Energy modelling of a mid 19th century villa

Baseline performance and improvement options
ENVIRONMENT AND SUSTAINABILITY SERVICES

Energy modelling of Mid 19th Century Villa
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## Contents

- Thermal Mass .............................................................................................................. 3
- Energy Simulation using the <Virtual Environment> .................................................. 4
- Design Scenarios ......................................................................................................... 4
- Design Scenarios ......................................................................................................... 6
- Results – Glazing options ........................................................................................... 7
- Results – Insulation options ........................................................................................ 8
- Results – Heating options ............................................................................................ 9
- Results – Combined design scenarios ......................................................................... 10
- Conclusions ................................................................................................................ 11
- Appendix ..................................................................................................................... 12
- Appendix ..................................................................................................................... 13
- Appendix ..................................................................................................................... 14
Introduction

IES have been commissioned by Historic Scotland to assess a traditional, two-storey sandstone villa in terms of its energy performance and internal comfort conditions. Dynamic thermal modelling will be used rather than Steady State calculation methods in an attempt to record results from an alternative software testing technique.

The performance of this building, located in Fife, is intended to provide generic results for traditionally constructed buildings with high thermal mass.

We have identified key issues and aim to show how these have been tested:

- Thermal mass
- Draughts in traditional constructed buildings
- Correct use of heating systems

Using the results from the dynamic thermal simulation, we will show effective ways these can be overcome and/or avoided and how these have been tested using dynamic thermal simulation techniques. Steady State calculation methods have no relevance when we are considering the effects of issues such as thermal mass in buildings and the effect on internal temperatures.

The results will attempt to show that the two main issues are with heating system operational profiles and insulation has been added to the traditional construction. Providing insulation within existing walls for example would be considered to negate the effects of thermal mass however thermal mass works even though insulation is in between the construction.

With the use of modern central heating, buildings with high thermal mass favour small boilers working at maximum output and therefore efficiency - longer periods of operation at lower output. Conversely, buildings with low thermal mass tend to have much wider changes in temperature and the boiler can cycle on and off constantly.
Energy Modelling of a two-storey detached villa

Baseline performance and improved conditions

**Energy Simulation using the <Virtual Environment>**

We can investigate thermal mass using simulation techniques that can take dynamic thermal effects into consideration. Steady state approaches would not be valid – all design scenarios will be carried out using the IES <Virtual Environment> dynamic thermal simulation application.

Dynamic thermal simulation involves creating a “Virtual” representation of a Building project which simulates the Building operation for a period of time (typically annual) and uses climate data for each hour of the year including air temperature, cloud cover, solar radiation (direct and diffuse), wind speed and direction and solar azimuth & altitude. The energy use is calculated through assessment of desired building operation, climate gains/losses and internal gains and simulation can account for effects such as Thermal Mass.

Energy simulations vary in capability and the simulation results can be improved by including solar & daylight penetration – solar gain can be assessed at the surface and take in effects of obstructions and self shading. Daylight sensors can be placed to share annual lighting simulation data with the energy model to account for energy efficient lighting schemes and wind and stack driven natural ventilation effects can also be analysed in addition to pressure driven air flow.

Energy Modelling – Levels of detail

In addition to the base option and design scenarios input data, the simulation requires location, orientation, building type – how the building is used, internal gains occupancy etc, HVAC equipment type and usage patterns, and building constructions. These are all detailed in the Appendix.
Design Scenarios

The building is to be assessed for its energy performance and thermal comfort conditions using dynamic thermal simulation methods. For the purposes of this report, thermal comfort has been recorded in terms of a comfort index and percentage of people dissatisfied (PPD).

This is to be achieved by analysing the relative effectiveness of various configurations of heating system operation patterns and how they react to the existing constructions. In addition, improved construction types will be evaluated in an attempt to justify that managing buildings more intelligently removes the requirement for improved constructions. The main concern is whether or not thermal mass in old construction is effective with modern heating techniques and usage patterns.

For all options assume:

- Typical family of 4 – no occupants during weekdays
- Radiators as main heating system
- Constructions (See Appendix)
- Traditional single-glazed units

Base option:

We will initially analyse the benefit of smaller emitters over a longer duration and larger emitters run over a shorter period to determine the most effective base option to be used in each design scenario.

The base option will also account for the following worst case settings:

- Fire place open – i.e. a ventilation source however not a heat source
- Typical use heating profile

Upgraded scenarios:

Glazing

- Close blinds
  - Analyse the effects of closing blinds between the hours of 1600 and 0800. Shading coefficient of 0.61 and short wave radiant fraction of 0.3 has been taken (from BRE data for typical internal blind). In line with CIBSE Guide C table 3.32 the thermal night time resistance for the blinds is assumed to be 0.05 m² K w⁻¹.
- Close shutters
  - Analyse the effect of closing wooden shutters between the hours of 1600 and 0800. Shading coefficient of 0.28 and short wave radiant fraction of 0.4 has been taken to achieve a U-value of 1.8 W/m²K when closed. Thermal night time resistance for the blinds is assumed to be 0.29 m² K w⁻¹.
- Close curtains
  - Analyse the effect of closing curtains in all rooms that have windows from 1600-0800. Shading coefficient of 0.49 and short wave radiant fraction of 0.3 has been taken (from BRE data for typical internal curtain). In line with CIBSE Guide C table 3.32 the thermal night time resistance for the curtains is assumed to be 0.07 m² K w⁻¹.
- Fit secondary glazing.
  - Analyse the effect of adding secondary glazing with a 50mm air cavity to improve the U value to 2.5 W/m²K including frame. The leakiness of the window in MacroFlo has been reduced to 1% to repent this remedial work.
Environment and Sustainability Services

- Retro fit double glazed units to existing timber (u – value 1.8)
  - Analyse the effect of retro fitting all single glazed 6mm panes with double glazed panes to give a U-value of 1.8 W/m²K. Fully draught-stripped therefore infiltration can also be improved.

  *note: these values are taken from Historic Scotland Thermal laboratory testing*

### Design Scenarios

#### Insulation

- Insulate attic space and coombes
  - Analyse the effect of adding 275mm insulation to the attic rafter space where there was none previously. This improves the U-value from 1.75 W/m²K to 0.14 W/m²K.

- Insulate floors from below
  - Analyse the effect of adding 200mm of insulation to the model ground floor space where there was none previously. This improves the U-value from 0.77 W/m²K to 0.16 W/m²K.

- Pelletized insulation blown into cavity behind lath and plaster
  - Analyse the effect of insulating the 40mm wall cavity – accepting that this is not the best option to maximise thermal mass.

- Insulate rear side of both external doors
  - Analyse the effect of adding 30mm of insulation to the inside surface of both external doors which improves the U-value from 3.3 W/m²K to 0.86 W/m²K.

#### Heating

- Reduce ventilation from open fire
  - Analyse the effect of closing off all the fireplace openings.

- Fit a small condensing boiler that is well matched to the load
  - Analyse the effect of replacing the existing boiler with a condensing type with an improved efficiency of 98%.

- Fit wood chip boiler
  - Analyse the effect of replacing the existing boiler with a wood chip model. The efficiency of the proposed biomass boiler is 92%.

- Input radiator sizes that have been fine tuned to meet the requirements of the space
  - Analyse the effect that limiting the heat output i.e. symbolising a correctly sized radiator, will have on room conditions.

- Model continuous low heat, with surge as required, instead of the typical once in the morning, once at night heating cycle.
  - Analyse heating operation at a constant, low output. Conditions to be maintained - 16°C in each heated zone.

- Model continuous low heat and input radiator sizes
  - Analyse heating operation at a constant, low output. Conditions to be maintained - 16°C in each heated zone. In addition, input radiator sizes.

- Model continuous heat with specific setpoint and setback temperature.
  - Analyse the effect of a continuous heating system. Conditions to be maintained – setpoint (peak) of 20°C during the hours of 0700-0800 and 1630-2300, and a setback (minimum) of 10°C during the hours of 2300-0700.
## Results – Glazing options

### Overall Building Results

<table>
<thead>
<tr>
<th>Energy</th>
<th>Improvement (annual energy)</th>
<th>Carbon emissions (KgCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>9.42</td>
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</table>

### Room Results - Living Area

<table>
<thead>
<tr>
<th>Peak airflow (ACH/hr)</th>
<th>Internal temp. (°C)</th>
<th>Environmental temp. (°C)</th>
<th>Comfort Index (daily mean - Jan 1st)</th>
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<tbody>
<tr>
<td>noon - Jan 1st</td>
<td>6</td>
<td>8.8</td>
<td>19.75</td>
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### Base Option

Model Base: open fire, typical heating profile, carpet, central heating using radiators

<table>
<thead>
<tr>
<th>Model</th>
<th>Base: open fire, typical heating profile, carpet, central heating using radiators</th>
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<td>Energy</td>
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</table>

### Design Scenarios

#### Glazing

- **Model_01 close blinds: profile 2200-0800, resistance (R) = 0.05**
  - Peak airflow: 6, Internal temp.: 7.8, Environmental temp.: 20.73, Comfort Index: 3, PPD: 65

- **Model_02 close shutters: profile 2200-0800, resistance (R) = 0.33 - to meet U-value of 1.8W/m²K when closed**
  - Energy: 9.15 MWh, Annual: 47.27 MWh, Cost: 1891 £, Improvement: 3 %, System: 9170, Total: 16043
  - Peak airflow: 6, Internal temp.: 8.8, Environmental temp.: 19.65, Comfort Index: 4, PPD: 62

- **Model_03 close curtains: profile 2200-0800, resistance (R) = 0.07**
  - Peak airflow: 6, Internal temp.: 8.8, Environmental temp.: 19.71, Comfort Index: 4, PPD: 62

- **Model_04 fit secondary glazing: to meet U-value of 2.5W/m²K**
  - Energy: 8.24 MWh, Annual: 42.48 MWh, Cost: 1699 £, Improvement: 12 %, System: 8241, Total: 15114
  - Peak airflow: 4.5, Internal temp.: 9.6, Environmental temp.: 19.61, Comfort Index: 4, PPD: 59

- **Model_05 retro fit double glazed units: to meet U-value of 1.8W/m²K**
  - Peak airflow: 1.4, Internal temp.: 11.6, Environmental temp.: 19.92, Comfort Index: 4, PPD: 47

- **Model_19 cumulative study of Model_01, 02, 03 and 04**
  - Energy: 8.16 MWh, Annual: 42.24 MWh, Cost: 1690 £, Improvement: 13 %, System: 8194, Total: 15067
  - Peak airflow: 4.5, Internal temp.: 8.6, Environmental temp.: 20.13, Comfort Index: 4, PPD: 62

- **Model_20 cumulative study of Model_01, 02, 03 and 05**
  - Peak airflow: 1.4, Internal temp.: 10.5, Environmental temp.: 20.18, Comfort Index: 4, PPD: 53
# Results – Insulation options

## Overall Building Results

<table>
<thead>
<tr>
<th>Model</th>
<th>Method Description</th>
<th>Peak (MWh)</th>
<th>Annual (MWh)</th>
<th>Cost/yr (£)</th>
<th>Improvement (%)</th>
<th>System</th>
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<td>1941</td>
<td>9411</td>
<td>16285</td>
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<td>06</td>
<td>Insulate attic space and coombes: Mineral wool - thickness 275mm</td>
<td>9.09</td>
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<td>Insulate floors: EPS slab insulation - thickness 200mm</td>
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<td>Insulate rear side of external doors: ESP slab - thickness 30mm</td>
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<td>Insulate rear side of external doors: ESP slab - thickness 30mm</td>
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## Results – Heating options

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### Design Scenarios

#### Heating

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<td>9411</td>
<td>16285</td>
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<tr>
<td>Model_11</td>
<td>close fire: No ventilation from open fire flues</td>
<td>7.77</td>
<td>40.65</td>
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<td>16</td>
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<td>14760</td>
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<td>Model_12</td>
<td>fit condensing boiler: high efficiency = 98%</td>
<td>7.79</td>
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<td>17</td>
<td>7779</td>
<td>14652</td>
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<td>Model_13</td>
<td>fit wood chip boiler: CO₂ emission factor = 0.025</td>
<td>8.30</td>
<td>42.72</td>
<td>1709</td>
<td>12</td>
<td>1067</td>
<td>7964</td>
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<tr>
<td>Model_14</td>
<td>input radiator sizes: calculated for each room type (see Appendix of this report)</td>
<td>6.65</td>
<td>37.81</td>
<td>1513</td>
<td>22</td>
<td>7336</td>
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<td>model continuous heat - setpoint 20°C, setback 10°C</td>
<td>9.00</td>
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<td>Model_22</td>
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# Results – Combined design scenarios

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## Base Option

Model_Base: open fire, typical heating profile, carpet, central heating using radiators

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## Design Scenarios

### Combined Scenarios

**Model_16:** Model_05 and Model_14 (double glazed panes + radiator sizes)

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<tr>
<td>6.54</td>
<td>37</td>
<td>1480</td>
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**Model_17:** Model_12 and Model_14 (radiator sizes + high efficiency boiler)

<table>
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<tr>
<td>5.50</td>
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**Model_18:** Model_05, _06, _11 & 15c (double glazed panes + insulate the attic + close the fire + continuous heat)

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<tr>
<td>6.56</td>
<td>37.87</td>
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</table>
Conclusions

In traditional dwellings, there are some key issues:

- Temporary blocking of flues in winter/when not in use – this provides high comfort conditions
- Intelligent combination in terms of heating settings/operation of heating system/boiler type
  - Effective use of boiler
  - Effective use of thermostat
- Interventions such as adding blinds, shutters are available to all

From the results the most effective design scenarios, in terms of energy performance, were upgrading the existing sashes with double glazed units and inputting the individual radiator size for each room type. These performed the best individually and in combination with each other – providing a 36% improvement on the base case.

The design scenarios contain a suite of moderate level interventions where the building is not altered in any way substantially; we aimed to carry out the iteration without fundamentally changing the relationship of the building. They are all frequently applied, readily achievable and are essentially all accessible to home owners.

The results form the basis of analysis carried out predominantly in winter when low temperatures are experienced. In summer, many of the features are beneficial.

It is worth noting that Dynamic Simulation Methods differ greatly from Steady State calculations and this system generally produces lower CO2 consumption figures when compared with Steady State figures.
Appendix

External Walls
Construction layers from outside to inside surface:
600mm Lime bonded rubble
40mm Cavity
20mm Plaster
Total thickness of construction = 632mm, Overall U-value of construction = 1.4 W/m²\(\text{k}\)

Ground Floor
Construction layers from outside to inside surface:
750mm Soil Base
200mm Air Gap
30mm Timber Floor Boards
10mm Carpet Finish
Total thickness of construction = 999mm, Overall U-value of construction = 0.7675 W/m²\(\text{k}\)

Ground Floor (Kitchen area only)
Construction layers from outside to inside surface:
750mm Soil
100mm Stone
Total thickness of construction = 850mm, Overall U-value of construction = 1.23 W/m²\(\text{k}\)

Roof
Construction layers from outside to inside surface:
8mm Slate Tiles
2mm Roofing Felt
20mm Timber Sarking Board
Total thickness of construction = 30mm, Overall U-value of construction = 3.6266 W/m²\(\text{k}\)
Appendix

Glazing

Construction layers from outside to inside surface:

6mm Clear Float Glass (Single Glazing)

Total thickness of construction = 6mm

Overall U-value of construction = 4.66 W/m²k

Building Systems

A gas-fired LPHW (Low Pressure Hot Water) heating system will be used throughout. A standard boiler circa 1980s with an efficiency of 65% will be assumed for the all design scenarios however an improved efficiency will be used in at least one option for comparison purposes.

Radiators will be present in all rooms and set-points will be based on the standard domestic internal temperature values from CIBSE Guide A.

Radiator sizing has been carried out based on the CIBSE steady state heat loss methodology (CIBSE Guide B1) which takes account of both fabric and infiltration heat losses. Outside winter design temperature has been taken as -5.6°C for Edinburgh. A 10% design margin is applied as a generic quick heat. It is assumed that one suitable sized radiator will meet the load. Based on this design methodology, the following total outputs are required from one or more radiators in a room:

- Living Room – 5538W
- Kitchen – 2021W
- Dining Room – 2965W
- Utility Room – 534W
- Toilet – 46W
- Bedroom 01 – 558W
- Bathroom – 367W
- Bedroom 02 – 675W
- Bedroom 03 – 509W
- Upper Landing – 189W
Internal temperatures to be maintained are as follows:

- Living area: 20°C
- Bedroom: 17°C
- Bathroom: 20°C
- Hall: 17°C
- Kitchen: 17°C
- Utility Room: 17°C

The system will operate on the basis that the occupants are out all day. The heating system operation time will be varied in an attempt to identify the most appropriate.

**Ventilation**

No mechanical ventilation will be modelled in any zones.

Infiltration rates for all zones have been assumed to be 0.5 ACH/hr due to the age of the building. This is an indicative value.

A constant opening of 2% has been identified as a suitable representation of trickle ventilation through the traditional sash & case windows.

Ventilation as a result of open fires will be accounted for in two rooms upstairs and two rooms on the ground floor. Additionally, two vents at the front of the building will ventilate the floor cavity.

**Boundary Conditions**

There are no adjacent buildings; however the ground temperature adjacencies have been set to 10°C all year round.

The weather file chosen for the analysis is the Edinburgh.TRY file. The file is a ‘test reference year’ file and thus contains typical weather data for a full year in the Edinburgh area. The file was chosen on the basis that it represent the nearest geographical location for which a suitable weather file exists.