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The Challenge of Modelling Solar Shading Products and Their Impact on the Built Environment

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Abstract

Improved insulation and glazing contribute to overheating in buildings, the incidence of which is rising. Blinds and shutters can reduce thermal gain if specified and used correctly and their value as passive and/or low energy products is now being acknowledged by construction professionals, who also recommend that building models include solar shading devices to reduce overheating in buildings. However, some software does not appear to generate accurate models of shading products and their impact as illustrated in a comparative study of recent real-time data from a refurbished residential building in London and the results of building simulations. This paper describes this study, reasons for the limitations in the models and proposes that software is updated to account for changing weather and climate.

Keywords Thermal Modelling; Solar Shading; Overheating, IES

1.0 Introduction

Over the last few decades, the emphasis on building performance and energy efficiency has resulted in increased insulation and reduced air infiltration into the built environment. While these strategies have successfully reduced demand for heating, they have also contributed to incidences of overheating in buildings in the UK during both typical and extreme weather events (i.e. ‘heatwaves’), which causes thermal discomfort and health problems for building occupants; overheating could also lead to a major increase in energy demand for cooling, which will negate the energy savings from reduced heating.

Although many building occupants and professionals continue to regard blinds and shutters as decorative features, research shows that both internal and external solar shading products can help to control solar radiation; this aids management of light and thermal conditions, which reduces energy consumption for heating and cooling and enhances the quality of the indoor environment and thus better living and working conditions (1).

As the benefits of solar shading and similar passive design solutions are becoming more widely recognised their use is being promoted by and to professionals associated with the construction industry (2, 3, 4); however, they are only truly effective if correctly specified and used and at present these criteria are not entirely understood by designers or developers. Furthermore, even when included in building designs, developers often fail to install them because they are seen as ‘expensive extras’ that can be omitted to reduce costs (5).

Both static and dynamic digital models have been used in the construction industry for many years to simulate building behaviour and performance. Their use is becoming increasingly important to evaluate optimum design solutions which should help to identify and apply adaptive and mitigation strategies to improve thermal comfort in existing buildings and/or new buildings. Modelling passive interventions in buildings is becoming an essential feature of energy performance assessments and software tools can also be used to demonstrate the impact on and importance of solar shading products in the built environment. In addition to building fabric, these models must include climatic conditions, which are critical to the development of solutions to combat new and unfamiliar external factors such as changes in weather and climate (6).

Accurate data in software is essential to generate accurate models and results because they will influence product selection and choice of mitigation strategy; conversely inaccurate output will have an adverse impact on this and building performance. It appears that there are differences between thermal gain and building performance in the real world and that predicted in simulations, which will have a negative impact on mitigation and adaptation strategies. This paper now describes a recent study that compares real world data with the results from a series of parallel mathematical models in order to test this hypothesis; we first compare real-time data and simulations of external temperatures and then examine their impact on interior conditions in a room without blinds to highlight the challenges faced by building modellers; we then briefly compare these results with results for a real-time and simulated room with blinds to emphasise these challenges.

2.0 Case Study

The aim of this research work is to determine the effectiveness of a commonly used thermal modelling tool and two weather data sets by analysing and comparing results from dynamic thermal simulations with those from real world case study. This particular study expands on data collected by a research team from London South Bank University (LSBU) between August and October 2016, to illustrate the benefits of blind use during summer months, particularly on exceptionally warm days. The lux levels and thermal behaviour of a building were monitored by measuring external temperature and its impact on and internal operative and glazed surface temperatures in a room without blinds and in a room with blinds; results and analysis were subsequently published in September 2017 (7).

2.1 Bayham Street Flats, Study and Real Data

The three-story building was originally built for commercial purposes and in 2016 it was converted into twenty loft-style apartments including an extension and two penthouse suites located above the original top floor (Figure 1). The façade of the building featured in the study is orientated south-west (241.58°), has heavily glazed windows and faces a busy road in the heart of north London. A 24-hour operative bus stop is located directly in front of the property and a 4.50m wide communal front yard and 2.11m high wooden fence separate the building façade from the pedestrian footpath.

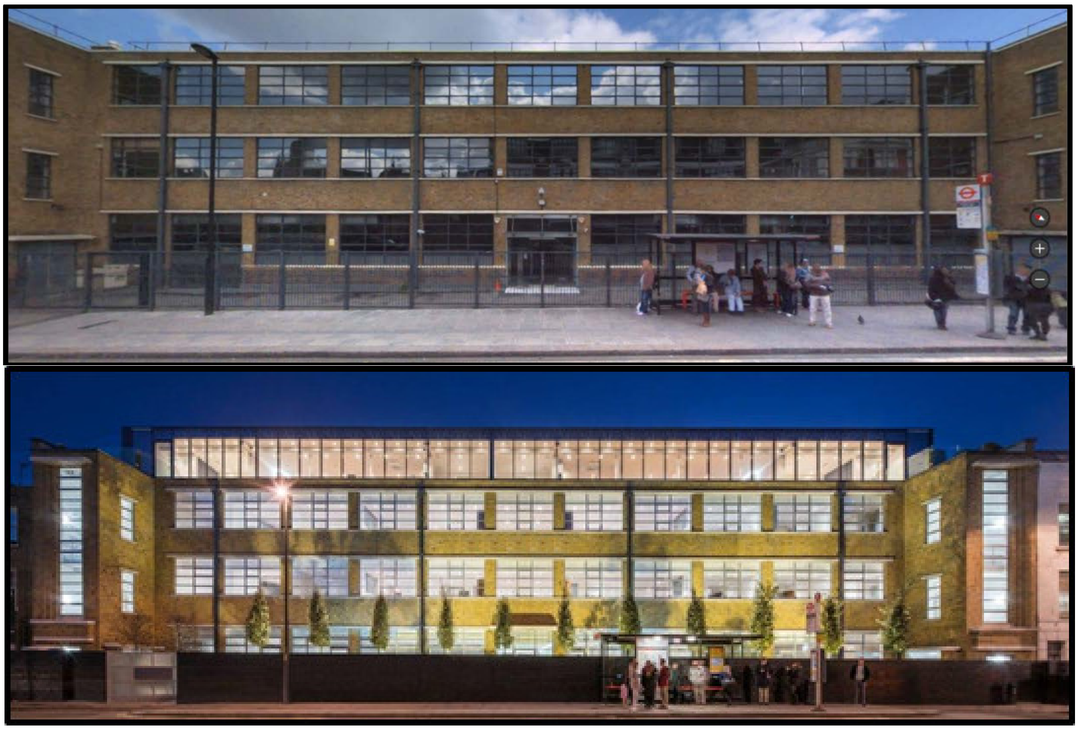

Figure 1 –Case Study building before and after the renovation

Both of the two-bedroomed apartments in the study (Units 13 and 18) have identical layouts and are located on the first and second floors respectively; in each bedroom (shown as rooms A and B) the finishes, surfaces and orientation are also identical. The glazed area of the bedroom windows is the same size, and their external surfaces are exposed to the same level of solar radiation as shown in Figure 2, which also shows where the various instruments were located in the real-time study).

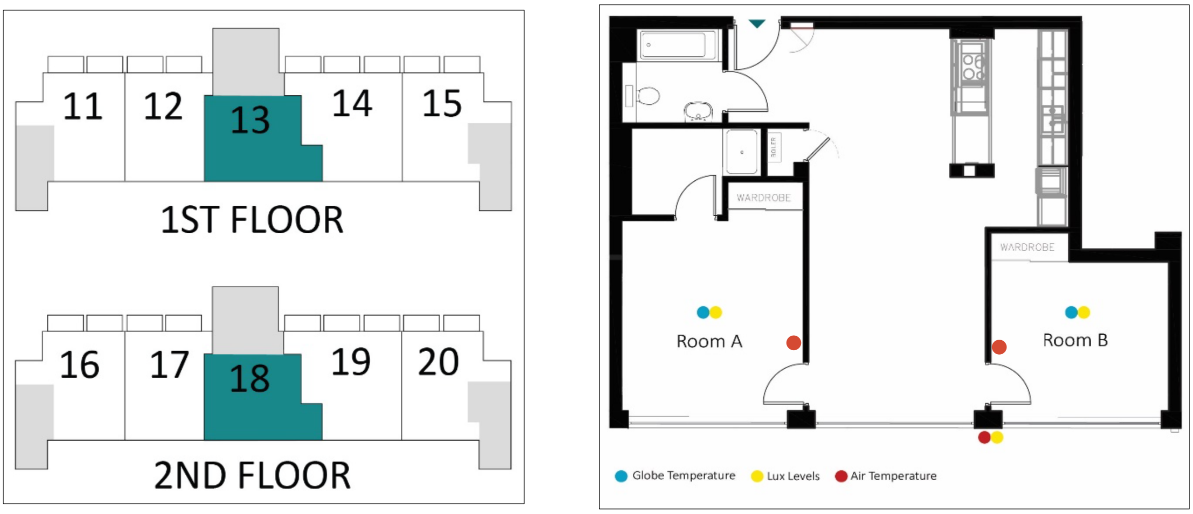

Figure 2 – Unit 13-18 layouts with sensor location (7)

During this initial study the entire building was untenanted, which made real-time monitoring relatively straightforward; this and the simulation were used to determine the thermal performance and possible risk of overheating in the building as advised by CIBSE in the related Technical Memorandum, TM52 (2). As stated above the real-time data was collected to identify the impact of different types of blind on lux levels and thermal behaviour in these residential properties (7). Table 1 shows industry specified properties of the Venetian horizontal slat blind used in this study.

<table>
<tr><th colspan="3">Blind System Specification for Aluminum Venetian - Silver (80mm)</th></tr>
<tr><td colspan="2">Solar Transmittance (τs)</td><td>0.0</td></tr>
<tr><td colspan="2">Solar Reflectance (Rs / ρs)</td><td>0.5</td></tr>
<tr><td colspan="2">Solar Absorptance (αs)</td><td>0.5</td></tr>
<tr><td colspan="2">Visible/Light Transmission (Tv)</td><td>0.0</td></tr>
<tr><td colspan="2">Visible/Light Reflectance (ρv)</td><td>0.5</td></tr>
<tr><td colspan="2">Visible/Light Absorptance (αv)</td><td>0.5</td></tr>
<tr><td colspan="2">SC=T + 0.87 x A*</td><td>0.435</td></tr>
<tr><td colspan="2">SWRF=T/SC**</td><td>0</td></tr>
<tr><td>Shading Coefficient (Sc)</td><td rowspan="3">Glazing Ref C: 0.59</td><td>0.49</td></tr>
<tr><td>Shading Factor (Fc)</td><td>0.6</td></tr>
<tr><td>Gtot</td><td>0.43</td></tr>
</table>

NOTE:
**Equation 1 – Calculation of Solar Shading Coefficient, IES methodology*
*** Equation 2 – Calculation of Short-Wave Radiation Fraction, IES methodology*
These formulae apply to a blind consisting of a single sheet of material, such as a roller blind or a closed slatted blind (10).

Table 1 – Blind system specification

The study is based on 16 days' data collected between August and October 2016, lighting and thermal measurements were recorded at 10 or 30 minute intervals from 8am until 4.30pm when the windows were closed; the windows were open between 4.30pm and 8am to allow the building to cool overnight in order to assess the impact of blind use on following days:

- Operative Temperature/s (OPT): a 40mm Ø black globe thermometer mercury sensor was used to measure and record the indoor thermal condition of each bedroom every ten minutes. The sensors were set up on a tripod and positioned in the middle of each room and at a height of 1.2m (Figure 3).
- Room Air Temperature/s – wall mounted temperature sensor, monitored every 10 minutes
- Glazing Surface Temperature/s: for monitoring the internal temperature of the window surface, a handheld surface temperature sensor was positioned adjacent to the centre of the internal window pane (centre glazed row, second panel from window bottom).

- External Air Temperature/s: an air temperature sensor was positioned in the front yard at ground floor level.

Figure 3 - Room A and B in Unit 18 with sensor setup 4

All internal and external sensors were carefully located to avoid direct solar radiation and to prevent any radiant heat from reaching the metal probes, in order to minimise any disturbance during the data collection procedure.

2.2 IES models

In this study Integrated Environmental Solutions Virtual Environment version 2017.0.1.0 software 7 was used to build the bespoke models and simulate the impact of blind systems in the building. During the renovation, the insulation and air tightness of the building were improved in compliance with the recommended values of the building regulations, and included in the model (11). Figure 4 shows the digital model, which, like the real-time study, includes the four bedrooms; as previously stated the real-time study included different internal and external solar shading products whereas the digital model only includes an aluminium Venetian blind. Virtual OPTs were measured to assess the effects of these various devices in rooms with and rooms without blinds.

Figure 4 – IES Model Viewer South-East façade

Component	Description of Intervention	Orientation
External Wall	On the existing external wall brickwork (two stretcher courses) has been applied an insulation layer (Polyisocyanurate type).	South West
Internal Partition	Brickwork and double plaster white paint walls.	-
Internal Ceiling/Floor	Introduced insulation (Polyisocyanurate type), 150mm cavity and plaster white paint. Oak wood flooring added to the walkable area.	-
Internal Doors	Disposed wooden doors, allowing air transfer between rooms.	-
Glazing	Renovation of windows included double low-e, argon filled glazing with a black/grey spacer. Aluminium and steel window frame. Top hung 100% openable crack length of two middle windows pane.	South West

Table 2 – Data of the fabric envelope implemented in IES building model

Analysis of the materials' composition and thermal characteristics revealed that the average thermal mass is 8.75 kJ/m^{2}K, and therefore the building is very lightweight. This and other design features in the model are the same as those in the real-time case study including levels of occupancy and window opening times: it is assumed that the apartments are vacant during the working week (Monday to Friday from 8am to 4.30pm) and therefore windows are opened 4.30pm and closed at 8am to allow the building to cool overnight. Similarly inhabitancy was included although factors that could contribute to internal heat gain (e.g. artificial lights and electronic equipment) are excluded.

2.2.1 Modelled passive cooling interventions

Additional mechanical ventilation was not considered as part of the real building renovation, and consequently cooling is dependent on windows being opened at some point during day or night. The residential property is located in a highly populated area and residents will probably keep windows closed during the day for security reasons. Furthermore, high noise levels deriving from the adjacent street will influence their decisions to open the windows at night. Table 3 lists these various parameters in the model.

Space Data	Type	Description	Operating Profile
System	Heating	No heating generator has been included	Off continuously
	Cooling	No Air Cooling System has been included (only free cooling during the night)	Off continuously
Ventilation	Naturally ventilate building	No mechanical ventilation has been considered in the design. The ventilation has been provided through opening window face to South East	4:30pm to 8am
	Infiltration	Infiltration rate 0.25 ac/hr	On continuously
Internal Heat Gains	Occu pancy	Replicated real case experiment, presence of a technician for recording temperature measurement and opening/closing windows. (sensible/latent heat gain 90/40W)	1h/day
	Artificial Lighting	Replicated real case experiment, no artificial lighting has been considered	Off continuously

Table 3 – Modelled system profile of the building

2.2.2 Modelled weather data

The initial model only used data from IES but weather data from Energy Plus was later included as a control. When assessing the building performance, historical weather data was found to be inconsistent and to exclude extreme temperatures such as those experienced in summer of 2016. In order to compensate for these gaps, simulated future weather data was added to the model; it was produced by the UKCP09 Generator 11 and morphed to obtain projections for 2030, 2050 and 2080. This may not be entirely satisfactory because there is no a clear documentation of (a) how new weather data (produced by new generator methods) affects energy simulation results or (b) how they compare to recorded weather data (13). Nevertheless, this was regarded as the best option for this research work because the simulated conditions were closest to those from the 2016 real-time study and included a comparative evaluation of external dry bulb temperatures and parameters such as external dry-bulb temperatures (^{o}C) and external global radiation (W/m^{2}) levels.

3.0 Results and Discussion

The simulations were based on specific days and all produced results which differ from those from the real-time studies; this is due to the differences between real climate (weather) data and that generated and implemented into the computer simulation. Figure 5 compares the dry-bulb temperature trends with the profile produced by the probabilistic weather generator and those from IES (10) and Energy Plus (14).

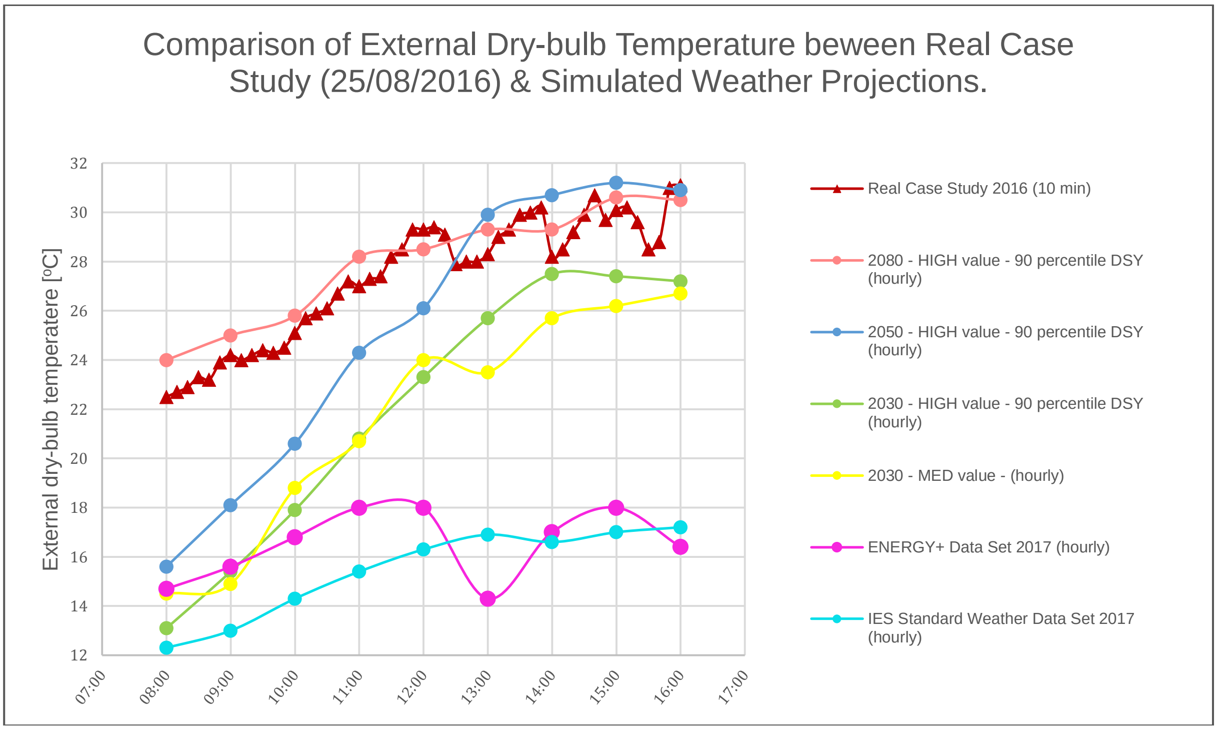

Figure 5 – A Comparison of External Temperature Profiles with differing Weather Files

It illustrates the considerable differences in temperature profiles: the results from the (morphed) 2080 model are closest to the acquired 2016 data while those from the ‘ordinary’ weather profiles, (i.e. the Energy Plus (14) and IES (10) data sets) are the least similar. Although the weather and climate conditions in 2016 were non-moderate and can be described as ‘heatwaves’, they highlight the shortcomings in current data sets, which will have a significant impact on current building models and mitigation strategies.

Hundreds or thousands of variables should be considered for modelling climate conditions during any day and, in addition to external temperature profiles, weather generators include other fundamental climate parameters such as direct and diffuse solar radiation (W/m2), wind speed (m/sec) and direction [E of N] (deg.), consideration of azimuth and altitude variations of the sun during the year. These parameters enable computer software to run comprehensive simulations and although the projections are probabilistic, they are closer to what really occurs in the external environment than temperature profiles alone. Consequently, lux levels were included in the simulations although it was necessary to make some assumptions (e.g. about cloud levels and their impact on lux) in order to run the simulations.

The results in Figure 6 show interior lux levels for 25 August 2016 during which cloud movement above and near the building location was consistent in the early morning and between 12pm and 2pm. In this case there is less difference between the lux levels in the various simulations than there is between those and the acquired data.

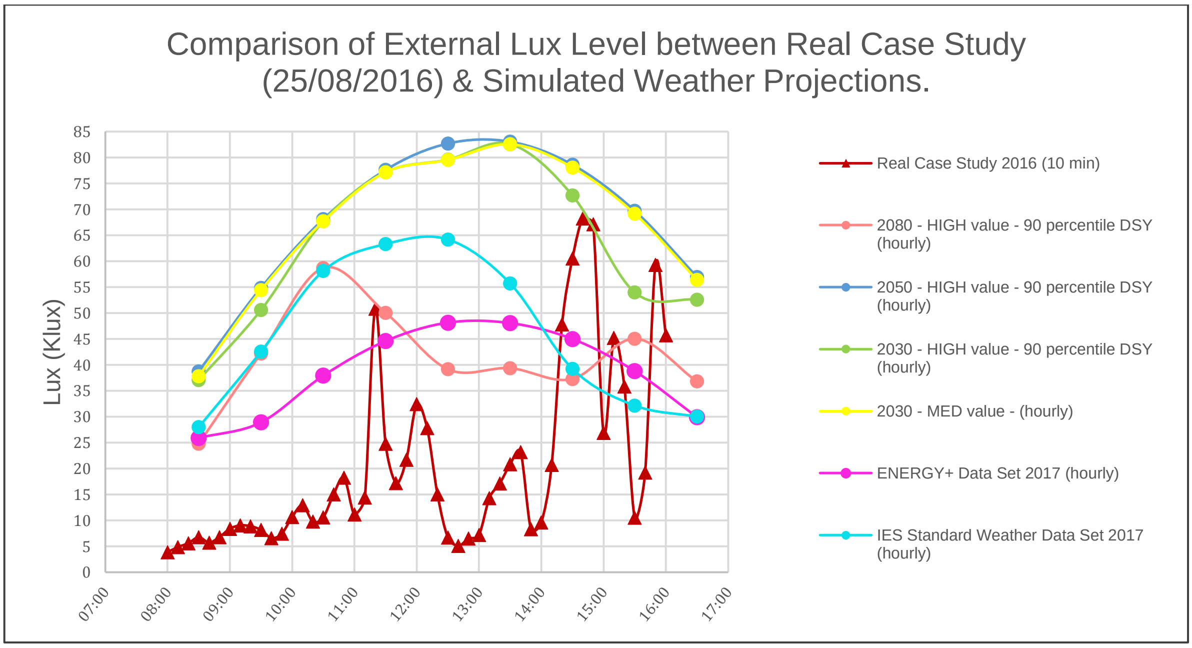

Figure 6 – A Comparison of Lux level profiles with differing Weather Files

Once again, the limitations of the software influenced the simulated results and although the IES Application, SunCast (Solar Shading Analysis), offers various operational features for solar shading analysis and produces energy values (kWh/m^2) directly for interior spaces in the model, function is restricted to the geometry of the built model. However, future work could include an additional application such as Simulation Cloud to improve accuracy of the model.

3.1 Results of Thermal Model

Table 4 lists the various parameters for the IES model. It should be noted that, unlike the real-time study, operative temperatures (OPTs) in this model were based on the average temperature whereas actual OPTs were recorded at specific points in the room. This further limitation has also affected results which should be regarded as representative rather than definitive. Nevertheless, the various thermal simulations produced a vast range of results for the simulated rooms with and without blinds.

Parameter	**Description**	**Interval**	**KEY**
External Air Temperature (^{o}C)	External dry bulb temperature	hourly	EXT AIRTEMP
Lux Level (Lux)	External illuminance level (given by global radiation [W/m2])	hourly	LUX
Internal Air Temperature (^{o}C)	Internal dry-bulb temperature	10min	INT AIRTEMP
Operative Temperature (^{o}C)	Average of internal operative temperature in the room	10min	OPTEMP
Glazing Temperature (^{o}C)	Internal glazed surface temperature	10min	GLTEMP
Fabric Temperature (^{o}C)	Internal blind fabric surface temperature	10min	FBTEMP

Table 4 - Parameters produced by IES

3.2 Results from Thermal Simulation without Internal Blind System

Figures 7, 8 and 9 show interior air temperatures, average operative temperatures and glazing temperatures respectively in a room without a blind. If we focus on the increase in temperature, the results from the real-world study show that overall temperature is higher (ΔT = 7 K) than the simulated profiles and that there is a sudden increase at 1pm which was not detected by the thermal simulation. This is due to direct solar radiation and heat gain through the glazing to a room without ventilation, the effect of which is intensified as external temperatures peak between 2pm and 4pm.

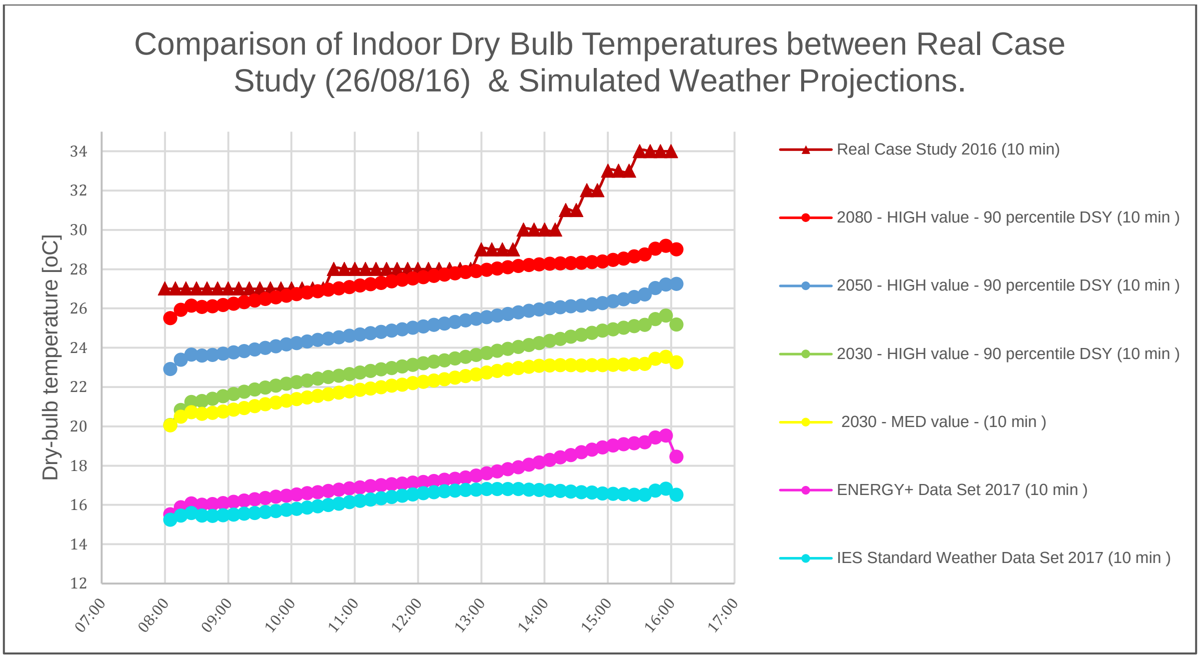

Figure 7 –Indoor Air Temperatures for a room without blind

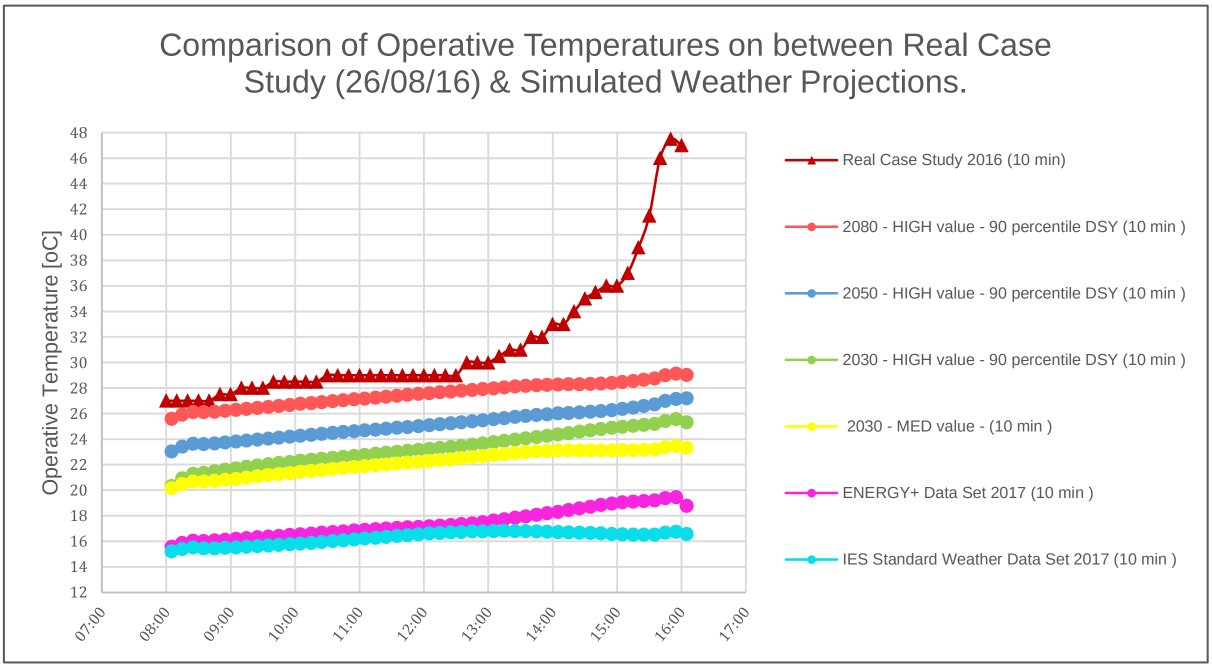

Figure 8 – Operative Temperatures for a room without blind

In the case of OPTs, (see Figure 8) the simulation shows evidence of overheating in all ‘High Value’ weather scenarios yet there are significant differences between real and simulated peak OPTs ranging between 18.39 and 30.77K. Further to this the operative temperature range in the real study is 20.1K and the closest simulated scenario (2080 – High) has a range of 3.52K. Figure 9 also compares real and simulated surface temperatures of the glazing and again there are considerable variations between the real data and that from the simulation.

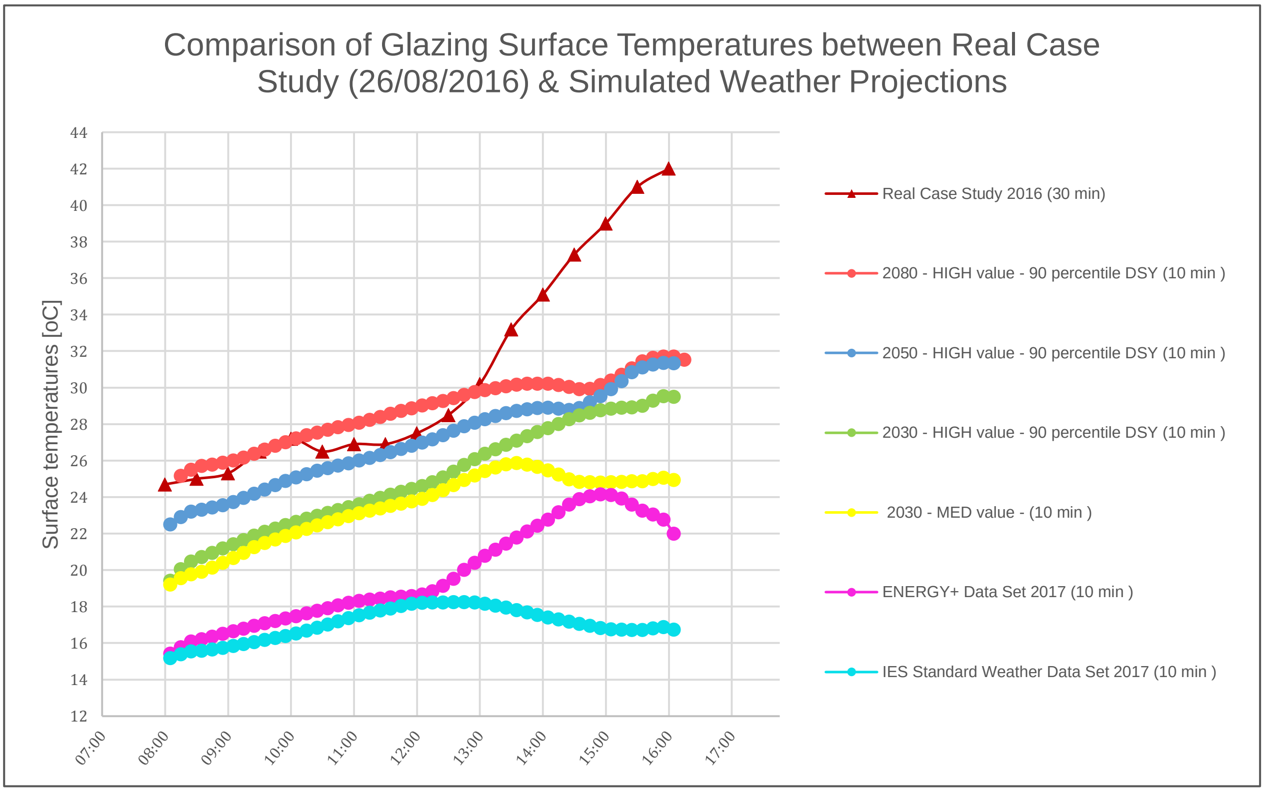

Figure 9 – Glazing Surface Temperatures for a room without blind

The final graph (Figure 10) compares real and simulated exterior temperatures and real and simulated interior operational temperatures. The real data was collected on 26th August 2016 while the simulations are based on High / 90th percentile projections for 31st July 2080, the hottest day in the model. Even in this example when the simulated external air temperature is higher than the real temperature, the simulated operative temperatures are up to 15°C lower than the actual operative temperature.

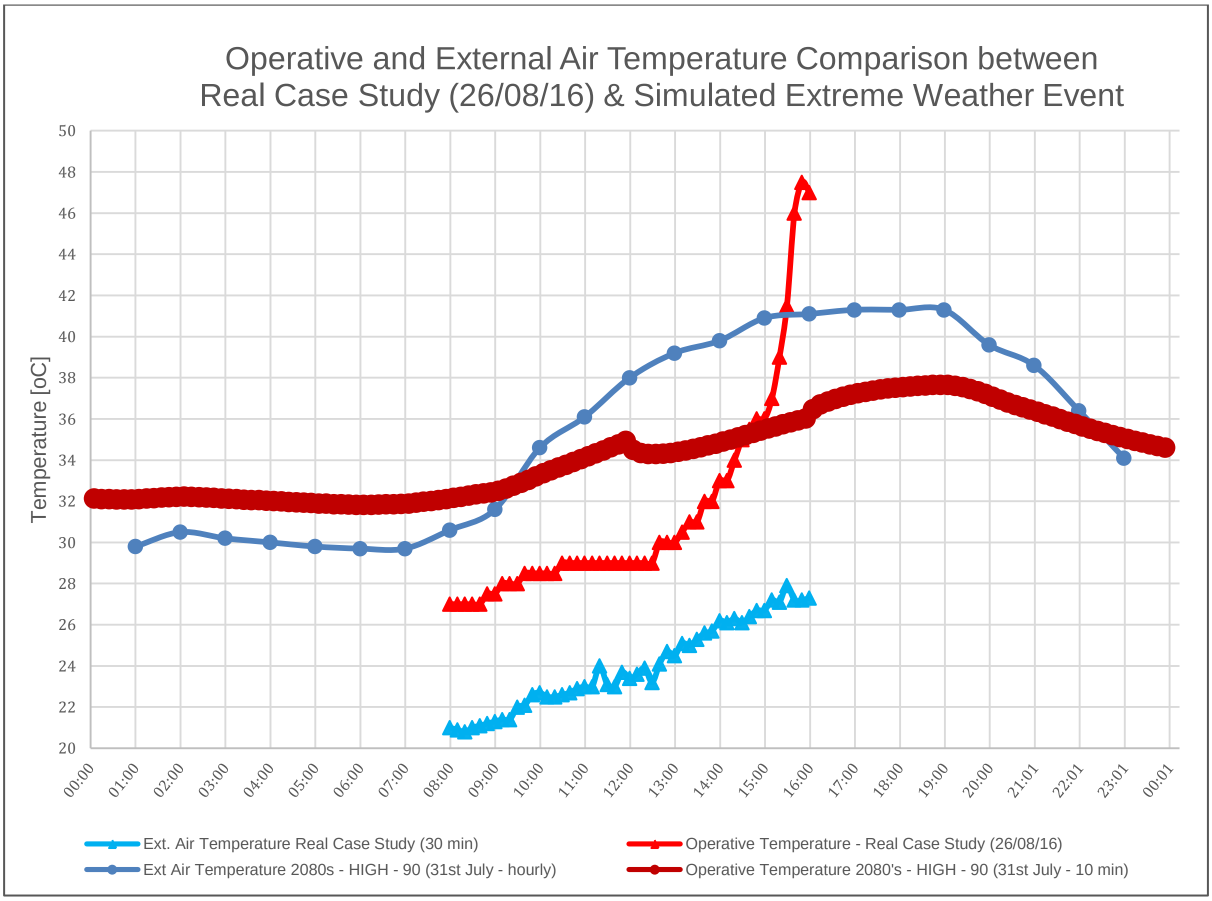

Figure 10 – Comparison of Exterior & Interior Temperatures during Extreme Weather Event

3.3. Results from Thermal Simulation with Internal Blind System

In the final part of the study identical simulation methods and parameters were used to generate models of rooms with blinds; IES and Energy Plus weather data used for 2017 scenarios were created for comparison with projected weather and climate scenarios for 2030, 2050 and 2080 and again these and the real-time results were compared. Although one single type of blind (internal Venetian) is modelled here the indicative results clearly show that use of solar shading products reduces thermal gain in both the real-time and building simulations. However, the patterns of results for both internal air and operational temperatures are almost the same as those from the models without blinds in that, unlike the real-time results, they do not include any significant rise after 1pm.

In Figure 11 it is observed that in the real case study operative temperatures reached 36^{o}C on 8th September in the room without a blind while that in the IES simulation only appeared to reach 15^{o}C and that in the 2080 future projection, 24.3^{o}C. While shading had a positive impact, and reduced operative temperatures by 6^{o}C in the real case study, it only reduced OPTs by 1.17^{o}C in the most extreme (2080) simulated scenario.

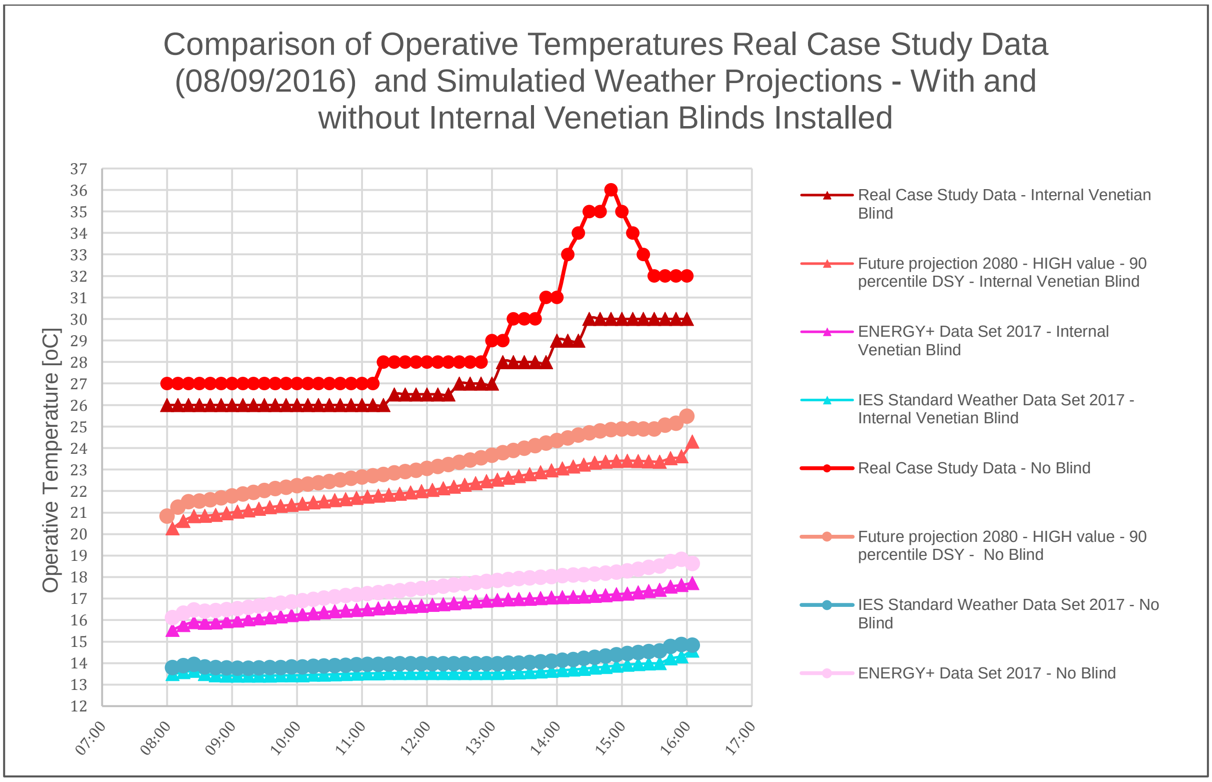

Figure 11 – Comparing Real Time Data and Simulated Operative Temperatures in a room with and without a blind

4.0 Conclusion and Recommendations

As climate and weather patterns change average external temperatures are rising and consequently the number, frequency and severity of extreme weather events such as heatwaves is also increasing. A real-time London-based case study in 2016 revealed that there are already serious examples of overheating in buildings during extreme weather events, which highlights the urgent need for adaptation and mitigation strategies.

Data acquired from this real-time study clearly demonstrates that solar shading products such as blinds make a significant contribution to the challenge of reducing unwanted heat in buildings. Consequently, construction and other experts are recommending that they be included in adaptive strategies to combat external weather and climate factors now and in the future. Determining building performance should enable designers and engineers to create appropriate adaptation and mitigation schemes but these are dependent on correct input data to produce accurate models for current and future scenarios and to minimise the requirement of additional interventions at a later date.

This paper compares the results of the real-time study with those from simulations created with a proprietary software tool. The results highlight the shortcomings of one commonly used software tool and two sets of weather data, which suggests that at best use of these tools is only suitable for indicative guidelines. Furthermore, because they currently fail to accurately simulate the impact of extreme weather conditions the resultant strategies to prevent over-heating will be seriously inadequate.

Finally, the key conclusions revealed by modelling passive design solutions are:

- The current and future weather projections appear to be obsolete when compared with real-time data collected during a London-based study during an extreme weather event.
- Modelling the impact of passive shading interventions indicates that they have a relatively minor impact on the indoor environment when compared with real-world environmental data collection and analysis.
- The software first omitted the solar heat gains during the extreme weather event and the subsequent mitigation effect of the blinds.
- Further longitudinal studies of real-world data and comparative simulations is required to reduce the performance gap and improve design optimisation strategies.

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