A SOCIO-TECHNICAL APPROACH TO THERMAL COMFORT AND HEATING BEHAVIOUR IN UK HOMES

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ABSTRACT

Understanding thermal comfort and heating behaviour is crucial for energy policy and practice on sustainable buildings. This paper proposes a socio-technical systems (STS) approach to analyse and compare occupant heating behaviour and thermal comfort at home. The domestic sector accounts for nearly one third of total UK energy use, and building energy demand per household in this sector remains flat despite large increases in energy efficiency. The main reason may lie in occupants' increased level of comfort. The research analyses empirical evidence collected from a sample of households living in Cambridge, UK. Adopting a STS approach, the paper uses both qualitative and quantitative methods to collect household data on comfort and heating patterns. It incorporates a series of observations, photo records, diary records, data logger monitoring, questionnaire surveys and interviews. The results show significant gap between heating behaviour and thermal comfort, and that the provision of heating does not necessarily lead to high level of thermal comfort satisfaction. An analysis using STS identifies the gap with the elements of technology, occupant, activity, composition, indicating the link between thermal comfort and home performance.

Key words: socio-technical systems, thermal comfort, heating behaviour

INTRODUCTION

Occupant daily domestic interactions account for one-third of UK energy consumption, and the main part of this relates to maintaining a comfortable indoor environment [1, 2]. The Government has mainly focused on energy-efficient buildings and technologies over the past decades. However, the predicted energy savings associated with energy efficient technologies frequently exceed actual savings made upon behavioural factors [3, 4, 5, 6]. Heating behaviour has the highest impact on domestic energy use [7]. This paper focuses on how occupants regulate their heating towards thermal comfort at home and it proposes a socio-technical approach for understanding why they act as they do. It also shows how social-technical systems strongly shape household thermal behaviour and comfort.

Thermal comfort has been studied for many decades. There have been two main approaches to thermal comfort: the steady-state model and the adaptive model [8]. Fanger developed PMV/PPD model based on heat balance equations [9], which treats all occupants the same and disregards location and adaptation to the thermal environment. Nicol and Humphreys later argued that humans can adapt to their indoor and outdoor environment [10], and proposed adaptive model which has been incorporated into internationally used standards such as ANSI/ASHRAE 55 [11] and EN 15251 [12]. Researches in thermal comfort have mainly adopted engineering and physiology-based approaches; studies on social and cultural aspects of thermal comfort are yet relatively unexplored.

An emerging focus on the subject of social and cultural aspects of comfort can be found in special issues of *Building Research & Information* and *Energy and Buildings*. Shove et al. suggested that indoor thermal expectations are historically and socially specific, and thus also likely to change in response to the society and technologies [13]. Similarly, Kempton and Lutzenhiser described and analysed how culture and technology influence what temperatures are considered as comfortable at different times and places [14]. Parkhurst and Parnaby argued that consumer comfort expectations are tempered by the relationship between production and consumption [15]. Furthermore, Healy addressed the questions on how thermal comfort standards shape both the built environment and lifestyles [16]. These studies provided details on how people regulate and use domestic technologies and systems, and how cultural myths guide people's daily comfort habits and thus energy consumption [17].

Much research on sustainable buildings with a socio-technical perspective has been focusing on overall user comfort (e.g. [3, 13, 15, 16, 18, 19]). Influential examples can be found in many recent works such as Shove's idea on how comfort preferences have changed within a socio-technical boundary [20], and Wilhite et al.'s view on how cultural and technological variations influence occupants' indoor practices [21]. While comfort has received increased attention within the field of sustainable buildings, thermal comfort has not been fully investigated with a holistic socio-technical systems (STS) approach.

This paper therefore proposes a holistic socio-technical systems (STS) approach to examine thermal comfort and heating behaviour at home, focusing on household as a system unit. It asks for what influences occupant heating behaviour has and how it impacts upon thermal comfort. It also identifies the parameters that have an impact on thermal comfort within the STS framework, so that they can be further tested with respect to their interrelationships, and then be implemented in policy and design strategies to increase both domestic comfort and energy savings.

Hence, while the research of this paper is set within a socio-technical framework, it does not examine societal and technological aspects of thermal comfort and behaviour with a top-down view. Rather, it frames household as a single unit for STS analysis with a bottom-up view. This study uses STS primarily as a way of framing heating behaviour in order to uncover the link between thermal comfort and home performance. It seeks to understand how heating behaviour within STS framework influences thermal comfort on an individual level, such as occupant, household composition, activity, and technology.

The next section outlines the methodology developed for the research. This is followed by the results, presented as empirical analyses with a detailed focus on occupant thermal behaviour and comfort from a socio-technical perspective. Finally, based on the findings, different heat-comfort factors are interpreted and the potential benefits from the use of socio-technical systems considered.

METHOD

The study uses qualitative, holistic approach in a sample of in-depth case studies in Cambridge, UK, including a study of households' comfort practices and their relation to daily activities and energy use behaviour. Empirical data is collected from 14 domestic case studies, including personal observations, photo records, daily activity diary-log records, data logger monitorings, questionnaire surveys, and semi-structured interviews. The selection of a sample is not aiming for representativeness or other forms of statistical extrapolation, but to understand the variety and complexity of occupant heating behaviour towards thermal comfort and to develop a sound base for the next research step. Within the dataset, there were several dimensions of variability among the participants, such as household composition, built form and dwelling type, as well as variations in terms of heating system and energy bill type.

Fourteen households were interviewed and monitored for this study, between January and March 2014 in Cambridge, UK. The interviews were carried out in all participants' homes respectively, with each lasted about 2 to 3 hours. Interviewees were briefed about the research topic before the interviews. A set of predesigned questions was used to guide the interviews, alongside spontaneous queries allowing new ideas for exploration during the interview. The surveys were carried out along with the interviews, after which the data loggers were planted inside participants' homes. The number of data loggers was determined according to the number of main rooms occupied by each household. During the one-week data-logger monitoring period, participant filled in their diary-logs respectively.

RESULTS

This section presents the results and analysis of the case study research. The general results are discussed in relation to the theoretical framework concepts developed from STS theory: occupant, composition, activity, and technology. As guided by the ethical conduct of the research, all the case studies have been depersonalized and their names have been changed in this paper.

Occupant

Personal lifestyle, attitudes, preferences have impacts on how occupants would like to heat their house and how comfortable they would feel thermally. These individual differences may be attributed to occupants' socio-demographic background such as age, education level, working status, income, etc. A variety of definitions on comfort from the interviewees' views elaborate the intangible construct of comfort, providing the context for thermal comfort evaluation. A majority of the respondents were, for example, relating comfort with environmental aspects, such as reasonable warmth, appropriate lighting, fresh air, cleanliness, lack of noise and bad smell, easily accessible toilet and shower, isolated room and feeling protected.

> *Comfort seems to be a mental state where you would not be distracted from the adversity of environment, unawareness of the surrounding* (Interview N).

Furthermore, interviewees perceived comfort from physical, psychological and social aspects, such as a sense of security, coziness and homeliness, feeling relaxed, life quality, fulfillment from work, physical activity, social life, wellbeing, feeling secure and at ease, intellectually stimulating environment, having a peace of mind and equanimity, and meaningful relationships with family and friends. Leo (interview L), for example, felt privacy is very important as a major component of comfort, thus he kept all of the window blinds down during the day even though this shuts out the daylight. In this circumstance, privacy and daylight both comprised the meaning of comfort in Leo's view, and the motivation of Leo's action (i.e. keeping the blinds down) was to gain privacy instead of daylight.

Therefore, comfort can contain several meanings simultaneously to an individual, such as financial comfort, freedom, control, flexibility or a pleasant environment. It means that when some aspects of their comfort needs have been meet, occupants feel satisfied irrespective of other aspects (i.e. low temperature, low lighting level). These various factors involved in the notion of comfort would impact on how occupants feel about thermal comfort, which may not necessarily be justified only by heat balance equation and physiology theories.

Composition

The interviewees are comprised of various household types, sizes, and tenure types. Household types include single, couple, family with children, single with children, extended family, and non-family household. In addition, household sizes range from 1 person to 5 persons or above. Meanwhile, tenure types are categorized into owner occupied, private rented, rented from local authorities, and rented from housing association. These various compositions of a household have influence on occupants' thermal behaviour such as how the heating is used and controlled, and how different rooms are occupied with different household members. For example, Natalia (Interview N) lived in a single private rented room in a shared Victorian house; her landlord controlled the heating system of the house. Nevertheless, she could open her windows, adjust room radiators, and use secondary heating. Other non-family household members regulated their individual rooms through room thermostats; and the overall energy performance of the home was influenced by each individual's thermal preferences and behaviour. Jessica (Interview J), on the other hand, lived in a modern apartment with her husband and children. Her room temperature was regulated subject to both the parents and children's preferences. The priority was given to her children as Jessica considered that a warmer temperature was good for the babies. Such compromise exists in a social setting where household members live together and prioritize different thermal preferences. Different tenure types also have an influence on thermal behaviour, such as whether the energy bill is included in the rental and how the dwelling is controlled.

Activity

The interviewees perform different activities in different places and times. These include the length of time spent at home, and on different activities in various spaces. It is therefore important to see how these variations link to heating behaviour in each room with different thermal sensations. From the monitoring results of all the interviewees, some of the temperatures in different rooms and times varied relating to occupant activities. Patterns can be found such as the temperature in bedrooms went higher in the evenings comparing with the daytimes, and living rooms peaked in the early evenings while cooking and dinner took place. For example, in a normal weekday, Alex (Interview A) worked at home office from 9am to 12am and 2pm to 7pm, and slept in the main bedroom with his wife between 11pm and 7am, spending the rest of time in other rooms (e.g. living room, exercise room) or out for work or leisure purpose. He turned heating on at 5-7am (23^{o}C) and 5-8pm (23^{o}C) for the whole house. The measured temperature varied with peaks in the evening in the living room (21^{o}C), and bottoms during night in the living room and office (15-16^{o}C). Here discrepancies existed between the set temperatures and measured temperatures. Nevertheless, Alex felt very satisfied about his thermal comfort at home.

Technology

The technologies, or building physical characteristics, shape the way occupants behave at home as well as thermal comfort. These include the arrangement of space, floor area, room orientation, dwelling type and age, energy and environmental performance of the dwelling and its individual elements (i.e. walls, roofs, floors, windows, heating and controls, hot water and lighting), heating system, user control, lighting, and appliances. Taking heating system for example, Ethan (Interview E) lived in a flat located in an old poorly insulated house built in 1960s. He shared the central heating control (in the kitchen) with 3 other housemates, and could not control heating temperature in his own room due to the unavailability of an individual programmer and his thermostat valve not working; he had to keep the windows open at night to cool down the indoor temperature. However, he still felt thermally dissatisfied due to high temperature at night.

DISCUSSION - CONCLUSION

This research proposes a STS approach to evaluate occupants' thermal comfort and heating behaviour at home. A combination of quantitative measurements and qualitative interviews has shown how different usage patterns of houses might relate to occupant comfort and home performance. A detailed analysis using STS was employed to identify the gap between heating behaviour and thermal comfort. Inspired by recent theoretical approaches, this analysis was used to explain differences within a socio-technical homogeneous group rather than by changes across time, space or culture.

The inclusion of socio-technical system theory into the study of thermal comfort and home performance provides insights. Compared with other theoretical approaches in the assessment of thermal comfort, the advantage of STS theory as presented here is therefore twofold: it combines the different elements that are relevant in the understanding of the theory and it focuses on the structural nature of thermal behaviour and comfort. The aim of this paper was to identify the socio-technical parameters influencing household thermal comfort and to compare thermal behaviour and comfort satisfaction. We investigated the applicability of socio-technical approach to thermal comfort and behaviour. The results have the potential to be used for improving future house design and retrofit. In conclusion, we were able to understand thermal behaviour and comfort at home and to identify the gap between the two using a socio-technical approach.

This study also has implications for socio-technical theory. STS theory has been critically developed since 1980s, drawing attention to the mutual formation of society and technology that influence each other at all levels. Four main elements of STS and how they relate to domestic thermal behaviour and comfort were presented. The advantage of these elements is that they provide a holistic framework to sustain STS structure in individual households, and thus illustrate at a micro level on the complexity of regulating indoor thermal comfort. These four aspects of STS not only display the collective structure of the system, but also show the interconnections among the parameters holding STS structure. To draw more general conclusions, the way ahead is to quantify the parameters relating to thermal comfort using STS framework in a broader material.

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