HISTORIC SCOTLAND

Technical Conservation Group

Technical Paper 5

Energy modelling of a mid 19th century villa

Baseline performance and improvement options

INTEGRATED ENVIRONMENTAL SOLUTIONS

IES
February 2009

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ENVIRONMENT AND SUSTAINABILITY SERVICES

Energy modelling of Mid 19th Century Villa

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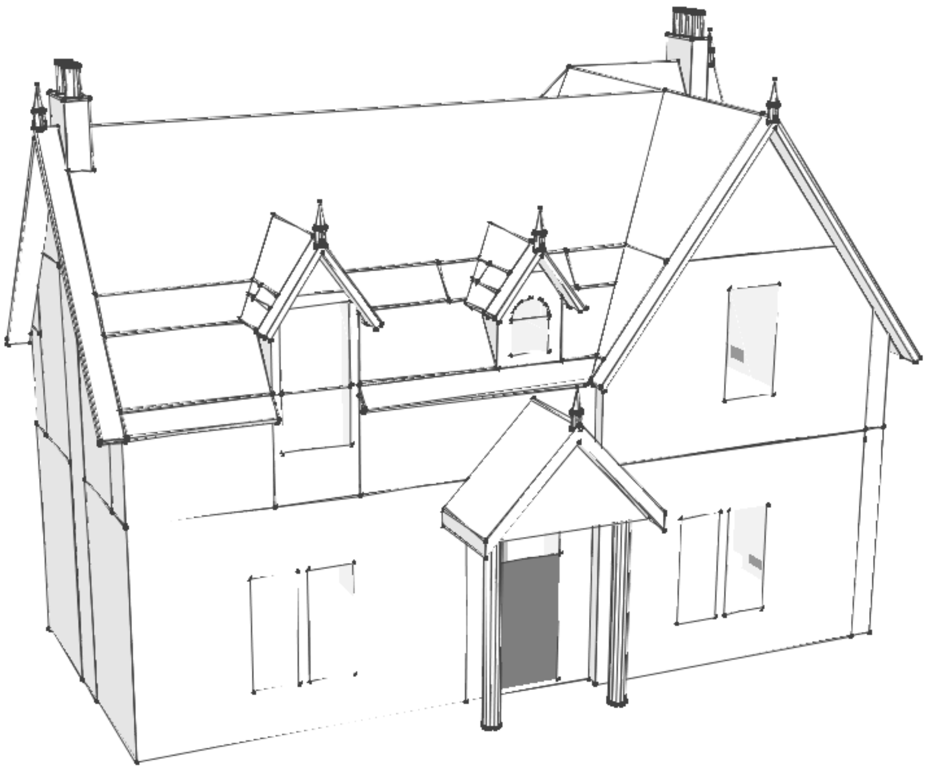


Contents

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.

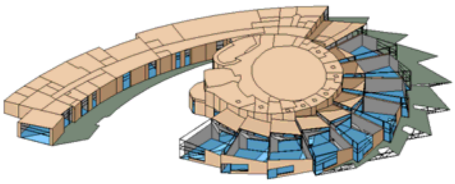
With the use of modern central heating, buildings with high thermal mass favour small boilers working at maximum output and therefore efficiency - longer periods of operation at lower output. Conversely, buildings with low thermal mass tend to have much wider changes in temperature and the boiler can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

Energy 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.

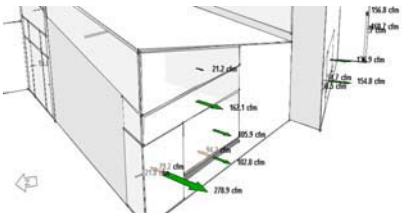
Dynamic thermal simulation involves creating a “Virtual” representation of a Building project which simulates the Building operation for a period of time (typically annual) and uses climate data for each hour of the year including air temperature, cloud cover, solar radiation (direct and diffuse), wind 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.



Solar penetration

Daylight sensors



Wind / Stack

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 0.05m² 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 0.29m² 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 0.07m² 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.*

- 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℃ 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℃ 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℃ during the hours of 0700-0800 and 1630-2300, and a setback (minimum) of 10° during the hours of 2300-0700.*

Results – Glazing options

	Overall Building Results						Room Results - Living Area				
	Energy			Improvement- (annual energy)	Carbon emissions ($KgCO_2$)		Peak airflow (ACH/hr)	Internal air temp. (ºC)	Environmental temp. (°C)	Comfort Index (daily mean - Jan 1st)	PPD (daily mean - Jan 1st)
	Peak (MWh)	Annual (MWh)	Cost/yr (£)	%	System	Total		noon - Jan 1st			
Base Option											
Model_Base: open fire, typical heating profile, carpet, central heating using radiators	9.42	48.51	1941		9411	16285	6	8.8	19.75	4	63
Design Scenarios											
Glazing											
Model_01 close blinds: profile 2200-0800, resistance (R) = 0.05	9.30	48.04	1921	1	9319	16192	6	7.8	20.73	3	65
Model_02 close shutters: profile 2200-0800, resistance (R) = 0.33 - to meet U-value of 1.8W/m²K when closed	9.15	47.27	1891	3	9170	16043	6	8.8	19.65	4	62
Model_03 close curtains: profile 2200-0800, resistance (R) = 0.07	9.33	48.07	1923	1	9326	16199	6	8.8	19.71	4	62
Model_04 fit secondary glazing: to meet U-value of 2.5W/m²K	8.24	42.48	1699	12	8241	15114	4.5	9.6	19.61	4	59
Model_05 retro fit double glazed units: to meet U-value of 1.8W/m²K	6.76	35.06	1403	28	6802	13676	1.4	11.6	19.92	4	47
Model_19 cumulative study of Model_01, 02, 03 and 04	8.16	42.24	1690	13	8194	15067	4.5	8.6	20.13	4	62
Model_20 cumulative study of Model_01, 02, 03 and 05	6.77	35.34	1414	27	6856	13730	1.4	10.5	20.18	4	53

Results – Insulation options

	Overall Building Results						Room Results - Living Area				
	Energy			Improvement- (annual energy)	Carbon emissions ($KgCO_2$)		Peak airflow (ACH/hr)	Internal air temp. (ºC)	Environmental temp. (°C)	Comfort Index (daily mean - Jan 1st)	PPD (daily mean - Jan 1st)
	Peak (MWh)	Annual (MWh)	Cost/yr (£)	%	System	Total		noon - Jan 1st			
Base Option											
Model_Base: open fire, typical heating profile, carpet, central heating using radiators	9.42	48.51	1941		9411	16285	6	8.8	19.75	4	63
Design Scenarios											
Insulation											
Model_06 insulate attic space and coombes: Mineral wool - thickness 275mm	9.09	46.74	1869	4	9067	15940	6	8.8	19.74	4	62
Model_07 insulate floors: EPS slab insulation - thickness 200mm	9.08	46.36	1855	4	8995	15868	6	7.5	22.10	4	50
Model_08 insulate the external wall cavity: Pelletized insulation - thickness 40mm	9.22	47.37	1895	2	9203	16076	6	9.1	19.80	3	60
Model_09 insulate rear side of external doors: ESP slab - thickness 30mm	9.30	47.86	1914	1	9285	16158	6	8.8	19.73	4	63
Model_21 cumulative study of all the above	7.40	37.27	1491	23	7231	14104	6	9.5	20.72	4	58

Results – Heating options

	Overall Building Results						Room Results - Living Area				
	Energy			Improvement- (annual energy)	Carbon emissions ($KgCO_2$)		Peak airflow (ACH/hr)	Internal air temp. (ºC)	Environmental temp. (°C)	Comfort Index (daily mean - Jan 1st)	PPD (daily mean - Jan 1st)
	Peak (MWh)	Annual (MWh)	Cost/yr (£)	%	System	Total		noon - Jan 1st			
Base Option											
Model_Base: open fire, typical heating profile, carpet, central heating using radiators	9.42	48.51	1941		9411	16285	6	8.8	19.75	4	63
Design Scenarios											
Heating											
Model_11 close fire: No ventilation from open fire flues	7.77	40.65	1626	16	7887	14760	1.5	11.1	19.73	4	51
Model_12 fit condensing boiler: high efficieny = 98%	7.79	40.10	1604	17	7779	14652	6	8.8	19.75	4	63
Model_13 fit wood chip boiler: CO_2 emission factor = 0.025	8.30	42.72	1709	12	1067	7964	6	8.8	19.75	4	63
Model_14 input radiator sizes: calculated for each room type (see Appendix of this report)	6.65	37.81	1513	22	7336	14209	6	7.9	19.75	3	74
Model_15 model continuous heat - setpoint 20℃, setback 10℃	9.00	56.18	2247	-16	10900	17884	6.0	10.0	20.57	4	57
Model_22 cumulative study of Model_11, 12, 13, 14 and 15	6.66	40.65	1626	16	1017	8001	1.41	11.1	18.19	4	58
Model_23 cumulative study of Model_11, 12, 13, 14 and 15a	6.87	46.89	1876	3	1172	8734	1.47	11.0	18.20	4	51

Results – Combined design scenarios

	Overall Building Results						Room Results - Living Area				
	Energy			Improvement- (annual energy)	Carbon emissions ($KgCO_2$)		Peak airflow (ACH/hr)	Internal air temp. (ºC)	Environmental temp. (℃)	Comfort index (daily mean - Jan 1st)	PPD (daily mean - Jan 1st)
	Peak (MWh)	Annual (MWh)	Cost/yr (£)	%	System	Total		noon - Jan 1st			
Base Option											
Model_Base: open fire, typical heating profile, carpet, central heating using radiators	9.42	48.51	1941		9411	16285	6	8.8	19.75	4	63
Design Scenarios											
Combined Scenarios											
Model_16: Model_05 and Model_14 (double glazed panes + radiator sizes)	6.54	37	1480	24	7178	14052	6	8	19.65	3	72.63
Model_17: Model_12 and Model_14 (radiator sizes + high efficiency boiler)	5.50	31	1240	36	6063	12937	6	7.87	19.75	3	74.13
Model_18: Model _05, _06, _11 & 15c (double glazed panes + insulate the attic + close the fire + continuous heat)	6.5612	37.87	1515	22	7346	14331	1	12.11	21.08	4	43.36

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/m²k

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/m²k

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/m²k

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/m²k

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℃ 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

Appendix

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 ºC 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.

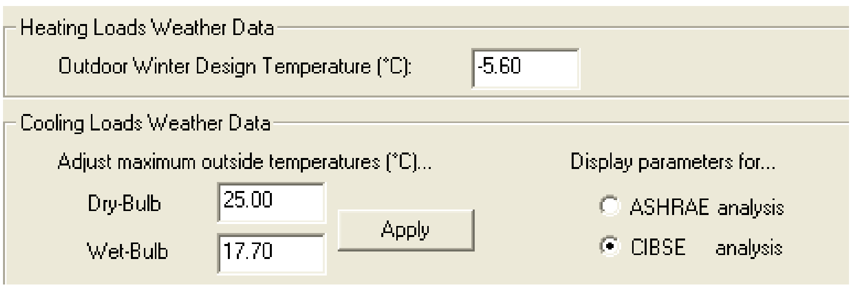


Figure 2: Weather data

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