Thermal comfort practices in non-domestic buildings within the organisational context

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ABSTRACT

The discrepancies between as-designed and in-use performance in buildings highlight the need to better understand how buildings are used and operated. In this context, socio-technical approaches are useful to investigate the occupant dimension of building performance. This paper applies Social Practice Theory to investigate the thermal comfort practices of occupants and facilities managers within the organisational context in four BREEAM Excellent buildings, two offices and two schools. The paper explores the notion of 'distributed agency' in non-domestic buildings. The data suggest that the actions of occupants and facilities managers are shaped by the organisational context. Monitored data of environmental performance served to illustrate the thermal conditions experienced by stakeholders and analyse the actions and practices enacted. The work advocates for the consideration of the multidisciplinary approaches to study the occupant dimension of building performance, particularly to investigate the multiple perspectives of stakeholders involved in the operation of buildings (occupants, facilities managers). This could help to inform strategies for the efficient management and operation of non-domestic buildings.

Keywords:

Thermal comfort, building performance, organisation, social practice theory, distributed agency

INTRODUCTION

Non-domestic buildings account for 20 per cent of carbon emissions in the UK. Although new buildings are designed to be energy efficient, they tend to underperform during operation. The performance gap, the mismatch between in-use and as-designed performance, has been also found in non-domestic buildings with green credentials such as BREEAM[1], as

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[1] BREEAM, the Building Research Establishment Environmental Assessment Method, is a voluntary rating system that evaluates the environmental impact of the built environment. Information can be found at https://www.breeam.com/

shown by De Wilde (2014) in a comparison between Display Energy Certificates (DEC) and Energy Performance Certificates (EPC).

Actions and behaviours of occupants determine the building energy use (Janda, 2011). The way that buildings are used and operated affect their performance (Turner and Frankel, 2008; Masoso and Goblers, 2010; D'Oca et al, 2018). The occupant factors (behaviours and practices) are estimated to cause 10-80% of the gap between as-designed and in-use energy performance (van Dronkelaar et al., 2016). In order to improve the performance of existing buildings, we need to consider how people use buildings, the occupant dimension of building performance. Improvements in building performance should also consider the indoor environmental conditions in buildings. Previous research show that the indoor conditions in buildings affect the occupants' health and wellbeing (Mendell and Heath, 2005). In relation to thermal comfort aspects, an increase in temperature leads to difficulty in thinking and concentration (Witterseh et al, 2002), increased time required for problem solving (Federspiel et al, 2002), work speed reduction (Pepler and Warner 1968), adverse effect on mental performance in school students (Wyon et al, 1979). This highlights importance to balance energy use management and the provision of good indoor thermal environments.

Social Practice Theory provides a valuable theoretical lens to investigate the occupant dimension of building performance. Social Practice Theory is a paradigm used to understand consumption and (un) sustainable behaviours (Warde, 2005; Shove et al, 2012). Social Practice Theory focuses on the social nature of behaviours and how they are shaped (Warde, 2005). Prominent theorists of practice agree that in analysing agency and structure in everyday life (social practices), we can understand the development of processes and patterns (Schatzki, 2001). Social practice theory has been used to investigate and promote environmentally sustainable practices (Hargreaves, 2011; Strengers and Maller, 2014). In relation to energy use in buildings, Social Practice Theory has been applied to investigate the provision of comfort in buildings and the implications for energy use (Shove and Walker, 2014); particularly in residential buildings (Gram-Hanssen and Georg, 2018; Hanssen et al, 2018). Most of this work has focused on the normalisation of thermal comfort expectations, standards, the interlock between technological change and technological transitions (Shove, 2003). Comfort in buildings has been studied an attribute and as an achievement that is supported by technological innovations (Shove, 2004; Chappells and Shove, 2005). Social Practice Theory has also been applied to investigate the everyday practices and the resulting energy use in office buildings (Watson, 2015). Buildings are used and operated by multiple stakeholders with 'particular motivations and drivers' whose actions affect the energy and indoor environmental performance of buildings (Cole, 2011). However, little has been done to investigate the everyday actions by occupants and facilities managers to modify the thermal environment in relation to the organisational context in non-domestic buildings.

Therefore, this work considers the organisational context in non-domestic buildings. It analyses the concept of 'distributed agency' in relation to thermal comfort practices. According to Schatzki, a prominent theorist of practice, the term 'agency' embeds three aspects that are relevant to study thermal comfort and its nexus with energy use in non-domestic buildings. Firstly, the term agency refers to the way someone acts (Schatzki, 2017 pp. 38). Agency, understood as action, is essential to practices. Secondly, agency refers to choice; people choose among options. Thirdly, agency refers to 'effect on the world'; actions of members of a group affect the state of social affairs. Distributed agency applies to situations that involve different stakeholders with different motivations and interests, whose individual and collective actions produce an outcome. In relation to thermal comfort, individual actions and collective practices affect the building performance.

METHODOLOGY

The study explored the notion of 'distributed agency' to investigate how everyday thermal comfort practices were shaped by the organisational context, an aspect that has not been studied previously. The case studies were four non-domestic BREEAM Excellent building, two offices and two schools. In order to study the notion of distributed agency, the work investigated three key stakeholders in the case studies: occupants, facilities managers and organisations. The occupants are the individuals who inhabit the buildings: teachers and students in school buildings and employees in offices. Occupants exert actions to modify their thermal experience and to achieve the preferred thermal conditions in the space that they use. The facilities manager is the person responsible for the operation and management of the building services and the building performance. In this role, the facilities manager supports the core business of the organisation by facilitating the provision of satisfactory indoor environmental conditions for the occupants. Occupants and facilities managers are the main stakeholders who interact with technologies in the everyday use and operation of buildings. The organisation is understood as the group who leads the core business and defines the norms and rules that guide the operation and use of the building. As this discussion focuses on thermal comfort, the analysis refers to technologies that enable the modification of the thermal conditions in the building, including passive and active building technologies.

The research applied Post Occupancy Evaluation methodologies such as monitoring studies of building performance and user studies informed by standardised methods such as the Building User Survey (BUS) (Guerra-Santin and Tweed, 2015; Hadjri and Crozier, 2016; Leaman and Bordass, 2001). A key aim of the work was to identify the seasonal and temporal variations in thermal practices and in the building performance during one year. This approach acknowledged that experiences and practices in buildings are not static since 'built environments are material and social events in a continuous state of becoming…' (Friedman, 2015). Building performance data illustrated the indoor conditions experienced in the buildings as background where actions and practices were enacted.

Case Studies

The case studies included four buildings BREEAM Excellent buildings: two offices and two schools. According to the Energy Performance Certificates, the buildings were designed to EPC rating A. They were naturally ventilated buildings. Provisions were made at design stage to reduce overheating risk. The case studies were awarded 1 credit for Thermal comfort (Issue 14 Health and Wellbeing). Dynamic thermal simulation modelling was deployed at design stage, following the recommendations by CIBSE AM 11 Building Performance Modelling, CIBSE Guide A Environmental Design and the Building Bulletin 87 Guidelines for Environmental Design of Schools. Table 1 summarises the key performance indicators of the case studies.

User studies

User studies were applied to investigate the actions and practices related to the provision and achievement[2] of thermal comfort. The user studies included semi-structured interviews and questionnaires. Semi-structured interviews were conducted with facilities managers and senior management team members in the organisations (ie. head teacher, company manager) to explore the organisational context and thermal comfort practices. Questionnaires were

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[2] The paper refers to 'provision' and 'achievement' of thermal comfort. The term 'provision' embeds the notion that thermal environments are created in buildings so occupants experience the thermal environments as agents with limited scope of action to modify their thermal experience. The term 'achievement' embeds the notion that occupants are actively engaged agents who modify their thermal experience. These terms are not mutually exclusive, they show different dimensions of thermal experience in buildings.

administered to the occupants (employees in offices, teachers and students in schools) to identify everyday practices. Two types of questionnaires were administered: 1) general questionnaires to identify the actions and satisfaction levels in the building; and, 2) seasonal questionnaires to report the actions and satisfaction with the indoor environmental conditions.

The general questionnaires included questions about the satisfaction with the indoor environment, knowledge of systems and controls, actions taken to achieve thermal comfort. The questions related to comfort, noise, lighting levels and personal controls followed the approach by the Building User Survey method[3]. However, since the purpose of this study was to explore ‘distributed agency’ and identify seasonal and temporal variations in practices, the questions were modified and tailored to address the study’s aim.

The seasonal questionnaires explored the occupants’ actions and satisfaction with the conditions ‘right here right now’ in the space where they were based (workstation, classroom). Two identical questionnaires were administered in a single day of the season to explore potential morning and afternoon variations between thermal perception, satisfaction levels and actions. The first questionnaire was administered in the morning (between 8.30am and 11.30am) and the second questionnaire was administered in the afternoon (between 1.00pm and 4.30pm). The actual time when the seasonal questionnaires were administered depended on the access granted and the availability of the research participants. The responses of the seasonal questionnaires were compared to monitored data that recorded the relevant thermal parameters in the spaces where the questionnaires were distributed; as per Fanger’s thermal comfort equation (Fanger, 1970). Table 2 summarises the number of questionnaires returned. Due to the limited number of responses available, the questionnaires were used to provide examples of thermal practices and thermal satisfaction. They are not meant to be representative or generalizable.

The mix of participants enabled to depict multiple perspectives about how the buildings were used by the occupants (data from employees in offices; and, teachers and students in schools), the medium and long term management of facilities (data from facilities managers and caretakers), the organisational norms and views related to the building use and management (data from the company managers and the head teachers).

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[3] The Building User Survey is an occupancy survey evaluation method used in the United Kingdom to investigate the occupant’s perspective in buildings.

Monitoring studies

Monitoring studies recorded a number of indoor environmental parameters and the energy use with different levels of granularity. Two types of monitoring studies were undertaken in the case studies: (1) seasonal monitoring and (2) long-term monitoring. The purpose of the seasonal monitoring was to investigate seasonal variations and variations of the indoor thermal conditions during one day of each season. The seasonal monitoring data was correlated to the two-part seasonal questionnaires. The purpose of the long-term monitoring was to identify the thermal environment conditions and the energy use in the building throughout a year. The long-term monitoring data was analysed in relation to the general questionnaire responses. In summary, the monitoring data was analysed in combination to the occupants' responses. The study primarily focused on the thermal conditions referring, as relevant, to other indoor environmental conditions.

Seasonal monitoring

During the seasonal visits, the environmental conditions were monitored at 10-minute intervals, recording the internal air temperature (°C), mean radiant (globe) temperature (°C), air velocity, relative humidity (%). The thermal parameters were only recorded in the spaces where the seasonal two-part questionnaires were administered during the seasonal visits. Illuminance levels (lux) and ambient noise levels (dB) were measured during the seasonal visits to illustrate the indoor environmental conditions. Illuminance levels and ambient noise levels were taken as spot measurements in different spaces in the case studies (offices, meeting rooms, circulation areas, classrooms as relevant). The equipment used for monitoring the indoor environmental conditions during the seasonal visits were: (1) Testo 435 anemometer to record the air velocity and the temperature; (2) Digital impulse sound level meter Dave D14-22C and calibrator Serial # 3742070; and, (3) Tes 1332 Digital lux meter, (4) Eltek squirrer data logger 1000 server to record the globe temperature, illuminance and relative humidity. The monitoring data served to compare the indoor conditions to the occupants' perception of the thermal environment and the actions taken to achieve thermal comfort (thermal comfort practices). This aimed to explore the seasonal variations and variations between morning and afternoon in the thermal practices and occupants' satisfaction.

Long-term monitoring

In addition to the monitoring activities conducted during the seasonal visits, the temperature, CO_2 levels and relative humidity were monitored for one year using a multi-sensor Extech Sd800 data-logger at 5-minute intervals in two locations per case study as an indication of the indoor conditions. This ‘light touch’ monitoring exercise gave an indication of the indoor conditions in selected sample areas in the case studies during one year (Table 2). Due to the limited resources available for the study, it was not possible to implement an extensive monitoring study. However, the seasonal surveys and the monitoring data recorded on the seasonal visits complemented the information obtained in the light-touch long-term monitoring study.

Additional data

All the case studies had gained the Energy Sub-metering credits (Issues Energy 2 ‘Sub-metering of Substantial Energy Uses’ and Energy 3 ‘Submetering of Areas/Tenancy’). This enabled the collection of information about electricity and gas use. Display Energy Certificates were available as reference to the energy performance of the case studies. Documents such as the Operation and Maintenance manuals, the BREEAM Post-construction reviews, the Energy Performance Certificates helped to identify the as-designed intentions and the in-use performance. Weather data was obtained from records from the closest Met Office weather stations. The mean outdoor air temperature per season recorded in each case study is illustrated in Table 4.

RESULTS

Description of thermal conditions in the case studies (monitoring study)

This section presents the long-term monitoring dataset (Table 5) and the temperatures recorded during the seasonal visits (Table 6) to illustrate the indoor conditions in the case studies. In Case Study 1, the long-term datasets in two monitored locations show average temperatures of 24.5 and 24.9 degree Celsius and maximum temperatures of 28.0 and 29.0 degree Celsius. The temperature exceeded 25^{o}C during 44 per cent and 23 per cent of the working hours, suggesting overheating problems (CIBSE Guide A, 2015). In Case Study 2, the monitoring datasets show that the indoor temperature ranged from 15.4 -35.1 degree Celsius during the monitored year. This suggests a lack of uniformity in the thermal conditions of different locations of the building. This problem was reported by the research participants during the seasonal visits. In Case Study 3, the monitoring datasets show average temperatures of 21.2 and 21.4 degree Celsius in two monitored locations and maximum temperatures of 25.2 and 25.7 degree Celsius. In Case Study 4, the monitoring datasets show that the average temperatures of two locations were 20.6 and 21.1 degree Celsius and the maximum temperatures were 25.5 and 25.7 degree Celsius.

Occupants' perceptions per season

The main reason of dissatisfaction was overheating. Overheating problems were reported in different seasons of the year (Table 7). The respondents in case studies 1 and 2 complained of overheating in summer. A minority of respondents complained of overheating in other seasons in case studies 1 and 2. More than 60% of respondents complained of overheating in different seasons of the year in case studies 3 and 4.

In Case Study 1 the indoor temperature recorded during the seasonal visits ranged from 21.6-25.6 degrees Celsius. The highest percentage of overheating complaints was reported in summer (71.43%). The temperatures recorded in the summer and in the spring visits were similar; however the percentage of complaints due to overheating reported in spring was lower than in summer.

In Case Study 2 the indoor temperature recorded during the seasonal visits ranged from 22.0-24.4 degrees Celsius. Compared to the other case studies, Case Study 2 had the shortest range of variation between the minimum and maximum temperatures recorded during the seasonal visits. The highest percentage of overheating complaints was reported in summer (85.71%). The temperatures recorded indoors during the summer and autumn visits were similar. The percentage of overheating complaints was lower in autumn, possibly due to adaptation strategies exerted in autumn, presented in the next section.

In Case Study 3 the range of temperatures recorded during the seasonal visits was 21.6-28.0 degree Celsius. Overheating complaints were reported in all seasons. The lack of opportunities to exert adaptation may explain the high percentages of perceived discomfort reported in different seasons (66.7% of respondents complained of overheating in summer, winter and spring and 100% in autumn).

In Case Study 4 the indoor temperature during the seasonal visits ranged from 19.8-31.8 degrees Celsius. The highest percentage of overheating complaints was reported in summer (100.0%). Although autumn and spring temperatures ranged from 19.8-23.8 degree Celsius, respondents reported overheating discomfort (60% of complaints in autumn and 77.78% in spring). It is unclear why the occupants reported dissatisfaction under those temperatures. The lack of adequate ventilation as per CO_2 levels may explain their dissatisfaction with the thermal conditions.

The CO_2 levels were monitored as proxy of ventilation in the case studies (Tables 8 and 9). ASHRAE recommends that CO_2 levels in indoor spaces do not exceed 1000 ppm (ASHRAE 2016). The CO_2 levels in case studies 2 and 3 were under 1000ppm the majority of the time in the monitored locations. The monitoring datasets collected during one year show that the CO_2 levels exceeded 1000ppm during 32.3% (location 1) and 31.7% (location 2) of the time in Case Study 1 and 49.9% (location 1) and 59.9% (location 2) of the time in Case Study 4 (Table 10). Those figures suggest poor ventilation.

Occupants' practices and organisational context

The occupants in all of the case studies expressed their willingness to take action to modify their immediate indoor environment to achieve comfort when the conditions were not satisfactory. In some instances, the organisation supported the occupants to take action to improve their thermal comfort in the case studies. Examples of actions taken by the research participants to improve the thermal comfort were: reconfiguration of spaces to match the location of workstations to individual thermal preferences (those who tend to feel hot moved their desks next to windows, those who tend to be cold moved next to radiators); personal adaptation (i.e. adding layers of clothes and having a hot drink, removing clothes and having a cold drink); operation of windows and doors; use of personal fans and fan heaters in individual workstations (Table 11).

Actions in office buildings

Occupants in Case Study 1 (office building) were encouraged by the organisation to exert adaptation strategies to achieve comfort: relocation of workstations in the office and the use of personal fans and lamps in the workstations and flexible dressing code. Employees working on the second floor, an open plan office area, were able to choose the location of their desks (next to a window, in the core of the space, on the perimeter of the office by a radiator) according to their thermal preferences.

Personal fans and fan heaters were used in 75% of the individual workstations in Case study 1. The organisation perceived that employees' comfort enhanced their productivity in Case Study 1. In Case Study 2 the organisation also supported occupants to exert personal adaptation (flexible dressing code, use of personal fans). While the occupants were willing to modify the thermal conditions of the spaces that they occupy, some of the building features and control strategies limited the occupants' ability to modify the thermal conditions; for example, automated operation of windows based on CO_2 levels, lack of controls at personal level, out of reach windows that could not be operated manually. This seemingly led to occupants' dissatisfaction; for example, the occupants criticised the automatic windows controlled on the basis of CO_2 levels because windows opened automatically when it was rainy, breezy or cold.

Actions in school buildings

The research participants in Case Study 3 expressed their desire to exert personal adaptation and to operate the building technologies in the spaces that they occupy. However, the organisational norms limited the adaptive opportunities available to teachers and students. In terms of personal actions, the dressing code for employees mandated that suit and tie should be worn all year to present a professional image to the students and the parents. Teachers and administrative staff had to wear suits all year and were not allowed to wear light clothing in summer, limiting the opportunities for personal adaptation. For the operation of building technologies, a school policy discouraged the operation of windows and blinds in the spaces adjacent to the main façade of the school building. The intention of this policy was to maintain the uniformity of the main façade to avoid that this facade looks as 'if it is missing some teeth' when some blinds were open while others remained closed. The operation of windows in upper floors was also restricted due to safety concerns.

In Case Study 4, the organisation supported the occupants to exert personal adaptation (flexible dressing code appropriate to the seasons, use of personal fans). While the occupants were willing to modify the thermal conditions of the spaces that they occupy, some of the building features in this case study limited the occupants' actions. For example, the teachers expressed their desire to use windows and doors to improve the ventilation in the classrooms, to modify the thermal environment and to provide fresh air. However, these actions were restricted by the design of the school. The manually operable classroom windows in the first floor opened to a buffer ventilation area. The ventilation area was originally designed for minimum occupancy, as a play area to be used only when the weather conditions did not allow the use of outdoor play area. The buffer area was a double-height space connected to the nursery area on the ground floor and adjacent to classrooms with manually operable windows on the first floor. However, the buffer area had been converted to a permanent play area for nursery children on the ground floor. This restricted the use of the operable windows of the classrooms in the first floor. When the windows in the classrooms in the first floor were open, the noise from the nursery in the ground floor disturbed the classroom activities. The noise level recorded in the classroom was 78dB when windows to the nursery area were open. While the doors of the classrooms could be opened for ventilation, the teachers preferred to keep the doors closed to avoid noise. During one seasonal visit, the noise produced in the corridor was 113.4dB. This was measured during a busy period where spaces adjacent to the corridor were used. Building Bulletin 93, Acoustic Design of schools: Performance standards, recommends maximum noise levels of 35dB for new buildings. When the classrooms overheated, the teachers switched off the lights in the classrooms to limit the heat gain. This action compromised the lighting levels in the classrooms. The lighting levels measured were 267-305lux. CIBSE Guide A advises maintained illuminance of 300-500 lux for educational buildings (CIBSE Guide A, 2015). The classrooms had windows at ceiling height that are automatically controlled on the basis of CO_2 levels. These windows opened to the exterior but could not be manually operated because they were out of reach (approximately 2.60m high).

In Case Study 4, the occupants wanted to modify the immediate environment. However, there were limited opportunities for the occupants to use effectively the building features (windows, doors) to modify the thermal conditions. A similar situation happened in case studies 2 and 3 where the usability of windows was limited. In Case Study 3, classrooms on the ground floor opened to an outdoor play area so the windows remained closed to avoid noise. These circumstances limited the effective operation of windows for natural ventilation. The lack of effective window operation seemingly resulted in CO_2 concentrations above the recommended limits. Another aspect criticised was the automatic windows controlled by CO_2 levels. Occupants perceived that the windows caused noise and disruption created when they opened automatically during learning activities (Case Study 3):

Interviewee Case Study 3: ‘some people ask for the ability of opening and closing windows manually rather than the automatic option because they are in control of it and you know

[when] it does not affect the classroom. Windows automatically opening are relatively quiet but still there is a distraction…'

Facilities managers' arrangements

In terms of facilities management arrangements, Case Study 1 did not have a facilities manager. Case studies 2 and 3 had facilities managers and Case Study 4 had a caretaker. Case Study 2 was part of the Estates portfolio of an institution and the central facilities management team was based offsite. A technician working in the building carried some ad-hoc facilities management duties and liaised with the off-site facilities management team. In terms of Building Management System (BMS), Case Study 1 did not have a BMS. The energy use data of the building was collected manually by the company manager. In Case Study 2, the BMS gathered data that was available to the central facilities management team. Case Study 3 had a BMS with data available on site. However, the BMS in Case Study 3 presented problems with the logging of energy data. The BMS had 20 electricity, gas and heat meters. Only 14 meters recorded values of use, of these, 2 did not show any change in the recoded values during one year monitoring period. From the 12 viable sub-meters, only 4 sub-meters showed reasonable comparison with the manual readings taken periodically by the facilities manager. Case Study 4 had a BMS but it was not in use. The problems with the BMS in case studies 3 and 4 limited the potential benefits of this technology and the proactive management of the building.

Facilities managers' practices and organisational context

For the case studies that had facilities managers (Case Study 2 off-site and Case Study 3 on-site); there were challenges to manage the indoor environment and the energy use. In Case Study 2, the facilities management role was fulfilled by an offsite team. Case Study 2 was part of the estate of an institution with the main headquarters in a different location. The Estates department dealt with the energy management of the building, including the automated building controls and the access to the data collected by the BMS. The central facilities management team defined the settings for the operation of the building (ie. heating setpoints, CO_2 levels for the automatic operation of windows). When a problem occurred in Case Study 2, a technician who acted as ad hoc facilities manager contacted the Estates department. The Estates department was perceived to be helpful although they were unable to respond immediately to the problems in Case Study 2. It was perceived that during busy periods, the central Estates department were unlikely to respond immediately to the problems because other buildings took priority ie. student dormitories, teaching spaces. The technician felt that the ability to modify the settings for the operation of the building should take place onsite to support the provision of comfortable spaces and the quick response to problems.

Case Study 4 had a caretaker. The caretaker in Case Study 4 reported that the CO_2 levels that triggered the operation of the windows were changed seasonally. The automatic windows opened more frequently in summer (to reduce overheating via natural ventilation) than in winter (to prevent heat loss and cold air coming from outside). The CO_2 levels that triggered the opening of windows in winter were 1250-1750ppm. In winter days, the CO_2 level to automatically open the windows could be set to 1750ppm. In summer season, the CO_2 levels that triggered the operation of the windows were 750-1550ppm. In mild summer days, the CO_2 levels could be as high as 1550ppm. This strategy, however, is problematic. Building Bulletin 101 advises that CO_2 levels should not exceed 1500ppm during occupation hours. ASHRAE recommends concentrations of CO_2 to not exceed 1000 ppm indoors (ANSI/ASHRAE 62.1). As proxy of ventilation, continuous CO_2 values above the recommended limits, suggest poor ventilation practices that may result in unhealthy indoor environmental conditions with negative consequences to the performance of the students. It can affect concentration, educational performance and educational attainment (Mendell and Heath, 2005). Table 12 summarises the maximum, minimum and average CO_2 levels recorded during occupied periods for two classrooms that were monitored during one year. Table 11 shows the frequency CO_2 levels recorded during the monitoring period. It shows that there were significant periods where the CO_2 levels exceeded the recommended limits. Taking ANSI/ASHRAE 62.1 as reference, the CO_2 levels in location 1 were 1000ppm or higher 47% of the occupied time between September 2013 and January 2014 and 62% between January and May 2014. The CO_2 levels in location 2 were 1000ppm or higher 42% of the occupied time between September 2013 and January 2014 and 51% between January and May 2014.

In terms of perceived organisational support to facilities managers to proactively operate the buildings, the facilities manager in Case Study 3 expressed his frustration with the expectations from the organisation about his role. He felt that he had little support from the organisation to promote activities to improve the thermal conditions and to reduce the energy use in the building. He perceived that he was expected to focus on the provision of the physical resources for the classrooms (sufficient space, number of computers, chairs and other resources for teaching) rather than the management of indoor environmental conditions and energy performance. The actions to manage the indoor environmental conditions were supported at organisational level if triggered by problems in the classrooms rather than as a planned long-term programme of management and maintenance. It should be noted that this was the only case study with onsite availability to BMS data and ability to modify the controls onsite. There were problems with BMS readings. However, there had been no support to fix the BMS problem which prevented the facilities manager from having robust recorded energy and environmental data for building management.

DISCUSSION

This work has investigated the thermal comfort practices by occupants and facilities managers in relation to the organisational context, exploring the concept of distributed agency. This paper explored the concept of distributed agency to recognise that, in the context of non-domestic buildings, the choice and the capacity to act is distributed between multiple stakeholders (individuals and organisations). Distributed agency refers to individual action, individual choice and collective action. The data show examples of thermal practices related to (1) actions of occupants, (2) facilities management arrangements and actions, (3) use of building technologies that affect the indoor thermal environment.

In relation to occupant’s actions, occupants are likely to exert actions to modify their thermal experience. This was evidenced by personal adaptation actions and the use of building technologies. The research identified the following strategies exerted by occupants: (1) rearrangement of the space (location of workstations in relation to individual thermal preferences in Case Study 1); (2) a range of adaptation actions in all of the case studies: adjustment of clothing levels, drinking hot or cold drinks, use of personal fans and heaters; (3) use of building technologies such as windows and doors. These actions are aligned to Adaptive Thermal Comfort literature (Brager and de Dear, 1998). In terms of facilities managers, the facilities managers’ duties were predominantly reactive in the case studies that had a designated facilities manager. The study did not suggest a proactive role to ensure the effective operation of the building or to manage the indoor environment conditions. These findings are aligned to challenges experienced by facilities managers as identified by Goulden and Spence (2015) and Pettersen et al (2017).

The second aspect of agency, choice, suggests that occupants have options to modify the situations that they experience. In the case of thermal comfort practices, this means that occupants can opt for a range of actions to modify the thermal conditions and their thermal experience, as outlined above. The data suggest that the actions of occupants (including adaptation opportunities) and the role of facilities managers are shaped by organisational norms. Organisational norms and policies influenced the adaptive opportunities available to occupants. In Case Study 1, the company supported the employees' actions to increase the thermal comfort in order to enhance employees' productivity. In Case Study 3, the organisational norms limited the adaptation opportunities available to occupants: restricted dressing code, restricted operation of windows and blinds due to aesthetics, reputation and safety reasons. In relation to facilities managers' agency, the lack of awareness by the organisation seemed to limit the opportunities available to facilities managers to proactively manage the thermal conditions and the energy use in the case studies. In relation to energy use, in Case Study 3, there were problems with the data collected by the BMS; however, the problem was not rectified. This limited the opportunities available to the facilities manager to use historical data to manage the building.

Finally, the notion of distributed agency as collective shared action that shapes 'social affairs' suggests that individual and collective thermal comfort practices are shaped by different stakeholders; including organisations in non-domestic buildings. Individual actions and practices are enacted within an organisational context that establishes norms that limit or encourage individual action. The data show that the organisations in the case studies showed different degrees of support to occupants to achieve comfort. In Case Study 1, the organisation supported employees to be more comfortable because they believe that increased comfort contributed to productivity. In Case Study 3, the organisation restricted the use of windows, blinds because of aesthetics concerns. Employees could not wear lighter clothes in summer because of the 'smart' dressing code set by the organisation. The organisations in the case studies did not seem aware of the benefits of energy management and the provision of good indoor environment. Only Case Study 1 referred to increased productivity in relation to thermal comfort.

While not the main focus of this paper, it should be noted that building technologies play a significant role in practices. Building technologies affect the thermal environment and the type of practices enacted in buildings. For example, the windows could not be operated in case studies 3 and 4, the school buildings, because they opened to noisy areas. Poor ventilation practices seemingly led to high CO_2 levels in two monitored classrooms in Case Study 4. In relation to facilities management technologies, the BMS designed to be a supportive technology presented problems in two case studies. This undermined its potential benefits as tool for the proactive management of energy use and indoor environmental conditions. The operation of the windows and the problems with the BMS suggest that technologies in the case studies limited the actions by occupants and facilities.

While direct cause-effect relationship between thermal practices and resulting building performance cannot be inferred from the data available; we could speculate that the limited actions available to occupants to modify the thermal conditions and to take personal actions (adaptive comfort) led to perceived discomfort in the buildings. In similar vein, the lack of proactive management of indoor conditions by facilities managers decreased the quality of the indoor environment.

CONCLUSIONS

This paper has applied social practice theory to consider the influence of the organisational context on thermal comfort practices in non-domestic buildings. Social Practice Theory encourages the holistic consideration of the social factors (people: individuals and groups, including organisations) the material factors (technologies) that influence the way buildings are used and the resulting performance. This paper has analysed the notion of distributed agency in non-domestic buildings in relation to thermal comfort practices. It has been argued that the everyday actions by occupants and facilities managers are influenced by the organisational context (drivers and norms) in non-domestic buildings. While distributed agency has been explored in relation to office energy metering and management (Whittle et al, 2015) to highlight the shared responsibility between different parties; this work further applied the concept of distributed agency to analyse thermal comfort practices in non-domestic buildings.

Literature on occupant factors in building performance tends to link poor performance to the wasteful occupant behaviour. While this may be partially true, considering occupants' actions in buildings within the organisational context may help to understand why wasteful and inefficient behaviours are enacted. Within the non-domestic sector we find great variation between the social and the material elements of practice: different stakeholders, different technologies, different types of occupants, different facilities management arrangements, different types of organisations. The diverse stakeholders in non-domestic buildings have different perspectives regarding the use and purpose of buildings. Distributed agency acknowledges that stakeholders have different motivations and interests, act individually and collectively share the responsibility of the resulting building performance: indoor conditions and energy use. The conventional perception is that stakeholders, in particular building occupants, are homogeneous. Comfort provisions are unlikely to take into account variations within spaces in buildings, variations between seasons, differences between expectations of different stakeholders. Such view reduces buildings as uniform and stable environments. Conversely, a multidimensional view of buildings can bring insights to energy use research to consider the complexity of occupants' factors. Buildings are expected to deliver multidimensional goals ie. increased occupant satisfaction, energy use reduction, provision of good indoor environmental quality for enhanced productivity, educational attainment to mention few examples. The occupant dimension of building performance puts people's experience as a central function delivered by buildings. Efforts to enhance building performance and quality, therefore, should take into account the social and cultural dimensions that shape people's experiences, expectations and practices in buildings.

Energy use research is increasingly adopting multidimensional perspectives and drawing from multidisciplinary approaches to address the complexity of energy challenges in buildings and built environments in different stages of the lifecycle. Efforts are informed by social science, engineering, user-centred design, environmental architecture and humanities which offer promising directions to respond to energy problems, and more broadly, to global sustainability challenges.

FUTURE WORK

Further research will examine how the organisational goals and individual goals could be aligned to support building performance targets, focusing on concerns that are relevant to stakeholders: increased satisfaction, better indoor environment, health and wellbeing of occupants, energy use reduction. Work in this area could utilise research that shows that good indoor environments have positive effects on occupants' health and wellbeing. Bringing attention to the non-energy benefits of building management could motivate individual and collective action. This work requires the in-depth understanding of stakeholders' actions and expectations in buildings. Research on this area is likely to question the notion of good building quality; aiming to balance occupants' experience in buildings and building performance.

LIMITATIONS

The paper focused on the analysis of thermal comfort practices within the organisational context. Therefore, it does not include a comprehensive building performance evaluation. The user studies and the monitoring studies illustrate the practices enacted given the thermal indoor environmental conditions experienced in the buildings during one year and during the day of the seasonal visit. The participant responses are not meant to be representative or generalisable. They offer insights related to occupants' actions and facilities management practices that took place within the organisational context. The work provides qualitative insights to research on occupant factors in building performance and energy use which are relevant to the achievement of energy and environmental performance targets in non-domestic buildings.

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Table 1 Summary of the case studies

Case Study	1	2	3	4
Building type	Office	Office	School	School
Location	South Wales	South West England	South East England	South Wales
BREEAM Rating	Exc.(73.89%)	Exc.(74.42%)	Exc.(71.97%)	Exc. (73.42%)
BREEAM version	Offices 2006	Offices 2006	Schools 2006	Schools 2006
Area m2	3736	1130	10996	2116
BER $KgCO_2/m^2$	24.88	14.81	13.5	8.50
TER $KgCO_2/m^2$	53.39	17.83	22.7	16.80
%better2006 regs	40.85	23.6	29.87	37.9
BREEAM Energy	14 credits	10 credits	14 credits	15 credits
EPC band (as-designed performance)	A	A	A	A
DEC band (in-use performance)	B 31	B34	D 79	C 62
KgCO2 in monitored year	n/a	36.6	59.8	34.0
Natural ventilated building	x	x	x	x
Window operation	Manual	CO_2 (Manual override)	CO_2 (Manual override)	CO_2 (Manual override)
Heating	Radiators	Underfloor heating	Underfloor heating	Underfloor heating
Water heating	Boiler	Solar	Solar	Solar
Low zero carbon technology energy supply			15%	15%

Table 2. Questionnaires returned per case study

Case Study	General Questionnaire	Satisfaction questionnaire (AM/PM)			
		Summer	Autumn	Winter	Spring
Case study 1	28	13	16	13	12
Case study 2	28	16	8	13	12
Case study 3	33	11	11	21	24
Case study 4	18	9	10	27	10

Table 3. Monitoring details in the case studies

Long-term monitoring	CS1	CS2	CS3	CS4
Long-term monitoring (1 year): temperature, relative humidity and CO2 levels	2 locations, offices	3 locations, offices	2 locations, classrooms	2 locations, classrooms

Table 4. Mean outdoor air temperature per season in the case studies, obtained from MetOffice weather data.

	spring	summer	autumn	winter
Case study 1	9.5	14.5	11.5	5.5
Case study 2	9.5	16.5	10.5	4.5
Case study 3	9.5	16.5	11.5	5.6
Case study 4	6.5	13.5	8.5	2.3

Table 5. Long term monitoring dataset- minimum, maximum and average temperatures in two monitored locations in the case studies (data for occupied periods only)

Long term monitored data (one year)	CS1	CS2	CS3	CS4
Number of monitored locations	2	3	2	2
Minimum temperatures in monitored locations	17.0 & 18.0	15.4, 18.2 & 16.9	16.0 & 17.0	15.5 & 16.0
Maximum temperatures in monitored locations	28.0 & 29.0	27.4, 35.1 & 27.7	25.2 & 25.7	25.5 & 25.7
Average temperatures in monitored locations	24.5 & 24.9	22.9, 23.2 & 22.9	21.2 & 21.4	20.6 & 21.1

Table 6. Indoor temperatures recorded during seasonal visit (Temperature ^{o}C)

Seasons	CS 1	CS 2	CS3	CS4
Summer	24.0-25.6	23.2-24.4	24.5-28.0	27.0-31.8
Autumn	21.6-22.6	23.7-24.1	21.6-22.6	21.7-23.8
Winter	23.0-24.5	22.0-24.0	22.6-23.3	20.0-21.0
Spring	24.0-25.4	22.0-24.5	24.8-25.5	19.8-21.5

Table 7. Percentage of respondents' complaints due to overheating

Seasons	CS 1	CS 2	CS3	CS4
Summer	71.43	85.71	66.70	100.0
Autumn	37.50	28.57	100.00	60.00
Winter	28.57	0.00	66.70	n/a
Spring	14.29	14.29	60.00	77.78

Table 8. CO_2 levels (ppm) recorded in the monitoring locations of the case studies during one year (data for occupied periods only)

	CS1		CS2			CS3		CS4	
Position	1	2	1	2	3	1	2	1	2
Maximum	2241	4267	1542	1802	1399	2317	1712	4033	4400
Minimum	301	348	318	314	329	393	336	348	359
Average	851	871	536	517	537	592	421	1151	954

Table 9. Frequency of CO_2 levels (ppm) recorded in the monitoring locations of the case studies during one year

	CS1		CS2			CS3		CS4	
Position	1	2	1	2	3	1	2	1	2
Under 1000ppm	67.7%	68.3%	99.87%	99.98%	99.99%	94.9%	99.5%	50.1%	40.1%
Between 1000-1500ppm	21.2%	18.6%	0.13%	0.02%	0.01%	4.6%	0.2%	20.3%	41.6%
Over 1500ppm	11.1%	13.1%	0%	0%	0%	0.5%	0.3%	29.6%	18.3%

Table 10. Case Study 4: Frequency (percentage) of CO_2 levels (ppm) recorded in two classrooms during different monitoring periods, percentages refer to only occupied periods (term time, Mon-Fri 8.00-4.00pm)

	Classroom 1		Classroom 2	
Period	19/9/13-8/1/14	8/1/14-1/5/14	19/9/13-8/1/14	8/1/14-1/5/14
Under 1000	53%	38%	58%	49%
1000-1500	21%	24%	24%	31%
Over 1500	26%	38%	18%	20%