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The PassivHaus Standard: minimising overheating risk in a changing climate

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ABSTRACT Building operational energy is responsible for approximately 40% of UK's CO_2 emissions (GOV.UK, 2014) with almost 25% in housing alone, mostly for space heating. This significantly contributes to climate change, which is now considered unavoidable (IPCC, 2013) and could affect occupants' thermal comfort and health (Public Health England, 2013). Given that our buildings are built for 50-100 year lifespans (de Wilde et al, 2008), measures to adapt our buildings to a changing climate need to be undertaken alongside climate change mitigation strategies.

This paper investigates the risk of overheating and the remedial measures required for future UK climate scenarios if the PassivHaus standard is applied.

A case-study dwelling was modeled and its performance assessed under present and future climate scenarios in London: 2050s and 2080s for a Medium and High emissions scenario. Findings indicated that while space-heating demand would be reduced by 45% by the 2080s, the case-study dwelling is likely to need some form of cooling from the 2050s onwards, unless passive adaptation measures are put in place. The most effective adaptation measure was found to be a combination of reduction on the glazing's g-value, summer night-time natural ventilation and solar shading.

The performance of the Building Regulations (2013) notional specification highlights that while it is predicted to lead to marginally lower overheating frequencies than the PassivHaus dwelling, its space heating demand will be up to five times higher in the 2080s. Hence measures for reducing space heating demand alongside measures to reduce future overheating are both necessary and need to be balanced. Findings indicated that the PassivHaus case-study performed well in a future changing climate if this goes hand in hand with overheating mitigation measures, taking into account user behaviour and occupancy patterns, applied now and in the future.

KEYWORDS: Climate change; Building overheating; PassivHaus; Low-energy housing.

Introduction

The building sector is responsible for ~ 30% of global greenhouse gases, from which 80% are generated through the operational energy consumption in buildings (UNEP, 2009). In the UK, building operation is responsible for ~ 40% of energy use (GOV.UK, 2014); the majority of energy use is in housing and is for space-heating. A changing climate is considered unavoidable (IPCC, 2013) and average future projections for the UK indicate milder and wetter winters, hotter and drier summers and an increase in both the temperature of the warmest day in summer and in the precipitation rate of the wettest day in winter (UKCCRA, 2012). Since buildings have a long lifespan (de Wilde et al, 2008), climate adaptation measures will need to be considered alongside climate mitigation strategies.

The purpose of this paper is to identify and balance both climate change mitigation measures with adaptation strategies by evaluating future climate change scenarios of a low energy building standard - the PassivHaus standard - compared to the current Building Regulations standard with the aim to assess the robustness of both standards in a future changing climate. The research results presented in this paper were derived by analysing and applying adaptation measures to a PassivHaus case-study located in the UK.

Methodology

Case-study: dwelling assessed

The studied dwelling is a 2010 certified PassivHaus located in Denby Dale, West Yorkshire. The building is a 118 m^2 two storey detached house characterised by cavity wall construction filled with fibrous insulating material and covered with natural Yorkshire stone. The U-values of the main construction elements are presented in Table 1. At present, although no significant overheating risk occurs (6% of the occupied year over 25ºC [i]), solar radiation is controlled with a roof overhang on the south elevation as well as vertical external solar blinds, protecting the double storey glazing on the south and west elevation.

PassivHaus Planning Package (PHPP 2007) model

The authors obtained the PHPP model for the case study; however the latter blinds were excluded from the original PHPP model and were therefore also excluded as a starting point. The case-study dwelling was modeled in the Leeds climate, which was the nearest climate data set available for the actual case study's location. Several other UK locations (Belfast, Edinburgh, London and Cardiff) were also modeled, of which London showed the highest overheating frequency, hence the justification to use London as the focus of this paper.

A disadvantage of PHPP is that since it is not a dynamic model, it considers the whole building as one zone for energy and comfort calculations. Without thermal zoning of separate rooms, possible overheating could occur in certain rooms but would not be identified by the model, therefore different room orientations or locations could not be investigated in this paper. Additionally, modeling of thermal mass was excluded due to PHPP's monthly or yearly instead of daily analysis. It is also acknowledged that user behaviour and internal heat gains from appliances can significantly affect dwelling overheating risk as noted by Ridley et al (2014), but has not been studied here. Ridley et al (2013) reported PHPP to be a good predictor of overheating risk compared to monitored summer data, though PHPP did appear to underestimate the actual risk for the Camden PassivHaus. For the same dwelling, monitored data indicates that overheating risks can vary in different rooms, from year to year and are also occupant dependent (bere: architects, 2014) – none of these variables were studied here.

Future climate projections and current climate data

Future UKCP09 Prometheus data was used to model future climates in the 2050s and in the 2080s under Medium (MeES) and High (HiES) emissions scenarios due to the fact that globally we are on a trajectory of medium to high emissions scenarios (Nakicenovic et al, 2000). TRYs data with 50% probability was utilised as there is equal probability that this climate scenario is exceeded or not and considered suitable for assessing a mean weather year and as per other research conducted, for example by McLeod et al (2013).

The Prometheus data excludes vertical radiation data; hence current radiation data was used. BRE Central London data was used for current climate data.

Evaluation of the performance of the case study dwelling

To investigate the robustness of the PassivHaus standard compared to the Building Regulations standard, the case-study dwelling was modeled in PHPP to meet the PART L1A (2013) notional dwelling's building fabric, with higher U-values and air permeability; as listed in Table 1. The dwelling's performance is assessed by evaluating its space heating demand (kWh/m^2a) and its overheating frequency (%) under the current climate and different future London climate scenarios. The PassivHaus standard stipulates a space heating demand of maximum 15 kWh/m^2a and that a building overheats when its internal temperature exceeds 25ºC more than 10% of the occupied year[ii]. For this reason these limits are used to assess the robustness of the PassivHaus standard in different scenarios.

The overheating criterion recommended by the PassivHaus standard is less lenient than the equivalent CIBSE (2006) benchmark for summer peak temperature in the UK, which is set at 1% of the occupied year over 28ºC in living spaces and 26ºC in bedrooms.

Table 1 Case-study's fabric U-values (W/m^2K) / G-values and PART L1A (2013) notional dwelling specifications.

Element or System	Values of the PassivHaus dwelling	Values of PART L1A (2013) notional dwelling
Roof U-value	0.096 W/m^{2}K	0.13 W/m^{2}K
Wall U-value	0.112 W/m^{2}K	0.18 W/m^{2}K
Floor U-value	0.104 W/m^{2}K	0.13 W/m^{2}K
Window U-value/ Glazing G-value	0.96 (glazing) W/m^{2}K; 0.6 W/m^{2}K (frame) / 0.51 or 0.53	1.4 W/m^{2}K / 0.63
Glazed Door U-value/ Glazing G-value	0.92 (glazing) W/m^{2}K; 0.6 W/m^{2}K (frame) / 0.51	1.4 W/m^{2}K / 0.63
Airtightness	0.33 ach at 50 Pa	5 m^3/m^2 hr at 50 Pa
Type of Ventilation	MVHR	Natural Ventilation

Overheating mitigation measures

To prevent overheating, 11 passive overheating mitigation measures, which can be applied now or in the future, were tested for the PassivHaus dwelling and are presented in Table 2, ordered according to their easiness of installation and their relative independence of occupant control (i.e. easiness of use). These measures are based on CIBSE TM55's recommendations (CIBSE, 2014) and those included by other studies such as Collins et al (2010) and Mavrogianni et al (2014). Seven of the eleven measures are shading devices which are evaluated according to their different shading coefficients[iii] , location (internal/external) and material reflectivity. External shading devices have the advantage of reducing solar radiation before entering the spaces (European Commission, n.d.), leading to a low shading coefficient (Olgyay, 1963) – see Table 2.

Table 2 Overheating mitigation measures individually applied to the PassivHaus case-study.

Easiness of use	Easiness of installation	Adaptation Measures	Characteristics
√	√	*Lower glazing g-value*	Reduction of the glazing's g-value from 0.53 and 0.51 to 0.36
n/a	√	*Summer night-time natural ventilation*	First floor operable windows assumed partly open ; Ground floor windows assumed closed; Single ventilation
n/a	√	*Shading in summer: Dark grey curtains*	Shading Coefficient 0.58 (Olgyay 1963)
n/a	√	*Shading in summer: White curtains*	Shading Coefficient 0.40 (Olgyay 1963)
n/a	√	*Shading in summer: Internal dark rollers*	Shading Coefficient 0.81 (Olgyay 1963)
n/a	√	*Shading in summer: Internal white rollers*	Shading Coefficient 0.41 (Olgyay 1963)
n/a	√	*Shading in summer: Internal dark blinds*	Shading Coefficient 0.75 (Olgyay 1963)
n/a	√	*Shading in summer: Internal white blinds*	Shading Coefficient 0.56 (Olgyay 1963)
n/a	√	*Shading in summer: External white-cream blinds*	Shading Coefficient 0.15 (Olgyay 1963)
√	n/a	*Double glazing instead of triple glazing*	Increase of U-value from 0.6 to 1.1 W/m^{2}K
√	n/a	*Increase of roof overhang's depth*	Increase of roof overhang's depth (south elevation) from approximately 1 m to 1.5 m.

Results and discussion

Case study performance over time

The overheating frequency and the space heating demand of the PassivHaus case-study are illustrated in Fig. 1 and highlights that the space heating demand follows a downward trend over time. By the 2080s (HiES), the space heating demand of the case-study is predicted to drop by 45%. Even in a warming climate there will still be demand for space heating, as also reported by McLeod et al (2013) and by Collins et al (2010).

However, overheating is expected to be a more regular occurrence, likely requiring cooling from the 2050s, unless remedial measures are put in place: overheating frequency is expected to increase from 6% at present to 31% by the 2080s (HiES) for the PassivHaus dwelling (Fig.1) and from 4% to 27% by the 2080s (HiES) for the PART L1A notional dwelling, which will see a 36% drop in space heating demand.

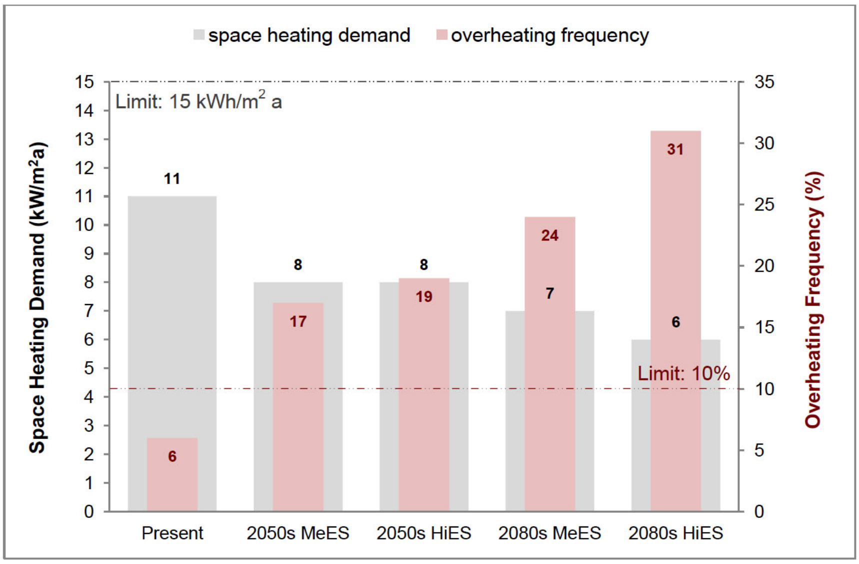

Fig. 1 PassivHaus dwelling performance over time in London: annual space heating demand (kWh/m^{2}a) decreases by the 2080s as the overheating frequency (%) increases, significantly exceeding the overheating frequency limit of 10%.

The results suggest that while the notional dwelling is expected to overheat slightly less than the PassivHaus, both standards will require remedial measures to reduce summer-time overheating. Similar trends were also observed by for example McLeod et al (2013) and Mavrogianni et al (2014); and Crawley (2008); though the exact space heating demand, overheating risk and when it occurs differ as they are based on different cases, types of buildings and different locations and due to different future weather data (type, scenario and probability) used. Using the CIBSE (2006) 26ºC and 28ºC overheating threshold, for London in the 2080s (HiES), there would still be a 23% and 15% overheating frequency respectively during occupied hours[iv].

PassivHaus dwelling adaptation to a future changing climate

The impact of the 11 overheating mitigation measures (as set out in Table 3) on annual space heating demand and on overheating frequency is presented below and highlights that the reduction of the glazing's g-value alone results in a significant decrease from 31% to 19% in the overheating frequency (both 2080s, HiES), a drop of 39% relative decrease. Glazing often requires replacement after 10-15 years (European Commission, 2010), so future window replacements with lower g-values would enable occupants to save money, while doing it in the future would not reduce beneficial winter solar gain at present.

Summer night-time natural ventilation is a cost-free measure which does not affect the space heating demand, however on its own its impact is limited to reducing overheating frequency from 31% to just 26% in the 2080s (HiES). McLeod et al (2013) also reported on the inefficiency of night-time ventilation as a sole means to eliminate the overheating risk. However there may be an increased effectiveness of night-time ventilation in the future due to the Urban Heat Island (UHI) due to a possible increased diurnal temperature range (Demanuele et al, 2012). Additionally, night-time ventilation should also be carefully designed due to security and urban noise risk (Mumovic and Santamouris, 2009) and for these reasons this study assumed that the windows of the first floor were kept partly open (tilted) but not cross ventilated (doors closed between rooms) and closed on the ground floor.

Summer shading is intended as a temporary summer measure, which does not affect winter space heating demand and - depending on the shading type and reflectivity - it has the potential to reduce the overheating frequency below the 10% boundary if installing external light-coloured blinds; eliminating the projected overheating risk by the 2050s entirely and to reduce its frequency below 10% by the 2080s. These findings are in line with other studies carried out, for example by McLeod et al (2013). External light-coloured blinds are the only intervention which on their own might reduce overheating frequency to below 10% by the 2080s (HiES). Significant overheating frequency reductions are also achieved by installing internal white curtains or white roller blinds and their use reduce the overheating frequencies below 10% with the exception of 2080s (HiES), when its predicted overheating frequency is expected to exceed 10%.

As expected, the least effective summer shading devices were the internal dark rollers and blinds, though they still reduce overheating frequency significantly: 26% and 35% relative reduction in the 2080s (HiES) respectively.

Increasing the roof overhang depth of the south elevation was also investigated, however as expected this does not reduce the overheating frequency significantly: still 27% overheating frequency in the 2080s (HiES). This is because its depth is limited by structural limitations but also to allow winter solar gain over time, leading to a small predicted additional space heating demand. Due to the structural difficulty and expense, its installation during the building's initial construction is advocated rather than at later stages.

Finally, the replacement of triple glazing by double glazing drops the overheating frequency from 31% to 27% in the 2080s (HiES). However, the present space heating demand exceeds the PassivHaus criteria of 15 kWh/m^{2}a by 3 kWh/m^{2}a until about the 2050s, when such measure may be an effective measure.

Alongside the 11 adaptation intervention measures, the impact of orientation was also briefly investigated with the aim to understand whether designing for winter solar gain (i.e. facing south) would still make sense in a future changing climate. As expected, overheating frequency is reduced by 11% from 31% to 20% (both 2080s, HiES), when the main living spaces are north-facing, but this is offset with an increased winter space heat demand of 72% or 8 kWh/m^{2}a at the present time. A similar model highlighted that an east-facing façade reduced overheating frequency from 31% to 28% (both 2080s, HiES), but leads to a 6 kWh/m^{2}a increase in space heating demand today. This indicates that future building design and building solar orientation may be more beneficial facing north instead of south. Comparison of two actual monitored PassivHaus dwellings in Wales reports that the dwelling with increased south-facing glazing overheated more significantly (Ridley et al, 2014).

Combined adaptation measures to mitigate overheating risk in a future changing climate

Of the 11 overheating mitigation measures, the reduction of the glazing's g-value, summer night-time natural ventilation and summer shading are the most effective measures at preventing overheating in a warming climate while relatively easy to install. However only external light-coloured blinds could solely eliminate the overheating frequency (and hence the likelihood of active cooling).

For the use of blinds and night-time natural ventilation to be effective, occupant behaviour is important (such as lowering/opening/closing the blinds and windows) (Mumovic and Santamouris, 2009). However, it cannot be controlled for or predicted by designers. One solution could be the installation of automatically controlled windows and shading devices, such as in the Camden PassivHaus (bere: architects, 2011). However, complicated control systems should be avoided - especially in dwellings - in order to be easily operated by occupants (Bordass, Bromley and Leaman, 1993).

It is therefore considered more robust to propose a combination of measures to reduce overheating frequency. For both standards, the combination of the reduction of the glazing's g-value, summer night-time natural ventilation, alongside a mixture of solar shading (internal/external, all light-coloured) indicate that the overheating frequency could be eliminated by the 2050s and reduce it to < 5% by the 2080s.

Conclusion

This paper highlighted that the use of PassivHaus standards is likely to increase the frequency of overheating over time by 30% (absolute increase), whereas space heating demand is anticipated to follow a downward trend, [45% reduction by 2080s (HiES)], but not reduced to zero.

Taking effectiveness at reducing overheating frequency and easiness/cost of the overheating mitigation measures into consideration, the reduction of the glazing's g-value, summer night-time natural ventilation and summer shading are the most effective measures to reduce summer-time overheating. Only external light-coloured blinds could reduce future overheating frequency significantly (2080s, HiEs), however the combination of these three measures could reduce overheating below 5% for both studied standards: PART L1A (2013) and PassivHaus. While the Part L1A (2013) notional dwelling is slightly more robust in terms of overheating [3% versus 4% overheating in 2080s (HiES)], its future space heating demand is about 4 times higher than the PassivHaus standard. The balance of both space heating energy use and overheating frequency over time, appears to be significantly more energy efficient now and in the future for the PassivHaus standard, indicating the efficacy of highly insulated and airtight dwellings to reduce energy use, even in a warmer future climate, as long as this goes hand in hand with some remedial measures applied now and in the future; such remedial measures will also be required for other building standards.

Note that the case study's performance described above is likely to differ from the building's actual performance. Even if buildings are designed to be comfortable, occupant behaviour is likely to affect their performance while modeling limitations and overheating criteria should be taken into consideration. Dynamic energy modeling and testing of (a.) different overheating thresholds; (b.) different user assumptions in models versus actual behaviour (c.) impact of internal heat gain from appliances and (d.) the effectiveness of thermal mass combined with night-cooling are recommended for further research.

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[i] For a PassivHaus dwelling, an occupied year is perceived to be 365 days a year (BRE n.d.).

[ii] ibid

[iii] In line with CIBSE Guide A, shading coefficient is *“the ratio of the instantaneous heat gain at normal incidence transmitted by a particular glass/blind combination to that transmitted by a reference glass, usually 3 mm or 4 mm thick clear glass”* (CIBSE, 2006).

[iv] The overheating frequencies derived by using the CIBSE thresholds were estimated by assuming an occupied year to be 365 days a year (BRE n.d.) to allow for comparison with the Passivhaus threshold.