Citation for published version

Nikolopoulou, Marialena and Kotopouleas, Alkis and Lykoudis, Spyridon (2018) From indoors to outdoors and in-transition; thermal comfort across different operation contexts. In: 10th Windsor Conference: Rethinking Comfort, 12-15 April 2018, Windsor.

DOI

Link to record in KAR

http://kar.kent.ac.uk/66790/

Document Version

Author's Accepted Manuscript

Proceedings of 10th Windsor Conference: **Rethinking Comfort**
Cumberland Lodge, Windsor, UK, 12-15 April 2018
Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

From indoors to outdoors and in-transition; thermal comfort across different operation contexts

Marialena Nikolopoulou[1], Alkis Kotopouleas[1] and Spyridon Lykoudis[2]

[1] Centre for Architecture and Sustainable Environment (CASE), Kent School of Architecture, University of Kent, Canterbury CT2 7NZ, M.Nikolopoulou@kent.ac.uk, A.G.Kotopouleas@kent.ac.uk
[2] Independent Researcher, Athens, Greece, slykoud@yahoo.com

Abstract: This paper focuses on the investigation of thermal comfort conditions in three very different operational contexts using meta-analysis of different studies within a similar climatic context in the UK. This includes extensive surveys indoors from offices, outdoors from urban areas, as well as indoors from airport terminals. Recent research in airport terminal buildings has highlighted that there are very different user groups, with diverse requirements for thermal comfort in such facilities. The paper investigates the hypothesis that staff working in the different areas have needs more similar to those of staff working in offices, while passengers use the building as a transition area with very different requirements and hence closer to the outdoor environment. Analysing and comparing the thermal comfort conditions from the different contexts, it explores the role of adaptation for thermal comfort attainment and satisfaction with the environment and the similarities of very different operational contexts in terms of their thermal comfort characteristics. Finally, the paper highlighted techniques for the potential transformation of thermal comfort scales, which can enable comparison between different types of surveys and inform the wider thermal comfort debate.

Keywords: meta-analysis, adaptation, scale transformation, surveys

1. Introduction

In the last 20 years, the field of thermal comfort has witnessed a significant increase in thermal comfort surveys in different operational contexts, which has provided a broader perspective from which to view comfort in urban environments. It has also enabled us to understand adaptation processes more closely and evaluate the subtle ways which they present themselves and their importance in achieving thermal comfort in different contexts.

This paper focuses on thermal comfort in three very different contexts; in offices, outdoor urban spaces and airport terminals, using meta-analysis of different studies within a similar climatic context in the UK. Recent research in airport terminal buildings has highlighted that there are very different user groups, with diverse requirements for thermal comfort in such facilities (Kotopouleas and Nikolopoulou, 2016). The paper investigates the hypothesis that staff working in the different areas have needs more similar to those of staff working in offices, while passengers use the building as a transition area with very different requirements and hence closer to the outdoor environment. Analysing and comparing the thermal comfort conditions from the different contexts, the paper explores the role of adaptation for thermal comfort attainment and satisfaction with the environment and the similarities of very different operational contexts in terms of their thermal comfort characteristics.

2. Research Framework

Before proceeding with explaining the data sources and methodology employed for the study, it is worth discussing the development of the hypothesis and the reason for the comparison of the different operational contexts. Recent research funded by the EPSRC to minimise the carbon footprint of airport terminal buildings, identified the occurrence of two distinct user groups with consistent differences in thermal comfort requirements (Nikolopoulou and Kotopouleas, 2016). Despite the identical environmental operation context, the analysis highlighted the difference in the way the terminal is perceived as transition vs. indoor workspace for passengers and staff respectively.

Such differences, which could only be justified by personal and cognitive factors discussed in the framework of psychological adaptation (Nikolopoulou and Steemers, 2003), led one of the authors to put forward the hypothesis that adaptive opportunity should in fact be treated as a continuum (Nikolopoulou, 1998, 2004). Nikolopoulou argued that on one end of the spectrum, conditions were fully controlled with no adaptation possible, e.g. in climate chambers, while on the other end, conditions were totally uncontrolled and variable, e.g. outdoors with adaptation developing fully both physically and psychologically (Fig. 1). She speculated that buildings occupied various points in between, according to the degree of adaptation they allowed for. Fully controlled HVAC buildings not allowing interaction between the occupants and the system would be closer to the climate chamber, whereas free-running buildings closer to the outdoor situation.

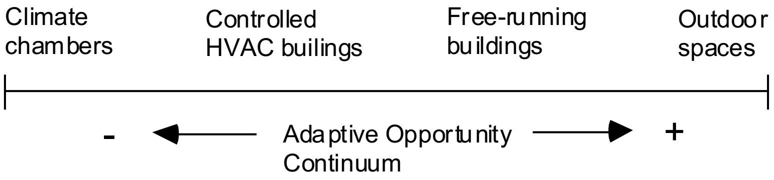


Figure 1: Schematic diagram of the adaptive opportunity continuum (Nikolopoulou, 1998)

Following this continuum, application of theoretical comfort models could then be compared with occupants' thermal comfort conditions. For example, as comfort models have been developed from surveys in climate chambers (e.g. Fanger 1970), it would be expected the two to be identical at the respective end of the spectrum. Moving towards the other end, the biggest difference would be expected for outdoor spaces, where research has indeed highlighted large discrepancies between theoretical models and actual outdoor thermal comfort conditions (Nikolopoulou *et al.*, 2001; Nikolopoulou and Lykoudis, 2006). With the built environment falling in between these two extremes, where the building envelope is sealed and the indoor conditions are fully controlled by a central HVAC system, it would be expected that theoretical models are very close to actual thermal comfort conditions, as a result of minimal adaptive opportunity. Indeed, this was corroborated by de Dear *et al.* (1997), who demonstrated that the PMV model (ISO 7730) describes well the thermal sensations for closely controlled buildings. However, in free-running buildings the difference between the two increases significantly (de Dear *et al.*, 1997). This behaviour could be argued to be due to the higher degree of adaptation where occupants interact with the buildings for environmental control.

Although the above model is simplified, it is reasonable to assume that differences in the degree of adaptation still exist even within each of these generic groups, although of smaller magnitude. For example, in free-running buildings, the degree of adaptive opportunity can vary between a cellular and an open plan room. Similarly, in outdoor areas, there is a variety of spaces, allowing access to sun and shade, etc.

With the recent field surveys from a different building typology, namely airport terminals, where distinct thermal comfort conditions were revealed for different user groups even within the same environment, the speculative model of the adaptive continuum is revisited to evaluate the possible role of adaptive opportunity and identify similarities with other physical contexts.

3. Data sources

The study comprises a review and meta-analysis of three extensive thermal comfort datasets, from different operational contexts including offices, airport terminals and outdoor urban settings. These include the ASHRAE RP-884 database that was used for the development of the first adaptive thermal comfort standard for indoors (ANSI/ASHRAE, 2004), the EU-funded RUROS database for outdoors (Nikolopoulou and Lykoudis, 2006) and the data from the EPSRC-funded project on airport terminals (Kotopouleas and Nikolopoulou, 2016, 2018). The ASHRAE RP-884 and RUROS databases include results from comfort surveys from different countries around the world. To enable comparison, between indoors/outdoors as well as airports, a common geographical ground needed to selected. Hence the focus was on the UK.

Offices were selected for the indoor environment, to enable a better comparison with working conditions of airport staff. The studies selected were by Nicol *et al.* in Oxford (1996) and by Williams in Liverpool, St Helens and Chester (1995). For the outdoor environment, the RUROS studies for the UK included the surveys by Steemers *et al.* in Cambridge (2001-02) and Kang *et al.* in Sheffield (2001-02). Finally, for the airport terminals, the surveys by Nikolopoulou and Kotopouleas from Manchester Terminals 1 and 2 and London City Airport (2013-14) were employed. The studies included summer and winter surveys except from Nicol et al. in Oxford (1996) which was carried out in summer only. In some ways, the comparison was limited to datasets available for the specific criteria in the climatic context investigated, and these were the only ones available to the authors, i.e. through the publicly available datasets for indoors and outdoors and the more recent work on airport terminals. A comparison of the relevant studies for the analysis is shown on Table 1.

Overall, there are 1374 participants in the offices, 3087 in the airports and 1957 in the outdoor surveys. The environmental parameters monitored are similar, including air temperature, globe temperature (Tglobe was not collected for the Williams study; also a black globe was used for indoors and grey globe outdoors for RUROS), relative humidity and air movement. Based on these measurements it was then possible to calculate mean radiant and operative temperatures.

It should be highlighted that the conditions included a mixture of mixed mode (some buildings in winter in Williams' study) and free-running case studies (Nicol's study was in naturally-ventilated buildings, as was some of Williams' buildings, while RUROS by definition was in the naturally occurring outdoor thermal environment). On the other hand, the airports were in full HVAC mode across both seasons.

Subjective data from the participants included thermal sensation, and in most cases information on gender, clothing and metabolic rate was also available. Thermal preference data were not available for the RUROS study; hence this parameter was not included in the analysis. A major difference between the studies indoors and outdoors was that the RUROS project employed a 5-point thermal sensation scale, as opposed to the ASHRAE 7-point scale, which had been introduced to aid the interviewing process of individuals after a pilot study outdoors, in what sometimes could be regarded as unfavourable conditions (Nikolopoulou *et al.,* 2001).

This was an important obstacle for potential comparison; hence it was critical to transpose the 5-point RUROS thermal sensation scale into a 7-point scale which could be directly comparable with the rest of the studies.

Table 1: Summary data of the comfort surveys employed for indoors, outdoors and airport terminals

		Nicol Summer NV(i)	**Williams Summer NV**	**Williams Winter NV**	**Williams Winter Mixed**	**Airports HVAC Summer & Winter**	**RUROS Summer & Winter**
General	Location	Oxford	Liverpool, St Helens and Chester			London & Manchester	Cambridge & Sheffield
	Environment	Indoors	Indoors			Indoors	Outdoors
	Case studies	3 office buildings	8 office buildings			3 airport terminals	4 urban locations
Participants	Sample	877	167	209	121	3087	1957
	Gender	✓	x	x	x	✓	✓
	Clothing ins.	✓	✓	✓	✓	✓	✓
	Thermal sensation	✓	Missing 19	✓	✓	✓	✓**(5-point)**
	Thermal Pref.	✓	x	x	x	✓	x
Indoor conditions	Tair	✓(at 0.6m)	✓(at 0.6m)	✓(at0.6m)	✓(at 0.6m)	✓(at 1.7m)	n/a
	Tg	✓(at 0.6m)	x	x	x	✓ (at 1.7m)	n/a
	Tmr	Missing 2	✓	✓	✓	✓ (at 1.7m)	n/a
	Top	Missing 2	✓	✓	✓	✓ (at 1.7m)	n/a
	RH%	✓	✓	✓	✓	✓ (at 1.7m)	n/a
	Air movement	missing 215 (at 0.6m)	✓ (at 0.6m)	✓ (at 0.6m)	✓ (at 0.6m)	✓ (at 1.7m)	n/a
Outdoor conditions	Tair	✓(ii)	✓(ii)	✓(ii)	✓(ii)	✓(meteo)	✓
	Tg(iii)	x	x	x	x	x	✓
	Tmr	x	x	x	x	x	✓
	RH%	✓(ii)	✓(ii)	✓(ii)	✓(ii)	✓(meteo)	✓
	Wind speed	x	x	x	x	x	✓

i Naturally Ventilated
ii Available data for min (at 6am) and max (at 3pm)
iii Tglobe was measured with a grey globe outdoors (as opposed to a black globe used indoors)

3.1. Transformation of RUROS 5-point to ASHRAE 7-point thermal sensation scale

Scale transformation has been investigated in other disciplines, particularly psychology, where the use of Likert scales, i.e. scales allowing individuals to express their dis/agreement in a particular statement, is commonly found. Previous studies that looked at 5- and 7-pt scale transformation have proposed two inverse equations for the estimation of equivalences between the two scale formats (Colman and Norris, 1997), and data gathered from a 5-point format can be readily transferred to 7-point equivalency using a simple rescaling method (Dawes, 2008) producing the same mean score. In the field of thermal comfort, probit and simple regression have been shown to have two important equivalences (Nicol *et al.,* 2012).

The rescaling process of the thermal sensation scale involved a two-step approach. Firstly, the extreme and middle categories of the 5-point scale were corresponded to the extremes and middle of the 7-point scale so that points ±2 become ±3 and 0 remains 0. The second step was to rescale points ±1. A simplified transformation would be the correspondence to points ±1.5 on the 7-point scale. This approach, however, assumes linearity between thermal sensation and the control variable (temperature) which - if not satisfied, e.g. due to measurement error or adaptation - may result in misleading findings (Nicol *et al.,* 2012).

Therefore, to rescale points ±1, the scale's interval property was investigated as to identify the relevant thermal distances between categories -2 and -1, -1 and 0, 0 and +1, +1 and +2, which in the linear approach would be equal to 1. For this purpose, logistic regression (with category +2 set as the reference category) and probit analysis were employed using air temperature (Tair), mean radiant temperature (Tmr) and globe temperature (Tglobe) as control variables.

To enable comparability, it was important to select indices available for all the studies. Correlation analysis of the RUROS data demonstrated that thermal sensation is better correlated with Tglobe (r=0.68, p<0.01) than with Tair (r=0.63, p<0.01) and Tmr (r=0.62, p<0.01). Globe temperature data however were available for only some of the indoor studies reviewed (Table 1). As a result, an operative temperature index was calculated for the RUROS data which could be tested as a control variable. The index was determined using the formula:

$$Top = [Tair * (10 * Vair)^{0.5} + Tmr] / [1 + (10 * Vair)^{0.5}]$$ (Humphreys *et al.*, 2015)

Where: Top is the operative temperature,
Tair represents air temperature,
Tmr is the mean radiant temperature (°C) and
Vair the wind velocity (m/s).

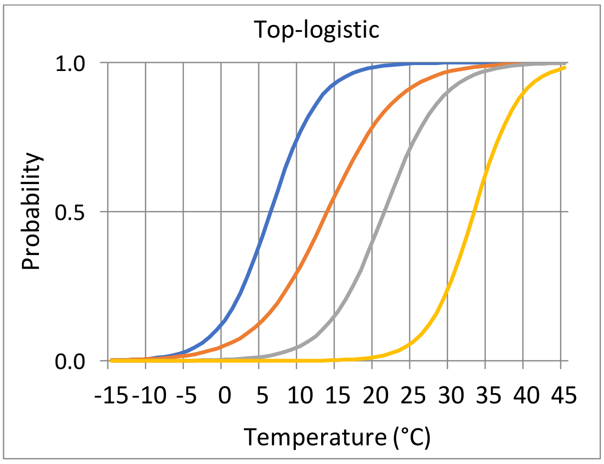
The results of the rescaling process for the different indices are presented in Figure 2 where the intersection between the sigmoid lines and the 0.5 line denote the logit/probit cut-off points, summarised in Table 2. These points correspond to a 50% percent probability of a vote change to the next category. Subsequently, the transformed scores of the (5-point scale) categories -1 and +1 were calculated from -3*(T[0] -T[-1])/(T[0] -T[-2]) and 3*(T[+1] - T[0])/(T[+1] -T[-1]) respectively, where T[-1] is the temperature cut-off point for "cool" sensation, T[0] for "neither cool nor warm", etc. Interestingly, the results revealed high consistency between the cut-off points (Table 2) as well as between the transformed points (Table 3) determined from the different control variables, and particularly between Top and Tglobe, which instilled further confidence for the selection of Top as the thermal index for the evaluation of comfort temperatures.

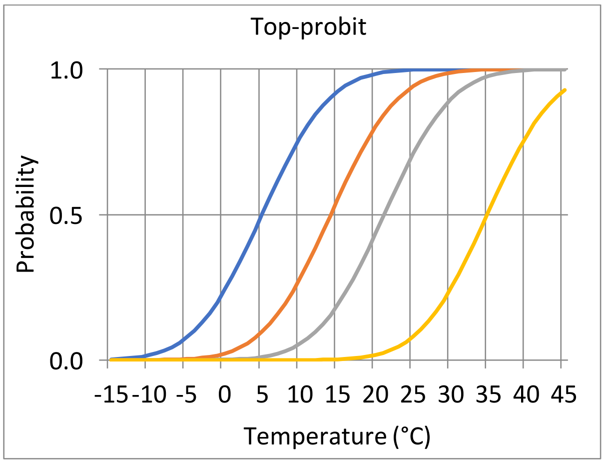
Table 2: Cut-off points for Top, Tair, Tglobe and Tmr derived from logistic regression and probit analysis.

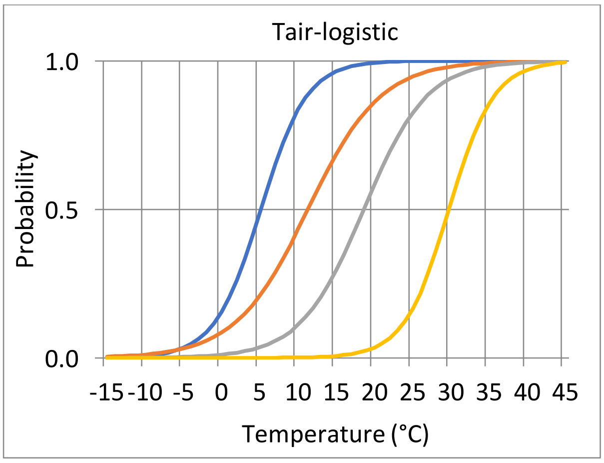
	Logistic regression				Probit analysis			
Thermal sensation	Top 50%	Tair 50%	Tglobe 50%	Tmr 50%	Top 50%	Tair 50%	Tglobe 50%	Tmr 50%
Very cold	6.1	5.1	6.0	5.2	4.9	3.1	4.8	-0.1
Cool	13.6	11.3	13.3	16.0	14.0	11.8	13.8	15.9
Neither cool nor warm	21.1	18.6	20.8	28.2	21.1	18.6	20.8	28.6
Warm	33.0	29.8	32.7	59.0	34.8	32.0	34.4	54.3

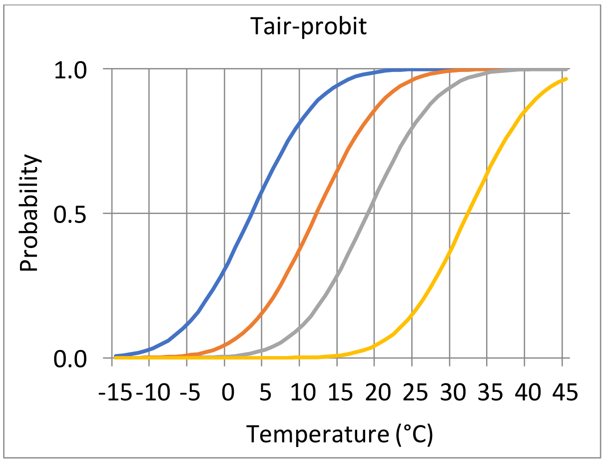
Table 3. Transformation of 5-point scale ±1 categories to 7-point scale.

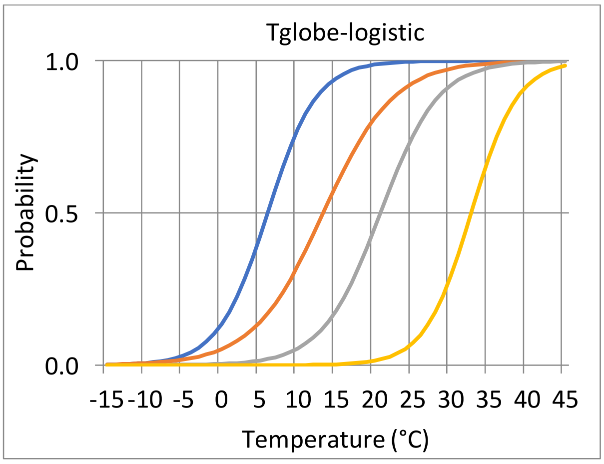
Method	5-point scale	7-point scale			
		Top	Tair	Tglobe	Tmr
Logistic regression	-1	-1.50	-1.62	-1.52	-1.59
	+1	1.84	1.82	1.84	2.15
Forced probit	-1	-1.31	-1.32	-1.31	-1.33
	+1	1.98	1.99	1.98	2.01

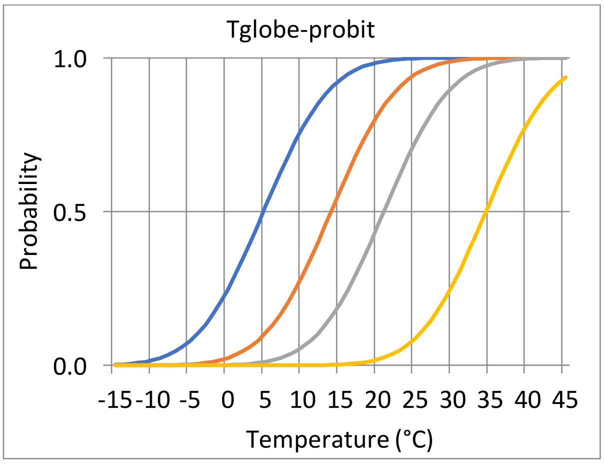

Top-logistic


Top-probit


Tair-logistic


Tair-probit


Tglobe-logistic


Tglobe-probit

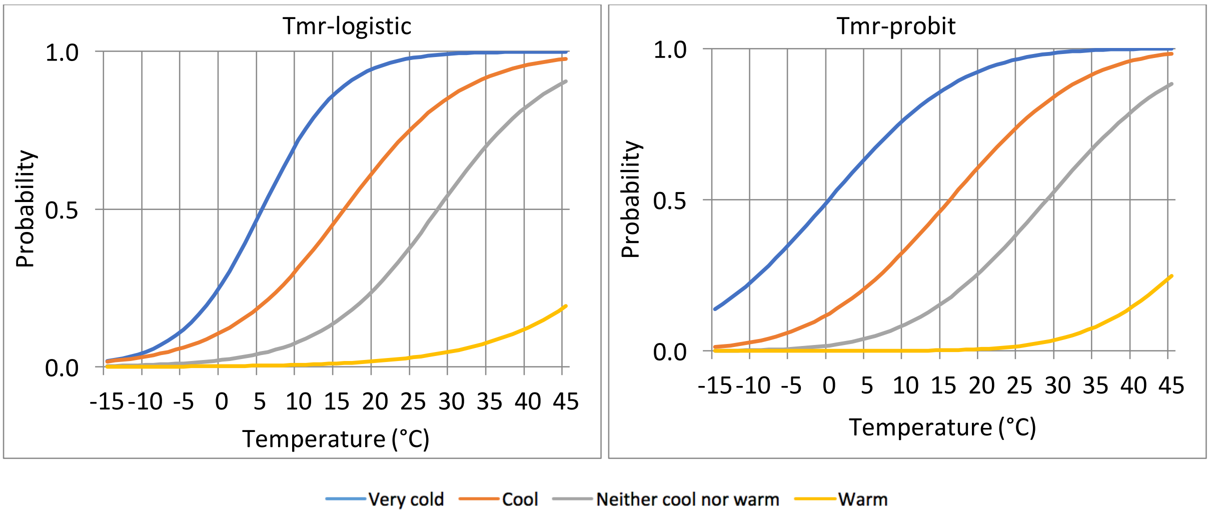


Figure 2: Logistic regression (left column) and probit analysis (right column) using Top, Tair, Tglobe and Tmr as control variables.

As shown in Figure 2, all the analysis for the transformation of the scales was done with both probit and logistic regression. This was due to the fact that the former method has been traditionally associated with the interpretation of data from field surveys in thermal comfort studies, while the latter, is being increasingly used for the analysis of thermal comfort surveys. The ease of use of logistic regression with modern statistical packages (as also highlighted by Nicol *et al.*, 2012), the more intuitive interpretation of its results, and the fact that the two methods provided very similar results led to the adoption of logistic regression results for the meta-analysis.

4. Meta-analysis

As the aim was to evaluate whether staff in airport terminals have comfort requirements closer to staff in offices, while passengers use the terminal as a transition area with more similarities to people found outdoors, it was necessary to separate the airport study in two distinct user groups, passengers and staff. The summary Table 4, shows that although the ratio of staff to passengers in the airports is roughly 1:5 in both seasons, nevertheless the sample is large enough to allow statistical analysis and comparable with the rest of the survey populations.

The data were analysed by means of the Statistical Package for Social Sciences (SPSS) and were initially subjected to quality checks to ensure high fidelity of the developed database totalling 6100 people.

Table 4: Cleaned up data on the sample of the population analysed for the different contexts.

	Airports Staff, HVAC	Airports Passengers, HVAC	Nicol, NV	Williams, NV	Williams, mixed	RUROS	Total
Summer	236	1188	875	148	n/a	1264	3711
Winter	229	1145	n/a	209	121	685	2389
Total	465	2333	875	357	121	1949	6100

A summary of the operative temperatures for the different studies at the different seasons is presented in Table 5. With the exception of the outdoor temperatures for RUROS, which demonstrate a large range and standard deviation, as would be expected for external conditions, the rest of the mean operative temperatures present a fairly uniform profile with a wider range of minimum and maximum temperatures for naturally ventilated buildings in the summer.

Table 5: Summary data for the operative temperature in the different studies

Study	Season	N	Top_min	Top_max	Top_mean	Std. Deviation
Airports Staff	summer	236	19.1	25.8	22.9	1.3
Nicol NV	summer	877	14.3	30.2	21.8	2
Williams NV	summer	167	16.6	25.9	21.9	1.7
Airports Passengers	summer	1188	19.4	26.3	22.8	1.3
RUROS	summer	1264	10.7	36.2	23.2	5.4
Airports Staff	winter	229	16.7	24.3	22.1	1.4
Williams NV	winter	209	18.6	25.9	21.9	1.5
Williams Mixed	winter	121	18.7	25.9	23.4	1.5
Airports Passengers	winter	1145	16.2	25.6	21.9	1.6
RUROS	winter	685	2.3	27.4	13.3	4.8

Following the transformation of the 5-point scale, analysis focused on understanding differences in thermal sensation and identifying the evidence of potential adaptive behaviour.

4.1. Clothing

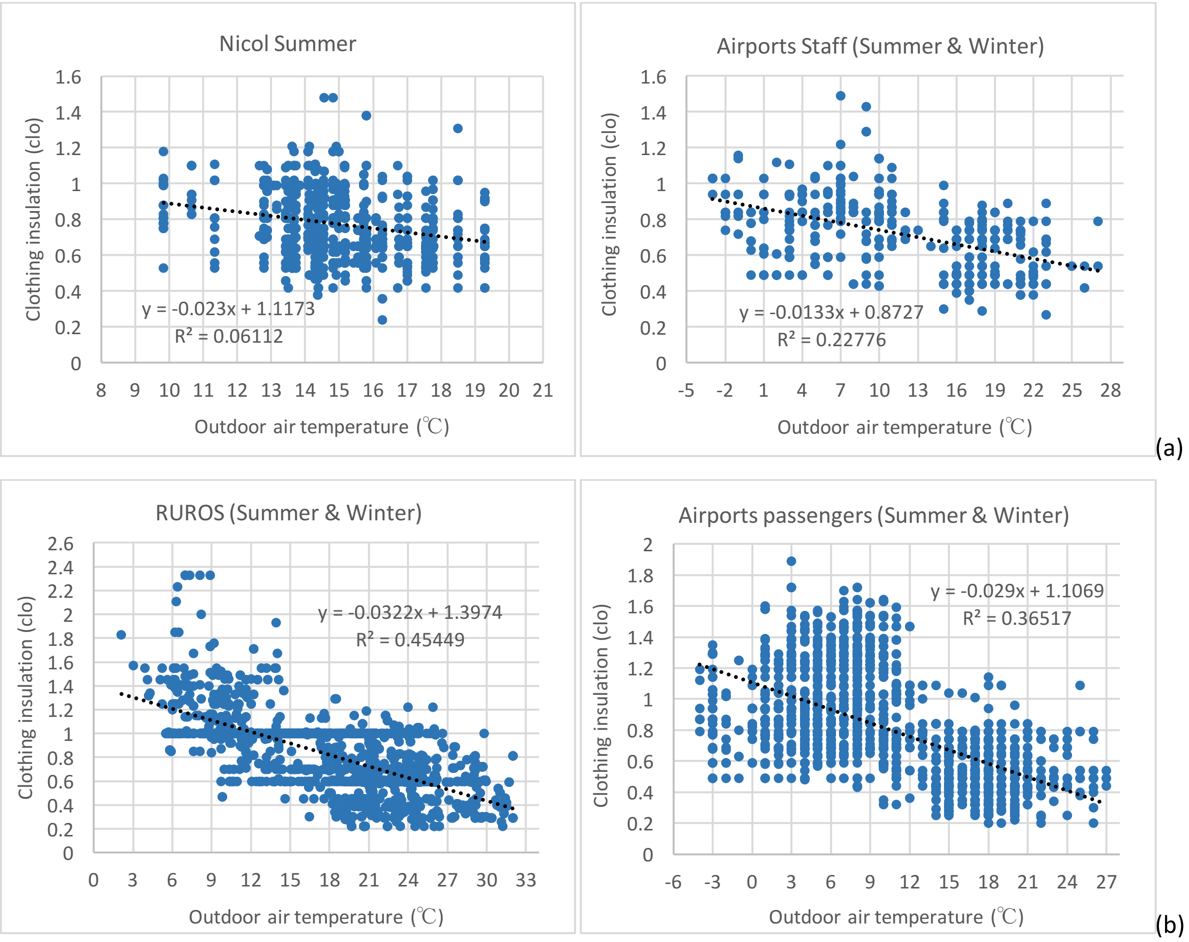


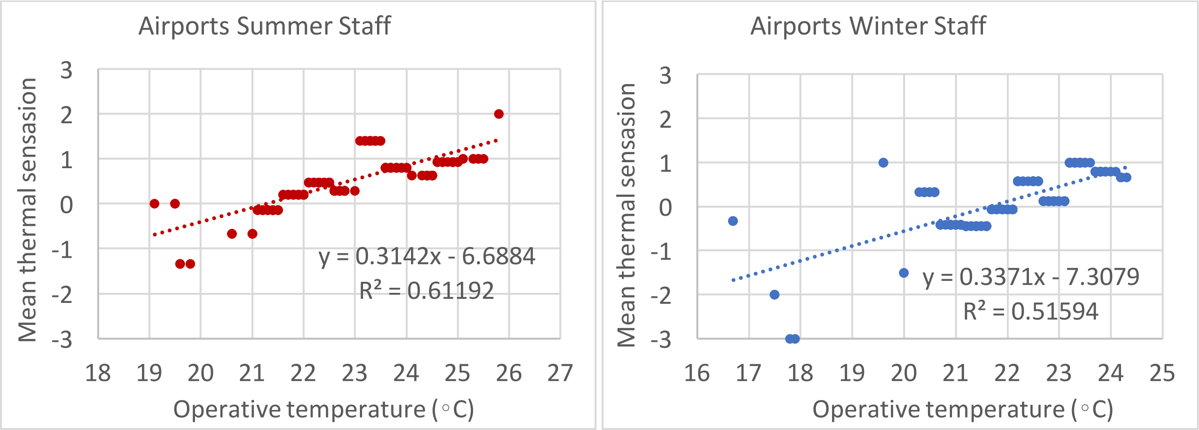
Figure 3: Clothing insulation as a function of outdoor air temperature for the different studies at different seasons, (a) for the staff-indoor group and (b) for the transition and outdoor group.

Considering clothing as a potential adaptive mechanism (Humphreys, 1977, 1979; Nikolopoulou and Lykoudis, 2016), clothing insulation levels were evaluated against outdoor air temperature. From the offices, only the Nicol study could be used. The data on external air temperature for Williams consisted of a fixed value per day, providing two external air temperatures for summer and another three for winter, which did not provide sufficient variation to inform the analysis.

The regression analysis of clothing insulation as a function or outdoor air temperature is presented in Figure 3. It is noticeable that passengers wear a wider range of clothing insulation, which is more comparable to clothing levels outdoors, with 37% and 46% of clothing varying along with external temperature at the two seasons. For airport staff, however, the clothing range worn is narrower, indicative of the set uniform for indoor conditions required in airports, more comparable to an office environment.

4.2. Neutral temperature

Neutral temperature, i.e. the temperature yielding a sensation of neither cold nor hot (Humphreys, 1976), was determined by means of weighted linear regressions using half-degree (°C) increments of operative temperature (de Dear *et al.*, 1997). The mean TS score was calculated for each bin and regression models were fitted between mean TS and operative temperature. Thermal neutrality was subsequently derived from solving the regression equations for TS = 0. The regression models were also used for the evaluation of the operative temperature ranges in which 80% and 90% of people would find the thermal conditions acceptable, in accordance to the statistical assumptions underlying the PMV/PPD heat-balance model (ISO 7730, 2005). All the parameters in the models, presented in Figure 4, achieved a statistical significance level of 99% or better.



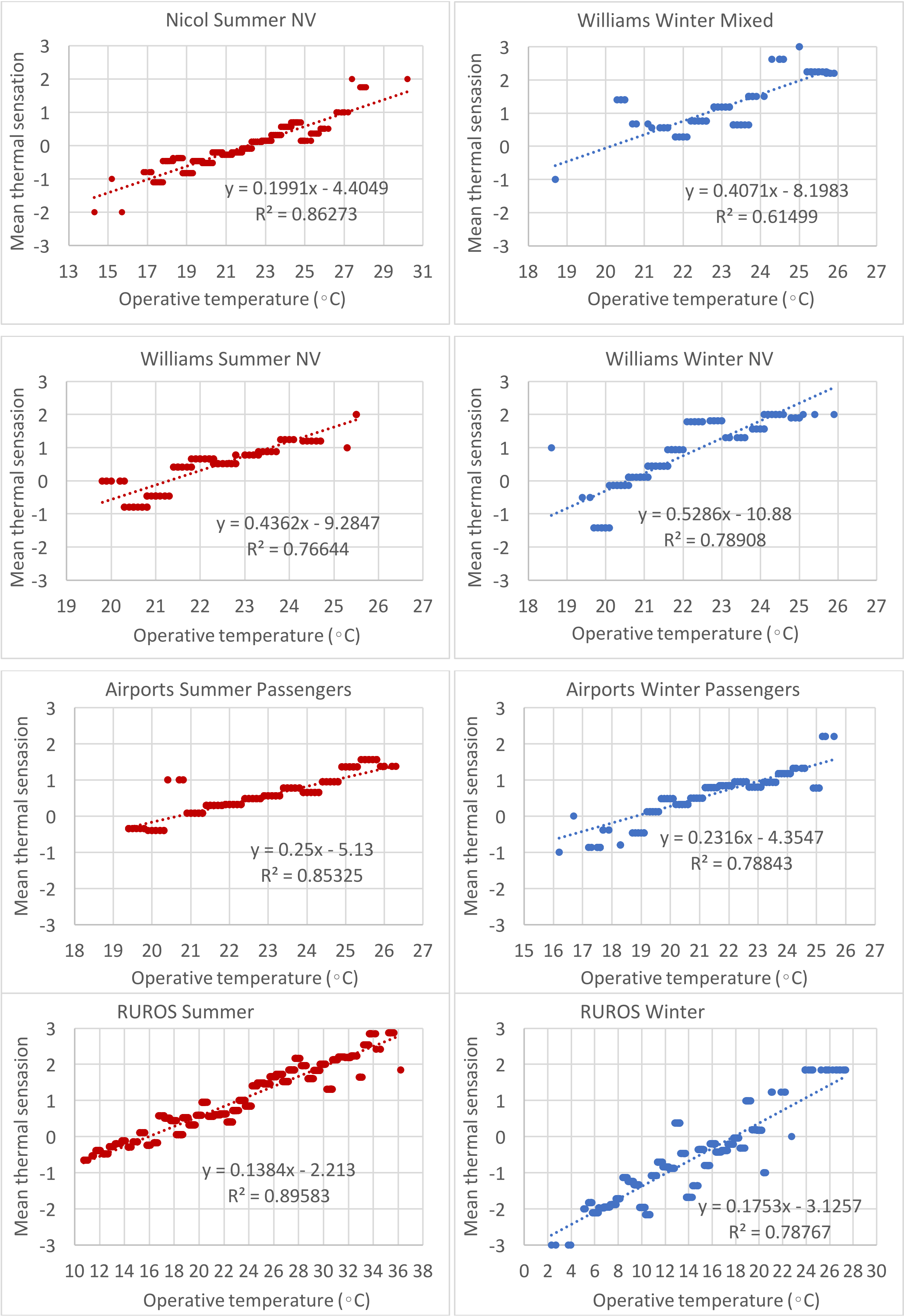


Figure 4: Mean thermal sensation as a function of operative temperature (°C) for the different studies

The analysis highlights a number of issues. Examining the slope of the equation as a measure of thermal sensitivity, it becomes apparent that in both winter and summer, airport passengers are less sensitive than the staff and more similar to the outdoor setting. A unit increase of passengers' TS would require a temperature rise of 4.0 °C in summer and 4.3 °C in winter, particularly comparable with 5.7 °C for outdoors in winter.

Airport staff, however, are more sensitive and closer to office staff. The temperature change required to alter airport staff's TS by 1 unit is nearly 3.0 °C for both seasons, similarly to office buildings where TS would not be altered with temperature changes below 3.7 °C in summer and 2.2 °C in winter.

Looking at neutral temperatures (Table 6), it becomes evident that Tn for airport staff is directly comparable to staff in offices in both seasons. For passengers, direct comparison with the outdoors is more difficult as airports are fully air-conditioned, and yet it is noticeable that in the summer Tn for passengers is lower than all office workers and airports staff, while in winter passenger's Tn is very close to Tn for the outdoor setting (at 18.8 °C and 17.8 °C respectively). In addition, the winter results derived from the evaluation of the 80% acceptability temperature ranges demonstrate a considerable similarity between the comfort zone for passengers and outdoor settings and particular tolerance to colder conditions (Table 6).

Table 6: Summary data for the neutral temperature in the different studies

Study	**Season**	**Building type**	**N**	**Slope**	**R^2**	**Tneutral** (°C)	**80% accept. (°C)**	**90% accept. (°C)**
Airports Staff	summer	HVAC	236	0.31	0.61	21.3	18.6-24.0	19.7-22.9
Nicol	summer	NV	875	0.20	0.86	22.1	17.9-26.4	19.6-24.6
Williams	summer	NV	148	0.44	0.77	21.3	19.3-23.2	20.1-22.4
Airports Passengers	summer	HVAC	1188	0.25	0.85	20.5	17.1-23.9	18.5-22.5
RUROS	summer	n/a	1264	0.14	0.90	16	9.8-22.1	12.4-19.6
Airports Staff	winter	HVAC	229	0.34	0.52	21.7	19.2-24.2	20.2-23.2
Williams	winter	NV	209	0.53	0.79	20.6	19.0-22.2	19.6-21.5
Williams	winter	Mixed	121	0.41	0.62	20.1	18.1-22.2	18.9-21.4
Airports Passengers	winter	HVAC	1145	0.23	0.79	18.8	15.1-22.5	16.6-21.0
RUROS	winter	n/a	685	0.18	0.79	17.8	13.0-22.7	15.0-20.7

5. Conclusions

As the results highlight, there is considerable difference in the adaptive capacity between the different groups analysed. The comfort temperatures for all employees, in the terminals and offices, are closer to the mean operative temperature (Tables 5-6), reflecting their long-term acclimatisation to the working thermal environment. On the other hand, passengers and people outdoors demonstrate wider adaptation capacity with a bigger difference between their mean operative and comfort temperature, while being less sensitive to these differences, as demonstrated by the low gradient of the respective equations for thermal sensation and neutral temperature.

In that respect, the paper succeeded in proving the hypothesis that the thermal comfort requirements of airport staff are closely compared to those of staff working in offices, as also found by the similar neutral temperatures for the two groups. However, the majority of the population in airport terminals is passengers, who inhabit the space as a transition space, more closely related to the comfort requirements of people using outdoor urban spaces, as the respective neutral temperatures highlighted. Once again, this brings to the forefront the important role of adaptation, both physical as well as behavioural and psychological, with experiences and expectations enabling the latter groups to achieve wider thermal comfort zones.

In fact, beyond the broad categories of different physical environments, it is the psychological adaptation that enables moving along the adaptive opportunity continuum, presented in Figure 1, based on the potential for adaptive capacity at a personal level, as manifested with the different groups at airport terminals. Further work in different climatic contexts and employing additional different databases could shed further light on the above, eliminating any implicit bias which may be inherent to specific datasets.

Such findings have important implications for energy use in buildings and particularly the high energy-consuming sector of airport terminals. From introduction of soft policies to address flexibility in clothing for staff uniforms, to the design of localised building services for staff rather than treating large volumes of air in terminals, it becomes apparent that thermal comfort surveys continue to play an important role not only for research but also for understanding human behaviour and ultimately improvements to the design of the built environment.

Finally, the work has shed some light on the technique of potential transformation of thermal comfort scales. The last 15 years have witnessed an increased amount of outdoor thermal comfort surveys, many of which have used a variety of thermal sensation scales from five-point (Nikolopoulou *et al.*, 2001; Nikolopoulou and Lykoudis, 2006; Aljawabra and Nikolopoulou, 2010; Nikolopoulou *et al.*, 2011) to nine-point (Kántor *et al.*, 2016). The paper identified possibilities for eventual comparison of such work from different geographical, climatic and socio-cultural contexts that will inform the wider debate on thermal comfort further.

6. References

Aljawabra, F. and Nikolopoulou, M., 2010. The influence of hot arid climate on the use of outdoor urban spaces and thermal comfort: do cultural and social backgrounds matter?, Intelligent Buildings International, Vol. 2, No. 3, pp. 198-217.

ANSI/ASHRAE Standard 55-2004. *Thermal Environmental Conditions for Human Occupancy*.

Colman, A.M. and Norris, C.E., 1997. Comparing rating scales of different lengths: Equivalence of scores from 5-point and 7-point scales, *Psychological Reports*, Vol.80, pp. 355-362.

Dawes, J., 2008. Do data characteristics change according to the number of scale points used? An experiment using 5-point, 7-point and 10-point scales, *International Journal of Market Research*, Vol. 50, No. 1, pp. 61–104.

de Dear, R.J., Brager, G.S. and Cooper, D., 1997. *Developing an Adaptive Model of Thermal Comfort and Preference,* Final Report on ASHRAE RP-884.

Fanger, P.O., 1970. Thermal Comfort., Danish Technical Press, Copenhagen.

Humphreys, M.A., 1979. The influence of season and ambient temperature on human clothing behaviour. In (eds.) P.O. Fanger and O. Valbjorn Indoor Climate: *Proc. of the first International Climate Symposium*, Copenhagen, 1978, Danish Building Research Institution, Copenhagen.

Humphreys, M.A., 1977. Clothing and the outdoor microclimate in summer, *Building and Environment*, Vol. 12, pp. 137-142.

Humphreys, M.A., 1976. Field studies of thermal comfort compared and applied, *J. Inst. Heat. & Vent. Eng*, 44, pp. 5-27.

Humphreys, M., Nicol, F. and Nikolopoulou, M., 2015. Environmental criteria for design, *Guide A: Environmental Design*, Chartered Institute of Building Services Engineers, CIBSE, London.

ISO 7730, 2005. *Ergonomics of the Thermal Environment - Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*.

Kántor, N., Kovács, A., Takács, Á., 2016. Seasonal differences in the subjective assessment of outdoor thermal conditions and the impact of analysis techniques on the obtained results, *International Journal of Biometeoroly,* Vol. 60, No. 11, pp 1615–1635.

Kotopouleas, A. and Nikolopoulou, M., 2016. Thermal comfort conditions in airport terminals: Indoor or transition spaces? *Building and Environment,* Vol. 99, pp. 184-199.

Kotopouleas, A. and Nikolopoulou, M., 2018. Evaluation of comfort conditions in airport terminal buildings, *Building and Environment,* Vol. 130, pp. 162-178.

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

Nikolopoulou, M., 2004. Outdoor Thermal Comfort. In (eds.) K. Steemers & M.A. Steane, *Architecture and Variety: Environmental Perspectives,* Spon Press, pp. 101-119.

Nikolopoulou, M., 1998. *Thermal Comfort in Outdoor Urban Spaces*, PhD thesis, University of Cambridge (unpublished).

Nikolopoulou, M., Baker, N. and Steemers, K., 2001. Thermal comfort in outdoor urban spaces: the human parameter, *Solar Energy*, Vol. 70, No. 3, pp. 227-235.

Nikolopoulou, M., Kleissl, J., Linden, P.F. and Lykoudis, S., 2011. Pedestrians' perception of environmental stimuli through field surveys: Focus on particulate pollution. *Science of The Total Environment*, Vol. 409, No. 13, pp. 2493-2502.

Nikolopoulou, M. and Lykoudis, S., 2006. Thermal comfort in outdoor urban spaces: Analysis across different European countries. *Building and Environment*, Vol. 41, pp. 1455-1470.

Nikolopoulou, M. and Steemers K., 2003.Thermal comfort and psychological adaptation as a guide for designing urban spaces, *Energy and Buildings*, Vol. 35, No. 1, 95-101.

Spagnolo, S. and de Dear, R.,2003. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia, *Building and Environment*, Vol. 38, pp.721-738.

Acknowledgements

The availability of the datasets has been pivotal for enabling such analysis. These include:
[1] Indoor Offices: ASHRAE RP-884 Adaptive Model Project - Data Downloader
http://sydney.edu.au/architecture/staff/homepage/richard_de_dear/ashrae_rp-884.shtml
[2] Outdoor urban spaces: EU FP5 project RUROS (Rediscovering the Urban realm and Open Spaces) databasehttp://alpha.cres.gr/ruros , EVK4-CT2001-00032.
[3] Airport terminals: EPSRC project "Integration of active and passive indoor thermal environment control systems to minimize the carbon footprint of airport terminal buildings", EP/H004181/1.