

---

This item was submitted to [Loughborough's Research Repository](#) by the author.  
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

## **Building orientation and occupancy patterns and their effect on interventions to reduce overheating in dwellings during heat waves**

PLEASE CITE THE PUBLISHED VERSION

[http://www.iesd.dmu.ac.uk/events/phd\\_conference\\_2010/papers/Porritt.pdf](http://www.iesd.dmu.ac.uk/events/phd_conference_2010/papers/Porritt.pdf)

PUBLISHER

Institute of Energy and Sustainable Development (IESD)

VERSION

VoR (Version of Record)

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Porritt, Stephen, Li Shao, Paul C. Cropper, and Chris I. Goodier. 2019. "Building Orientation and Occupancy Patterns and Their Effect on Interventions to Reduce Overheating in Dwellings During Heat Waves". figshare. <https://hdl.handle.net/2134/9772>.

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.



For the full text of this licence, please go to:  
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

## **Building orientation and occupancy patterns and their effect on interventions to reduce overheating in dwellings during heat waves**

**S. M. Porritt<sup>1\*</sup>, L. Shao<sup>1</sup>, P. C. Cropper<sup>1</sup>, C. I. Goodier<sup>2</sup>**

<sup>1</sup> Institute of Energy and Sustainable Development, De Montfort University, Leicester, UK.

<sup>2</sup> Department of Civil and Building Engineering, Loughborough University, UK

\* Corresponding author Tel: +44(0)116 255 1551 ext 6856; Fax: +44(0)116 257 7981. Email address: [sporritt@dmu.ac.uk](mailto:sporritt@dmu.ac.uk) (Stephen Porritt)

### **Abstract**

Multi-zone dynamic thermal simulation linked to a nodal airflow model, was used to assess and rank the effectiveness of selected passive heat wave mitigating interventions for reducing overheating during a heat wave period. The simulations were carried out for Victorian terraced houses in South East England using two different occupancy profiles: a family and an elderly couple and two different building orientations: front north facing and south facing.

The ranking of interventions for bedrooms, where occupied hours are similar, remain broadly the same for both orientations and occupancy profiles, the most effective being the addition of external wall insulation in all cases. However in living rooms, which are unoccupied during daytime hours for the family but occupied for the elderly couple, the ranking order changes significantly. For elderly occupancy external window shutters replace external wall insulation as the most effective intervention when the living rooms face north and are the most effective for both occupancy profiles when the building is rotated to face south. Adding internal wall insulation reduces overheating in living rooms for the family occupancy scenario, but is found to increase overheating for elderly occupancy compared to the base case. When considering interventions to reduce overheating in dwellings, it is therefore critical to take into account the residents and their corresponding occupancy profile as well as building orientation.

### **Keywords**

Heat wave; housing; overheating; adaptation; building simulation

# 1 Introduction

The European heat wave in August 2003 lasted for 10 days and claimed the lives of over 35,000 people. More than 2,000 of these excess deaths were in the UK (Johnson et al, 2005). The victims were mostly elderly and vulnerable and the situation was exacerbated by the urban heat island effect in major cities including London, where recorded temperatures were up to 10<sup>0</sup>C higher than surrounding rural areas (GLA, 2010). Such extreme weather events are predicted to increase in both frequency and severity over the coming decades (Jenkins, G. J. et al, 2009). The low level of UK housing stock replacement means that over 70% of the dwellings that will be occupied in 2050 have already been built (Arup, 2008). The need to plan for adaptation of existing buildings is being recognised in the UK by both local government, where 90% of local authorities are planning for adaptation to climate change, using National Indicator (NI) 188 (IEMA, 2009) and by central government with the recent publication of departmental adaptation policies (UK Government, 2010a).

Several reports and guideline documents have been produced that give general advice on adapting dwellings for future climates (e.g. CIBSE, 2005; Orme et al, 2003; EST, 2005 and Arup, 2008). The research presented here expands on previous published work by quantifying the effect of a range of passive interventions, specifically during heat wave periods and ranking them in order of effectiveness. The effects on the ranking order due to different occupancy profiles and building orientations are being modelled for a range of targeted dwelling types. Combinations of interventions are also being assessed and will be presented in future papers. Decision makers will have to prioritise available resources and need to know which interventions are most effective for any given dwelling and occupancy combination, which this research seeks to address. This project is part of the Community Resilience to Extreme Weather (CREW) project, funded by the Engineering and Physical Sciences Research Council (see Acknowledgements).

## 2 Methodology

The effectiveness of selected passive interventions was assessed using Integrated Environmental Solutions Virtual Environment, version 5.9.2 (IES, 2009). This software package combines multi-zone dynamic thermal simulation with a nodal airflow model and was chosen because it has a comprehensive feature set, is widely used in industry and academia and is validated for use in dynamic thermal modelling in the UK (UK government, 2010b).

### 2.1 Simulation model

A range of dwelling types is being assessed for the research project, selected to represent the housing stock of South East England. This is the area of the UK predicted to be most at risk from future overheating (Jenkins, G. J. et al, 2009) and the target area for the CREW project. Construction properties and levels of insulation for the targeted dwellings were determined by analysing the latest UK government housing data from the English House Condition Survey (EHCS) (CLG, 2009) and the Energy Saving Trust's Homes Energy Efficiency Database (HEED) (EST, 2009). The results presented here are for Victorian terraced houses, constructed in the late 19<sup>th</sup> century. Figure 1 shows the simulation model and the floor plans.

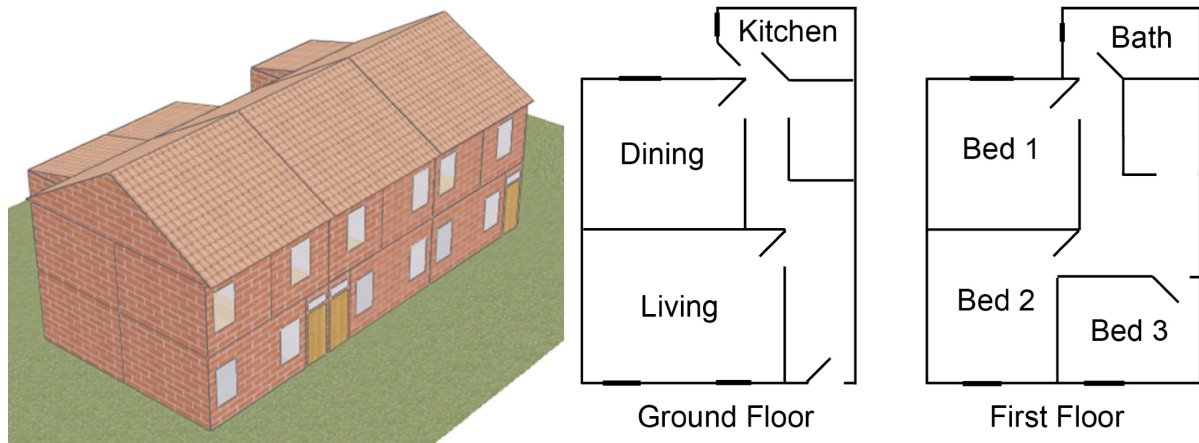


Figure 1. Terraced houses simulation model and floor plans

The simulation model is a short row of three terraced houses, located in a Greater London suburban area. Two building orientations were modelled, front north facing and south facing (see **Section 2.4**). The construction is solid brick walls, with suspended timber ground floors and clay tiled roofs. In common with many properties of this type rear extensions, constructed during the 20<sup>th</sup> century, house the kitchens and bathrooms and have solid concrete floors and uninsulated cavity walls. The windows are assumed to be double-glazed, in common with around 80% of such properties and the lofts have 100mm of joist level insulation (CLG, 2009). The open fireplaces are assumed to be sealed and have fitted gas fires. The double-glazing and lack of open fireplaces improve the air tightness. Infiltration was estimated to be 0.5 air changes per hour ( $\text{ach}^{-1}$ ), calculated using tables from the Building Research Establishment (BRE, 2002). Table 1 summarises the construction and thermal properties for the simulation model.

Internal gains for people and appliances were determined using CIBSE (CIBSE, 2006) and ASHRAE (ASHRAE, 2001) guideline values. Sensible gain values were set as follows: seated adults 65 W/person; sleeping adults 43 W/person and sleeping children 30 W/person. Appliance gains of 150W for the living rooms (TV) and 100W for children's bedrooms (computers) were set to follow occupied hours (switched off when asleep). Low energy lighting is assumed and 30W lighting heat gains are included for living rooms.

The maximum amount of window opening was set to be 25% of the glazed area. For the base case model during occupied hours, opening commences when the room dry resultant temperature reaches 22<sup>0</sup>C and opens to the full open able area by 28<sup>0</sup>C.

Element	Details	U-Value (W/m <sup>2</sup> K)	Solar Absorptivity
Main house walls	Solid brick (0.215m) with internal plaster (0.019m)	2.21	0.6
Rear extension walls	Brick and block with uninsulated cavity and plaster	1.34	0.6
Roof	Red clay tiles with joist level glass fibre insulation (0.1m)	0.36	0.7
Internal partitions	Solid brick (0.105m) with plaster (0.019m) each side		-
Ground floor main house	Suspended timber with underlay and carpet, cavity (0.3m) to ground (clay to 0.75m)	0.91	-
Ground floor extension	Solid concrete (0.1m) uninsulated to ground (clay to 0.75m)	0.89	-
Windows	Pre-2002 double glazing, plain float glass (6mm) with air gap (12mm). PVC frame (15% of window area). Crack flow coefficient 0.13 ls <sup>-1</sup> m <sup>-1</sup> Pa <sup>-0.6</sup>	3.13 (inc. frame)	-
External doors	Wooden, crack flow coefficient 0.27 ls <sup>-1</sup> m <sup>-1</sup> Pa <sup>-0.6</sup>		-

Table1. Terraced house base case model construction and thermal properties

## 2.2 Weather data

There are three options for the choice of simulation weather data. The first is to use current standard UK simulation weather files, however these do not contain heat wave periods of the severity expected later this century. The second is to use weather data from European locations such as Rome (de Wilde, 2008) and Milan (Gaterell, 2005) to approximate the South East England climate towards the end of this century. The drawback to this approach is the change in latitude, which affects solar shading calculations. Other weather variables may also differ, including humidity and wind speed. The third option, adopted in this research and in the CIBSE TM36 report (CIBSE, 2005), is to use future predicted UK weather data derived by a morphing procedure (Belcher et al, 2005). The London Heathrow CIBSE test reference year was morphed to represent a predicted year assuming the UKCIP 2080s medium high emissions scenario (Hulme et al, 2002). The weather file contains a period towards the end of June (Figure 2) where the raised mean summer temperatures are followed by a heat wave period lasting four days, during which peak daytime temperatures are around 35°C.

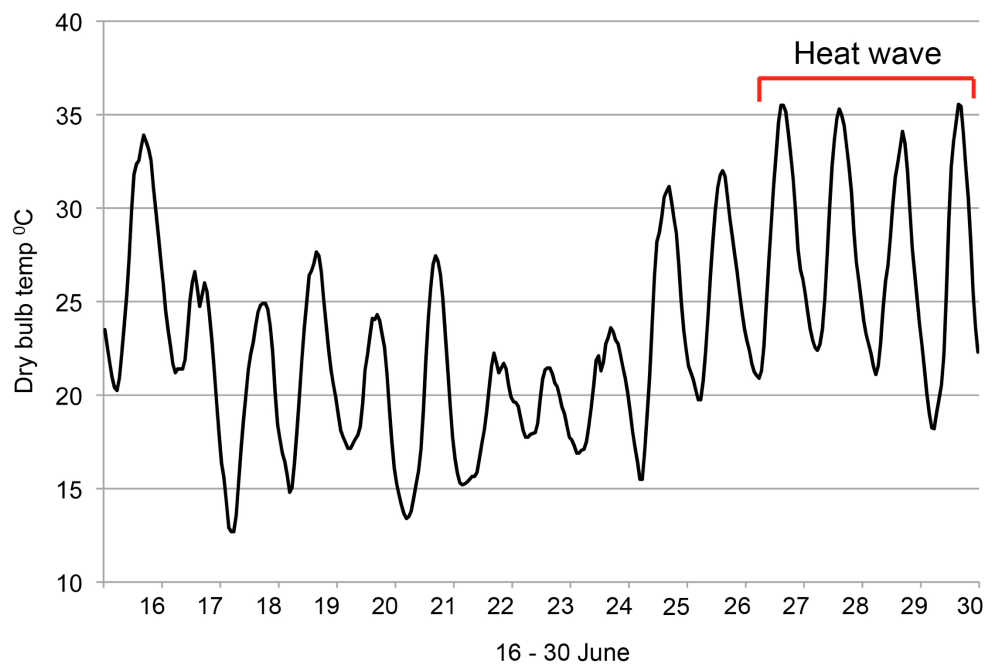


Figure 2. Simulation weather period dry bulb temperature

### 2.3 Passive cooling interventions

Selected passive cooling interventions (Table 2) were applied in turn to the base case model to assess their effectiveness in reducing overheating during the 4-day heat wave period (Figure 2).

Category	Adaptation
<b>Insulation</b>	<ul style="list-style-type: none"> <li>• Increase loft insulation from 100mm to 300mm</li> <li>• Add external wall insulation to solid walls</li> <li>• Add internal wall insulation to solid walls</li> </ul>
<b>Solar</b>	<ul style="list-style-type: none"> <li>• Fit internal window blinds, closed during the day</li> <li>• Fit external window shutters, closed during the day</li> <li>• Fit 1m deep overhangs above south-facing windows</li> <li>• Paint external walls a light colour (lower solar absorptivity) to reflect solar radiation</li> <li>• Paint the roof a light colour (lower solar absorptivity) to reflect solar radiation</li> <li>• Fit low-e double glazing to reflect solar radiation</li> </ul>
<b>Ventilation</b>	<ul style="list-style-type: none"> <li>• Night ventilation: allow ground floor windows to open at night</li> <li>• Window rules: prevent window opening if outside air is warmer than inside air</li> </ul>

Table 2. Modelled interventions

The interventions fall into three categories:

#### *Insulation:*

To reduce the transfer of heat through the solid brick walls two types of wall insulation were modelled, internal and external. In each case the insulation layer was 50mm thick phenolic foam, producing a wall U-value of  $0.35 \text{ W/m}^2\text{K}$ , the value required under current building regulations for extensions to existing properties (HMSO, 2006). The external wall insulation included a 10mm outer layer of cement render with the same solar absorptivity value (0.6) as the base case brick walls. The effect of increasing the thickness of loft insulation to 300mm to meet the current building regulations U-value of  $0.16 \text{ W/m}^2\text{K}$  was also modelled.

#### *Control of solar gains:*

Presets within the Apache software module in IES allow the addition of external shutters and internal blinds to reduce solar gain through windows. In each case they were set to close between 0900 and 1800. The external shutters block all solar radiation, whereas the internal blinds have a shading coefficient of 0.61 and short wave radiant fraction of 0.3 to simulate venetian blinds. Fixed overhangs, added to south facing windows, block high altitude solar radiation. A range of sizes was assessed using the SunCast module in IES and a depth of 1.0m was seen to be effective in blocking most direct solar radiation during the simulation period, whilst still being a manageable size. The effect of upgrading the double-glazed windows to low emissivity double-glazing was also simulated. For the low emissivity windows the outer surface of the inner pane is coated to reflect solar radiation, reducing transmittance from 0.78 to 0.69 and increasing resistance from  $0.173 \text{ m}^2\text{K/W}$  to  $0.3247 \text{ m}^2\text{K/W}$  compared to the base case glazing.

The effect of painting the walls and roof with a reflective coating to reduce solar gains was simulated by reducing the solar absorptivity of the surfaces to 0.3, the value given in the Apache user guide for a whitewashed surface. However, this value could increase over time as the surfaces become dirty.

#### *Modifications to ventilation:*

It was assumed for the base case model that residents would start to open windows above a trigger temperature ( $22^\circ\text{C}$ ) even if the air outside was warmer than the air inside, leading to an increase in room air temperature during hotter parts of the day. The window rules intervention prevents windows being opened in such situations. Finally, in the base case model ground floor windows were assumed to be closed at night for security reasons. The night ventilation intervention allows opening of ground floor windows to take advantage of night cooling for the building fabric, assuming the security issues can be overcome.

## **2.4 Occupancy and building orientation profiles**

The simulations for the base case model and each intervention were carried out four times. In the first two simulation runs the front of the terrace faced north, meaning that the living rooms were facing north and the main bedrooms (bed 1) were facing south. The first simulation run assumed occupation by a typical family of two adults and two children,



leaving the house unoccupied during the daytime. The second run assumed occupation by an elderly couple, at home during the daytime. Table 3 shows the occupancy profiles for the living rooms and main bedrooms.

	Living rooms	Main bedrooms
Family	1700 - 2230	2230 - 0700
Elderly Couple	0800 - 2130	2130 - 0800

Table 3. Occupied hours for living rooms and main bedrooms

The simulations were then repeated with the model orientation changed so that the front of the terrace faced south, producing a total of four sets of simulation results.

## 2.5 Overheating assessment

The Chartered Institute of Building Services Engineers (CIBSE) report TM36 (CIBSE, 2005) predicts the reduction in occupied hours over the CIBSE comfort threshold temperatures of 26°C for bedrooms and 28°C for other living areas (CIBSE, 2006) that may be achieved for a combination of interventions for a selected range of building types. However, recording hours over threshold temperatures does not necessarily distinguish between two overheating cases. For example, a bedroom at 28°C for one hour would appear to overheat to the same extent as one at 32°C for one hour. Reporting the number of degree hours over the threshold temperature therefore gives a more accurate representation of the severity of the overheating problem and enables better comparison of the relative effectiveness of interventions. Each degree centigrade over the threshold temperature in each hour adds up to give the number of degree hours during the occupied period, so for example two hours at 30°C in the bedroom would record 8 degree hours. This approach has been used in other research (e.g Orme et al, 2003) and is the method chosen to quantify the degree of overheating in this research.

## 3 Results and discussion

Dynamic thermal simulations were performed on the base case model and for the interventions listed in Table 2, for the two building orientations and two occupancy profiles. The dry resultant temperature for the living rooms and main bedrooms in the three terraced houses was computed for each hour over the 4-day heat wave period (Figure 2) and the average dry resultant temperature at each hour for each room type was calculated.

The results presented in this paper show the effect of the interventions on the number of degree hours over CIBSE comfort threshold temperatures for the living rooms and main bedrooms (bed 1 in Figure 1).

### 3.1 Intervention ranking for main bedrooms

The stacked bar charts in Figures 3 and 4 show the effect of interventions on the number of degree hours over the CIBSE comfort threshold temperature of 26<sup>0</sup>C, during occupied hours, for the main bedrooms. Each chart shows the effect of the interventions for the two occupancy profiles, with the terrace oriented such that the main bedrooms face south (Figure 3) and north (Figure 4).

The first observation is the increase in the number of degree hours of overheating for the elderly occupancy profile, which is due to the slightly higher number of occupied hours for the elderly couple. The charts show the ranking order for the family occupancy profile, but it can be seen from the elderly profile stacked bars that the ranking order is broadly the same for both occupancy profiles.

External wall insulation is the most effective intervention for all cases, reducing the number of degree hours over 26<sup>0</sup>C by between 32% (south facing) and 37% (north facing). The external wall insulation shields the outer brick surface from direct solar radiation, whilst leaving the internal plastered walls exposed to provide radiative cooling. The increased effectiveness of external wall insulation when the main bedrooms are facing north is due to the presence of a west facing main bedroom wall when the model is rotated, which receives a large amount of direct solar radiation during the afternoons. External window shutters are ranked second, reducing degree hours by 21% when facing south and 26% when facing north. The increased effectiveness of shutters when the main bedrooms are north facing is due to the larger total south facing glazed area when the terrace is rotated. Internal doorways are assumed open during the day, allowing convection of the heat gains through the houses. Internal wall insulation is the third most effective intervention, reducing degree hours by between 18% and 21% and is less effective than external wall insulation (of the same U-value) due to a reduction in radiative cooling from the inner wall surfaces and heat gains being more effectively trapped within the rooms. Reducing the solar absorptivity of the walls by painting them a lighter colour reduces degree hours by 16-18%, the slightly greater reduction again being seen when the model is rotated to introduce a west facing main bedroom wall. Other interventions that have a fairly modest but noticeable effect, reducing degree hours by between 5% and 10%, include internal venetian blinds; lower solar absorptivity (lighter coloured) roof tiles; modifying the window opening rules to prevent opening when the outside air is warmer than the air inside and fixed external shading over south facing windows. Increasing the level of loft insulation and replacing the existing double-glazing with low emissivity double-glazing have a minimal effect, only reducing degree hours by 1-2%.

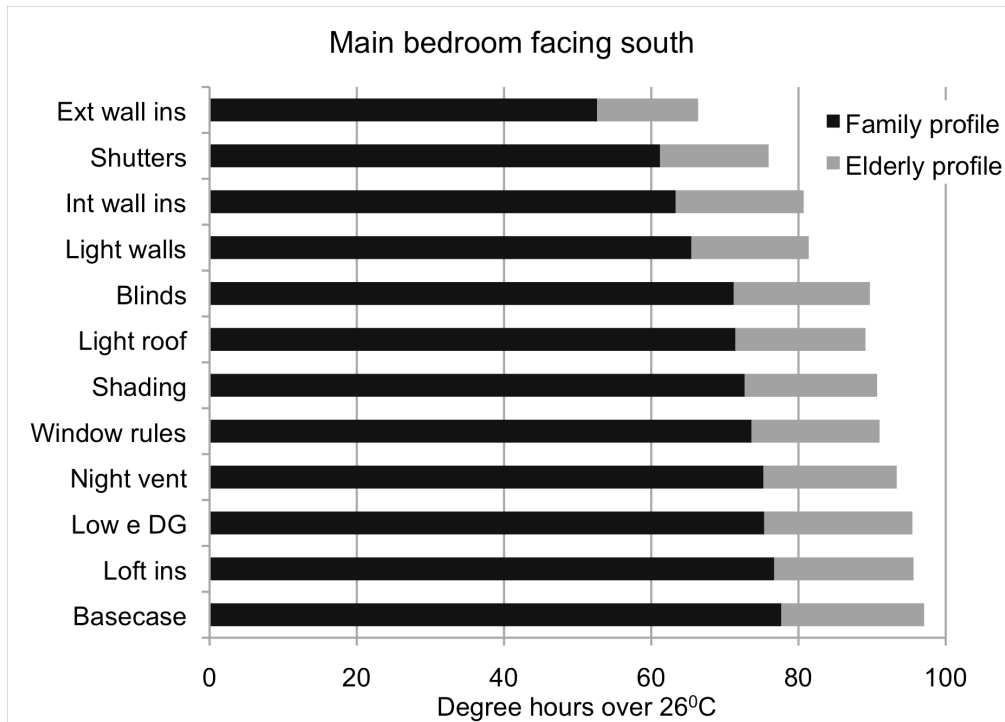


Figure 3. Intervention ranking for main bedrooms facing south (4 day heat wave)

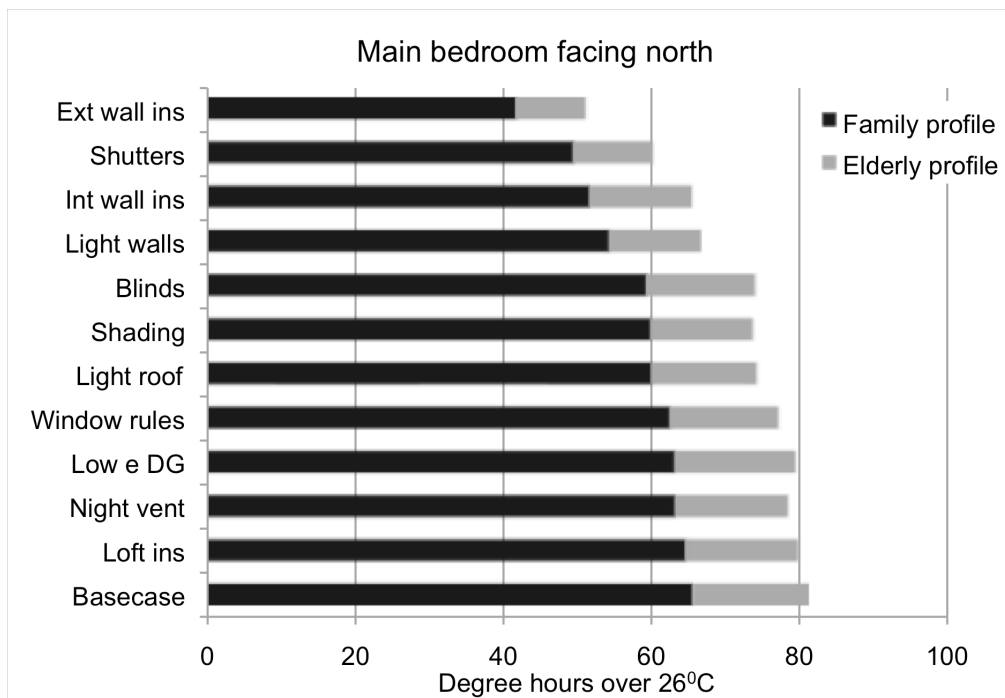


Figure 4. Intervention ranking for main bedrooms facing north (4 day heat wave)

### 3.2 Intervention ranking for living rooms

The occupancy profiles for the living rooms are very different, with the family assumed to be out of the house during the daytime and the elderly couple at home, occupying the living room during daytime and evening hours. The charts in Figures 5 and 6 show the effect of the interventions on degree hours over 28°C for the two profiles and building orientations. The charts show the much higher degree hours of overheating experienced by the elderly occupants.

External wall insulation is still the most effective intervention for the family profile when the living rooms are north facing, reducing degree hours over 28°C by 42% compared to the base case, but is seen to be less effective when north facing living rooms are occupied during the daytime, producing a 22% reduction. Here external window shutters become the most effective intervention, reducing the number of degree hours by 32%. When the building is rotated so that the living rooms face south, shutters become the most effective intervention for both occupancy profiles, reducing degree hours by 34% for the family profile and 41% for elderly occupancy. External shading by overhangs above the south facing windows are more effective when the living rooms face south, particularly for the elderly profile where it becomes the second ranked intervention, producing a 22% reduction in degree hours.

Preventing the windows from opening if the outside air is warmer than the inside air (window rules) is a more effective intervention in living rooms, which are occupied during hotter parts of the day. For north facing living rooms with the elderly occupancy profile it is the second best intervention, reducing degree hours over 28°C by 27%.

Night ventilation of the ground floor rooms cools the thermal mass of the solid walls and provides a radiative cooling benefit that persists into the hotter daytime period, which is particularly beneficial for the elderly occupancy profile, reducing degree hours by 17% when the living room is south facing and 24% when north facing. Light coloured walls consistently reduce overheating under all scenarios, reducing degree hours by between 14% and 19%. Internal blinds reduce the number of degree hours by between 9% and 12%, but are less effective than external shutters because much of the solar radiation is trapped inside the room. Increasing the loft insulation, light coloured roof tiles and changing to low emissivity double-glazing are of little benefit, as was the case with the main bedrooms.

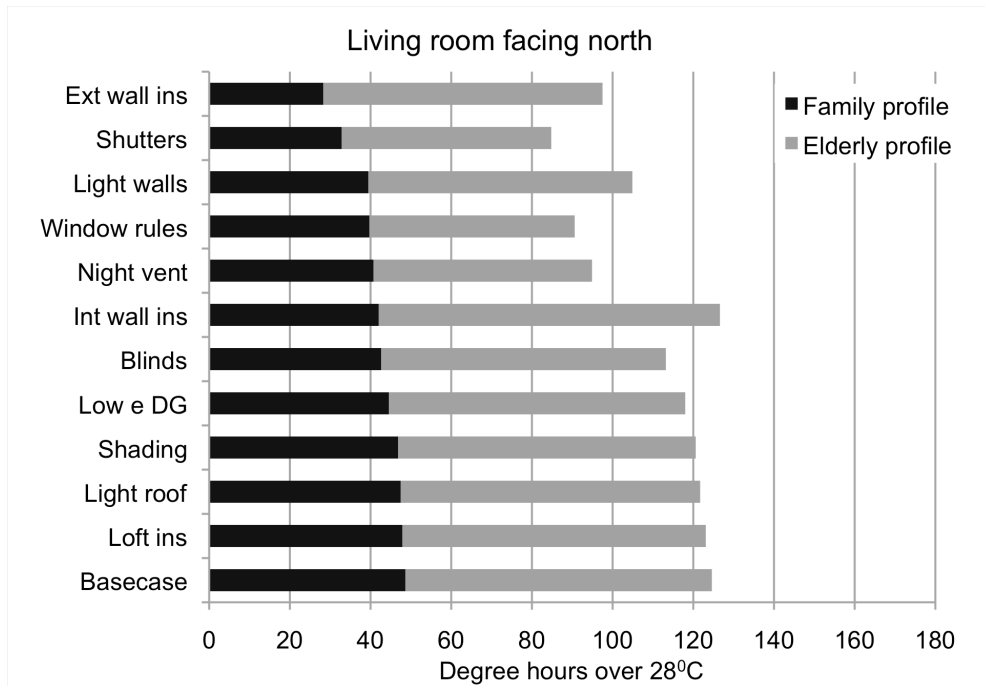


Figure 5. Intervention ranking for living rooms facing north (4 day heat wave)

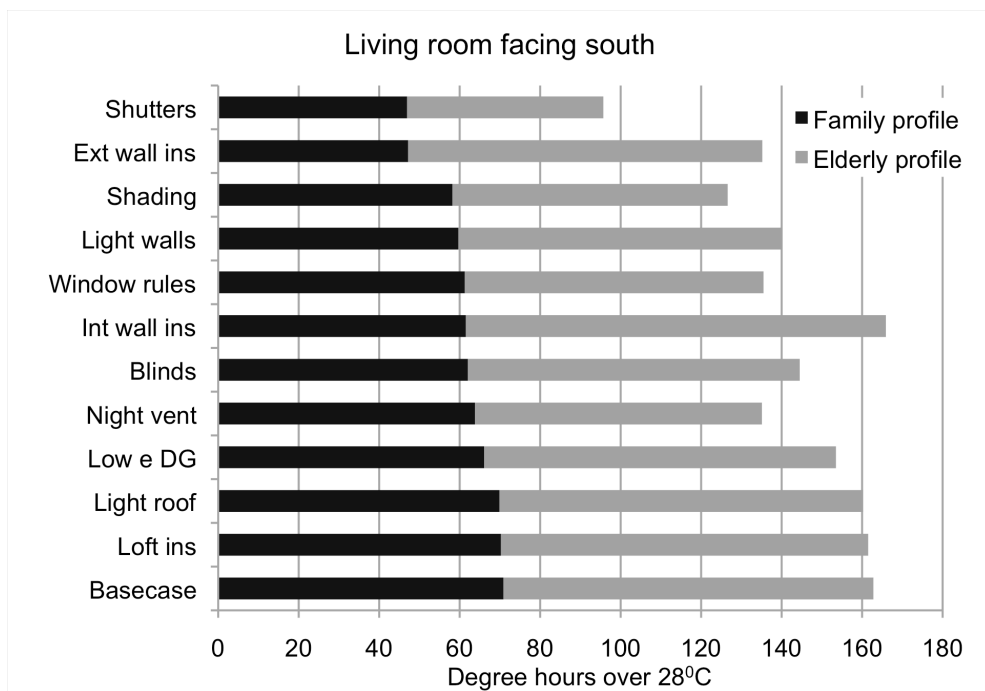


Figure 6. Intervention ranking for living rooms facing south (4 day heat wave)

## 4 Conclusions

The results demonstrate the potential to reduce overheating during heat waves for a range of passive interventions. The ranking order is broadly the same for both orientations and occupancy profiles for the main bedrooms, where occupied hours are similar. External wall insulation was found to be the most effective intervention, followed by external shutters, internal wall insulation and light coloured walls. The least effective interventions for the main bedrooms were found to be increasing the loft insulation depth to 300mm, changing to low emissivity double-glazing and night ventilation of ground floor rooms.

For living rooms however, the change in ranking order between simulation options was found to be more significant. Unlike the family scenario, where the houses are unoccupied during daytime hours, the elderly residents occupy the living rooms during the hottest parts of the day and are subjected to a much higher number of degree hours over the comfort threshold temperature of 28°C. Here the choice of wall insulation type is shown to be particularly important. The addition of external wall insulation is again seen to be very effective, being the highest ranked intervention for family occupancy when the living room is facing north and still one of the higher ranked interventions for the other scenarios. For the family profile the addition of internal wall insulation is also effective, though less so than external wall insulation. However, for the elderly profile the addition of internal wall insulation results in an increase in degree hours of nearly 2% compared to the base case model as internal gains are retained in the room and radiative cooling from the solid walls is reduced. The elderly profile results show that measures that reduce solar gains through the windows are the most effective interventions when the living rooms face south and are occupied during daytime hours.

Those responsible for adapting the UK housing stock to cope with climate change will need detailed information to make cost effective decisions. This research shows the importance of considering not only the dwelling details but also the occupancy profiles when choosing appropriate interventions.

## Acknowledgements

This research is funded by the Engineering and Physical Sciences Research Council (EPSRC) as part of the “Community Resilience to Extreme Weather” (CREW) project (grant number EP/F036442/1). Their financial support is gratefully acknowledged. Further details are available at [www.extreme-weather-impacts.net](http://www.extreme-weather-impacts.net)

## References

Arup (2008). Your home in a changing climate (for Three Regions Climate Change Group). Greater London Authority. ISBN 978 1 84781 133 2 London.

ASHRAE (2001) Handbook: Fundamentals 2001. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

Belcher, S., Hacker, J. and Powell, D. (2005) Constructing design weather data for future climates. Building Services Engineering Research and Technology, 26(1):49–61.

BRE (2002) Building Research Establishment. BREDEM-8 Model description 2001 update. BRE, Watford, UK.

CIBSE (2005) CIBSE TM36: Climate change and the indoor environment: Impacts and adaptation. (Principal authors Hacker, J.N., Holmes, M.J., Belcher, S.B., and Davies, G.D.). Chartered Institute of Building Services Engineers, London.

CIBSE (2006). CIBSE Guide A: Environmental Design. Chartered Institute of Building Services Engineers, London.

CLG (2008) Communities and Local Government. National Indicators for Local Authorities and Local Authority Partnerships: Handbook of Definitions. Revised edition May 2008, HM Government, DCLG, London

CLG (2009) English house condition survey public dataset. Available on CD-Rom from EHCS Project Team, CLG, Eland House, Bressenden Place, London SW1E 5DU. Product code 09ACST06138.

de Wilde, P., Yaqub, R., and Beck, M. (2008) Uncertainties in predicting the impact of climate change on thermal performance of domestic buildings in the UK. Building Services Engineering Research and Technology, 29(1):7–26.

EST (2005) Energy Saving Trust CE129: Energy efficiency best practice in housing: Reducing overheating – a designer’s guide. Technical report, Energy Saving Trust, London.

EST (2009) Energy Saving Trust Homes Energy Efficiency Database (HEED). Online (restricted access): [www.energysavingtrust.org.uk/heedonline/](http://www.energysavingtrust.org.uk/heedonline/) Last accessed 20<sup>th</sup> April 2010.

IES (2009) Integrated Environmental Solutions Virtual Environment: [www.iesve.com](http://www.iesve.com) (MacroFlo and Apache user guides accessed from within the software).

Gaterell, M. R. and McEvoy, M. E. (2005) The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings. Energy and Buildings, 37:982–995.

GLA (2010). Greater London Authority. Mayor of London’s draft climate change adaptation strategy. Online: [http://www.london.gov.uk/climatechange/sites/climatechange/staticdocs/Climiate\\_change\\_adaptation.pdf](http://www.london.gov.uk/climatechange/sites/climatechange/staticdocs/Climiate_change_adaptation.pdf) Last accessed 20<sup>th</sup> April 2010.

HMSO (2006). The Building Regulations 2000: Conservation of Fuel and Power Part L1B. Conservation of fuel and power in existing dwellings (revised April 2006). The Stationery Office (Office of the Deputy Prime Minister), London. ISBN-13 978 1 85946 218 8.

Hulme, M., Jenkins, G. J., Lu, X., Turnpenny, J. R., Mitchell, T. D., Jones, R. G., Lowe, J., Murphy, J. M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. (2002) Climate change scenarios for the united kingdom: The UKCIP02 scientific report. Technical report, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK.

HEMA (2009) The Institute of Environmental Management and Assessment. Special Report: Adapting to Climate Change Survey, Lincoln, UK.

Jenkins, G. J., Murphy, J. M., Sexton, D. S., Lowe, J. A., Jones, P. and Kilsby, C. G. (2009). UK Climate Projections: Briefing Report. Met Office Hadley Centre, Exeter, UK.

Johnson, H., Kovats, R. S., McGregor, G., Stedman, J., Gibbs, M. and Walton, H. (2005) The impact of the 2003 heat wave on daily mortality in England and Wales and the use of rapid weekly mortality estimates. *Eurosurveillance*, 10(7-9):168–171.

Orme, M., Palmer, J. and Irving, S. (2003) Control of over-heating in well insulated housing (FaberMaunsell Ltd.). In Proceedings of the CIBSE/ASHRAE Conference in Building Sustainability, Value and Profit, Edinburgh, 24-26 September, 2003.

UK Government (2010a) HM Government departmental adaptation plans. Available online: <http://www.defra.gov.uk/environment/climate/programme/across-government.htm> Last accessed 30th April, 2010.

UK Government (2010b) Building Energy Calculation Software Approval Scheme. AECOM and Department of Communities and Local Government. Online: [www.ukreg-accreditation.org/ND-ApprovedSoftware.php](http://www.ukreg-accreditation.org/ND-ApprovedSoftware.php) Last accessed 20th April 2010.