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Influence of heat cost allocation on occupants' control of indoor environment in 56 apartments: Studied with measurements, interviews and questionnaires

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ABSTRACT

People who pay their energy bills individually based on meter readings tend to spend less energy than people who pay collectively e.g. based on floor areas. It has been hypothesised that these savings are an effect of lower indoor temperatures and ventilation rates during heating seasons. The aim of this paper was to study the indoor environment in buildings with collective and individual heat cost allocation plans, to investigate how the heat cost allocation influenced occupant behaviour and how occupants controlled the indoor environment.

The effects of the heat cost allocation type were studied by comparing indoor environmental measurements between two buildings: one with collective payment and one with individual payment. The measurements were collected at 5 min intervals at a central location in each of 56 apartments in Copenhagen, Denmark over a period of two months. Questionnaires and semi-structured interviews showed a strong influence of the heat cost allocation plan on the occupants' control strategies. Occupants whose heating bills were based on floor area focused on a healthy and comfortable indoor environment. Occupants whose heating bills were based on meter readings focused on energy conservation and heat cost savings at the expense of thermal comfort and air quality.

The differences in average temperature, average CO_2 concentration and average vapour pressure were 2.8 °C, 161 ppm, and 93 Pa, respectively between apartments with collective and individual heat cost allocation.

1. Introduction

People are different; in behaviour, expression and knowledge. Seen from the built environment's perspective, this explains why energy consumption can differ by up to 300% in similar residential buildings [1].

Since the first Twin Rivers study [2], the effects of occupant behaviour and the potential energy savings have been proven in multiple studies (e.i. [3–6]). The studies showed how significant energy savings can be achieved through changes and optimisation of the occupant behaviour. However, occupants will not change behaviour if they are not motivated [7] and actions to motivate occupants and provide them with assessment tools seem necessary to reduce energy consumption.

In a review by Abrahamse et al. [8], various intervention methods aimed to reduce energy consumption were described. One of these intervention methods described the way in which the energy bill was presented. The energy bill is normally sent to occupants as a monthly, quarterly or yearly bill as a simple form of feedback. Abrahamse reported energy savings between 2.5% and 3.7% for the medium and high consuming households when comparative feedback was introduced [8]. Experiments with comparative feedback presented with the heating bill were conducted in Oslo in 1995 [3] and have been continued in several studies (i.e. [9]), showing that when occupants were made aware of their consumption in a social perspective, it decreased.

Cholewa et al. [10] compared the energy consumption for heating in 40 Polish apartments over 17 heating seasons. Half of the apartments had an individual payment plan while the other half paid collectively. The study showed a difference of 26,6% on average between the two payment plans, occurring as a result of the control of the thermal indoor environment – actual measurements of the

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thermal environment were not part of the study. In the heating season 2011/2012, submetering was introduced in all apartments. In the subsequent three heating seasons the difference in the energy consumption between payment types decreased to 2.6%, indicating that when occupants became aware of their consumption it was reduced.

Whether the heating bill encourages occupants to reduce or increase their heating consumption, heating bills may have a direct influence not only on the indoor temperature but also the indoor air quality and moisture content. Both Wilhite et al. [3], Abrahamse [8], and Cholewa [10] showed reductions in energy consumption, however, the interventions' effects on the indoor environment were not investigated.

Gunay et al. [11] showed that the temperature in Canadian apartments with bulkmetering was higher than in apartments with submetering. Tenants in submetered apartments primarily kept the temperature low to keep the energy bill low, but also for environmental reasons. The paper further showed, that occupants in submetered apartments were more likely to heat different areas to different temperatures, where as bulk metered apartments rarely adjusted their thermostats [11]. In the Canadian study, the average temperature was 2 °C higher in the bulk metered apartments than in the submetered apartments during the heating season. A similar study by Levinson et al. [12] studied if including or excluding utilities in the rent would make apartments more attractive for the tenants. The study found a temperature difference of 0.6 °C−1.7 °C between apartments with utilities-included contracts and utilities not included contracts not including utilities. Both studies showed that the metering as a feedback method acted as a significant driver for the occupants' control of the indoor temperature.

In two reviews by Fabi et al. ([13,14]). the driving forces of window opening behaviour and space heating demand were surveyed. The identified drivers were grouped in five categories: Physical Environment, Contextual, Psychological, Physiological and Social [14]. Sardianou [15] has surveyed the variables affecting the heating consumption in Greek dwellings, identifying the following variables; age of respondents, number of persons in household, ownership conditions, size of dwelling, and household annual income. Andersen et al. [16] surveyed variables affecting window opening and heating behaviour in Danish dwellings. The paper concluded that heating consumption was affected by outdoor temperature, solar radiation, and ownership conditions. Frontczak et al. [17] found that 70% of their survey respondents, were *at least a bit aware of how their behaviour influenced energy use and indoor environmental quality* ([17] page 62). The identified drivers represented all five of Fabi's categories [14], constituting the complexity of identifying, modelling, and changing occupant behaviour, but also demonstrating the necessity to quantify the effects of all behavioural drivers.

The aim of this paper was to investigate and quantify the heat cost allocation as a psychological driver for occupant behaviour regarding control of the indoor environment. The effects of the heat cost allocation on the indoor environment were quantified, and explanations to of the observed differences were discussed.

This paper is based on measurements in Danish apartments, in which the thermal environment is directly linked to the energy consumption through the room by room thermostat controlled water based heating system and the window opening frequency.

2. Method

2.1. Measurements and method

Measurements of air temperature [°C], relative humidity [%] and CO_2 concentration [ppm] were taken in 56 apartments in two buildings in Copenhagen, Denmark (Building 1 and Building 2). Measurements were taken in a central hall way at 5 min intervals from 1st March 2013 to 30th April 2013, using internet-connected sensors [18]. The sensors were located approximately 1.5 m above the floor.

Building 1 was conducted in the 1970's and houses two, three and four room apartments. 39 apartments participated in the experiment. The apartments did not have individual energy meters, and heating costs were based on the individual apartment's floor area (Collective payment). Building 2 was conducted in the 1930's and houses two room apartments. 17 apartments participated in the experiment. All apartments in Building 1 paid a fixed monthly amount, which was adjusted once a year based on the actual heat consumption. The occupants in Building 2 have individual heat cost allocators and distribute heating costs based on these. (Individual payment). Both buildings were heated with water based convectors/radiators. The supply water temperature was controlled centrally based on outdoor temperature while the flow of water was controlled by thermostatic radiator valves on each radiator. In effect, the occupants controlled the temperature by adjusting the thermostats and by opening and closing windows.

The project was part of a bigger study on how indoor environmental feedback can affect occupants' control of the indoor environment. All occupants in the monitored apartments had access to the measurements of the indoor environment in their own apartment on a personal website throughout the two months.

2.2. Semi-structured interviews and questionnaire

Qualitative interviews were conducted in both buildings. The aim of the interviews was to survey the heating and ventilation strategies in each apartment. The interviews were conducted as semi-structured interviews and performed at the end of the experiment. The interviews were conducted with 10 occupants from 10 apartments (four from Building 1 and six from Building 2). The interviewees were selected by the building managers and represent a wide range of the occupants. The interviews were conducted in the occupants' apartments. A detailed description of the interview method was presented in the report by Andersen [19].

A questionnaire was sent to the occupants to survey the indoor environment regulation strategy. The questionnaire was sent to all apartments that participated in the experiment. The questionnaires were distributed at the end of the experiment period. The questionaire contained questions related to regulation strategies, understanding/perception of the term *indoor environment* and questions about the functionality of the feedback system. The latter was not included in this paper.

2.3. CO_2 sensor calibration

The CO_2 sensors in the measuring units were self-calibrating over time. Self-calibrating was done by identifying the lowest measured CO_2 concentration over the previous weeks' measurement, assuming that this was the outside concentration (400 ppm). If the CO_2 concentration didn't reach the outside concentration for an entire week, the CO_2 sensor would have assigned 400 ppm to the lowest recorded concentration and the measured concentrations would be too low. In such cases, the measured concentration would be below 400 ppm once the actual CO_2 level returned to outdoor concentration.

The sensors were installed in the beginning of March 2013 or earlier. To allow for a manufacturer recommended calibration period, the first six days were excluded in the data analysis for all measured parameters.