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Impact of the Envelope Geometry on Cooling Demand in Very Airtight UK Dwellings under Current and Future Weather Projections

Yahya Lavafpour*, Steve Sharples

School of Architecture, University of Liverpool, Liverpool L69 7ZN, United Kingdom

Abstract

The Passivhaus strategy employs super insulation to reduce the heat transfer through the building envelope. It has been argued that super insulated homes are vulnerable to summer overheating risks, even in the current climate. The UK is expected to experience hotter and more extreme summers in the coming decades and the risk of buildings overheating may become very significant in future climate scenarios. The Passivhaus approach can use much of the solar energy from its relatively large glazing in south facade but this large glazing may eventually lead to overheating in summer time. The study used parametric design modelling to generate differently inclined facade geometries for south elevations. Each elevation was then simulated by means of dynamic building simulation software in order to examine to what extend inclined wall mitigate summer overheating risk for Passivhaus dwellings in the UK under alternative future weather projections.

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Keywords: Passivhaus, Overheating, Inclined south-facade;

1. Introduction

In the design stage, architects mostly consider the geometry of the building as an aesthetic matter and ignore the importance of geometry in the energy consumption and environmental performance of the building. On

* Corresponding author. Tel.: +44-7572419938;
E-mail address: y.lavaf-pour@liverpool.ac.uk

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the other hand, sometimes the architectural aesthetics are being neglected due to an over focusing on energy efficient matters, which can result in cube-shaped homes with small windows. Nevertheless, energy simulation is mostly conducted after the building design stage and it is not integrated into design decision making [1]. Passive design choices in the early architectural design stage, when the architect tends to use sketching to generate and explore the first design alternatives i.e. equal to RIBA stage C of design [2], represent important strategies towards decreasing energy demand in buildings. The massing and shape of the building is one of the first passive features of the design and can be considered as a good starting point for any sustainable design.

Historically, a single detached house has typically been built in a cubic or rectangular shape. However, the hi-tech movement and massive improvement in material technology has allowed new forms and shapes in designing buildings. During the past decade there has been an ongoing interest towards nonrectangular and prismatic building shapes [3]. Buildings with prismatic forms have received great attention in architectural journals and had a dominant impact on the cities in which they are built (Fig 1). This study sets out to investigate to what extent the geometric form of a Passivhaus dwelling in the UK could mitigate the overheating risk for current and future weather scenarios. In this paper a particular focus was the optimum inclination of a south facade to make use of the geometry to self-protect the building.

Fig. 1. (a) Museum of 21st Century Arts by Zaha Hadid; (b) the new building of the Geodynamics Institute, Athens by Zerefos Tessas Architects [3]

11. Background and literature review

One of the main challenges in designing a Passivhaus is the forming of the large openings for the south elevation [4]. The Passivhaus Primer publication states “In order to benefit from the useful solar gains a Passivhaus requires the glazing to be optimised on the south façade with reduced glazing on the North façade” [5]. Passivhaus tries to benefit from the higher levels solar energy incident on the south façade (in the northern hemisphere), and so Passivhaus dwellings are designed with a large area of glazing on the south facade. There is not much glazing on north and east facing façades, and in most cases no glazing in the west façade to avoid discomfort heat gain through openings (Fig 2). Taking into account the climate change warnings from the Chartered Institution of Building Services Engineers (CIBSE) and Zero Carbon Hub [6, 7] these large openings, combined with very high levels of air tightness and thermal insulation, may lead to a summer overheating risk in the future, especially for the most at-risk cities, like London, where urban heat island impacts will add to the overheating problems [8].

Fig. 2. (a) Larch house [25], (b) Unity College Passivhaus [9], (c) The Go Home Passivhaus [10]

Chan and Chow [11] examined the thermal performance of an office building with inclined walls set at different angles in 3 different climates in China. The results of this study showed that an inclination angle of 120° (i.e. 30°beyond the vertical) was appropriate for an inverted pyramidal buildings in Hong Kong but that inclined walls were not of benefit in Shanghai and Beijing climates. Further, it has been argued [11] that by casting shadows on a building then the reduction in cooling load can eventually lead to an increase the heating loads for certain climates. However, Zerefos et al. [3] examined the energy behaviour of a case study in Athens with polygonal and prismatic envelope shapes. Their research suggested that the prismatic formed building had lower solar gain compared to its orthogonal counterpart and consumed nearly 8% less energy in an annual cycle. They concluded that prismatic buildings performed better compared with rectangular buildings in terms of incident solar radiation and annual energy consumption.

McLeod et al. warned that Passivhaus and other super insulated dwelling types were already at risk of overheating in the UK and Northern Europe [12]. This could lead more home owners to install air-conditioning systems to avoid summer time thermal discomfort, an approach that is not going in the same direction as the UK government's target of 'zero carbon' buildings in the UK. The risks of overheating in super insulated Passivhaus dwellings have been highlighted in a number of studies [13-15]. These studies from northern Europe call for more investigation for UK Passivhaus dwellings since they have a relatively similar climate: "*There is, however, a growing body of evidence that modern energy efficient, i.e well insulated, airtight, dwellings are suffering from overheating, and that in some cases this is resulting in adverse health effects for the occupants of these properties.*" [16]. Data derived from a national survey of summertime overheating risk in English homes [17] indicate that older homes (pre-1919) are less at risk of overheating compared with well insulated post-1990 homes. The results showed that, despite the relatively cool summer of 2007, 80% of bedrooms in newer homes exceeded CIBSE's static overheating criteria. Housing Health and Safety Rating System Operating Guidance [18] considers that high temperatures can increase cardiovascular strain and trauma, and where temperatures exceed 25°C, mortality increases and there is an increase in strokes. Dehydration is also a problem, primarily for the elderly and the very young.

2. Case study

The building chosen for case study was Larch House, a 3 bedroom, 87 m^2 floor area timber framed detached Passivhaus dwelling in Ebbw Vale, Wales. The house is one of the social housing prototypes built for the United Welsh Housing Association [19] in corporation with BRE [20], Blaenau Gwent Council [21], and the Welsh

Assembly Government [22]. It was the first Code Level 6 zero carbon Passivhaus in the UK [23]. The building achieved an outstanding draught-free construction, with an air tightness result of 0.2 ac/h @ n50. The building uses external roller blinds to prevent summer overheating. It should be noted that the blinds have been assumed to be operational by occupants in the summer time. Similar to many Passivhaus dwellings, Larch House has a large glazing area on the south elevation (55 % of the façade area). In particular, a central part of the Passivhaus principle is to make use of solar gains in winter to reduce the heating demand [5] and this means that there is a potential for overheating in summer time. Therefore, it is necessary to assimilate shading strategies to reduce this risk. In Larch House, in common with many Passivhaus dwellings, shading is controlled by internal or external blinds. However, this approach requires occupant attention and understanding. Findings from the monitored performance of the first London Passivhaus dwelling [24] reported no change in occupant behaviour with regard to the efficient use of internal shading and window openings when occupant were asked if they would change their opening and blind use behaviour. It has been also observed that the occupants of Larch House do not use the blinds to their best advantage [25].

2.1 Pilot study

Environmental modelling was undertaken using the dynamic commercial software package DesignBuilder [26], which is based upon EnergyPlus, the U.S. DOE building energy simulation program for modelling building heating, cooling, lighting, ventilating, and other energy flows. Even small changes in external wall geometry will affect the internal zoning and partitions. In this study, in order to narrow down the number of input parameters, an initial pilot study was undertaken with a simple cube shape to test the performance of the software in terms of changing wall inclination. Then these data were used to implement more sensible parameters to the existing case study with more complicated and realistic thermal zones.

The pilot modelling study used a simple rectangular box with 50% glazing in the south facade to represent the large south glazing of Passivhaus. The pilot study examined the relationship between the angle of inclination and cooling demand for weather data from two different UK locations - the original location of the Larch House case study (Ebbw Vale) and London (as this location is more likely to be effected by the impact of any UK climate change due to the urban heat Island [8]). It should be noted that all alternatives were simulated with the same building characteristics required for Passivhaus standards, including the same treated floor area, U-values, construction materials and glazing size. Building fabric characteristics for both pilot and case study were set to the U-values of 0.095 W/m^{2}K, 0.74 W/m^{2}K 0.076 W/m^{2}K and 0.86 W/m^{2}K for external walls, roof, floor slab, and external windows respectively. The HVAC template used for the simulations was supply and extract mechanical ventilation with heat recovery system switched on and dedicated hot water boiler for DHW supply. In this regard environmental control were set to 20°C and 24°C for heating and cooling set point temperatures. Results from the pilot study analysis (see Fig 3) show that the inclination angle has a noticeable impact on summer cooling for both climate zones; however, it ceases having any further impact as the angle reaches 115˚ from the horizontal. As was expected, the cooling demand decreased as the inclination angle increased. The same trend was found for the two climate zones for current and future weather files. The results showed that the reasonable angle of inclination for the case study can be obtained from the interval Θ= (90˚-115˚) in order to determine the design of envelope shape that provides solar access in winter while performing as a self-shading facade in the summer.

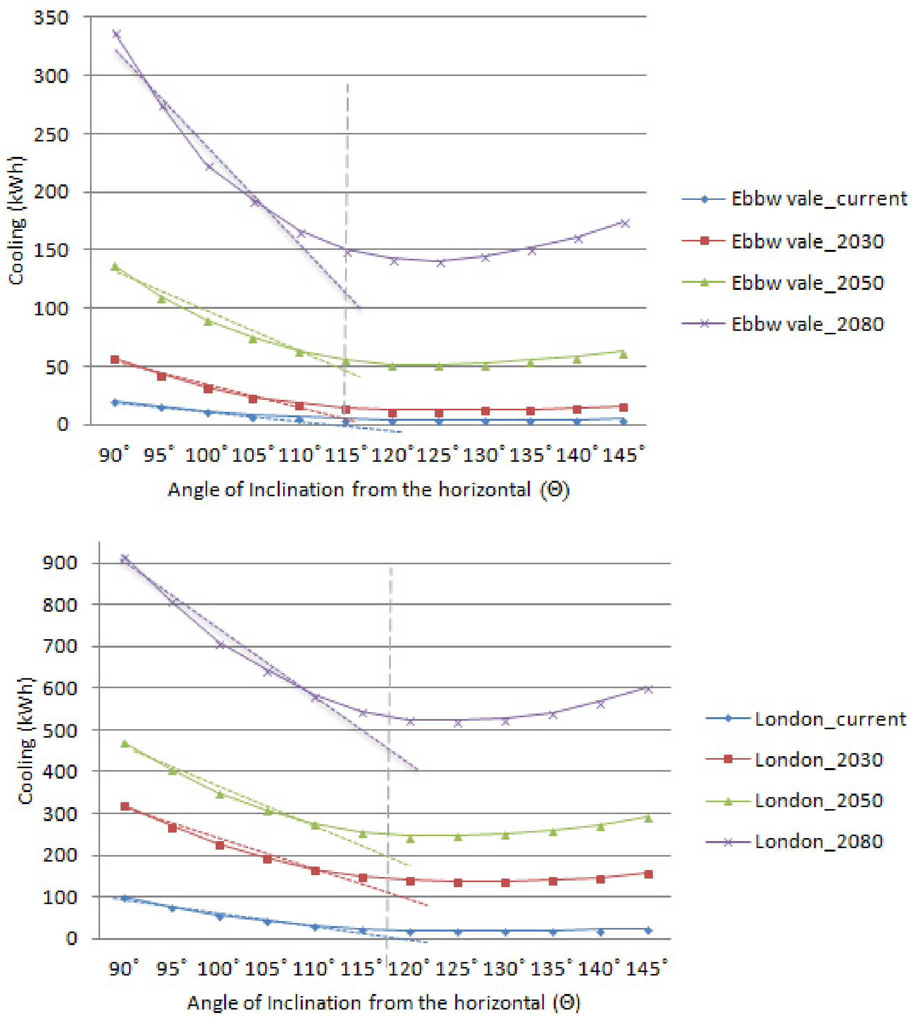

Fig. 3. Cooling load for pilot study in a) Ebbw Vale and b) London

2.2 Simulation

Larch House was designed by bere:architects [27] to achieve a dramatic reduction in energy use and CO_2 emissions without causing difficulty and reducing occupant comfort levels. For this research the first step was to model Larch House using DesignBuilder. A comparison of the dynamic building simulation and the PHPP steady state model was conducted. The key criteria focused in this study i.e. specific heating and cooling energy demand, were compared to validate the model. The results derived from the dynamic simulations were compared with to the Passive House Planning Package (PHPP) worksheet directory of the house to validate the accuracy of the DesignBuilder model simulation outputs. After checking the simulation data the inclination of the south facade was altered to replace with the original vertical wall (Θ=90˚). As a result of the pilot study's findings the different angles of inclination tested were in the interval Θ= 90˚ to 115˚for current and future weather files, including high emission tested reference year 50 percentile weather files for 2030, 2050 and 2080.

The weather data used in this study were obtained from the Centre for Energy and Environment, Exeter University [28]. The weather files were created using the UKCP09 weather generator for current and future including Test Reference Year (TRY) and Design Summer Year (DSY) for 2030, 2050 and 2080. For each time period the medium (A1B) and high (A1Fi) emission were available for 10, 33, 50, 66 and 90 percentiles, differing dramatically from medium emission TRY 10 percentile to high emission DSY 90 percentile. In this study the average values of future probabilistic scenarios were used rather than the best or worst case scenarios. This study tried to obtain an indication of trends of what might happen rather than absolute real values of temperatures and energy use. The Design Summer Year (DSY) tends to give warmer summers and this might be more suitable when looking only at summer time conditions. However, since this study considered the whole year energy performance then the TRY data would be more representative of the year. Investigating the influence of shading on the energy requirements obviously mostly refers to the summer time. Nevertheless, the simulation should not be conducted only for summer time only as shading affects both cooling and heating systems for a complete annual cycle. Thus, in this study for simulation purposes the 50 percentile high emission TRY weather data (A1FI_50%_TRY) for 2030, 2050 and 2080 were used.

A series of dynamic simulations considering different angles of south façade inclination, including 95˚, 100˚, 105˚, 110˚ and 115˚, were carried out for two climate zones, Ebbw Vale and London, using current and future climate scenarios. The simulations were conducted to examine the risk of overheating in Larch House. The simulation found that, overall, the house performance was at a high standard, especially in the heating period for current weather, but that there was a risk of overheating – a risk that was aggravated under future weather scenarios.

Figures 4 to 7 illustrate that inclination angle can play a major role in the heating and cooling demand of the house. Figure 4 shows slight changes in cooling load under current weather situation for Ebbw Vale when the inclination angle increases. The changes, however, for London in the current climate show a downward trend when the inclined wall casts a shadow on the south facade. Overall, the simulation results demonstrate that there is a small risk of overheating for current weather and that the inclined wall can overcome the risk of overheating, especially for London. Data derived from the simulation reveal that London will experience a dramatic increase in summer temperatures and cooling demand may become crucial in the near future. For Ebbw Vale, this risk is only marginally increased. However, it generally appears to be important to implement passive design strategies to mitigate the potential overheating problem.

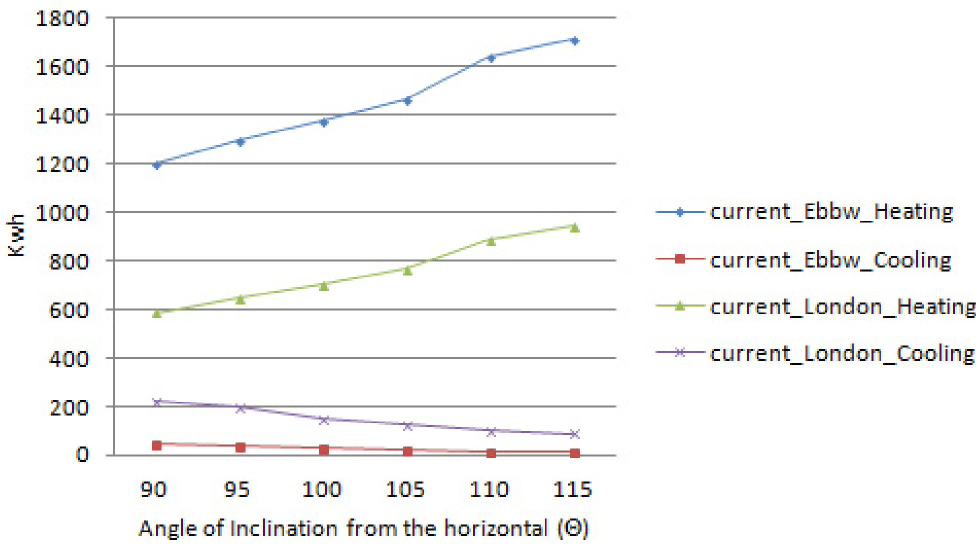

Fig. 4. Cooling and heating load for current climate in Ebbw vale and London

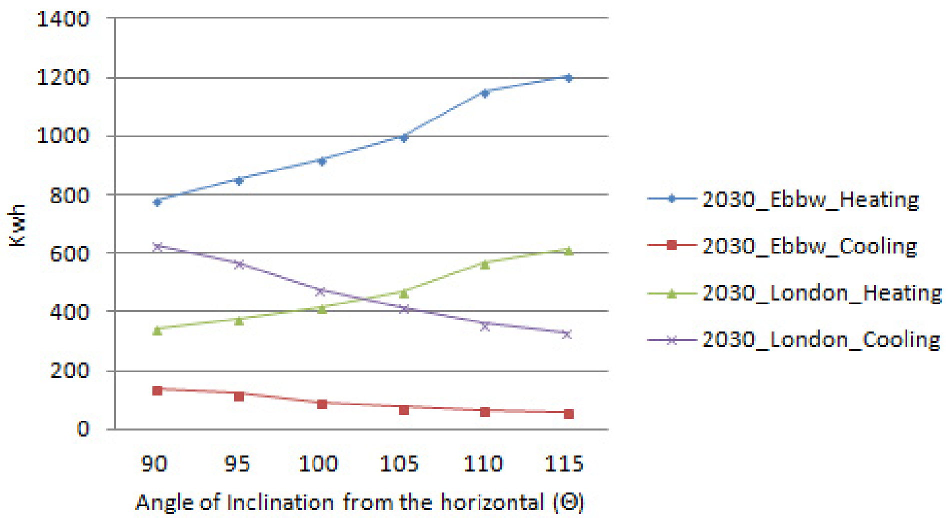

Fig. 5. Cooling and heating load for 2030 climate in Ebbw vale and London

It is clear from Figure 5 that cooling demand in Larch House rises from 45 kWh to nearly 150 kWh in the summer time to cover the electricity needed for extra cooling facilities. It can be seen in Figure 5 that the cooling demand will surpass the heating demand in a high airtight Passivhaus with a vertical south facade in 2030 high emission 50 percentile London climate. It is worth mentioning that for all simulations external roller blinds as they operate in the case study will remain intact. With reference to the curves in Figure 5 regarding the cooling and heating demand for 2030 in both Ebbw Vale and London zones, an inclination angle of 100˚ in Ebbw Vale reduces the electricity cooling load need by 35%. The inclination angle seems to be steeper for the London climate. The best inclination angle for London was 105˚ from the horizontal. This will decrease the high exposed solar gain in summer time whilst still providing adequate solar gain for the heating period.

In 2050, the cooling loads for both locations show an upward trend and as the inclination angle increases from 90˚ to 115˚ so the cooling demand falls from 284 to 132 kWh and 886 to 520 kWh for Ebbw Vale and London respectively (Fig 6). Under the 2050, high emission 50% weather projection an inclination angle of 115˚ for London leads to equal cooling and heating demand for a Passivhaus similar to the case study. Despite the self shading geometry, the building will experience overheating in summer and further consideration needs to be taken into account to minimize the electricity demand for cooling on hot summer days. An inclination of 110˚ in Ebbw Vale will result in an increased heating demand of 24% while this inclination will decrease the cooling demand by 40%. An inclination angle of more than 110˚ shows a sudden leap in heating load and it is probably because of the overshadowing that arises as a consequence of the greater inclination angle.

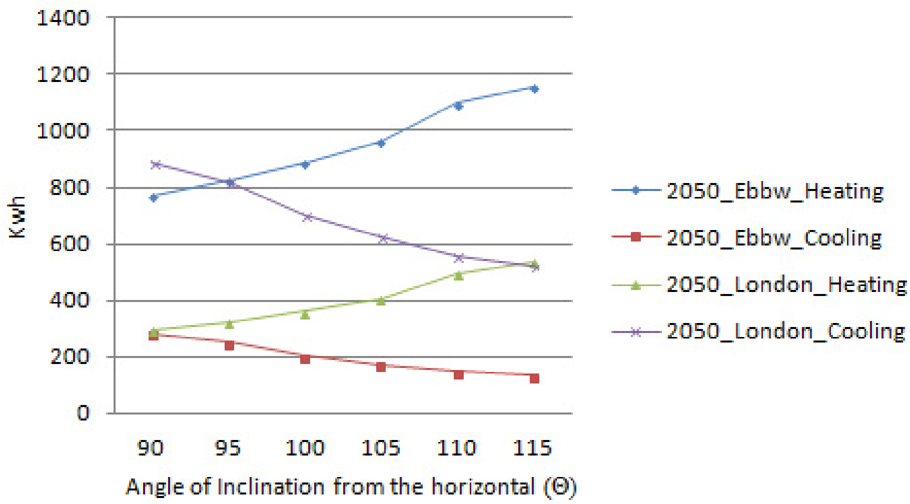

Fig.6. Cooling and heating load for 2050 climate in Ebbw vale and London

Figure 7 shows a dramatic rise in cooling demand for a high airtight Passivhaus dwelling in London under high emission 50 percentile 2080 weather condition. It is evident that a self-shading building can significantly reduce the cooling demand. The cooling load in this case will exceed the Passivhaus requirement of 15 kWh/m^2. Figure 7 illustrates that a Passivhaus similar to the case study under this weather scenario will require over 22 kWh/m^2. This number can be reduced to 12 kWh/m^2 with an inclination of 115˚ for the south facade. Moreover, an inclined south facade with an angle of 110˚ for Ebbw Vale will drop cooling needs by 50% compared with the vertical south facade while the heating will rise by less than 38%. Overall, for a 2080-A1-50% weather projection, extra shading is highly required, though it will not overcome the overheating risk and further considerations i.e. supplementary natural ventilation, should be investigated in this regard.

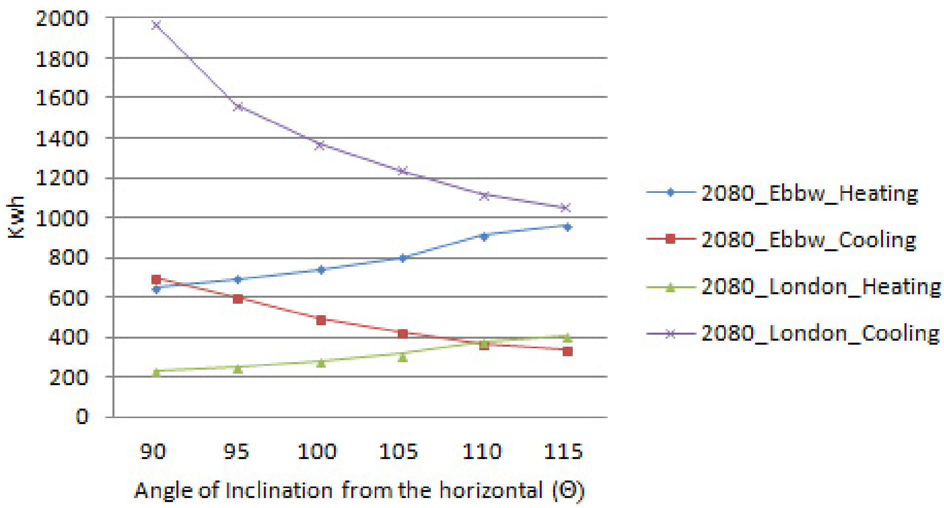

Fig.7. Cooling and heating load for 2080 climate in Ebbw vale and London

3. Conclusion

This study examined to what extent an inclined wall could mitigate summer overheating risk in a Passivhaus dwelling in the UK for current and future weather circumstances. The results of the simulations show that the envelope shape will affect energy efficiency of the building and potentially will reduce cooling load. In order to enhance sustainability in design, energy performance should be considered at the early design stage rather than post occupancy. Values from energy simulation should be provided for architects at the envelope shape design stage. At this case any design generated by this system will assist designers to implement energy performance information into envelope shape design process. For this study a computer model was used to examine the potential risk of summer overheating in a typical UK Passivhaus dwelling for today's weather and under future climate scenarios. The data revealed that an inclination of 95-110°, depending on the location in the UK, could reduce the risk of overheating in Passivhaus dwellings with a large glazed south-facade. Simulation data indicate that there would be serious overheating issues in London in the near future and that buildings which do not show any particular concern regarding designing with suitable shading will suffer from overheating.

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