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Using Tilted Façade to Reduce Thermal Discomfort in a UK Passivhaus Dwelling for a Warming Climate

Yahya Lavafpour*, Steve Sharples

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

Abstract

This study investigated the potential negative impacts of future UK climate change on dwellings. In particular, the risk of overheating was considered for a Passivhaus dwelling in London. The study used dynamic simulation modelling software to investigate the potential use of building geometry to control current and future overheating risks in the dwelling for London climate. Specifically, the focus was on the optimum inclination of a south façade to make use of the building's shape to self-protect itself. A range of different inclined façades were examined to test their effectiveness in reducing the overheating risk. The research found that implementing a 115° tilted façade could completely eliminate the risk of overheating in current climate, but with some consequence for natural ventilation and daylighting. Future overheating was significantly reduced by the tilted façade. However, geometric considerations could not eradicate completely the risk of overheating particularly by the 2080s. The study also used CFD modelling and sensitivity analysis to investigate the effect of the façade geometry on the wind pressure distributions on and around the building surface. This was done to assess natural ventilation flows for alternative façade inclinations.

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Keywords: Tilted facade; Passivhaus; Overheating; Climate Change

1. Introduction

The UK government has set a target to reduce CO2 emission to 80% of 1990 levels by 2050 [1]. This will require a major improvement on building insulation. In respond to the government target a number of energy efficient strategies have been implemented to UK housing sector including the German Passivhaus standard. It is believed the

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

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Passivhaus standard has the potential to become the template for zero carbon design in the UK. However, 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 Passivhaus designs should employ *"professional planning"* such as relevant orientation, shading and ventilation, to overcome summer overheating risk [2]. There are number of design aspects towards ceasing overheating in dwellings e.g. fixed shading device however, the scope of the presented study focused on self-shading envelopes. Therefore the study investigated the implementation of different façade geometries to examine if potential benefits can be achieved by the form of the building.

1.1. Passivhaus

Passivhaus employs super insulation to reduce the heat transfer through the building envelope. *"A Passive House is a building, for which thermal comfort can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions – without the need for additional recirculation of air."*[2]. However, natural ventilation should be provided not only to provide fresh air for the occupants, necessary to maintain acceptable air-quality levels, but also for cooling and it has a direct effect on the occupants thermal comfort [3]. To obtain Passivhaus certification a building needs to meet few main criteria: [4]:

- Maximum Specific Space Heat Demand of 15 kWh/m2.
- Total Specific Primary Energy Demand of Maximum 120 kWh/m2.
- Airtightness of maximum 0.6 h^{-1} at 50 Pa.
- Living areas must not exceed 25 °C for more than 10 % of the hours in a given year.

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. Zero Carbon Hub [5] reveals *"there is 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."*

1.2. Shading device

It has been highlighted in many studies that shading and protecting the indoor area from the direct sun beams have the most pronounced influence in terms of the overheating parameters. For a passive house large glazing area, could lead to overheating in summer if internal/external blinds are not operating on their best. In majority of Passivhaus dwellings shading is controlled by internal or external blinds which requires occupant attention and understanding. It is argued that people mostly operate blinds not because of thermal comfort but rather visual comfort and privacy [6] and this cause failure of primary function of blinds in dwellings [7].

The Larch House PHPP analysis [8] of overheating in summer showed the overheating frequency would reach to 42% (assuming overheating as inside temperature higher than 25 ˚C for more than 10% of occupied hours) without the external blinds, while this number reduces dramatically to 6% with external blinds operating. However, it is assumed that occupant use the blinds to their best performance. The fact which is not calculated in this statistics is the potential failure of using blinds by occupants. For instance, assuming occupants using the blind 80%-70% efficiency, this would make the number of overheating frequency to 13-17% in current summer time (exceeding 10% limit).

Schweiker [9] showed how occupants' behavior in terms of controlling windows and blinds can make a different result in overheating frequency. To minimize the negative impact of the occupant's dismiss which can seriously contribute to the amount of overheating the design of the building envelope can recover the failure of the overall building performance.

1.3. Weather data for simulation

CIBSE hourly weather data files are available under medium and high emission scenarios with different percentile probabilities (10, 30, 50, 60, 90) for both Test Reference Year (TRY) and Design Summer Year (DSY) weather data [10]. For the modelling in this paper an average pessimistic scenario of TRY high emission 50 percentile probability was chosen. London (Islington) weather files were considered to simulate the model as it is within an area of England projected to feel the greatest temperature rise and it is most likely to be effected by the impact of any UK climate change due to the urban heat Island.

2. Methodology

This research focused on the impact of the south façade inclination on energy performance of a Passivhaus dwelling in Islington (London) under alternative future weather projections. Inclination angle (ϴ) was manipulated to test the effectiveness of the façade inclination at 5 degree intervals starting from 90° i.e. vertical façade to 140° i.e. 50° beyond the vertical. For generating different facade inclination variables in the form of parameters were modified to alter building design. In order to test a number of different inclined facades, a Passivhaus unit was undertaken with a simple cube shape (47 m^2) to enhance controllability on form generation and test the performance of the software in terms of changing wall inclination. Afterwards, these data can be used to implement more sensible parameters to the existing case studies with more complicated and realistic thermal zones. Each elevation was then simulated by means of dynamic building simulation software (DesignBuilder [11]) in order to examine to what extend the building shape will influence the future performance of Passivhaus dwellings. The proposed tilted façade was then analyzed through a Computational Fluid Dynamic (CFD) using ANSYS Fluent [12] to calculate its effect on natural ventilation rate.

3. Heating and cooling simulations

Results from the alternative shape analysis (see Fig 1) show that the inclination angle has a noticeable impact on the cooling and heating demands. The graph illustrates the annual cooling and heating demand for the Passivhaus unit in Islington (London) incorporating current and future weather scenarios. Heating and cooling was set to be operated by natural gas and electricity respectively. The curves compare the amount of heating load for different south façade inclinations. As expected for heating demand there is an upward trend as the inclination grows. The trend is almost similar for different future weather data however the slope is steeper, when the inclination angle stretches beyond 115°. The reason for this is that over-shadowing occurs during the winter. The bar chart gives current and future data concerning the energy requirements for cooling load to ensure the set point temperature of 25°C during the summer. In contrast to heating demand the cooling load decreases as the inclination angle increases towards the horizontal. There is a consistent downward trend as the angle leans towards the ground however it stops having much effect when the angle reaches to 115°. It can be seen that there is a modest cooling need for current climate to escape from overheating in summer which can be eliminated by implementing a steeper façade. It can be observed that the cooling demand rose significantly by the second half of the century where the self-shading strategy promises a substantial drop in overheating risk for future climates in London. However a data analysis in all aspects of energy consumption is required to determine the design of envelope shape that provides solar access in winter while performing as a self-shading facade in the summer. This will also provide thermal comfort to promise a long term efficient design. According to the data revealed, applying a tilted wall with 115° inclination angle is beneficial to reduce potential of overheating for current and especially future climate.

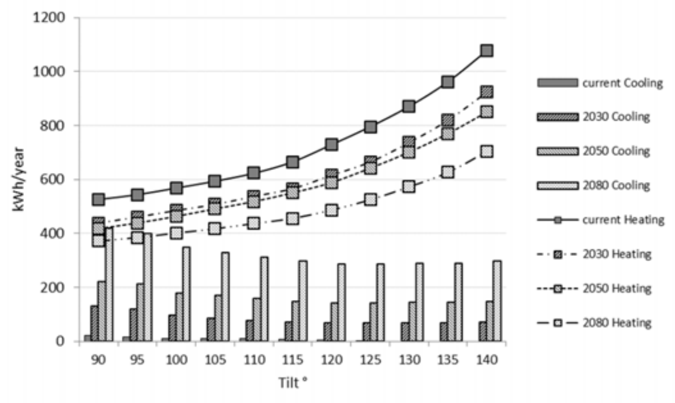
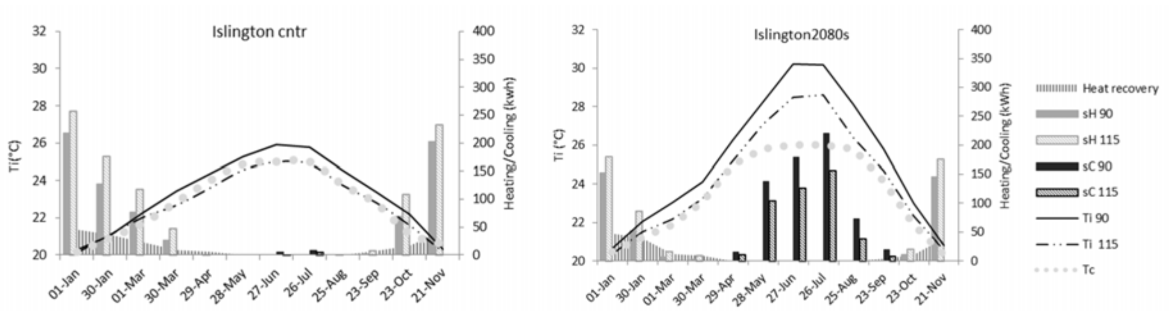


Fig. 1. Heating and cooling demand for different façade geometries under four climate periods

Figure 2 gives an indication of the performance of the Passivhaus unit under current and future weather scenario. The charts indicate the ratio of the correlation between cooling and heating demand when comparing the vertical (Θ=90°) and suggested tilted façade (Θ=115°). The curves indicate operative temperature of the pilot unit with vertical and tilted south façade for current and future climate predictions. Dotted line indicates the suggested comfortable temperature which Passivhaus standards aims to achieve during a whole year cycle. The bar charts give the amount of cooling and heating needed to bring both alternatives i.e. 90° and 115° within the thermal comfort zone. Passivhaus due to its ultra-insulation is capable of maintaining an internal temperature of 20°C. Heat recovery system also operates by relying on the heat given off by appliances, occupants and solar gain. However a small amount of supplementary heating is required during the coldest period of the year [13].

With the vertical glazed façade in south elevation the pilot unit experienced a relatively modest overheating during the hottest months of the year, therefore to ensure comfortable indoor environment, the unit required a small proportion of supplementary cooling which was eliminated by implementing the tilted façade of 115°. For future high medium weather scenarios, supplementary cooling leapt to the point where the energy consumption of the summer time surpassed the energy demand for winter heating, of which the great amount is provided by recovery system. Introducing a steep wall where most of the glazing is located though, will cut the amount of supplementary cooling up to 50 percent whereas the energy consumption for heating climbed marginally ensuring it does not exceed the maximum energy demand requirement of Passivhaus standards. Cooling demand can further trimmed by additional natural ventilation strategies and night purge cooling by enhancing the amount of air flow inside the building during summer time.



a) b)

Fig.2. The amount of energy i.e. supplementary heating (sH) and cooling (sC) required to provide comfort temperature
a) Current Islington (London), b) 2080's Islington (London)

4. Natural ventilation and CFD analysis

The main strategy to maintain thermal comfort during summer is to: i) Prevent overheating that occurs primarily due to incident solar radiation entering into a space [14] and ii) dissipate excess heat using natural ventilation [15]. Understanding the airflow pattern and pressure distribution on building envelop is essential for evaluation of wind-induced natural ventilation and thermal comfort. Natural ventilation is achieved by air flow through the building envelop which can be unintentional i.e. flow of outdoor air through cracks and holes in the structure and intentional i.e. doors and window openings. Airtight energy efficient buildings tend to minimize infiltration rate from 3.0 ACH (leaky houses) to just about 0.6-0.2 ACH (Passivhaus). In a Passivhause an unintentional inflow is negligible and will result to reduce the heating load dramatically. When occupants feel wind flow across their body they feel more comfortable [16]. Not only comfortable temperature but adequate air velocity is required in the occupied space to provide thermal comfort for occupant. Therefore, it is important to assess whether or not the proposed façade would affect the air flow volume within the building.

CFD analysis was conducted using ANSYS FLUENT software. Three wind directions were tested to assess the impact of the tilted façade (115°) on the airflow volume. The data from the CFD analysis (Figure 3) shows that pressure on the façade of the tilt wall would decrease if the wind angle of incidence (INC) is 0° (i.e. wind is facing the tilt façade opening) this will lead to a lower air flow through the building. However the air volume entering the building was enhanced when the wind angle of incidence is set to be INC=90° (wind facing the side tilt facade) or 180° (wind facing the opposite tilt facade). For these two cases the higher negative pressure on the outlet was experienced leading to a higher pressure difference between the inlet and outlet. This will cause a stronger suction act from the outlet opening and consequently higher natural ventilation.

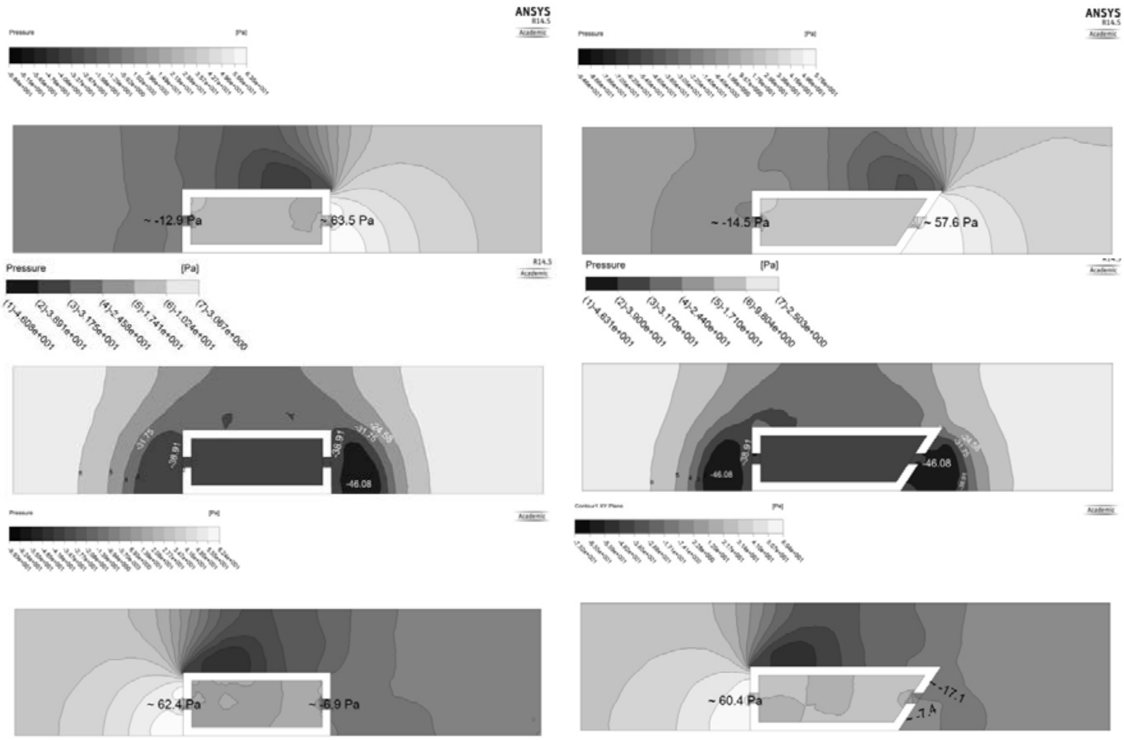


Fig.3. Pressure distribution on the outlet and inlet opening for vertical and tilted façade under 3 wind directions
Wind incidence angle 0° (Top), 90° (middle), and 180° (bottom)

5. Discussion and conclusion

Negative impacts of the future climate change, in particular overheating risks were considered for future performance of the Passivhaus dwelling which is well-known for its low energy demand for space heating. A Passivhaus uses large windows to provide passive heat gain and a better daylighting and view. Generally people prefer to live in a house with large windows. Psychologically this will also improve the occupants' well-being. In order to benefit from large area of glazing, summer overheating should be considered carefully to minimize discomfort hours especially in future climate. Despite of the advantages of large glazing of the Passivhaus, well insulation has been employed as one of the crucial strategies for reducing CO2 emissions. The building regulations in the UK have urged developers and architects to design buildings with high insulation. On the other hand, the part L building regulations addresses the importance of overheating risk in a more elaborated way than before by highlighting that overheating should be considered alongside insulation.

Overheating for future housing developments was discussed and some useful interventions were reviewed within the study. Shading the glazing from direct solar irradiation, is believed to be the most effective passive strategy in reducing annual overheating rate for housing sector. Professional planning addressed in Passivhaus principles suggests using external blinds and overhangs to protect the buildings from undesirable solar gain. Nevertheless this study has investigated the effect of the self-shading façade as an environmental design approach.

Overall, the study presented a sensitivity analysis of building facade inclination as a function of cooling demand for Passivhaus dwellings. The results of the simulations showed the envelope shape will affect energy efficiency of the buildings and potentially will reduce probable serious overheating risks in future summers. CFD analysis was conducted to examine the effect of the altered façade on wind behavior. 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. It was concluded that a tilted façade of 115° can eliminate current and reduce future overheating risk for London climate.

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