1 °C increase in air temperature (ibid, 2013). Worldwide strategies to reduce air temperature in indoor environments and increase people's adaptive opportunities include: 'Cool Biz' in Japan, 'Cool Asia', Cool United Nations 'Cool UN', 'Warm Biz' and 'Cool Work' in the UK (Lakeridou et al. 2012). However, understanding the impact of these approaches requires improvements in our understanding of people's thermal perception and their tolerance to temperature changes in real situations.

Dynamic environments not only offer better thermal comfort opportunities than fixed interior environments, but can also enhance thermal comfort perception (Parkinson, de Dear & Candido 2012). Thermal comfort research is now expanding beyond the boundaries of fixed interior spaces and sedentary activities into vibrant, variable and dynamic thermal situations that people experience in their everyday lives. Recent research has examined transient thermal environments (Liu et al. 2014; Parkinson, de Dear & Candido 2012), transitional spaces (Hui & Jie 2014; Pitts 2013; Vargas & Stevenson 2014), people's thermal history (De Vechi, Candido & Lamberts 2016), psychological factors (Knez et al. 2009; Nikolopoulou, Marialena & Steemers 2003) and thermal alliesthesia

(Parkinson & De Dear 2015). Taken together, these studies reveal new opportunities to adjust people's thermal perception in a positive way by incorporating thermal variability into environments such as PCS 'Personal Comfort Systems' (Zhang, Arens & Zhai 2015), temporal and spatial thermal alliesthesia (Parkinson, De Dear & Candido 2015) and repeated short-term (seconds) thermal experiences (Vargas & Stevenson 2014).

Transitional spaces

People experience thermal transitions either when moving between different spaces, or as temperatures vary in one space over time. *Transitional spaces* are spaces within a building which are also connected with the exterior environment (Kwong & Adam 2011). These have been variously described as: semi-outdoors buffer zone, buffer spaces, in-between spaces, physical links, bridges between the interior and exterior environments, semi-enclosed or half-open spaces (Chen et al. 2011; Hwang et al. 2008; Pitts & Bin Saleh 2007). Together these transition spaces form a hierarchy of microclimates.

Vernacular and historic buildings, as climate moderators, contain implicit evidence of tacit cultural knowledge about adaptive thermal transition between the outdoor climate and the microclimate indoors (Olgyay 1963). In David Boswell Reid's Victorian design for the new House of Commons of 1852, the intermediate transitional lobbies played a passive but nonetheless crucial environmental role, acting as an air lock to protect the fine-tuned conditions of the main debating chamber, permitting sensitive adjustments to be made to temperature and airflow in response to feedback from the occupants (Schoenefeldt 2014). One of the most sophisticated examples of environmental transitioning is the Glasgow School of Art by Charles Rennie Mackintosh (1897-1910). Entry is through a double-door ‘air lock’ into a lobby space directly above the boilers, warming the floor. Access to the studios is via an east-west corridor on each level, to the south of a massive spine wall. The wall carries ducts with adjustable hinged openings supplying tempered air, permitting the thermal conditions of each space to be fine-tuned. The main studios to the north of the wall are noticeably cooler, while the corridors and transitional spaces to the south are warmer and exposed to solar gain. There is an implicit recognition of the experience of different spaces for different activities: the cooler conditions in the large studios encourage physical activity (painting, sculpture), while the sunnier, warmer and smaller, transitional spaces to the south, fitted out with seating booths and desks, are suited to calmer activities such as reading and relaxation. (Lawrence 2014).

Studies exploring the perception of temporal temperature variations have been conducted since the early 1970s, including investigation of subjects in transient states, and fluctuations and sudden temperature changes when people move from the exterior to interior environments (Hensen 1990). Griffiths and McIntryre have highlighted the importance of exploring *small temperature changes* and the discrepancies between the different effects of large and small temperature changes on people’s thermal and pleasantness perceptions (Griffiths & McIntyre 1974). Despite these early studies, however, detailed fieldwork investigation has been limited, and no guidance has been developed for inclusion in international standards.

Factors influencing people’s thermal comfort in transitional spaces

Recent work in adaptive comfort theory has rediscovered the role of transitional spaces and transient conditions (short-term experiences). Studying the factors that influence people’s thermal comfort perception in these spaces is, however, challenging due to rapid changes of multiple variables across different temporal and spatial scales, considered next.

Thermal history refers to previous thermal conditions that influence people’s current thermal perception (Nikolopoulou, Marialena & Steemers 2003). The impact of thermal history on perception depends on the extent to which a person’s current thermal state affects their future thermal experience, which varies according to the time of exposure (Candido et al. 2010; Chun & Tamura 2005; Song, Wong & Huang 2011). Studies show that transient visitors and staff experience different thermal perceptions in airport terminals. Employees were 1.6 times more sensitive to temperature changes than visitors, who were more tolerant of cooler conditions (Kotopouleas & Nikolopoulou 2014).

Thermal perception of *step-change temperatures* has been explored in extreme hot and humid climates, however studies in moderate climates are limited. (Liu et al. 2014) conducted laboratory work in China to explore step-change temperatures in transient environments. by climatic chambers at 32°C, 30°C and 28°C and an air-conditioned room at 25°C, creating temperature differences of 7°C, 5°C and 3°C. Relative humidity was fixed at 60% and wind speed at 0.1 m/s. Participants (20 male undergraduate students) were asked to move from one space to another in different thermal directions, with varying temperature differences and time of exposure. During the first four minutes, there was a significant difference in thermal sensation after moving from 32°C to 30°C and 32°C to 28°C. Kwong and Adam (2011), conducted research in enclosed transitional spaces (lift lobbies) in Malaysia. Undergraduate participants moved from indoor spaces (air-conditioned to 16-20°C) to a lift lobby (23-32°C; relative humidity: 63-78%). The majority of participants (79%) found the environment of the lift lobby acceptable. Researchers reported that overall the thermal acceptability was high, because the thermal experience only lasted a short period of time.

Kelly and Parson (2010) found that a significant change occurs in the skin's thermo-receptors, and in people's thermal sensation, when subjects move from neutral to cold environments, but less so when moving in the opposite direction. Similar results were found in a study conducted by (Du et al. 2014) when comparing people's mean skin temperature after moving from an environment at 22°C to one between 12°C - 17°C. A substantial difference was found when participants moved to cooler environments, but not warmer environments. Jin et al. (2011) determined that a 5°C difference was the limit of acceptable temperature change for people moving to) warmer conditions. In all cases, it was found that a delay in thermal sensation can occur depending on the preceding thermal conditions experienced. Interestingly, this delay was not only associated with large temperature changes, but also with small temperature changes or between spaces with the same temperature (Jin et al. 2011).

Thermal direction refers to the order in which people experience temperature changes, from cold to hot or vice versa. Qi (2011) carried out research related to temperature change in enclosed transitional spaces (lift lobbies) in Malaysia. Participants (undergraduate students) moved from indoor spaces (16-20°C, RH:72.6%) to a lift lobby (28°C). Researchers reported that the majority of participants (79%) found the environment of the lift lobby acceptable. Although some participants were uncomfortable with the sudden temperature change and the majority preferred cooler environments, researchers reported that overall the thermal acceptability was high, as the thermal experience only lasted a brief period of time (Jin et al. 2011).

Examples of *psychological factors* influencing people's thermal perception in transient conditions are thermal expectations and thermal alliesthesia. *Thermal alliesthesia* describes thermal pleasure in non-uniform environments using a conceptual model to explain why a particular environment can be perceived as pleasant for certain people and unpleasant for others. Jitkhajornwanich and Pitts (2002), conducted research on building entrances in the hot-humid climate of Thailand. They analysed *expectations* and *perception* before and after moving from the exterior to the interior environment, identifying significant differences between thermal expectations and actual thermal sensation, as well as between air conditioned and naturally ventilated buildings. The thermal neutrality of participants in transitional spaces (from 26.1°C to 27.6°C) was significantly higher than ISO Standards.

Research aims

Innovations in the design of lobbies in a wide range of building typologies have recently challenged assumptions about thermal comfort provision for different types of users (short and long term) and building functions. Lobby spaces are designed to accommodate many people moving and interacting at the same time (Channell 2012) or to move the individual to a collective environment, and are spaces where people have the opportunity to meet and socialise (Kilpatrick 2010). A multifunctional lobby can be used as a reception area, an orientation or information point, a space for waiting or meeting, and even a setting for presentations (daab 2006). However, the lobby is also a thermal connector with other interior spaces, through stairs, lifts, corridors or further transitional spaces such as atriums or courtyards. Given these conditions, it may be possible to exploit the short-term thermal experience of the lobby to alter people's long-term thermal history and help to reduce energy consumption at the same time. This is important because reducing the AC set-point in intermediate spaces by 5° C may lead to an energy saving of 2% in cooling systems and up to 11% in heating systems (Pitts & Bin Saleh 2007). The lobby space is an appropriate setting to study thermal transitions because:

- It is an independent space with complex thermal connections to other interior areas
- It exemplifies the dynamic thermal transitions people experience everyday

- People experience repeated thermal transitions in lobby areas
- It offers a long-term opportunity to improve thermal adaptation to the indoor environment.

This paper therefore aims to evaluate the experience of thermal transitions in lobby spaces when walking from the exterior to interior environment. It focuses on the perception of short-term thermal history in naturally ventilated (NV) Higher Education Institution (HEI) buildings in a moderate climate. Lobby spaces in HEI buildings provide particularly good case studies for exploring thermal transitions because students are transient users of university buildings and move between buildings many times a day in large numbers. HEI buildings in the UK are also required to reduce CO_2 emissions by 80% against the 1990 baseline by 2050 (HEFCE 2010), and are in urgent need of new energy saving solutions.

The objectives are: To identify thermal variations in transitional spaces; in this case exploring lobby areas in NV buildings operating with heated spaces during winter.

- To quantify significant variations and typical changes (patterns) in people's thermal perception of an interior space, caused by the prior thermal experience of a transitional lobby space.
- To develop an understanding of how thermal connections and manipulation of transitional spaces can positively modify people's thermal perception in the long-term.

Methodology

Evidence from many experiments has demonstrated the importance of fieldwork to the study of the adaptive thermal comfort model (de Dear & Brager 1998; McCartney & Nicol 2002; Nicol, F. 2004; Nicol, F., Humphreys & Roaf 2012; Nicol, J. F. & Humphreys 2009; Rijal et al. 2007). Empirical fieldwork ('real-world-research') provides robust results, allows predicted effects to be tested and solves problems which experiments in climate chambers (although often more accurate), cannot resolve out with a real-world context (Leaman, Stevenson & Bordass 2010). The quantitative methodology of this study was shaped by previous thermal comfort methodologies involving people in dynamic states, including previous work related to transitional spaces and temperature changes. Additionally, two pilot experiments were conducted to refine the survey procedure, in summer 2012 and in early 2013.

A preliminary survey was conducted by the researchers to identify the most typical lobby typologies and configurations in Higher Education Institutions (HEI) in the UK. A random selection of 50 HEI faculty buildings constructed between 2007 and 2012 were sampled. Based on the findings, a typical lobby unit typology was proposed as follows:

- Double-door entry doors (draught lobby) with parallel sliding doors (from 2.5 to 3.0 metres in width and from 2.5 to 3.5 metres height)
- Distance between two parallel doors (draught lobby) from 2.5 to 3.5 metres
- An average lobby height of 3.2 metres (min: 2.5m, max: 5m)

- Average dimension of the immediate circulation areas: 5.6 metres width, 6.2 metres length, and 5.7 metres height
- Lobby unit used mainly as a circulation space (no social areas included)
- Rectangular floorplan
- Naturally ventilated building operation with heated spaces in winter

For the purpose of this study, a typical lobby unit includes the main entrance of the building, the draught lobby (double door entry doors), and circulation areas not defined by vertical elements (walls or doors) that connect the draught lobby with interior spaces. The case study buildings for this study were selected based on the characteristic of the typical lobby described above.

The city of Sheffield (North-England) was selected for the case study as its moderate climate brings the potential opportunity to eliminate the use of air conditioning and promote adaptive design. Sheffield's average minimum temperature varies from 2.0°C to 1.7°C, during December-February, and its average maximum temperature varies around 21°C, during July-August (Met Office 2015). There is year-round rainfall (8-13 rain days per month). The peak average wind speed occurs during November-March, with fluctuations between 10.9 and 12.3 m/sec. The minimum average wind speed occurs in spring and summer (between 5.2 and 3.9 m/sec). Relative humidity in Sheffield fluctuates around 80%, sometimes peaking at 90% during spring (Met Office 2015).

Three University of Sheffield buildings were selected for this study: the Sir Henry Stephenson building (HS), Jessop West building (JW) and ICOSS (Interdisciplinary Centre of the Social Sciences) building (ICS) (**Figure 1**). These buildings were selected because their layouts reflect the typical lobby typology defined earlier. They have similar connections between spaces (allowing a replication of similar spatial sequences in different buildings) and similar building operations (NV during summer and heated spaces during winter).

Case study 1: Sir Henry Stephenson building (HS)

Case study 2: ICOSS building (ICS)

Case study 3: Jessop West building (JW)

Figure 1. Case study buildings: Sir Henry Stephenson building (HS), Jessop West building (JW) and Interdisciplinary Centre of the Social Sciences (ICOSS) building (ICS).

Participants

Based on the HESA (Higher Education Statistics Agency) annual report (2013-2014), it was determined that a representative sample of the HEI population would contain at least 80% undergraduate students from 18-24 years old. Participants were randomly selected from the university campus. A total of 1,749 volunteers were involved in this study, 155 in spring, 487 in summer, 447 in autumn and 660 in winter (**Table 1**). Participant's demographics are illustrated in **Table 2**. Regarding participant's previous activities, 90% were performing sedentary activities during the 30 minute period before walking to the case study buildings. 85% spent from 1 up to 15 minutes 'walking relaxed', 0.9 $m.s^{-1}$=2.0 met (CIBSE-GuideA 2015) from a previous interior space to the exterior of the case study buildings. 84% were exposed to heated environments during autumn and winter and 50% were exposed to AC-cooled environments during summer. Finally, 56% claimed to be living in Sheffield for less than one year before the survey. Participants performing metabolic activities above 2.0 met (e.g. cycling and gym work) were eliminated from the study.

Table 1. Number of participants per season and building.

	Spring		*Summer*		*Autumn*		*Winter*		*All Seasons*	
Route	A	B	A	B	A	B	A	B	A	B
HS	44	30	84	97	89	81	107	102	324	310
JW	19	15	39	48	66	64	108	82	232	209
ICS	47	0	106	113	73	74	128	133	354	320
All buildings	110	45	229	258	228	219	343	317	910	839
	155		487		447		660		**1749**	

Table 2. Participants' demographics.

	Gender	**Weight (Kilograms)**	**Height (metres)**
Participants	Male= 1,062	Minimum=42	Minimum=1.42
N= 1,749	Female=687	Maximum=118	Maximum=2.20
		Mean=67	Mean=1.71
		SD=13.29	SD=0.10
	Age (years)	**Age (group)**	**Nationality group**
	Minimum=18	18-24 =81%	UK= 45%
	Maximum=72	25-30=15%	International=55%
	Mean=22	31-35=3%	(from 83 different countries)
	SD=4.3	Over 35=1%	

The clothing value was registered individually during the survey, clothing was deliberately not controlled in order to mirror the behaviour of participants in their everyday lives. Participants wore the same clothes that they were wearing outside, and no behavioural adaptation using clothing was observed during the survey. The mean clothing values for each season was: spring=0.72, summer=0.57, autumn=1.01 and winter=1.06.

Measurement equipment

Four sets of equipment, one for each space (exterior, draught lobby, circulation space and seminar rooms) were mounted on tripods. A small digital clock was attached to each tripod so that the time it took for participants to move to each space could be included in the questionnaires. Air temperature, wind speed, relative humidity and globe temperature were measured simultaneously while people were answering the questionnaires (**Figure 2**). Outdoor Equipment was located at 1.70 metres and 1.10 metres above the ground (ASHRAE 2004). In the draught lobby, circulation and seminar rooms, equipment was located 1.10 metres above the floor and in the centre of the space. All equipment started recording measurements 30 minutes before the survey began to ensure that the instruments adjusted to their surroundings (CIBSE-GuideA 2015; Nicol, F., Humphreys & Roaf 2012). Measurements were taken every 5 seconds and all data loggers were protected from direct solar radiation, the equipment is described in **Table 3**.

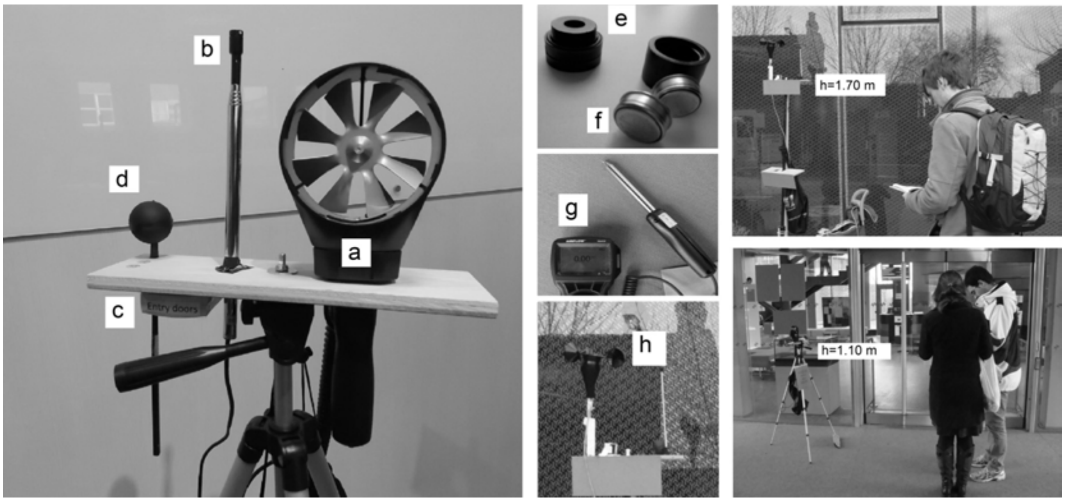


Figure 2. Equipment: (a) vane anemometers (TSI Airflow LCA 501), (b) OMEGA hot-wire anemometer, (c) data-loggers (HOBO-U12-012), (d) globe thermometer using a Thermochron i-button inside a black painted 40 mm table

tennis ball, (e) water-proof capsule for i-button, (f) Thermochron i-button, (g) portable manual hot wire anemometer (BSRIA TA-410), and (h) cup anemometer (OMEGA OM-CPWind 101A).

Table 3. Equipment specifications.

Variable	**Equipment**	**Measurement Range**	**Accuracy**	**Resolution**
Outside wind speed	OMEGA (OM-CP-Wind 101A Kit series	0 to 100 mph (0.8 to 45 m/s).	± 2.0 mph from 0 to 10 mph; ± 2.5% of reading from 10 to 100 mph	0.085 mph at 10 second reading interval
Air temperature and relative humidity (interior and exterior)	HOBO Data logger U-12	Temperature: -20° to 70°C RH: 5% to 95% RH	Temperature: ± 0.35°C from 0° to 50°C. RH: ±2.5% from 10% to 90% RH (typical), to a maximum of ±3.5%	Temperature: 0.03°C at 25°C RH: 0.03%
Exterior air temperature and relative humidity (back-up)	i-button hygrometer DS1923 inside a waterproof capsule	-20°C to +85°C; 0 to 100%RH	Better than ±0.5°C from -10°C to +65°C	8-Bit (0.6%RH) or 12-Bit (0.04%RH)
Indoor air flow	Air flow vane LCA501	0.25 to 30 m/s	±1% of reading ±0.02 m/s	0.01 m/s (1ft/min)
Indoor air flow	Hand-held manual anemometer TA 410	0 to 20 m/s	±5% of reading or ±0.025 m/s	0.01m/s (1ft/min)
Globe temperature	Globe thermometer using a 40mm ping pong ball and an i-button inside the ball.	i-button: DS1922L -40 to +85°C	±0.5°C from -10°C to +65°C	Selectable 8-bit = 0.5°C 11-bit = 0.0625°C

Equipment Limitations

Due to the limited budget, it was not possible to conduct three-dimensional measurements of wind speed and variable direction as recommended by (Johansson et al. 2014). The OMEGA cup anemometer that was employed does not register wind speeds below 1.75 mph (0.8 m/s).,Therefore wind speeds were only recorded above 1.75 mph. This was justifiable as participants in the pilot experiment found it very difficult to state their perception of low wind speeds. Although vane anemometers are not ideal for measuring multi-directional wind speed, they were only used indoors, facing the direction of the wind flow as influenced by the shape of the draught lobby and circulation spaces. Data from the vane-anemometers was compared with readings from hot-wire anemometers, which have been employed in previous indoor thermal comfort studies, e.g. (De Vecchi et al. 2015). The globe thermometers used in this study are also limited in accuracy, consisting of a 40 mm ping pong ball with an i-button data-logger inside. It was not possible to use small thermocouples or a resistance probe as recommended in (EN.ISO.7726 2001). However, the level of accuracy was good enough for some tentative conclusions to be drawn from this study.

Equipment Calibration

All equipment was obtained calibrated from the manufacturer, except for the vane anemometers (TSI Airflow LCA 501) and portable manual hot-wire anemometer (BSRIA TA-410), which were supplied by the Faculty of Engineering at The University of Sheffield. All anemometers had a calibration certificate, issued by the manufacturer, covering the experimental period. All the equipment was tested under the same climatic conditions (a closed and shaded office) for 24 hours. The measurement values were consistent with the accuracies and resolutions stated by the manufacturers in **Table 3**. It was not possible to compare the globe temperature measurements with a calibrated device on a limited budget. However, in this exercise globe temperature measurements correlate very close to air temperature under non-variable interior conditions under limited solar radiation (overnight).

Fieldwork

The measuring periods were selected based on Met-office data in order to represent typical warm, cold and transitional periods. Spring surveys were conducted on 4 days from 28th May 2013 to 7th June, summer surveys were conducted on 9 days from 24th June to 1st August autumn surveys were conducted on 12 days from 27th September to 21st October 2013, and winter surveys were conducted on 11 days from 9th February 2014 to 28th February. Surveys normally lasted from 30-40 minutes between 11:00-17:00 on consecutive days in each building, although some surveys were conducted in different buildings on the same day at different times. A comparison between historic climate records for Sheffield (1981-2010) and average temperatures during the survey period (2013-2014) taken from the local weather station within the university (Geography department) shows that the climatic conditions in 2013-2014 were typical of the 1981-2010 period (**Figure 3**).

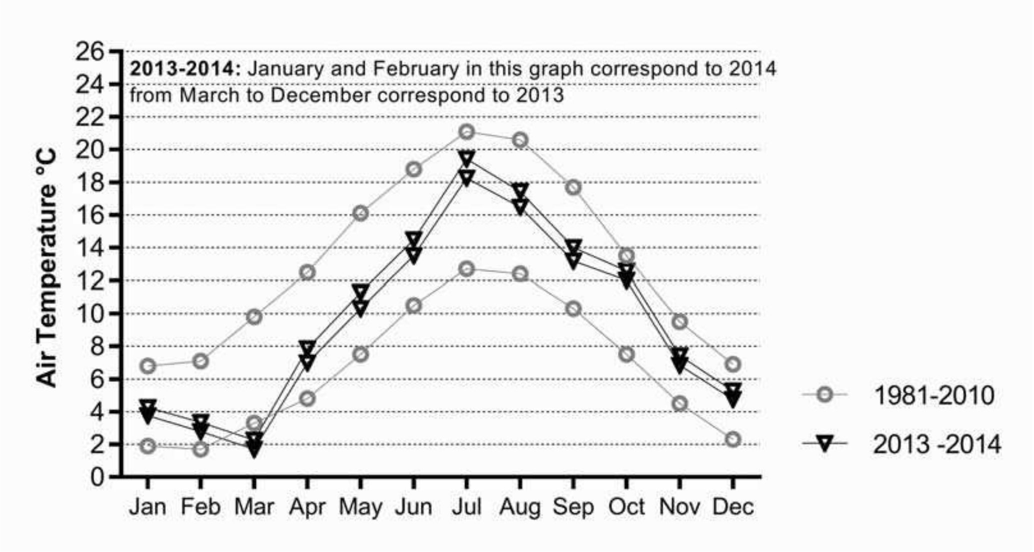


Figure 3. Comparison between historic climate records for Sheffield (1981–2010) taken from the UK Met-Office and average temperatures during the survey period (2013–14).

Questionnaires and procedure

Two very short 'right here, right now' thermal comfort questionnaires were used depending on the route that participants followed from the outside to the final destination (seminar room). Both questionnaires recorded information about demographics, clothing, previous activities and thermal comfort (**Appendix 1**). Questionnaire A was designed for participants walking to the seminar room using the lobby area. It had four sections corresponding to the four spaces in which they were walking (exterior, draught lobby, circulation and seminar room). Questionnaire B was designed for participants entering directly from the exterior to the seminar room (two sections: exterior and seminar room). The seven-point ASHRAE scale was used to measure people's thermal sensation vote, a three-point McIntryre scale to evaluate thermal preferences as used by

(Jitkhajornwanich & Pitts 2002) and a three-point scale to measure perception of temperature change. Wind speed perception and relative humidity was measured with a seven point scale (Tsutsumi et al. 2007). Questionnaire A was designed to be completed in under 10 minutes and questionnaire B in under 7 minutes.

The experiment started immediately after participants arrived at the meeting point outside the case study buildings. Participants were assessed over periods lasting from 5 to 10 minutes. The survey was coordinated to capture a large number of participants under similar climatic conditions in periods of time from 30 to 40 minutes. Volunteers participated only once, and were assigned only one route in order to reduce bias. Participants were asked to follow trajectory A or B and to answer each section of the questionnaire at specific points (**Figure 4)**. The experiment lasted from 5 (Group B) to 7 (Group A) minutes on average per participant, with about 30 seconds spent in each space (exterior, entry doors, circulation and seminar room). Participants answered each section of the questionnaire next to the data-logging equipment in each space. The trajectories and equipment location in each building are illustrated in **Figure 5** for HS building, **Figure 6** ICS building and **Figure 7** JW building.

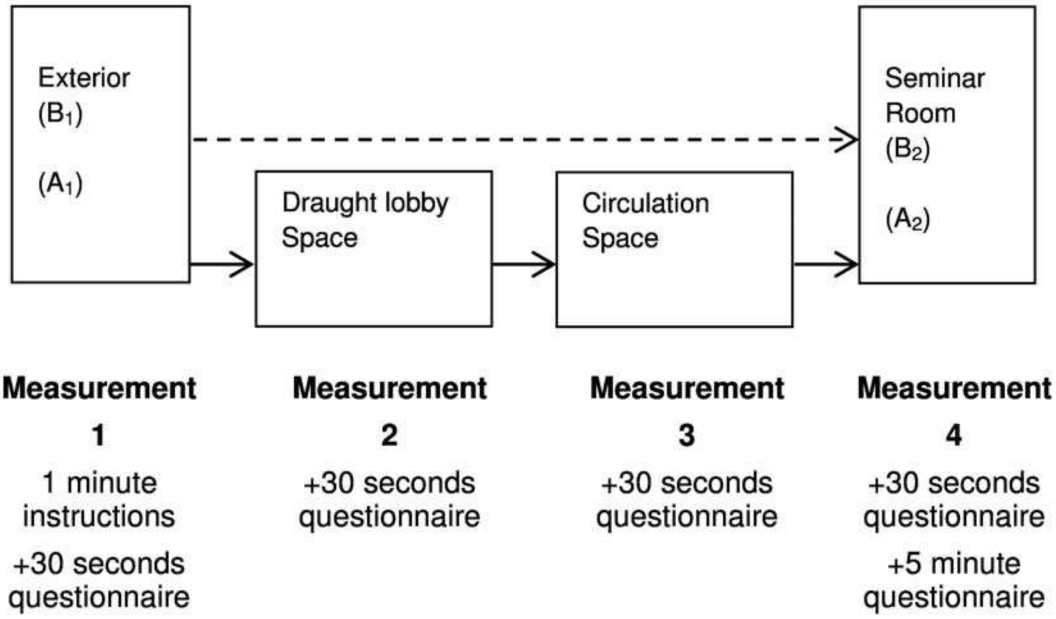


Figure 4. Survey procedure for routes A and B.

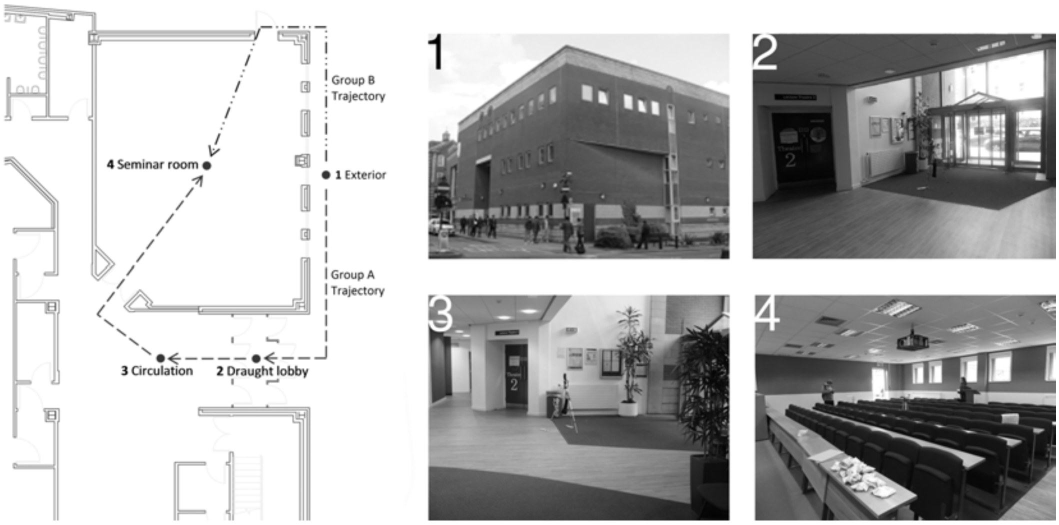


Figure 5. Routes A and B in the Sir Henry Stephenson (HS) building.

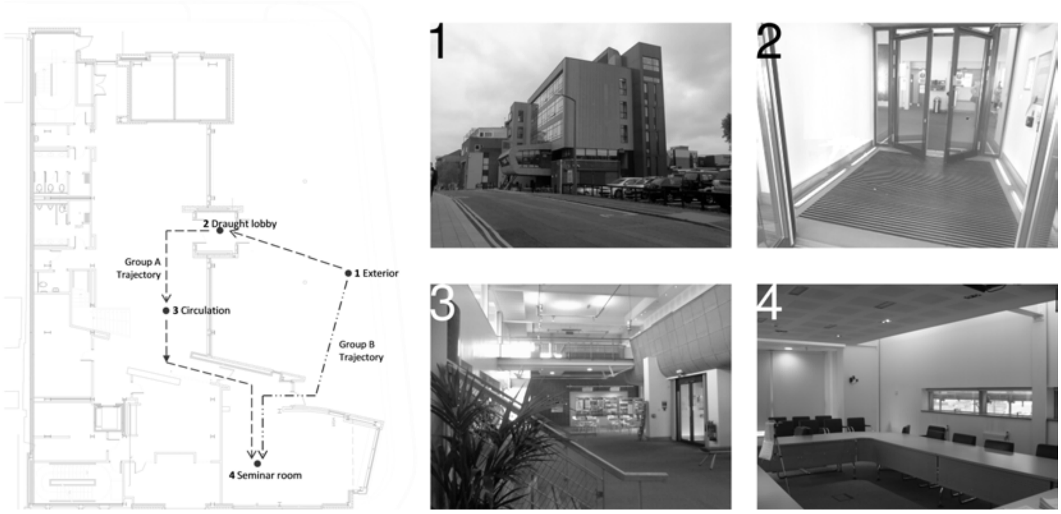


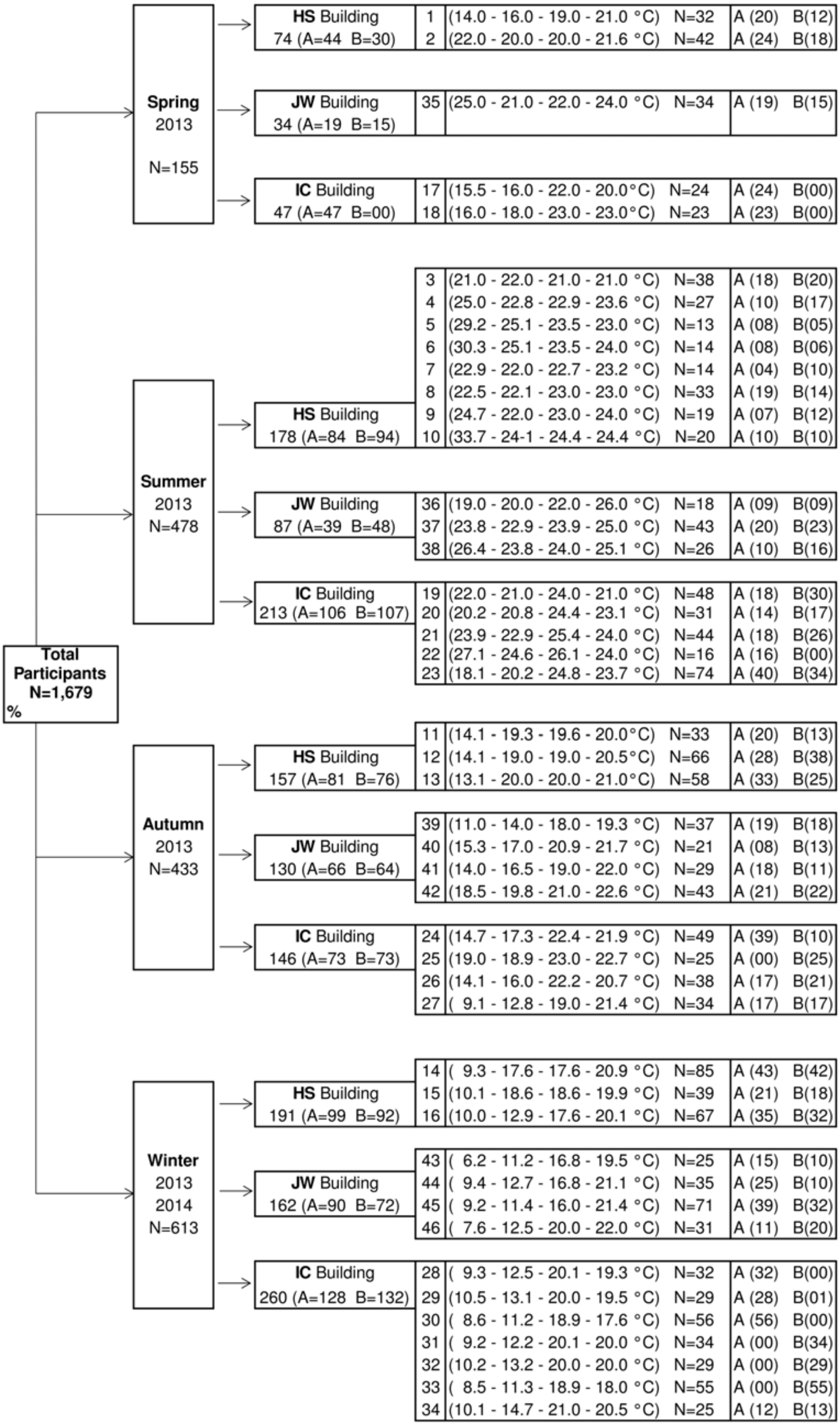
Figure 6. Routes A and B in the Jessop West (JW) building.

Figure 7. Routes A and B in the Interdisciplinary Centre of the Social Sciences (ICOSS) (ICS) building.

Results

The results are presented in three sections. The first section includes a description of the physical measurements outside and inside the monitored buildings. The second section reports results from the 1,749 participants, providing an overview of thermal perception outside the buildings (EXT) and inside the seminar rooms (SR) in the four seasons of the year. Detailed information about the distribution of participants between buildings and seasons is illustrated in **Table 1.** The third section focuses on thermal perception in the transitional spaces. From the total sample, 1,679 participants were divided into 46 thermal bins in A or B groups for further statistical testing (**Figure 8**). In some cases it was not possible to have A and B participants due to the building operation, therefore a few thermal bins only included one group.

- Thermal analysis of 37 sequences (exterior-draught lobby-corridor-seminar rooms) was first conducted in Group A (829 participants).
- Comparisons before and after moving from the exterior to the interior were conducted in 28 sequences, which included large sample sizes of groups A and B (1,206 participants).



Total Participants N=1,679
%

Spring 2013 N=155	**HS** Building 74 (A=44 B=30)	1	(14.0 - 16.0 - 19.0 - 21.0 °C)	N=32	A (20)	B(12)
		2	(22.0 - 20.0 - 20.0 - 21.6 °C)	N=42	A (24)	B(18)
	JW Building 34 (A=19 B=15)	35	(25.0 - 21.0 - 22.0 - 24.0 °C)	N=34	A (19)	B(15)
	IC Building 47 (A=47 B=00)	17	(15.5 - 16.0 - 22.0 - 20.0°C)	N=24	A (24)	B(00)
		18	(16.0 - 18.0 - 23.0 - 23.0°C)	N=23	A (23)	B(00)
Summer 2013 N=478	**HS** Building 178 (A=84 B=94)	3	(21.0 - 22.0 - 21.0 - 21.0 °C)	N=38	A (18)	B(20)
		4	(25.0 - 22.8 - 22.9 - 23.6 °C)	N=27	A (10)	B(17)
		5	(29.2 - 25.1 - 23.5 - 23.0 °C)	N=13	A (08)	B(05)
		6	(30.3 - 25.1 - 23.5 - 24.0 °C)	N=14	A (08)	B(06)
		7	(22.9 - 22.0 - 22.7 - 23.2 °C)	N=14	A (04)	B(10)
		8	(22.5 - 22.1 - 23.0 - 23.0 °C)	N=33	A (19)	B(14)
		9	(24.7 - 22.0 - 23.0 - 24.0 °C)	N=19	A (07)	B(12)
		10	(33.7 - 24-1 - 24.4 - 24.4 °C)	N=20	A (10)	B(10)
	JW Building 87 (A=39 B=48)	36	(19.0 - 20.0 - 22.0 - 26.0 °C)	N=18	A (09)	B(09)
		37	(23.8 - 22.9 - 23.9 - 25.0 °C)	N=43	A (20)	B(23)
		38	(26.4 - 23.8 - 24.0 - 25.1 °C)	N=26	A (10)	B(16)
	IC Building 213 (A=106 B=107)	19	(22.0 - 21.0 - 24.0 - 21.0 °C)	N=48	A (18)	B(30)
		20	(20.2 - 20.8 - 24.4 - 23.1 °C)	N=31	A (14)	B(17)
		21	(23.9 - 22.9 - 25.4 - 24.0 °C)	N=44	A (18)	B(26)
		22	(27.1 - 24.6 - 26.1 - 24.0 °C)	N=16	A (16)	B(00)
		23	(18.1 - 20.2 - 24.8 - 23.7 °C)	N=74	A (40)	B(34)
Autumn 2013 N=433	**HS** Building 157 (A=81 B=76)	11	(14.1 - 19.3 - 19.6 - 20.0°C)	N=33	A (20)	B(13)
		12	(14.1 - 19.0 - 19.0 - 20.5°C)	N=66	A (28)	B(38)
		13	(13.1 - 20.0 - 20.0 - 21.0°C)	N=58	A (33)	B(25)
	JW Building 130 (A=66 B=64)	39	(11.0 - 14.0 - 18.0 - 19.3 °C)	N=37	A (19)	B(18)
		40	(15.3 - 17.0 - 20.9 - 21.7 °C)	N=21	A (08)	B(13)
		41	(14.0 - 16.5 - 19.0 - 22.0 °C)	N=29	A (18)	B(11)
		42	(18.5 - 19.8 - 21.0 - 22.6 °C)	N=43	A (21)	B(22)
	IC Building 146 (A=73 B=73)	24	(14.7 - 17.3 - 22.4 - 21.9 °C)	N=49	A (39)	B(10)
		25	(19.0 - 18.9 - 23.0 - 22.7 °C)	N=25	A (00)	B(25)
		26	(14.1 - 16.0 - 22.2 - 20.7 °C)	N=38	A (17)	B(21)
		27	(9.1 - 12.8 - 19.0 - 21.4 °C)	N=34	A (17)	B(17)
Winter 2013 2014 N=613	**HS** Building 191 (A=99 B=92)	14	(9.3 - 17.6 - 17.6 - 20.9 °C)	N=85	A (43)	B(42)
		15	(10.1 - 18.6 - 18.6 - 19.9 °C)	N=39	A (21)	B(18)
		16	(10.0 - 12.9 - 17.6 - 20.1 °C)	N=67	A (35)	B(32)
	JW Building 162 (A=90 B=72)	43	(6.2 - 11.2 - 16.8 - 19.5 °C)	N=25	A (15)	B(10)
		44	(9.4 - 12.7 - 16.8 - 21.1 °C)	N=35	A (25)	B(10)
		45	(9.2 - 11.4 - 16.0 - 21.4 °C)	N=71	A (39)	B(32)
		46	(7.6 - 12.5 - 20.0 - 22.0 °C)	N=31	A (11)	B(20)
	IC Building 260 (A=128 B=132)	28	(9.3 - 12.5 - 20.1 - 19.3 °C)	N=32	A (32)	B(00)
		29	(10.5 - 13.1 - 20.0 - 19.5 °C)	N=29	A (28)	B(01)
		30	(8.6 - 11.2 - 18.9 - 17.6 °C)	N=56	A (56)	B(00)
		31	(9.2 - 12.2 - 20.1 - 20.0 °C)	N=34	A (00)	B(34)
		32	(10.2 - 13.2 - 20.0 - 20.0 °C)	N=29	A (00)	B(29)
		33	(8.5 - 11.3 - 18.9 - 18.0 °C)	N=55	A (00)	B(55)
		34	(10.1 - 14.7 - 21.0 - 20.5 °C)	N=25	A (12)	B(13)

Figure 8. Grouping of thermal bins per building and season of the year.

Thermal conditions

Exterior

The overall mean air temperatures at the exterior of the buildings (HS+JW+ICS) during the surveys were spring = 19.1°C (SD=4.3), summer = 23.14°C (SD=3.9), autumn = 14.1°C (SD=2.9) and winter = 9.6°C (SD=2.2) (**Table 4**). A one way ANOVA test reveals significant differences at the $p < .05$ level in exterior air temperature values between the four seasons of the year, F (3, 1745) = 538, $p = .01$. The difference between the mean scores was medium (effect of size = 0.48). **Table 4** also illustrates a comparison between the collected measurements, data from the university's weather station and two related studies conducted in Sheffield. It can be seen that air temperatures and relative humidity are within the ranges recorded by the local weather station and finding from previous studies (Nikolopoulou, M. & Lykoudis 2006; Pitts 2010). An ANOVA test revealed significant differences in exterior air temperatures between buildings in the four seasons of the year (see values in **Figure 9**) $p=.01< .05$, as well as RH, $p=.01 < .05$. Multiple comparisons between buildings (Post-hoc tests, Turkey HSD) indicated no significant differences in relative humidity in spring between HS (mean=18.5 °C) and ICS (mean=15.74 °C). During winter, no significant differences were found between JW (mean=9.48 °C and HS=10.3 °C).

Table 4. Exterior and interior climatic conditions during the short-term (minutes) surveys in 2013-2014 and results from related projects conducted in Sheffield, UK.

	Exterior	*Spring*	*Summer*	*Autumn*	*Winter*
Sheffield 2013-2014 ***short-time (minutes) measurements during surveys**	Air Temperature	*(May-Jun)* **Mean= 19.1 °C** *Min=14.0 °C* *Max=25 °C* *SD=4.34*	*(June-July)* **Mean= 23.2 °C** *Min=17.0 °C* *Max=36 °C* *SD=3.90*	*(Oct-Nov)* **Mean= 14.1 °C** *Min=8.0 °C* *Max=20.0 °C* *SD=14.23*	*(February)* **Mean=9.6 °C** *Min=21.0 °C* *Max=25.0 °C* *SD=9.66*
	RH	**Mean= 50%** *Min=32%* *Max=78%* *SD=16.7*	**Mean= 51%** *Min=34%* *Max=75%* *SD=13.7*	**Mean= 70%** *Min=42%* *Max=89%* *SD=11.1*	**Mean= 61.7%** *Min=30%* *Max=85%* *SD=9.65*
	Wind speed	Mean= 0.14 m/s *Min= < .05 m/s* *Max=< .05 m/s* *SD=.17*	Mean=0.10 m/s *Min= < .05 m/s* *Max=3.0 m/s* *SD=.41*	Mean=0.04 m/s *Min= < .05 m/s* *Max=< .05 m/s*	Mean=0.9 m/s *Min= < .05 m/s* *Max=< .05 m/s*
Sheffield 2013-2014 University weather station	Air Temperature	**Mean= 9.4 °C** *Min=-2.16 °C* *Max=21.14 °C*	**Mean= 18.6 °C** *Min=7.4 °C* *Max=29.7 °C*	**Mean= 9.11 °C** *Min=-2.8 °C* *Max=21.7 °C*	**Mean= 4.6 °C** *Min=-3.6 °C* *Max=13.0 °C*
***24/7 hours measurements**	RH	**Mean=69%**	**Mean=72%**	**Mean=82%**	**Mean=81%**
Sheffield Pitts, 2010 ***monthly measurements**	Air Temperature	*May* **Mean= 13.7 °C** *Min=0.4 °C* *Max=29.1 °C*	*June* **Mean= 15.4 °C** *Min=4.9 °C* *Max=28.0 °C*	*October* **Mean= 9.7 °C** *Min=-3.0 °C* *Max=21.3 °C*	*February* **Mean= 9.7 °C** *Min=5.1 °C* *Max=16.3 °C*
Sheffield	Air Temperature	**Mean= 13.1°C**	**Mean= 21.3°C**	**Mean= 16.7°C**	**Mean= 9.5°C**
2001-2002	RH	Mean= 60%	Mean= 69%	Mean= 63%	Mean= 49%
RUROS	Wind speed	Mean= 0.5m/s	Mean=1.0m/s	Mean=0.9 m/s	Mean=0.5m/s

Interior climatic conditions in the seminar rooms during the surveys in the four seasons of the year during the short-time measurements.

	Seminar rooms	**Spring**	**Summer**	**Autumn**	**Winter**
Sheffield 2013-2014	Air Temperature	Mean= 21.9°C	Mean= 23.5°C	Mean= 21.1°C	Mean= 20.0°C
***short-time (minutes)**	RH	Mean= 41%	Mean= 49%	Mean= 50%	Mean= 40%
measurements during surveys	Wind speed	< .05m/s	< .05m/s	< .05m/s	< .05m/s

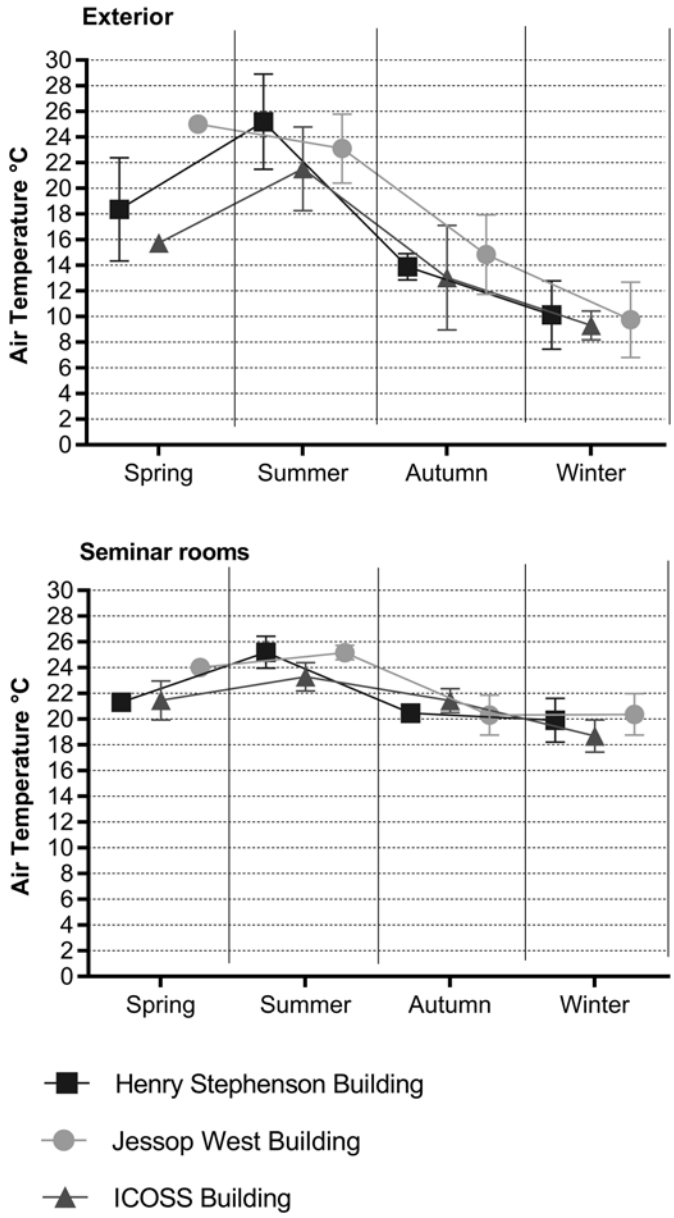


Figure 9. Exterior and interior air temperatures in the three case study buildings during the four seasons of the year.

Interior (seminar rooms)

Interior mean air temperatures for the three buildings in the four seasons of the year are illustrated in **Table 4**. Multiple comparisons between seasons using a one way ANOVA test reveal significant differences at the $p < .05$ level in interiors (SR) between the four seasons of the year: F (3, 1161) = 538, $p = .01$. The difference between the mean score (spring = 21.9°C, summer = 23.5°C, autumn = 21.1°C and winter = 20.0°C) was medium (effect of size = 0.48). Multiple comparisons between buildings and a Post-hoc test (Turkey HSD) indicated no significant ΔT differences between HS and ICS in spring and summer and no significant differences between ICS and JW in autumn and winter.

Transitional spaces

Figure 10 illustrates the thermal variability across the interior spaces in the three buildings in each season. The largest temperature differences were registered during winter. Mean air temperature differences (ΔT) between the exterior (EXT) and seminar room (SR) were the largest (10.1°C in HS, 9.3°C in ICS and 10.6°C in JW buildings). In summer, the mean air temperature differences between EXT and SR were smaller (2.1°C in HS, 1.7°C in ICS and 2°C in JW). The linear regressions in **Figure 11** show a strong correlation between the EXT and draught lobby (DL) (r2 = .74, $p = 0.01 < .05$) in the three buildings across all seasons of the year. This correlation decreased towards the interior spaces; between EXT and circulation space CS (r2 = .60, $p = 0.01 < .05$) and between EXT and SR (r2 = .54, $p = 0.01 < .05$). When analysing the air temperature correlations between consecutive spaces, the strongest correlation was found between EXT and DL ($r^2 = 0.74$, $p = 0.01 < .05$), followed by the DL and CS ($r^2 = 0.54$ $p = 0.01 < .05$) and CS and SR ($r^2 = 0.43$ $p = 0.01 < .05$). In the same way, relative humidity and wind speed in the DL, CS and SR also gradually changed from the exterior to the interior.

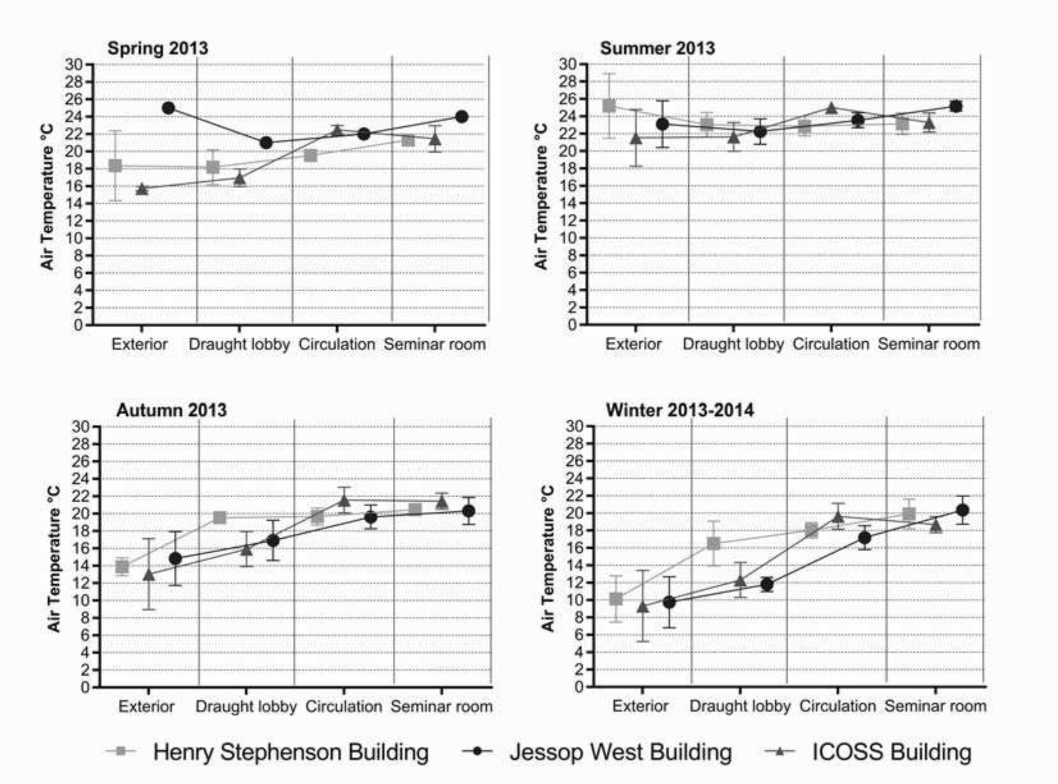
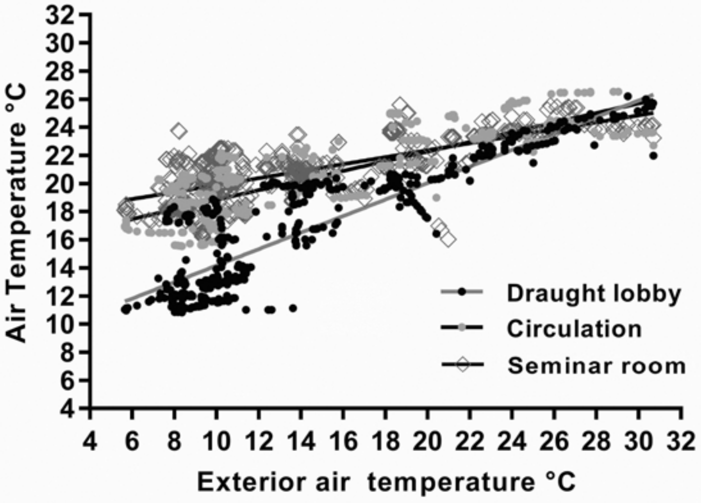


Figure 10. Air temperatures in the transitional spaces of the three buildings in the four seasons of the year (2013–14).



Exterior - Draugh lobby
$r^2=.7412$
$P=0.0001<.05$
$Y = 0.5851*X + 8.397$

Exterior - Circulation
$r^2=.6089$
$P=0.0001<.05$
$Y = 0.3429*X + 15.41$

Exterior - Seminar room
$r^2=.5449$
$P=0.0001<.05$
$Y = 0.2514*X + 17.38$

Figure 11. Air temperature correlations between spaces: (a) exterior and draught lobby, (b) exterior and circulation space, and (c) exterior and seminar room.

Participant's thermal perception

Due to the equipment limitations in this study described before, relative humidity and wind speed are included as a reference but thermal perception is based on air temperature values. Participants were reluctant to describe their perceptions of relative humidity and air speed. Several commented that as these two variables were not extreme at the time of the survey they were difficult to evaluate. Small scales (i.e., 1 to 3 points) may be more appropriate for use in climates without extreme physical variables. In **Figure 12**, it can be seen that the majority of participants' perceptions of air speed and relative humidity were within the comfortable band. For relative humidity, the mean values were 'just right', 'slightly dry', and 'too dry'. For wind speed in DL, CS and SR the mean values were 'just right', 'slightly still', 'still' and 'much too still'. Exterior wind speed was a little higher than interior spaces with a mean value between 'just right' and 'slightly breezy'.

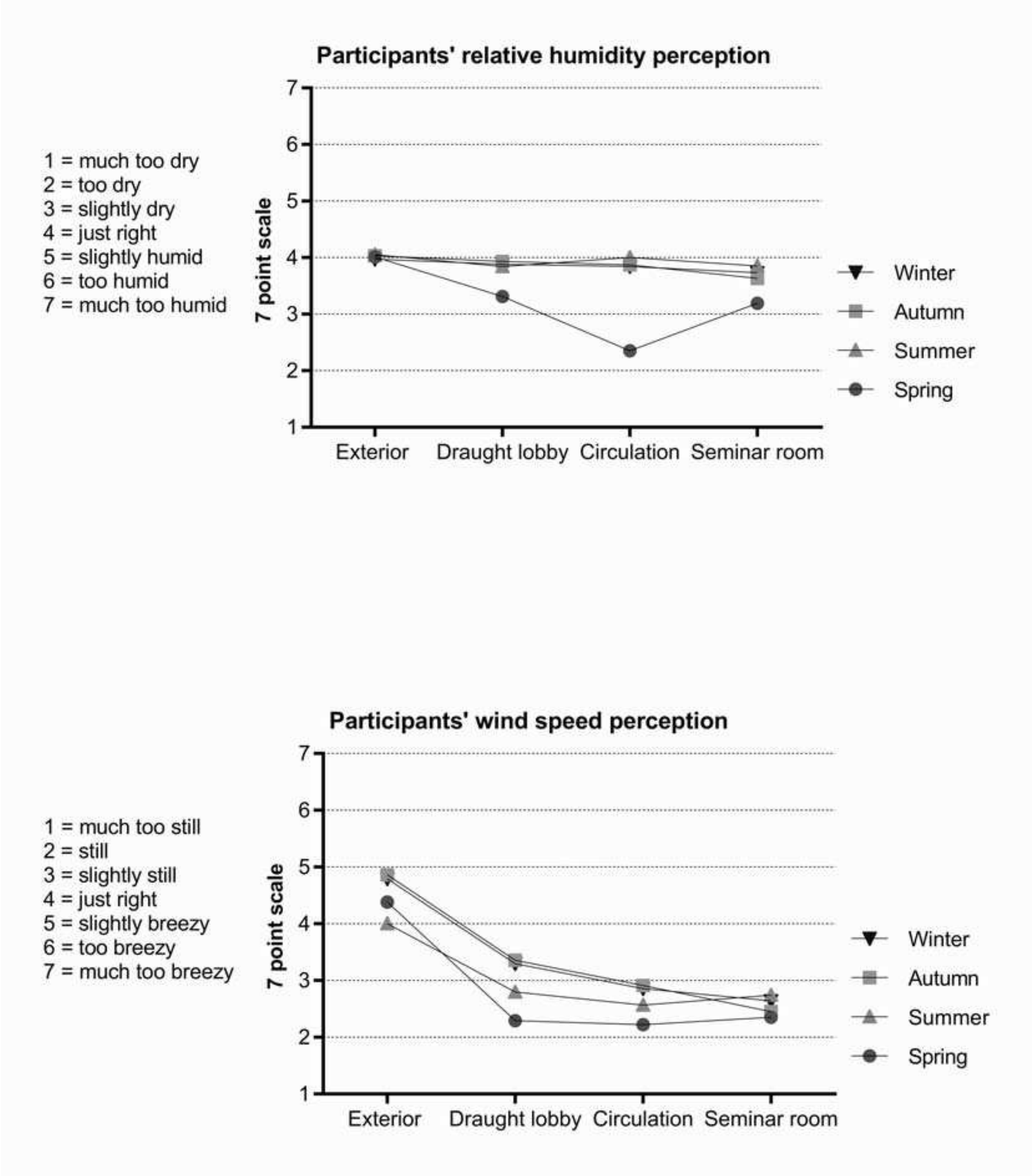


Figure 12. Participants' relative humidity and wind speed perception during the survey.

Exterior and Interior

In this study, based on the PPD thermal index assumption that people voting in the three central categories (-1, 0, +1) of the 7-point thermal sensation scale are satisfied with the thermal environment (de Dear et al. 2015) at the exterior 54% of the participants were comfortable in spring, 67.9% in summer, 50.5% in autumn and 43.3% in winter (**Figure 13**). This figure shows that in spring and summer the percentage of thermal sensation votes in the central categories increased by 30% and 10% respectively when participants arrived in the seminar rooms. In autumn and winter, the percentage of votes in the central categories increased by 15% and 26% respectively with a dramatic change in distribution towards the warm band.

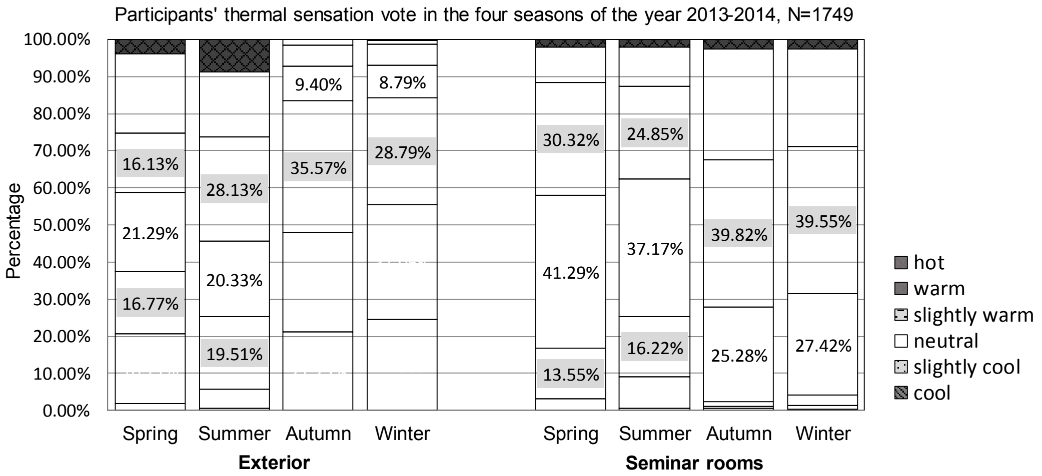


Figure 13. Participants' seasonal thermal perception of the exterior and in the seminar room.

Findings from the complete dataset (exterior – interior) demonstrate the effect of seasonal climatic conditions on the thermal sensation vote (TSV) of participants in the exterior environment, and the TSV range in which participants preferred 'no change' to thermal conditions. **Figure 14** shows that participants tagged their thermal perception to a given temperature differently depending on the season of the year. For instance, when looking at the mean value and standard deviation lines, 14°C was perceived as 'cold' in spring and summer but 'warm' in autumn and winter; this pattern was also found in the seminar room, though it was less pronounced. **Figure 15** shows the TSV range outside and in the seminar room when the thermal preference was ‘no change’. At the exterior measuring point in spring and summer 90% of votes were distributed from cool to warm, and in autumn and winter 95% of votes were distributed from cool to warm. In the seminar room, in spring and summer, the distribution of TSV votes when thermal preference was ‘no change’ was within the same range as the exterior. By contrast, in autumn and winter, the distribution of TSV votes when thermal preference was ‘no change’ shifted from the cold band (cool and slightly cool) at the exterior measuring point to the warm band (slightly warm and warm) in the seminar room.

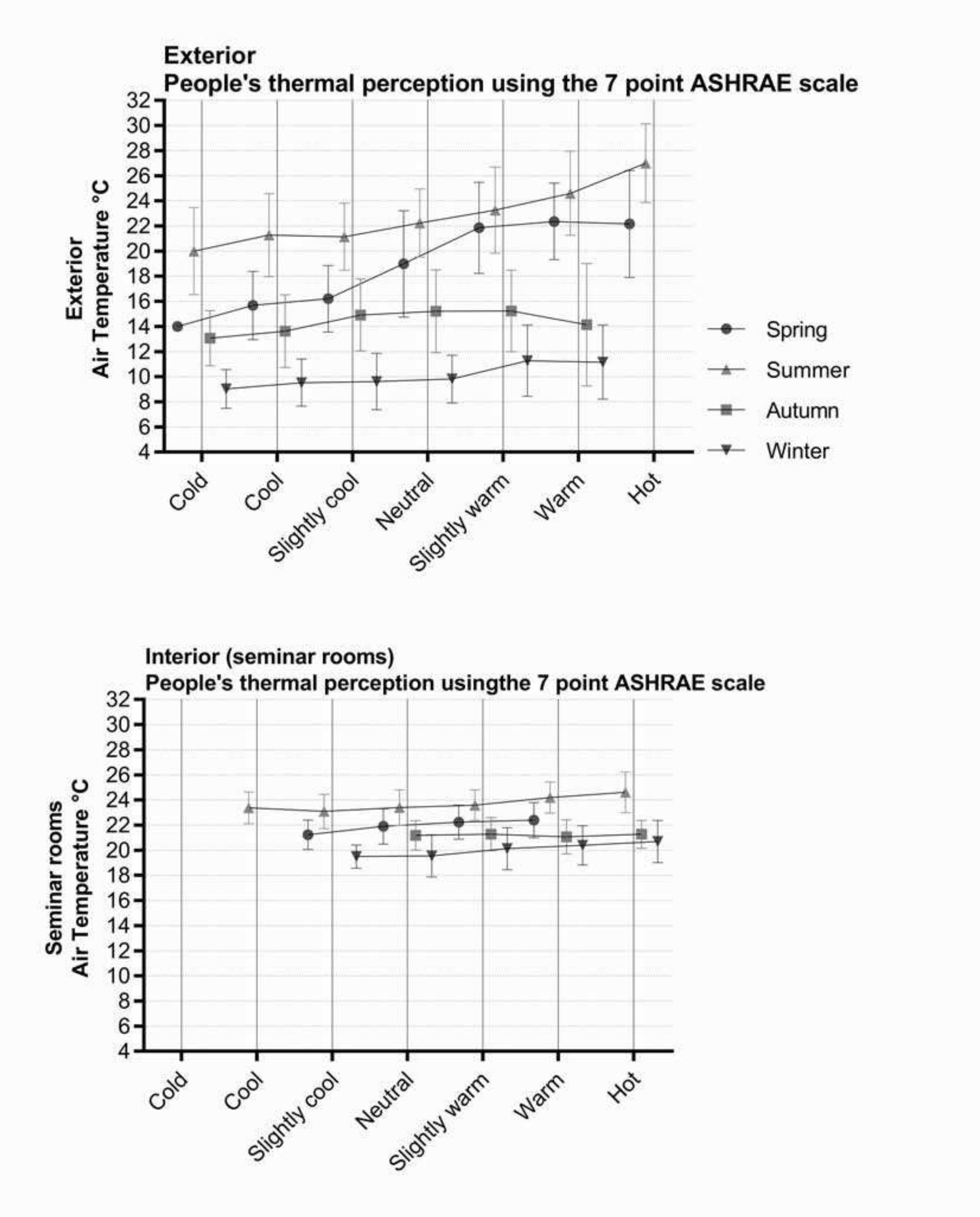


Figure 14. Participants' thermal comfort perception in the exterior space and seminar room in the four seasons of the year.

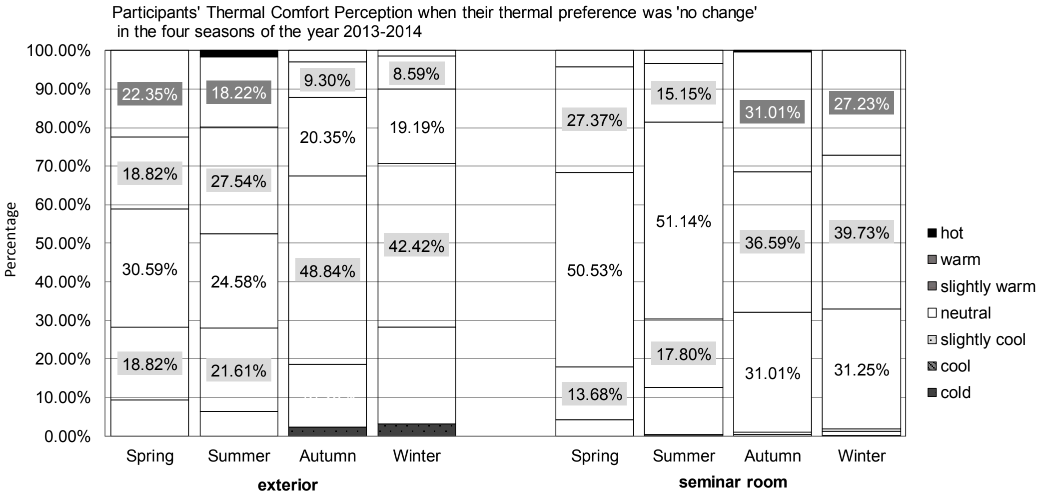


Figure 15. Participants’ thermal sensation vote in the four seasons of the year when their thermal preference was ‘no change’.

Thermal patterns in transitional spaces

In order to analyse the effect of the use of the lobby space on TSV, participants were grouped in *thermal bins*. Each bin corresponded to individuals who participated under the same range of exterior climatic conditions on the same day, in the same building around the same time. The exterior air temperature (when constant without abrupt changes) was taken into account when grouping in bins. The maximum time range where air temperature and RH did not change dramatically was around 30 minutes (ΔT from .05 °C – 1 °C in most cases). From a total of 1,749 participants, 1,679 were organized into 46 thermal bins. Each thermal bin had a different *thermal direction* (order in which air temperature changes from one space to another). The mean air temperature was calculated for each space in the sequence. 36 group-A bins with the largest sample sizes were selected for further analysis.

Table 5 compares the demographics of the two groups of participants in each sequence (Pearson Chi- square test). **Table 6** summarises the age, weight and clothing value (clo) of participants (T-test for independent groups). There were significant demographic differences between the two groups (**Table 5**) but no significant differences in age, weight and clo value (**Table 6**). Despite these demographic differences the Mann-Whitney U test results **(Table 7)** reveal that outside of the buildings there was no significant difference in TSV. This is very important, as it shows the subjects from the selected bins had very similar thermal perceptions of the exterior environment at the beginning of the survey. A Friedman test was used to compare repeated measurements of TSV immediately after moving from one space to another. The Wilcoxon signed rank test was then used to identify where there was a significant difference in the sequence. Based on this analysis, a key finding was the identification of three new thermal patterns shaped by the TSV of participants in relation to temperature changes from one space to another. These patterns were:

- *'Flat pattern'* (4 bins): Primarily occurring during spring and summer. It involves a relatively small air temperature range between spaces (20°C – 23°C) and only up to 2°C temperature difference (ΔT) between spaces.
- '*Sudden pattern*' (18 bins): From cold to hot, corresponding primarily to autumn and winter. It includes much larger air temperature ranges between the four spaces (-6.2°C – 26°C), with up to 13°C ΔT between spaces.
- '*Irregular pattern'* (15 bins): Includes ΔT from cold to hot or hot to cold without any consistent order. The majority of these thermal bins were

identified in summer. The air temperature ranges between the four spaces was 8.5°C – 27°C with up to 10°C ΔT between spaces.

Table 5. Comparison of demographics of group A and B participants.

				Building	**Gender** *Male Female*	**Nationality** *UK International*	**Years of residence in Sheffield** *>1 year <*
					Pearson Chi-Square Sig. (2-sided)	Pearson Chi-Square Sig. (2-sided)	Pearson Chi-Square Sig. (2-sided)
Flat sequences N= 4	**N**	**A**	**B**				
Sequence 2 N=42	42	24	18	HS	.200	.047*	.856
Sequence 3 N=38	38	18	20	HS	.357	.260	.782
Sequence 7 N=14	14	4	10	HS	---	---	---
Sequence 8 N=33	33	19	14	HS	.084	.416	.024*
Sudden Sequences N=18							
Sequence 1	32	20	12	HS	1.00	1.00	.314
Sequence 11	33	20	13	HS	1.00	1.00	.515
Sequence 12	66	28	38	HS	.256	.004*	.647
Sequence 13	58	20	13	HS	.261	.086	.072
Sequence 14	85	43	42	HS	.700	.275	.037*
Sequence 15	39	21	18	HS	.290	.429	.173
Sequence 16	67	35	32	HS	.001*	.792	.987
Sequence 18	23	23	0	ICS	---	---	---
Sequence 24	49	39	10	ICS	.419	.496	1.00
Sequence 27	34	17	17	ICS	.078	.438	1.00
Sequence 34	25	12	13	ICS	.695	.160	.226
Sequence 36	18	9	9	JW	---	---	---
Sequence 39	37	19	18	JW	.638	1.00	.362
Sequence 42	43	39	10	JW	.091	.289	.232
Sequence 43	25	15	10	JW	1.00	1.00	.442
Sequence 44	35	25	10	JW	.458	.053	1.00
Sequence 45	71	39	32	JW	.267	.839	.246
Sequence 46	31	11	20	JW	.012*	1.00	.372
Irregular Sequences N=15							
Sequence 4	27	10	17	HS	.219	.621	.448

Sequence 17	24	24	0	ICS	---	---	---
Sequence 19	48	18	30	ICS	.154	1.00	.644
Sequence 21	44	18	26	ICS	.728	.738	1.00
Sequence 22	16	16	0	HS	---	---	---
Sequence 23	74	40	34	ICS	.370	.498	.497
Sequence 26	38	17	21	ICS	.415	.046*	.973
Sequence 28	32	32	0	ICS	---	---	---
Sequence 29	29	28	1	ICS	---	---	---
Sequence 30	56	56	0	ICS	---	---	---
Sequence 35	34	19	15	HS	.603	.053	.901
Sequence 37	43	20	23	JW	.494	.004*	.000*
Sequence 38	26	10	16	JW	.004*	.234	.109
Sequence 40	21	8	13	JW	---	---	---
Sequence 41	29	18	11	JW	.196	.316	.268

*Statistically significant p <.05

Note: In sequences with small sample sizes (including a group size less than 5), Fisher's Exact Test values have been used (Exact Sig. 2-sided). In all other sequences the Pearson Chi-Square Asymp. Sig. Test (2-sided) was employed.

Table 6. Age, weight and clothing of group A and B participants.

					Age T-test (independent)			**Weight**			**Clothing Value (clo)**		
					Mean value		Sig.	*Mean value*		Sig.	*Mean value*		Sig.
Flat Sequences (4)	**N**	**A**	**B**	**Bldg.**	A	B	**p**	A	B	**p**	A	B	**p**
Sequence 2	42	24	18	HS	22.3	22.3	.964	74.9	63.0	.003*	0.56	0.70	.029*
Sequence 3	38	18	20	HS	23.9	24.7	.503	68.1	65.6	.617	0.68	0.61	.312
Sequence 7	14	4	10	HS	27.0	23.7	.243	71.3	67.0	.457	0.48	0.56	.638
Sequence 8	33	19	14	HS	24.4	23.0	.085	68.1	69.1	.792	0.70	0.61	.381
Sudden Sequences (18)													
Sequence 1	32	20	12	HS	21.7	22.8	.036*	61.8	65.8	.318	0.91	0.90	.803
Sequence 11	33	20	13	HS	23.3	22.0	.278	70.2	72.0	.676	1.00	1.00	1.00
Sequence 12	66	28	38	HS	20.2	20.6	.599	63.8	62.8	.779	1.00	1.02	.395
Sequence 13	58	20	13	HS	22.2	21.7	.407	66.2	76.1	.018*	1.03	1.00	.389
Sequence 14	85	43	42	HS	21.6	21.8	.610	66.6	67.4	.688	1.02	1.04	.543
Sequence 15	39	21	18	HS	24.2	20.8	.155	73.1	67.4	.149	1.04	1.00	.361
Sequence 16	67	35	32	HS	20.3	22.7	.003*	65.4	72.8	.023*	1.08	1.03	.373
Sequence 18	23	23	0	ICS	25.7	---	---	68.3	---	---	0.79	---	---
Sequence 24	49	39	10	ICS	20.9	19.4	.017*	67.3	69.5	.629	1.00	1.00	1.00
Sequence 27	34	17	17	ICS	21.2	20.8	.565	65.4	71.2	.150	1.00	1.05	.325
Sequence 34	25	12	13	ICS	24.9	24.8	.956	64.00	69.2	.286	1.17	1.00	.166
Sequence 36	18	9	9	JW	25.3	24.3	.611	62.8	69.7	.314	0.86	0.59	.016*
Sequence 39	37	19	18	JW	20.2	19.9	.763	64.8	65.8	.796	1.05	1.06	.892
Sequence 42	43	39	10	JW	22.8	20.8	.286	61.6	68.6	.053	1.00	1.00	1.00
Sequence 43	25	15	10	JW	22.7	22.6	.926	69.7	67.8	.740	1.00	1.00	1.00
Sequence 44	35	25	10	JW	22.5	22.8	.867	71.3	68.6	.622	1.04	1.10	.504
Sequence 45	71	39	32	JW	23.7	22.6	.410	65.5	65.8	.943	1.10	1.06	.553

Sequence 46	31	11	20	JW	22.9	23.3	.840	76.6	66.3	.033*	1.00	1.00	1.00
Irregular Sequences (15)													
Sequence 4	27	10	17	HS	25.7	23.6	.117	73.8	66.8	.290	0.53	0.50	.590
Sequence 17	24	24	0	ICS	21.4	---	---	68.1	---	---	0.89	---	---
Sequence 19	48	18	30	ICS	23.7	23.8	.908	66.4	67.9	.653	0.62	0.66	.555
Sequence 21	44	18	26	ICS	20.0	18.8	.185	61.4	66.6	.147	0.56	0.49	.283
Sequence 22	16	16	0	HS	22.4	---	---	63.3	---	---	0.52	---	---
Sequence 23	74	40	34	ICS	19.1	20.2	.225	64.9	69.3	.122	0.48	0.60	.002*
Sequence 26	38	17	21	ICS	21.1	21.8	.396	63.4	69.7	.211	1.00	1.04	.329
Sequence 28	32	32	0	ICS	21.8	---	---	63.5	---	---	1.09	---	---
Sequence 29	29	28	1	ICS	24.9	48.0	.015*	67.8	64.0	.763	1.03	1.00	.854
Sequence 30	56	56	0	ICS	21.0	---	---	72.0	---	---	1.06	---	---
Sequence 35	34	19	15	HS	21.7	21.0	.207	68.5	65.4	.484	0.54	0.51	.645
Sequence 37	43	20	23	JW	24.1	23.7	.678	60.9	68.1	.089	0.78	0.52	.001*
Sequence 38	26	10	16	JW	27.4	24.1	.077	70.9	61.4	.035*	0.53	0.58	.445
Sequence 40	21	8	13	JW	19.9	21.7	.298	71.4	63.1	.076	1.11	1.07	.732
Sequence 41	29	18	11	JW	24.9	20.0	.206	69.2	66.5	.657	1.00	1.08	.341

* Statistically significant p <.05

Note: In sequences with small sample sizes (including a group size less than 5), Fisher's Exact Test values have been used (Exact Sig. 2-sided). In all other sequences the Pearson Chi-Square Asymp. Sig. (2-sided) Test was employed.

Table 7. Thermal sensation vote of groups A and B (survey beginning from exterior).

Exterior				Mann-Whitney Test	Thermal sensation votes	
					Mean vote	
				Asymp.Sig. (2-tailed)	A	B
Flat sequences N= 4	**A**	**B**				
Sequence 2 N=42	24	18	HS	.394	1.16	.888
Sequence 3 N=38	18	20	HS	.294	.166	.600
Sequence 7 N=14	4	10	HS	.374	1.25	.600
Sequence 8 N=33	19	14	HS	.009*	.368	-.571
Sudden Sequences N=18						
Sequence 1 N=32	20	12	HS	.363	-1.00	-1.25
Sequence 11 N=33	20	13	HS	.937	-1.30	-1.38
Sequence 12 N=66	28	38	HS	.929	-1.75	-1.78
Sequence 13 N=58	20	13	HS	.564	-2.16	-1.66
Sequence 14 N=85	43	42	HS	.023*	-2.16	-1.66
Sequence 15 N=39	21	18	HS	.070	-1.66	-1.00
Sequence 16 N=67	35	32	HS	.350	-1.54	-1.15
Sequence 18 N=23	23	0	ICS	---	---	---
Sequence 24 N=49	39	10	ICS	.579	-.871	-.600

Sequence 27 N=34	17	17	ICS	.036*	-2.11	-1.05
Sequence 34 N=25	12	13	ICS	.260	-1.50	-2.30
Sequence 36 N=18	9	9	JW	.780	-.333	-.111
Sequence 39 N=37	19	18	JW	.362	-2.10	-2.38
Sequence 42 N=43	39	10	JW	.737	-1.14	-.909
Sequence 43 N=25	15	10	JW	.227	-2.20	-1.70
Sequence 44 N=35	25	10	JW	.557	-1.68	-1.20
Sequence 45 N=71	39	32	JW	.403	-1.51	-1.81
Sequence 46 N=31	11	20	JW	.119	-1.09	-1.55
Irregular Sequences N=15						
Sequence 4 N=27	10	17	HS	.564	1.30	1.00
Sequence 17 N=24	24	0	ICS	---	---	---
Sequence 19 N=48	18	30	ICS	.597	.166	.000
Sequence 21 N=44	18	26	ICS	.154	.500	1.19
Sequence 22 N=16	16	0	HS	---	---	---
Sequence 23 N=74	40	34	ICS	.566	-.225	-.323
Sequence 26 N=38	17	21	ICS	.150	-1.17	-.714
Sequence 28 N=32	32	0	ICS	---	---	---
Sequence 29 N=29	28	1	ICS	---	---	---
Sequence 35 N=34	19	15	HS	.885	1.21	1.20
Sequence 30 N=56	56	0	ICS	---	---	---
Sequence 37 N=43	20	23	JW	.010*	-.150	.695
Sequence 38 N=26	10	16	JW	.600	1.40	1.12
Sequence 40 N=21	8	13	JW	.848	-1.37	-1.53
Sequence 41 N=29	18	11	JW	.189	-1.44	-1.00

The effect of each thermal pattern on TSV is described in the following section. Due to the large number of thermal sequence graphs (36), a significant example for each sequence was selected to exemplify the effect of the pattern in an individual case. In addition, the corresponding groups to each pattern are presented together in a single graph to illustrate the overall trend. **Appendix 2** provides the detailed statistical results for each individual sequence of each group. Results and '*p'* values in the text indicate general trends.

Flat patterns

From the Friedman and Wilcoxon signed rank test (using Bonferroni adjusted alpha values), it was found that small temperature changes (< 2°C) in Group A did not have a significant effect on participants' TSV ($p > .05$), which was close to the central range (-1, 0, +1) when they moved from one space to another (**Figure 16**). Participants' mean thermal comfort preferences also stayed in the central category, '*no change'*. In Group A the mean perception of temperature change between spaces was '*gradual*'. An example of a flat pattern is illustrated in **Figure 17**, in which TSV was maintained within the central comfort band ('*slightly cool'*, '*neutral*' and '*slightly warm'*) in the four spaces. Using the Mann-Whitney U test, Groups A and B were compared immediately after arriving in the seminar room. In all the flat sequences, there was no significant difference between A and B ($p > .05$) after moving to the interior space. Results of each sequence in this pattern can be seen in **Appendix 2.**

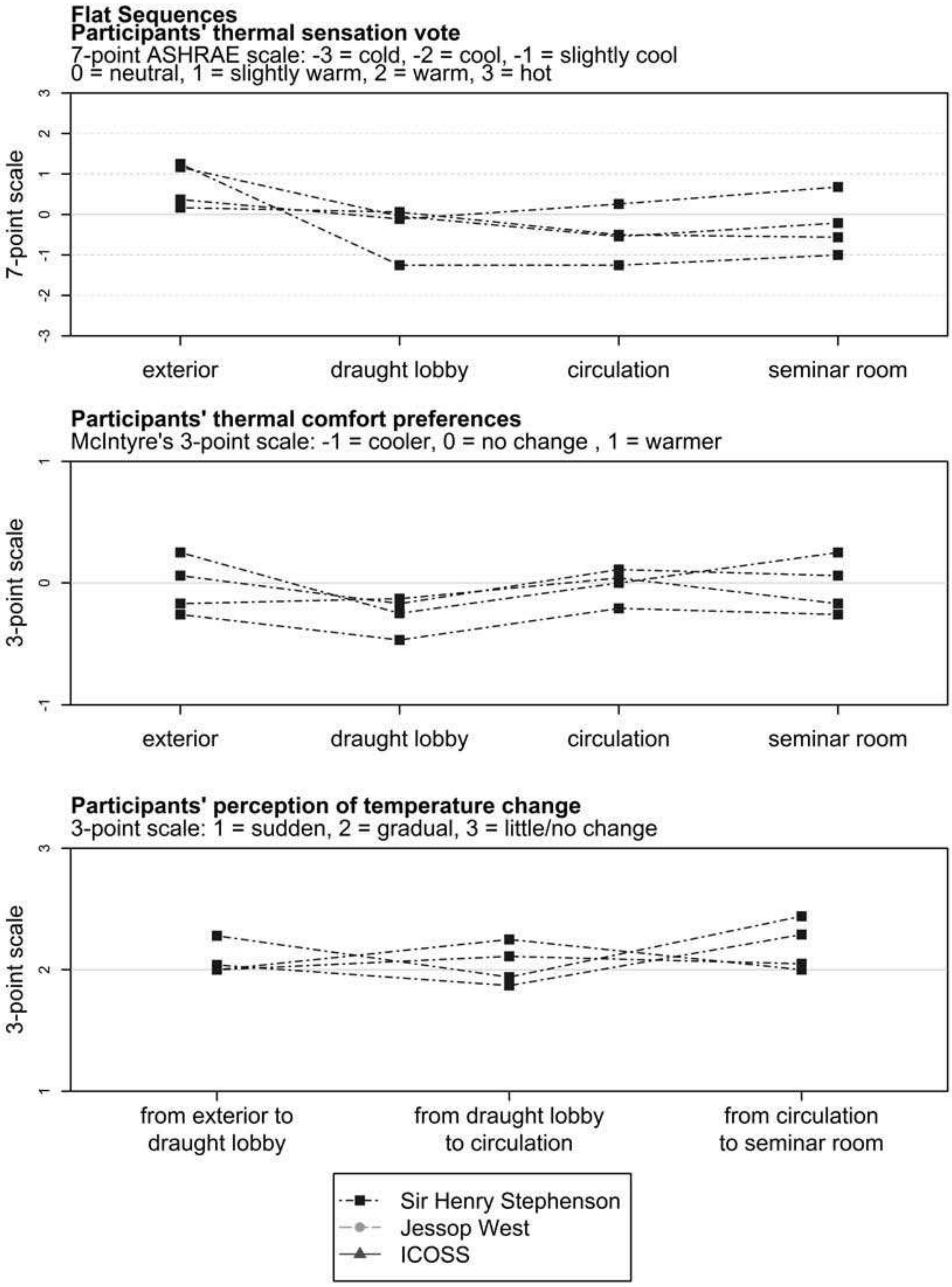


Figure 16. Flat sequence (group A): participant's thermal sensation vote, thermal preference and perception to temperature change from one space to another.

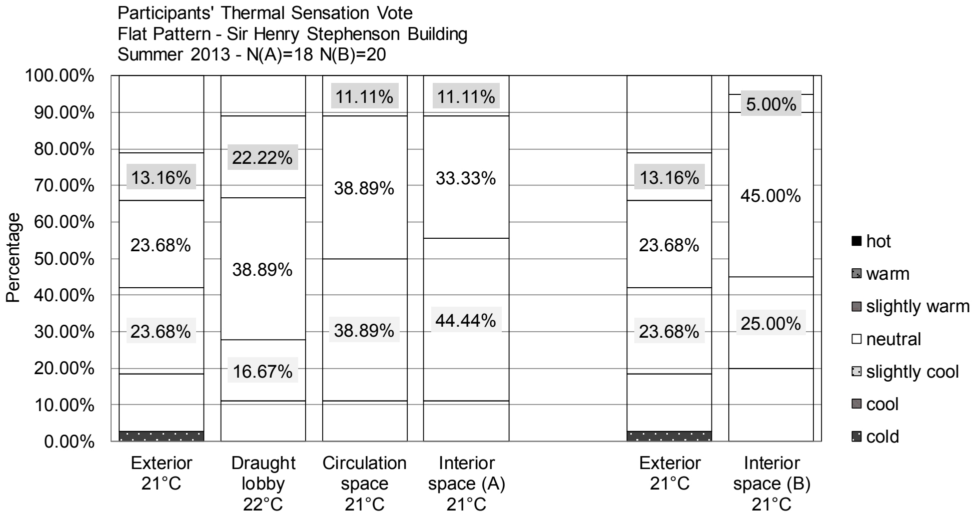


Figure 17. Example of participants' thermal perception in a flat sequence.

Sudden patterns (from cold to hot)

Figure 18 illustrates the thermal comfort perception, thermal comfort preference and perception of temperature change for participants in group A in the four spaces. As subjects move towards the interior space their thermal perception moves in the same direction (from cold to hot). Thermal preferences move in the opposite direction, towards 'cooler'. The perception of temperature change was variable with the majority between 'sudden' and 'gradual'. In all the sudden sequences, results from the Friedman and Wilcoxon signed rank test (Bonferroni adjusted alpha test) reveal significant differences ($p < .05$) in thermal perception between spaces with temperature differences > 2°C. In air temperature ranges from 6 – 13°C, an increase in temperature of 1 – 9°C results in a significant change in TSV, as subjects always prefer to be warmer. TSV is more variable with a temperature range from 14 – 23°C. However, in temperatures above 24°C, small temperature changes (±1°) are always significant. Statistical values for each sequence can be seen in **Appendix 2.** The Wilcoxon Signed Rank test shows significant differences in TSV before and after using the lobby space (**Appendix 2**). When comparing the perception of temperature changes in the seminar room, a larger percentage in Group B (56.5%) perceived a ‘sudden’ temperature change than in Group A (29.1%). Interestingly, in the seminar room, a slightly larger percentage of Group B (70.8%) preferred ‘no change’ compared to Group A (61.7%). An example of a sudden pattern is illustrated in **Figure 19**.

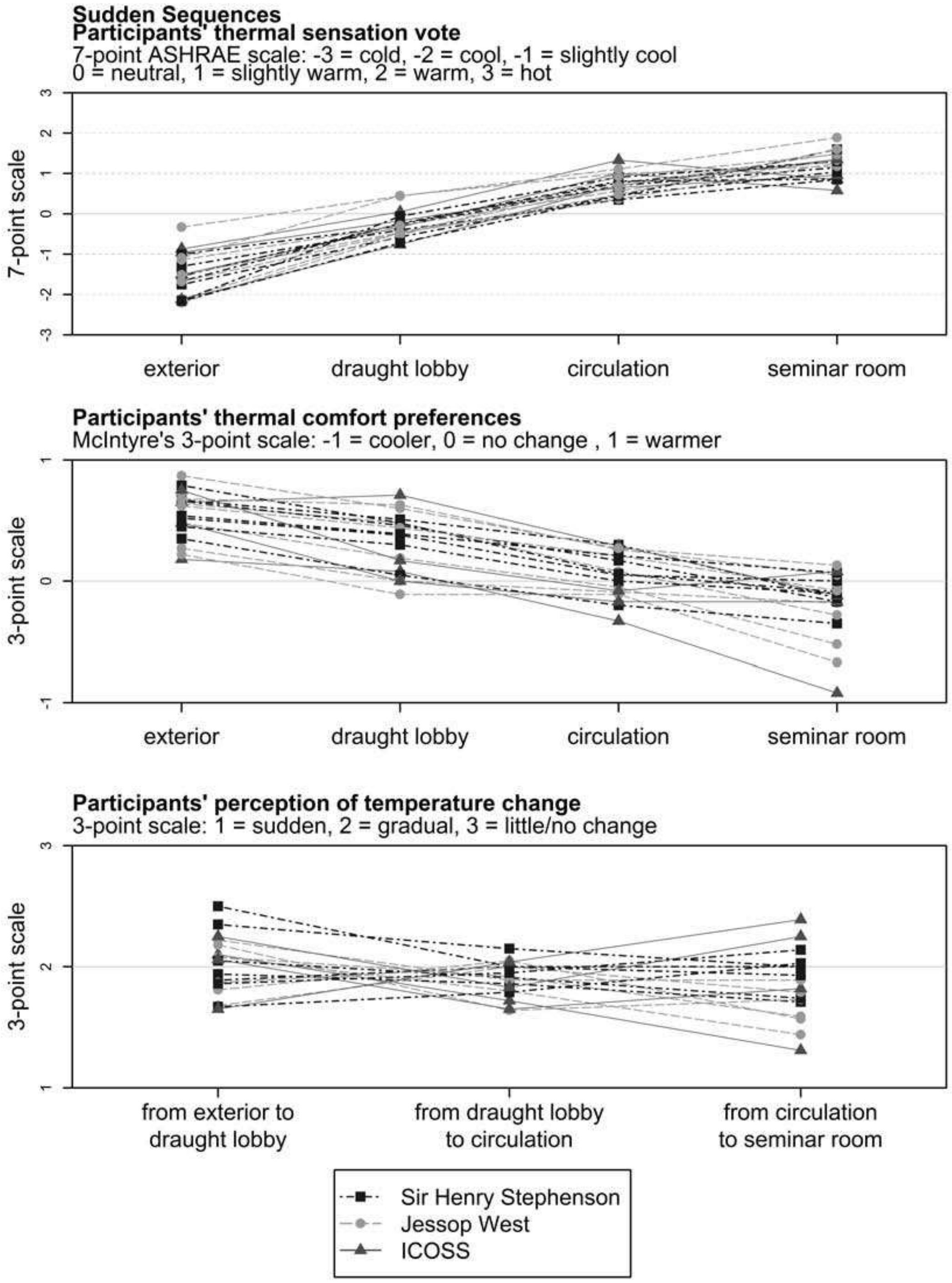


Figure 18. Sudden sequence (group A): participant's thermal sensation vote, thermal preference and perception to temperature change from one space to another.

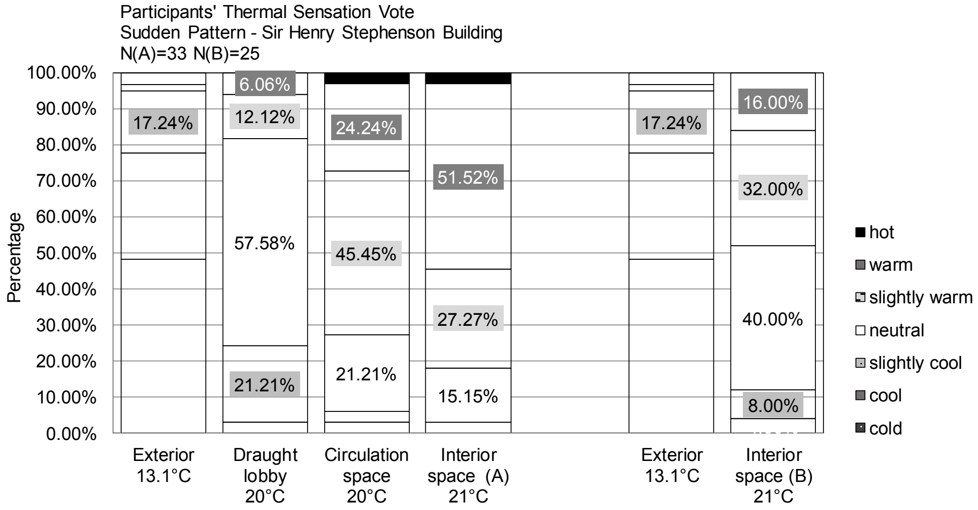


Figure 19. Example of participants' thermal perception in a sudden sequence, from cold to hot.

Irregular patterns

In irregular sequences, Friedman tests reveal significant differences (p < .05) in thermal perception between the spaces in all cases (**Figure 20**). A Wilcoxon Signed Rank Test revealed no significant differences in TSV between the exterior and draught lobby spaces when temperature differences were less than ±2°C. However, with temperature ranges from 25 – 27°C (hot band) and 8 – 16°C (cold band), temperature changes of ±1°C revealed significant differences in TSV. Likewise, there were no significant differences in responses when the temperature differences between the circulation space and interior space were less than ±2°C. However, a temperature difference of ±1°C was significant when the sequence involved a temperature range from 23 – 26°C. Statistical values for each sequence can be seen in **Appendix 2**. An example of an irregular pattern is illustrated in **Figure 21.**

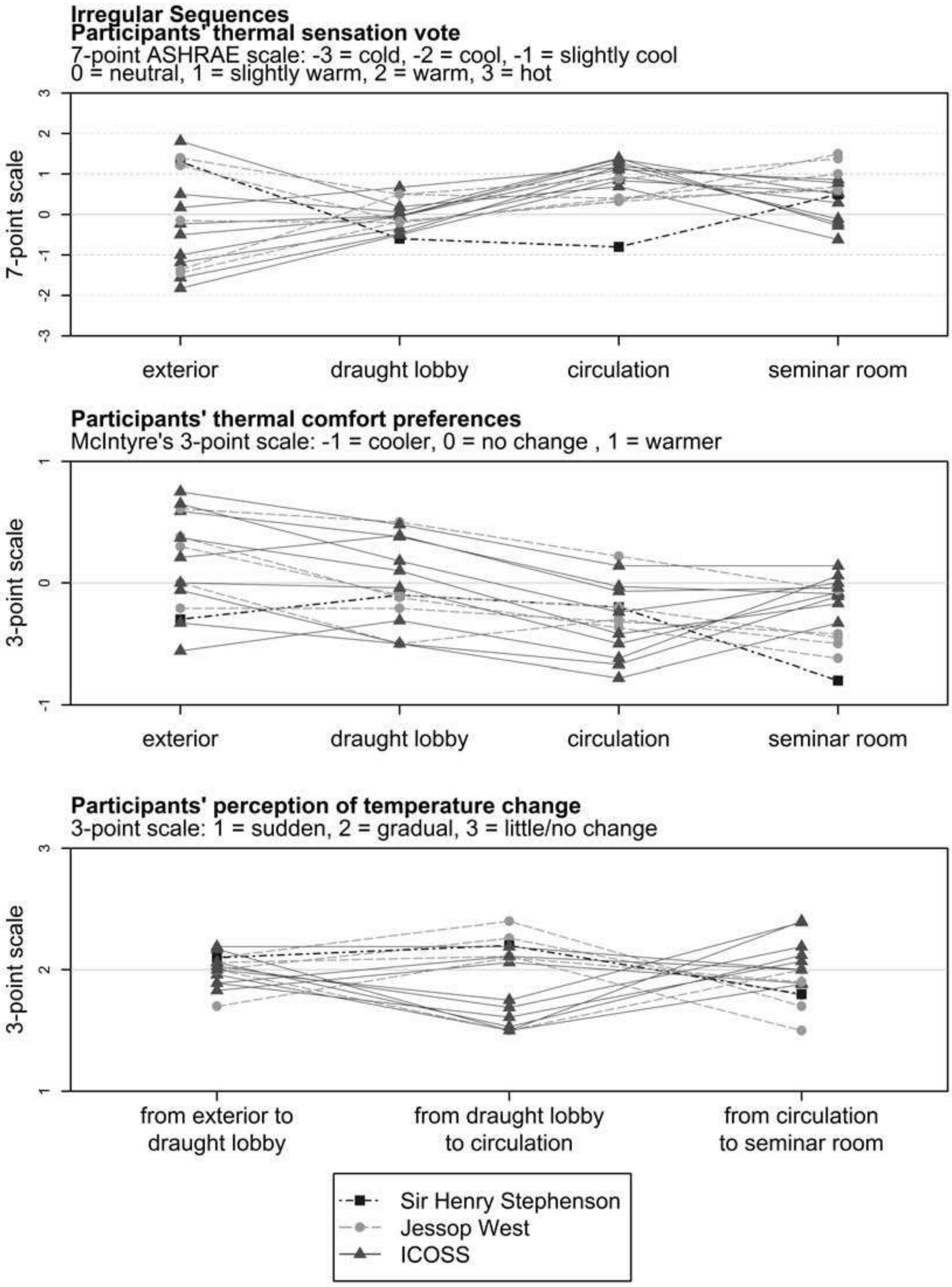


Figure 20. Irregular sequence (group A): participant's thermal sensation vote, thermal preference and perception to temperature change from one space to another.

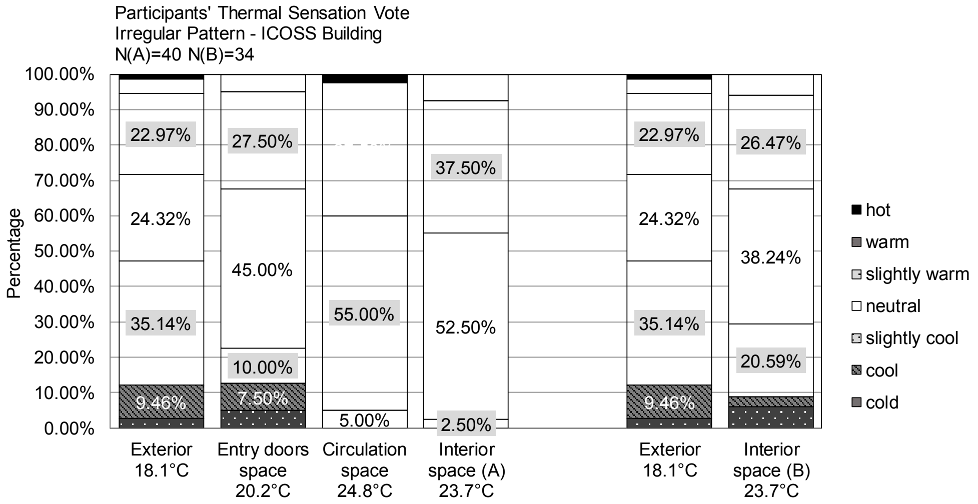


Figure 21. Example of participants' thermal perception in a irregular sequence.

Discussion

The findings clearly illustrate the influence of the seasonal exterior temperature on the way that the lobby space is thermally connected to other transitional spaces (circulation space). Linear regression illustrated a strong correlation between the exterior and draught lobby, which decreased towards the interior spaces (circulation and seminar rooms). Importantly, the effects of the seasonal exterior climatic conditions were found to have an impact on thermal perception of the interior environment. This was revealed by comparing the way people tag the same temperature in different way depending on the season of the year.

Thermal patterns and energy saving

Flat patterns identified in this study confirm that there is an opportunity to reduce the set point temperature in AC lobby units to be closer to the exterior air temperature, with only a ±3°C difference required between the exterior and lobby unit. *Sudden temperature* changes show that differences of 1 – 9°C have a significant effect on perception when moving from cold to hot conditions in temperature ranges of 6 – 13°C. This effect was not identified with temperature ranges from 14 – 23°C, but it become significant again in temperatures above 24°C, even when the difference was as small as ±1°C. These results support the findings of Du et al. (2014) who did not identify significant changes in perception when subjects moved to a warmer environment if their mean skin temperature was in a 12 – 22 °C range, but did identify significant differences when subjects moved in the opposite direction (from hot to cold). Results from sudden patterns can also be compared with previous laboratory work (Wu & Mahdavi 2014), in which multiple groups of six people were analysed under different thermal conditions. They found that TSV is consistent with the direction of temperature changes in a sequence of spaces. While sudden sequences can immediately satisfy participants' thermal preferences, they do not help to trigger improved thermal adaptation in subsequent interior spaces.

Irregular connections, with changes of thermal direction, result in variable thermal responses, amplifying or delaying responses over a short period of time. In some cases, however, the sum of these very short delays or increments seem to be large enough to ensure no overall significant differences in thermal perception between spaces with large temperature differences, or significant differences between spaces with the same temperature. The latter effect was also identified by Jin (2011) when analysing step change temperatures in ranges from 24 – 30°C. Arbitrary uncontrolled alterations leading to changes in people's perceptions are therefore not recommended in transitional spaces, particularly in extreme temperatures, where people respond quicker to very small temperature changes. Liu (2014) also identified significant differences in thermal sensation when people moved between spaces in in extreme hot temperatures (38°C, 30°C and 28°C) in different orders, with temperature differences of 3 – 7°C. Careful consideration needs to be given to the provision of *thermal variability* during the transition from exterior to interior, in order to reduce thermal discomfort and energy use by air conditioning or space heating systems.

While gradual thermal transitions promote improve thermal adaptation to indoor environments, even *sudden patterns* (with changes of temperature in the same direction and within certain limits) can trigger more positive thermal adaptation than sudden single-step changes of temperature from the exterior to the interior. This fieldwork demonstrates that thermal comfort can be found in non-uniform environments and that corrective changes to thermal comfort are possible. Repeated short-term (seconds and minutes) thermal experiences have the potential to trigger a positive effect on thermal perception in the long term (seasons and years). Further research is required to measure these effects.

It is also worth considering the immediate exterior climatic conditions (a few meters away from the main entrance). A gradual thermal transition can be extended to a few metres before arriving in the lobby unit, by taking advantage of landscape design to develop suitable trees placement (shade), pavement colours, greenery, geometric configurations, landscape interventions, water features and canopies. For instance, trees in urban areas can cool the air up to 1.5°C (Coutts et al. 2016) and water bodies act as cooling elements and can reduce the air temperature of their surroundings by up to 0.8 °C (Theeuwes, Solcerová & Steeneveld 2013). Green walls can also cool the air immediately next to them from 2°C up to 6.3°C (Cameron, Taylor & Emmett 2014; Tan, Wong & Jusuf 2014)

Study limitations

These study results should be interpreted with caution, as they may not apply to all building types, climate regions or types of transitional spaces and connections. Further research should consider the social functions of such spaces used over longer periods of time in relation to thermal comfort. The impact of cultural effects on individual results was outside the scope of this study. Due to the equipment limitations described in the methodology, this research has focused on the effects of air temperature and relative humidity on thermal comfort. Wind speed has been described in order to demonstrate how this was controlled in the experiment, but globe temperature measurements have not been included.

Conclusions

This research has shown that in moderate climates the length of exposure and the way that spaces are thermally connected can significantly modify thermal perception and preferences in seconds. The order in which thermal connections are experienced can delay or bring forward changes in thermal perception. The understanding of these new patterns as a background to thermal perception is a significant contribution to the discourse on thermal comfort. Gradual thermal transition from the exterior to the interior (*flat sequences*) improves a subject's thermal adaptation once inside a building. *Sudden* temperature changes in the same thermal direction (in this case from cold to hot) are more effective in providing thermal comfort than *Irregular sequences*, which provoke a wide range of thermal responses due to the effect of different temperature changes in different thermal directions.

- In flat patterns, temperatures range between spaces from 20°C to 23°C. Increments of 2 °C did not have a significant effect on TSV after participants moved from one space to another. Therefore, the use of the lobby area did not have a significant impact on TSV.
- In sudden patterns (winter), exterior temperatures range from 6 °C to 13 °C. Temperature changes from +1 to + 9 °C were always significant. With temperature ranges between spaces of 14°C to 23 °C results were variable. With exterior temperatures above 24 °C, small temperature changes (±1°) were always significant. The constant thermal direction (from cold to hot) of temperature changes between spaces had a significant impact on thermal preferences in the seminar room (participants wished to be 'cooler'). However, the results from comparisons between groups A and B were variable.
- In irregular patterns, the change of thermal direction in the routes affected thermal perception and preferences in different ways.

Thermal perception will vary in large lobby units hosting different activities and different types of users and the design of these spaces should provide different adaptive opportunities to allow people to attain comfort in different ways. The three thermal patterns presented in this paper can usefully inform design strategies of transitional spaces.

The use of gradual temperature changes in a single thermal direction is recommended for moderating thermal comfort perceptions; however, irregular patterns could also be used in a positive way when the objective is to reverse the effect of previous thermal conditions. This in turn can help contribute towards the development of long-term strategies to reduce AC usage and to adjust thermal connections in NV buildings in order to enhance thermal experience, while at the same time reducing energy use in buildings.

Impact on policy

A particular contribution of this work is an increased knowledge of the factors influencing thermal comfort in dynamic and transient states, which could help to inform international standards by establishing more specific dynamic thermal comfort parameters. International standards and rating systems (e.g. LEED and BREEAM) need to take into account the effect of people's thermal history in their thermal responses, including a *seasonal adjustment* in the interpretation and tagging of air temperatures in different seasons of the year. Transitional spaces should be considered separately from indoor and outdoor environments in relation to thermal adaptation strategies. Consideration of the design of transitional lobby units should be extended to include HVAC commissioning criteria, as well as post occupancy evaluation codes and protocols. Standards need to include a more detailed classification of different lobby uses by building type. For instance, while in some cases the lobby is used as a social space for longer periods of time (e.g. in a hotel), in other cases it is used in a more dynamic way, or merely as a transitional area (e.g. university buildings and offices).

While historic buildings such as the Glasgow School of Art are often more voluminous than modern examples, the increased spatial inefficiency may be compared with the cost of additional HVAC technology in their contemporary counterparts. The floor to ceiling height in office buildings today is often necessarily reduced by the need for large service zones between floors. The use of HVAC in some buildings may be unavoidable, but evidence suggests that the 'Performance Gap' is often biggest in buildings that are more reliant on 'active' environmental systems, and that passive design (including provision of transitional spaces and the promotion of adaptive behavior) has an important role to play in helping the UK meet its CO_2 emissions targets. This study is a first step towards providing guidance for the environmental design of these kinds of spaces. Significant variations in participants' responses in each season of the year were demonstrated in this study. Taking advantage of this natural adaptation, lobby units can dramatically reduce the use of heating systems during winter by considering thermal comfort perception in the exterior environment as a starting point and adjusting the air temperature of the lobby unit and interior space to be closer to the exterior temperature. The temperature threshold and set points can thus be expanded in transitional lobby spaces in the UK to reflect outdoor temperatures ±3°C and thus help to reduce CO_2 emissions.

Recommendations for future research

The results of this study imply a move away from steady state calculations for buildings towards more complex modelling which, in turn, requires further research to establish more appropriate parameters and probabilities to work with for a given population moving through a particular configuration of thermal spaces.

The findings from this study indicate that it is important to consider people's short and long term thermal history in thermal comfort research, as well as the effect of people's thermal adaptation to the climatic conditions of the four seasons of the year. Findings established for outdoor thermal comfort strategies and those for transitional spaces need to be urgently cross-correlated in order to create a more joined-up approach to building design and tackle increasingly sudden temperature changes due to climate change. The study of dynamic lobby units should include examples of different types of user (staff, visitors or residents) and activity (walking, waiting and socialising), possibly with better-defined spatial boundaries for each type of activity. Finally, more qualitative research, moving away from rigid or controlled procedures, need to be explored in order to visualise other socio-cultural aspects of thermal perception.

Overall, thermal comfort research demands more ethnographic observation and qualitative research work linked with other fields (human health, landscape, psychology), currently missing from most studies in this area. Our understanding of thermal comfort perception can thus be improved by moving away from steady state models of fixed environments to understanding the *dynamic state* of subjects in *variable environments*.

Bibliography

ASHRAE 2004, *ANSI/ASHRAE Standard 55-2004*, ASHRAE, Atlanta, GA.

Cameron, RWF, Taylor, JE & Emmett, MR 2013, 'What is ‘cool’ in the world of green façades? How plant choice influences the cooling properties of green walls', *Building and Environment*, vol. 73, pp. 198-207.

Candido, C, de Dear, R, Lamberts, R & Bittencourt, L 2010, 'Cooling exposure in hot humid climates: are occupants 'addicted'?', *Architectural Science Review*, vol. 53, pp. 59-64.

Channell, C 2012, *Lobby | WBDG, Whole Building Design Guide*, National Institute of Building Science, 2015, <http://www.wbdg.org/design/lobby.php>.

Chen, CP, Hwang, RL, Chang, SY & Lu, YT 2011, 'Effects of temperature steps on human skin physiology and thermal sensation response', *Building and Environment*, vol. 46, no. 11, pp. 2387-97.

Chua, KJ, Chou, SK, Yang, WM & Yan, J 2013, 'Achieving better energy- efficient air conditioning - A review of technologies and strategies', *Applied Energy*, vol. 104, pp. 87-104.

Chun, C & Tamura, A 2005, 'Thermal comfort in urban transitional spaces', *Building and Environment*, vol. 40, no. 5, pp. 633-9.

CIBSE-GuideA 2015, *Environmental design, CIBSE Guide A*, The Chartered Institution of Building Services Engineers London, London.

Coutts, AM, White, EC, Tapper, NJ, Beringer, J & Livesley, SJ 2016, 'Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments', *Theoretical and Applied Climatology*, vol. 124, no. 1, pp. 55-68.

daab 2006, *Lobby Design*, daab gmbh, London - NY.

de Dear, R & Brager, GS 1998, 'Thermal Adaptation in the Built Environment: a Literature Review'.

de Dear, R, Kim, J, Candido, C & Deuble, M 2015, 'Adaptive thermal comfort in Australian school classrooms', *Building Research & Information*, vol. 43, no. 3, pp. 383-98.

De Vecchi, R, Sorgato, MJ, Pacheco, M, Cândido, C & Lamberts, R 2015, 'ASHRAE 55 adaptive model application in hot and humid climates: the Brazilian case', *Architectural Science Review*, vol. 58, no. 1, pp. 93-101.

De Vechi, R, Candido, CM & Lamberts, R 2016, 'Thermal history and comfort in a Brazilian subtropical climate:'cool' addiction hypothesys', *Revista Ambiente Construido*, vol. 16, no. 1, pp. 7-20.

Du, X, Li, B, Liu, H, Yang, D, Yu, W, Liao, J, Huang, Z & Xia, K 2014, 'The response of human thermal sensation and its prediction to temperature step-change (cool-neutral-cool)', *PloS one*, vol. 9, no. 8, p. e104320.

EN.ISO.7726 2001, *Ergonomics of the thermal environment - Instruments for measuring physical quantities*, British Standards.

Griffiths, ID & McIntyre, DA 1974, 'Sensitivity to Temporal Variations in Thermal Conditions', *Electricity Council Research Centre, Capenhurat, Cheater, England*.

HEFCE 2010, *Carbon reduction target and strategy for higher education in England*. Bristol: Higher Education Funding Council for England.

Hensen, JLM 1990, 'Literature review on thermal comfort in transient conditions', *Building and Environment*, vol. 25, no. 4, pp. 309-16.

Hui, SCM & Jie, J 2014, 'Assesment of thermal comfort in transitional spaces', paper presented to Change in Building Services for Future, Hong Kong,China.

Hwang, RL, Yang, KH, Chen, CP & Wang, ST 2008, 'Subjective responses an comfort reception in transitional spaces for guests versus staff', *Building and Environment*, vol. 43, no. 12, pp. 2013-21.

Jin, Q, Lin, D, Zhang, H, Li, X & Xu, H 2011, 'Thermal sensations of the whole body and head under local cooling and heating conditions during step-changes between workstation and ambient environment', *Building and Environment*, vol. 46, no. 11, pp. 2342-50.

Jitkhajornwanich, K & Pitts, AC 2002, 'Interpretation of thermal responses of four subject groups in transitional spaces of buildings in Bangkok', *Building and Environment*, vol. 37, no. 11, pp. 1193-204.

Johansson, E, Thorsson, S, Emmanuel, R & Krüger, E 2014, 'Instruments and methods in outdoor thermal comfort studies – The need for standardization', *Urban Climate*, vol. 10, pp. 346-66.

Kelly, L., & Parson, K. (2010). Thermal comfort when moving from one environment to another. Paper presented at the Windsor Conference, Adapting to Change: New Thinking on Comfort, Cumberland Lodge, Windsor, UK, 7-9 April 2010.

Kilpatrick, DR 2010, *The theatre lobby experience: the audience's perspective*. Columbia, MO: University of Missouri Columbia.

Knez, I, Thorsson, S, Eliasson, I & Lindberg, F 2009, 'Psychological mechanisms in outdoor place and weather assessment: towards a conceptual model', *Int J Biometeorol*, vol. 53, no. 1, pp. 101-11.

Kotopouleas, A & Nikolopoulou, M 2014, 'Understanding thermal comfort conditions in airport terminal buildings', paper presented to 8th Windsor Conference: Counting the Cost of Comfort in a changing world, Cumberland Lodge, Windsor, UK, 10th-13th April.

Kwong, QJ & Adam, NM 2011, 'Perception of Thermal Comfort in the Enclosed Transitional Space of Tropical Buildings', *Indoor Building Environment*, vol. 20, no. 5, pp. 524-33.

Lakeridou, M, Ucci, M, Marmot, A & Ridley, I 2012, 'The potential of increasing cooling set-points in air-conditioned offices in the UK', *Applied Energy*, vol. 94, pp. 338-48.

Lawrence, R 2014, 'The Internal Environment of the Glasgow School of Art by Charles Rennie Mackintosh', The Journal of Construction History, vol. 29, pp. 99–128.

Leaman, A, Stevenson, F & Bordass, B 2010, 'Building evaluation: practice and principles', *Building Research & Information*, vol. 38, no. 5, pp. 564-77.

Liu, H, Liao, J, Yang, D, Du, X, Hu, PC, Yang, Y & Li, B 2014, 'The response of human thermal perception and skin temperature to step-change transient thermal environments', *Building And Environment*, vol. 73, pp. 232-8.

McCartney, KJ & Nicol, JF 2002, 'Developing an adaptive control algorithm for Europe', *Energy and Buildings*, vol. 34, no. 6, pp. 623-35.

Met Office 2015, *Sheffield, UK, weather report 1981-2010*, 2015.

Nicol, F 2004, 'Adaptive thermal comfort standards in the hot-humid tropics', *Energy and Buildings*, vol. 36, no. 7, pp. 328-637.

Nicol, F, Humphreys, M & Roaf, S 2012, *Adaptive Thermal Comfort, Principles and Practice*, Routledge, Abingdon, Oxon.

Nicol, JF & Humphreys, MA 2009, 'New standards for comfort and energy use in buildings', *Building Research & Information*, vol. 37, no. 1, pp. 68-73.

Nikolopoulou, M & Lykoudis, S 2006, 'Thermal comfort in outdoor urban spaces: Analysis across different European countries', *Building and Environment*, vol. 41, no. 11, pp. 1455-70.

Nikolopoulou, M & Steemers, K 2003, 'Thermal comfort and psychological adaptation as a guide for designing urban spaces', *Energy and Buildings*, vol. 35, no. 1, pp. 95-101.

Olgyay, V 1963, *Design with climate, bioclimate approach to architectural regionalism*. Princeton: Princeton University Press.

Parkinson, T & De Dear, R 2015, 'Thermal pleasure in built environments: physiology of alliesthesia', *Building Research & Information*, vol. 43, no. 3, pp. 288-301.

Parkinson, T, de Dear, R & Candido, C 2012, 'Perception of Transient Thermal Environments: pleasure and alliesthesia', paper presented to 7th Windsor Conference: The changing context of comfort in an unpredictable world, Cumberland Lodge, Windsor, UK.

Parkinson, T, De Dear, R & Candido, C 2015, 'Thermal pleasure in built environments: alliesthesia in different thermoregulatory zones', *Building Research & Information*, vol. 44, no. 1, pp. 20-33.

Pitts, A 2010, 'Occupant acceptance of discomfort in atrium building: to sweat or to shiver?', paper presented to Adapting to Change: New Thinking on Comfort, Cumberland Lodge, Windsor, UK.

---- 2013, 'Thermal Comfort in Transition Spaces', *Buildings*, vol. 3, no. 1, p. 122.

Pitts, A & Bin Saleh, J 2007, 'Potential for energy saving in building transition spaces', *Energy & Buildings*, vol. 39, no. 7, pp. 815-22.

Qi, J. K., & Nor, M. A. (2011). Perception of thermal comfort in the enclosed transitional space of tropical buildings. Indoor and Built Environment, 20(5), 524–533.

Rijal, HB, Tuohy, P, Humphreys, MA, Nicol, JF, Samuel, A & Clarke, J 2007, 'Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings', *Energy and Buildings*, vol. 39, no. 7, pp. 823-36.

Schoenefeldt, H 2014, 'The Temporary Houses of Parliament and David Boswell Reid's architecture of experimentation', Architectural History, vol. 57, pp. 175-215.

Song, JF, Wong, NH & Huang, K 2011, 'The effect of short term experinece on people's thermal perception', paper presented to 7th International Symposium on Heating, Ventilation and Air Conditioning - ISHVAC, Shanghai, China.

Tan, CL, Wong, NH & Jusuf, SK 2014, 'Effects of vertical greenery on mean radiant temperature in the tropical urban environment', *Landscape and Urban Planning*, vol. 127, pp. 52-64.

Theeuwes, NE, Solcerová, A & Steeneveld, GJ 2013, 'Modeling the influence of open water surfaces on the summertime temperature and thermal comfort in the city', *Journal of Geophysical Research: Atmospheres*, vol. 118, no. 16, pp. 8881-96.

Tsutsumi, H, Tanabe, SI, Harigaya, J, Iguchi, Y & Nakamura, G 2007, 'Effect of humidity on human comfort and productivity after step changes from warm and humid environment', *Build. Environ.*, vol. 42, no. 12, pp. 4034-42.

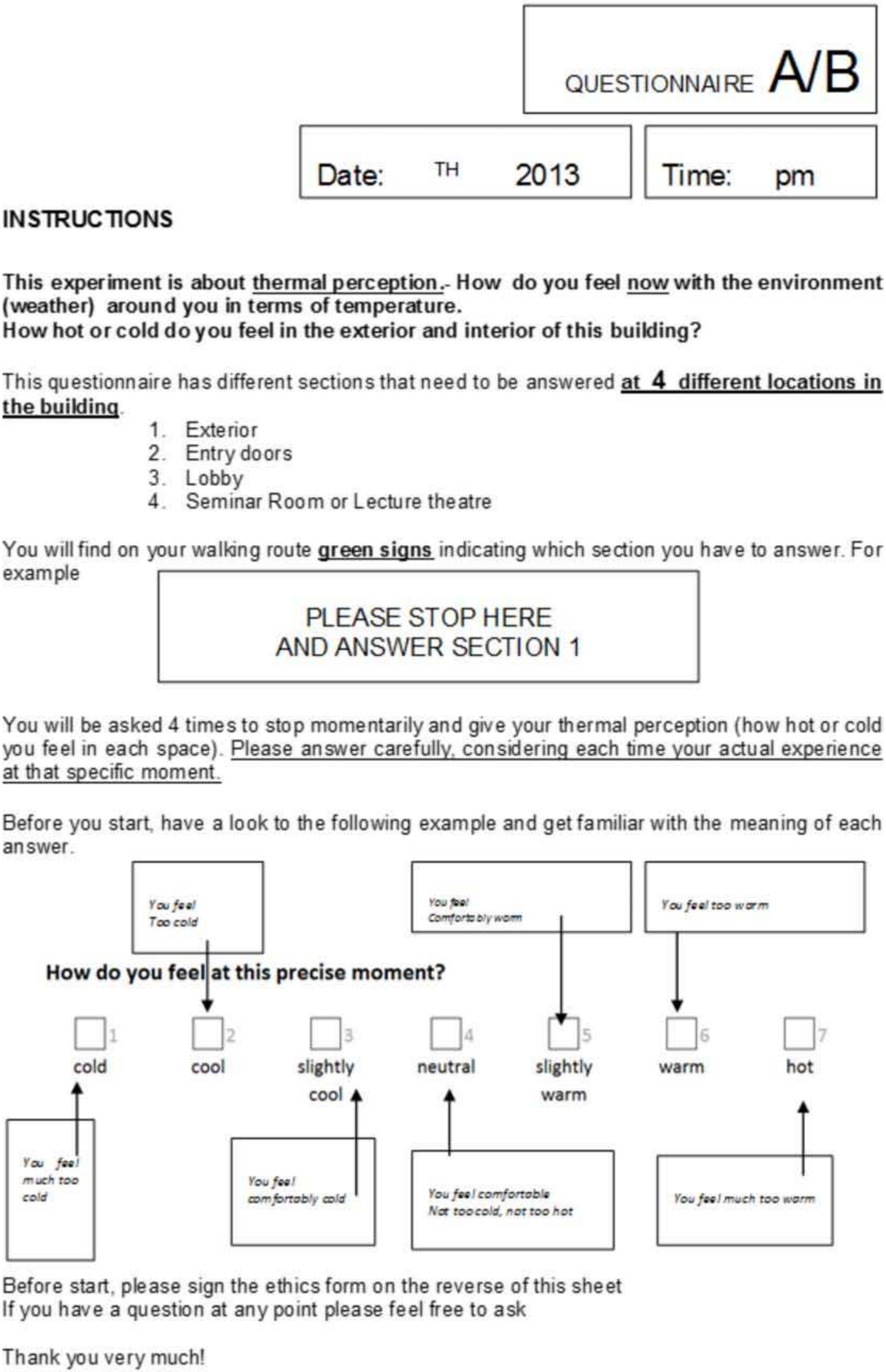
Vargas, GA & Stevenson, F 2014, 'Thermal Memory and Transition in Lobby Spaces', *Energy Procedia*, vol. 62, pp. 502-11.

Walker, G, Shove, E & Brown, S 2014, 'How does air conditioning become ‘needed’? A case study of routes, rationales and dynamics', *Energy Research and Social Science*, vol. 4, pp. 1-9.

Wu, Y-C & Mahdavi, A 2014, 'Assessment of thermal comfort under transitional conditions', *Building and Environment*, vol. 76, pp. 30-6.

Zhang, H, Arens, E & Zhai, Y 2015, 'A review of the corrective power of personal comfort systems in non-neutral ambient environments', *Building and Environment*, vol. 91, pp. 15-41.

Appendix 1



QUESTIONNAIRE **A/B**

Date: TH 2013

Time: pm

INSTRUCTIONS

This experiment is about thermal perception.- How do you feel now with the environment (weather) around you in terms of temperature.
How hot or cold do you feel in the exterior and interior of this building?

This questionnaire has different sections that need to be answered **at 4 different locations in the building**.

1. Exterior
2. Entry doors
3. Lobby
4. Seminar Room or Lecture theatre

You will find on your walking route **green signs** indicating which section you have to answer. For example

PLEASE STOP HERE
AND ANSWER SECTION 1

You will be asked 4 times to stop momentarily and give your thermal perception (how hot or cold you feel in each space). Please answer carefully, considering each time your actual experience at that specific moment.

Before you start, have a look to the following example and get familiar with the meaning of each answer.

You feel Too cold

You feel Comfortably warm

You feel too warm

How do you feel at this precise moment?

☐1 cold
☐2 cool
☐3 slightly cool
☐4 neutral
☐5 slightly warm
☐6 warm
☐7 hot

You feel much too cold

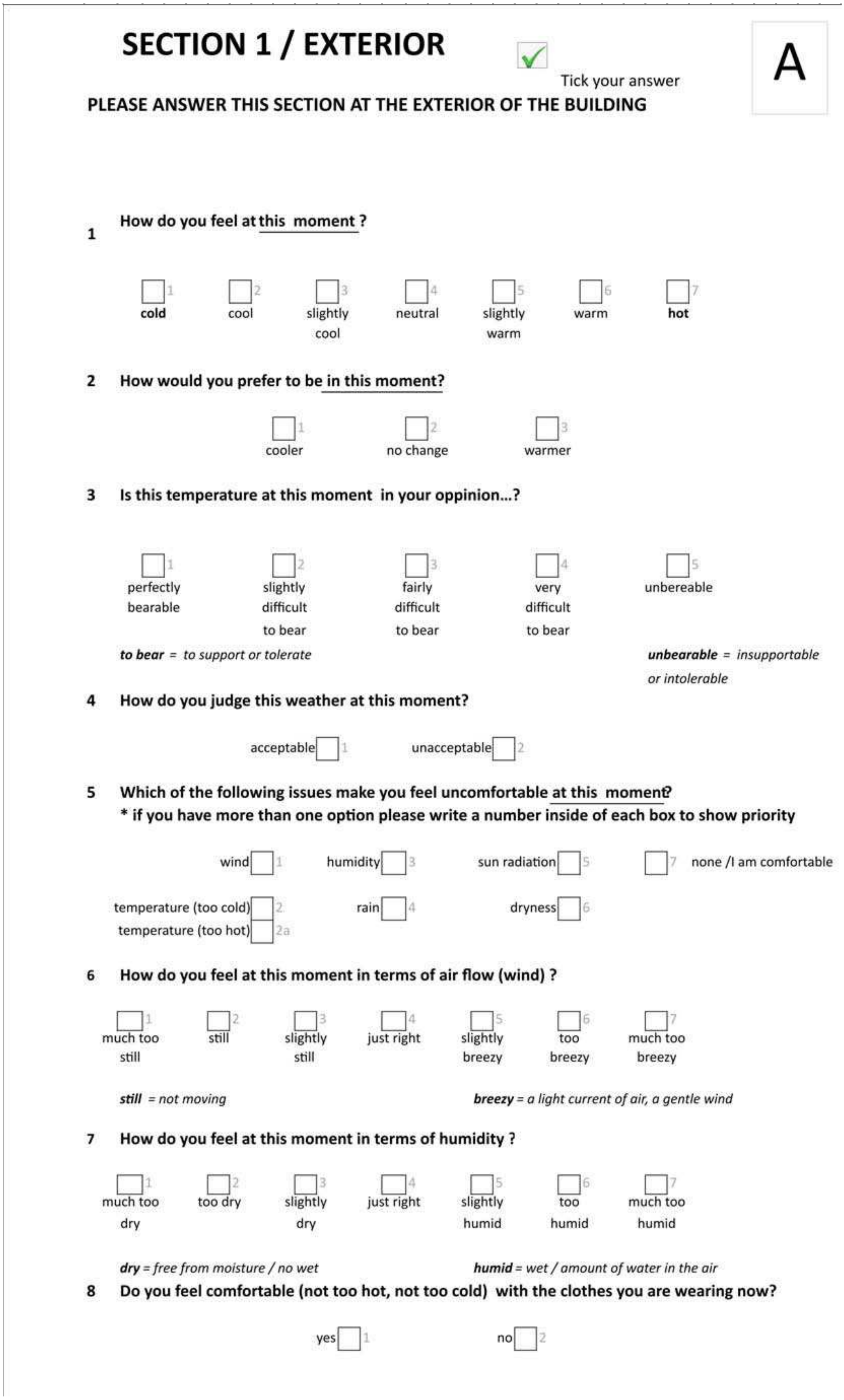
You feel comfortably cold

You feel comfortable Not too cold, not too hot

You feel much too warm

Before start, please sign the ethics form on the reverse of this sheet
If you have a question at any point please feel free to ask

Thank you very much!



SECTION 1 / EXTERIOR

✓ Tick your answer

A

PLEASE ANSWER THIS SECTION AT THE EXTERIOR OF THE BUILDING

1 How do you feel at this moment ?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
cold	cool	slightly cool	neutral	slightly warm	warm	**hot**

2 How would you prefer to be in this moment?

☐ 1	☐ 2	☐ 3
cooler	no change	warmer

3 Is this temperature at this moment in your oppinion...?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
perfectly bearable	slightly difficult to bear	fairly difficult to bear	very difficult to bear	unbereable

***to bear** = to support or tolerate*

***unbearable** = insupportable or intolerable*

4 How do you judge this weather at this moment?

acceptable ☐ 1 unacceptable ☐ 2

5 Which of the following issues make you feel uncomfortable at this moment?
*** if you have more than one option please write a number inside of each box to show priority**

wind ☐ 1 humidity ☐ 3 sun radiation ☐ 5 ☐ 7 none /I am comfortable

temperature (too cold) ☐ 2 rain ☐ 4 dryness ☐ 6
temperature (too hot) ☐ 2a

6 How do you feel at this moment in terms of air flow (wind) ?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too still	still	slightly still	just right	slightly breezy	too breezy	much too breezy

***still** = not moving*

***breezy** = a light current of air, a gentle wind*

7 How do you feel at this moment in terms of humidity ?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid

***dry** = free from moisture / no wet*

***humid** = wet / amount of water in the air*

8 Do you feel comfortable (not too hot, not too cold) with the clothes you are wearing now?

yes ☐ 1 no ☐ 2

☑ Tick your answer

A

SECTION 2 / ENTRY DOORS

PLEASE ANSWER THIS SECTION BETWEEN THE TWO ENTRY DOORS

9 How do you feel at this moment?

☐1	☐2	☐3	☐4	☐5	☐6	☐7
cold	cool	slightly cool	neutral	slightly warm	warm	hot

10 How would you prefer to be at this moment?

☐1	☐2	☐3
cooler	no change	warmer

11 How do you feel the change in temperature between this space (ENTRY DOORS) and the OUTSIDE of the building?

☐1	☐2	☐3
sudden	gradual	little /no change

sudden *= occurring quickly and unexpectedly*

gradual*= progressing slowly or by degrees*

12 How do you feel at this moment in terms of air flow?

☐1	☐2	☐3	☐4	☐5	☐6	☐7
much too still	still	slightly still	just right	slightly breezy	too breezy	much too breezy

still *= not moving*

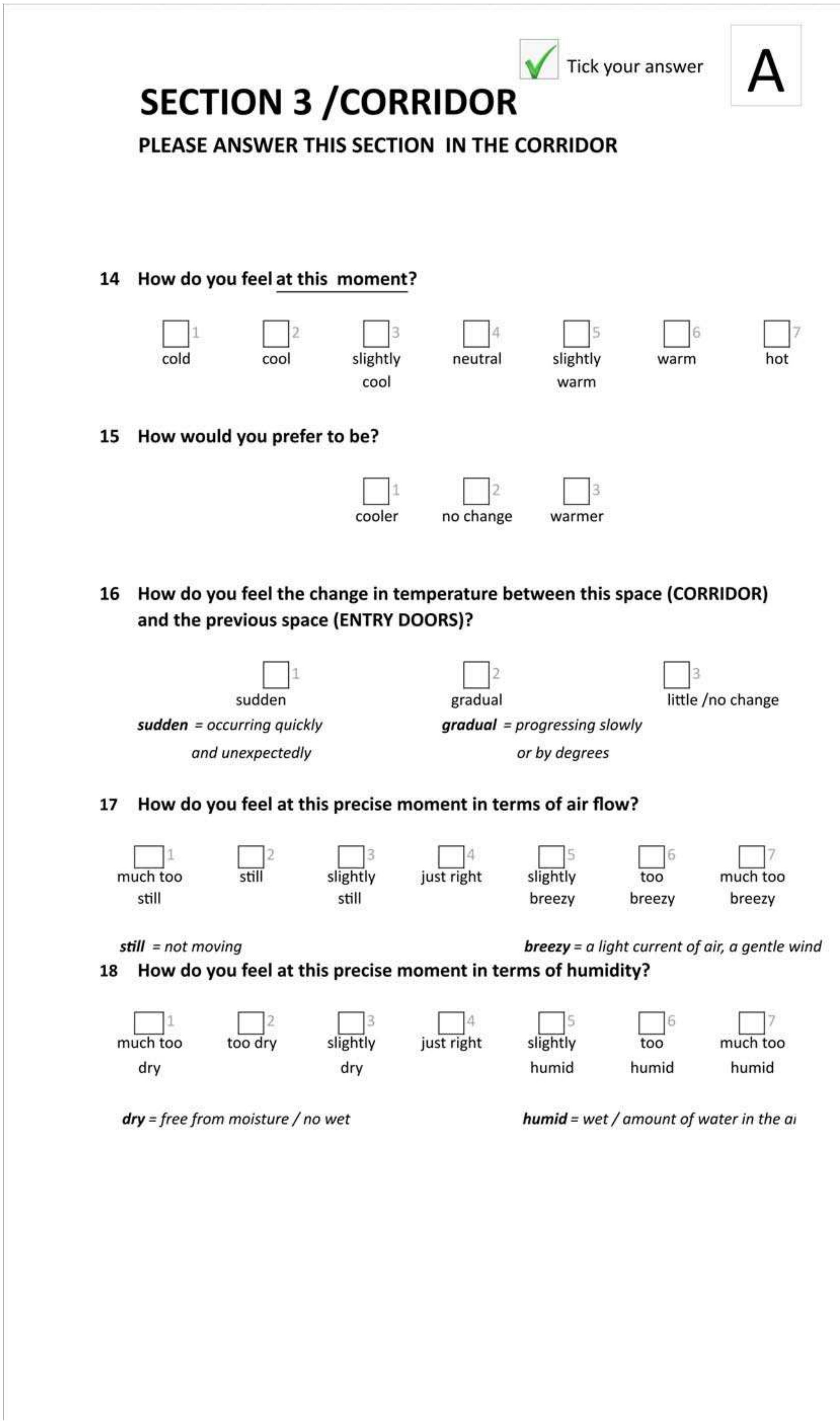
breezy *= a light current of air, a gentle wind*

13 How do you feel at this moment in terms of humidity?

☐1	☐2	☐3	☐4	☐5	☐6	☐7
much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid

dry *= free from moisture / no wet*

humid *= wet / amount of water in the air*



✓ Tick your answer

A

SECTION 3 /CORRIDOR

PLEASE ANSWER THIS SECTION IN THE CORRIDOR

14 How do you feel at this moment?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
cold	cool	slightly cool	neutral	slightly warm	warm	hot

15 How would you prefer to be?

☐ 1	☐ 2	☐ 3
cooler	no change	warmer

16 How do you feel the change in temperature between this space (CORRIDOR) and the previous space (ENTRY DOORS)?

☐ 1	☐ 2	☐ 3
sudden	gradual	little /no change

sudden *= occurring quickly and unexpectedly*

gradual *= progressing slowly or by degrees*

17 How do you feel at this precise moment in terms of air flow?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too still	still	slightly still	just right	slightly breezy	too breezy	much too breezy

still *= not moving*

breezy *= a light current of air, a gentle wind*

18 How do you feel at this precise moment in terms of humidity?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid

dry *= free from moisture / no wet*

humid *= wet / amount of water in the ai*

☑ Tick your answer

A

SECTION 4 /SEMINAR ROOM

PLEASE ANSWER THIS SECTION INSIDE THE SEMINAR ROOM OR LECTURE THEATRE

19 How do you feel at this precise moment?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
cold	cool	slightly cool	neutral	slightly warm	warm	hot

20 How would you prefer to be?

☐ 1	☐ 2	☐ 3
cooler	no change	warmer

21 How do you feel the change in temperature between this space (SEMINAR ROOM) and the previous space (CORRIDOR)?

☐ 1	☐ 2	☐ 3
sudden	gradual	little /no change

sudden *= occurring quickly and unexpectedly*

gradual *= progressing slowly or by degrees*

22 How do you judge this interior environment in terms of temperature?

☐ 1	☐ 2
acceptable	unacceptable

23 How do you feel at this precise moment in terms of air flow?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too still	still	slightly still	just right	slightly breezy	too breezy	much too breezy

still *= not moving*

breezy *= a light current of air, a gentle wind*

24 How do you feel at this precise moment in terms of humidity?

☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7
much too dry	too dry	slightly dry	just right	slightly humid	too humid	much too humid

dry *= free from moisture / no wet*

humid *= wet / amount of water in the air*

ABOUT YOU

PLESE TAKE A SEAT AND ANSWER SECTION 5

25 **Gender** male ☐ 1 female ☐ 2

26 **Nationality or Country** ____________________

27 **Age** years ____________

29 **Weight** kilograms ____________ **OR** stones / pounds ____________

30 **Height** Metres/centimetres ____________ **OR** feet / inches ____________

31 **How long have you been in Sheffield?**

____________ How many years? **or** ____________ How many months? **or** ____________ How many days? **or** ____________ how many hours? I am visitor

32 **What clothes are you wearing right NOW ?**

* tick twice or more if you are wearing many layers of the same clothes

UNDERWEAR (tick as many as appropiate)

male (one piece) ☐ 1 (0.03) **female** (two pieces innerwear) ☐ 3 (0.04)

(male)long underwear buttons ☐ 2 (0.15)

long underwear top ☐ 4 (0.20)

MID LAYER (tick as many as appropiate)

short sleeved shirt / blouse ☐ 5 (0.17)

long sleeved shirt / blouse ☐ 6 (0.34)

leggings ☐ 7 (0.15)

trousers ☐ 8 (0.24)

shorts ☐ 9 (0.08)

long skirt ☐ 10 (0.23)

short skirt ☐ 11 (0.14)

dress ☐ 12 (0.29)

OUTER LAYER (tick as many as appropiate)

jacket ☐ 13 (0.42)

sweater ☐ 15 (0.25)
or jumper

sleeveless vest ☐ 16 (0.17)

coat ☐ 14 (0.48)

FOOTWEAR (tick as many as appropiate)

shoes /trainers ☐ 17 (0.02)

boots ☐ 18 (0.10)

sandals ☐ 19 (0.02)

tights ☐ 20 (0.02)

NO socks or tights ☐ 21 (0.0)

short socks ☐ 22 (0.02)

long socks ☐ 23

Are you carrying a backpack with you?

No ☐ 1 yes ☐ 2

ABOUT YOU

33 Have you been in this building before?

this is the first time ☐ 1 a few times ☐ 2 many times ☐ 3

34 Where have you been most of the time during the last 30 minutes?

indoors ☐ 1 outdoors ☐ 2

35 How did you arrive to this building from the place or building you were before?

walking/relaxed ☐ 1 2.0 running ☐ 3 3.8 other ☐ 5

walking/fast ☐ 2 2.6 cycling ☐ 4 4.0

36 How long did your journey take to this place from the building or interior space you were before?

minutes ______________

37 Have you had lunch or breakfast during the last hour?

yes ☐ 1 no ☐ 2

38 What were you doing in the last 30 minutes in the place or building you were before coming here?

sitting (passive work) ☐	1	**sitting (active work)** ☐	2	**standing relaxed** ☐	3	**standing working** ☐	4
reading	1.0	laboratory work	1.2	reading	1.6	active laboratory work	2.0
writing		active work with arms		writing		active work with arms	
computer work		workshop		computer work			
attending a lecture							
high activity ☐	5	**doing execise** ☐	8				
workshop	3.0		3.6				

40 Does the place you usually use to work or study have air conditioning (cooling) during summer?

yes ☐ 1 no ☐ 2

41 Does the place you usually use to work or study have air conditioning (heating) during winter?

yes ☐ 1 no ☐ 2

42 Does your accommodation or house have air conditioning (cooling) in summer?

yes ☐ 1 no ☐ 2

42 Does your accommodation or house have air conditioning (heating) during winter?

yes ☐ 1 no ☐ 2

Appendix 2

Statistical comparison of participants' thermal sensation vote when moving from one space into another (Friedman test and Wilcoxon signed rank test) and comparison between A and B at the seminar room (Mann-Whitney test).

Flat Sequences

				Conditions						
Seq	**Blg**	**A**	**B**	**EXT**	**DL**	**CS**	**SR**	**Friedman test**	**Wilcoxon Signed Rank test**	**Mann-Whitney test**
2 N=42 Spring	HS	24	18	22.0 °C 39% RH < 0.8 m/s	20.0 °C 43% RH 0.30 m/s	20.0 °C 43% RH < 0.25 m/s	21.6 °C 42% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.023 (DL-CS) p=0.001 (CS-SR) p=0.007	0.029
3 N=38 Summer	HS	18	20	21.0 °C 38% RH < 0.8 m/s	22.0 °C 38% RH < 0.25 m/s	21.0 °C 42% RH < 0.25 m/s	21.0 °C 39% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.002 (CS-SR) p=0.004	0.524
7 N=14 Summer	HS	4	10	22.9 °C 55% RH < 0.8 m/s	22.0 °C 55% RH < 0.25 m/s	22.7 °C 50% RH < 0.25 m/s	23.2 °C 48% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.001	0.090
8 N=33 Summer	HS	19	14	22.5 °C 69% RH < 0.8 m/s	22.1 °C 69% RH 0.30m/s	23.0 °C 63% RH < 0.25 m/s	23.0 °C 60% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.009	0.001

Sudden Sequences

				Conditions						
Seq	**Blg**	**A**	**B**	**EXT**	**DL**	**CS**	**SR**	**Friedman**	**Wilcoxon**	**Mann-Whitney**
1 N=32 Spring	HS	20	12	14.0 °C 78% RH < 0.8 m/s	16.0 °C 63% RH < 0.25 m/s	19.0 °C 56% RH < 0.25 m/s	21.0 °C 45% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.023 (DL-CS) p=0.001 (CS-SR) p=0.007	0.029

11 N=33 Autumn	HS	20	13	14.1°C 79% RH < 0.8 m/s	19.3°C 79% RH < 0.25 m/s	19.6°C 79% RH < 0.25 m/s	20.0 °C 79% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.002 (CS-SR) p=0.004	0.524
12 N=66 Autumn	HS	28	38	14.1 °C 67% RH < 0.8 m/s	19.0 °C 58% RH < 0.25 m/s	19.0 °C 50% RH < 0.25 m/s	20.5 °C 48% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.001	0.090
13 N=58 Autumn	HS	20	13	13.0 °C 49% RH < 0.8 m/s	20.0 °C 43% RH < 0.25 m/s	20.0 °C 37% RH < 0.25 m/s	21.0 °C 39% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.009	0.001
14 N=85 Winter	HS	43	42	9.3 °C 61% RH < 0.8 m/s	17.6 °C 50% RH < 0.25 m/s	17.6 °C 37% RH < 0.25 m/s	20.9 °C 37% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.000	0.000
15 N=39 Winter	HS	21	18	10.1 °C 50% RH < 0.8 m/s	18.6 °C 43% RH < 0.25 m/s	18.6 °C 36% RH < 0.25 m/s	19.9 °C 35% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.000 (CS-SR) p=0.763	0.922
16 N=67 Winter	HS	35	32	10.0 °C 63% RH < 0.8 m/s	12.9 °C 53% RH < 0.25 m/s	17.6 °C 43% RH < 0.25 m/s	20.1 °C 42% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.123 (DL-CS) p=0.000 (CS-SR) p=0.000	n/a
18 N=23 Spring	ICS	23	0	16.0 °C 49% RH < 0.8 m/s	18.0 °C 43% RH < 0.25 m/s	23.0 °C 36% RH < 0.25 m/s	23.0 °C 40% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.007 (DL-CS) p=0.002 (CS-SR) p=0.080	n/a
24 N=49 Autumn	ICS	39	10	14.7 °C 67% RH < 0.8 m/s	17.3 °C 56% RH < 0.25 m/s	22.4 °C 44% RH < 0.25 m/s	21.9 °C 46% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.001	0.533
27 N=34 Autumn	ICS	17	17	9.1 °C 78% RH < 0.8 m/s	12.8 °C 59% RH < 0.25 m/s	19.0 °C 45% RH < 0.25 m/s	21.4 °C 48% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.001 (CS-SR) p=0.028	0.634
34	ICS	12	13	10.1 °C	14.7 °C	21.0 °C	20.5 °C	p <.05	(EXT-DL) p=0.013	0.270

N=25 Winter				61% RH < 0.8 m/s	46% RH < 0.25 m/s	36% RH < 0.25 m/s	39% RH < 0.25 m/s		(DL-CS) p=0.011 (CS-SR) p=0.206	
36 N=18 Summer	JW	9	9	19.0 °C 50% RH < 0.8 m/s	20.0 °C 46% RH < 0.25 m/s	22.0 °C 42% RH < 0.25 m/s	26.0 °C 36% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.121 (DL-CS) p=0.014 (CS-SR) p=0.008	0.190
39 N=37 Autumn	JW	19	18	11.0 °C 81% RH < 0.8 m/s	14.0 °C 68% RH 0.41 m/s	18.0 °C 56% RH < 0.25 m/s	19.3 °C 54% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.006 (CS-SR) p=0.002	0.578
42 N=43 Autumn	JW	39	10	18.5 °C 71% RH < 0.8 m/s	19.8 °C 65% RH < 0.25 m/s	21.0 °C 60% RH < 0.25 m/s	22.6 °C 58% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.001	0.060
43 N=25 Winter	JW	15	10	6.2 °C 62% RH < 0.8 m/s	11.2 °C 58% RH < 0.25 m/s	16.8 °C 42% RH < 0.25 m/s	19.5 °C 58% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.004 (DL-CS) p=0.001 (CS-SR) p=0.011	0.600
44 N=35 Winter	JW	25	10	9.4 °C 60% RH < 0.8 m/s	12.7 °C 54% RH < 0.25 m/s	16.8 °C 43% RH < 0.25 m/s	21.1 °C 45% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.000	0.141
45 N=71 Winter	JW	39	32	9.2 °C 58% RH < 0.8 m/s	11.4 °C 51% RH 0.32 m/s	16.0 °C 39% RH < 0.25 m/s	21.4 °C 34% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.000 (CS-SR) p=0.000	0.003
46 N=31 Winter	JW	11	20	7.6 °C 57% RH < 0.8 m/s	12.5 °C 43% RH < 0.25 m/s	20.0 °C 31% RH < 0.25 m/s	22.0 °C 32% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.008 (DL-CS) p=0.083 (CS-SR) p=0.527	0.980

Irregular Sequences

				Conditions						**A - B**
Seq	**Blg**	**A**	**B**	**EXT**	**DL**	**CS**	**SR**	**Friedman**	**Wilcoxon**	**Mann-Whitney**
4	HS	10	17	25.0° C	22.8° C	22.9° C	23.6 °C	p <.05	(EXT-DL) p=0.007	0.001

N=27 Summer				52% RH < 0.8 m/s	56% RH < 0.25 m/s	53% RH < 0.25 m/s	51% RH < 0.25 m/s		(DL-CS) p=0.317 (CS-SR) p=0.026	
17 N=24 Spring	ICS	24	0	15.5 °C 59% RH < 0.8 m/s	16.0 °C 55% RH < 0.25 m/s	22.0 °C 40% RH < 0.25 m/s	20.0 °C 46% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.096 (DL-CS) p=0.000 (CS-SR) p=0.000	n/a
19 N=48 Spring	ICS	18	30	22.0 °C 57% RH < 0.8 m/s	21.0 °C 56% RH < 0.25 m/s	24.0 °C 51% RH < 0.25 m/s	21.0 °C 57% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.058 (DL-CS) p=0.090 (CS-SR) p=0.001	0.285
21 N=44 Summer	ICS	18	26	24.0 °C 38% RH < 0.8 m/s	23.0 °C 38% RH < 0.25 m/s	25.4°C 35% RH < 0.25 m/s	24.0 °C 46% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.322 (DL-CS) p=0.000 (CS-SR) p=0.001	0.086
22 N=16 Summer	HS	16	0	27.1 °C 40% RH < 0.8 m/s	24.6 °C 45% RH < 0.25 m/s	26.1 °C 40% RH < 0.25 m/s	24.0 °C 46% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.002 (DL-CS) p=0.059 (CS-SR) p=0.001	n/a
23 N=74 Summer	ICS	40	34	18.1 °C 73% RH < 0.8 m/s	20.2 °C 61% RH < 0.25 m/s	24.8 °C 49% RH < 0.25 m/s	23.7 °C 51% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.304 (DL-CS) p=0.000 (CS-SR) p=0.000	0.015
26 N=38 Autumn	ICS	17	21	14.1 °C 74% RH < 0.8 m/s	16.0 °C 63% RH < 0.25 m/s	22.2 °C 47% RH < 0.25 m/s	20.7 °C 52% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.015 (DL-CS) p=0.000 (CS-SR) p=0.013	0.056
28 N=32 Winter	ICS	32	0	9.3 °C 59% RH < 0.8 m/s	12.5 °C 58% RH < 0.25 m/s	20.1 °C 39% RH < 0.25 m/s	19.3 °C 42% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000 (CS-SR) p=0.013	n/a
29 N=29 Winter	ICS	28	1	10.5 °C 65% RH < 0.8 m/s	13.1 °C 53% RH < 0.25 m/s	20.0 °C 39% RH < 0.25 m/s	19.5 °C 42% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.000 (CS-SR) p=0.154	n/a
30 N=56	HS	56	0	8.6 °C 75% RH	11.2 °C 60% RH	18.9 °C 41% RH	17.6 °C 42% RH	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.000	n/a

Winter				< 0.8 m/s	< 0.25 m/s	< 0.25 m/s	< 0.25 m/s		(CS-SR) p=0.031	
35 N=34 Spring	ICS	19	15	25.0 °C 32% RH < 0.8 m/s	21.0 °C 38% RH < 0.25 m/s	22.0 °C 39% RH < 0.25 m/s	24.0 °C 34% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.001 (DL-CS) p=0.084 (CS-SR) p=0.109	0.918
37 N=43 Summer	JW	20	23	23.8 °C 38% RH < 0.8 m/s	22.9 °C 19% RH < 0.25 m/s	23.9 °C 19% RH < 0.25 m/s	25.0 °C 37% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.941 (DL-CS) p=0.022 (CS-SR) p=0.001	0.404
38 N=26 Summer	JW	10	16	26.4 °C 36% RH < 0.8 m/s	23.8 °C 16% RH < 0.25 m/s	24.0 °C 15% RH < 0.25 m/s	25.1 °C 39% RH < 0.25 m/s	P= 0.09	(EXT-DL) p=0.086 (DL-CS) p=0.655 (CS-SR) p=0.414	0.421
40 N=21 Autumn	JW	8	13	15.3 °C 84% RH < 0.8 m/s	17.0 °C 77% RH < 0.25 m/s	20.9 °C 63% RH < 0.25 m/s	21.7 °C 61% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.017 (DL-CS) p=0.257 (CS-SR) p=0.046	0.972
41 N=29 Autumn	JW	18	11	14.0 °C 81% RH < 0.8 m/s	16.5 °C 74% RH < 0.25 m/s	19.0 °C 64% RH < 0.25 m/s	22.0 °C 60% RH < 0.25 m/s	p <.05	(EXT-DL) p=0.000 (DL-CS) p=0.014 (CS-SR) p=0.001	0.808