BUILDINGS & CITIES

Learning to sail a building: a people-first approach to retrofit

SPECIAL COLLECTION: NET ZERO RETROFIT OF THE BUILDING STOCK

RESEARCH

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ABSTRACT

To decarbonise the built environment, it is widely assumed that 'fabric-first' building upgrades are essential. An alternative, people-first approach is proposed that could deliver energy and carbon reductions at scale and speed. The approach begins by re-examining some rarely questioned assumptions around historical practices and building science. Physics and thermal physiology can inform a reassessment of the causes of thermal discomfort, and show why using air temperature alone as a measure of the thermal environment is inherently problematic. Historical sources reveal the forgotten ways people were made more comfortable in the days before space-conditioning. Together, these encourage a deeper examination of how buildings were constructed, maintained and operated prior to the Industrial Revolution. These insights can be harnessed to develop a practical new trajectory for building operation and retrofit. Preliminary results are reported from two ongoing UK field studies. Co-creation workshops and simple environmental monitoring are being used to encourage occupants to learn to 'sail' (*i.e.* passively manage) their own buildings more effectively to support their own needs. It is not yet possible to put numbers on the energy and carbon saved, but these early experiments may encourage professionals and policymakers to give much greater consideration to 'people-first' climate action.

POLICY RELEVANCE

A common approach to decarbonising buildings is a focus on 'fabric-first' retrofits, which tend to be disruptive, carbon-intensive, expensive and will take decades to convert the stock. Feedback is also exposing disappointing savings, and risks to both building fabric and occupant health. This approach often seeks to update buildings to 'modern' standards, using models that have proved problematic, and frequently ignoring in-use performance. Conversely, a 'people-first' approach can empower occupants to identify what might improve things, trial simple interventions, and make rapid, low-risk alterations to improve their health and thermal comfort. This can draw on and adapt proven, low-cost historical methods. This alternative 'soft' approach uses facilitators to help occupants 'learn to sail' (*i.e.* effectively operate) buildings more effectively and sustainably. The insights will also enable any capital measures to be more precisely targeted.

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1. INTRODUCTION

> We are suffering from an attempt to know our way into the future, instead of live our way.
>
> (Sharpe 2020: 89)

The climate emergency has encouraged ambitious plans for bringing the existing building stock up to what are regarded as 'modern standards', primarily through upgrading buildings and their mechanical systems (*e.g.* the European Union's 'renovation wave'; EU 2024). This 'fabric-first' approach is proving problematic, and not just in terms of cost, timescale and upfront carbon (Eyre *et al.* 2023). Despite all the policies this century, building energy use in the Global North remains stubbornly high. Fabric-first retrofits have sometimes also undermined the lifespan of a building and the health of its occupants (Apps 2021; DESNZ 2025; Historic England 2024), particularly for solid-wall 'greatcoat' buildings that deal with heat and moisture in very different ways from modern, layered 'raincoat' construction (Pender 2024a). They may also increase overheating in summer (Gupta *et al.* 2015), which will worsen as global temperatures climb.

Meanwhile, debate has been shifting from 'efficiency' towards 'sufficiency' (Saheb 2021), as now recognised in the United Nations' (UN) Intergovernmental Panel on Climate Change's (IPCC) strategy for the built environment:

> [Sufficiency is] a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human well-being for all, within planetary boundaries.
>
> (IPCC 2023: 105, n. 155)

Might expectations be unrealistic for technology, efficiency, standards and markets to deliver a net zero building stock? In other words, could the lack of success actually be arising from unquestioned paradigms about buildings and comfort? Are there viable alternatives for professionals and policymakers to achieve a net zero building stock and provide thermal satisfaction?

This paper explores an alternative approach to transitioning the building stock to net zero. The first part considers some crucial but often-overlooked background science, interweaving building physics with thermal physiology (the branch of medical science devoted to understanding the interactions of animals with their thermal environments). The understandings correspond well with evidence of pre-industrial approaches to providing thermal comfort. They suggest potential for an alternative 'people-first' route to retrofitting that could combine quick reductions in energy demand with improvements in occupant health and wellbeing.

The second part briefly introduces two ongoing projects in the UK, in churches and in dwellings. These seek to understand how knowledge support might best be used to help occupants, building managers and advisors understand their own thermal comfort and discomfort, and to manage this using less energy. As the projects develop, it is hoped they will reveal the potential of a people-centred 'soft' approach to retrofitting, and whether policymakers, fond of 'market-led' solutions, could encourage this low-key 'bottom-up' approach.

1.1 CURRENT AND PAST PRACTICE

In spite of its shortcomings, air temperature is widely used as a proxy for thermal comfort, as the head of the UK Medical Research Committee (MRC), Leonard Hill, was already warning more than a century ago:

> For the purposes of controlling the heating and ventilation of rooms the thermometer has [...] acquired an authority which it does not deserve.
>
> (Hill *et al.* 1916: 184)

Research findings and engineering standards reveal a more complex situation, as is also clear to anyone who has tried to relate thermostat settings to their own feelings. Air temperature is easy to measure, but too much reliance on it has led to fundamental sources of discomfort being neglected, and demonstrably effective actions undervalued. A simple example is the impact

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of awnings on overheating. While shading does lower indoor air temperatures somewhat, the greatest impact from direct sunlight is on occupants and the surfaces around them, which can be unpleasant, even in winter (Oliveira & Corvacho 2021; Bessoudo *et al.* 2010). Worse still, the reliance on air temperature measurement has led to the belief, promoted by the heating, ventilation and air-conditioning industry, that indoor air temperature must be precisely controlled (Cass & Shove 2018).

For the most part, the Global North constructs in ways that require large inputs of energy and carbon. The resulting buildings are too often short-lived, energy-intensive and expensive to maintain, in comparison with vernacular and pre-carbon buildings (Pender 2024a; Calder 2021; Patterson 2024). The common perception that pre-carbon buildings were uncomfortable and unhealthy does not really seem to be supported by the evidence (*e.g.* Thompson 1957), though more historical and anthropological research is desirable. Physical evidence also questions current assumptions, *e.g.* recent experiences of people in older houses in England (Wise *et al.* 2021), and the effectiveness of buildings based on vernacular principles in the Global South (Borràs 2024; Ramchurn 2014; Lari 2024). It is notable that 'traditional' approaches to construction usually allow for quite high levels of air exchange between interior and exterior, while surveys (Leaman & May 2019; MHCLG 2025) and reports from building pathologists (Hutton + Rostron 2024) suggest mould and other moisture-related problems have accompanied requirements to seal and insulate. Continuous mechanical ventilation is often advocated as a way of improving air quality and moisture management, but in practice it too often fails to meet design expectations (*e.g.* MHCLG 2019).

In the words of Patterson (2015): collectively and individually, society has forgotten how to 'sail' (*i.e.* passively manage and operate) buildings. Thermal comfort, the driver behind so much energy and carbon use, illustrates the power of grasping first principles before framing remedial standards based on conventional wisdom. Conclusions from thermal physiologists (*e.g.* van Marken Lichtenbelt *et al.* 2022) mesh closely with what is known about how buildings were operated in the Global North before the Industrial Revolution (Pender & Lemieux 2020), and current practice in much of the Global South (Moscoso-García & Quesada-Molina 2023).

2. PHYSIOLOGY AND THERMAL COMFORT

Thermal physiology—*i.e.* how mammals control their core body temperatures so their organs can undertake critical tasks—has great implications for how buildings are designed and occupied. Insights of experts in this field can help to unlock rapid, effective, low-cost, low-risk action: knowledge that is not yet common currency for building designers, engineers, lobbyists and policymakers.

Much of the knowledge underlying historic approaches to managing comfort would have been considered 'common sense', so was never explicitly recorded, making it challenging to reference in the manner of scientific journals (albeit not for historians). Evidence of the pre-industrial past is amply revealed in the many thousands of illuminations (paintings) within medieval manuscripts; the architectural detailing of ancient buildings; housekeeping records; the vestiges of old 'comfort' elements such as the hooks used to hang wall cloths; and wall paintings depicting draperies (Figure 1) (Pender 2024a).

2.1 THERMAL PHYSIOLOGY IN THE CONTEXT OF BUILDINGS

A widespread misunderstanding is that 'heat' impinges on the body from outside to produce comfort or discomfort, so air temperature needs to be controlled. In reality, the bodies of all warm-blooded animals generate the heat needed to survive, largely from food. For human organs to operate correctly, the core temperature must be held within a tight band, typically 37 ± 0.5°C. Even under cold conditions, some of the heat human bodies produce needs to be lost (*e.g.* McIntyre 1980: ch. 4). Therefore an elaborate thermoregulatory system exists that can react quickly to changes in what activity is being done and in what surroundings. The heat-exchange mechanisms are complex, with so many different and interrelated factors that precise quantification becomes impossible (Pallubinsky *et al.* 2023). Metabolic rates change continually, depending on activity

Figure 1: (left) Musicians surrounded by fabric.

Source: Livre des propriétés des choses de Barthélemy l'Anglais, traduit du latin par Jean Corbichon, *c.*1445–50 (detail). Courtesy: Bibliothèque nationale de France, Paris, Département des Manuscrits, Français 22532, f. 336^{r}. Public domain.

(right) At St Albans Cathedral, the shaft bases of the medieval windows (which now appear stranded) were positioned to finish above the draperies that once caught downdraughts off the glass.

Source: Isabelle Lapore.

levels and actions, including eating and drinking. How heat leaves the body depends not just on details of clothing and the surrounding environment, but on a plethora of unique physiological factors, including body size, shape and posture, and how well individual thermoregulatory systems are working. Perceptions of comfort and discomfort depend on even more variables, including health and individual preference. There is also a mental element, *e.g.* a fire's glow makes people feel warmer.

Nor is heat balance the simple thermodynamic often assumed by non-medics. For example, when a person begins to lose too much heat, a principal thermoregulatory response is to reduce blood flow to the skin and the extremities. When people sit still (so generating less heat), hands and feet may become cold, even in relatively benign environments. Gloves will not warm chilled hands much until the thermoregulatory system has registered a safer heat balance, *e.g.* when the person moves about or has a hot drink. To convince the thermoregulatory system that it is safe to allow blood back, medics apply heat directly to the base of the neck, under the arms and the groin, where major blood vessels are to be found close to the surface. This explains the effectiveness of hot water bottles in the lap and heated seat cushions. In the past, short-haired lapdogs were bred specifically for this purpose.

2.2 FORMS OF HEAT LOSS AND GAIN

Bodies lose (and sometimes gain) heat by radiation, convection and conduction; and by evaporation. These processes are not independent, but one can make some broad observations. For naked people in still air, loss by radiation into the surroundings dominates. Although clothing reduces this component, it still remains high, especially when the surrounding surfaces are cold. Evaporative heat losses are driven by sweating and respiration, and depend on the velocity, humidity and temperature of the air. Conduction losses arise when parts of the body touch colder materials. They are small (usually well under 5%), but can reach dangerous levels when people are immersed in icy water, or lie flat on cold surfaces. Cold hands and particularly cold feet have a disproportionate effect on perceived comfort (*e.g.* McIntyre 1980: 234–240).

If a person is losing too much heat from their core, and withdrawing blood from skin and limbs is an insufficient remedy, other thermoregulatory responses will be induced, such as goosebumps and shivering. When a person needs to increase heat loss, blood is sent into their skin and sweating and panting begin, to increase evaporation. High humidities makes evaporation more difficult, but it can still be increased by air movement, explaining the effectiveness of fans for comfort (*e.g.* Miller *et al.* 2021). Figure 2 shows Streblow's (2010) model of relative proportions of heat loss, for a relaxed seated person in light clothing, in a space where the air and all surrounding surfaces are at the same temperature (horizontal *x*-axis), with air movement at 0.1 m/s. At a uniform 22°C, about half the heat loss is by radiation, 30% by convection and 20% as latent heat (10% respiration, 10% evaporation). As the surrounding temperatures fall, convective heat losses increase rapidly, radiant heat losses even more so, while latent heat losses stay much the same. In solid-walled buildings, walls and floors will usually be colder than the air, particularly when any heating is intermittent, making radiant losses still higher, reducing indoor comfort in winter and improving it in summer. As temperatures rise, convective losses decrease rapidly and radiative losses more slowly, both ceasing at about 35°C, as evaporation dominates.

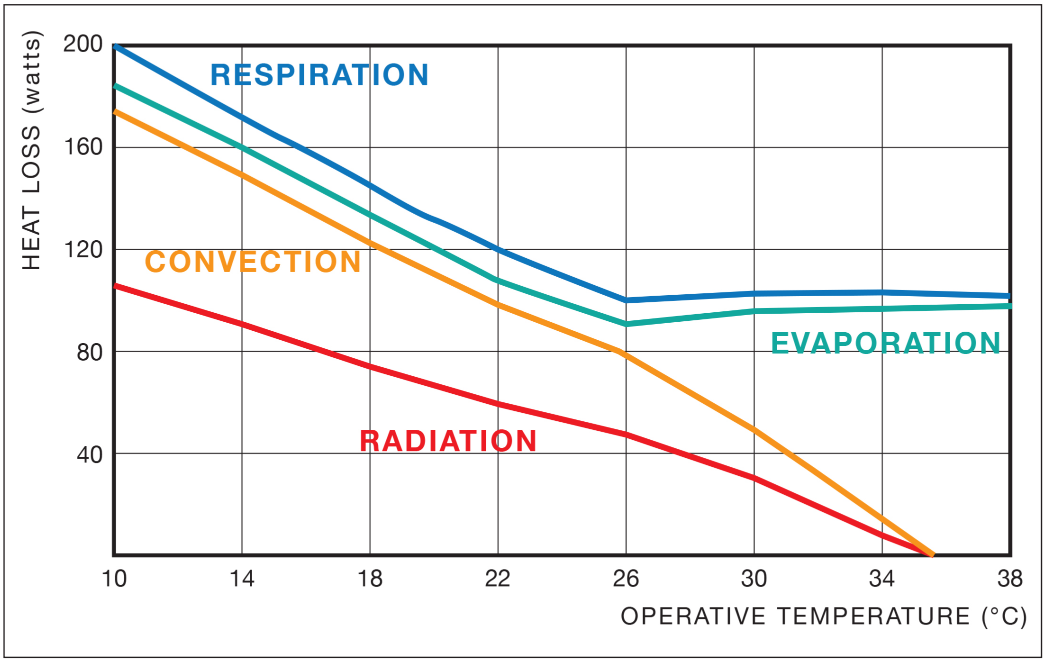

Figure 2: Heat loss from the human body according to the 33 Node Comfort Model, assuming light clothing and an environment with equal surface and air temperatures at the values shown on the *x*-axis, and an air velocity of 0.1 m/s.

Source: Adapted from Streblow (2010).

To capture some of this complexity, environmental engineers often combine the contributions of radiation, convection and air velocity into a single index: the 'operative temperature' (*e.g.* CIBSE 2021: 1–2, 1–3). However, this is easily confused with air temperature alone. A recent review of data from mechanically conditioned offices in the US (Dawe *et al.* 2020) in fact concluded that air and radiant temperatures were so similar that it would seldom be worthwhile to account for radiation separately. This is surprising as large windows can be significant sources of local radiant discomfort, even in well-insulated buildings. The data reviewed may have come largely from sensors located according to 'good practice', *i.e.* in representative positions, deliberately away from local stressors such as radiation and draughts.

Halawa *et al.* (2014) argue for taking proper account of thermal radiation, and this is something that becomes particularly important in older and solid-walled buildings, and those with intermittent heating (or even none), or wherever surface temperatures are unlikely to be the same as air temperatures. Tackling radiative heat losses directly can have a strong impact on comfort, without controlling air temperature. In large spaces such as churches, for example, local pew heating or underfloor heating can be extremely effective.

3. LEARNING FROM HISTORY

Over time, people developed sophisticated methods to control how much heat was drawn from the body into the surroundings. Medieval illuminations are a goldmine of information about the pre-carbon past, showing not only climate-appropriate clothing (voluminous and layered, with soft head coverings), but also fixtures including porches, wooden ceilings, shutters and furnishings. A widespread element, still found in vernacular buildings in the Global South, is placing radiant barriers between occupants and cold surfaces nearby, most often draperies, canopies, rugs and panelling. These are commonly misinterpreted as purely decorative, but their purpose must also have been practical. Incoming radiant heat can quickly warm hangings of organic materials such as cloth and wood. Fabrics even reflect some infrared energy back from occupants nearby. Medieval images (Figure 3) often show windows open in winter too. The ongoing war in Ukraine provides a modern example: with power supplies targeted and winter heating lost, social media recommended sleeping in tents pitched indoors—those who did were surprised how comfortable they found it.

Figure 3: Medieval images usually show the windows open, even in winter.

*Source: Barthélemy d'Eyck et le Maître du Boccace de Genève, c.*1460 (detail); from *Le Livre de Thezeo*. Courtesy: Austrian National Library (ONB), Vienna, Codex Vindobonensis Palatinus 2617, f. 14v. Public domain.

Draperies were also used to control draughts, hung across doorways and stretched onto frames or pinned to pillars to partition spaces in both churches and dwellings. When windows began to be glazed, these were adapted to become curtains. The earliest glass windows were in ecclesiastical buildings, and paintings of church interiors show draperies hung to catch cold downdraughts (Figure 1). A feature of many of these passive measures was their flexibility. Many radiant breaks could easily be taken down when cooling was required; housekeeping books of country houses advise that tapestries are stored away in summer.

In paintings, draperies are rarely shown covering walls entirely, but to provide localised comfort, especially for sedentary occupants. Scholars are almost always shown protected by strips of cloth or by desks with plinths and wooden canopies (the stalls in medieval choirs must have served a similar purpose). At festivities, people obliged to stay still are protected, while active participants benefit from the cooling effect of bare surroundings (Figure 4). This approach, recognising that spaces are often shared by people doing different things, has distinct advantages over current practice, where a single temperature is chosen to suit a 'standard' occupant.

Widespread use of draperies to control comfort may help to explain the importance of medieval industries around clothmaking, tapestries, painted hangings, canopies and tents, reflecting where people were prepared to spend their limited funds (Figure 5). They were by no means restricted to the rich: inventories of basic almshouse fittings include painted cloths (Nicholls 2017, 2025). Fireplaces were for cooking rather than heating, with thermal comfort as a pleasant side effect. Medieval images often show large hearths with very small fires; when not in use for cooking, they are depicted closed with panels, screens or moveable furniture.

Figure 4: In Pieter Bruegel the Elder's wedding paintings, the brides (who cannot dance) are protected from radiant chilling by cloths hung behind them, from walls or even trees.

Source: Pieter Bruegel the Elder, *The Peasant Wedding*, 1567. Courtesy: Kunsthistorisches Museum, Vienna. Public domain.

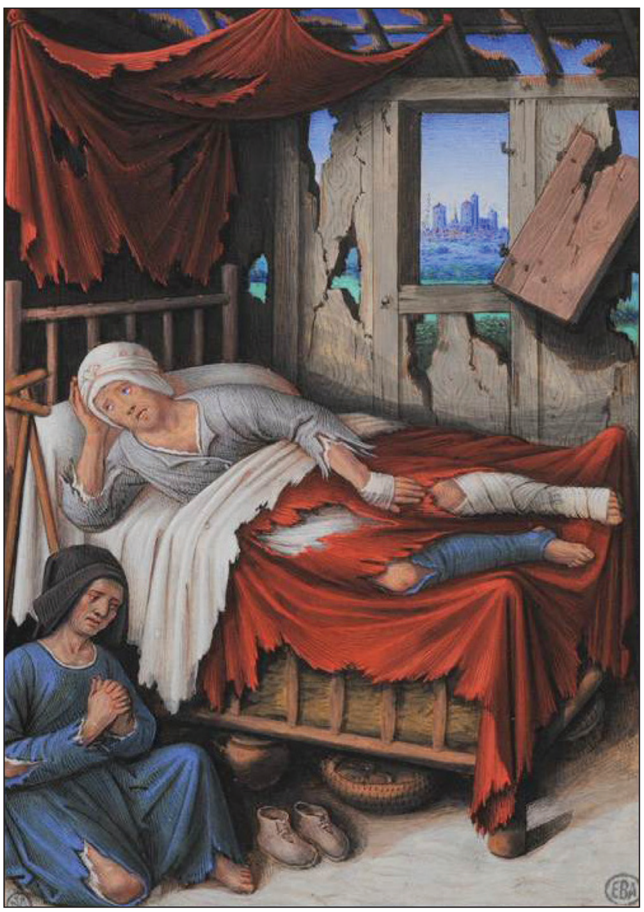

Figure 5: In a series entitled 'The Four Conditions of Society', 'Poverty' depicts a house with draperies (with holes in these as well as in walls and roof).

Source: Jean Bourdichon, *Les quatre états de la société*, 1500–10. Courtesy: Ecole Nationale Supérieure des Beaux-Arts, Paris, MS Fr. 2374. Public Domain.

Radiant breaks were clearly important before space heating became widespread, but disappear from paintings of UK interiors towards the end of the 17th century. This may be a consequence of the plague (moving draperies from house to house was forbidden in the London Mayor's plague rules), and 18th-century interiors show wooden panelling instead. In the Global South, they remain common, and not just in cold climates: many hot places can be cold at night, and draperies and rugs are a cheap, simple and decorative way to alleviate discomfort.

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With the Industrial Revolution, things changed dramatically (Powell 1980), as mutually reinforcing trends gathered pace. When transport had been difficult and expensive, building expertise had developed using materials nearby, which also encouraged progressive improvement towards solutions that best met local conditions. Occupants knew how their buildings were meant to work and how they needed to be maintained, using what was ready to hand. Fossil fuels led to cheaper materials: glass, iron and steel, and then new mortars based on cement rather than lime and earth. As transport became cheaper, the raw ingredients needed for manufacture could be brought together in one convenient place, and the products then sent to distant markets.

Glazed windows in domestic buildings introduced new problems of discomfort, including overheating: quickly addressed by inventions including vertically sliding sash windows (to improve the control of ventilation, both day and night), and external shading. In the 19th century, awnings rapidly developed into sophisticated devices to keep rooms cooler without obstructing ventilation (Pender 2021) (Figure 6). Learning may have been reinforced by insights from vernacular buildings in colonised hot countries (*e.g.* with shading and ventilation prioritised in the humid tropics, and thermal mass, small windows, light colours, wind towers, *etc.* in arid areas).

Figure 6: Late 19th-century advertisement for awnings.

Source: English Heritage (2011: 154).

With central manufacturing, regional differences began to disappear. Speculative development burgeoned as people moved into cities from the countryside, and prioritised quick construction. Terrace housing and walls of one brick thick or less were a common response to developers' desire to save space, time and money. Building skills became increasingly siloed and professionalised, and ever more dependent on standardised components.

At much the same time, Enlightenment theories of science and technology began to push aside traditional knowledge. A romantic view of old buildings also began to infect their care, with critical fixtures such as ceilings and renders deliberately removed in an antiquarian fervour to reveal the 'bones' of antiquity. This resulted in a cascade of moisture and other problems that interfered with a building's past ability to improve comfort conditions (Klemm & Wiggins 2015; Pender 2024b, 2024c).

Daniel Fahrenheit's invention in 1724 of the first practical thermometer was of central importance, allowing air temperature to be measured objectively for the first time. Enlightenment scientists and engineers (notably the Americans Benjamin Franklin and Benjamin Thompson, later Count Rumford) were enthralled, going on to develop new theories around comfort based on air temperature, together with stoves and fireplaces. The Rumford grate, introduced at the end of the 18th century, rapidly became fashionable in Britain: perhaps unsurprisingly, as large glass windows and the disappearance of wall cloths must have made Georgian houses very cold. With coal now relatively cheap, rich households soon installed grates in almost every room. But the massive airflow up the chimneys increased draughts, so by the mid-19th-century draperies were again popular (Panton 1890).

Soon, however, the tuberculosis epidemic led to a renewed desire for bare structures and fresh air; and Florence Nightingale's approach influenced hospital and building design until after the Second World War. The discovery of antibiotics allowed air exchange to be restricted, and central heating and air-conditioning became increasingly popular. The first energy crisis in 1973 led to further ventilation reductions to save fuel, but increased problems of indoor air quality and mould growth.

4. THE EROSION OF PRACTICAL KNOWLEDGE

During the First World War, many traditional building capabilities were lost, reinforcing the trend away from craft skills. Pressure was on to build faster, more cheaply and more 'scientifically'; and layered 'raincoat' construction began to dominate (Pender 2024b). The Second World War led to further economies: while synergies between Modernist aesthetics, materials shortages, and cost savings saw useful and effective traditional devices (including awnings and even water-shedding features such as drip moulds, overhangs and window mouldings) eliminated from new construction and even from refurbishments. Design came to depend on complex materials and technologies, while general and specialist contractors supplanted local builders. In the process, both professionals and occupiers began to lose insights into how their buildings worked, and how to manage discomfort. Today's environmental controls with complex interfaces continue to make it difficult for people to operate systems effectively or economically (Lomas *et al.* 2018; Bordass *et al.* 2007).

A paucity of the routine feedback loops to reinforce robust practice has allowed problems to multiply. Suppliers tend to resist acknowledging issues with their products, at least until failure becomes widespread or catastrophic. Demonstrably robust, inexpensive and sustainable systems such as earth construction have fallen by the wayside, because a market- and profit-driven world makes it difficult to support low-cost approaches using non-patentable materials, even when these might do a job as well or better. Until recent developments in computation, it was also difficult for engineers to calculate the stability of time-proven building techniques such as earth and rubble walls. 'Determinate' situations, easier to calculate, became the de facto approach.

Recent research into the structural and thermal performance and water resistance of 'greatcoat' solid walls has produced many pleasant surprises and called some of the assumed benefits of layered construction into question. However, today's culture remains risk averse and tends to rely on standards, models and manufacturer guarantees, not case studies and practical evidence.[1]

The unintended consequences of replacing deep knowledge by standards and markets has become self-feeding. Raincoat envelopes tend to prove less robust than greatcoat construction, simply because water from leaks and condensation can easily be concentrated and then trapped and hidden until the damage is serious. This is of particular concern where fabric-first retrofits add impermeable layers to greatcoat envelopes.

5. CURRENT APPROACHES TO TEMPERATURE, VENTILATION AND HEALTH

Many people now assume an ideal indoor environment must be controlled by air temperature, typically at a stable 21–24°C. Recent research in thermal physiology suggests this desire for thermal neutrality can be positively unhealthy. Where people become habituated to tightly controlled environments, their thermoregulatory systems begin to shut down, making them less able to adapt to changing conditions (Pallubinsky *et al.* 2023); instead, people seek ever tighter control. A vicious circle of addiction then plays into the hands of the suppliers of technical equipment, increasing demand for their goods and services. As Cooper (1998: 79) observed in a history of air-conditioning in America:

> When natural climate was the ideal, mechanical systems sometimes fell short, but when quantitative standards [...] became the measure, natural climate was found wanting. [...] When no town could deliver an ideal climate, all towns became potential markets.

Medical researchers are now establishing links between insufficient exposure to wide-ranging thermal conditions and modern health issues including obesity, high blood pressure and diabetes (Sellers *et al.* 2024; Khovalyg *et al.* 2023). Encouragingly, the research suggests some reversibility: where people are trained to regain their thermoregulatory fitness, their general health tends to improve too.

5.1 ARE NEUTRAL THERMAL CONDITIONS DESIRABLE?

Other questions surround the desirability of tight control over temperature. Any chosen set point necessarily suits only a narrow group of occupants undertaking a narrow range of tasks. For example, a temperature chosen for a sedentary reader will be too hot for someone cleaning the floor. Neutral conditions can also be equivalent to sensory deprivation. Heschong (1979) explored thermal delight in buildings. The topic (known scientifically as 'alliesthesia': the perceived pleasure or displeasure of stimuli) was reawakened by de Dear (2011) and has attracted subsequent interest, including by DeKay & Brager (2023) who explore its wider implications for design. Positive responses to variability may explain why conditions regarded as unacceptable in air-conditioned spaces are not just tolerated, but often preferred, in some naturally ventilated and mixed-mode buildings. The key appears to be where individuals have the agency to make their own changes to suit their needs (*e.g.* Bordass *et al.* 1995).

Shove (2020) points out the extent to which comfort is socially determined, with expectations evolving alongside available technology. This is then reinforced by marketing and lobbying by commercial interests (Shove *et al.* 2008). Adaptive comfort theory (Nicol *et al.* 2012) helps to reformulate retrofit from the viewpoint of sufficiency. Brager *et al.* (2015) suggest that the commonly specified indoor temperature range of 21–24°C could be widened to 18–28°C by exploiting adaptive opportunities, and to 16–30°C by adding personal comfort systems such as local fans and heaters (Arens & Zhang 2022). Even greater ranges could well become possible where occupants have the tools to respond rapidly to any 'crises of discomfort' (Haigh 1981). Where residents tried out this approach in 23 dwellings in Belgium, mean winter temperatures indoors dropped from 19 to 15°C over three years (van Moeseke *et al.* 2024).

While more relaxed control can save energy and improve wellbeing, the danger is going too far too quickly. Much housing in the UK is damp (MHCLG 2025), which not only increases the thermal conductivity of the building envelope but can also trigger mould and rot, with consequent risks to the health of the building and its occupants.

6. CURRENT APPROACHES TO RETROFITTING UK DWELLINGS

A framework for preparing and implementing domestic retrofit plans, BS PAS 2035 (BSI 2019), is currently mandatory for UK government-sponsored programmes (a new 2023 version, revised in 2024, takes effect in 2025). PAS 2035 was formulated largely by professionals (designers, suppliers, educators and regulators) involved in major interventions. For this, it represented a major advance and stimulated better training and accreditation of retrofit coordinators and the retrofit advisers who prepare initial plans. Key principles of the document include:

- a strategic whole-building-as-a-system approach (some previous programmes had used lists of approved measures only, leading to problems with air quality, moisture, decay and overheating)
- interventions may need to be phased, but always in relation to a strategic overview and systemic approach
- each building is unique, not least in terms of its construction and its condition
- retrofit should be 'fabric first', based on insulating the envelope before adopting build-tight-ventilate-right principles
- a retrofit coordinator must be appointed to oversee the work from start to finish, including handover and review thereafter.

For landlords with portfolios—who must consider strategies for their stock in the light of government zero carbon policy—the resulting retrofit plans make some sense. For example, MEES (a mandatory minimum energy efficiency standard introduced in 2015) forbade letting of UK buildings with Energy Performance Certificate (EPC) grades worse than F. A further requirement, for Grade C by 2030, was abandoned in 2023, but may be re-introduced.

A central problem with this formulaic approach is that EPCs are based on theoretical models of energy savings.[2] These are known to overestimate energy use in older buildings (Few *et al.* 2023); they also rate the building alone, with no reference to its actual energy use or how it is occupied and operated. This might be acceptable for landlords who need to accommodate a wide range of tenants, but not for the nearly two-thirds of UK households that are owner-occupied. Occupiers are naturally more concerned with actual than theoretical energy use. Most cannot afford a deep retrofit, nor tolerate the disturbance. They prefer to intervene in stages, as opportunities arise (*e.g.* when extending, re-roofing or replacing a failing boiler).

Designers sometimes argue that such semi-standardised, relatively low-cost retrofit plans are inevitably blunt instruments, and clients should go on to commission a full professional service. Realistically, few will want to pay for this. The results could also disappoint: a recent, detailed professional plan for a housing estate was still based on theoretical calculations, ignoring both metered energy use and actual thermal performance. Essentially, it sought to re-invent the estate, not to confront the present reality.

7. PROJECTS TO INVESTIGATE PEOPLE-FIRST RETROFIT

Can occupants, conditioned to being reactive, learn to take better control of their buildings: making modest changes, 'sailing' often forgotten passive systems and 'driving' their active systems more economically? Some authorities assume not. For example, in its zero carbon roadmap the UK Green Building Council (UKGBC) (2021: 26) states:

> The opportunity for widespread behaviour change has been considered, with a cautious approach to expectations that occupants will be able to reduce thermostats [thermostat settings] without improvements to building fabric—one of the supporting arguments for the fabric first retrofit programme.

The history of how occupants managed comfort in the past suggests otherwise. Today, even occupants who already have some agency seldom appreciate the benefits it already has until a researcher points it out to them (Khan 2017; and private communications), let alone what further opportunities they might exploit. To see what might be possible, in 2023 the authors started on two projects to test simple ways of upskilling ordinary building users and their professional advisers, and stimulate long-term engagement in operating their buildings more sustainably. The findings are preliminary. By summarising them here, it is hoped others may be inspired to explore this promising strand of rapid climate action. Longer term results will be reported once the projects have been fully analysed.[3]

7.1 PROJECT 1: PEOPLE-FIRST MEASURES IN CHURCHES

The Historic Heat project is a response to the Church of England's ambition of 'net zero' operational carbon by 2030. The project team and Diocesan support officers are working directly with more than 100 managers and front-line volunteers in more than 85 churches (Pender *et al.* 2024). Each church was first visited by one of the team, who briefly surveyed the building and discussed the practical needs and problems with volunteers from the parish. On this visit, the researcher became familiar with the building's condition, systems and records; discussed user needs; and began to establish an empathic relationship with the volunteers that proved critical to sustaining trust and subsequent engagement. The principal researcher must be experienced so they can give informed feedback during these conversations, while junior researchers can be trained by assisting and participating.

At this meeting, the people-first approach was also introduced, while simple wireless long-range wide-area network (LoRaWAN) sensors were installed to monitor air temperature and relative humidity (RH). Each church has one exterior and at least two interior sensors that send data continuously to a central system, which calculates derived values, including absolute humidity, dew-point temperature and vapour pressure, presenting the results graphically on a web-based dashboard. Each church can access its own dashboard and interrogate the graphs and underlying data in detail, while researchers and the Diocese can read the full dataset. Volunteers in each church can add markers via their online interfaces, including observations about comfort and discomfort; the timing of special services and extreme weather events, and any actions taken in the spirit of experiment. Volunteers are encouraged to develop their own theories about how their building works, and to relocate the indoor sensors to test their theories and consequent interventions. The monitoring has helped volunteers recognise problems, *e.g.* if indoor absolute humidities are high, there might be an undetected water leak.

Heating accounts for 80% of a typical church's energy demand, making it a major candidate for action. Monitoring has confirmed that air heating can be particularly expensive in these massive buildings with tall ceilings; and air temperature an unreliable indicator of comfort. Previously unknown issues also came to light, *e.g.* one churchwarden thought their heating was programmed to start an hour before a service, while it actually came on eight hours earlier and overshot, before settling back to the set temperature, which itself was probably too high.

Central to the project is whether one can empower building users by giving them basic knowledge from history and science, and encouraging co-creation. Occupants and experts have come together in two principal ways:

Workshops for volunteers and professional advisors, held in different church buildings involved in the project. These aimed for:

- knowledge transfer via active learning (Silberman 1996) to debunk assumptions and introduce participants to the basics of comfort and energy use
- encouraging deeper thinking around heating, ventilation and maintenance
- co-creation, with participants working together with researchers to investigate potential problems and solutions.

Continued technical support, including:

- access to the environmental monitoring data
- a series of information videos
- the chance to discuss data and ideas with project officers and experts, and to obtain support for experimentation.

Active learning promotes creativity, reflection and memorable engagement. For example, workshop attendees found themselves role-playing water molecules interacting with building materials. Subsequent discussions confirmed that participants had gained a deeper and more intuitive understanding of complex issues than lectures alone could have done. Activities such as creating collages of comfort and discomfort, and experimenting in groups with tools including infrared cameras, draperies, heated cushions and cloths, gave extensive opportunities for co-creation. Discussing, theorising and laughing as a group helped embed the understandings being developed.

Each workshop took place in a different building, and was adapted to suit, so participants could immediately apply the thinking to the building's specific features and problems. This not only helped volunteers from that church, but also widened the understanding of all attendees, including the architects, engineers and surveyors, and the presenters themselves. A very popular activity (especially fruitful in medieval buildings) was hunting for signs of comfort methods used in the past (Figures 1 and 7). Participants have been keen to test simple passive approaches, including radiant breaks, devices to control ventilation and draughts, and personal comfort systems, especially heated cushions, where products suited to church pews are already available. There was particular enthusiasm for the idea of using cloth to trap downdraughts from windows, with one set of attendees quickly experimenting in their own church and finding that cloth greatly improved comfort and reduced the desire for heating, findings supported by thermographic images.

Figure 7: Manuscript illustrations reveal many elements used for comfort that have since been forgotten.

*Source: Christine de Pizan Presents her Manuscript to Queen Isabeau of Bavaria, France, c.*1410–14 (detail). Courtesy: British Library, London, Harley MS 4431, f. 3^{r}. Public domain. Annotations: Robyn Pender.

Participants showed tremendous creativity. For example, one volunteer observed that every church inevitably contains a range of environments, and every user has different preferences. She wondered if this could be turned to advantage by 'comfort mapping' the church, perhaps using coloured cushions, so turning a building's quirks from problems to be solved into features to be exploited. In the enthusiastic discussion that followed, others suggested involving congregants in

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the mapping, so they could also appreciate the underlying principles. With these and many other experiments now underway, feedback is confirming the potential for people-first retrofit to bring about rapid improvements in comfort and energy performance.

7.2 PROJECT 2: PEOPLE-FIRST DOMESTIC RETROFIT

The people-first approaches and methods used in the above-mentioned church examples can be extended to dwellings. A volunteer project in a village conservation area in Northern England is testing whether a similar approach to the church project could work in dwellings (Leaman *et al.* 2024). It responds to concerns of the North York Moors Association about the impact some intrusive retrofits have had on the appearance and durability of the sandstone buildings that help to give the area its character. A donation covered the purchase of equipment to monitor temperature and RH in the principal living room and main bedroom of 10 houses, with CO_2 monitoring added, as a proxy for occupancy and air quality. As in the churches, the aim is to empower individual occupiers with insights, reinforced by monitoring data, experiments and local conversations. Introductory surveys incorporated discussions with occupants; assessment of their heating, ventilation and water systems; spot checks of air temperature, RH and CO_2; and investigations of building condition using moisture meters, infrared thermography and smoke pencils for air leakage. The proprietary monitoring system initially selected ran into problems with wireless communication in the hilly location, so in early 2025 the team switched to the same LoRaWAN equipment as the churches, with a similar user interface.

Moisture management quickly emerged as a major concern: the village is exposed, while the weather in late 2024 had been unusually wet. Six houses are built of the local sandstone, which appears prone to moisture retention. Over the years, many houses have had some retrofit measures installed, especially roof insulation, full or partial double-glazing and one heat pump. In several houses, these have reduced ventilation too much, while one 1960s house, fully insulated internally a decade ago, shows numerous symptoms of trapped moisture from surface and interstitial condensation, together with rainwater ingress around poorly installed replacement windows.

Building condition is a critical risk factor in retrofit (whether fabric- or people-first), with complex problems arising from fabric type, maintenance, ventilation, heating and other environmental issues; and from systems and controls and equipment; and occupants and their activities. Maintenance and moisture problems will be a priority as the project continues.

8. CONCLUSIONS

This paper argued that thermal satisfaction can be achieved by low-cost, low-risk actions by harnessing an understanding of thermal physiology, *e.g.* by taking proper account of how thermal radiation and air movement affect human physiology. Thermal comfort does not depend only on internal air temperature. The placement of radiant barriers (*e.g.* the use of draperies and other materials) between occupants and cold surfaces nearby can be effective solutions and reduce the need to achieve and maintain a narrow range of indoor temperatures.

The projects outlined here are not sufficiently advanced to make robust statements about how much energy and carbon people-first retrofit can save. However, other research suggests major opportunities. For example, van Moeseke *et al.* (2024) studied 23 dwellings in Brussels, where occupants were helped to explore the effects of clothing, adaptation and personal comfort systems on space heating requirements. Over the three-year project, average indoor temperatures fell from 19 to 15°C, energy used for heating halved and electricity consumption stayed the same. The authors note that some savings might have been at the expense of neighbours. They also reported that, as the project continued, changes were increasingly clothing related, with personal comfort systems used less frequently. This fits with conclusions about the benefits of recovering thermoregulation, and that once occupants know they have the agency to tackle discomfort quickly, they become more relaxed about the actual conditions. Alliesthesia may also be involved: encountering and recovering from slight discomfort can be more pleasurable than avoiding it altogether.

Gary Raw, an expert in psychology and comfort at the Building Research Establishment (BRE) in the 1990s, once observed: 'People are the best measuring instruments; they are just harder to calibrate.' A people-centred approach to retrofit allows occupants to calibrate themselves, by paying attention to their own senses and learning to trust them. The background science and history suggests this could support the sufficiency agenda, improving occupant health whilst using considerably less upfront and operational energy and carbon.

As participants in the church project shared their experiences, they became more confident and adventurous. Both volunteers and professionals also took insights back into their own homes. By contrast, a too-common experience of standard retrofit planning is a gulf between the prospects offered and the shortcomings of the completed project. In spite of this, statutory authorities tend to focus on market solutions, regulations and grants, which by their very nature favour large-scale intrusive technical interventions, fostering efficiency and consumption, not sufficiency. Many authorities, not least local councils, also lack the time and expertise needed to support occupants effectively, by patiently providing knowledge support and encouraging simple interventions, better maintenance and fostering appropriate local skills.

A champion on the ground is essential: the lynchpin of Project 2 is a retired electronics engineer who also works in the local repair café. He helps residents with simple interventions, including draughtproofing, secondary glazing and screens; organises events; tests, certifies and lends equipment such as heated panels and cushions; and reviews the monitoring. There is a need for local advisers embedded in communities, informed by the background science and history, and familiar with realistic low-cost measures: 'barefoot house-doctors'. Even more important is for communities to experiment together, share stories of what did and did not work, and build a corpus of local knowledge. They could then go on to network with others (perhaps facing slightly different challenges), progressively developing practical understandings of how to care for the built environment until they become 'common sense' once again.

The research described here is an initial attempt to explore that pathway. Run on shoestrings by passionate researchers and volunteers, it was deliberately aimed at the grassroots. Co-creation demonstrably helped volunteers regain confidence in working with the buildings they love, to support the environments they need. People-first retrofit also proved popular with professional attendees who frequently expressed frustration with ill-considered imperatives to impose risky interventions on well-loved buildings that have been in successful use for many decades (often centuries), and all in the name of standardised outcomes that may not even be desirable. Framed thoughtfully, people-first action could be extended from churches and dwellings to buildings of all types, including commercial properties. Indeed, it could help overcome the many barriers against effective carbon action that arise from tenant–landlord relationships, who pays and who profits. Where measures are people- and passive-first, everyone can potentially benefit.

8.1 WHAT NEXT FOR RESEARCH AND PRACTICE?

Critical to success has been researchers and communities working together. Could local authorities facilitate this? Schools? Universities? Discussing people-first retrofit in neutral territory such as church halls and libraries may attract the many people and businesses keen to make a difference, but wary of marketing and greenwashing.

For 'market solutions', can policymakers turn away from product-based measures and mass markets to outcome-based ones, grounded in local services? Local builders and other tradespeople, typically small and medium-sized enterprises (SMEs), are well placed to support maintenance and simple low-cost measures, and develop and pass on solutions they find successful in their neighbourhoods. The Optimised Retrofit programme in Wales (FMB Cymru 2021; Welsh Government 2025) showed that pointing retrofit action toward SMEs can be a good step towards sustainability (Morgan *et al.* 2024), and provide local economic multiplier effects. One possibility might be to work with bodies such as the Federation of Master Builders (FMB) to offer members active learning and monitoring similar to those described here.

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A people-first approach to retrofit—starting with making occupants, professionals and property managers familiar with the underpinning fundamentals of science and history—has enormous potential to benefit buildings of all types, ages and uses, and avoid their tenants, owners and managers feeling railroaded into costly and risky major interventions. While considerable positive reinforcement is required before most people learn to trust their own senses, once improvements are seen and felt, lived experience can drive good practice forward. Low-cost wireless monitoring appears key: once data are made accessible to occupants with some basic analysis, issues can be examined and discoveries shared. Could starting small and going viral in this way provide the momentum needed to tackle the climate emergency?

NOTES

1 Withdrawal of government funding from UK national research institutes, including the Building Research Establishment (BRE), has also made it increasingly difficult to maintain knowledge bases, and for proponents of traditional materials and systems to produce evidence of efficacy in the forms demanded by specifiers, insurers and regulators.

2 An example: two owner-occupiers attended a local retrofit study day and subsequently commissioned PAS 2035-style plans, independently and two years apart. They both found the results unhelpful and discouraging (PHCAAC 2025). The recommendations were based on theoretical calculations for the buildings as artefacts, not as systems with their actual occupancy included. Low-cost measures were largely absent, whilst some proposed upgrades were both expensive and technically and logistically questionable. These included expensive changes to roofs and rear walls, which were at great risk of being discarded by a new buyer, who in this locale is very likely to extend upwards and outwards.

3 Monitoring 85 churches for nearly two years has produced an unprecedented amount of data for this sector. The authors are currently testing innovative artificial intelligence (AI)-based approaches on the dataset, including extracting general information such as typical patterns of heating and distribution curves for temperature and RH. They are also comparing the daily and seasonal hygrothermal responses of churches of different ages and constructions.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA ACCESSIBILITY

The data are currently confidential to the buildings concerned, the researchers and the Diocese of Sheffield. In due course, the authors plan to make the data available in an anonymised form. Important findings will also be summarised in a second paper.

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