Abstract
This paper presents the results of a parametric study based on the CIBSE TM59 standard for the assessment of overheating in homes and carried out on a naturally ventilated with MVHR archetype two-bed flat located in London. The aim of the study was to produce guidelines that could be used to incorporate the necessary design features to meet TM59 before design teams engage in detailed modelling. The results show how challenging it is to pass future weather files and the necessity of integrating: night ventilation or alternatively fans, thermal mass and solar control measures, in order to achieve a pass.

Introduction
Climate change and the role of the built environment: the UK case
Since the industrial revolution, the increase in anthropogenic greenhouse gas (GHG) emissions has been recognised as the main driver of the observed global warming (IPCC, 2014). Aiming to avoid a shift in a more dangerous climate regime, it has been agreed that measures to reduce greenhouse gas emissions have to be undertaken (IPCC, 2014).

Following the Kyoto Protocol (UN, 2018), UK Government has been taking part to international negotiations to cut emissions. As a result of these negotiations, in 2008 the UK Government published the UK Climate Change Act which sets a target for the reduction of GHG emissions of 80% below the 1990 baseline by 2050 across all sectors (Climate Change Act 2008 (c.27), 2008).

In the UK, the building sector is the second most emitting sector after the transport sector, accounting for around 34% of the total emissions, mainly due to the use of fossil fuels for heating and the use of electricity for lighting, appliances and heating (CCC, 2015). Of this 34%, the residential sector accounts for 64% of the emissions while the commercial and public sectors account for 27% and 10%, respectively (CCC, 2015).

In this scenario, climate change mitigation and adaptation policies for residential and commercial buildings were put in place, in order to reduce GHG emissions and address resilience to climate change. These policies were primarily focused on reducing energy demand for space heating delivering highly insulated and airtight designs, in both new build and retrofit (NHBC Foundation, 2012).

However, airtight design in conjunction with poor ventilation, increases the risk of overheating not only during the hot season or heatwaves but over the whole year. This causes thermal discomfort and, for some sections of the population, health issues (NHBC Foundation, 2012; AECOM, 2012; V. Jones, Goodhew, & De Wilde, 2016; Vellei, Ramallo-González, Kaleli, Lee, & Natarajan, 2016). In turn, this encourages the use of air conditioning, with a related increase in GHG emissions. An effective design needs to limit any increase in GHG emissions and also provide a thermally comfortable environment. In the UK, the risk of overheating is particularly high in southern regions and in urban areas because of the urban heat island effect (NHBC Foundation, 2012).

Thermal comfort and overheating: definition and assessment in the UK
The Chartered Institution of Building Services Engineers (CIBSE) defines overheating as “the state of mind that expresses dissatisfaction with the environment caused by prolonged high temperatures” (CIBSE, 2015).

Several factors influence the risk of overheating within a space (NHBC Foundation, 2012; NHBC, 2012):
- The location in terms of climatic region, urban or rural area, of the assessed space within the building (top floor, etc.) and in relation to its surroundings;
- The design of the space in terms of layout (orientation, single side or dual aspect ventilation, proximity to hotter spaces), of envelope design (fabric performance, glazing area, shading elements), the thermal properties of the constructions and natural and/or mechanical ventilation design.
- The occupants’ behaviour, that ranges from the type of occupant activities within the space to the operational use of it.

Metrics involving human perception are resistant to definition. However, several building occupant overheating models have been developed (Forgiariini Rupp, Giraldo Vásquez, & Lamberts, 2015). Two principle models are used in industry: the PMV model, based on experiments in climate chambers, and the
Adaptive model, based on field surveys (CIBSE, 2013; CIBSE, 2016; ASHRAE, 2017). The PMV model has seen broad application in industry but sets fixed requirements throughout the year. As its name suggests, the adaptive comfort model on the other hand makes allowance for occupants’ capacity to adapt to prolonged periods of exposure to warm weather. As such, it is well suited to free running and naturally ventilated buildings (CIBSE, 2013; CIBSE, 2016; ASHRAE, 2017).

In order to assess and limit the risk of overheating in domestic and non-domestic buildings in the UK, several standards based on thermal comfort studies have been released. These guides outline methodologies to assess overheating risk based on criteria that give specific thresholds to define if a space is passing or failing. Looking at the most recent regulation on the subject for the assessment of domestic buildings, the Standard Assessment Procedure (SAP) (BRE, 2012), the Passive House Planning Package (PHPP, 2015), CIBSE Guide A (CIBSE, 2016) and CIBSE TM52 (CIBSE, 2013) methodology have been the most commonly used tools, up to the release of TM59 (CIBSE, 2017). SAP and PHPP are generally considered limited compared to CIBSE TM52 since they do not capture the dynamic relationship between the internal and external environment (Bateson, 2014; ZCH, 2015). Although CIBSE TM52 was primarily conceived for application to non-domestic buildings, over the last years, it has been largely used to assess both commercial and residential buildings through dynamic modelling, with a wide degree of freedom in the assumptions of internal gains and usage patterns.

CIBSE TM59

The recently published CIBSE TM59 (CIBSE, 2017) was released with the intent of specifically addressing overheating assessment in homes. Alongside its application of the adaptive comfort model, it standardises assumptions of the internal gains and usage profiles, based on the dwelling type (one bed, two bed or three bed flat) and window opening profile, allowing, a benchmarking comparison between different designs (CIBSE, 2017).

In addition to this, CIBSE TM59, addresses the use of future weather files for demonstrating mitigation options under more extreme weather events and to explore the performance where there is a particular concern (CIBSE, 2017).

The standard defines two criteria (CIBSE, 2017):

- "Criterion (a): For living rooms, kitchens and bedrooms: the number of hours during which the difference between the operative temperature and maximum adaptive temperature greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 percent of occupied hours (equivalent to Criterion 1 in TM52 (CIBSE, 2013))”.

- “Criterion (b): For bedrooms only: to guarantee comfort during the sleeping hours the operative temperature in the bedroom from 10 pm to 7 am shall not exceed 26 °C for more than 1% of annual hours”.

Both criteria have to be met to pass TM59 (CIBSE, 2017). It has to be noted that based on TM59 these percentages are calculated over the occupied hours, where bedrooms are occupied 24h and living rooms are occupied exclusively during daytime (CIBSE, 2017).

Whilst a standardised approach brings great advantages for comparison and to set targets for minimum compliance, its simplifications mean it has to forgo exploration of some of the subtleties of how a dwelling will be used in practice. Secure ventilation, operation of blinds and acoustics are a few examples not fully defined in the standard and which as designers we must also consider in providing resilient solutions.

Research aim and objectives

The aim of the research was to produce guidelines that could be used to incorporate the necessary design features to meet TM59 comfort criteria for an archetype flat in London before design teams engage in detailed modelling.

Objectives:

- To test and examine the standard across a range of feasible parameters.
- To investigate modifications to the TM59 standard recommendations

Simulation

The case study

The research involves the analysis of an individual dwelling. The general arrangement of its rooms is considered archetypal of new build, high-density residential apartment buildings in London. It was chosen following review of recent practice projects and the London Housing Design Guide space standards (Greater London Authority (GLA), 2010). Government statistics and targets indicate that London new build flats, as analysed in this study, represent an average of 65% of new build dwellings in Greater London and 14% (4-5%) of new build dwellings in England (MHCLG, 2018; GLA, 2017; DCLG, 2017).

The dwelling analysed is a top floor naturally ventilated two bed flat with open plan living room/kitchen and served by mechanical ventilation with heat recovery (MVHR)(fig.1). The location was selected to represent parts of the Capital where the greatest increases in housing density are expected: the urban part of London outside the GLA’s central activities zone (CAZ) and represented by the London Heathrow weather file.

Figure 1: Archetype flat plan (1.single bedroom, 2. double bedroom, 3.living room)
Research design and simulation tools

The dynamic simulations were carried out using IES-VE 2017 Apache Sim module (IES, 2017). Simulation results files were processed and analysed in Microsoft Excel (Microsoft, 2018) to carry out the TM59 criteria tests.

Fixed assumptions were made for fabric transmittance and air tightness. Internal gain loads and usage profiles were also fixed based on the TM59 guidelines. The remaining parameter values were varied.

Glazing area, solar transmittance and openable façade area formed the parametric variable space. Remaining variables were assembled into a set of 27 scenarios, each of which were simulated across the parametric space.

Fixed inputs, parametric variables and scenario variables are reported and discussed in the following subsections.

Assumptions: Fixed inputs

Typical values for fabric elements were assumed based on a flat type achieving the Fabric Energy Efficiency Standard (FEES) (HM Government, 2013) and based on a typical specification we might propose during the planning stage (table 1).

Table 1: Fabric properties

<table>
<thead>
<tr>
<th>Item</th>
<th>Performance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>0.15 W/m²K</td>
</tr>
<tr>
<td>Floor</td>
<td>0.1 W/m²K</td>
</tr>
<tr>
<td>Roof</td>
<td>0.1 W/m²K</td>
</tr>
<tr>
<td>Window/Door</td>
<td>1.2 W/m²K</td>
</tr>
<tr>
<td>Air Tightness</td>
<td>3 m³/m²/s/50Pa</td>
</tr>
<tr>
<td>Thermal Bridging</td>
<td>0.08 W/m³K</td>
</tr>
</tbody>
</table>

Infiltration rates were assumed equal to 0.15 air changes per hour (ach) (CIBSE, 2013) based on the air tightness reported in table 1. A constant extract flow rate of 0.48 ach was modelled to take into account kitchen and toilets extract, the flow rate was calculated based on the geometry and Part F recommendations (HM Government, 2010).

Internal gains loads and usage profiles for occupancy, equipment and lighting were assumed based on TM59 tables for a two-bed living/kitchen flat (CIBSE, 2017).

Heat losses from pipework were assumed equal to 30.2 W, considering 3 meters of pipework and maximum heat loss per meter equal to 10.7 W/m (CIBSE, 2017).

Internal doors were assumed fully open during the occupied hours as recommended in TM59 (CIBSE, 2017).

Category II, normal level of expectation, was assumed as thermal comfort category (BS EN 15251, Table 2).

Assumptions: parametric variables

For the envelope, three parametric variables were the most important in this study: the extent of glazed area, the solar transmissivity of the glazing (g-value) and the extent of opening ventilation area.

Representing the glazing areas as percentages of room floor areas and responding to the façade designs observed in practice, that shows less glazing in bedroom than living rooms, the following four glazing area specification pairs were used:

- Bedroom-Living room: 20%-30%, 25%-40%, 30%-50%, 40%-60%

Six values were modelled as percentages of façade area openable for ventilation:

- 5%, 10%, 15%, 20%, 25%, 30%

Five values were analysed for solar transmittance, the lower values being reliant on means of external shading:

- 0.15, 0.25, 0.32, 0.4, 0.55.

The distribution of glazing area was applied evenly on the two sides of each living room façade facing south and west. Blinds were not modelled in this study.

The combination of these variables produced a parametric variable space of 120 data points.

Assumptions: scenario variables

Unlike the parametric variables, scenarios were assembled with differing ventilation strategies in response to the success of a particular parametric space at achieving passes under TM59 and in order to examine sensitivities to aspect, orientation, thermal mass and future climate. The twenty-seven scenarios combining these variables are summarised in table 3.

Ventilation strategies included varied opening operation profiles as described in table 2. It is noted that not all these meet with the definitions given in the TM59 standard. The scenarios also include use of mechanical boost on the ventilation and increased air speed, such as might be achieved using ceiling fans.
Overall, the model space contained a matrix of 120 archetype flats (fig.3) as a result of the parametric variables combination and a total of 360 analysed rooms. Based on TM59 guidelines, windows should be modelled as open when the space is occupied and internal dry bulb temperature exceeds 22°C (CIBSE, 2017). Night ventilation can be included if additional security and rain protection details are incorporated into the design (CIBSE, 2017).

In this study, night ventilation in living rooms and bedrooms, and a variation of the opening operational profiles were modelled. Where night ventilation was modelled in living rooms, half of the daytime available openable area was modelled open at night time. Across the study, the opening operational profiles reported in table 2 were tested.

Table 2: Opening operational profiles

<table>
<thead>
<tr>
<th>Profile</th>
<th>Daytime*</th>
<th>Night-time*</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Tr&gt;22°C</td>
<td>-</td>
</tr>
<tr>
<td>P2</td>
<td>Tr&gt;22°C and Text&lt;28°C</td>
<td>-</td>
</tr>
<tr>
<td>P3</td>
<td>Tr&gt;22°C</td>
<td>Tr&gt;22°C</td>
</tr>
<tr>
<td>P4</td>
<td>Tr&gt;22°C</td>
<td>Continuously open</td>
</tr>
<tr>
<td>P5</td>
<td>Tr&gt;22°C and Text&lt;28°C</td>
<td>Continuously open</td>
</tr>
</tbody>
</table>

*Tr: internal dry bulb temperature, Text: external dry bulb temperature

Night ventilation was tested using both an opening profile governed by the room temperature (P3, table 2) as well as assuming the windows continuously open (P4-P5, table 2) since it was considered unrealistic to assume a manual or automatic control overnight for a dwelling. An additional opening temperature profile based on both internal and external temperature for daytime was tested compared to the TM59 recommendation; (P2-P5, table 2). This assumption was driven by the fact that when external temperatures are particularly high and above the maximum adaptive temperature threshold, natural ventilation might not be beneficial for the mitigation of overheating (AECOM, 2012).

Besides, mechanical ventilation boost should not be included in the assessment according to TM59 and might be an unpractical solution at night because of the noise level, this option was modelled to test its effect.

The elevated summer air speed was assumed equal to 0.1 m/s where no ceiling fans were modelled in the space and to 0.2 m/s where they were included in the analysis.

The effect of thermal mass was studied in living rooms in conjunction with night ventilation strategies. In order to make the living space more thermally massive, a 4 cm exposed concrete layer was added to the ceiling construction. As a result, two types of thermal mass were tested across the study: “very lightweight” (k-value 30 kJ/m²K) and “lightweight” (k-value113 kJ/m²K) (BRE, 2012). Thermal mass was not tested in bedrooms since the release of the heat at night might cause thermal discomfort (CIBSE, 2015).

A worst-case SW orientation was primarily tested across the study and a NE orientation (bedrooms facing north, and living room north-east) was tested in specific cases.

For scenarios where dual aspect passes were readily achieved, the test dwelling was modelled with single aspect living space.

In the single aspect option, only the openings on the south façade of the living room were assumed to be open as shown in figure 2.

Figure 2: Dual and single aspect layouts

Both the London Heathrow-2020s-high emissions scenario-50th percentile (LH-2020s-high-50th) and the

Table 3: Scenarios summary table

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Bedrooms</th>
<th>Livingrooms</th>
<th>Elevated Summer Air Speed</th>
<th>Mechanical Boost</th>
<th>Thermal Mass</th>
<th>Orientation</th>
<th>Weather File</th>
<th>Living Space Ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P1</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>NE</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>2</td>
<td>P1</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>3</td>
<td>P1</td>
<td>P1</td>
<td>0.2</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>4</td>
<td>P1</td>
<td>P1</td>
<td>0.2</td>
<td>-</td>
<td>very lightweight</td>
<td>NE</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>5</td>
<td>P1</td>
<td>P1</td>
<td>0.1</td>
<td>1</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>6</td>
<td>P2</td>
<td>P2</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>7</td>
<td>P1</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>NE</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>8</td>
<td>P2</td>
<td>P2</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>9</td>
<td>P3</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>10</td>
<td>P3</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>11</td>
<td>P3</td>
<td>P1</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2020</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>12</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>13</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>14</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>15</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>16</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>17</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>18</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>19</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>20</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>1</td>
<td>very lightweight</td>
<td>NE</td>
<td>2010</td>
<td>Dual Aspect</td>
</tr>
<tr>
<td>21</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>22</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>23</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>24</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>25</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>26</td>
<td>P4</td>
<td>P4</td>
<td>0.1</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2010</td>
<td>Single Aspect</td>
</tr>
<tr>
<td>27</td>
<td>P4</td>
<td>P4</td>
<td>0.2</td>
<td>-</td>
<td>very lightweight</td>
<td>SW</td>
<td>2050</td>
<td>Dual Aspect</td>
</tr>
</tbody>
</table>
London Heathrow-2050s-high emissions scenario-50th percentile (LH-2050s-high-50th) weather files were tested in this study (CIBSE, 2014). If a model run failed to pass under 2020 weather, it was not then tested under the more onerous 2050 weather.

In this paper, we will refer to a set as a model space that contains 120 archetype flats (fig.3). Each flat in the set is characterized by the fixed variables previously described in this section and a certain combination of parametric variables. Each set differs from the other for the scenario variables modelled in it. A description of all the simulation scenarios is reported in table 3.

**Discussion and results analysis**

In this study, results have been analysed on a macro scale and are presented and discussed for each scenario in terms of:

- Percentage of rooms passing per criterion and TM59 check over the total rooms (360).
- Percentage of rooms passing per type of room over the total rooms per type (120).

The aim was to look for trends at the variation of the scenario variables. However, once identified the successful scenario, it is necessary to look at the specific case results in order to individuate the correct combination of glazing area, openable area and g-value for room type that actually achieve a TM59 pass.

**Dual aspect (LH-2020s-high-50th)**

Initially, a TM59 approach (S2-S1, graph1-2) was tested assuming no night ventilation, no ceiling fan, and openings controlled by the internal temperature profile with a threshold at 22°C (P1, table 4). Under these assumptions, no rooms passed TM59 for both SW and NE orientation (S2-S1, fig.5). The addition of mechanical boost at night (S5, fig.5) or the use of an alternative opening profile based on both internal and external temperature (P2, table 4) still led to no passes (S6, fig.5). The only beneficial measure, exclusively for living rooms, was the introduction of a ceiling fan with an assumed air speed of 0.2 m/s, which raised the number of passing living rooms from 0% (S2, fig.6) to 38% (S3, fig.6).

Starting from these results, the introduction of night ventilation in bedrooms was studied (fig.7-8). Overall, this resulted in a significant shift up in the number of rooms passing TM59, from 0% (S2, fig.6) to 23% (S9, fig.8), without any secondary beneficial effect on the living spaces independently from the orientation (S9 – S7, fig.8). The north facing scenario (S7, fig.8) had around 17.5% of TM59 pass more for bedrooms compared to the south facing (S9, fig.7). Assuming the openings continuously open at night (S13, fig.7) instead of using the TM59 opening profile based on the internal temperature threshold (S9, fig.7) resulted in about 5% more TM59 passes compared to the TM59 approach. This confirms the necessity of introducing a ceiling fan in the living rooms in order to pass the TM59 check in the absence of night ventilation (S3, fig.5).

The introduction of night ventilation in both bedrooms and living rooms resulted in living rooms passing TM59 check without the introduction of a ceiling fan (S14-S17, fig.10). The shift in the amount of pass is particularly evident in the NE facing flats (S17, fig.9). Generally, the
living spaces are favoured by using a temperature profile (P5, table 4) that controls the opening during the day based on both internal and external temperatures (S19, fig.10). This profile (P5, table 4 - S19, fig.10), compared to the recommended TM59 (P4, table 4 - S14, fig.10) results in a percentage increase of pass in dual aspect living rooms of 15%, although it does not seem to help the bedrooms (S14–S19, fig.10).

Lastly, the effect of the introduction of thermal mass in the living spaces was studied (fig.11-12). The results show that this is particularly effective in living rooms with an overall increase of passes of 25% (S14-S23, fig.12). The use of a ceiling fan in these spaces still results extremely effective (S 26, fig. 12) as well as the use of an opening profile (P5, table 4) based on both internal and external temperature (S21, fig.12).

Looking at the distribution of TM59 pass depending on the g-value per simulation set, these are widely distributed over the analysed range with a trend to decrease for higher values. The distribution is highly flattened when the air speed is increased and slightly flattened when thermal mass is incorporated.

Overall, it resulted that:

- Bedrooms and dual aspect living rooms cannot pass without night ventilation independently if the flat is north or south facing;
- Dual aspect living rooms can pass without night ventilation if a ceiling fan is introduced;
- Mechanical boost at night is not particularly effective;
- The use of a profile that shuts the window when the external temperature is above 28°C during daytime is extremely effective in living rooms but not in bedrooms;
- The use of thermal mass in living rooms greatly increases the number of living rooms passing TM59.

Dual aspect (LH-2050s-high-50^th)

Based on the results for the dual aspect combinations and the LH-2020s-high-50^th and the initially drawn conclusions, the following strategies, which were considered the most likely to pass, were also tested using the LH-2050s-high-50^th weather file:

- TM59 opening profile during the day with windows continuously open at night in bedrooms for SW and NE orientation, tested with and without fan (S12, S8, tab.3),
- Integration of night ventilation in living rooms tested without fan (S15, S18, tab.3)
- Integration of thermal mass in living rooms for SW orientation, tested with and without fan (S24-27, tab.3).

The outcomes of these simulations showed how achieving a pass using this weather file is almost impossible and how it is necessary to rely on more advanced cooling passive measures. The only scenario, which resulted in some pass, exclusively in the living rooms, was the one that incorporated thermal mass, night ventilation and ceiling fans.
Lastly, single aspect living rooms were modelled using the LH-2020s-high-50th weather file, the following were analysed:

- TM59 opening profile during the day with windows continuously open at night in bedrooms and living rooms for SW orientation, tested without fan (S16, tab.3).
- Integration of thermal mass in living rooms for SW orientation, tested without fan (S25, tab.3).
- Integration of thermal mass in living rooms for SW orientation, tested without fan (S22, tab.3) and assuming that openings are closed when outside temperature is above 28°C.

From the comparison of single aspect with dual aspect, it emerges how single aspect living rooms pass more easily than in the dual aspect besides the lower ventilation rate (S16-S25, fig.14). This might be due to the reduction of the ventilation gain when external temperatures are particularly high, since in this case, natural ventilation might not be beneficial for the mitigation of overheating.

On the other hand, in flat with single aspect living rooms, bedrooms struggle to pass due to the reduction of cross ventilation (S16-S25, fig.13-14). The use of a profile that shuts openings when external temperatures are above 28°C (S22, fig.13-14), does not particularly affect the results (S25-S22, fig.13-14) contrarily to what happens with the dual aspect (S25-S22, fig.11-12).

### Conclusion

Overall, the results show that achieving a pass using a future weather file (LH-2050s-high-50th) in the London context is quite challenging if a combination of several design measures such as the use of solar control, night ventilation, thermal mass and fans, is not put in place. Meeting the TM59 criteria is feasible under the LH-2020s-high-50th weather file both for single and dual aspect. However, night ventilation is a fundamental requirement to achieve a pass both in living rooms and bedrooms if ceiling fans are not part of the design. TM59 is not particularly clear about the opening profile that should be used for night hours, it seems reasonable to assume that for domestic use openings should be modelled continuously open and not governed by the temperature at this time.

The research shows that closing the openings when outside temperature is above a certain threshold is particularly effective in dual aspect living rooms but not in bedrooms and it does not significantly affect the results in single aspect living rooms. Although this type of operational profile is uncommon in the everyday practice in a mild summer climate country, it is common in hotter countries and could occur through adaptation to new conditions.

The use of thermal mass in the living rooms in conjunction with night ventilation is extremely effective to achieve a pass both in single and dual aspect layouts. Where thermal mass is included, the pass rate is less sensitive to the glazing g-value.

The use of fans greatly affects the results since even a slight increase of the air speed pushes the maximum adaptive temperature up considerably. Where fans are included, the sensitivity of pass rate to glazing g-value is significantly reduced.

Based on this study, achieving a pass in a flat where night ventilation is limited for security (ground floor) or acoustic comfort reasons or where ceiling fans are not included might be extremely challenging if not impossible, especially under future weather conditions, and the use of air conditioning might be necessary.

### TM59 online tool for architects

In order to drive the architects in their definition of the flat design at the initial stages, an interactive online tool was created for the selection of the optimal combination of glazing area, openable area, and g-value depending on the scenarios applied. Based on the previous results, some strategies were discarded a priori since they failed to pass TM59. A screenshot of the web tool and how it looks is shown in figure 15.

**Figure 15: Screenshot online interactive tool**

**Conclusion**

In order to drive the architects in their definition of the flat design at the initial stages, an interactive online tool was created for the selection of the optimal combination of glazing area, openable area, and g-value depending on the scenarios applied. Based on the previous results, some strategies were discarded a priori since they failed to pass TM59. A screenshot of the web tool and how it looks is shown in figure 15.
The use of thermal mass as passive design measure was influential in meeting the target in living rooms, this should be further investigated relatively of how this can be integrated in traditional construction.

The aim of this study was to produce guidelines for initial stage design for architects. Summarising the results in a readily understandable way, whilst preserving the nuances involved is yet another challenge. The proposed solution is to present the outcomes as an online interactive tool (fig.15). Further work is needed to refine this for practical application.

References


