Energy savings of “tailored-to-occupant” dynamic indoor temperature setpoints

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A dynamic thermal environment that temporarily exceeds the boundaries of the thermal comfort zone can be an approach to reduce energy use in buildings while providing occupants with instances of thermal delight and positive stimulation. This work presents “tailored-to-occupant” dynamic heating profiles based on in-situ-measured occupancy in a Swiss case study office and compares resulting heating energy demand with rather static setpoints used in practice and established by current standards.

Keywords: occupant-centric buildings, energy reduction, heating demand, dynamic temperature setpoint, open space office

Introduction

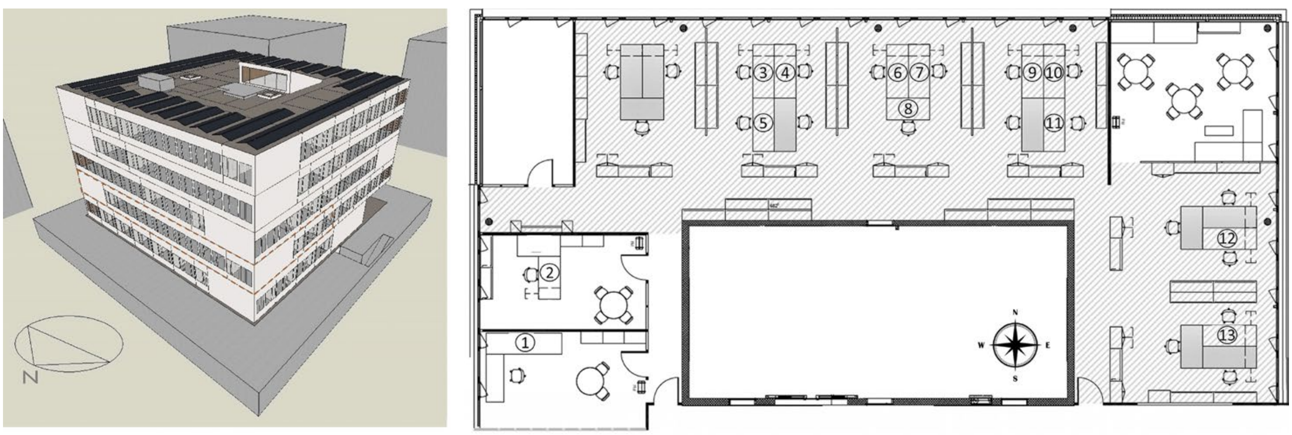
Indoor temperatures setpoints in buildings are typically fixed and set according to standardized regulations on indoor thermal comfort such as ISO 7730 [1] and ASHRAE 55 [2]. Thus, the common way for operating HVAC systems in buildings is to avoid deviations of the indoor temperature from the steady-state, most often the indoor temperature is kept within 2 K around the set point [3]. However, such a practice of tight indoor temperature settings has resulted in significant operational energy use in buildings [4]. Alternatively, energy-expensive *static indoor temperature setpoints* can be challenged by *dynamic occupant-aware setpoints*. Such profiles can be developed by considering recent physiological research, such as [5-7], showing that mild cold exposure could positively affect the body's energy metabolism and glucose metabolism. The studies also demonstrated that people could well adapt to a variation in the indoor temperature, including mild cold. In other words, short exposure of people to indoor temperatures beyond the typical thermoneutral range during the day could be acceptable for occupants and beneficial from a health perspective. Thus, if temperature profiles introducing short-term beyond neutral thermal exposure can be adapted by considering the daily routines of people, *less stringent* requirements for temperature control can directly contribute towards operational *energy* reduction in buildings [22]. Therefore, we explored dynamic heating approaches with more easing heating setpoints with respect to the practice and permitted under the current standard setpoints during heating months (November-February) for a specific open space office located in Lausanne, Switzerland. The objective of this work is to present novel "*tailored-to-occupant*" heating approaches and how these, with respect to actual operational heating settings and standardized profiles according to the Swiss national standard SIA 2024:2015 [9], can affect the building energy performance.

Case study office monitoring and energy simulation

For developing tailored dynamic heating profiles in the specific case study, it is crucial to firstly gain insights into the real occupancy of the space, as well as understanding typical indoor temperature profiles. For that reason, the 224 m² open space Swiss office was monitored as part of the eCOMBINE project described in [10]. The overview of the building is shown in **Figure 1**a, and the floor plan of the open space office located on the first floor of the building and occupied by a maximum of 22 employees is provided in **Figure 1**b. In particular, for this work, we refer to measured operative temperature values based on data collected for two weeks in Fall (28.10. – 09.11.2019) and Winter (27.01. – 07.02.2020) at the desk level of the occupants and occupancy measurements taken under 13 employees' work desks. The actual heating setpoint profile was rather static, varying in the range of 22.5-24°C with no nocturnal setpoint. It serves as a *baseline* for further analysis of simulated energy use. Building energy simulations were performed in DesignBuilder using an Ideal Air Loads System by modeling the open space as a single thermal zone. The hourly simulation was run for the period from the start of November to the end of February, accounting for the winter months in Switzerland, using Typical Meteorological Year (TMY) based on historical weather data (2002). As the *standard-based scenario*, 21°C during working hours and 16°C of nighttime setback is considered per Swiss standard SIA 2024:2015 [13].

Dynamic heating setpoint profiles

To adapt the setpoint profiles to the specific occupancy of the space, the daily average, minimum, and maximum occupancy rates are profiled, as shown in **Figure 3**. This allowed for defining 9 different types of occupancy patterns: an *early* arriver (6 am),



(a) (b)

Figure 1. Case study open space office: (a) overview of the building (studied office façade is highlighted), (b) floor plan of the selected open space office (shaded in grey) with the numbering of monitored desks.

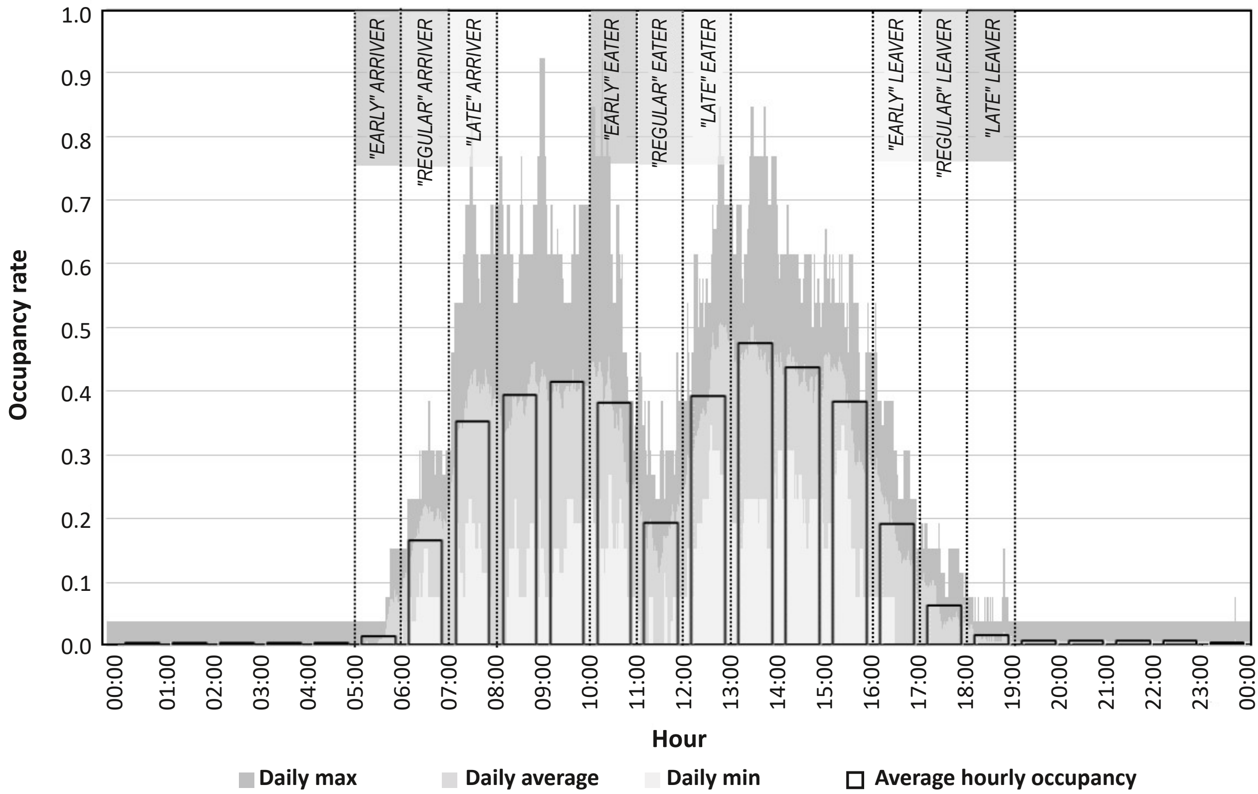


Figure 2. Real occupancy in the case study building: average, minimum, and maximum daily profiles (minutely) and hourly occupancy rates.

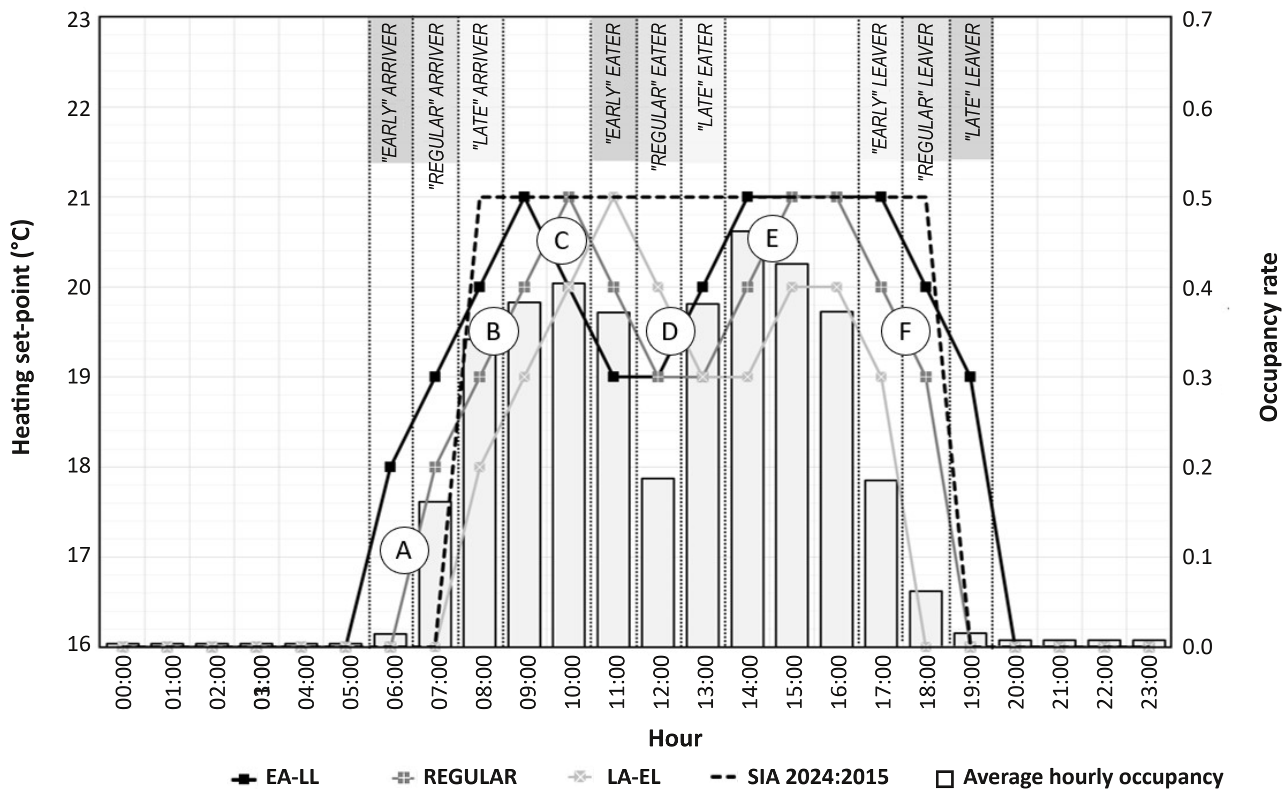


Figure 3. Heating set-point profiles for (i) early arriver (EA) - late leaver (LL), (ii) regular, (iii) late arriver (LA) - early leaver (EL), and (iv) based on SIA 2024:2015. The heating setpoint profiles are plotted against hourly occupancy rates (averaged over the previous hour).

regular arriver (7 am), and *late* arriver (8 am); an *early* eater (11 am), *regular* eater (12 pm), and *late* eater (1 pm); and, finally, an *early* leaver (5 pm), *regular* leaver (6 pm) and *late* leaver (7 pm). Based on these patterns, horizontal variations/shifts of alternative heating profile designs are introduced to evaluate their impact on the energy demand for space heating. In particular, the concept behind the design of the alternative heating profiles, shown in **Figure 4**, follows the following assumptions:

A. *At arrival*, the temperature setpoint is set at 18°C since the employees arrive from outdoors and likely have higher acceptability towards lower indoor thermal conditions (prior walking/biking to get to work results in elevated metabolic rate, and a person entering an indoor warmer space from cold outdoors is expected to feel the pleasure of a rising temperature).
B. *After arrival*, to stimulate the thermal pleasure of the employees typically performing sedentary work, the temperature will constantly rise for three consecutive hours, reaching a peak of 21°C (ΔT=3°C);
C. *During mid-morning*, due to increasing occupancy and heat gains from occupants and electric equipment, the temperature setpoint will start to drop, allowing for stimulating employees' alertness after a few continuous sedentary working hours;
D. *During lunch*, when occupants are usually not sitting at their desk, the temperature setpoint is reduced down to 19°C;
E. *After lunch*, due to elevated metabolic rates after the meal intake, the heating setpoint will first remain low and then rise in the afternoon hours (ΔT=1-2°C) to compensate for continuous sedentary work at a low metabolic rate;
F. *In the afternoon*, the setpoint will drop to 19°C to avoid potential drowsiness at prolonged exposure to a constant and warm environment, and then further drop towards the end of the working day as people start departing from the office until reaching the nocturnal setback of 16°C.

The definition of extreme patterns such as "*early arriver-late leaver*" (EA-LL), and "*late arriver-early leave*r" (LA-EL) allowed for exploring different energy-saving scenarios, assuming that the "*early arriver - late leaver*" (EA-LL) profile represents the highest consumer scenario, while the "*late arriver - early leaver*" (LA-EL) profile represents the lowest consumer scenario.

Heating energy demand reduction

The results of the heating demand of different setpoint profiles are presented in **Figure 4**. The comparative analysis shows the reduction in the heating demand with respect to the *baseline* scenario. The *standard-based* scenario (SIA 2024:2015) allows for reducing the demand by –51%, while the dynamic heating setpoint profiles allow for further reducing the demand by –53% ("*early arriver-late leaver*"), by –56% ("*regular*"), and up to –59% ("*late arriver-early leaver*"), respectively.

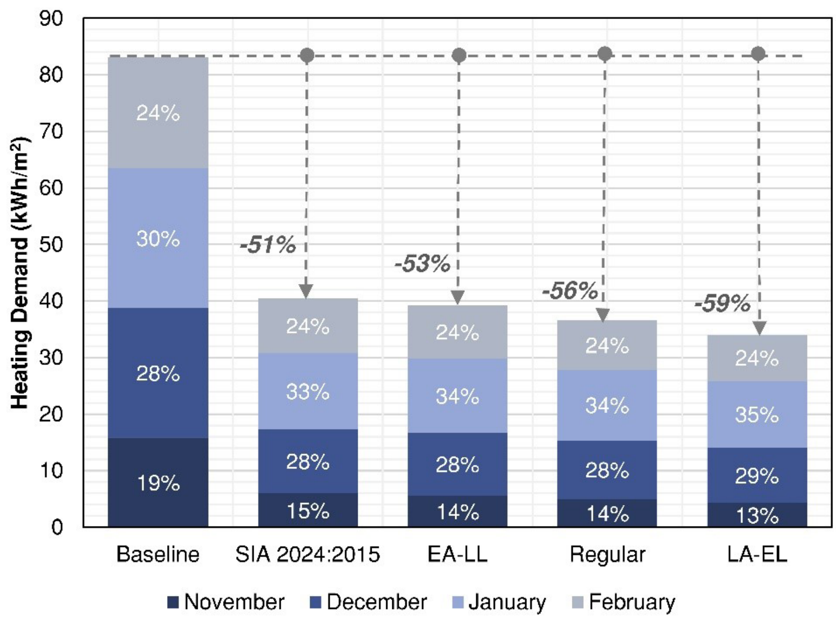


Figure 4. Energy demand for space heating according to different heating setpoint profiles.

The most impacting months on the heating demand in all scenarios are December (28-29%) and January (30-35%). As expected, the profile LA-EL resulted in the lowest heating demand among all three dynamic profiles due to the shortest working hours (8 hours/day), while EA-LL resulted in 6% more heating demand due to the longest working hours (12 hours/working day). Notably, EA-LL heating demand was 2% less than the standardized scenario at a constant 21°C during working hours. These results highlight that there is a potential improving building energy performance by modifying the thermostat operation of the case study office.

Conclusions

The advantage of existing buildings is the possibility to know more about occupants compared to the design stage. Thus, by considering the daily routines of employees and the corresponding occupancy profiles, *tailored-to-occupant* heating approaches can be defined rather than using standard ones. As a concrete example, occupancy of the case study open space office in Switzerland is analyzed, and three setpoint profiles **EA-LL** ("*early arriver-late leaver*"), **regular**, and **LA-EL** ("*late arriver-early leaver*") are identified, based on the hours of individuals coming to work, having lunch, and departing from work. Dynamic daily temperature profiles are drawn in the range of 18-21°C with a 1K/h drift rate by aiming to introduce more moments of positive alliesthesia, and slightly more exposure to a cooler environment to keep employees potentially alert during prolonged sedentary work and avoid potential drowsiness. All in all, this work demonstrated that by implementing customized heating profiles, heating energy demand could be reduced up to 60% compared to the existing practice. Obviously, this can be achieved by going to a certain extent beyond the comfortable range of temperatures. While such thermal environments are not very acceptable in the current practice, there is a great chance that this would change in the future as more attention to human well-being in buildings is paid. ■

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