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Revisiting the adaptive control algorithm to UK office buildings

Stella Pasalidou[1], Stephanie Gauthier[2] and Leonidas Bourikas[2]

[1] MSc Energy and Sustainability, Faculty of Engineering and the Environment, University of Southampton, SO17 1BJ, United Kingdom, sp2n17@soton.ac.uk
[2] Sustainable Energy Research Group, Faculty of Engineering and the Environment, University of Southampton, SO17 1BJ, United Kingdom

Abstract: The current standard adaptive control algorithm was developed twenty years ago from field studies in 26 buildings across Europe. In the UK, the correlation between comfort temperature and measures of outside temperature was around 0.2. In this paper, we review the results of 1,081 surveys from 84 participants carried out in two buildings in the UK between 2017 and 2018. Results show significant but very low relationships between comfort temperature and measures of outside temperature. While the buildings were in free-running mode, participants exposed to similar environmental conditions felt consistently different. Some participants reported felling cold and other hot. These results lead to the assumption that sets of personal algorithms should be developed to control localised solutions.

Keywords: Thermal comfort; Adaptive thermal comfort; Building controls; Field studies

1. Introduction

The indoor comfort state of occupants in passive buildings is directly related to the outdoor environmental conditions (Olesen, 2018). Outdoor daily mean temperature is not constant and people have learnt to adjust to new thermal environmental conditions through physiological, behavioural and psychological adaptation mechanisms (Brager & de Dear, 1998). With the aim to predict the thermal demand of the occupants, the current standard thermal comfort model (CEN, 2007) suggests that the prior daily outdoor running mean temperature over a 7-day period influences one's indoor thermal state. Twenty years ago, field studies in 26 buildings across Europe have enabled the inception of an adaptive control algorithm, which established a relationship between indoor comfort temperature (T_C) and running mean outdoor temperature for index α=0.80 (T_{RM80}) (McCartney & Nicol, 2002). This index (α) determines weighing applied to each of the prior seven daily mean outdoor temperature. For example, α = 0.1 would give most of weight to the previous day (day n-1), while α = 1 would give equal weight to all seven days. For a variable weather like UK, where daily mean outdoor temperature may vary by 7^{o}C from one day to the next, the value of α is crucial in establishing the comfort temperature. To establish the value of α, McCartney & Nicol (2002) reviewed correlations between T_C and various measures of running mean outdoor temperature for different indexes (α varying between 0.33 and 0.99). This resulted in an optimum value of 0.80 for α, while the correlation coefficients varied between ~0.1 and ~0.6. For the UK dataset, the correlation coefficients were estimated at ~0.2. The aim of this paper is to revisit these results, using a new dataset from field studies carried out in two buildings in the UK between 2017 and 2018.

2. Research Design

The project took place at the University of Southampton for a twelve-month period (July 2017 to July 2018). Two mixed-mode low-energy academic office buildings from two of the university’s campuses were monitored and evaluated. Building 85 in Highfield campus and Building 176 in Boldrewood campus. Three floors of each building were monitored in order to gather objective quantitative data such as temperature, humidity and CO_2 levels. In addition, occupants’ surveys were undertaken in both buildings for the twelve-month period allowing subjective quantitative and qualitative data to be gathered. The dataset comprises of 1,081 surveys from 84 participants who submitted weekly responses via a web-based survey and answered to questions such as “How do you feel right now?” or “How would you prefer to feel?” Furthermore, participants provided answers on how they perceived indoor environmental conditions such as “How do you find the air movement?” or “How do you find the air quality?”. Prior to the analysis, the dataset was reviewed. Answers from participants, who submitted less than 5 questionnaires, was excluded of the dataset. After this screening, the analysis followed a five-step process, summarised in Figure 1.

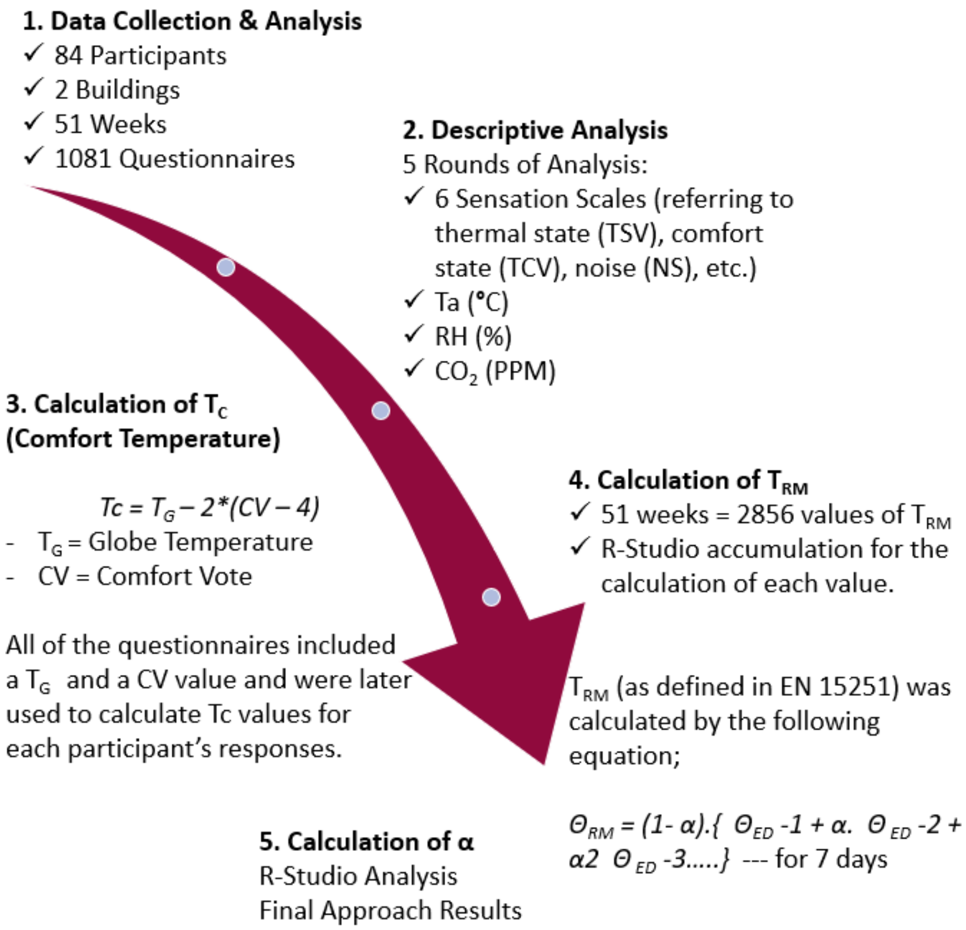

Figure 1. Research design formed for the execution of the project.

3. Results

First the study reviewed participants’ reported thermal comfort vote (CV), which was one of the questions in the surveys allowing the participants to state how they were feeling at the time of the survey (7-point scale). The analysis was aiming to understand the relation between CV and environmental parameters, in particular indoor temperature (T_a) and outdoor temperature (T_{oi}) (see Figure 2).

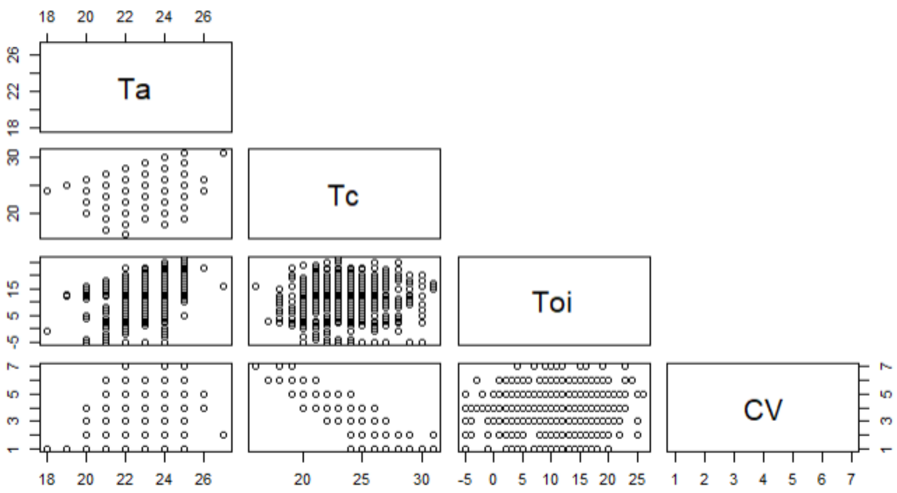

Figure 2. Scatter-graph showing the relation between T_C, CV, T_{OI}, and T_a of the entire dataset.

Results show that the correlations between CV, T_C, T_a and T_{oi} are significantly lower than what was expected, see Table 1.

Table 1. Correlation coefficients and p-values between CV, Tc, Ta and Toi.

Parameters	Pearson p-value	Pearson cor. coeff.	Spearman p-value	Spearman cor. coeff
T_c - T_{oi}	<0.05	0.0995	<0.05	0.1107
Ta - T_{oi}	<0.05	0.4026	<0.05	0.3651
CV - T_{oi}	<0.05	0.1002	<0.05	0.0739

Then the study reviewed the correlations between T_C and various measures of the outside temperature. Results are statistically significant ($p < 0.05$) but the correlation coefficients are very low (adjusted $R^2 < 0.01$) (See Table 2 and Figure 3). Furthermore Table 2 shows that the correlations for the different values of α differ very little.

Table 2. Overall correlations between comfort temperature and various measures of the outside temperature. (with T_{OI} outdoor temperature at the time of the survey (°C), T_{OD} daily mean outdoor temperature (°C) and T_{RM} running mean outdoor temperature (°C))

Independent variables	Correlation coefficient (Adjusted R^2)	P-value
T_{OI}	0.009	< 0.05
T_{OD}	0.005	< 0.05
$T_{RM(0.33)}$	0.007	< 0.05
$T_{RM(0.45)}$	0.007	< 0.05
$T_{RM(0.70)}$	0.008	< 0.05
$T_{RM(0.80)}$	0.008	< 0.05
$T_{RM(0.90)}$	0.007	< 0.05
$T_{RM(0.94)}$	0.008	< 0.05
$T_{RM(0.96)}$	0.008	< 0.05
$T_{RM(0.99)}$	0.008	< 0.05

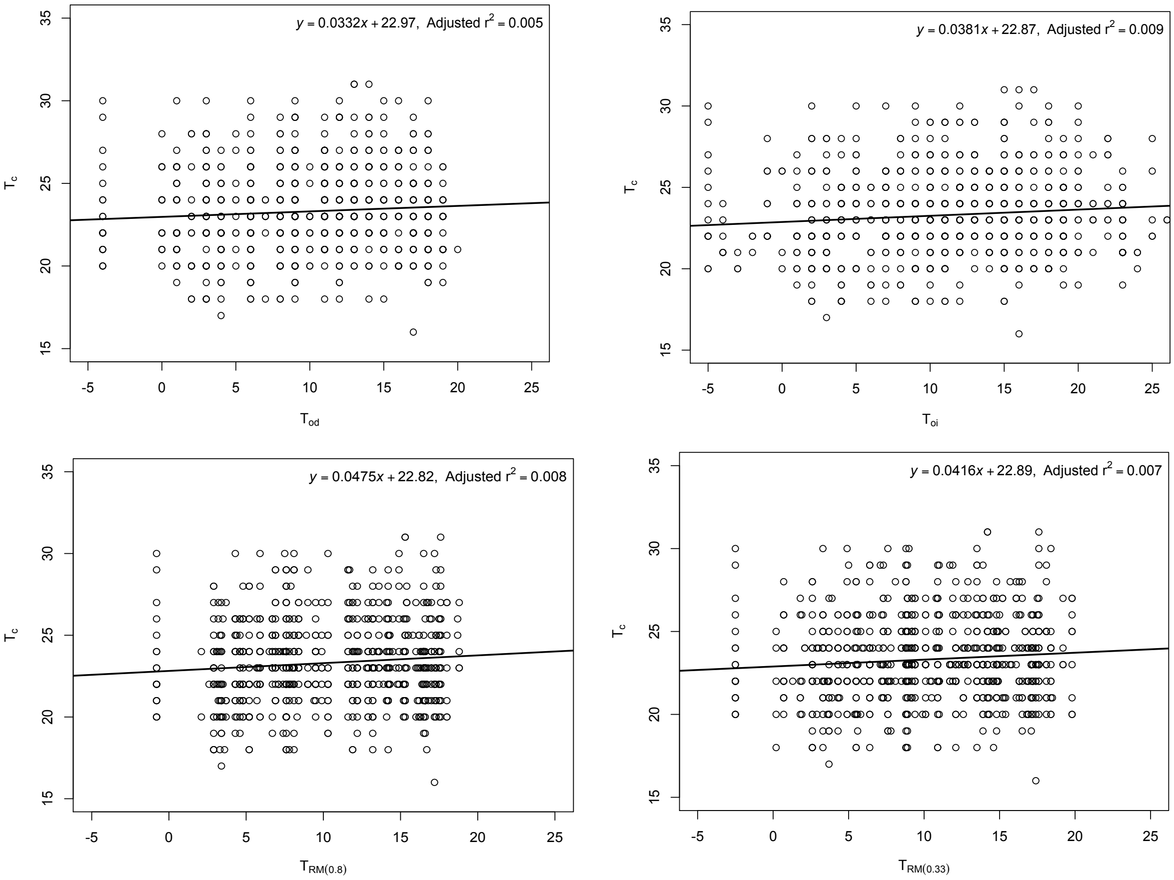

Figure 3. Overall correlations between comfort temperature and various measures of the outside temperature. (with T_{OI} outdoor temperature at the time of the survey (°C), T_{OD} daily mean outdoor temperature (°C), T_{RM} running mean outdoor temperature for index 0.33 and 0.80 (°C)).

Further analysis reviewed the seasonal relationships between T_C and running mean outdoor temperature for index α=0.80 (T_{RM80}) (See Figure 4). Spring is illustrated by season 1, summer by season 2, autumn by season 3 and winter by seasons 4. Results show that the relationship between the independent and dependent variable is low for each of the season.

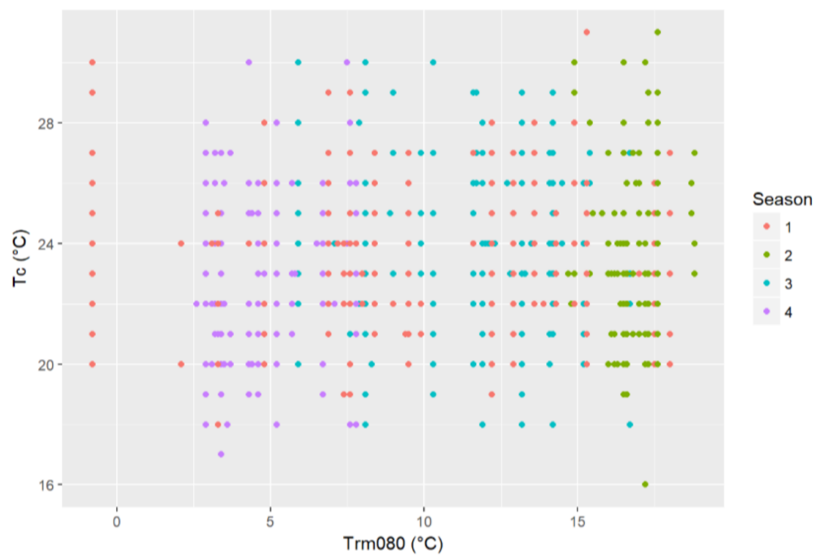

Figure 4. Relationship between T_C and T_{RM080} for different seasons.

Finally, the study reviewed the variations and range in T_C. Figure 5 shows the responses of a sample of the participants who submitted different responses in terms of indoor thermal comfort while being in the same indoor environment and experiencing the same environmental conditions. Although the indoor temperature (T_a) was similar (~24^{o}C), some participants stated that they were feeling hot while some others claimed that the indoor environment was cold. This result could be the strongest indication that the development of personalized models could be the key solutions towards a more relevant predictive thermal comfort algorithm.

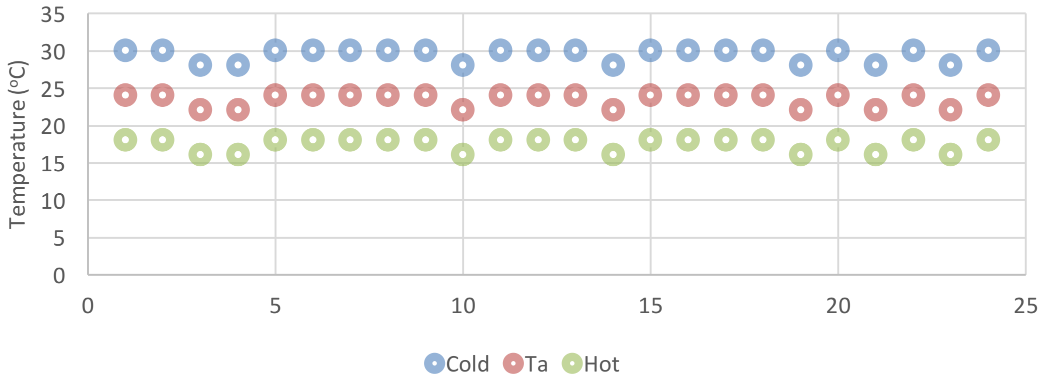

Figure 5. Range of T_c (blue to green) while T_a was around 24 ^{o}C (red) for different surveys.

4. Conclusion

In summary, the correlations between comfort temperature and various measures of the outside temperature were significantly low. For this dataset, it seems that participants' indoor comfort is not related to outdoor temperature. This finding may reflect a new trend as people may be disconnected from external weather conditions. Furthermore, while the buildings were in free-running mode, participants exposed to similar environmental conditions felt consistently different. Some participants reported felling cold and other hot. Therefore, one might suggest that personal thermal comfort algorithms could be the key answer for a more relevant predictive thermal comfort model.

To follow from this conclusion, different climates may need necessary adjustments of a thermal comfort model. If personalised models are in fact the key to indoor thermal comfort, the question then becomes; "What would be a relevant model in a multinational country like England where people from across the globe share the same work environment?" While such question might be answered in future research, this study demonstrates that comfort temperature levels differ significantly between occupants in a common environment. Comfort temperature ranged from 16^{o}C up to 31^{o}C resulting in 31% of recorded comfort temperature that could be consider too cold or too hot. Could this mean that the equation used to estimate comfort temperature has an unknown uncertainty?

5. References

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