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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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1 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 five minute intervals at a central location in each of 56 apartments in Copenhagen, Denmark over a period og 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 93Pa, respectively between apartments with collective and individual heat cost allocation.

2 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], [4], [5], [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 persepctive, 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, occuring as a resultof the control of the thermal indoor environment – actual measurements of the 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 bulkmetered apartments rarely adjusted their thermostats [11]. In the Canadian study, the average temperature was 2 °C higher in the bulkmetered 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 to 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 behavior in Danish dwellings. The paper concluded that heating consumptionwas 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 explainations 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.

3 Method

3.1 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 five minute 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.

3.2 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 periode. 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.

3.3 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.

3.4 Infiltration rate assessment

To assess the air change rate, the natural infiltration rate was calculated using the decay method [20]. The CO_2 concentration for each apartment was analysed to locate decay situations suitable for calculating the infiltration rate. The calculated infiltration rates were based on 40 situations

from both buildings found on 5 days between 1st March and 30th April to minimize the impact of the outside weather.

4 Results

In Table 1 and Table 2, the measurements were compared with the recommended criteria in EN 15251-2007 [21] which provides design values to create a healthy and comfortable indoor environment in residential buildings.

Table 1 Time distribution in defined intervals for measurements in heating season for Building 1

Building 1 (Collective payment)	**Recommen-dation**	**Below [%]**	**Within [%]**	**Above [%]**	**Standard deviation**
Temperature	20-25 °C	0	88	12	1.5°C
CO_2 concentration	< 1000 ppm	-	96	4	292 ppm
Relative humidity	30-60%	88	12	0	13%

Table 2 Time distribution in defined intervals for measurements in heating season for Building 2

Building 2 (Individual payment)	**Recommen-dation**	**Below [%]**	**Within [%]**	**Above [%]**	**Standard deviation**
Temperature	20-25 °C	50	50	0	1.6°C
CO_2 concentration	< 1000 ppm	-	82	18	527ppm
Relative humidity	30- 60%	37	63	0	10%

The average temperature, CO_2 concentration, relative humidity, and vapour pressure in the two buildings differed by 2.9°C, 157pmm, 9.8 percentage point, and 93 Pa , respectively.

Figure 1 through Figure 6 show the measurements distribution and the summation curve of the measurements. The summation curves were made for each apartment and as an average for Building 1 and Building 2.

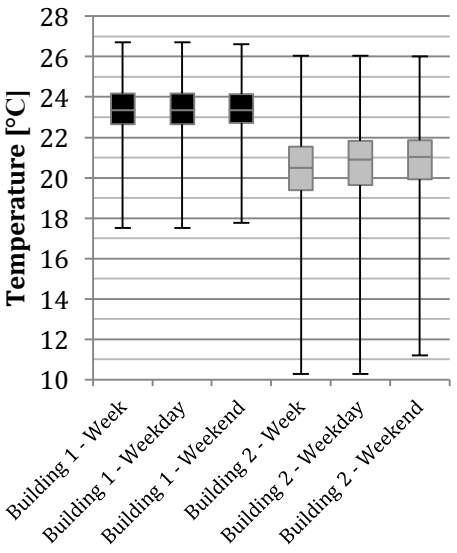

Figure 1 Boxplot representing the median, 25th percentile, 75th percentile and min/max measurements of the temperature [°C] from March 2013 through April 2013.

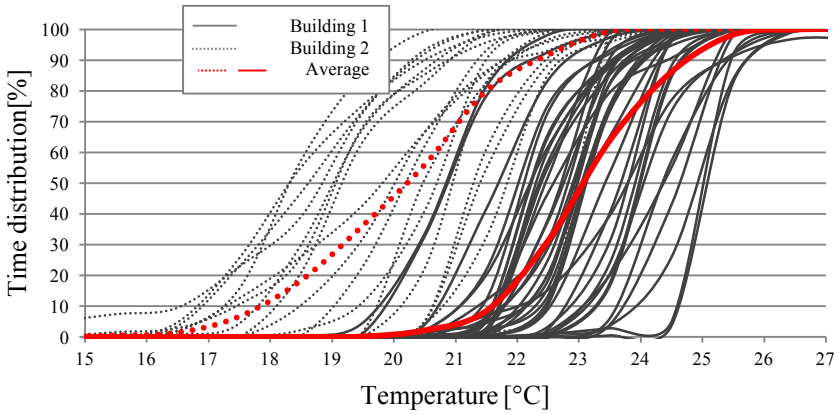

Figure 2 Average temperature summation curve of Building 1 and Building 2, and temperature summation curve of each apartment [°C]

The maximum CO_2 concentrations measured were 3398 ppm in Building 1 and 8934 ppm in Building 2.

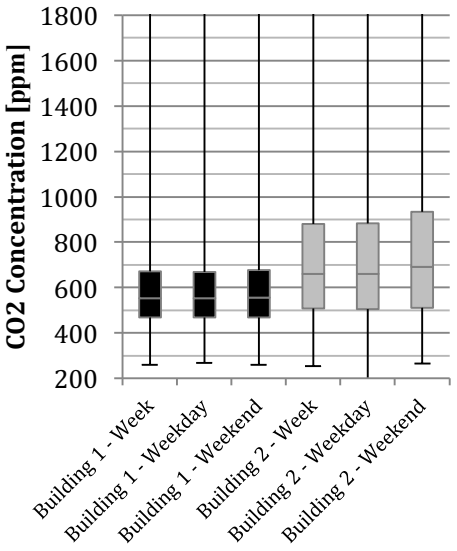

Figure 3: Boxplot representing the median, 25th percentile, 75th percentile and min/max measurements of the CO_2 concentration [ppm] from March 2013 through April 2013.

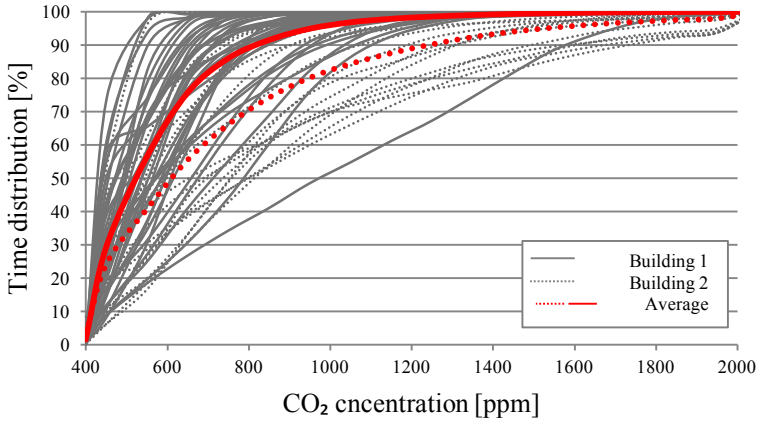

Figure 4 Average CO_2 concentration summation curve of Building 1 and Building 2, and CO_2 concentration summation curve of each apartment [ppm]

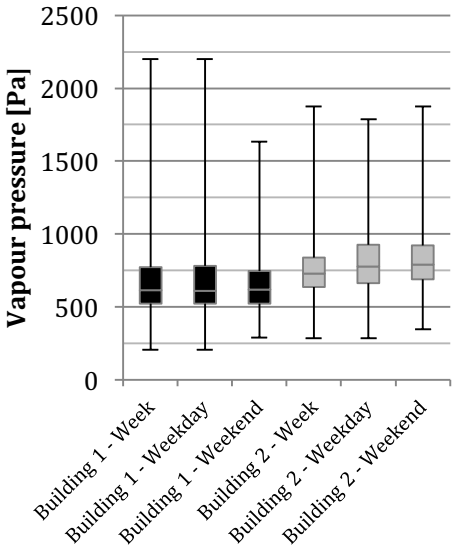

Figure 5 Boxplot representing the median, 25th percentile, 75th percentile and min/max measurements of the tvapour pressure [Pa] from March 2013 through April 2013.

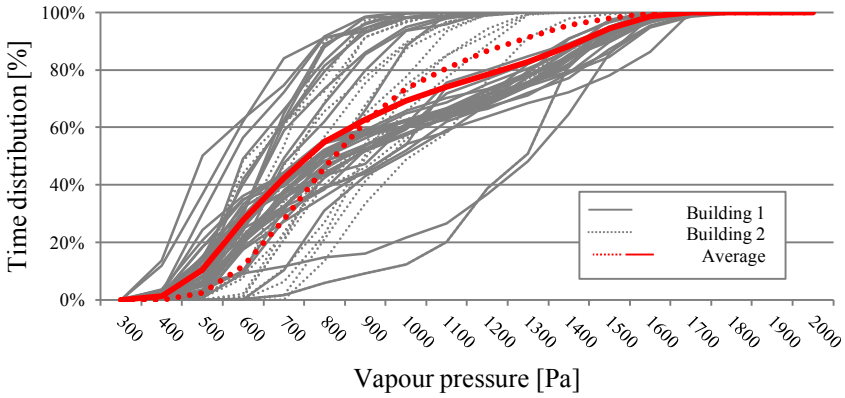

Figure 6 Average vapour pressure summation curve of Building 1 and Building 2, and vapour pressure summation curve of each apartment [Pa]

4.1 Difference between weekdays and weekends

To survey the relationship between the control of the indoor environment and the occupancy, the difference between weekdays and weekends was visualized in Figure 7 through Figure 9.

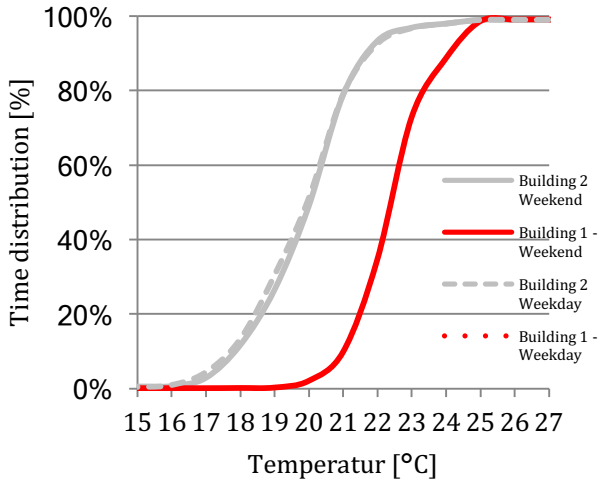

Figure 7 Average temperature summation curve for weekdays and weekends in the heating season [°C].

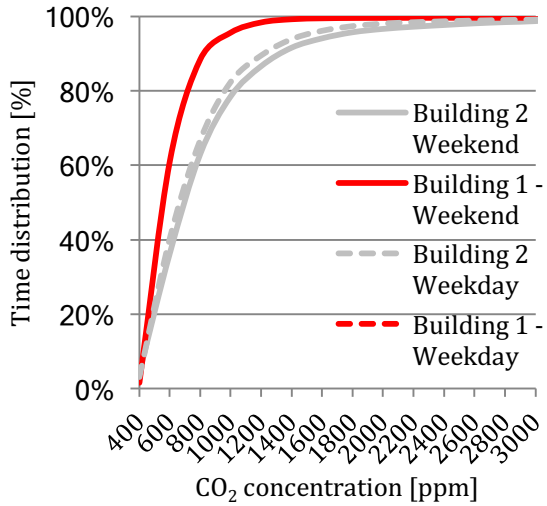

Figure 8 Average CO_2 concentration summation curve for weekdays and weekends in the heating season [ppm]

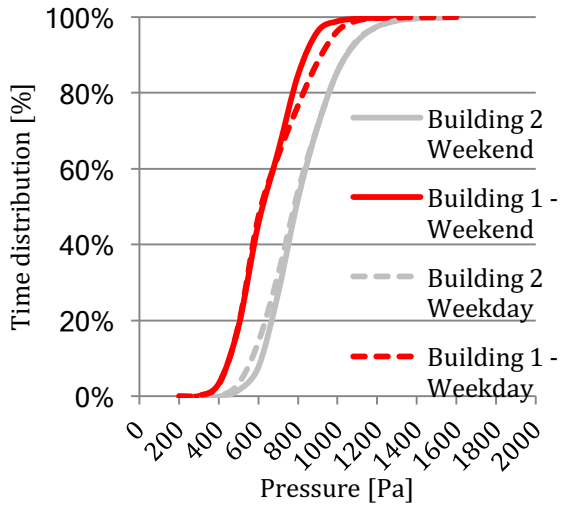

Figure 9 Average vapour pressure summation curve for weekdays and weekends in the heating season [Pa].

4.1 Daily differences

The daily differences were investigated by determining the distribution of the measurement on an hourly basis. The hourly distribution for Building 1 and Building 2 was presented side by side in

Figure 10 through Figure 12. The figures presented the hourly average value and the 5th, 25th, 75th and 95th percentile of the measurements. The minimum and maximum values were excluded as they represent one measurement at a certain time in one specific apartment.

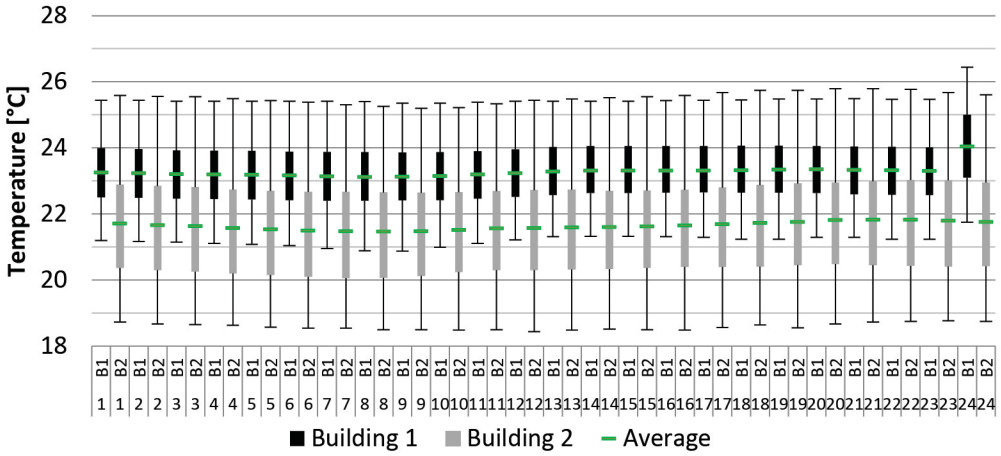

Figure 10 Hourly temperature distribution of Building 1 (Black) and Building 2 (Grey), with the box representing the 25th and 75th percentile. Whiskers representing the 5th and 95th percentile. Green mark shows the average value.

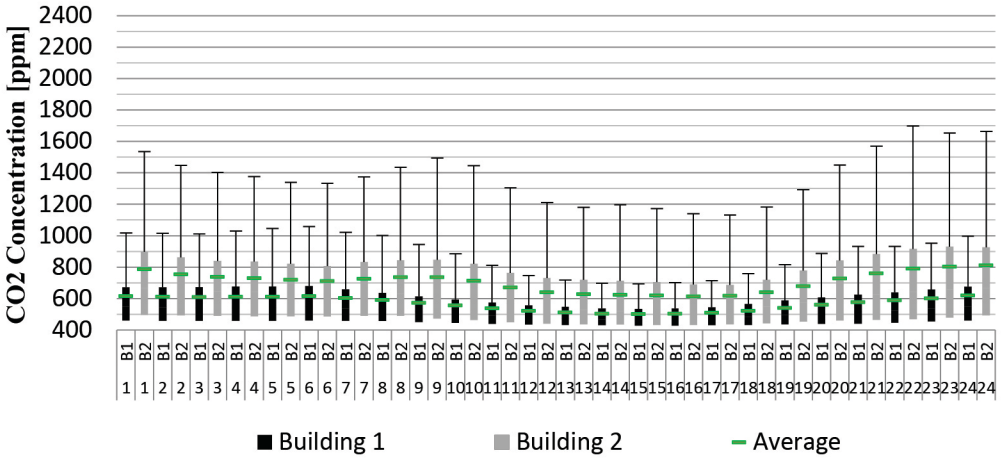

Figure 11 Hourly CO_2 concentration distribution of Building 1 (Black) and Building 2 (Grey), with the box representing the 25th and 75th percentile. Whisker representing the 95th percentile. Green mark shows the average value.

In association with Figure 11, the assessment of the infiltration rate based on decay of the CO_2 concentration found average infiltration rates of 4.1 h^{-1} in Building 1 and 2.7 h^{-1} in Building 2.

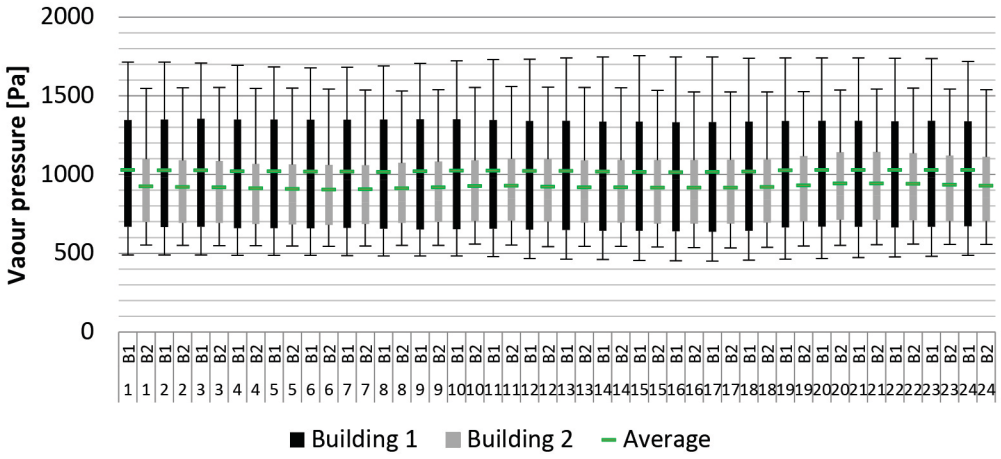

Figure 12 Hourly vapour pressure distribution of Building 1 (Black) and Building 2 (Grey), with the box representing the 25th and 75th percentile. Whiskers representing the 5th and 95th percentile. Green mark shows the average value.

4.2 Findings of semi-structured interviews

4.2.1 Primary indoor environment focus

The occupants' primary focus related to the indoor environment in Building 1 was a *nice and comfortable indoor environment.* Some interviewees expressed environmental awareness as they attempted to use as little heat as possible. In Building 2, the occuants'primary focus was on obtaining a low heat consumption, in some cases to the extent that occupants accepted uncomfortable temperatures in favour of a low heating bill.

4.2.2 Indoor environment regulation strategy

In Building 1, the interviewees did not pursue a distinct regulation strategy and they were all aware that the heating cost were settled collectively. All occupants stated that they rarely regulated the thermostat setting and that the thermostat setting was lower in the bedroom than in the living room.

All interviewees in Building 2 exhibited energy conserving behaviour and most had a distinct strategy to regulate the thermal environment. One important observation was that 3 of 4 interviewees expressed that they were not sure how effective their strategy was in conserving energy.

3 of 4 interviewees expressed that maintaining a comfortable temperature was difficult, but acheivable when leaving the thermostat setting on 4 or 5 (out of 5) for longer periods. Questions about the usage and control of the thermostats revealed widespread misunderstandings of the functionality of thermostats, e.g. some occupants used the thermostat as an on-off valve.

4.3 Relevant questions and answers to questionnaire

The questionnaire response rate totalled of 42 %. The response rate for each building was 35% and 60% for Building 1 and Building 2, respectively. Table 3 presented selected questions and answers.

Table 3 Selected questions and responses [n] for Building 1 and Building 2

Question	Building 1 (Collective payment)		Building 2 (Individual payment)	
	Yes	No	Yes	No
1 – Do you have a defined strategy for the thermostat setting?	5	8	4	4

2 – Do you have a defined strategy for venting the apartment?	Yes		No		Yes		No	
	10		3		4		4	
3 – How often is the thermostat setting changed?	Daily	Monthly	Yearly	Never	Daily	Monthly	Yearly	Never
	2	4	5	4	5	1	1	1
4 – How often is a window opened for venting?	Daily	Monthly	Yearly	Never	Daily	Monthly	Yearly	Never
	13	1	0	0	7	2	0	0

4.4 Sensor position

The measurements were performed in a hallway, a central located position in the two apartment types. To determine the difference between the central location and decentral locations such as the living room, bedroom or kitchen, additional measurements were performed in five apartments. A comparison of the measurements showed that the central locations were not able to detect the peaks in the indoor environment that occurred at the decentral positions. This was further enhanced by the occupants' ability to open and close a door between the central and decentral positions. However, seen over a period of time, the differences in the average values between the central hallway and the living room were less than 15% in 5 of 5 apartments for the temperature, 2 of 5 apartments for the relative humidity, and 3 of 5 apartments for the CO_2 concentration.

5 Discussion

5.1 Average differences

The differences in the average temperature, humidity and CO_2 concentration between the two buildings supported the findings by Gunay et al. [11] and indicate notable impact of the heat cost allocation type.

The lowest average temperatures were found in Building 2. In order to verify that these temperatures were not a result of a poor building envelope or poorly operated systems, the maximum temperatures of Building 2 were assessed. The average of the maximum temperatures was 22.4°C with a standard deviation of 1.2°C. Comparing these temperatures with the recommendations of EN 15251-2007 showed that a theoretical comfortable temperature could be reached in all studied apartments in Building 2. The interviews further showed that the low temperatures were by choice, as two interviewees in Building 2 stated that high temperatures could be reached by setting the thermostats on 4 or 5 (maximum position was 5) for longer periods [19].

5.2 Regulation strategies

There was a clear difference in average temperatures between the two buildings. This was also evident in the box plots and summation curves in Figure 1 throughFigure 6, differences that should be seen as differences in the regulation strategies.

The differences in the regulation strategies were further investigated by the daily variations between the maximum and minimum temperatures. The average daily variation for Building 1 and Building 2 was 1,4°C and 0,9°C pointing to a more stable thermal environment with collective payment (Building 2). Figure 10 showed the hourly variation between the 95th percentile and the 5th percentile indicating a stable variation throughout the day. This was further investigated by dividing the day into eight periods: early night (00:00-03:00), late night (03:00-06:00), early morning (06:00-09:00), late morning (09:00-12:00), early afternoon (12:00-15:00), late afternoon

(15:00-18:00), early evening (18:00-21:00), and late evening (21:00-24). This devision was chosen as each time interval represents a typical event e.g. dinner is typically prepared and served in the early evening. The temperature variations were calculated for each apartment each day,recording the largest average temperature difference between the periods *early morning* and *early evening*: 0.06°C for Building 1 and 0.09°C for Building 2. A difference opposing a more stable regulation of the temperature with collective payment than with individual payment.

When asked about the regulation strategy in the interview, all occupants in Building 1 stated not to have a distinct regulation strategy, adding that they rarely regulated the thermostat setting – a strategy that could be defined as a passive strategy. The passive regulation strategy was supported by the questionnaire revealing that 9out of15 regulated the thermostat *yearly or never.* In Building 2, the regulation strategy was more active. The majority of interviewees and respondents stated to have a thermostat regulation strategy. This corresponded well with the higher standard deviation of the temperature measurements in Building 2 than in Building 1.These findings were in agreement with the findings of Gunay et al. [11].

10 of 13 respondents in Building 1 and 4 of 4 respondents in Building 2 stated to have a window opening strategy. However, 13 of 14 respondents and 7 of 9 respondents in Building 1 and Building 2 respectively, stated to open a window daily for venting purposes. This indicated that the heat cost allocation type wasn't the final driver for the window opening frequency. Andersen et al. [22] reported that the CO_2 concentration in residential buildings is a major driver for window opening. The difference in the CO_2 concentration presented in Table 1 and 2 indicated that occupants with individual payment were willing to accept higher CO_2 concentrations and therefore postponed window oening compared to occupants in buildings with collective payments.

Figure 11 showed a difference between the hourly average CO_2 concentrations which appeared to be notably lower in Building 1 than in Building 2. Assessment of the natural infiltration rate showed a higher infiltration rate in Building 1 than in Building 2, partially explaining the higher CO_2 concentrationsin Building 2.

In most households the occupancy differs between weekdays and weekends. However, there were only small differences between weekdays and weekends in the three measured parameters (Figure 7 through Figure 9). This indicates that the occupancy was only loosely related to the control of the indoor environment.

5.3 Assessment of the IEQ

The recommendations used were based on EN 15251-2007 category II recommendations for residences and presented in Table 1. EN 15251-2007 recommended that the intervals should not be exceeded for longer than 5% of the measured period. Table 1 and Table 2 showed that none of the parameters complied with the 5% recommendation.

The average temperature of 23.5 °C as well as a temperature distribution with temperatures exceeding the recommendations for 12% of the time showed an energy savings potential in Building 1. The frequency and duration of window openings were not monitored However, as the CO_2 concentration was within the recommendation for 96 % of the time and the relative humidity was below the recommendation for 88% of the time, it could indicate long periods of venting and that an optimization of the regulation strategy would decrease the heating consumption.

In Building 2, the temperature measurements were below the recommendation for 50 % of the time, the CO_2 concentration above for 18 % of the time and the relative humidity below for 37 % of the time. This distribution indicated a low heating setpoint and short and insufficient venting periods. The interviews showed, that the occupants had difficulties assessing if their regulation strategies were efficient and that they had difficulties adjusting the thermostats. The interviews further showed a crucial lack of knowledge on how to operate thermostats, in line with the findings of Peffer et al. [23]. Figure 11 showed the average, the 75^{th} percentile and the 95^{th} percentile CO_2 concentration to be above the recommended value, indicating unresponsiveness to poor air quality. As the occupants were already driven by low heating costs and were willing to engage in active control of the indoor environment, a comfortable indoor environment and low energy consumption seemed achievable with an higher knowledge level and the right tools to assess the indoor environment.

The relative humidity measurements were below the recommendations in EN 15251-2007 and the risk of condensation was therefore low. Figure 12 further visualized a stable vapour pressure for both buildings with minimal variation through out the day.

5.4 Heat cost allocation as a behavioural driver

The measurements showed differences between the two buildings, differences that could have occurred because of difference in the state of the heating system, insulation level and the state of the windows etc. or because of the regulation of the indoor environment. Analyses' of building components were not performed precluding an estimation of the effects there of. However, all interviewees stated it was possible to obtain comfortable temperatures, demonstrating the heat cost allocation as a driver affecting the occupants' regulation of the indoor environment. A demographic survey was neither part of the interviews nor the questionnaires, however, the average annual income of inhabitants in the municipality of Building 1 is 278€ higher than that of inhabitants in the municipality of Building 2 [24]. A difference so small that it is acceptable to ignore.

In relation to the literature reviews by Fabi et al. [13] and [14], the results showed the drivers to be hierarchical with some drivers overruling others. This was evident in Building 2, where low heating bills were valued higher than thermal comfort. In Building 1, the desire to save money on the energy bill was not strong enough to overrule the desire for high indoor environmental quality.

5.5 Heat cost allocation in building performance simulations

Hong et al.[25] surveyed the advances in the field of occupant behaviour in building performance simulations. The study described how model inputs are typically collected specifically for the purpose of the study, making the inputs model specific [25]. This means that if the user model is used to model the occupant behaviour in another building, the user profiles of the two buildings would need to have similarities to be valid in later simulations

The findings of this paper showed that heat cost allocation type affected the indoor environment, the interviews further showed a direct correlation between the heat cost allocation type and the occupants' attitude towards the thermal environment. Fabi et. al [14] showed that many different drivers affects the occupant behavior, in the same manor D. Yan et al. [26] described the complexity of having too many user inputs ending up with an over-fitted model. This means that the heat cost allocation should not be te only user input in a user model, but could be used as a characteristic in the five user profiles describe by van Raaij et al. [27] and Guerra-Santinet al. [28].

5.6 Validity of the CO_2 sensor

When using a self-calibrating CO_2 sensor, it was necessary to reach the outside concentration at least once a week in the surveyed rooms to achieve accurate measurements. In cases where the sensor did not reach outside concentrations within a week, the reference concentration would drift upwards and the sensor would have measured concentrations lower than 400 ppm once the concentration returned to outdoor levels.

Figure 3 indicated CO_2 concentration measurements below the outside concentration (approximately 400 ppm), which occurred due to the self-calibrating abilities of the CO_2 sensor. 0.3% of the CO_2 measurements in Building 1 and 1 % of the CO_2 measurements in Building 2 where below 370 ppmIt was therefore assumed that the effects of the deviations were negligible.

6 Conclusion

The heat cost allocation in two apartment buildings had an impact on the indoor environment. Whereas the average temperature measured in apartments with collective heat cost allocation was 2.8°C higher compared to apartments with individual heat cost allocation, the average CO_2 concentration and average vapour pressure were 161 PPM and 93 Pa lower.

The heat cost allocation type was identified as a driver for the regulation of the indoor environment. Individual payment plans triggered a more active regulation strategy compared to buildings with collective heat cost allocation. The occupants in apartments with individual heat cost allocation tended to focus on the cost of heating and accepted uncomfortable temperatures for extended periods of time. In contrast, occupants in apartments with colletive heat cost payment schemes focused on creating a comfortable and healthy indoor environemnt with little attention to the cost of heating.

It was suggested, that the heat cost allocation type as a psychological driver, overrules the driving forces of the phycial environment, if present.

7 Reference

[1] Andersen R. The influence of occupants ' behaviour on energy consumption investigated in 290 identical dwellings and in 35 apartments 2009.

[2] Socolow R. The Twin Rivers Program on Energy Conservation in Housinh: Highlights and Conclusions 1977.

[3] Wilhite H, Ling R. BUILDIPIG AND M e a s u r e d energy savings from a more informative energy bill 1995;22:145–55.

[4] Guerra Santin O, Itard L. Occupants' behaviour: determinants and effects on residential heating consumption 2010:37–41. doi:10.1080/09613211003661074.

[5] Maier T, Krzaczek M, Tejchman J. Comparison of physical performances of the ventilation systems in low-energy residential houses. Energy Build 2009;41:337–53. doi:10.1016/j.enbuild.2008.10.007.

[6] Iyer M, Kempton W, Payne C. Comparison groups on bills: Automated, personalized energy information. Energy Build 2006;38:988–96. doi:10.1016/j.enbuild.2005.11.009.

[7] Schultz PW, Nolan JM, Cialdini RB, Goldstein NJ, Griskevicius V. The constructive, destructive, and reconstructive power of social norms. Psychol Sci 2007;18:429–34. doi:10.1111/j.1467-9280.2007.01917.x.

[8] Abrahamse W, Steg L, Vlek C, Rothengatter T. A review of intervention studies aimed at household energy conservation. J Environ Psychol 2005;25:273–91. doi:10.1016/j.jenvp.2005.08.002.

[9] Darby S. Smart metering: what potential for householder engagement? Build Res Inf 2010;38:442–57. doi:10.1080/09613218.2010.492660.

[10] Cholewa T, Siuta-Olcha A. Long term experimental evaluation of the influence of heat cost allocators on energy consumption in a multifamily building. Energy Build 2015;104:122–30. doi:10.1016/j.enbuild.2015.06.083.

[11] Burak Gunay H, O'Brien W, Beausoleil-Morrison I, Perna A. On the behavioral effects of residential electricity submetering in a heating season. Build Environ 2014;81:396–403. doi:10.1016/j.buildenv.2014.07.020.

[12] Levinson A, Niemann S. Energy use by apartment tenants when landlords pay for utilities. Resour Energy Econ 2004;26:51–75. doi:10.1016/S0928-7655(03)00047-2.

[13] Fabi V, Andersen RV, Corgnati S, Olesen BW. Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models. Build Environ 2012;58:188–98. doi:10.1016/j.buildenv.2012.07.009.

[14] Fabi V, Andersen RV, Corgnati SP, Venezia F. Main physical environmental drivers of occupant behaviour with regard to space heating energy demand. Heal Build 2012 2012.

[15] Sardianou E. Estimating space heating determinants: An analysis of Greek households. Energy Build 2008;40:1084–93. doi:10.1016/j.enbuild.2007.10.003.

[16] Andersen RV, Toftum JJ, Andersen KK, Olesen BW. Survey of occupant behaviour and

control of indoor environment in Danish dwellings. Energy Build 2009;41:11–6. doi:10.1016/j.enbuild.2008.07.004.

[17] Frontczak M, Andersen RV, Wargocki P. Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing. Build Environ 2012;50:56–64. doi:10.1016/j.buildenv.2011.10.012.

[18] Wilke G. IC Meter 2015. www.ic-meter.com (accessed March 15, 2015).

[19] Andersen RK. Experiences from the project Dynamic Heat Cost Allocation 2013.

[20] Cui S, Cohen M, Stabat P, Marchio D. CO2 tracer gas concentration decay method for measuring air change rate. Build Environ 2015;84:162–9. doi:10.1016/j.buildenv.2014.11.007.

[21] En DS. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. 2007.

[22] Andersen R, Fabi V, Toftum J, Corgnati SP, Olesen BW. Window opening behaviour modelled from measurements in Danish dwellings. Build Environ 2013;69:101–13. doi:10.1016/j.buildenv.2013.07.005.

[23] Peffer T, Pritoni M, Meier A, Aragon C, Perry D. How people use thermostats in homes: A review. Build Environ 2011;46:2529–41. doi:10.1016/j.buildenv.2011.06.002.

[24] Denmark S. Statistic Denmark 2016:http://www.statbank.dk/statbank5a/SelectVarVal/sav.

[25] Hong T, Taylor-lange SC, Oca SD, Yan D, Corgnati SP. Advances in research and applications of energy-related occupant behavior in buildings. Energy Build 2015. doi:10.1016/j.enbuild.2015.11.052.

[26] Yan D, O'Brien W, Hong T, Feng X, Burak Gunay H, Tahmasebi F, et al. Occupant behavior modeling for building performance simulation: Current state and future challenges. Energy Build 2015;107:264–78. doi:10.1016/j.enbuild.2015.08.032.

[27] van Raaij WF, Verhallen TMM. Patterns of residential energy behavior. J Econ Psychol 1983;4:85–106. doi:10.1016/0167-4870(83)90047-8.

[28] Santin OG. Behavioural Patterns and User Profiles related to energy consumption for heating. Energy Build 2011;43:2662–72. doi:10.1016/j.enbuild.2011.06.024.