BUILDINGS & CITIES

SPECIAL COLLECTION: ENERGY SUFFICIENCY IN BUILDINGS AND CITIES

RESEARCH

New insights into thermal comfort sufficiency in dwellings

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ABSTRACT

Domestic heating is a major contributor to energy consumption and must be minimised to achieve climate targets. Building on the concept of addressing the distinct heating needs of individuals and buildings separately, the Slowheat project implemented a three-year transdisciplinary real-world laboratory focusing on adaptive heating practices. This initiative involved 23 households in Brussels, Belgium, in a collaborative exploration of the sufficiency of heating: minimising heating while meeting needs for comfort. Starting with a mean thermostat setting of 19°C, participants reduced their indoor temperature to a long-term mean close to 15°C thanks to adequate warming of individuals through personal comfort systems, clothing and physiological adaptation. It resulted in a 50% reduction in heat consumption, without an increase in electricity consumption. These results exceed those of similar published experiments. The qualitative analysis highlights the multiple dimensions of social practices related to heating and underscores the key influence of control and comfort in sustaining significant temperature reduction.

POLICY RELEVANCE

This paper presents the findings of the Slowheat project, which engaged 23 households in the Brussels-Capital Region over three years around the idea of 'heating people, not buildings'. The subgroup involved in the quantitative analysis achieved a reduction in heating consumption close to 50%, without an increase in electricity consumption and with normalised indoor temperatures around 15°C. The results indicate that the potential for reducing energy consumption through changes in domestic heating practices is greater than previously documented in the literature, at least among climate-conscious and educated individuals. A co-creation approach was used. Key factors are highlighted that facilitated or inhibited the adoption of a sufficient heating practice. In doing so, it provides a framework for scaling up the Slowheat project. Furthermore, this shows the need for individuals to gain greater control over their indoor environments. Four dimensions of control are emphasised, including the crucial aspect of social norms, for which policy instruments may play a role.

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1. INTRODUCTION

1.1 THE FORGOTTEN QUESTION OF INDOOR TEMPERATURE

Space heating is by far the largest source of energy consumption in European households. At the European Union level, the residential sector accounts for 27% of the final energy consumption, with 64.4% of that consumption related to space heating (EUROSTAT 2024). Consequently, significant efforts are underway to reduce this consumption and the related CO_2 emissions, focusing on building retrofitting through the so-called 'Renovation Wave' (European Commission 2020). The Renovation Wave is founded on seven key principles, the first being 'Energy efficiency first'. None of these principles addresses the concept of sufficiency. As a result, the strategies developed by member states also overlook these approaches. For instance, although the retrofitting strategy in the Brussels-Capital Region of Belgium identifies non-technological solutions as potential levers, the related actions are limited to communication and accompanying measures without any quantitative objectives (Gouvernement de la Région de Bruxelles-Capitale 2019).

Most of the research examining the potential for households to reduce their energy consumption focuses either on the implementation of energy efficiency measures or on 'behaviour change' (Sahakian *et al.* 2021). Regarding the latter, a meta-analysis of 1115 articles finds that the energy-saving potential for households ranges from 10% to 25% (Zhang *et al.* 2018). These studies generally rely on a statistical analysis of the determinants of energy consumption and do not encourage residents to critically assess their space heating habits. Studies on the feedback provided to users show similar results (0–20%) (Karlin *et al.* 2015).

The lack of emphasis on energy-saving measures rooted in behavioural changes, such as the voluntary reduction of indoor temperature, is unsurprising. It appears that research into indoor temperature in residential settings is largely confined to health-risk situations, such as overheating during heatwaves or unhealthy living conditions associated with fuel poverty in winter. Notably, 'there is no data available about heating and ventilation practices on European level' (Bierwirth & Thomas 2019: 17), indicating a significant research gap and underscoring the prevailing focus on efficiency over sufficiency. In a unique overview of European space heating practices, Sahakian *et al.* (2019) observe indoor temperatures variations ranging from 18°C in the UK (bedroom temperature in winter) to 21°C in Finland (no specific room/season mentioned). The narrowness of this range prompts scrutiny, especially considering reports of comfort at temperatures of 6–31°C (Shove 2003). Furthermore, in Nepal's current extremely cold climate, comfortable temperatures have been recorded as low as 10.7°C (Rijal 2021). This suggests that factors determining indoor temperature extend beyond physiology to encompass technical, psychological and social dimensions. It also highlights the need for a broader exploration of what constitutes a comfortable indoor environment to unlock the potential for saving energy through reduced indoor temperatures. A recent meta-analysis of 133 articles concludes that individual needs and built environments vary so much that what a warm, healthy temperature should be cannot be defined (Barlow *et al.* 2023). This observation is pivotal because it suggests that temperature alone may not be the optimal indicator of wellbeing in buildings, thereby emphasising the potential for alternative methods to maintain bodily warmth.

Reducing indoor temperatures should be approached cautiously given the potential health risks and humidity issues often associated with low temperatures (Bierwirth & Thomas 2019). Nevertheless, some studies have explicitly asked residents to lower the heating temperature in their living spaces (Laakso *et al.* 2021; Sahakian *et al.* 2021; Van Loy *et al.* 2021). However, these studies typically set a target temperature (18°C), considered a narrow range of temperatures, lasted only a few weeks or months, and remained relatively theoretical as they did not measure the energy savings.

1.2 THE IDEA OF HEATING THE BODY

Principles exist that support alternative approaches to achieving thermal wellbeing. Specifically, the theory of alliesthesia, which emphasises thermal delight rather than mere neutrality, provides a conceptual framework for creating pleasant, non-uniform thermal environments (de Dear 2011).

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This theory suggests that pleasure arises from environments with contrasting thermal conditions rather than homogeneous ones. For example, it might support the idea of enjoying a mildly cold environment when combined with direct heating of specific parts of the body (Parkinson & de Dear 2015). In other words, this approach focuses on heating the body rather than the building. Although, as Shove (2018) has pointed out, the emphasis on energy efficiency has diverted Western societies from adopting sufficient approaches such as this one, the concept of heating the body remains relevant today. This idea can be traced back to Heschong's (1979) pioneering work, and is evident in recent papers, press articles (Butler 2022) and low-tech-oriented blogs (De Decker 2015).

According to the adaptive comfort theory, the ability to adjust behaviours, expectations and physiological responses to the environment is crucial for achieving thermal comfort (Brager & de Dear 1998). Figure 1 summarises these adaptation processes, highlighting the distinction between involuntary physiological adaptations and voluntary actions triggered by discomfort. A substantial body of literature supports the relevance of the adaptive theory approach in discussing occupants' behaviours in office spaces and summer conditions. However, research on thermal adaptation in cold houses is more limited. Nicol & Roaf (2017) demonstrates how central heating systems can be viewed as a powerful adaptive solution, allowing for temperature increases compared with free-running buildings. Nonetheless, the widespread use of central heating may be suspected of inhibiting other forms of adaptation, such as clothing (Verbruggen *et al.* 2020).

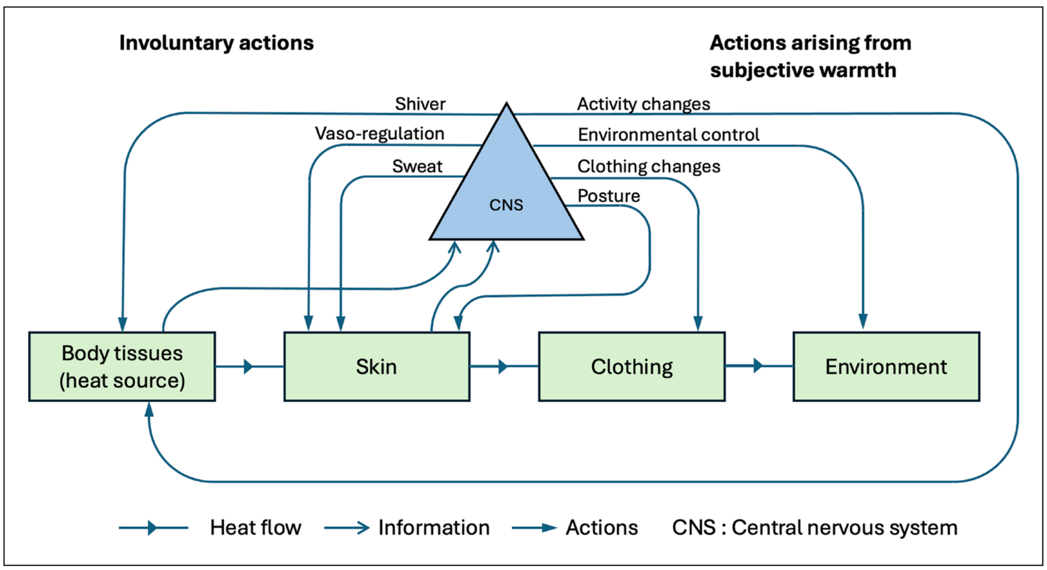

Figure 1: Thermal regulatory system according to adaptive comfort theory.

Sources: Nicol & Humphreys (1973); Nicol & Roaf (2017).

Although Figure 1 does not elaborate on the various types of environmental controls, these are obviously diverse, ranging from modifications to the general indoor environment to creating small-scale tailored thermal environments or dedicated heat flows on specific body parts. Recently, devices known as personal comfort systems (PCSs) such as heated blankets, radiant panels, heated chairs, *etc.* have been developed and tested, mostly in controlled environments (Song *et al.* 2022). PCSs have been demonstrated to compensate for reductions in ambient temperature by several degrees in office spaces (Song *et al.* 2022), saving energy while providing greater comfort than indoor air heating (He *et al.* 2022). However, no comprehensive research explores the impact of PCSs in residential settings.

1.3 RESEARCH QUESTION

Expanding on the concept of 'heating the body, not the building', the Slowheat project investigated how this idea could facilitate the development of a sufficient heating practice, its potential impact on energy consumption, and the barriers and opportunities for its implementation. It hypothesised that PCSs might enable adaptive actions in mildly cold houses by fulfilling the physiological need for warmth while reducing energy consumption.

The rest of the paper is structured as follows. The next section describes the project's methodological framework. The third section presents three elements: the quantitative results; a description of the adaptive actions taken by participants and the influential parameters identified; and the formal definition of a heating practice referred to as 'slowheating', including its underlying principles and observed limitations. The discussion later turns to the idea of slowheating as an adaptive practice, the key concept of control and insights on the sufficiency of heating practices before emphasising the limitations of this research.

2. METHOD

2.1 GENERAL FRAMEWORK

The Slowheat project gathered 23 households (including the researchers themselves) in the Brussels area in a co-creative approach. The experience was designed as a real-world laboratory (RwL) as defined by Beecroft & Parodi (2016): a research-oriented, long-term, transformative and transdisciplinary change initiative focusing on sustainability in a specific context. Slowheat lasted three years, from October 2020 to September 2023, combined architectural, engineering and sociological approaches, and focused on an accompanied transformation of heating practices towards resilience and sustainability.

A particularity of RwLs is the possibility to integrate non-scientific knowledge into the research process (Jahn & Keil 2016). So does the co-creation approach taken throughout the project, also promoted for overcoming difficulties in altering daily practices that are not easily changed through public policies alone (Itten *et al.* 2021). In such an approach, academic researchers and other actors (in this case households) share their knowledge and skills. They are all involved in the research process to the same degree, but not in the same way (Morrissette 2013), to produce more systemic knowledge.

Rather than demonstrating the effectiveness of a predetermined heating solution, the intention was to develop a heating practice from the bottom up. Therefore, most aspects of this research were defined by the participants. There were, however, four principles set from the very beginning:

- *Autonomy*

  Each participant was invited to explore the concept of heating the body in its own way and at its own pace, according to her/his specific situation.

- *Documentation*

  Researchers provided acquisition material and frameworks such as temperature loggers, notebooks, *etc.* It was then up to participants to document their experiences.

- *Exchange*

  All participants were asked to participate in various types of exchange exercises, such as panel discussions, interviews, writing of blog posts, brainstorming, *etc.*

- *Wellbeing*

  Slowheat was not about one's ability to withstand cold. Participants were explicitly asked to make sure they maintain enjoyable living conditions, although how to reach wellbeing and what exactly wellbeing meant was under scrutiny. Further, participants were frequently reminded that they were not in a 'race to the coldest', although a competitive effect might have influenced some participants.

Considering all this and referring to the RwL categories defined in the Energise project (Heiskanen *et al.* 2018: 63), Slowheat could be described mostly as 'pioneering practice' since it creates:

> a temporary time and space where established practices are provisionally disrupted to facilitate individual and collective learning.

However, features from other types of RwL were present, such as impact monitoring, social normalisation inside the group or tailoring support based on identified needs.

2.2 PARTICIPANT RECRUITMENT, HOUSING DESCRIPTION AND REPRESENTATIVITY

Recruitment of participants was voluntary. It relied on word on mouth and social or professional networks of the project partners. Each participant was involved in several, if not all, research steps (protocol design, quantitative data collection, qualitative data collection, analysis, diffusion). Since the project lasted three years, some early participants reduced their involvement over time, while others joined the group after the first or second winter, resulting in some holes in the data collected (for details on the participants and their dwellings, see the supplemental data online). Although a budget was available to compensate for the time spent by participants, only one participant applied for it.

The group of 23 participants consisted of 11 women and 12 men, ranging in age from their 20s to their 60s. Some lived alone, others as couples with or without children. The group included professionals from a variety of intellectual professions. Four participants had professional experience in the building industry related to energy matters: one civil servant acting as an energy coach, one renovation coach, and two researchers in comfort and energy. The research's originality is that, following the co-creation approach, the professional researchers involved (*i.e.* the five authors of this paper) also took part in the RwL.

The dwellings occupied by the participants (80% owned) ranged from apartments to detached or terraced houses with Energy Performance Certificates (EPC) ratings from B to G on the local EPC scale. Dwelling sizes varied from 40 to 150 m^2/inhabitant. All but two had centralised space heating (18 with a gas boiler, two with an oil boiler, one unknown). The exceptions are a B-class house equipped with a wood stove and a G-class house equipped with direct electric heaters. Based on self-declarations and visits, none had pre-existing humidity problems.

It was deemed necessary to keep the group small to keep it manageable and favour a sense of belonging among participants. The participants shared three important characteristics worth mentioning: (1) a common interest in reducing their energy consumption for both economic and environmental reasons, the latter prevailing in most cases; (2) all participant were highly educated (level 4 or higher on the International Standard Classification of Education (ISCED) scale (UIS 2012); and (3) all participant were economically and technically able to heat their dwelling, meaning that they could 'go back to normal' at any time if needed.

2.3 RESEARCH STEPS

Figure 2 presents the overall project's timeline. The main steps are now described.

Slowheat was launched in October 2020 against the backdrop of the COVID-19 pandemic. Throughout the project, the co-research group gathered in monthly workshops to strengthen the group's cohesion. These meetings provided a forum for collective analysis and research planning, enabling the authors to review progress and facilitate a continuous cycle of ideation–experimentation–observation–analysis–discussion. For the first six months most meetings were virtual, which complicated the process of fostering a sense of community among participants.

For the first winter (2020–21), participants embarked on a ground-up exploration to determine the feasible reduction in indoor temperature without resorting to any specific or innovative alternatives to space heating. The objective was to pinpoint the initial barriers and evaluate the temperature range that the group could sustain while exploring individual comfort limits. The guiding principle was to lower the indoor temperature to uncover new dimensions of comfort, while ensuring that the home remained a place of satisfaction and health. Participants were explicitly encouraged to mitigate any cold-induced discomfort through any available means, including adjusting the thermostat upwards if needed.

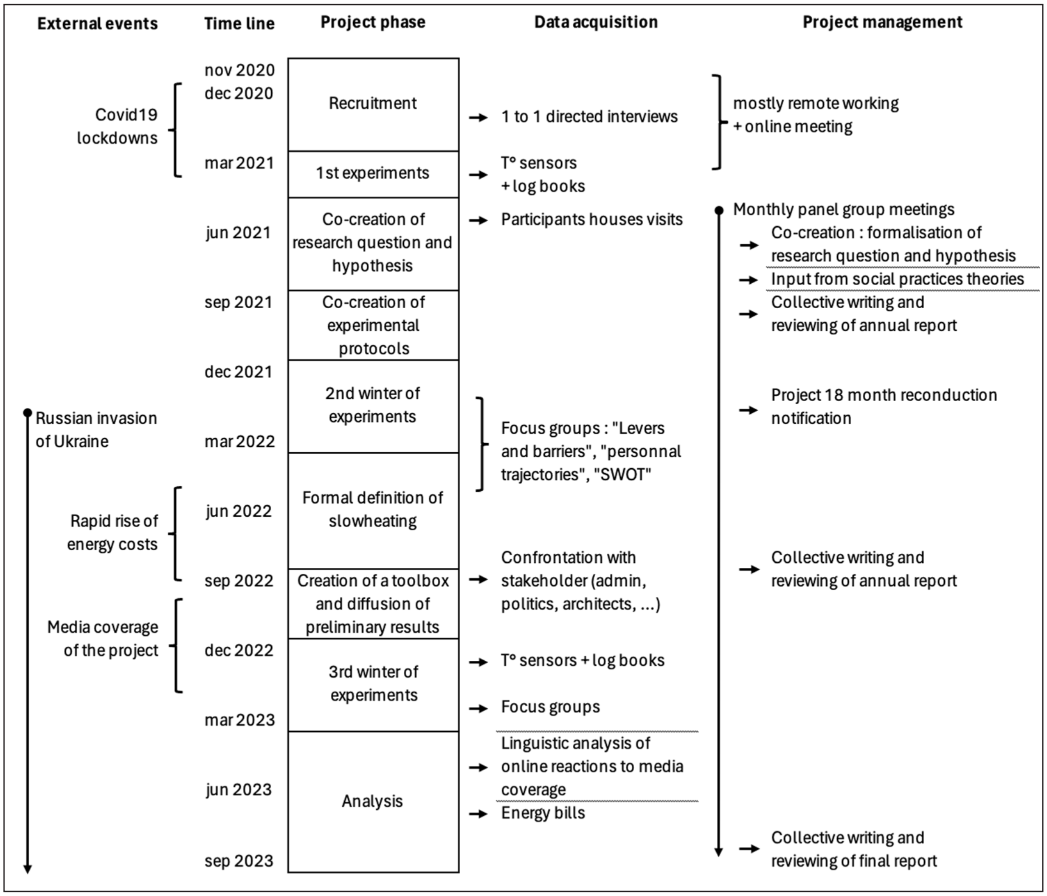

Figure 2: Research timeline, including influential external events and data acquisition methods.

The second winter (2021–22) was marked by the introduction of PCSs. The group embarked on a wide range of experiments to explore the lowest indoor temperature at which PCSs were sufficient to ensure wellbeing. A minimal temperature, chosen by each participant, was always maintained by central heating. Each participant was encouraged to purchase any type of PCS using project funds, although none requested a refund. Table 1 describes the type of equipment purchased and tested by the participants. By encouraging everyone to test these solutions, participants were able to identify the most viable options for their specific lifestyles. This approach laid the groundwork for the third and last year.

Table 1: Personal comfort systems (PCSs) tested during the project.

EQUIPMENT	VISUAL (COMMERCIALS)	POWER RANGE (W)	TYPE OF USE
Heating blanket		100	• Homeworking • Sitting at rest
Small infrared panel		300	• Homeworking • Studying • Exiting the shower

(Contd.)

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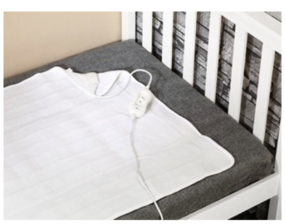
EQUIPMENT	VISUAL (COMMERCIALS)	POWER RANGE (W)	TYPE OF USE
Large infrared panel		400	• Homeworking
Radiant heater		1,200	• Temporary warm spot in the living room
Heating desk pad		80	• Homeworking
Heated bed cover		100	• Preheating the bed before going to sleep
Heating chair		30	• Homeworking

The final winter (2022–23) unfolded against the backdrop of the Russian invasion of Ukraine and the energy crisis in Europe. By this time, the group's heating practices had become more refined and stable, enabling the authors to establish a common protocol for measuring indoor temperatures over longer periods and collecting energy bills when available.

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2.4 QUALITATIVE DATA ACQUISITION

Qualitative data regarding adaptive changes were collected throughout the project, relying on self-declaration. An individual directed interview was conducted at the project's outset, covering topics such as existing heating practices, representations associated with low temperatures, and participants' expectations regarding the dwelling and the project.

During the summer of 2021, the monthly meetings were mostly dedicated to collectively appropriating the research question and formulating hypotheses. To help the group take a step back and identify influencing parameters, elements of social practice theory were introduced. In particular, inspired by Schatzki (1997) and Gram-Hanssen (2010), a decomposition of influencing factors was proposed, distinguishing between: (1) practical understanding or skills; (2) representations, commitments, goals and meanings; (3) collective aspects (*i.e.* standards, rules, procedures and laws); and (4) infrastructures and material objects. During these meetings, tools such as Ishikawa diagrams, conceptual maps and round table discussions were used. Significant time was also dedicated to the peer review of project reports and broad publications based on preliminary findings.

Focus groups were conducted during and after the winter of 2022 with small random subsets of participants (three to four people each, including one professional researcher). These sessions followed predetermined semi-directed questionnaires and were recorded for later transcription and cross-analysis. The topics included the levers and barriers in changing heating practices, leading to intermediate results such as strengths, weaknesses, opportunities and threats (SWOT) matrices. It was at some point hypothesised that the identification in the group of life experiences, socio-economic or cultural parameter might explain the ability to adopt adaptive strategies. Several focus groups and a questionnaire were developed in this direction, but later proved of limited interest, mostly due to the small size of the group, and were abandoned. A second wave of focus groups was held after the last summer, with the same focus on the levers and barriers to adaptative changes.

2.5 QUANTITATIVE DATA ACQUISITION

Temperatures for part of the first winter and for the third and final winter were measured every 30 min in one location in each dwelling (the living room) using calibrated Elitech RC-5+ data loggers. Several non-recording temperature displays were also distributed to participants to help them better understand their dwelling's thermal behaviour. During the first winter, long-term time series could not be collected due to a slower-than-expected start to the project. Logbooks were developed and distributed to complement temperature measurements, but were scarcely used by the participants.

Although recommendations on the proper use of temperature recorders were provided, it was suspected that some manipulations or poorly chosen sensor positions might influence the results. Therefore, all data points showing a variation > 1.5°C/30 min were considered suspicious. On average, 99.87% of the data collected during the last winter passed this test. The sensor with the highest anomaly rate showed 1.25% of suspicious points, caused by direct sunlight on the sensor in the late afternoon during the longest days of the heating season. The impact on the mean temperature in this worst case remained at < 0.1°C. For each household's living room, the temperature distribution was calculated for the coldest day (24 h), week, month and two-month periods based on indoor temperature.

Energy bills (heat and electricity) were collected to assess energy savings, using a specific reference mean derived from each participant's accessible bills from the years before the project. In cases where these were not accessible, irrelevant (due to retrofitting or recent moves) or based on shares of a collective heating system rather than actual consumption, those results were excluded from the analysis. Since in all cases but two the domestic hot water was produced by the same boiler as space heating, it was not possible to distinguish between these two uses. The heat consumptions therefore represent both. Participants occasionally cited an increase in the number, duration or temperature of baths and showers as an adaptive strategy. Thus, merging both heat uses was deemed appropriate.

A climate normalisation based on heating degree-days (HDDs) 15/15 TX.TN 00-24 was conducted for heating bills to avoid the impact of climatic variations over the years. HDDs were calculated for the specific duration of each bill based on official temperature readings at the Royal Observatory of Belgium in Brussels. Since the collected bills did not cover similar time spans and start at a different datum, the number of HDDs is different for each bill. HDD15/15 was used to be consistent with the range of indoor temperatures observed in the dwellings. Higher outdoor temperatures such as 16.5°C are often used to determine HDDs, but in this study it would have implied that heat demand was suspected for outdoor temperatures higher than those observed in one's dwelling, which would not make sense.

3. RESULTS

3.1 TEMPERATURE AND ENERGY CONSUMPTION REDUCTION

Quantitative results are presented at the group level, with detailed information by dwelling available in the supplemental data online.

Table 2 presents indoor temperature at the group level. Figure 3 shows the distribution of collected temperatures at the group level for the coldest two-month period of the third winter. It decomposes the dataset between supposedly occupied and unoccupied hours. Since their actual presence could not be rigorously monitored, the distinction between occupied and unoccupied periods relies on the indoor temperature quartiles, the warmest quartile being assimilated to the occupied period. The limited difference between both profiles indicates that the participants did not resort to significantly different thermostat settings for days and nights.

		MEDIAN (°C)	MEAN (°C)	STANDARD DEVIATION (°C)	PARTICIPANTS
Before the project	Thermostat setting	19.0	19.0	1.6	17
First winter	Coldest week	16.7	17.6	1.9	9
	Coldest day	15.8	16.9	2.1	
Third winter	Coldest two months	15.0	15.1	1.9	18
	Coldest month	14.5	14.7	2.0	
	Coldest week	13.7	13.5	2.6	
	Coldest day	12.5	12.6	2.5	

Table 2: Indoor temperature thermostat setting before the project and indoor temperature measured in participants' living rooms during the project.

Note: Medians, means and standard deviations are calculated for the whole group of participants for various time spans. Both occupied and unoccupied periods are included. Time periods are expressed as the 'coldest' regarding the living room temperature of each household.

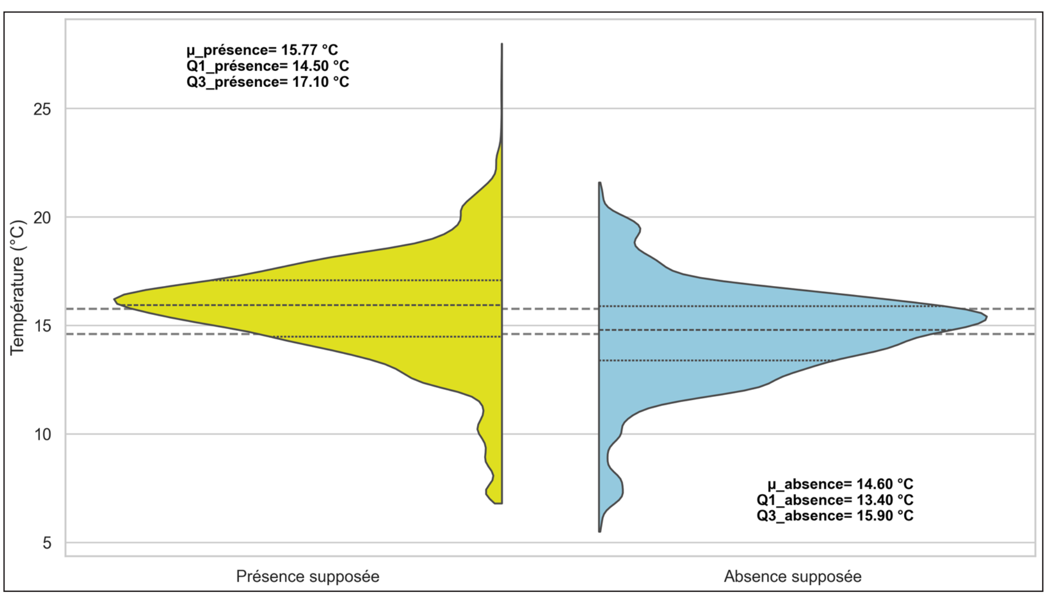

Figure 3: Cumulative distribution of the indoor temperature measured in each participant's living room on an hourly basis during the third winter's coldest two months.

Note: Only the warmest (left) of the coldest (right) quartile of each day in each dwelling is considered, assuming these represent occupied or unoccupied periods, respectively.

Participants' self-declared mean daytime thermostat setpoint before the project was 19°C (based on 17 answers). Considering only participants with consistent data, it can be seen that a significant reduction ($p = 0.005$) was already achieved in the first months of the project (from 18.7 to 16.8°C, data from six participants), although the comparison between a thermostat setting and an actual temperature is debatable. A significant ($p = 0.005$) mean temperature reduction of 2.7°C can be observed between the first and third winters for the coldest week (from 16.9 to 14.2°C, data from five participants). However, measurements over a limited period (such as a week) may overestimate the potential for energy savings in the long term, as motivation may fade over time. At the group level, the long-term mean (standard deviation) indoor temperature during the third winter was 15.1°C (1.9°C). Compared with thermostat settings, the third winter shows a significant ($p < 0.001$) reduction of 3.9°C (from 18.8 to 14.9°C, data from 15 participants). According to Figure 3, the indoor temperature in the living-room during occupied hours is believed to be around 1°C higher than at night. A conservative approach is therefore to consider that the temperature reduction experienced by occupants is 0.5°C lower (*i.e.* 3.4°C instead of 3.9°C).

Although no transversal comfort surveys were conducted, satisfaction regarding indoor conditions was discussed during group meetings and focus groups after the last winter. Participants expressed the fact that despite sometimes experiencing cold, they enjoyed the combination of mild cold indoor air and direct heating.

When comparing energy bills for the third year of the project with the reference ones, average reductions of 50% in gas consumption (for 11 participants, on an HDD-adjusted basis) and 14% in electricity consumption (for nine participants) are observed. The reduction in gas consumption of approximately 15%/°C is consistent with the known impact of temperature reduction on space heating demand, although slightly higher (*e.g.* Fabi *et al.* 2013). It is possible that the energy impact has been overestimated since most dwellings are apartments or row houses, which benefit from heat exchanges with their neighbours. To illustrate this point, compare participant ID06 (a duplex consisting of the two lower levels of a row house) and ID08 (a semi-detached house). The first achieved a 96% reduction in heating consumption by barely never turning the heating on (the remaining consumption is domestic hot water), while the second saved only 45%, although the temperatures measured in their houses over two months were 16.0 and 14.8°C, respectively. Clearly, participant ID06 benefitted from a more favourable equilibrium between heat losses, passive gains and neighbouring conditions. Further research with thermal simulation is needed to break down this saving between the actual reduction in space heating need, the potential compensatory transfer towards hot water and the benefit of thermal flows from adjacent dwellings. The decrease in electricity consumption was unexpected, since PCS use should slightly increase it. It should be noted that the last winter was affected by a significant increase in energy costs following the Russian invasion of Ukraine. Hence, it may be assumed that the increase in electricity usage for PCSs was offset by electricity savings in other areas.

3.2 BEHAVIOURAL ADAPTATIONS AND INFLUENTIAL FACTORS

3.2.1 Identified adaptations

Although the project hypothesised that PCSs would be the key to adapting to lower indoor temperatures, these were progressively put aside and replaced by adaptations in clothing habits. Thermal underwear in particular was mentioned, along with extra layers of sweaters or ponchos. In some cases, dedicated winter clothes such as mittens or caps were used indoors. Participants also paid attention to their clothes' details, such as the ability to adjust the size with elastics or to cover the head with a hood. Blankets were almost unanimously used when seated at rest.

The use of active PCSs was limited to long-term static situations, such as homeworking, reading or screen watching. Heated blankets were used in all static situations, while heated desk pads proved useful only when working. Short-term 'heat boosts' were enjoyed by some, thanks to radiant heating devices, *e.g.* in bathrooms while exiting the shower or placed in front of sitting places. These were also used when returning from outside in cold weather or as a 'thermal break' between household chores.

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Some participants made spatial adaptations to their dwellings, such as adding indoor curtains between rooms to reduce draughts and increase thermal zoning. Overall, the reduced temperatures did not lead to major changes in lifestyles. Identified changes were the displacement of specific activities, such as homeworking, to rooms identified as warmer, and modifications to hygiene routines such as taking warm showers in the middle of the day. A preference to more active routines was sometimes expressed. For example, one participant started using a training bike while homeworking. More consequential adaptations such as grouping family activities in a limited, heated space were scarce.

3.2.2 Facilitating factors

Although not often used, access to PCSs was considered crucial for enabling the reduction in indoor temperature. They alleviated fears related to cold by providing an alternative comfort solution if needed. Moreover, they allowed the project narrative to be framed positively: participants were exploring an alternative heating solution, not merely reducing temperatures.

All participants noted physiological adaptation, perceiving two to three weeks as the minimum time required for this adjustment. A similar period was necessary to adapt to new routines. An experimentation phase was essential for fine-tuning solutions and tailoring them to individual needs. Participants also mentioned that living in lower temperatures became easier each year, though it is unclear if this was due to physiological adaptation or psychological habituation.

More broadly, the co-creation process was seen as a key success factor. It enabled participants to develop a strong rationale for this practice, bolstering their confidence and assertiveness when facing criticism from friends and relatives. Sharing tips and advice helped overcome difficulties, and it was through experimentation and trial and error that the most effective methods for each household were discovered. This process, of course, required time and support.

3.2.3 Inhibiting factors

Participants expressed frustration regarding the quality and ergonomic of PCSs. Common complaints included limited control over the heating power, the constraint of being wired or the lack of fine tuning to specific needs (*e.g.* a chair that would heat the back but not the hips). Participants highlighted the limitations of available market options, lamenting the lack of diversity and innovation in this area. Additionally, participants rejected some available solutions due to aesthetics, fabric type or the ecological footprint of batteries. As a result, many found that turning to clothing was often easier, more efficient and better suited to daily life.

Interestingly, participants noted that the indoor temperature they maintained at the end of the project was sometimes determined by factors other than thermal comfort. Difficulties drying laundry were often mentioned. Two participants observed the growth of mould (one on a thermal bridge, one on a poorly ventilated surface) and adapted their indoor temperature accordingly. Concern about air-quality and humidity control emerged as a significant issue. The distribution of thermohydrometers to participants proved to be helpful in raising awareness about proper environmental control. This highlights the importance of balancing humidity production, temperature levels and ventilation practices to maintain healthy, mildly cold indoor environments.

In some cases, limited control over central heating systems inhibited temperature reductions. Indeed, some participants, mainly tenants, did not have full access to their space heating systems and had to cope with standardised settings programmed by property managers, which restricted their ability to fine-tune their indoor temperature.

Once a household had settled into a new heating practice, the most challenging situations occurred when inviting friends and relatives. Various strategies were developed, ranging from temporarily heating the space as before to inviting guests to experience PCSs, with varying degrees of success. Some participants noted that being at odds with social norms was a major difficulty.

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3.3 DEFINITION OF SLOWHEATING AS A PRACTICE

Through discussions among participants, a heating practice termed 'slowheating' was developed. Alongside the core idea of dissociating the heating of the body from that of the building, four key principles were identified:

- *Openness*

  Recognising that there are many legitimate ways to define thermal satisfaction, acknowledging that everyone has their own legitimate thermal needs that must be respected.

- *Multimodality*

  Since thermal needs vary according to space, time and areas of the body, there is a necessity for diverse heating solutions that must be identified empirically.

- *Control*

  To meet their heating needs when feeling cold, individuals must have control over both their space and personal heating solutions.

- *Effectiveness*

  When selecting a personal heating solution, it is important to consider its effectiveness through a detailed analysis of actual needs. Participants collectively suggested an indicative hierarchy (Table 3).

CLASS	INDICATIVE POWER	GROUP OF SOLUTIONS	EXAMPLES
A: Non-energy solutions	0 W	Clothing, partitioning, acclimatation, metabolic activity, *etc.*	Thermal underwear, space-dividing curtains, internal nomadism, *etc.*
B: Close-to-body heating by conduction	±50 W/body	Heated clothes or furniture in direct contact with the body	Heated chairs, jackets or blankets, hot-water bottles, *etc.*
C: Close-to-body heating by radiation	±300 W/body	Radiating objects placed close to, but not in contact with, the body	Infrared panels, *etc.*
D: Room-scale heating	±1,500 W/room in Belgium	Electric air heater or room-scale controlled heating	Heating a single room following the actual occupation pattern
E: Dwelling-scale heating	> 5,000 W/house in Belgium	Centralised heating	Keeping the dwelling at a fixed threshold temperature according to building needs (moisture control) or thermal comfort

Table 3: Hierarchy of thermal comfort support solutions as consensually developed in the Slowheat project.

Although solutions in Table 3 are sorted based on their indicative power to provide comfort with minimal energy consumption, this classification also aligns with the empirical priorities identified by participants based on the suitability of the solutions in their daily lives. As previously discussed, clothing emerged as the most obvious and efficient adaptive solution. Heating objects designed to be touched ranked second and were used for prolonged periods. Radiating objects, perceived as somewhat similar to traditional central space heating solutions, were considered only when the class A or B solutions were inadequate.

4. DISCUSSION

4.1 SLOWHEATING AS AN ADAPTIVE PRACTICE?

As stated by Nicol & Roaf (2017: 712):

> the adaptive approach was based on the assumption that building occupants will take conscious actions [...] in addition to the involuntary physiological responses of the body [...].

Today's common space heating actions in Belgium fall short of such an approach: it often consists merely of pushing a button twice a year—to turn it on in autumn and off in spring. This is starkly different from regularly feeding a wood stove, for instance. The indoor climate is produced automatically by a relatively complex system that most users do not understand (Peffer *et al.* 2011).

To re-develop a heating practice based on adaptive actions, the authors had to secure a space for experimentation (several years of co-creation), and to identify a hint of a solution as a starting point (PCSs). It was found that PCSs were mainly used transiently and that the experience of slowheating is above all one of gradual acclimatisation and adaptation of clothing practices. Thus, the authors have experienced the joint creation of a new indoor microclimate with bodies and practices adapted to it. This is why slowheating is not simply an 'eco-gesture', but rather the creation of a new practice that primarily relies on adaptive capabilities. This involves first learning to understand one's body signals, then relying simultaneously on one's involuntary physiological reactions and conscious ability to adapt by rationally evaluating various environmental, technical, or behavioural solutions and acting accordingly.

Looking back at the social practice theory framework, it appears that the facilitating factors were to be found mostly in the infrastructure and material objects dimension (PCSs) and the collective dimension (co-creation approach). The inhibiting factors were to be found in all four dimensions: skills (lack of understanding of building physics and heating technologies), infrastructure and material objects (low-quality or unsatisfactory PCSs, uncontrollable heating systems), representations (fear of cold), and the collective dimension (guests). Therefore, any attempt to reproduce this experience or spread the practice of slowheating should consider all these dimensions from the very beginning.

4.2 CONTROL IS KEY

A transversal reading of the facilitating and inhibiting factors points to control as key for the implementation of adaptive person heating practices. The integration of new adaptative practices requires a greater degree of decision-making about and the responsibility for energy consumption, as individuals must actively decide when and how much energy to consume, rather than relying on automatic systems. This may require a greater degree of effort and engagement on the part of the individual, but ultimately leads to greater autonomy and control over one's own comfort. Since the adaptive comfort theory stresses the role of conscious actions, this is not new knowledge. However, this experience highlights four dimensions of control:

- *Adequate devices*

  PCSs were deemed crucial even if not often used. They allowed countering the fear of cold and gave a back-up solution by quickly and efficiently tackling periodic experiences of cold. In contrast, and out of step with Nicol's (2017) emphasis on the environmental control permitted by central heating, central heating systems were sometimes inhibiting more sufficient adaptive practices by hindering occupants' fine control in time and space. PCSs therefore represent a useful complement to central heating if the latter is limited to maintaining a bottom temperature setpoint.

- *Conscious role of the body*

  Participants expressed a feeling of improved connection and understanding with their physiological reactions. It allowed for more tolerance of discomfort and more confidence in their bodies' abilities. Their perceptions of cold and heat have evolved, many experiencing a new pleasure in feeling contrasts. In short, one has come out of the 'anaesthesia of the body' that defines modern comfort according to Boni (2019). This raises anew the question of the place of bodies in the theory of social practices (Wallenborn & Wilhite 2014).

- *Impact of skills and knowledge*

  The previous dimensions required an improved understanding of building physics (mostly humidity control) and heating-systems management. The researchers observed a lack of prior general knowledge about these topics among participants. This can be a barrier to the effective adoption of slowheating because it limits people's ability to understand and reclaim their space-heating practices. Further, a deconstruction of one's feelings and images associated with cold was necessary to empower participants. At the beginning of the project, cold was often associated with poverty, discomfort or illness. Warmth, on the other hand, was generally perceived as synonymous with comfort, good health and conviviality. A warm home was associated with hospitality, relaxation and a welcoming atmosphere for guests. These representations evolved during the project. In the end, cold was not seen negatively. It was, for example, associated with an invigorating environment, while warmth was described as causing a heavy or sleepy atmosphere. Further, the idea of contrast between a cold environment and clearly identified heat sources was considered favourable.

- *Uncontrollable parameters*

  Despite the previous three dimensions, some parameters remain out of the control of individuals. The authors had to question social norms, which are interwoven with the social and the technical, such as the common expectations in terms of indoor temperature induced by the widespread use of central heating. Such norms resulted, for example, in incomprehension among friends and relatives. To challenge this, it was necessary to have frequent collective discussions. It is not possible, by definition, to change a social norm on its own, but forming a supportive and legitimating group ready to question it proved effective.

4.3 INSIGHTS ON SUFFICIENCY

The results allow for three insights on the matter of sufficiency of heating practices to be made.

First, the quantitative results of Slowheat show a greater potential in indoor temperature reduction than the previous research highlighted above in the introduction (Karlin *et al.* 2015; Zhang *et al.* 2018). Hence, these results hint at a larger-than-expected potential for energy savings through adaptive practices, in particular in the context of climate-concerned populations.

Second, Slowheat allows a revisiting of Spengler's (2016) proposal to focus on defining the minimum necessary: 'how much of what is enough?'. The results highlight that the association between temperature and comfort is not as deterministic as imagined, since acclimatisation and PCSs allowed for a significant temperature reduction without loss in quality of life. Hence, the issue of heating sufficiency should be examined with a deeper understanding of what defines thermal comfort, pleasure and wellbeing in physiological, psychological and social dimensions. The present research therefore reinforces Chappells & Shove's (2005: 33) assertion that:

> There is more to comfort than temperature, but exactly where expectations lie along this range is, largely, a matter of culture and convention.

If sufficiency relies on 'the necessity to differentiate needs from wants' (Gough 2017), the results stress that while thermal wellbeing is undoubtedly a need, it should not be equated with home heating, which is just one way of addressing it.

Third, and associated with the previous point, it is important to acknowledge the dire situations many experience due to inadequate housing and to avoid using Slowheat's results as a pretext for inaction concerning these situations. Similar environmental conditions will be experienced differently if they result from a voluntary sufficiency approach or arise from a situation of precariousness.

4.4 LIMITATIONS AND FURTHER STUDIES

The first winter was affected by the COVID-19 outbreak and consecutive lockdowns, making in-person meetings impossible. This, of course, complicated the recruitment of participants and the forging of a research community, resulting in limited quantitative data for this period. The last winter was affected by the cost-of-living crisis that followed the Russian invasion of Ukraine. Heating and hygiene have been identified as the practices primarily impacted by this crisis in Sweden (Brauer *et al.* 2024). It can therefore be assumed that part of the observed saving originated in this crisis. In British households, domestic electricity and gas consumption dropped by 8.4% and 10.8%, respectively, during that winter (Zapata-Webborn *et al.* 2024). Part of these

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reductions can be connected to an increased use of PCSs, such as hot water bottles (Totty *et al.* 2024). To identify the influence for these contextual factors, a follow-up study in a few years would be useful.

Adding to these contextual factors, it is known that effort-based changes are difficult to sustain (Bouton 2014). However, three elements gives the authors confidence in the durability of the results: (1) they are based on bills after a three-year project and therefore already reflect long-term changes; (2) a large set of influential factors, including social and affective factors, was considered, which should encourage long-term changes; and (3) participants declared their pleasure at having enhanced control over their indoor environment and willingness to carry on.

The limited number of participants is of course a major limitation. The project gathered like-minded environmentally concerned and educated people, with a disproportionate number of building professionals. Considering this, the quantitative results should probably be seen as overoptimistic compared with the potential in a broader or different audience.

The co-creation process, although it helped empower participants, was challenging to manage. Scientists in the group expressed frustration when autonomous experimentation by participants made it difficult to gather comparable and robust data. Protocols were suggested for quantitative and qualitative data-gathering that were sometimes poorly followed, resulting in the loss of valuable data, and undermining the consolidation of general conclusions. Therefore, elaborating on Slowheat as a proof of concept, further study should embrace a more traditional observational approach, while integrating the need for support groups and peer-to-peer exchanges in their protocols.

5. CONCLUSIONS

By combining a real-world laboratory (RwL) set-up and a co-creation approach, the Slowheat project revivified the old idea of heating the body rather than the house. The RwL set-up allowed for *in situ* exploration of heating solutions known as personal comfort systems (PCSs) mainly studied in controlled environments and for office applications. PCSs proved to be important adaptive opportunities and successfully triggered a change in heating practices. But PCSs only were not enough to sustain these changes, since in the end most participants relied more on clothing. A heating practice based on PCSs also proved difficult in the presence of guests, requiring participants to explain and sometimes adjust their heating practices to be hospitable.

The co-creation approach proved essential in framing a research community that developed a heating practice based on adaptive capabilities and going beyond 'eco-gestures', which they called 'slowheating'. It involves first learning to understand one's body signals and then relying simultaneously on both one's involuntary physiological responses and conscious ability to adapt though environmental, technical or behavioural solutions. This community and the theoretical background it developed gave the participants legitimacy and confidence when confronted with conservative social norms. The social and collective dimensions therefore appear as essential as the technological dimension for further diffusion of this heating practice.

The mean (SD) indoor temperature chosen by participants at the end of the project was 15.1°C (1.9°C), while the mean thermostat setting before the project was 19°C. Heating consumption dropped by 50% on average, although part of this reduction hides heat flows from neighbouring heated spaces. Electricity consumption dropped by 14% despite the use of PCSs. The cost-of-living crisis occurring during the project probably induced electricity saving behaviours that offset the electricity consumption of PCSs. While several limitations were identified with regards to the generalisation of these figures, they indicate a promising potential for energy saving.

Finally, this research contributes to the discussion on the sufficiency of heating practices. It supports the idea that the basic need for thermal wellbeing should not be equated with home heating, which is only one way of addressing it. In this experiment, the positive approach of sufficiency (to provide a sufficient level of comfort and wellbeing) was not at odds with the negative approach (to reduce current levels of energy consumption).

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COMPETING INTERESTS

The authors are funders and volunteer members of a non-profit organisation working to popularise slowheating as a sufficient heating practice. This organisation was created after completion of this research.

DATA ACCESSIBILITY

The data, other than those included in the article and supplemental data online, are available from the corresponding author upon request. The data are not publicly available due to containing information that could compromise the privacy of the research participants.

ETHICAL APPROVAL

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SUPPLEMENTAL DATA

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