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Potential adaptive behaviour to counteract thermal discomfort in spaces with displacement ventilation or underfloor air distribution systems

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SUMMARY
Building occupants behave in various adaptive ways to restore thermal comfort when in a state of thermal discomfort. These adaptive actions affect building energy use and indoor environmental quality. This paper reports part of a draft risk study, here we focus on potential adaptive behaviour to counteract discomfort in rooms with displacement ventilation (DV) and underfloor air distribution (UFAD) systems. The most likely adaptive behaviours to be taken are: adjust clothing, open/close windows, adjust thermostat and change workstation. No conclusive relationship was found on whether these behaviours are influenced by overall or ankle thermal sensation. Females stated more frequently than males that they would open/close windows, while more males expressed the intention to use heaters and complain to building managers.

PRACTICAL IMPLICATIONS
In displacement or underfloor air distribution systems uncomfortable occupants are likely to adapt by modifying their clothing, open/close windows, adjust thermostats, and change workstations. This insight may be helpful in the design and operation of buildings by facilitating more opportunities for the likely adaptive behaviours.

KEYWORDS
Occupant behaviour, underfloor air distribution, displacement ventilation, thermal comfort, thermal adaptation

1 INTRODUCTION
Humphrey's adaptive principle states: "*If a change in the thermal environment occurs, such as to produce discomfort, people react in ways which tend to restore their comfort*" (Humphreys, 1997). These reactions are classified under three categories: *(i) personal adjustment* - i.e. adjusting clothing and activity, *(ii) environmental adjustment* - i.e. turning on fans or heaters *(iii) psychological adjustments* - i.e. putting up with it (Azizi et al, 2015). These adaptive behaviours have influence on building energy use and indoor environmental quality (Fabi et al, 2012).

The objective of the current study was to investigate the most likely adaptive behaviours that occupants are likely to undertake to counteract discomfort associated with DV and UFAD systems. In DV and UFAD, occupants complain of cold feet and draft due to low supply air temperature and relatively high velocity (Hanzawa and Nagasawa, 1990; Melikov et al., 2005). The analysis herein, report a part of a draft risk study (not yet published).

2 METHODS

The experimental facilities, setup and procedure were the same as the one of Schiavon et al (2016). However, in this analysis only 51 responses (32 males; 19 females) were considered, the experimental period was two hours and the study included two clothing conditions: ankles exposed (shorts) and ankles covered (pants). Occupants were exposed to various combinations of ankle velocity (0.1 m/s – 0.6 m/s) and temperatures (16.5 ˚C – 22.5 ˚C). Figure 1 shows the experimental procedure. During the breaks, participants were encouraged to take measures to stay thermally neutral.

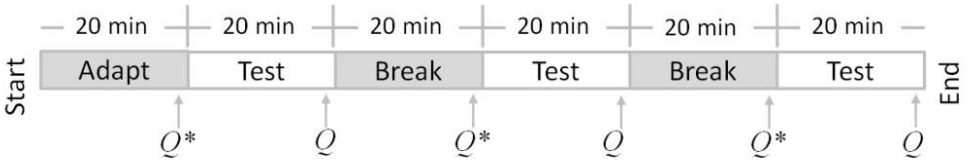

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Figure 1: Experimental schedule: Q – full survey, Q^* – partial survey

Participants performed sedentary work and responded to questionnaires about thermal comfort. Those who indicated being thermally uncomfortable were chosen for this analysis, and they also answered a hypothetical question about their likely adaptive behaviour to counteract discomfort. All statistical analysis was carried out with SPSS software (Wagner, 2014) with independent t-test analysis and equal variances assumed.

3. RESULTS

Figure 2 shows the overall adaptive responses (Fig. 2A) and the distribution of these responses by sex (Fig. 2B). As shown here, the most popular adaptive choices were: adjust clothing (28), open/close windows (19), adjust thermostat (19) and change workstation (14). Exploring how the choices were distributed by sex, more males than females chose 'use heater' ($p < 0.006$; $t = -2.91$) and 'complain to manager' ($p < 0.071$, $t = 1.87$). On the other hand, more females than males chose 'open/close windows' ($p < 0.046$, $t = -2.02$) and 'change workstations' (not close significant).

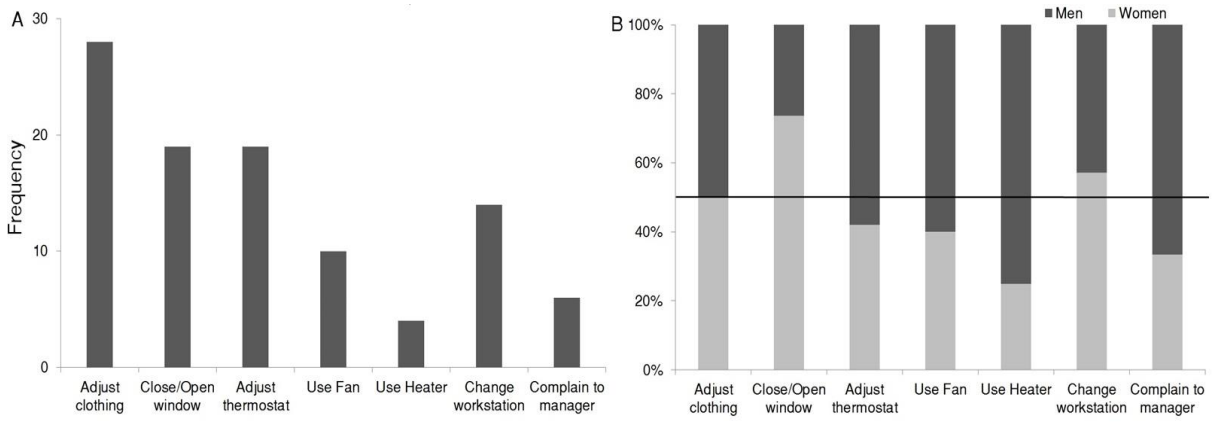

Figure 2: (A) overall adaptive response; (B) distribution of adaptive response by sex;

Figure 3 shows the overall thermal sensation (Fig. 3A) and ankle thermal sensation (Fig. 3B) as a function of adaptive behaviour. As seen here, it is hard to deduce whether the occupants' adaptive choices were dependent on overall or ankle thermal sensation. However, the trend on overall thermal sensation makes intuitive sense as opposed to ankle thermal sensation i.e., the

choices to ‘use fan’ and ‘use heater’ make sense with regard to the overall thermal sensation scores. On ‘adjust clothing’ (Fig.3A), the participants indicated to adjust clothing with an overall thermal sensation weighing on the cold side.

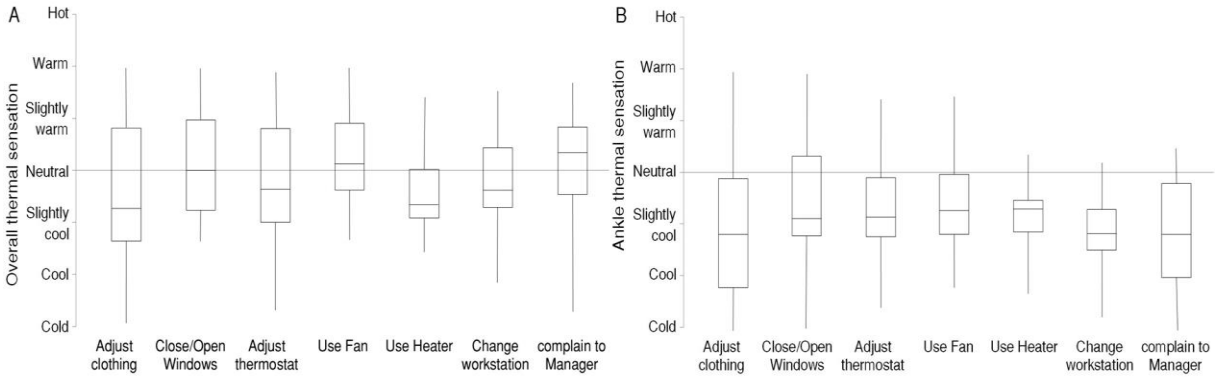

Figure 3: (A) overall thermal sensation as a function of adaptive behaviour; (B) ankle thermal sensation as a function of adaptive behaviour.

4 DISCUSSION

The behaviours’ assessed in this study are representative of common thermally driven adaptive behaviours’ in offices. As shown here as well as by other researchers, personal adjustment like adjusting clothing is ranked high and is common between males and females (Azizi et al, 2015). This gives an opportunity to encourage clothing adjustment as an adaptive option. In this respect, Aziz et al (2015) has cited cases were organisation a relaxed corporate dress code so as to encourage more personal thermal adjustment. Strict organisational dress codes i.e., organisational attires (uniforms) or corporate dress codes (suits), may hinder clothing adjustment and consequently override thermal comfort considerations (Brager and de Dear, 2001). This will result in occupants resorting to other adaptive means which may have energy implications. Clothing as an adaptive option has low initial costs and a clear energy benefit. Thus, organisations should aim at a more flexible dress code.

Another observation, clothing adjustment has a relationship with overall thermal sensation, as people chose to adjust clothing when the thermal sensation was cool. This confirms the idea that the ability to adjust clothing is mainly effective to counteract cool conditions. In warm conditions, there may be social constraints on how much the clothing level can be reduced.

An interesting finding also is that males are more likely than females to use personal heaters and complain to building managers. On the other hand, this study also shows that females are more likely than males to use windows although other studies (Langevin et al, 2015) show that women are less likely than men to use windows. The difference between the preferred adaptive action and the action that is really taken may be tied to access and operational constraints (Langevin et al, 2015). The recommendation here is that, since ‘open/close windows’ and ‘adjust thermostat’ were among popular choices here, building managers/designers need to make easy-operable-windows and thermostats easily accessible to occupants. Removing constraints serves as an incentive to take up such adaptive behaviours.

The analysis herein is limited by the number of responses especially from the females, as there were more male than female responses. Thus, it is difficult to get conclusive preferential adaptive choices between males and females. However, basing on the overall responses,

insight is given on the potential adaptive behaviour occupants would undertake in spaces with UFAD or DV.

5 CONCLUSIONS

Based on the findings of this study, the likely adaptive behaviours in spaces with UFAD or DV are: adjust clothing, open/close windows, adjust thermostat and change of workstation.

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