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Thermal Comfort in Traditional Dwellings, a Comparison between Physical Measurements and Simulated Data.

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Abstract: Summertime overheating is constantly increasing in every building, either new or old, due to global warming and climate change. The air temperatures in the UK are expected to increase by +4.4°C significantly affecting thermal comfort conditions in domestic buildings. High internal temperatures can be affected by different factors including occupants' behaviours, ventilation rates and design strategies. This paper analyses two semi-detached houses to assess risks of overheating under real weather conditions. Dynamic Thermal Simulation (DTS) is conducted, and the results are compared with the data obtained from physical measurements to assess the accuracy of the simulations in comparison to actual measurement. The results show significant discrepancies between the monitored and simulated data. Thermal comfort in the living areas exceeded the acceptable ranges defined by CIBSE TM59, particularly those facing south on the first floor. A sensitivity analysis conducted to assess the main factors affecting the accuracy of the results when conducting dynamic thermal simulations. According to the results, the ground temperature followed by U-values of the building fabrics are the key factor that could significantly affect the simulation results.

Keywords: Overheating; Thermal Comfort; Dynamic Thermal Simulation; Monitoring.

1. Introduction

Rapid urban growth in the post-war period led to an increased use of structures with cheap and simplified technologies. The dwellings built before 1970, present a very weak thermal insulation with strong transmittance values of the cladding materials. According to Barbiero [1], building sector is responsible for around 40% of the total energy consumption, and 36% of the total greenhouse gas emissions in Europe. The post-war housing era has a significant role in today's high energy consumption figures due to inappropriate energy conservation strategies. Refurbishment has therefore become a major strategy to improve energy performance of the old housing stock. To design an efficient refurbishment strategy, it is important to firstly understand the problems to avoid creating other issues such as overheating which may lead to thermal discomfort for the occupants. The global warming is making the situation even more complex as the risk of overheating is believed to significantly increase. External air temperatures in the UK are expected to rise by up to 4.2° C in winter and 5.4°C in summer by 2070 with the frequency and intensity of heat waves also expected to increase [2]. Rising external temperatures increase significantly the risk of overheating, cooling load and energy consumption in buildings, with the problem being particularly acute in office buildings. It is increasingly realised that building design and refurbishment strategies should no longer be grounded on historic climatic data but should instead focus on the potential scenarios and changes that a building might be facing during its life.

Refurbishment practices have become very common, especially in the past few years, to improve the energy performance of these buildings. These refurbishment strategies usually consist of the replacement of insulation layers in walls and roof and the renovation of fixtures [1]. According to EST [3], a sustainable and bioclimatic manner of technical improvements should be considered to reduce carbon dioxide emissions and increase a sense of well-being. Yet, buildings with limited ventilation or high internal loads are subject to a higher risk of overheating, which could be worsen by add-on insulation [4]. Moreover, the indoor temperatures are influenced by different factors such as orientation, air permeability, thermal mass and u-value ground temperature [4]. Effective use of solar shading and daylight control would significantly help to reduce risk of overheating and thermal discomfort [5]. The risk of overheating during summertime is higher due to higher exposure to solar gains [6]. Yet, according to Jones [7], similar homes may have very different indoor temperatures during the same period due to dissimilar occupants' behaviours.

More research is required to understand how buildings should be improved in a more practical way to improve their energy performance and reduce the cooling load through better design while retrofitting should be conceived to reduce the risk of overheating. To this end, this study aims to assess thermal comfort conditions in a typical semidetached house located in the suburban residential area of Loughborough, UK. Dynamic thermal simulation is conducted in EnergyPlus to assess and mitigate risk of overheating (based on the initial data provided in [8]). The purpose of this analysis is to establish whether internal temperatures would achieve comfort requirements set by CIBSE TM59 [9] standards. The results are then compared with the physical measurements and the results of other simulation packages to assess the possible reasons for differences between the measured and simulated results; with the aim to identify the most critical factors that may affect the results of simulation.

2 Case study building

A typical semidetached two-storey house constructed in the 1930s was selected as the case study building. This type house represents 16.7% of the UK housing stock, and this is the reason why they have been selected [10]. Compared to the national housing stock, 30.5% of this type houses have uninsulated cavity walls, 38.5% have similar levels of loft insulation and 80.8% are fully double glazed [10]. This pair of adjoining semidetached houses (Fig.1) are located in Loughborough (East Midlands, UK), have the same mirrored geometry (Fig.2), configuration and construction [11]. The two houses are naturally ventilated. The windows are identical in size and openings areas, as well as the floor area which is 85.4m^2 with a total volume of 209.2 m^3. These three bedrooms houses are one of the most popular types in the UK with uninsulated brick cavity walls and uninsulated suspended timber floors ventilated below by air bricks. Table 1 shows the building elements and their estimated U-values used in the simulations. The house was retrofitted in 2016 with 300mm of insulation above the first-floor ceiling and double-glazed windows and doors [12]. The main entrance is on the south façade, leading to a hallway, and the kitchen and dining room are located at the north and are separated by a wall. The dining area has a glazed door facing the garden, while the living room, at the south, features a bay window. On the first floor, there are three bedrooms, two of them are large size rooms and one is a single room (around 8m2), one bathroom and a separate small WC. The adjoining semidetached houses will unavoidably affect each other in terms of shadowing, heat transfer via the party wall and protection from the wind.

Figure 1. (Left): Case study houses viewed from the front which face south. The house pictured on the left is the West house, while the right house in the one facing East.; (Right): Case study houses viewed from the rear, this façade face north [11].

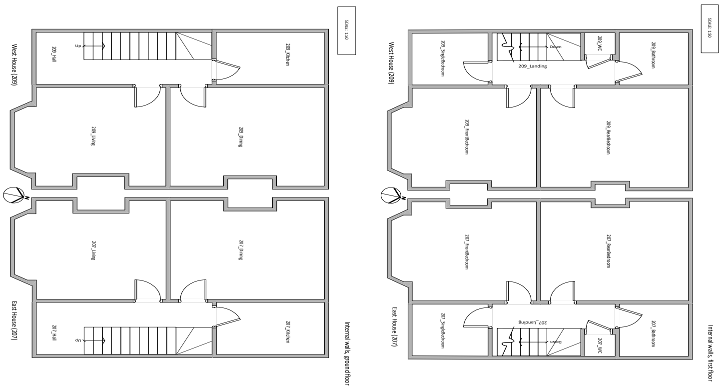

Figure 2. (Left): Ground Floor plan; (Right): First Floor plan

Table 1. Summary of the construction elements, areas and estimated U-values [11]

Building element	Description	U-value Area (m^2)	U-value (m^2)(W/m^{2}K)
Roof	300mm fiberglass, pitched with clay tiles over vapour-permeable membrane	0,16	45,6
External walls	Uninsulated brick cavity	1,6	89,2
Internal partition wall	Solid brick covered with gypsum plaster	2,1	53,9
Party walls	Uninsulated brick cavity covered with gypsum plaster	0,5	42,2
Ground floor (except kitchen)	Suspended timber (uninsulated)	0,8	37,6
Ground floor (kitchen)	Solid concrete (uninsulated) uPVC double glazing	0,7	5,7
Windows (north and south)	uPVC double glazing	1,4	20,3
Windows covered (east and west)	uPVC double glazing with aluminium foil on glazing and 50mm PIR foil-backed insulation board inserted into the frame	0,46	2,7
External doors	uPVC with double glazing	1,4	5,5
External doors glazing covered (east and west)	uPVC double glazing with 50mm PIR foil-backed insulation board over glazing only	0,46	0,51

3. Materials and Methods

A 3D model of the two houses using OpenStudio SketchUp plugin uploaded into EnergyPlus for thermal comfort simulations. A sensitivity analysis is carried out on air permeability, thermal mass, ground temperature and u-value; followed by thermal comfort assessment based on the criteria set by CIBSE TM59 [9] and BSEN 15251 [13] Category II threshold.

3.1 Assessment criteria

DTS is conducted in EnergyPlus to evaluate the effects of overheating and thermal comfort in the case study buildings. The risk of overheating is evaluated using three different criteria. A building is assumed to be overheated if it fails any two of the three criteria defined by CIBSE TM52. All three criteria are defined in terms of ΔT, which is the difference between the operative temperature and the maximum acceptable temperature (Table 2) [14].

Table 2. Overheating assessment criteria.

Up to 1% of occupied	Assessment Criteria	Unacceptable Deviation
Criterion 1	Percentage of occupied hours during which ΔT (ΔT = Top−Tupp(∘C)) is greater than or equal to 1°C	Up to 3% of occupied hours
Criterion 2	Annual hours when the predicted temperature exceeds 26°C	Up to 1% of occupied hours

Criterion 1

For each hour between 09:00 and 22:00 in living spaces and all hours in the day for bedrooms, the difference between the predicted operative temperature (Top) and the upper-temperature threshold (Tupp) is calculated to derive ΔT, which is rounded to the nearest whole degree:

$\Delta T = T_{op} - T_{upp} (\circ C)$

The number of hours where ΔT must be equal to or exceed 1°C between May and September is then calculated [15]. Criterion 1 is failed if the number of hours is more than 3% of the occupied hours between May and September. The final result for this criterion in the following simulation is likely to be much higher than the expectations, this is due to the chosen period. Having selected three of the warmest weeks of the year (16 June 2017 – 6 July 2017) the overheating risk percentage is very high, but it is important to keep in mind that this factor should be spread from May to September. Therefore, the risk of overheating should be essentially much lower than reported.

Criterion 2

For the UK, the CIBSE suggested operative temperature for thermal comfort and overheating criteria in free-running buildings that are broadly consistent with both deterministic and adaptive thermal comfort models for typical UK conditions [16]. The overheating criteria are that not more than 1% of annual hours during the time range 10 pm -7 am, should be above a certain operative temperature, this being 28°C except for bedrooms in dwellings, for which a lower threshold of 26°C is specified. Thermal comfort in an adaptive approach is affected by occupants' behaviours and expectations in naturally ventilated buildings. Based on this method of evaluation, it is proposed that occupants' perception regarding thermal comfort is affected by their thermal circumstances [14]. The overheating occurs when the number of hours exceeds the prefixed value assumed by Category II [9,13] upper comfort threshold (Tupp), where

$T_{upp} = 0{:}33Trm + 21.8°(C°)$

T_{rm} = running mean of outdoor air temperature (°C).

This is the equation to estimates comfortable temperature in naturally ventilated buildings.

Table 3. Summary of Simulation Conditions

Condition category	Simulation conditions
Simulation period	16 June 2017 – 6 July 2017
Location	Suburban area of Loughborough, UK
209_Window opening	Curtains open during the day, windows open if the room temperature exceed 22°C during occupied hours
207_Window opening	Curtains open during the day, windows closed at all times

3.2 Monitoring & Occupancy

To simulate the occupancy and monitor the temperature inside the house with two different scenarios, the windows were covered, and sensors were installed in the case study building. In order to minimize differences between the case study buildings, aluminium foil and 50 mm polyisocyanurate insulation boards were attached to the west and east facing windows. External sensors/loggers were installed to monitor the local weather for 21 days in summer from 16 June to 6 July. Internal temperatures were recorded, and occupancy was replicated using four pseudo-real occupants (in accordance to CIBSE TM59 occupancy schedules [9]. For the purpose of the simulation, the windows are considered to be closed during day and night, however blinds and curtains were considered to be open from 08:00 to 23:00, in accordance to TM59 sleeping schedule. The assumption was that the house was occupied 24h a day during the whole period with no exceptions. The prediction can be identified as "blind" and "open". The first term describes the prediction run through computer programs, with knowledge limited to materials, dimensions, orientation and layout. The second term, "open", is the actual measurements calculated inside and outside the buildings, which are affected also by the climate. The lighting gain was assumed to be 2W/m^2 of the floor area, in the kitchen and living room. The internal gain is split according to TM59, in 75% in the living room and 25% in the kitchen.

4. Results

The simulation was run during the summer period to match the actual weather data collected, between the 16th of June and the 6th of July. The house located at West (209) was simulated with the curtains open during the day and the windows open only if the room temperature exceeds 22°C during occupied hours. The second house, located at East (207), was simulated with the curtains open during the day and the windows always closed during the entire day.

Table 4 shows the number of times when temperature exceeded the defined limit as well as the percentage of the overheating risk for each living space/zones in each house (kitchen, living and single, front and rear bedroom). The West house (209), thanks to the openable windows that allow ventilation, has a lower risk of overheating compared with the East house (207), where the windows are kept closed during the entire simulation period. The risk of overheating in house 207 is extremely high in most of the living spaces, especially in the front bedroom. This room is particularly overheated because of its orientation in addition to a large south facing bay window, that without any shading system allows direct sun and heat to enter the room. The rear bedroom (facing North) is also at risk, but this is mainly due to an absence of ventilation. Indeed, the rear bedroom of the house 209, which has the same properties, has a much lower risk of overheating meaning that natural ventilation is one of the most important factors that influence thermal comfort. The single bedroom in house 207 is the most overheated area with a higher number of hours exceeding the maximum standard for criterion 1 and 2.

Table 4. Risk of overheating in house 207 and 209

House	Zone	%	Criteria 1	Criteria 2
209	Kitchen	1.78	9	23
209	Living	6.34	32	49
209	Single Bedroom	7.73	39	25
209	Front Bedroom	4.36	22	9
209	Rear Bedroom	3.57	18	22
207	Kitchen	5.55	28	45
207	Living	16.66	84	118
207	Single Bedroom	3.53	178	108
207	Front Bedroom	30.15	152	98
207	Rear Bedroom	19.04	96	88

Figure 3 shows the temperature ranges in CSB 207 and 209 when the windows are open and/or closed. In 209, where the windows are openable, temperature goes above the T(max) for four days causing a moderate thermal discomfort for the occupants. However, the situation is significantly more critical in 207, as the windows are constantly closed, resulting in a drastic increase in temperature (T(max)) for a period of nine days. The temperature reached the upper limit for three days indicating sever overheating. In 209, the temperature is noticeably more stable meaning that the thermal shock between day and night is limited.

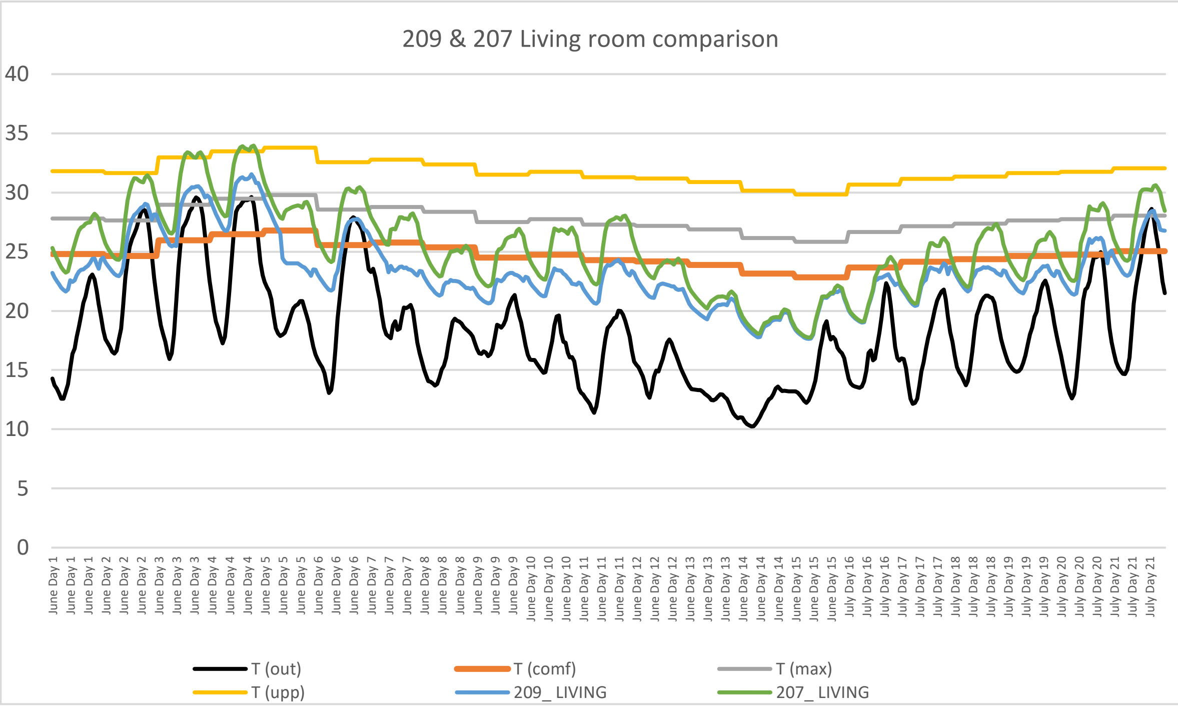

Figure 3. 209 & 207 Living room comparison.

A sensitivity analysis was considered to assess the influence of different variables on risk of overheating:

a) air permeability +/-10%,

b) U-value +/-10%,

c) thermal mass +/-10%; and

d) ground temperature +/-1°C and +/-5°C.

Table 5 summaries the results of the simulations for the above configurations. According to the results, ground temperature, air permeability (+10%) and U-value (+10%) have a significant impact on risk of overheating. Contrarily, the factors which are likely to increase the overheating risk are ground temperature (+5°C) and U-value (-10%). These factors which increase the risk of overheating are respective of 8,5% and 6,9% in the living room 209 and, 25,5% and 18,3% in the living room 207. The ground temperature, in every criterion, appear to be the most significant factor that may affect the outcomes meaning that it is critical to accurately know the ground temperature to achieve accurate results. This value is obviously more important especially for areas where the external boundary is defined as ground (i.e. the kitchen and living room in the CSB).

Table 5. Summary of Simulation result. Linked to Figure 3

209 living room	%	Cr.1	Cr.2
Air permeability -10%	6,5	33	49
Air permeability +10%	6,1	31	49
U-Value -10%	6,9	35	49
U-Value +10%	6,3	32	48
Ground Temperature -5°C	4	22	35
Ground Temperature +5°C	8,5	43	68
Ground Temperature -1°C	5,7	29	46
Ground Temperature +1°C	7,5	38	50
Thermal mass -10%	7,3	37	50
Thermal mass +10%	5,7	29	46

207 living room	%	Cr.1	Cr.2
Air permeability -10%	18	91	127
Air permeability +10%	15,6	79	111
U-Value -10%	18,3	92	133
U-Value +10%	15,6	79	105
Ground Temperature -5°C	10,5	53	71
Ground Temperature +5°C	25,5	129	177
Ground Temperature -1°C	15	76	105
Ground Temperature +1°C	18,2	92	133
Thermal mass -10%	18	91	122
Thermal mass +10%	15,4	78	115

Cr.1 = Criterion 1; Cr.2 = Criterion 2

Figure 4 shows a comparison between different bedrooms (single bedroom, front bedroom and rear bedroom) of the house 209. The temperature difference is higher during the warmest days (i.e. 17th of June to the 20th of June). During this period the single bedroom, which is south facing, is the hottest zone of the three, but the orientation does not seem to be the only reason. The high glazing to floor area ratio seems to be another major factor that increases the risk of overheating. Looking closely at the simulation result of 209, the front bedroom (Table 6) the factor that mostly reduced the overheating risk is ground temperature (-5°C), followed by the air permeability +10% and the U-vale +10%. According to the results, the ground floor areas are mainly affected by the ground temperature while the rooms located on the first floor are more affected by the air permeability and the U-value.

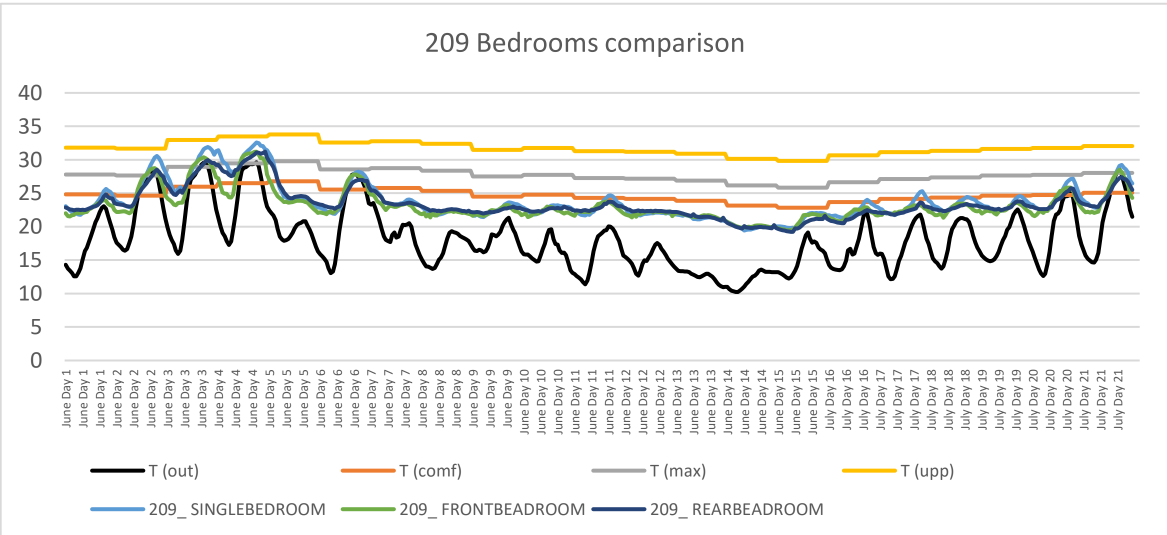

Figure 4. 209 bedrooms comparison.

Table 6. Summary of the Simulation result. This table is linked to Graph N.2 and N. 4

209 single bedroom	%	Cr.1	Cr.2
Air permeability -10%	7,9	50	40
Air permeability +10%	7,5	38	59
U-Value -10%	7,5	38	58
U-Value +10%	7,9	40	60
Ground Temperature -5°C	7,5	38	57
Ground Temperature +5°C	8,1	41	60
Ground Temperature -1°C	7,5	38	59
Ground Temperature +1°C	7,9	40	60
Thermal mass -10%	7,9	40	60
Thermal mass +10%	7,5	38	58
209 rear bedroom	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	3,5	20	39
Air permeability +10%	3,3	17	37
U-Value -10%	3,1	16	38
U-Value +10%	3,5	18	38
Ground Temperature -5°C	1,7	9	32
Ground Temperature +5°C	4,3	22	43
Ground Temperature -1°C	3,3	168	37
Ground Temperature +1°C	3,9	181	39
Thermal mass -10%	4,1	21	40
Thermal mass +10%	2,7	14	36
209 front bedroom	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	4,5	23	33
Air permeability +10%	4,3	22	33
U-Value -10%	4,3	22	33
U-Value +10%	4,5	23	33
Ground Temperature -5°C	4,1	21	33
Ground Temperature +5°C	4,9	25	35
Ground Temperature -1°C	4,3	22	33
Ground Temperature +1°C	4,5	23	33
Thermal mass -10%	4,9	25	33
Thermal mass +10%	4,1	21	33

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

Figure 5, shows the comparison of the simulation results with the physical measurements. The physical measurements are tested inside the house thanks to the equipment that also took into consideration the pseudo-real occupancy, assuming that the houses were occupied 24h a day with no difference between weekdays and weekends. The analysis of the measured results focuses on the period from 16 June to 6 July 2017. Between 17 and 21 June, there was a five-day warm spell during which the outdoor temperature reached an hourly peak temperature of 29.7°C on 18 June with a peak global solar irradiance of 936 W/m2 on 5 July. The final day of the experimental period, 6 July, was also warm. Between these dates, the outdoor temperature rarely exceeded 21°C. The graph shows how the simulation produces results which are easily influenced by factors such as the infiltration rate and the U-Value. The physical measurements do not have a wide thermal excursion as shown in the simulation, but the temperature is kept constant. This is a key point because keeping the temperature constant, the thermal comfort inside that dwelling increases. During this simulation, the ground temperature is the most significant source of uncertainty, that also determinate the big difference between the simulation and the actual test. With it, the infiltration rate represents an important factor that varies with the wind pressures and indoor to outdoor temperature differences. Moreover, many other important factors which determinate the credibility of the simulation are the U-value that directly affected the predicted peak room temperatures and the air permeability. The last factor taken into consideration is the thermal mass of the internal walls; improving the quality of this factor, also the simulation outcome will drastically change.

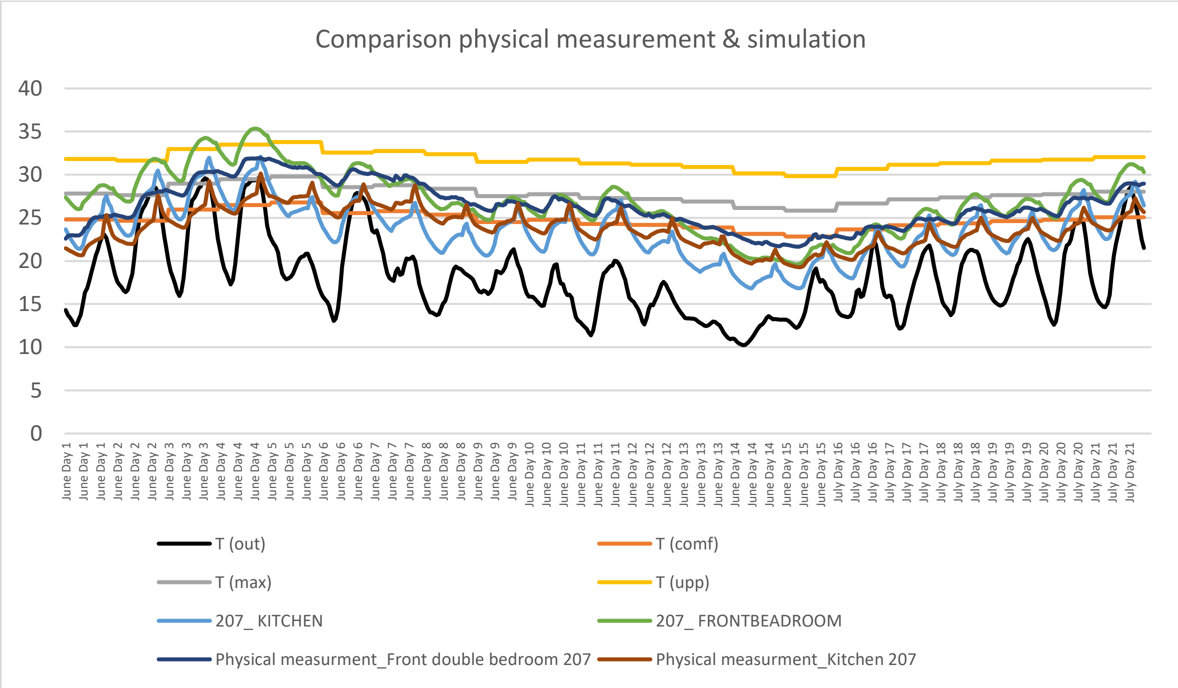

Figure 5. Comparison physical measurement & simulation.

Additional simulations were run (Table7) to study the effects of each single factor on risk of overheating in each room. According to the results the 207 single bedroom is always the room mostly at risk, while the north facing 209 kitchen has a very low risk of overheating. Moreover, the ground floor rooms, in general, are cooler during the summer due to their direct contact with the ground as well as the buoyancy effects. Behavioural effects were simulated by means of opening and closing the windows in house 209. In house 209, the curtains are open during the day and the windows are opened when the room temperature exceeds 22°C during occupied hours. Analyzing and comparing the results reveal that in the 209 front bedroom, the simulated and the physical measurements are very similar when the temperature is equal or lower than 22°C. On the contrary, when the temperature exceeds 22°C and the windows are open, the difference between the simulated and physical measurement increases significantly.

Comparing the results of the 207 kitchen reveal that the situation is different in comparison to the bedrooms explained above. In this case the physical measurement is constantly higher than the simulated result and, the gradient is also much more linear, due to the closed windows which prevents a thermal shock keeping the temperature always above the 22°C.

Table 7. Summary of the Simulation result.

207 kitchen	%	Cr.1	Cr.2
Air permeability -10%	6	31	47
Air permeability +10%	5,5	28	44
U-Value -10%	6,1	31	48
U-Value +10%	5,3	27	44
Ground Temperature -5°C	1,1	6	23
Ground Temperature +5°C	13,6	69	95
Ground Temperature -1°C	4,5	23	37
Ground Temperature +1°C	7,1	36	53
Thermal mass -10%	6,5	33	49
Thermal mass +10%	4	24	42
209 kitchen	**%**	**Cr.1**	**Cr.2**
Air permeability -10%	1,7	9	24
Air permeability +10%	1,7	9	21
U-Value -10%	1,5	8	23
U-Value +10%	1,7	9	21
Ground Temperature -5°C	0,5	3	10
Ground Temperature +5°C	4,4	21	39
Ground Temperature -1°C	1,5	8	19
Ground Temperature +1°C	2,1	11	25
Thermal mass -10%	2,1	11	25
Thermal mass +10%	1,5	8	22

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

Table 8 shows how each criterion affects the result giving the percentage of overheating risk for every room simulated. Looking at the results from a different point of view reveal that the ground temperature is the factor which mostly affects the outcome of the simulation, therefore is crucial to accurately calculate and consider this input to avoid major discrepancies.

The 209 kitchen is always the room with the lowest overheating risk due to its location and orientation on the ground floor and facing north. Similarly, the 207 single bedroom is always the room prone to overheating due to being on the first floor and facing the south. The risk of overheating in 207 single bedroom is also linked to its high solar gain to volume ratio.

Table 8. Summary of the Simulation result.

Air permeability -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,1	31	47
209 Kitchen	**1,7**	9	24
207 Living	8	91	127
209 Living	6,5	33	49
207 Front Bedroom	33,5	169	185
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	21,4	108	151
209 Rear Bedroom	3,9	20	39
207 Single Bedroom	**37,3**	188	214
209 Single Bedroom	7,9	40	60

Air permeability +10%			
	%	Cr.1	Cr.2
207 Kitchen	5,5	28	44
209 Kitchen	**1,7**	9	24
207 Living	15,6	79	111
209 Living	6,1	31	49
207 Front Bedroom	26,7	135	169
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	16,2	82	127
209 Rear Bedroom	3,3	17	37
207 Single Bedroom	**32,3**	163	186
209 Single Bedroom	7,5	38	59
U-Value -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,1	31	48
209 Kitchen	**1,5**	8	23
207 Living	18,2	92	133
209 Living	6,9	35	49
207 Front Bedroom	33,1	167	185
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	21	106	150
209 Rear Bedroom	3,1	16	38
207 Single Bedroom	**37,5**	189	213
209 Single Bedroom	7,5	38	58
U-Value +10%			
	%	Cr.1	Cr.2
207 Kitchen	5,3	27	44
209 Kitchen	1,7	9	21
207 Living	15,6	79	105
209 Living	6,3	32	48
207 Front Bedroom	26,7	135	171
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	17,2	87	131
209 Rear Bedroom	3,5	18	38
207 Single Bedroom	**32,5**	164	187
209 Single Bedroom	7,9	40	60
Ground temperature -5°C			
	%	Cr.1	Cr.2
207 Kitchen	1,1	6	23
209 Kitchen	**0,5**	3	10
207 Living	10,5	53	71
209 Living	4	22	35
207 Front Bedroom	23	116	155
209 Front Bedroom	4,1	21	33
207 Rear Bedroom	11,7	59	107
209 Rear Bedroom	1,78	9	32
207 Single Bedroom	**29,3**	148	175
209 Single Bedroom	7,5	38	57
Ground temperature +5°C			
	%	Cr.1	Cr.2
207 Kitchen	13,6	69	95
209 Kitchen	**4,1**	21	39

207 Living	25,5	129	177
209 Living	8,5	43	68
207 Front Bedroom	37,3	188	208
209 Front Bedroom	4,9	25	35
207 Rear Bedroom	25,1	127	164
209 Rear Bedroom	4,3	22	43
207 Single Bedroom	**41,1**	209	229
209 Single Bedroom	8,1	41	60
Ground temperature -1°C			
	%	Cr.1	Cr.2
207 Kitchen	4,5	23	37
209 Kitchen	**1,5**	8	19
207 Living	15	76	105
209 Living	5,7	29	46
207 Front Bedroom	28,1	142	173
209 Front Bedroom	4,3	22	33
207 Rear Bedroom	17,6	89	132
209 Rear Bedroom	3,3	17	37
207 Single Bedroom	**33,3**	168	192
209 Single Bedroom	7,5	38	59
Ground temperature +1°C			
	%	Cr.1	Cr.2
207 Kitchen	7,1	36	53
209 Kitchen	**2,1**	11	25
207 Living	18,2	92	133
209 Living	7,5	38	50
207 Front Bedroom	31,3	158	182
209 Front Bedroom	4,5	23	33
207 Rear Bedroom	20,2	102	147
209 Rear Bedroom	3,9	20	39
207 Single Bedroom	**35,9**	181	205
209 Single Bedroom	7,9	40	60
Thermal mass -10%			
	%	Cr.1	Cr.2
207 Kitchen	6,5	33	49
209 Kitchen	**2,1**	11	25
207 Living	18	91	122
209 Living	7,5	38	50
207 Front Bedroom	30,9	156	181
209 Front Bedroom	4,9	25	33
207 Rear Bedroom	19,6	99	140
209 Rear Bedroom	4,1	21	40
207 Single Bedroom	**34,9**	176	203
Thermal mass +10%			
	%	Cr.1	Cr.2
207 Kitchen	4	24	42
209 Kitchen	**1,5**	8	22
207 Living	18	91	122
209 Living	5,7	29	46
207 Front Bedroom	29,5	149	175
209 Front Bedroom	4,1	21	33

207 Rear Bedroom	29,5	149	175
209 Rear Bedroom	2,7	14	36
207 Single Bedroom	**35,5**	179	198
209 Single Bedroom	7,5	38	58

[1] Cr.1 = Criterion 1; Cr.2 = Criterion 2

5. Conclusion

The summertime overheating in the UK homes is becoming a major issue. Simulations are great tools to assess the risk of overheating in new and existing buildings; however, the accuracy of simulations depends greatly on the input data. The aim of this research was to compare the results of physical measurements with computer simulations to test the accuracy of data and then suggest solutions to reduce the gap between simulations and actual conditions when it comes to thermal comfort in residential buildings. The results of this research show that the ground floor areas are mostly affected by the ground temperature whereas the U-values and of the building elements and the air permeability figures are more significant on the upper floors, although the ground temperature is still influential. Therefore, arguably, the ground temperature is the most important variable that should be accurately calculated and considered in simulations to achieve accurate results and reduce discrepancies. Further research is required to assess the effects of a combination of different variables on the outcomes.

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