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Occupant-centred temperature reduction in an energy efficient site

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Abstract. In this study we focus on the energy saving potential and the user acceptance of indoor air temperature reduction in an energy efficient district, consisting of seven residential buildings. The two major findings in this paper constitute a field of unresolved tension. From a technical point of view, temperature reductions of 1.5 K, to approximately 21.5 °C, allow to save some 25 % of the total heating energy. The human dimension, however, suggests that a reduction of indoor air temperature is associated with only limited acceptance. In future work we will set out to explore how acceptance ratings might evolve over longer timespans.

1. Introduction and Background

The building sector accounts for 50 % of the total energy consumption in Switzerland (i.e. 850k TJ), with 66 % being attributed to space heating [2]. However, does this considerable energy demand also imply a large potential for energy conservation? Most research aims to contribute to this question through the introduction of technical innovations, such as efficient heating systems for reducing net energy demand or performant insulation for lowering the total energy demand (e.g. [7]). These so-called *energy efficiency* measures have proved to be effective means for saving heating energy. However, due to the vast technological progress and more rigorous regulations in the building sector, the relative impact of building characteristics on energy demand is decreasing, while the impact of user behavior moves to the center of interest ([4]).

In this paper we focus on a district in Küsnacht (ZH, CH), consisting of seven buildings and 70 households, of which 35 participate in the study. The district was built in 2016, is heated by a low-temperature network, apartments have an automatic ventilation system and buildings are well insulated. The room for energy efficiency measures is therefore nearly exhausted. We thus put our focus on occupant-centered *energy sufficiency* measure [9]. In the heating season 2018/19 indoor temperatures were reduced by approximately 1.5 K to a threshold value of 21.5 °C. This is still well above the recommendations of the SIA 2024. Subsequently, occupants' acceptance and perception of these lower indoor temperatures were measured via an online-survey.

This approach addresses a series of research gaps. First, there is a general lack of intervention studies where comprehensive occupant feedback is collected in a residential context. One reason might be difficult to obtain consents for participation. In this project, access to occupants was facilitated by the building cooperative. Second, given the important role of space heating in terms of total energy consumption, there is a lack of intervention studies aiming at the reduction of indoor temperature – for example, a recent literature review shows that only two out of 100 studies on energy-saving



interventions, focus on space heating [3]. Third, most research on the relation between heating energy consumption and occupant behavior has focused on drivers of energy use, such as lifestyle [4] or window opening patterns [5]. Much less attention has been paid to the more general issue of occupant-centered indoor temperature reduction (e.g. [14]).

Finally, for a long time the rule of the thumb has been applied saying that reducing indoor temperature by 1 K makes for a 6 % reduction of the heating demand [1]. However, with the rising energy efficiency of buildings, the relative saving potential of temperature reduction has increased. Surprisingly, there is a lack of empirical evidence, where the relation between heat demand and temperature reduction has been quantified.

From the above context, two questions are addressed by our research:

1. How much energy can be conserved through a reduction of indoor air temperature by approximately 1.5 K?
2. How accepted is the reduction of indoor air temperature by occupants?

The two questions cover technical as well as human dimensions of energy sufficiency and will therefore be explored through the combined prism of engineering and social sciences, as for instance stipulated by [13]. The remainder of this paper is structured as follows: The experimental setting and the methodological approach for quantifying energy savings and exploring occupants' acceptance is explained in Section 2 and results are shown in Section 3. The paper ends with a concluding discussion.

2. Methodological Approach

In the following three sections, i) details about the types of buildings and the implementation of the temperature reduction, ii) the approach for quantifying energy savings and iii) the assessment of occupant perception and acceptance are discussed.

2.1. Reducing Indoor Air Temperatures

The heating system in the district under investigation is special in such that an efficient low-temperature network is combined with a low-tech implementation. Each building has an own heat pump. The temperature regime between apartments is regulated through hydrologic pressure solely. Apartments have no additional thermal switches that allow users to regulate temperatures on their own. On the one hand, this prevents users from interfering with the experimental setting. On the other hand, however, previous research has suggested that feeling entirely at the mercy of a system might reduce the acceptance of interventions [7].

Temperatures in ten apartments, were observed during the heating season 2017/18. Temperatures were found to be usually above 23 and often around 24 °C. This is considerably higher than the default-values from SIA (SIA 2024). In September 2018 a more extensive measurement campaign started, incorporating some 35 apartments, using one measurement device per apartment. The relatively high indoor air temperatures from the previous heating season could be confirmed. Additionally, high temperature variations across buildings and across apartments were observed, suggesting that the initial hydraulic calibration was of poor quality and has never been examined.

Since temperatures can only be reduced for entire buildings and should not fall significantly below a defined threshold temperature of 21.5 °C, the potential for temperature reduction is directly dependent on the apartment with the coldest temperature. For this reason, in December 2018, the temperature monitoring was used to improve the hydraulic calibration, with the aim of reducing temperature variations within and across buildings. On February 4, 2019, the indoor temperatures in all seven buildings were reduced through adjustments of the heating curve of each heat pump. Indoor temperatures were controlled on a fine granularity. If indoor temperatures fell below, or remained clearly above the threshold temperature of 21.5 °C, additional hydraulic adjustments were made (February 2019).

2.2. Quantifying Heating Energy Savings

Heating energy savings are quantified for each building separately. Savings are computed comparing the heating energy consumption before and after the temperature reduction in January 2019. Energy meters at each heat pump measure heat consumption with a temporal resolution of one minute. Outdoor air

temperatures are measured every 15 minutes. Both measurements are aggregated to daily values, representing the sum of heating energy and the average daily outdoor temperature. The two values can now be used to train a statistical model that predicts daily energy consumption using average outdoor temperature. We use robust linear regression and a bi-square Tukey estimator that is less sensitive to the outliers in the data. Separate regression models are trained for the time before and after the temperature reduction. The models allow to estimate a daily energy consumption and thus the computation of daily energy savings.

2.3. Assessing Occupant's Perception and Acceptance

Occupants interested in participating in a study on topics related to energy conservation in a residential context, temperature reduction being one example, signed a consent for participation. Occupants from 35 of all 70 households agreed to participate in the study.

In autumn 2018 occupants were informed that as part of a larger initiative to reduce the energetic footprint of the district, the heating system will be optimized in the forthcoming heating season. Details about the intervention were not communicated. Thus, the experiment can be considered a blind test. On February 24, almost three weeks after the intervention, an online survey was conducted to assess on occupants' perception and acceptance of the indoor air temperature and humidity, possible adaptive behavior (warmer clothes, additional heating devices), as well as environmental attitudes¹. All these factors might impact individual variation in thermal comfort. An online questionnaire was sent to the 35 households participating in the study and a total of 67 individual occupants.

Temperatures were reduced in all buildings simultaneously. Due to the relatively small sample size, no control group was incorporated. Instead, a before/after comparison was conducted. For this purpose, the feedback from a baseline survey from the heating season 2017/18 was used. Finally, spontaneous feedback from occupants by the housing management regarding indoor air temperature was recorded systematically.

3. Results and Interpretation

Results are presented for technical and social dimensions of the intervention separately.

3.1. Temperature Reduction and Energy Savings

Figure 1 shows temperature profiles (A) and heating energy consumption (B) for the time before and after the intervention, for one of the seven buildings under investigation.

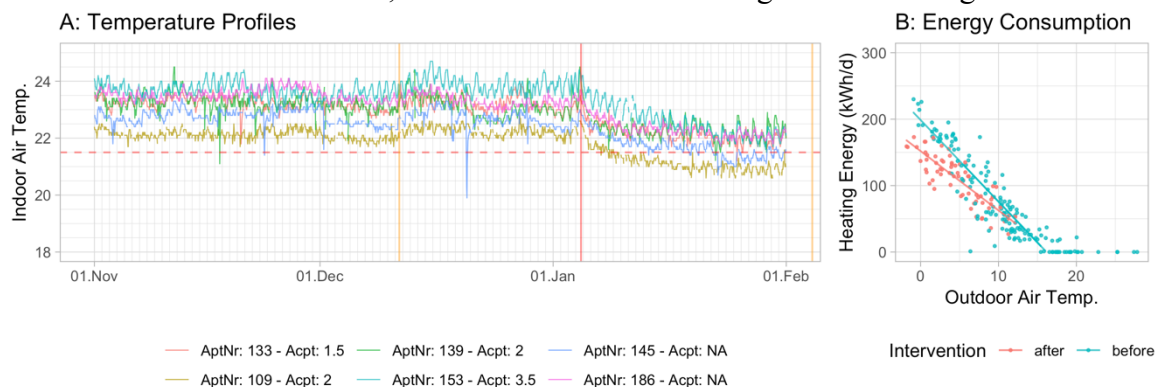


Figure 1: A: Temperature profiles for six apartments within one building. Apartment labels incorporate the acceptance rating of indoor air temperatures if available (1 (too cold) – 2 – 3 (ideal) – 4 – 5 (too warm), NA = not available). The vertical lines represent the two hydraulic adjustments (orange) and the temperature reduction (red). The horizontal dashed line indicates the target temperature of 21.5 °C. B: Comparison of daily heating energy consumption and average outdoor temperature, for the days before (blue) and after (red) the temperature reduction. The lines represent the interpolated regression functions.

¹ Link to a PDF version of the survey: https://www.dropbox.com/s/5xv3grju4tktr67/Umfrage_Heizung.pdf?dl=0

The profiles of the six apartments in Figure 1; A show that the temperatures in December, before the temperature reduction (to the left of the red vertical line), lie between 22 and 24.5 °C. After the reduction, temperatures drop and converge to the target temperature of approximately 21.5 °C. Temperature variations between the six apartments, all within the same building, are relatively large, with hydraulic pressure adjustments (orange vertical lines) having a positive effect for reducing the variation. However, the amount of energy saving is still hampered by the temperature of the coldest apartment (i.e. AptNr. 109).

Figure 1; B shows heating energy consumption per day in comparison to outdoor air temperature for the same building as in A. The temperature reduction had a visible impact on heating energy consumption. Red points lie below blue points, indicating that given a certain outdoor air temperature, less heating energy is consumed after the temperature reduction.

Table 1 shows that within the first month after the intervention, 15 MWh of heating energy could be preserved. Applied to average daily temperature between 2014 and 2018, estimated energy savings sum up to between 30 and 50 MWh per year. In relative terms, the temperature reduction of approximately 1.5 K accounts for 25 % of the total heating energy consumption.

Table 1: Heating energy savings in total and relative numbers.

Heating Energy Savings	Total	Relative
<i>since the intervention</i>	15 MWh/30d	25 %
<i>between 2014 and 2018</i>	30-50 MWh/a	25 %

3.2. Occupants' Perception and Acceptance

33 of all 67 questionnaires were completed and returned, which results in a response rate of almost 50 %. Three questions – on the acceptance of A) energy conservation measures, B) efficient heating systems and C) temperature reduction as a measure for saving energy - occurred twice in the questionnaire. The first time, acceptance was assessed in the beginning of the survey. The second time right after the information block, which provided participants with information on the temperature reduction in their apartments and the corresponding energy saving potential. Figure 2 summarises all responses for the first (*no info*) and second (*info*) occurrence of the three acceptance questions.

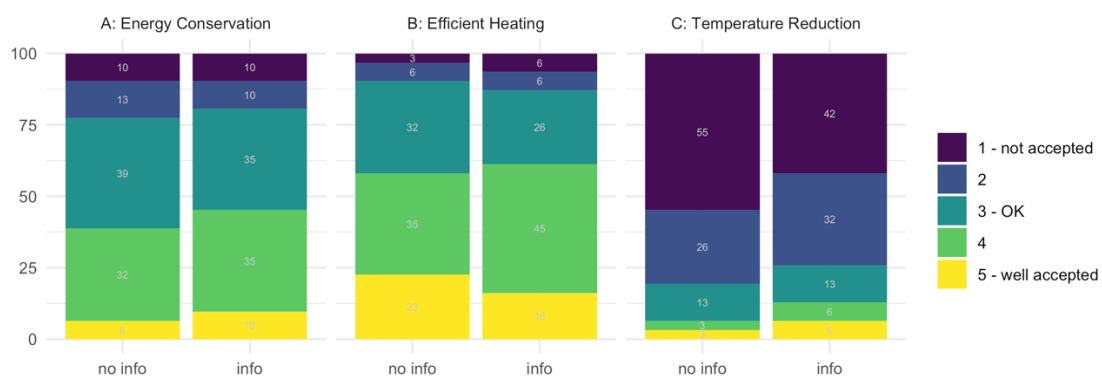


Figure 2: Responses to three questions on the acceptance of energy conservation measures in general (A), efficient heating systems (B) and temperature reduction as a measure for energy conservation (C). Questions were asked before (*no info*) and after (*info*) participants were informed on the intervention and the potential energy savings and health effects in particular.

Most intriguing is the relatively low acceptance of temperature reduction as a measure for energy savings (Figure 2; C). A majority of participants rated it as a *not accepted* measure (55 %). The acceptance increased after participants were informed about the conducted temperature reduction and

the motives behind it (energy saving and healthier indoor climate). However, still more than 70 % of all participants believed that reducing temperatures is rather not acceptable (< 3 in the Likert Scale).

Responses to the two other questions confirmed that residents have a high acceptance for environmental topics (Figure 2; A and B), with responses being largely independent of the information about the intervention. Interestingly, only 50 % of all respondents reported to have perceived a change in indoor air temperature since the beginning of the intervention. Somewhat in contrast to this finding are responses to the question of *how* temperatures were perceived (Figure 3; A). Temperatures are generally rated as quite cool. This is most evident for living room temperatures, which are rated as *too cold* by 26 % of all participants and as *OK* by only 29 % (*Livingroom 2018/19*). The acceptance for similar low air temperatures in bathrooms and kitchens is higher (*Bath, Kitchen 2018/19*).



Figure 3: A: Distribution of perceived temperature ratings in different rooms. The last row represents the perception of temperatures from a baseline inquiry in the heating season 2017 / 18. B: Ratings of behavioural changes, triggered by the temperature reduction.

The last two bars in Figure 3; A show the temperature perceptions in apartments in the current (*Apartment 2018/19*) and in last year's heating season (*Apartment 2017/18*). The comparison suggests that the temperature reduction of approximately 1.5 K translates into significantly lower ratings. The rating of *OK* temperatures dropped for instance by almost 35 % from last to this year's heating season.

The relatively large variation in room temperatures across apartments (c.f. Figure 1; A) allowed us to test the hypothesis whether the variation in measured temperatures might explain the variation in perceived comfort. From a long list of derivatives from measured temperatures, such as *median* or *mean temperature*, *average temperature of the coldest day* or *temperature drop from before to after the intervention*, no conclusive relation between measured and perceived temperatures could be identified. Ratings as shown in Figure 1; A support this finding.

When asked for behavioral changes that have been triggered by cool indoor air temperatures, occupants showed a clear preference for the option wearing *Warm Clothing* (Figure 2; B). An increased intake of hot beverages or food turned out as a less favored option. Only few people shifted to critical behaviors, such as operating a mobile *Electric Furnace*, the effect of which could not be identified in an analysis of household electricity consumption. Seven out of totally 70 households (10 %) complained spontaneously to the housing management because of low indoor temperature and mentioned specific issues, such as cold floor temperatures. This issue has also been raised in the survey. Therefore, we carefully controlled return flow temperatures to the heat pumps and additionally used a thermal imaging camera to assess floor surface temperatures in one apartment, both with the result of measuring 23 °C. This corresponds to a standard operation temperature of a low-temperature heating system.

4. Concluding Discussion

Two research questions were addressed in the present study: How much energy can be saved through temperature reductions in modern buildings? And, importantly, how well accepted are temperature reductions as a measure for energy conservation, if a certain affinity for environmental issues can be assumed? Our results impressively show that some 25 % of the total heating energy can be preserved through a temperature reduction of only some 1.5 K. This is significantly more than the expected 6 % /

K [1]. Room temperatures remained largely over 21.5 °C during the experiment, which is well above the minimum threshold as for instance suggested by the SIA (i.e. 21 °C, SIA 2024). The calibration of hydraulic settings to limit variations in room temperatures across apartments turned out as a critical technical challenge.

The feedback from occupants clearly underlines that temperature reduction only gains limited acceptance as a measure for energy conservation. On the one hand, it is well known that individual comfort, with indoor air temperature being a prototypical example, poses a particular challenge to be changed to a more sufficient behavior (e.g. [10]). Our research shows that this is also the case for residents who have consciously decided to live in an energy-efficient district and who attest an affinity for environmental issues.

Concerning the critical feedback from occupants, two issues have to be taken into account. First, strategic answers may have influenced participants answers in the direction of lower satisfaction, in order to induce an increase of temperatures in their buildings. Second, occupants were most evidently dissatisfied with the cold floor temperatures. However, floor temperatures were verified to corresponded to standard operation temperatures for this type of heating system. As a response, a flyer was sent to all households, explaining the functioning of modern heating systems and mentioning possible adaption strategies, such as wearing house shoes.

One central issue that has not been tackled in this study and which constitutes a broader research gap concerns the long-term adaption to low temperature regimes (e.g. [6]). The described experiment will be continued in the following heating season, in order to test if acceptance ratings might increase, if lower indoor air temperatures become the new standard.

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