

New insights into thermal comfort sufficiency in dwellings

Geoffrey Van Moeseke (Author), Denis De Grave (Author), Amélie Anciaux (Author), Jean Sobczak (Author), Grégoire Wallenborn (Author)
Buildings & Cities. 2024-08-13 | Journal article. DOI: [10.5334/bc.444](https://doi.org/10.5334/bc.444)

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. The paper details the co-creation approach utilised and highlights the factors that either facilitated or inhibited the adoption of a sufficient heating practice. In doing so, it provides a framework for scaling up the *Slowheat project*. Furthermore, the paper emphasises the need for individuals to gain greater control over their indoor environments and elaborates on four dimensions of control, including the crucial aspect of social norms, for which policy instruments may play a role.

Keywords

Heating, housing, sufficiency, personal comfort system, thermal comfort

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 CO₂ 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 1,115 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, 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), 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 at 6°C to 31°C (Shove, 2003a). 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 well-being in buildings, thereby emphasising the potential for alternative methods to maintain bodily warmth.

Of course, 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 well-being. 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). 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 pioneering work (Heschong, 1979), 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 01, taken from Nicol & Humphreys (1973), 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).

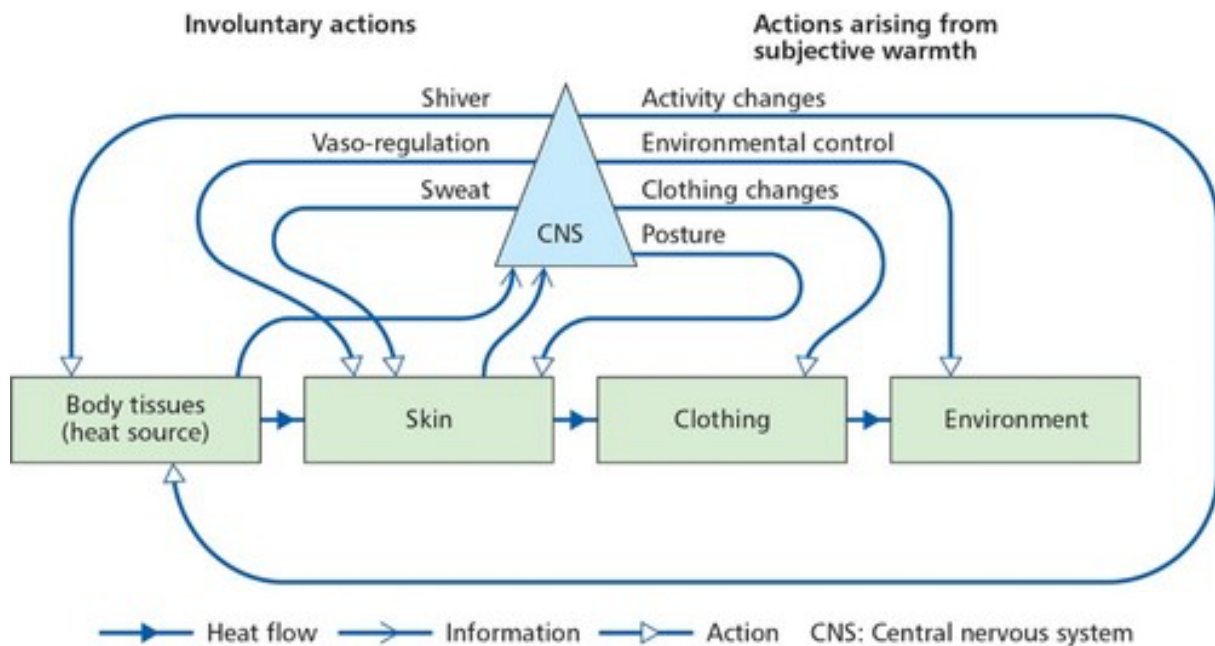


Figure 01: Thermal regulatory system according to adaptive comfort theory. Figure taken from (Nicol & Humphreys, 1973; Nicol & Roaf, 2017)

Although figure 01 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. This paper is divided into two sections and a discussion. The first next section describes the project’s methodological framework. The second 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 (Morrisette, 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... 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 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), *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's steps (protocol's 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 20's to their 60's. Some lived alone, others as couples with or without children. The group included professionals from a variety of intellectual professions. Four participants had a 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 150m²/inhabitant. All but two had centralized 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 participants were highly educated (level 4 or higher on the International Standard Classification of Education (ISCED) ISCED scale (UNESCO Institute for Statistics, 2012); and 3) all participants 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 02 presents the overall project's timeline. The main steps are now described.

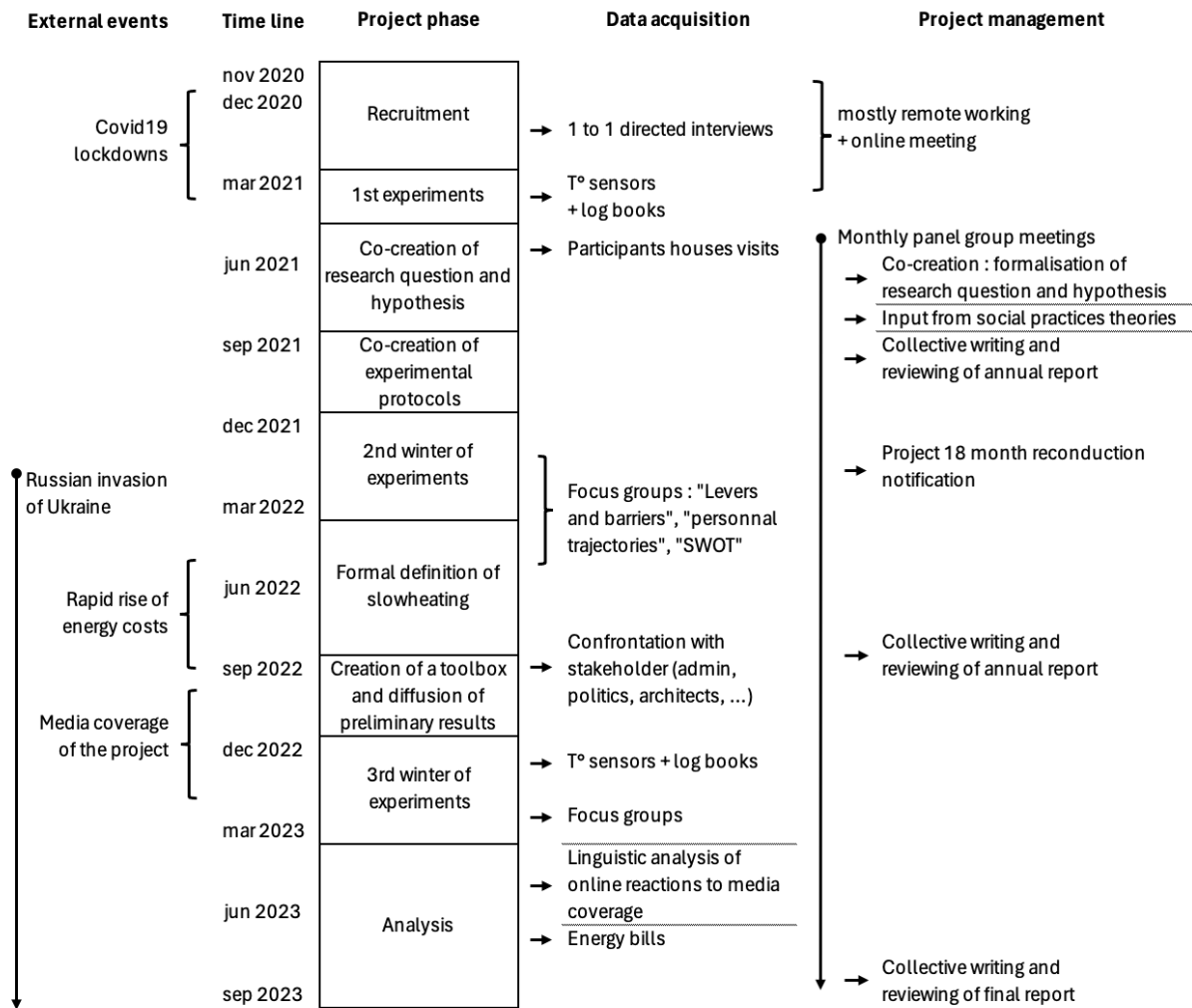


Figure 02: Research timeline, including influential external events and data acquisition methods

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 – observations – analysis – discussion. For the first six months most meetings were virtual, which complicated the process of fostering a sense of a community among participants.

For the first winter (2020–2021), we 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. Our 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.

The second winter (2021–2022) was marked by the introduction of PCSs. The group embarked on a wide range of experiments to explore the lowest indoor temperature at which PCS were sufficient to ensure well-being. 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 01 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 01: Personal comfort systems tested during the project.

Equipment	Visual (commercial)	Power range (W)	Type of use
Heating blanket		100	- Homeworking - Sitting at rest
Small infrared panel		300	- Homeworking - Studying - Exiting the shower
Large infrared panel		400	- Homeworking
Radiant heater		1200	- To 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 (2022–2023) 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.

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 (3-4 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-economical 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 minutes 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 $> 1.5^{\circ}\text{C} / 30 \text{ min}$ 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 $< 0.1^{\circ}\text{C}$. For each household's living room, the temperature distribution was calculated for the coldest day (24 hours), 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 consumption 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 (HDD) 15/15 TX.TN 00-24 was conducted for heating bills to avoid the impact of climatic variations over the years. HDD 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 HDD 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 $16,5^{\circ}$ are often used to determine HDD, 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 02 presents indoor temperature at the group level. Figure 03 shows the distribution of collected temperatures at the group level for the coldest two-month period of the third winter. It decomposes the data set 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.

Table 02: Indoor temperature thermostat setting before the project and indoor temperature measured in participants' living rooms during the project.

		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 2 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	

Note: Medians, means, and standard deviation values 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.

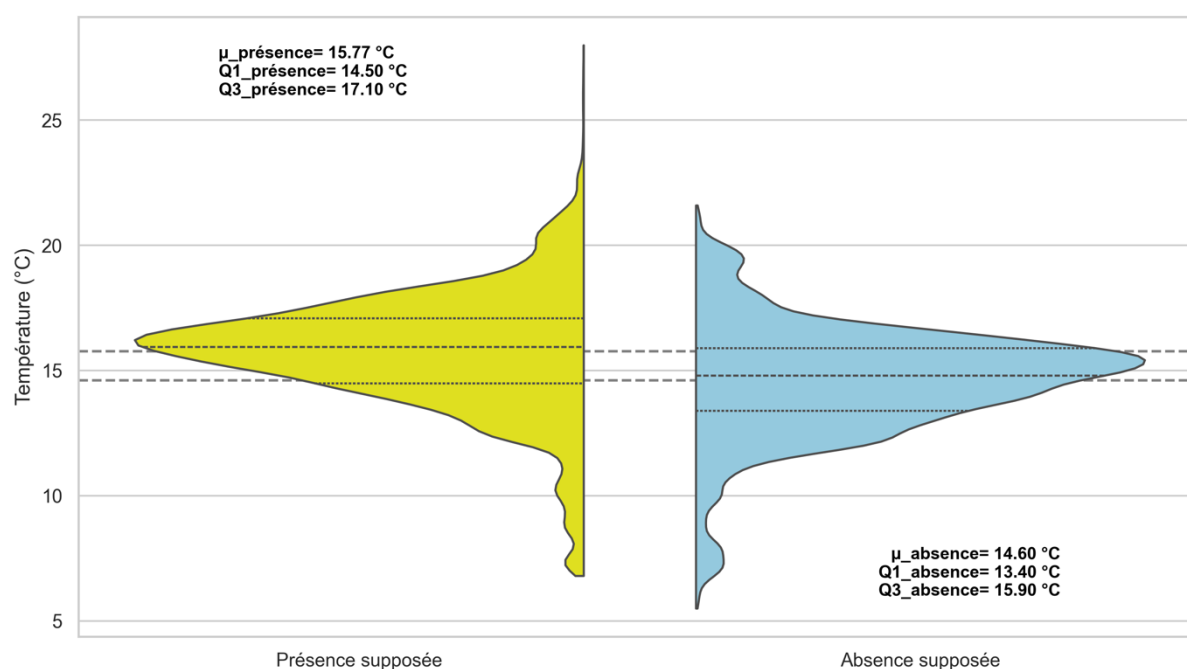


Figure 03: Cumulative distribution of the indoor temperature measured in each participant's living room on an hourly basis during the third winter's coldest two months. Note : Only the warmest (left) of the coldest (right) quartile of each day in each dwelling is considered, assuming these represent 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, 6 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 winter for the coldest week (from 16.9 to 14.2°C, 5 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 indoor temperature (standard deviation) during the third winter was 15.1°C (1.9°C). Compared with thermostat settings, the third winter shows a significant (p -value<0.001) reduction of 3.9°C (from 18.8 to 14.9°C, data from 15 participants). According to figure 03, 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 (3.4 in place 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, an average reduction of 50% in gas consumption (for 11 participants, on an HDD adjusted basis) and of 14% in electricity consumption (for 9 participants) is observed. The reduction in gas consumption of approximately 15% per degree Celsius is consistent with the known impact of temperature reduction on space heating demand, although slightly higher (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 and 14.8 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 PCSs 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.

1
2 The use of active PCSs was limited to long-term static situations, such as homeworking,
3 reading or screen watching. Heated blankets were used in all static situations, while heated
4 desk pads proved useful only when working. Short term “heat boosts” were enjoyed by
5 some, thanks to radiant heating devices, e.g. in bathrooms while exiting the shower or
6 placed in front of sitting places. These were also used when returning from outside in cold
7 weather or as a “thermal break” between household chores.

8
9 Some participants made spatial adaptations to their dwellings, such as adding indoor
10 curtains between rooms to reduce draught and increase thermal zoning. Overall, the reduced
11 temperatures did not lead to major changes in lifestyles. Identified changes were the
12 displacement of specific activities, such as homeworking, to rooms identified as warmer, and
13 modifications to hygiene routines such as taking warm showers in the middle of the day. A
14 preference to more active routines was sometimes expressed. For example, one participant
15 started using a training bike while homeworking. More consequential adaptations such as
16 grouping family activities in a limited, heated space were scarce.

17 18 *3.2.2 Facilitating factors*

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

24
25 All participants noted physiological adaptation, perceiving two to three weeks as the
26 minimum time required for this adjustment. A similar period was necessary to adapt to new
27 routines. An experimentation phase was essential for fine-tuning solutions and tailoring
28 them to individual needs. Participants also mentioned that living in lower temperatures
29 became easier each year, though it is unclear if this was due to physiological adaptation or
30 psychological habituation.

31
32 More broadly, the co-creation process was seen as a key success factor. It enabled
33 participants to develop a strong rationale for this practice, bolstering their confidence and
34 assertiveness when facing criticism from friends and relatives. Sharing tips and advice helped
35 overcome difficulties, and it was through experimentation and trial and error that the most
36 effective methods for each household were discovered. This process, of course, required
37 time and support.

38 39 *3.2.3 Inhibiting factors*

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

1
2 Interestingly, participants noted that the indoor temperature they maintained at the end of
3 the project was sometimes determined by factors other than thermal comfort. Difficulties
4 drying laundry were often mentioned. Two participants observed the growth of mould (one
5 on a thermal bridge, one on a poorly ventilated surface) and adapted their indoor
6 temperature accordingly. Concern about air-quality and humidity control emerged as a
7 significant issue. The distribution of thermohydrometers to participants proved to be helpful
8 in raising awareness about proper environmental control. This highlights the importance of
9 balancing humidity production, temperature levels, and ventilation practices to maintain
10 healthy, mildly cold indoor environments.

11
12 In some cases, limited control over central heating systems inhibited temperature reductions.
13 Indeed, some participants, mainly tenants, did not have full access to their space heating
14 systems and had to cope with standardised settings programmed by property managers,
15 which restricted their ability to fine-tune their indoor temperature.

16
17 Once a household had settled into a new heating practice, the most challenging situations
18 occurred when inviting friends and relatives. Various strategies were developed, ranging
19 from temporarily heating the space as before to inviting guests to experience PCSs, with
20 varying degrees of success. Some participants noted that being at odds with social norms
21 was a major difficulty.

22 23 **3.2 Definition of slowheating as a practice**

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

- 27 1. Openness: Recognizing that there are many legitimate ways to define thermal satisfaction,
28 acknowledging that everyone has their own legitimate thermal needs that must be
29 respected.
- 30 2. Multimodality: Since thermal needs vary according to space, time, and areas of the body,
31 there is a necessity for diverse heating solutions that must be identified empirically.
- 32 3. Control: To meet their heating needs when feeling cold, individuals must have control over
33 both their space and personal heating solutions.
- 34 4. Effectiveness: When selecting a personal heating solution, it is important to consider its
35 effectiveness through a detailed analysis of actual needs. Participants collectively suggested
36 an indicative hierarchy, (Table 03).

37
38 *Table 03: Hierarchy of thermal comfort support solutions as consensually developed in the*
39 *Slowheat project*

Class	Indicative power	Group of solutions	Examples
A Non-energy solutions	0 W	Clothing, partitioning, acclimatation, metabolic activity...	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...
C Close to body heating by radiation	± 300 W/body	Radiating objects placed close to – but not in contact with – the body.	Infra-red panels...
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 Housing scale heating	> 5 000 W/house in Belgium	Centralised heating.	Keeping the housing at a fixed threshold temperature according to building needs (moisture control) or thermal comfort.

Although solutions in Table 03 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), "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 falls 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 redevelop a heating practice based on adaptive actions, we had to secure a space for experimentation (several years of co-creation), and to identify a hint of a solution as a starting point (PCs). It was found that PCs 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 experienced the joint creation of a new indoor microclimate with bodies and practices that are 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

1 adapt by rationally evaluating various environmental, technical, or behavioral solutions and
2 acting accordingly.

3
4 Looking back at the social practice theory framework, it appears that the facilitating factors
5 were to be found mostly in the infrastructure and material objects dimension (PCSs) and the
6 collective dimension (co-creation approach). The inhibiting factors were to be found in all
7 four dimensions: skills (lack of understanding of building physics and heating technologies),
8 infrastructure and material objects (low quality or unsatisfactory PCSs, uncontrollable
9 heating systems), representations (fear of cold) and the collective dimension (guests).
10 Therefore, any attempt to reproduce this experience or spread the practice of slowheating
11 should consider all these dimensions from the very beginning.

12 13 **4.2 Control is key**

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

23
24 1. Adequate devices. PCSs were deemed crucial even if not often used. They allowed
25 countering the fear of cold and gave a backup solution by quickly and efficiently tackling
26 periodic experiences of cold. In contrast, and out of step with Nicol's (2017) emphasis on the
27 environmental control permitted by central heating, central heating systems were sometimes
28 inhibiting more sufficient adaptive practices by hindering occupants' fine control in time and
29 space. PCSs therefore represent a useful complement to central heating if the latter is limited
30 to maintaining a bottom temperature setpoint.

31
32 2. Conscious role of the body. Participants expressed a feeling of improved connection and
33 understanding with their physiological reactions. It allowed for more tolerance of discomfort
34 and more confidence in their bodies' abilities. Their perceptions of cold and heat have
35 evolved, many experiencing a new pleasure in feeling contrasts. In short, one has come out
36 of the "anaesthesia of the body" that defines modern comfort according to Boni (2019). This
37 raises anew the question of the place of bodies in the theory of social practices (Wallenborn
38 & Wilhite, 2014).

39
40 3. Impact of skills and knowledge. The previous dimensions required an improved
41 understanding of building physics (mostly humidity control) and heating-systems
42 management. The researchers observed a lack of prior general knowledge about these topics
43 among participants. This can be a barrier to the effective adoption of slowheating, because it
44 limits people's ability to understand and reclaim their space heating practices. Further, a
45 deconstruction of one's feelings and images associated with cold was necessary to empower
46 participants. At the beginning of the project, cold was often associated with poverty,
47 discomfort, or illness. Warmth, on the other hand, was generally perceived as synonymous

1 with comfort, good health, and conviviality. A warm home was associated with hospitality,
2 relaxation, and a welcoming atmosphere for guests. These representations evolved during
3 the project. In the end, cold was not seen as negatively. It was, for example, associated with
4 an invigorating environment, while warmth was described as causing a heavy or sleepy
5 atmosphere. Further, the idea of contrast between a cold environment and clearly identified
6 heat sources was considered favourable.

7
8 4. Uncontrollable parameters: Despite the previous three dimensions, some parameters
9 remain out of the control of individuals. The authors had to question social norms, which are
10 interwoven with the social and the technical, such as the common expectations in terms of
11 indoor temperature induced by the widespread use of central heating. Such norms resulted
12 for example in incomprehension among friends and relatives. To challenge this, it was
13 necessary to have frequent collective discussions. It is not possible, by definition, to change a
14 social norm on its own, but forming a supportive and legitimating group ready to question it
15 proved effective.

16 17 **4.3 Insights on sufficiency**

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

20
21 First, the quantitative results of *Slowheat* show a greater potential in indoor temperature
22 reduction than the previous research highlighted above in the introduction (Karlin, 2015;
23 Zhang et al., 2018). Hence, these results hint at a larger-than-expected potential for energy
24 savings through adaptive practices, in particular in the context of climate-concerned
25 populations.

26
27 Second, *Slowheat* allows revisiting Spengler's (2016) proposal to focus on defining the
28 minimum necessary: "how much of what is enough?". The results highlight that the
29 association between temperature and comfort is not as deterministic as imagined, since
30 acclimatisation and PCSs allowed for a significant temperature reduction without loss in
31 quality of life. Hence, the issue of heating sufficiency should be examined with a deeper
32 understanding of what defines thermal comfort, pleasure, and wellbeing, in physiological,
33 psychological, and social dimensions. We therefore reinforce Shove's (2003b) assertion that
34 "There is more to comfort than temperature, but exactly where expectations lie along this
35 range is, largely, a matter of culture and convention". If sufficiency relies on "the necessity to
36 differentiate needs from wants" (Gough, 2017) the results stress that while thermal well-
37 being is undoubtedly a need, it should not be equated with home heating, which is just one
38 way of addressing it.

39
40 Third, and associated with the previous point, it is important to acknowledge the dire
41 situations many experience due to inadequate housing and to avoid using *Slowheat's* results
42 as a pretext for inaction concerning these situations. Similar environmental conditions will be
43 experienced differently if they result from a voluntary sufficiency approach or arise from a
44 situation of precariousness.

45 46 **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-Webb et al., 2024). Part of these 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. Conclusion

By combining a real-world laboratory (RwL) set-up and a co-creation approach, the slowheat project revived 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 PCS's 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 one's conscious ability to adapt through 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 PCs. The cost-of-living crisis occurring during the project probably induced electricity saving behaviours that offset the electricity consumption of PCs. 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 well-being 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 well-being) was not at odds with the negative approach (to reduce current levels of energy consumption).

Acknowledgments

The authors thank all the participants of the Slowheat project. They also thank the Université Libre de Bruxelles and Université Catholique de Louvain for supporting the article publication charge.

Authors contributions

Conceptualisation: GvM, DdG, AA, GW; data curation: GvM, DdG; formal analysis: DdG, AA; funding acquisition: DdG; investigation: GvM, DdG, AA, JS, GW; methodology: GvM, DdG, AA, JS, GW; project administration: GvM; supervision: GvM; visualisation: DdG; writing (original draft): GvM, DdG, AA, JS, GW; writing (review and editing): GvM, GW.

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, published supplementary file are available on request from the corresponding author, GvM upon request. The data are not publicly available due to containing information that could compromise the privacy of the research participants.

Ethical approval

The research framework was approved by the Ethics Commission of the Research Institute of Psychology of the Université catholique de Louvain under (reference “Projet 2021—32”).

Funding

The Slowheat project was supported by INNOVIRIS, the public administration that funds and supports research and innovation in the Brussels-Capital Region (Grant reference numbers 2020-COC-1b & 2022-COC-101a).

Bibliography

- Barlow, C. F., Daniel, L., Bentley, R., & Baker, E. (2023). Cold housing environments: defining the problem for an appropriate policy response. *Journal of Public Health Policy*, 44(3), 370-385. <https://doi.org/10.1057/s41271-023-00431-8>
- Beecroft, R., & Parodi, O. (2016). Reallabore als Orte der Nachhaltigkeitsforschung und Transformation: Einführung in den Schwerpunkt. *TATuP - Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis*, 25(3), 4-8. <https://doi.org/10.14512/tatup.25.3.4>
- Bierwirth, A., & Thomas, S. (2019). *Energy sufficiency in buildings : Concept paper for ECEE*. <https://www.energysufficiency.org/libraryresources/library/items/energy-sufficiency-in-buildings-concept-paper/>
- Boni, S. (2019). *Homo comfort*. Elèuthera.
- Bouton, M. E. (2014). Why behavior change is difficult to sustain. *Preventive Medicine*, 68, 29-36. <https://doi.org/10.1016/j.ypmed.2014.06.010>
- Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. *Energy and Buildings*, 27(1), 83–96. DOI: [https://doi.org/10.1016/S0378-7788\(97\)00053-4](https://doi.org/10.1016/S0378-7788(97)00053-4)
- Brauer, H. B., Hasselqvist, H., Håkansson, M., Willermark, S., & Hiller, C. (2024). Re-configuring practices in times of energy crisis – A case study of Swedish households. *Energy Research & Social Science*, 114, 103578. <https://doi.org/10.1016/j.erss.2024.103578>
- Butler, P. (2022, April 6). ‘Heat the human, not the home’: Martin Lewis guide for ‘desperate’ households. *The Guardian*. <https://www.theguardian.com/business/2022/apr/06/martin-lewiss-cost-of-living-guideoffers-advice-to-desperate-households>
- Chappells, H., & Shove, E. (2005). Debating the future of comfort: Environmental sustainability, energy consumption and the indoor environment. *Building Research & Information*, 33(1), 32–40. DOI: <https://doi.org/10.1080/0961321042000322762>
- de Dear, R. (2011). Revisiting an old hypothesis of human thermal perception: Alliesthesia. *Building Research & Information*, 39(2), 108–117. DOI: <https://doi.org/10.1080/09613218.2011.552269>
- De Decker, K. (2015). Restoring the old way of warming: Heating people, not places. *Low-Tech Magazine [Blog]*. <https://solar.lowtechmagazine.com/2015/02/restoring-the-old-way-of-warming-heating-peoplenot-places/>
- European Commission. (2020). *A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives*. Brussels Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662>

- 1 EUROSTAT. (2024). *Disaggregated final energy consumption in households - quantities*.
2 https://ec.europa.eu/eurostat/databrowser/view/nrg_d_hhq/default/table?lang=en
- 3 Fabi, V., Andersen, R. V., & Corgnati, S. P. (2013). Influence of occupant's heating set-point
4 preferences on indoor environmental quality and heating demand in residential
5 buildings. *HVAC&R Research*, 19(5), 635-645.
6 <https://doi.org/10.1080/10789669.2013.789372>
- 7 Gough, I. (2017). *Heat, Greed and Human Need* Edward Elgar Publishing.
- 8 Gouvernement de la Région de Bruxelles-Capitale. (2019). *Stratégie de réduction de l'impact*
9 *environnemental du bâti existant en Région de Bruxelles-Capitale aux horizons 2030-*
10 *2050* Retrieved from [https://renolution.brussels/sites/default/files/media-](https://renolution.brussels/sites/default/files/media-documents/strategie_reno_fr.pdf)
11 [documents/strategie_reno_fr.pdf](https://renolution.brussels/sites/default/files/media-documents/strategie_reno_fr.pdf)
- 12 Gram-Hanssen, K. (2010). Standby Consumption in Households Analyzed With a Practice
13 Theory Approach. *Journal of Industrial Ecology*, 14(1), 150-165.
14 <https://doi.org/https://doi.org/10.1111/j.1530-9290.2009.00194.x>
- 15 He, Y., Parkinson, T., Arens, E., Zhang, H., Li, N., Peng, J., Elson, J., & Maranville, C. (2022).
16 Creating alliesthesia in cool environments using personal comfort systems. *Building*
17 *and Environment*, 209, 108642.
18 <https://doi.org/https://doi.org/10.1016/j.buildenv.2021.108642>
- 19 Heiskanen, E., Laakso, S., Matschoss, K., Backhaus, J., Goggins, G., & Vadovics, E. (2018).
20 Designing Real-World Laboratories for the Reduction of Residential Energy Use:
21 Articulating Theories of Change. *GAIA - Ecological Perspectives for Science and*
22 *Society*, 27(1), 60-67. <https://doi.org/10.14512/gaia.27.S1.13>
- 23 Itten, A., Sherry-Brennan, F., Hoppe, T., Sundaram, A., & Devine-Wright, P. (2021). Co-creation
24 as a social process for unlocking sustainable heating transitions in Europe. *Energy*
25 *Research & Social Science*, 74, 101956.
26 <https://doi.org/https://doi.org/10.1016/j.erss.2021.101956>
- 27 Jahn, T., & Keil, F. (2016). Reallabore im Kontext transdisziplinärer Forschung. *Gaia*, 25(4), 5.
28 <https://doi.org/10.14512/gaia.25.4.6>
- 29 Karlin, B., Zinger, J. F., & Ford, R. (2015). The effects of feedback on energy conservation: A
30 meta-analysis. *Psychological Bulletin*, 141(6), 1205–1227. [https://doi.org/](https://doi.org/https://doi.org/10.1037/a0039650)
31 <https://doi.org/https://doi.org/10.1037/a0039650>
- 32 Laakso, S., Jensen, C. L., Vadovics, E., Apajalahti, E.-L., Friis, F., & Szöllőssy, A. (2021). Towards
33 sustainable energy consumption: Challenging heating-related practices in Denmark,
34 Finland, and Hungary. *Journal of Cleaner Production*, 308, 127220.
35 <https://doi.org/https://doi.org/10.1016/j.jclepro.2021.127220>
- 36 Morrisette, J. (2013). Recherche-action et recherche collaborative : quel rapport aux savoirs
37 et à la production de savoirs? *Nouvelles pratiques sociales*, 25(2), 35-49.
38 <https://doi.org/https://doi.org/10.7202/1020820ar>
- 39 Nicol, F. (2017). Temperature and adaptive comfort in heated, cooled and free-running
40 dwellings. *Building Research & Information*, 45(7), 730-744.
41 <https://doi.org/10.1080/09613218.2017.1283922>
- 42 Nicol, J. F., & Humphreys, M. A. (1973). Thermal comfort as part of a self-regulating system.
43 *Building Research and Practice*, 1(3), 174-179.
44 <https://doi.org/10.1080/09613217308550237>
- 45 Nicol, J. F., & Roaf, S. (2017). Rethinking thermal comfort. *Building Research & Information*,
46 45(7), 711-716. <https://doi.org/10.1080/09613218.2017.1301698>

- 1 Parkinson, T., & de Dear, R. (2015). Thermal pleasure in built environments: Physiology of
2 alliesthesia. *Building Research & Information*, 43(3), 288–301. DOI:
3 <https://doi.org/10.1080/09613218.2015.989662>
- 4 Peffer, T., Pritoni, M., Meier, A., Aragon, C., & Perry, D. (2011). How people use thermostats in
5 homes: A review. *Building and Environment*, 46(12), 2529–2541. DOI:
6 <https://doi.org/10.1016/j.buildenv.2011.06.002>
- 7 Rijal, H. B. (2021). Thermal adaptation of buildings and people for energy saving in extreme
8 cold climate of Nepal. *Energy and Buildings*, 230, 110551.
9 <https://doi.org/https://doi.org/10.1016/j.enbuild.2020.110551>
- 10 Sahakian, M., Naef, P., Jensen, C., Goggins, G., & Fahy, F. (2019). Challenging conventions
11 towards energy sufficiency: Ruptures in laundry and heating routines in Europe.
12 *ECEEE 2019 Summer Study*.
- 13 Sahakian, M., Rau, H., Grealis, E., Godin, L., Wallenborn, G., Backhaus, J., Friis, F., Genus, A. T.,
14 Goggins, G., Heaslip, E., Heiskanen, E., Iskandarova, M., Louise Jensen, C., Laakso, S.,
15 Musch, A.-K., Scholl, C., Vadovics, E., Vadovics, K., Vasseur, V., & Fahy, F. (2021).
16 Challenging social norms to recraft practices: A Living Lab approach to reducing
17 household energy use in eight European countries. *Energy Research & Social Science*,
18 72, 101881. <https://doi.org/https://doi.org/10.1016/j.erss.2020.101881>
- 19 Schatzki, T. R. (1997). Practices and actions a Wittgensteinian critique of Bourdieu and
20 Giddens. *Philosophy of the social sciences*, 27(3), 283-308.
- 21 Shove, E. (2003a). *Comfort, Cleanliness and Convenience: The Social Organization of*
22 *Normality*. Berg Publishers.
- 23 Shove, E. (2003b). Converging Conventions of Comfort, Cleanliness and Convenience. *Journal*
24 *of Consumer Policy*, 26(4), 395-418. <https://doi.org/10.1023/A:1026362829781>
- 25 Song, W., Zhang, Z., Chen, Z., Wang, F., & Yang, B. (2022). Thermal comfort and energy
26 performance of personal comfort systems (PCS): A systematic review and meta-
27 analysis [Review]. *Energy and Buildings*, 256, Article 111747.
28 <https://doi.org/10.1016/j.enbuild.2021.111747>
- 29 Spengler, L. (2016). Two types of ‘enough’: sufficiency as minimum and maximum.
30 *Environmental Politics*, 25(5), 921-940.
31 <https://doi.org/10.1080/09644016.2016.1164355>
- 32 Totty, J. P., Austin, O., Anwar, M. U., Muthayya, P., & Phipps, A. R. (2024). The cost of keeping
33 warm: a relationship between a rise in the cost of domestic energy and burn injuries
34 caused by personal heating equipment. *Burns*.
35 <https://doi.org/https://doi.org/10.1016/j.burns.2024.03.025>
- 36 UNESCO Institute for Statistics. (2012). International Standard Classification of Education:
37 ISCED 2011. In (pp. 85 p.). Montreal: UIS.
- 38 Van Loy, N., Verbeeck, G., & Knapen, E. (2021). Personal Heating in Dwellings as an
39 Innovative, Energy-Sufficient Heating Practice: A Case Study Research. *Sustainability*,
40 13(13), 7257. <https://www.mdpi.com/2071-1050/13/13/7257>
- 41 Verbruggen, S., De Ceuster, E., Delghust, M., & Laverge, J. (2020). Clothing behaviour in
42 Belgian homes. Paper presented at the E3S Web of Conferences 2020. DOI:
43 <https://doi.org/10.1051/e3sconf/202017206006>
- 44 Wallenborn, G., & Wilhite, H. (2014). Rethinking embodied knowledge and household
45 consumption. *Energy Research & Social Science*, 1, 56-64.
46 <https://doi.org/https://doi.org/10.1016/j.erss.2014.03.009>

- 1 Zapata-Webborn, E., Hanmer, C., Oreszczyn, T., Huebner, G., McKenna, E., Few, J., Elam, S.,
2 Pullinger, M., Cheshire, C., Friel, D., Masters, H., & Whittaker, A. (2024). Winter
3 demand falls as fuel bills rise: Understanding the energy impacts of the cost-of-living
4 crisis on British households. *Energy and Buildings*, 305, 113869.
5 <https://doi.org/https://doi.org/10.1016/j.enbuild.2023.113869>
- 6 Zhang, Y., Bai, X., Mills, F. P., & Pezzey, J. C. V. (2018). Rethinking the role of occupant
7 behavior in building energy performance: A review. *Energy and Buildings*, 172, 279-
8 294. <https://doi.org/https://doi.org/10.1016/j.enbuild.2018.05.017>