Energy Proceedings
Vol 55, 2025

ISSN 2004-2965

Analysing the Effects of Common Passive Cooling Strategies in UK Homes

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ABSTRACT

With rising summer temperatures and the increasing frequency and intensity of heatwaves, the risk of overheating in the UK is becoming a larger problem. During the heatwave affecting the country in July 2022, temperatures in London reached over 40°C for the first time in recorded history. With only 2% of homes in the UK having active cooling, most residents must rely on passive strategies to combat heat. Using information obtained from deliberative workshops conducted within the EPSRC-funded 'Flex-Cool-Store' project, this paper makes use of a commercial building modelling software, IES VE, to simulate the effects of common passive cooling strategies and assesses the effects of each one.

Keywords: passive cooling strategies, IES VE, heatwaves

1. INTRODUCTION

The UK Meteorological Office predicts that the UK will face warmer summers alongside an increase in the frequency and intensity of heatwaves [1]. Heatwaves have already proven to cause severe consequences: In the summer of 2022, in the UK alone 2,985 people died from heat-related incidents [2]. Although in general the UK population has underestimated the health impacts arising from heatwaves and normally associate warmer temperatures with a time to relax and outdoor activities [3], these perceptions are changing.

The Department for Business, Energy & Industrial Strategy conducted a survey throughout 2017-2019 to assess thermal comfort in homes. A relevant finding was that only 2% of homes had air conditioning units, 50% used fans, and 44% had no electrical cooling equipment [4]. It is inferred most UK households thus rely upon passive cooling strategies to combat overheating.

The UK Government has released guidance on combatting overheating advising residents on how to stay cool [5]. Whilst much of the report focuses on adjusting behaviour, there is information as to how to cool dwellings. Passive cooling strategies mentioned are:

1. Close blinds or curtains on windows exposed to direct sunlight.
2. Close external shutters or shades (if present).
3. Open windows (if it is safe to) when the air feels cooler outside than inside (e.g. at night), and ventilate the dwelling.

During 2022, as part of work carried out within the EPSRC-funded 'Flex-Cool-Store' project, 4 deliberative workshops were conducted with a range of householders over South West England. These examined participants-lived experience of heatwaves and their approaches to combatting overheating in their homes [6]. Coping strategies cited included covering inner window areas with foil, installing insulation or shutters, ventilation, closing internal shutters, and opening/closing windows.

In line with the previous findings, this paper studies the efficacy that passive cooling strategies may have on reducing indoor temperature in typical UK dwellings. From the alternatives, window covering, opening/closing windows, and combinations of both approaches were selected as these were believed to be the most effective.

Using IES VE, a commercial building modelling software, alongside typical meteorological year (TMY) weather files and weather station data, detailed thermal models were created to estimate indoor temperatures within a detached house and a flat. Temperatures experienced during an average summer and from the recorded heatwave experienced in 2022 were examined. The models were assessed for three UK locations to understand the effect of passive strategies in each place.

2. MATERIAL AND METHODS

2.1 Dwelling properties

The most common dwelling types in the UK as per the housing survey in [7] are: terraced, detached, semi-

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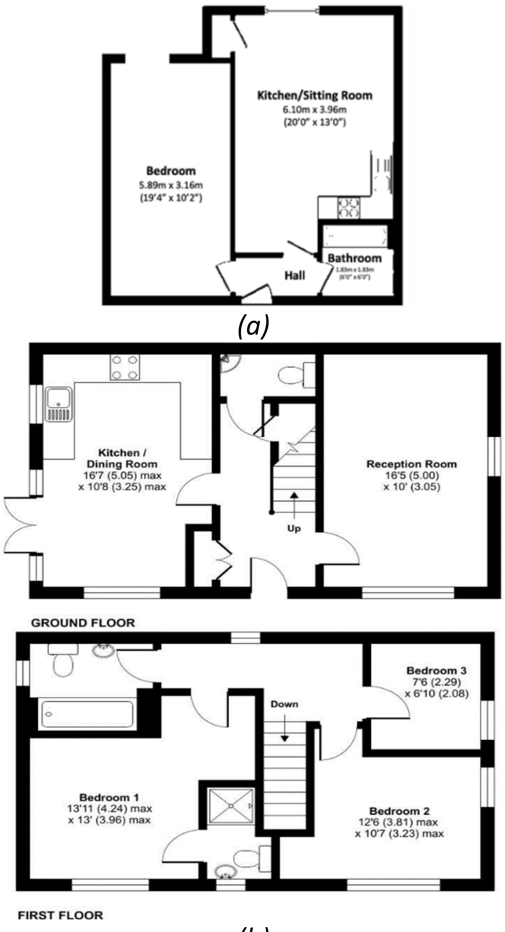
This is a paper for the 16th International Conference on Applied Energy (ICAE2024), Sep. 1-5, 2024, Niigata, Japan.

detached houses, bungalows, and flats. For this work, a typical detached house and a top floor corner flat were selected as these dwellings are the most susceptible for overheating. Floor plans and images used to create the models were obtained from [8] and are shown in Fig. 1.



(a)

(b)

Fig. 1 Floor plans for: (a) flat; (b) detached house [8].

Thermal efficiency has a large impact upon indoor temperature, with less thermally efficient surfaces leading to increased conduction gains. Thus, the best and worst case efficiencies for UK buildings were adopted in this paper. These were obtained from [9] following a detailed review on building constructions in the UK.

In a detached house walls face in all directions. However, with the chosen floor plan (Fig. 1b), the largest and highest quantity of windows are on the south wall. To emphasise overheating, a north-facing dwelling was thus used. The selected flat has two exposed walls with windows on the north-facing wall only. Thus, an overall south-facing dwelling was used (Fig. 1a).

2.2 Locational data

London, Manchester, and Glasgow were selected to assess the effects of location, with London having the highest average temperature and Glasgow the lowest. TMY files were adopted from [10] for each location, and weather station data for July 2022 was obtained from [11]. Energy Plus Weather (EPW) files were created for each place to accurately model the 2022 heatwave and visualise its effect for each passive strategy. In addition, an average summer was simulated for London to assess the long-term effects of each passive cooling approach.

2.3 IES VE

IES VE is a commercially licensed software and validated against standards from ASHRAE and CIBSE. A verification of the modelling methodology here adopted was reported in [9] to provide confidence in the results.

2.4 Modelling approach

2.4.1 Window operation

IES VE's MacroFlo package was adopted to simulate window operation. This allowed specifying window/door opening schedules. Top-opening windows were selected. It was assumed only 20% of the window areas were operable—in line with restrictions above the ground floor to maximum openings of 100 mm [12]. In other words, windows could not be opened too wide.

Three scenarios were selected to simulate realistic window operation: Always open, always closed, and opened on a schedule (closed from 6am to 9pm).

2.4.2 Covered windows

Transmittance is the fraction of light passing through a material [13]. Its value ranges from 0 to 1, with higher values allowing more light through. To simulate the effects of covering windows with an opaque reflective surface to keep solar radiation from entering the dwelling, window transmittance values were set to 0 while keeping the window closed. A control simulation was run with standard glass for a suitable comparison.

2.4.3 Covered windows

Additional simulations were carried out with covered windows (as discussed in Section 2.4.2) and both scheduled and constant window openings (see Section 2.4.1) to understand the effects of a combined approach.

2.5 Dwelling temperatures

To simplify the output results for each dwelling, individual room temperatures were combined into a single average temperature T_{avg} using

$$T_{avg} = \frac{\sum_{i=1}^{n} a_i T_i}{\sum_{i=1}^{n} a_i} \quad (1)$$

where a_i is the individual room area and T_i is the individual room temperature.

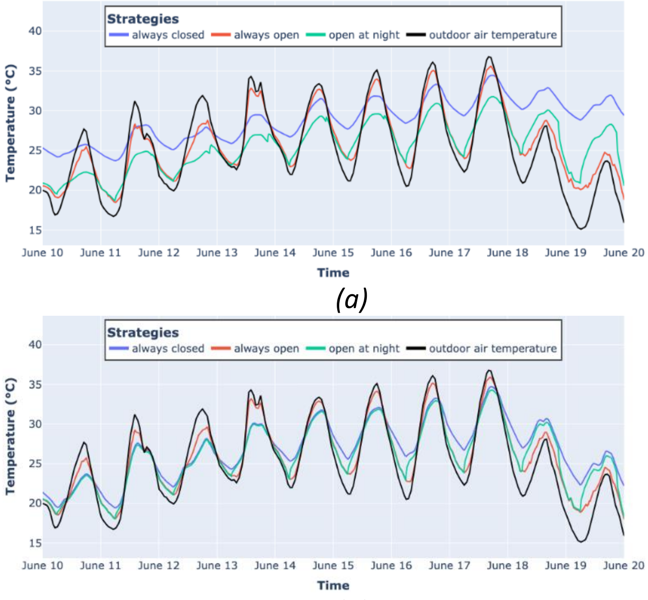
3. RESULTS AND DISCUSSION

3.1 Window operation

Figs. 2 and 3 show the effect of window operation for a detached house and a flat in London during the TMY adopted in this paper (between 10th and 20th June). Window operations were assessed for dwellings with a high and a low thermal efficiency. In all figures, the outdoor air temperature is shown with a black trace. The combined average indoor temperature when windows are always closed is shown with a blue trace, while a red trace shows the temperature when the windows remain always open. The green trace shows the temperature for an opening schedule as described in Section 2.4.1.

Based on Fig. 2, opening windows at night (green trace) is the best passive strategy. These results reinforce the effectiveness of night-purge ventilation [14]. This passive method works by opening windows only when the outdoor temperature is lower than indoors, causing cooler air to enter the dwelling and reduce the internal temperatures. However, if not done properly, opening windows when the external temperature is higher may cause a sharp increase in average internal temperature. This effect is captured by the model in Fig. 2a on June 12th when the window opens at 9 pm (green trace).

It is worth noting that night-purge ventilation for ground floor windows may not always be practical due to security concerns or for buildings not having operable windows. Leaving the windows closed (blue trace) during a heatwave and opening them when the outdoor temperature drops (red trace) is a suitable workaround.



(a)

(b)

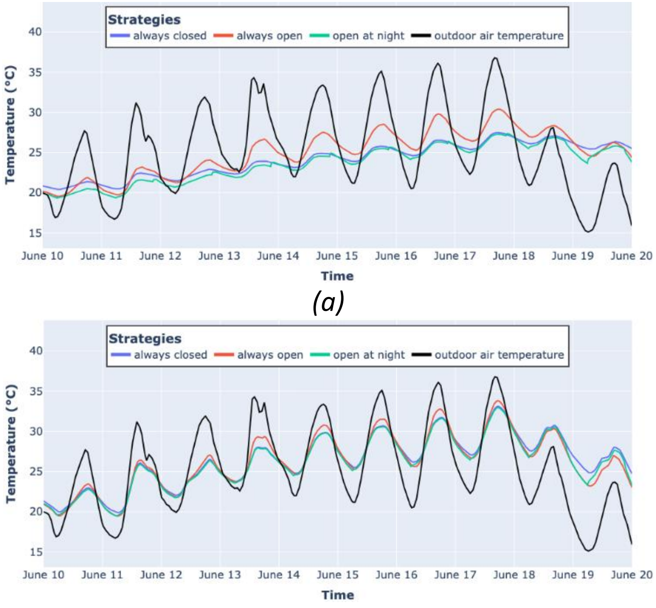
Fig. 2 Effects of window operation. House with: (a) high thermal efficiency; (b) low thermal efficiency.

Opening the windows in detached homes with a high thermal efficiency (and thus high insulation) is clearly vital, as without doing so the indoor temperatures following spikes in the ambient temperature will remain high. This is visible in Fig. 2a after June 18th, where heat is retained for prolonged periods (see blue trace).

As shown in Fig. 2b, all strategies also have a similar behaviour for a detached house with a low thermal efficiency. Night-purging provides the best temperature reductions. However, the effects of each strategy are significantly muted. This is because the low thermal efficiency of the external surfaces allows for heat gains entering the building freely from conduction gains.

From Fig. 3, for flats the difference between each strategy is minimal irrespective of the dwelling's thermal efficiency. This is because the chosen flat layout has a small total window area (Fig. 1a), so ventilation due to window opening has a reduced impact. For flats with low thermal efficiency (Fig. 3b), the choice of passive strategy during a substantial rise in ambient temperature is redundant. Both night-purging (green trace) and closing windows (blue trace) have a similar effect. Night-purging cools the flat marginally under these circumstances. Leaving the windows open (red trace) causes an increase of ≈1°C in peak temperature for a few hours. As the draught entering the building provides a cooling effect similar to a fan, leaving the windows open in older dwellings may be beneficial, removing the need for fans.

Since the effect of window operations on the indoor temperature of flats is not pronounced, only detached houses are explored in the paper beyond this point.



(a)

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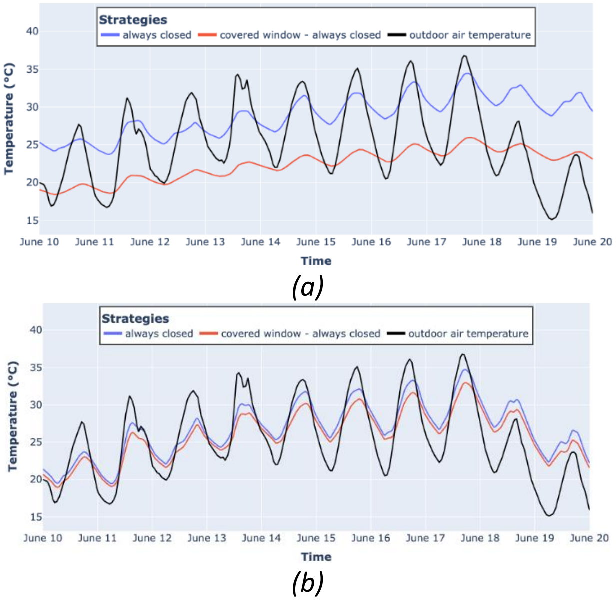
Fig. 3 Effects of window operation for a flat with: (a) high thermal efficiency; (b) low thermal efficiency.

3.2 Windows covered

Fig. 4 shows the effect of covering windows on the indoor temperature of a detached house in London (red trace) compared to simply keeping windows closed (blue trace). Blocking out the solar radiation with an opaque material has a profound effect on internal temperature for the house with a high thermal efficiency (Fig. 4a), with a reduction of ≈8°C at peak times. This result was expected as covering windows prevents solar gains into the dwelling. However, such an effect is muted in a less thermally efficient house (Fig. 4b, ≈1-2°C at peak times).

Although covering windows is useful to reduce indoor temperatures, this method prevents natural light from entering the building, which may cause drowsiness, mood impairment and poorer cognitive performance in residents [15]. Furthermore, whilst highly effective during a heatwave, window covering may be difficult to install and may need to be removed as soon as temperatures drop—otherwise, an increased heat demand may be experienced during colder months.



(a)

(b)

Fig. 4 Effects of covering windows. House with: (a) high thermal efficiency; (b) low thermal efficiency.

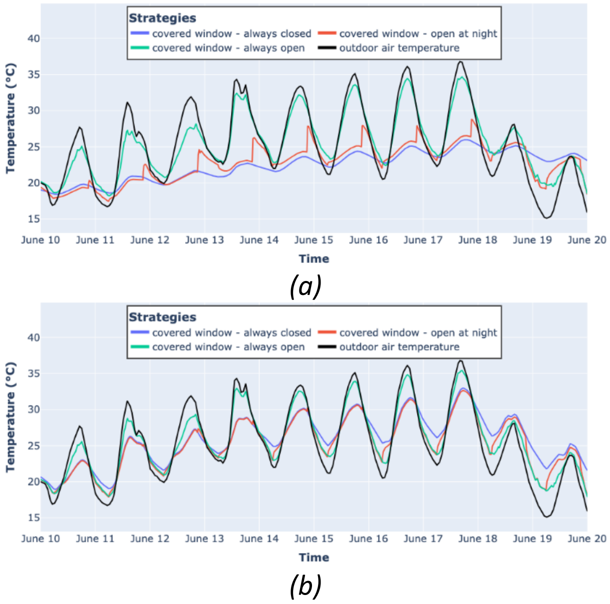
3.3 Combined methods

Fig. 5 shows results for a combination of window operation strategies. Night-purging is the best approach when combined with window covering (red trace). However, as seen on June 12th, if a window is opened too early, the additional heat gain cancels out the benefits of the covers.

Without careful control of opening times, leaving the windows closed is important during a heatwave (blue trace). This is because having much lower internal temperatures, upon opening windows, may cause a quick inrush of hot air. However, leaving windows open and covered (green trace) is ill advised as the increased ventilation counters the decrease in solar gains.

For a house with a low thermal efficiency (Fig. 5b), night-purging provides the best results. However, these effects are marginal compared to leaving the windows closed (blue trace), with incorrect window opening times having less severe impacts on internal temperature.

Based on the results in this section, night-purging, if done correctly, results in the dwelling cooling down faster at night.



(a)

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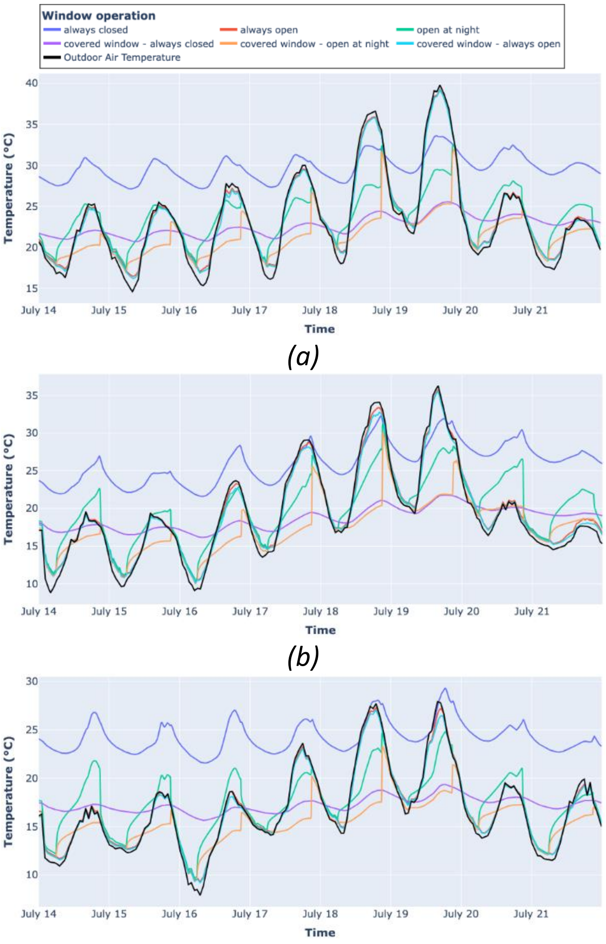
Fig. 5 Effects of combined strategies. House with: (a) high thermal efficiency; (b) low thermal efficiency.

3.4 Effects of dwelling location during a heatwave

The effects of a heatwave on indoor temperature may be significantly influenced by geographical location. This is examined in this section by assessing the effect of ambient temperatures recorded during the heatwave experienced in July 2022 on the average indoor temperature of a detached house. For this exercise, data from London, Manchester, and Glasgow were used. Simulation results are shown in Fig. 6.

Ambient temperatures in London reached above 40°C (black trace, Fig. 6a). Therefore, leaving windows open (red trace) may have caused internal temperatures to dramatically increase, as shown on July 19th. At peak ambient temperatures, an increase of ≈9°C is observed.

In Glasgow, the outdoor temperature only briefly reached 28°C (black trace, Fig. 6c). Thus, cooling provision is less important. Night-purging (green trace) could have easily kept internal temperatures to the low 20 degrees. Thus, methods such as window covering (purple, orange, blue traces) may have not been needed.



(a)

(b)

(c)

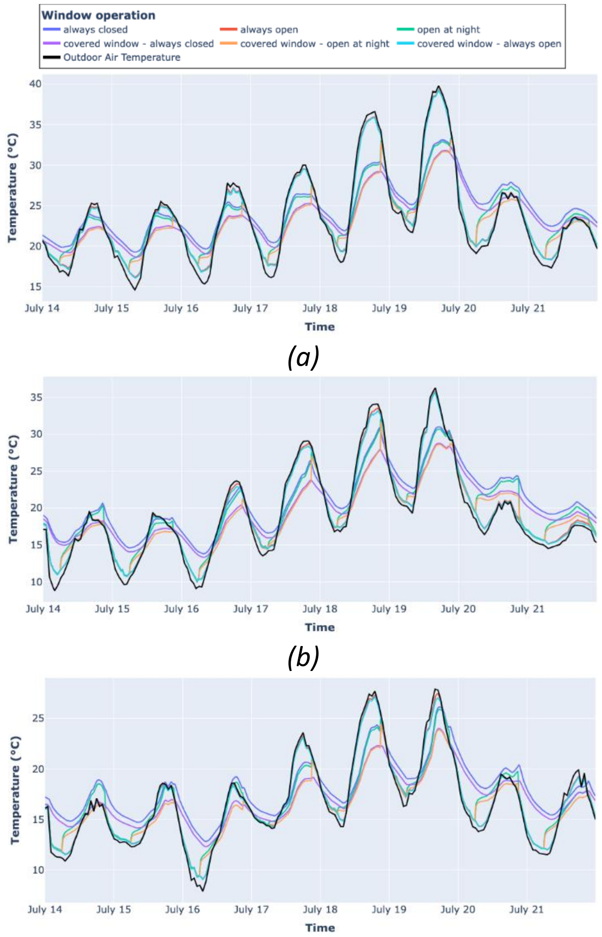
Fig. 6 Effects of location on passive strategies for a high thermal efficiency detached house in: (a) London, (b) Manchester, (c) Glasgow.

An adequate cooling strategy for Manchester differs (Fig. 6b). Adopting night-purging only may lead to indoor temperatures reaching the high 20 degrees (green trace). Thus, window covering may be further needed to reduce internal temperatures as in Glasgow (orange). However, this would only be successful if night-purging was done at adequate hours. As shown, an incorrect opening time may cause a significant increase in indoor temperature. In this case, purging before a heatwave and keeping windows closed throughout was more effective (purple).

As shown in Fig. 7, for a dwelling with low thermal efficiency, passive strategies are less effective. Results match with those in Fig. 2. For instance, Fig. 7a shows that in London all passive methods assessed fail to reduce overheating, with temperatures reaching the high 20 degrees and above. In these cases, either improving the thermal efficiency of the dwelling (via new windows, roof insulation, cladding) or installing active cooling would have been required for thermal comfort.

The World Health Organization recommends fans and air conditioning set-points at 27°C to combat overheating, with temperatures beyond that putting stress on the heart and kidneys [16]. Based on the heatwave data adopted, heat-related health concerns would have been less severe in Manchester and Glasgow. For these locations, night-purging combined with fans would have been suitable to reduce health risks. However, for less thermally-insulated homes in London, further measures would have been required to reduce the health risks.

The results presented in this section lead to an interesting reflection. If the intensity of heatwaves continues to rise, dwellings in London may be forced to install active cooling, whilst passive strategies may be required even in northern cities such as Glasgow.



(a)

(b)

(c)

Fig. 7. Effects of location on passive strategies for a low thermal efficiency detached house in: (a) London, (b) Manchester, (c) Glasgow.

3.5 Discussion on the limitations of the methodology

The modelling approach assumes there is no external shading and considers standalone buildings. To counteract this, all dwellings were assumed empty and heat gains from equipment, people and lighting were ignored. Particularly in exposed buildings, temperatures can increase further due to unmodelled heat gains.

Only two cooling passive strategies were studied. Additional methods such as closing blinds and external shutters can be studied as part of future work.

4. CONCLUSIONS

This paper conducted a detailed analysis of common passive cooling strategies to combat overheating in UK dwellings. Weather conditions obtained from weather stations during the heatwave in July 2022 were also simulated. These were used to assess the effects of the same heatwave in three geographical locations.

The most effective approach was inside window covering with an opaque material combined with night-purging. However, night-purging at incorrect times may lead to high indoor temperatures. The worst strategy involves leaving windows open, as this causes internal temperatures to match ambient temperatures. Passive strategies in poor-thermally efficient dwellings are less effective due to the additional conduction gains.

Dwelling location had a significant impact on the strategies required to combat overheating. Even when very high temperatures may be reached in the south of England, this was not the case in Scotland. As such, a suitable cooling strategy must be chosen carefully. In other words, while it may be sufficient for some locations to keep windows closed or open to prevent overheating, active cooling may be the only solution in other places. Establishing these boundaries in a warming world will be critical to a) prevent health risks and mortality, b) reduce overheating in dwellings, c) restrict adoption of active cooling to locations that really need it, d) reduce peak electricity loads due to active cooling during heatwaves.

ACKNOWLEDGEMENT

The work presented in this paper was supported by the Engineering and Physical Sciences Research Council (EPSRC), UK Research and Innovation, through the project 'Flexibility from Cooling and Storage (Flex-Cool-Store)' under grant EP/V042505/1.

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