The effect of shading, infiltration and ventilation levels on overheating and heating demands in UK residential buildings.

Case study: Trent Basin Regeneration

ZINA ABDULLA[1], LUCELIA RODRIGUES[2]

[1] Faculty of Engineering, Al-Nahrain University, Baghdad, Iraq
[2] Department of Architecture and Built Environment, University of Nottingham, Nottingham, UK

ABSTRACT: Overheating in UK buildings is gradually becoming a widely addressed issue due to two main factors. The first being the climate change which is causing mean temperatures to rise all over the world, and the second being design methods used in low energy buildings. As the main goal in UK low energy buildings is reducing the heating demands, the summer cooling demands are rarely dealt with. As the usage of high levels of insulation and maximizing solar gains can help significantly in reducing heating demands in winter, it makes the building more prone to overheating in high temperatures. This paper investigates the potential of overheating in UK housing, in the Regeneration of Trent Basin housing in Nottingham, which was a project under construction and designed according to the Zero Carbon Hub fabric energy efficiency standards. Design solutions as shading, infiltration and natural ventilation were also investigated to resolve the overheating issue, while keeping the heating demands as low as possible to meet the standard that was aimed for in the original design. Further testing was conducted to investigate the possibility of meeting Passive House standards, without changing the construction method, design layout or orientation. The dynamic simulations were run using Design builder software and PHPP (Passive house planning package).
Keywords: Overheating, low energy houses, Passive House standards, natural ventilation, shading.

INTRODUCTION

As a result of the world wide climate change, the UK climate is getting warmer. With the annual average temperature all over the UK increasing by 1°C during the past century (Jenkins et al, 2009), it is expected that the mean summer temperature in the east midlands in particular will increase by 0.4-2.5°C by 2020, and by 1-4.7°C by 2050 (UK climate projections, 2014).

The UK government had ambitiously aimed in 2007 for all new houses to meet a zero carbon dioxide emission goal from 2016 (DCLG, 2010). This includes emissions associated with the energy use for heating (Rodrigues & Nikiforiadis, 2013). These regulations meant an increase in insulation levels, airtightness and also using low levels of thermal mass due to the use of modern method constructions (Rodrigues, Gillott & Tetlow, 2013). The high performance of these houses may reduce the heating demands but be more sensitive to high summer temperatures causing the buildings to overheat (Rodrigues & Nikiforiadis, 2013).

Previous studies have investigated overheating in future climatic scenarios, (Peacock et al., 2010) expect 18% of houses in south England will have installed air conditioning by the year 2030 due to overheating. Buildings built to Passive House standards are also prone to overheating, and many reports have been documented confirming the occurrence of overheating in Passive House dwellings in the UK (McLeod et al., 2013). This study was performed to investigate the overheating occurrence in the current climate and ways to avoid overheating through design solutions while maintaining low heating demands.

The Trent Basin houses were chosen as they were being built according to the Zero Carbon hub fabric energy efficiency standard (FEES), which aims to help deliver the UK government's goal of zero carbon emission homes from 2016 (Zero carbon hub, 2015). The author has conducted testing on one of the typical units in the first phase of the regeneration. Aiming for meaningful results which could aid the designers to deliver better performing houses for the future phases, or by making possible changes to the units currently under construction.

Design solutions included proposing shading for the south façade glazing, changing infiltration levels, glazing areas, window types and ventilation levels. Each proposal was studied in a separate simulation case, to reach the optimum design case that would meet Passive House standards.

THE TRENT BASIN REGENERATION HOUSING

The Trent Basin is located 2km south east of Nottingham city centre and was being regenerated by developer Blueprint, the project team was a mix of national and local businesses as architects Marsh-Grochowski, urban designers Urbed, landscape designers Landscape projects and others (Blueprint, 2015). The development was meant to be constructed in five phases delivering a total of 160 houses. The first consisting of 41 dwelling units which was a live project, was to be delivered by the year 2016, see Figure 1.

Figure 1: Trent Basin Regeneration / Phase 1 (images © Blueprint)

Low energy houses were proposed that meet FEES, that recommends maximum heating and cooling energy demands of 39 kWh/m2/year for apartment blocks and mid-terrace homes and 46 kWh/m2/year for end terrace, semi-detached and detached homes (Zero Carbon Hub, 2015).

The houses were designed to be built of brick and block construction, with large window areas to maximize daylight levels. Shading devices were proposed in the early stages of the design as shown in Figure 1, but were removed from the design later for financial reasons (Blueprint, 2015).

METHODOLOGY

The first step in this study was to select a residential unit for simulation, ideally it would be the unit with the most vulnerable façade to solar gains. The unit was chosen using Ecotect analysis for solar access. Each façade was analysed in order to select the façade receiving the most amount of solar gains. Ecotect shadow analysis was also performed in order to study whether the residential units were overshadowing each other.

After selecting a residential unit for simulation, a model was built in Design builder software and thermal analysis was performed to calculate the internal temperatures. In addition PHPP (Passive house planning package) was used to calculate the percentage of overheating and also heating demands. Optivent (Optimass ventilation) was used to calculate the levels of natural ventilation according to the proposed window areas.

After performing simulation analysis on the base case residential unit, several cases were built representing different design solutions. Thermal analysis was performed on each of these cases to study the effect of each parameter on the amount of overheating in summer, and heating demands in winter. The purpose of these several simulation cases was to reach the optimal design solution that would achieve Passive House standards.

BASE CASE SELECTION

A model of the project was built in Ecotect software. Shadow and solar analyses were performed at 12:00 pm summer solstice. The solar analysis was performed on the main three façade orientations as shown in Figure 2.

Figure 2: Ecotect shadow and solar analyses for 12:00 pm summer solstice

The results of the solar access analysis, as shown in Table 1, showed that façade 1 was receiving the most amount of solar radiation. The building block was formed by 5 terrace houses. A typical unit within that block was chosen for simulation.

Table 1: Solar access analysis results for 12:00 pm summer solstice

Facade	Deviation from north °	Solar Radiation Wh
Façade 1	165	499149
Façade 2	146	485717
Façade 3	226	364253

The unit was a 3 storey terrace house, with an orientation deviating 15° from south. The first floor contained the living area, dining and kitchen area. The upper floors contained four bedrooms and a terrace. As shown in Figure 3.

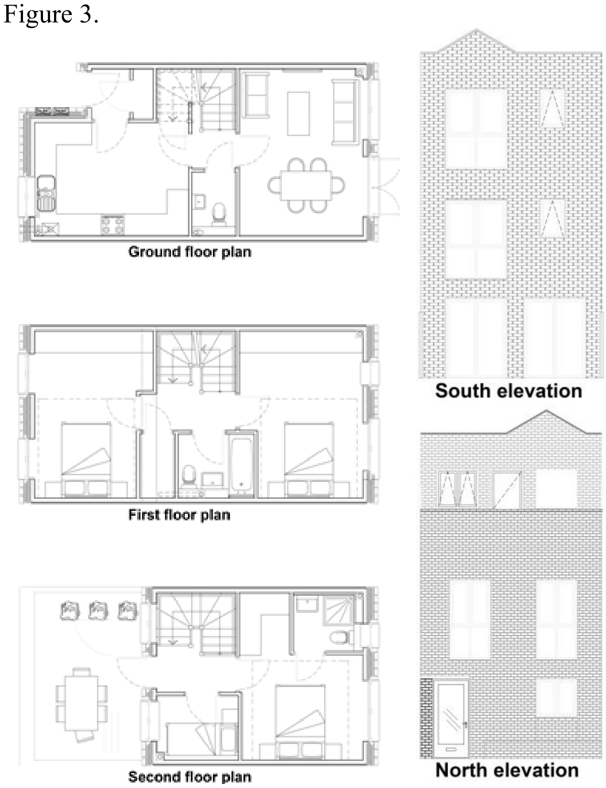

Figure 3 Building drawings (images © Marsh–Grochowski Architects)

BASE CASE ASSUMPTIONS

The assumptions for both simulation software were as follows:

- Occupancy: The base case was simulated with four occupants. Providing internal gains of 80 W/p. With a utilization pattern of a typical UK household, full occupancy during the weekends, and no occupancy from 8am-4pm at weekdays. No holidays were accounted for during the year.
- Lighting: The lighting was automatically calculated in PHPP software according to the treated floor area and the result was 21W.
- Appliances: Appliances included Kitchen appliances as dishwasher, clothes washer, freezing and refrigerating, and cooking using natural gas. Consumer electronics and small appliances were also calculated giving a total amount of 2137kWh.
- DHW: The DHW consumption was 25 litre/person/day at 60°C.
- Comfort temperatures: The comfort levels were chosen according to the CIBSE guide A, which in dwelling areas gives a maximum summer comfort temperature of 25°C (CIBSE guide A, 2006, p1-8), therefore 25°C was used as a benchmark to calculate overheating percentages.
- Weather: The weather data for the design builder simulation was taken from the US department of energy, Energy efficiency and renewable energy. As for the PHPP simulation the climate data was provided by BRE (building research establishment).
- Calendar: it was assumed that the summer period covers from 1st of May to the 30th of September.
- Construction: As for the construction of the unit, it was designed to be built of brick and block with a lightweight timber roof. The build-up of the external walls, roof, partition walls and ground was inputted into design builder defining the layers. The software calculates the U-values according to the type of material and thickness. Table 2 shows the construction layers of the external walls, and the U-value calculated. Table 3 show the layers of the lightweight timber roof. For this calculation the timber beams and studs were calculated as 24% of the wall build up.

Table 2: External wall U-value

Area section	**Ψ[W/(mK)]**	Thickness mm	U-Value **W/(m²K)**
Air gap	0.18	20	
Concrete block	0.5	100	
Insulation	0.034	200	
brick	0.8	100	
			0.085

Table 3: Roof U-value

Area section	**Ψ[W/(mK)]**	Thickness mm	U-Value **W/(m²K)**
Plywood	0.090	12	
Batt insulation	0.043	180	
Plywood deck	0.130	180	
Timber firring	0.130	230	
Wool insulation	0.040	100	
Timber beam	0.130	200	
plaster	0.250	20	
			0.085

- Heating and cooling: No active heating or cooling was assumed.
- Window areas: The base case design had north and south facing windows. The south facing windows had a total area of 14.82m2, and the north facing windows had a total area of 14.68 m2.
- Window type: Double, low-E, argon filled glazing with a U-value of 1.3 W/ (m²K) was used for the windows.
- Shading: No shading was used in the base case.
- Natural Ventilation: Natural ventilation levels were calculated using Optivent. As Optivent is a steady state calculation software, natural ventilation was tested for the south facing zones. In particular the bedroom on the first floor. Using the window areas from the base design. The calculation was performed for the worst case scenario when the temperature difference between the indoor and

outdoor air is 1°C. The outdoor air temperature was 26°C which is the peak summer temperature in Nottingham. Having one sided ventilation and very low stack height due to having one opening only, the achieved ventilation level was 1.91 ac/h as shown in Figure 5. The free openable area was 20% for all windows. As shown in the graph, this achieved level of ventilation was not efficient for cooling. As the window areas on the north façade are marginally different from the south façade, the same ventilation value was used for the building as a whole.

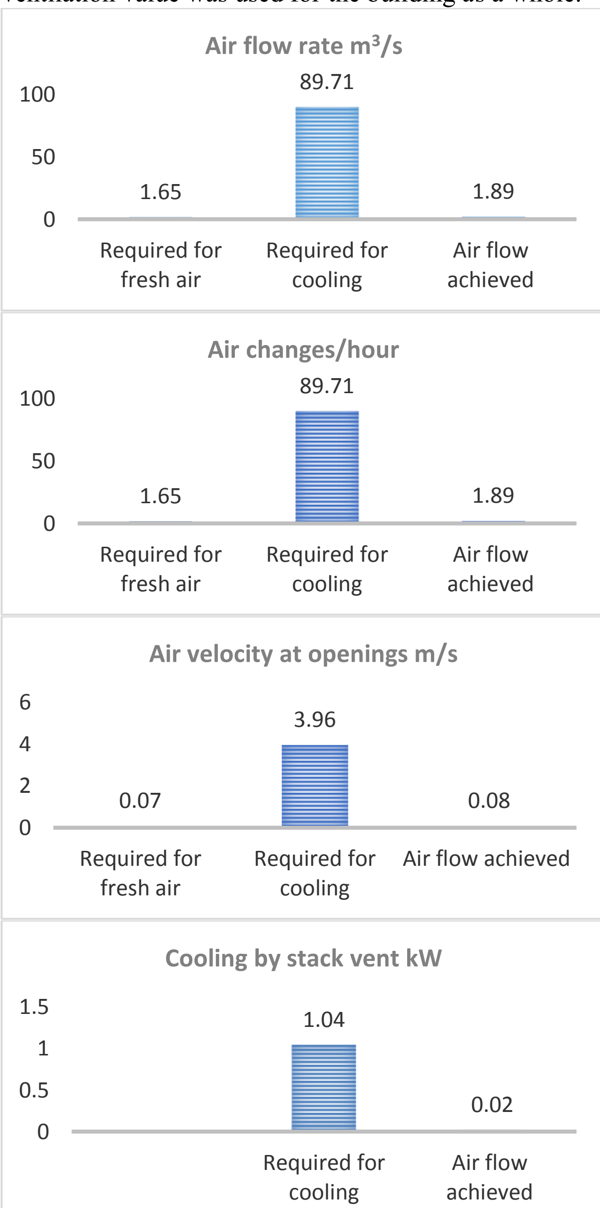

Figure 4: Optivent results

-Infiltration: The architects were aiming for 3.5 m3/ h.m2 @n50 p, as that is the rate given by FEES.

SIMULATION

A simulation model of the base case residential unit was built in design builder. As the unit is a mid-terrace house, the adjacent units were also modelled to ensure accuracy of the calculation due to the heat flow through the partition walls, see Figure 5. Each zone was assigned to the according schedule i.e. domestic-lounge, domestic-bedroom, domestic-dining etc. An annual comfort analysis was performed for the whole 1st floor of the terrace house. Results were given as the average daily air temperature for the indoor spaces.

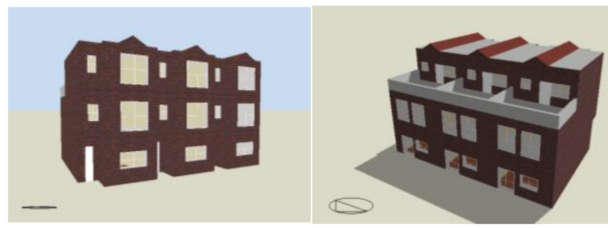

Figure 5: Design builder simulation model

Further testing was performed using PHPP software. Using the same base case assumptions, and calculating the treated floor area. As for the infiltration rate, PHPP software recommends infiltration rates inputted in ac/h, giving the net air volume (250 m3 for the base case), it calculates the rate in m3/ h.m2 @n50 p, this value is calculated in a simplified way by using the envelope area with exterior dimensions, thus deviating from the definition in EN 13829 (PHPP, 2013, version 8.4). PHPP calculates the heat demands of the building and also the percentage of overheating.

BASE CASE RESULTS

As for the design builder results, the indoor air temperatures, as shown in Figure 6, indicate that the indoor temperature was above comfort levels from mid-June to October. Reaching a Peak temperature of 29°C, representing a period of 36.9% of the year. Therefore it can be concluded that the building is not comfortable for 36.9% of the year due to overheating.

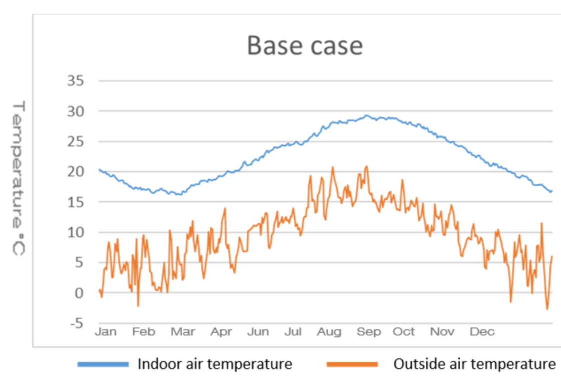

Figure 6: Design Builder results – Indoor Air temperatures

As for the PHPP results, as shown in Table 4, the heating demand was 20kWh/m².a, it does meet the FEES which recommends the highest heat demand for a mid-terrace house at 39 kWh/m².a. The results also show an overall overheating amount of 27%. It should be noted that the difference in overheating values is due to the fact that PHPP calculates the building as a whole, whereas the author's calculation in design builder was for one floor of the house. However, 27% of overheating is still a high amount and considered uncomfortable.

Table 4: PHPP Base case results

Case	Heat demand kWh/m².a	Overheating %
Base Case	20	27

FURTHER SIMULATION CASES

Several simulation cases were built in PHPP applying a number of different design solutions ranging from adding shading, changing infiltration values, ventilation levels window areas and types. The rest of the assumptions remained the same as the base case assumptions. Each case is explained in text and a summary of all cases and results can be found in table 5.

- Case A: The first design solution to explore was adding shading to the south facing windows. The shading device was designed according to the 12:00pm sun angle in summer solstice which in Nottingham is 60°. The shading device was designed to provide 100% shading at that moment in time. Consequently it would provide a shading reduction factor of 55% for all south facing windows through the summer period. This value is automatically calculated in PHPP according to the overhang depth and window areas. Figure 7 shows the design of the overhang, which may be used as a balcony also and not a mere shading device. The depth of the overhang is 1.2m for the larger windows and 0.6m for the smaller windows. The depth of the overhang blocks the summer high sun, reducing solar gains, while during winter allowing the low angled sun to penetrate the building. The south façade shading was used in all the further cases.

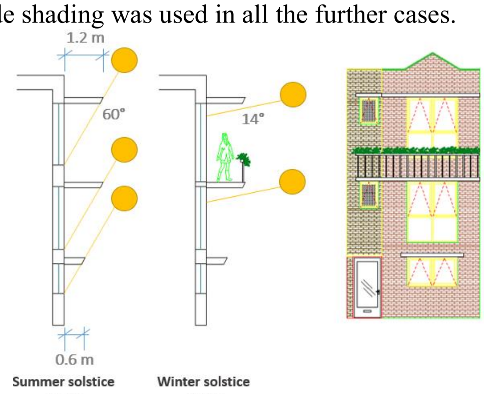

Figure 7: Shading device

- Case B: In this case the shading was used adding to it an increase in infiltration levels. The infiltration level was increased to 6 m3/ h.m2 @n50 p (0.6 ac/h), which is the maximum amount of infiltration allowed in Passive House standards. The rest of the assumptions remained the same as the base case.
- Case C: In this case the south façade shading was used, and the north facing windows area was reduced by 25%.
- Case D: In this case the south façade shading was used, and the south facing windows area was reduced by 25%.
- Case E: Here the south façade shading was used, and the window type was changed to Passive House certified climaguard triple glazing.
- Case F: This was the final case, which assumptions were built after studying the results of the former cases. For this case, the south façade shading was used, however, the north facing windows area was reduced by 25% and the free open window area was increased from 20% free open area to 40% free open area. Which after optivent testing, resulted in a summer ventilation value of 3.8 ac/h.

RESULTS AND DISCUSSION

Simulation was run for each case individually to study the effect of each parameter on the heat demands and overheating levels. A summary of the cases and there results are shown in table 5.

It is clear from the case results that in case A, shading had a great impact on reducing overheating, as the reduction was over 15%, with an impact on heat demands increasing it by 1 kWh/m2 a. Therefore the same parameter was used in the rest of the cases, in addition to investigating other design solutions. Case B was simulated with an increase in the infiltration rate up to 6 m3/h.m2 @n50 P in addition to the shading. The effect on overheating was 1% reduction, but it did increase the heat demands by 2 kWh/m2 a. As for cases C and D, the window areas were reduced. Reducing the north facing windows by 25% resulted in lower values of overheating and a significant drop in the heat demand lowering it to 15 kWh/m2 a. which meets Passive House standards for heat demands. As for the reduction of south facing window areas resulted in lower values of overheating but an increase in heat demands due to lower levels of solar gains. In case E the type of windows was changed to triple glazing Passive House certified windows. As the triple glazed windows did cause an increase in overheating, however it had a positive impact on the heat demand lowering it to 15 kWh/m2a. The final case, case F, which was simulated with 55% summer shading, reduced north window areas by 25% and an increase in the free open areas of all windows from 20% to 40% resulting in a higher rate of natural ventilation of 3.8 ac/h. The results were 15 kWh/m2a in heat demand and 0.0% overheating occurrence. Therefore the building in this final case meets Passive House standard in heat demand and also achieves thermal comfort levels during the year.

Table 5: PHPP cases summary and results

	Base Case	Case A	Case B	Case C	Case D	Case E	Case F
South façade Shaded %	0	55%	55%	55%	55%	55%	55%
Open window area %	20%	20%	20%	20%	20%	20%	40%
Natural Ventilation value ac/h	1.91	1.91	1.91	1.91	1.91	1.91	3.8
Infiltration $m^3/h.m^2$ @n50 P (according to PHPP calculation)	3.5	3.5	6 (0.6 ac/h)	3.5	3.5	3.5	3.5
Type of glazing	Double glazing low E	Double glazing low E	Double glazing low E	Double glazing low E	Double glazing low E	Triple Glazing	Double glazing low E
South windows area	Base design	Base design	Base design	Base design	Reduced by 25%	Base design	Base design
North windows area	Base design	Base design	Base design	Reduced by 25%	Base design	Base design	Reduced by 25%
Heating demand kWh/ m^2a	20	21	23	15	24	15	15
Over-heating %	27%	12.20 %	11.10 %	3.50 %	5.30 %	12.30 %	0%

CONCLUSIONS

Low energy housing in the UK is showing remarkable results in reducing heat demands. However the performance in summer high temperatures may differ. The author has taken on a study of a live project of the Trent Basin regeneration in Nottingham which was being built to meet FEES. Simulation testing on the selected residential unit showed overheating occurrence during a period of 27% of the year. On the other hand the heating demand of the same unit was 20 kWh/m2a which meets the FEES of 39kWh/m2a. A parametric study showed that several design solutions had various impacts on both the heating demand and overheating occurrence. It was concluded that optimized shading for south facing windows and ventilation had the greatest impact on reducing overheating. The added shading caused a marginal increase in the heating demand but still met FEES. Other parameters included infiltration, which increased the heating demand and did not show a major impact on overheating. Window areas were also studied and reducing south window areas showed a reduction in overheating but a substantial increase in heating demand due to a smaller amount of solar gains. Reducing north windows on the other hand, in addition to the shading devices and increased ventilation helped achieve Passive House standards. Another parameter that was explored was using triple glazed windows as a substitute for double glazed windows. This decision helped meet Passive House standards too. But after a discussion with the developers it was decided that adding triple glazed windows may not be feasible due to cost. Therefore it is recommended that the developers take into consideration adding shading to the south facing façade, reducing north facing window areas and increasing free open window areas. These design solutions have helped reach the optimal performance of the building of 15 kWh/m2a in heat demand and 0% overheating all around the year.

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