Prediction of overheating in synthetically occupied UK homes: dataset for validating dynamic thermal models of buildings

Loughborough University

Overheating modelling exercise

Guidance for modellers

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Version 1

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Version control

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1.0	First release	N/A	BMR	20/06/2019

Original publication

This document contains guidance for modelling the Loughborough University Matched Pair test houses. In line with the methodology set out in Roberts et al. (2019), the document was used to support work to validate the summertime temperature predictions of dynamic thermal models, as reported in:

Roberts, B.M., Allinson, D., Diamond, S., Abel, B., Das Bhaumik, C., Khatami, N. and Lomas, K.J. (2019). Predictions of summertime overheating: Comparison of dynamic thermal models and measurements in synthetically occupied test houses. *Building Services Engineering Research and Technology.* 40 (4), 512-552. Available at: https://doi.org/10.1177/0143624419847349.

Supporting files and data

Supplementary information to the paper is provided. This 'guidance for modellers' document, indoor temperature data, weather data, floor plans, site plans and elevation drawings are available in the Loughborough University Research Repository (Figshare). Available at: https://doi.org/10.17028/rd.lboro.8094575.

Contents

Chapter 1

Physical description of the test houses

This chapter begins by describing the geometry of the houses and their construction elements. Later the construction materials of each element is listed.

There are two test houses arranged in an adjoining semi-detached pair. They face south with 209 Ashby Road (West house) on the west side and 207 Ashby Road (East house) on the east side. The houses are in a suburban residential area of Loughborough, UK (52.771071°N, 1.224264°W) (figure 1.6). The front of the dwellings faces south-southeast (160°) towards a front garden and a road, the rear of the properties faces north to a large back garden. There are neighbouring houses of similar roof heights to the east and west (figure 1.5). There are two small (1.3 m x 2.1 m x 2.4 m) brick outbuildings on the north side of the houses, 1.5 m away which are visible on the local site plan (figure 1.5, local site plan also provided as '.dwg/.dxf/.pdf'.).

(a) Two test houses from the front (south) side. West house (209) left, East house (207) right.

(b) Two test houses from the rear (north) side. East house (207) left, West house (209) right.

Figure 1.1: The two adjoining semi-detached test houses where data was collected on Ashby Road in Loughborough, UK.

Figure 1.2: South elevation windows closed.

Figure 1.3: South elevation top-hung windows open.

Figure 1.4: Aerial photograph of the two test houses with neighbouring dwellings. North is top of photo. Google Maps 2016.

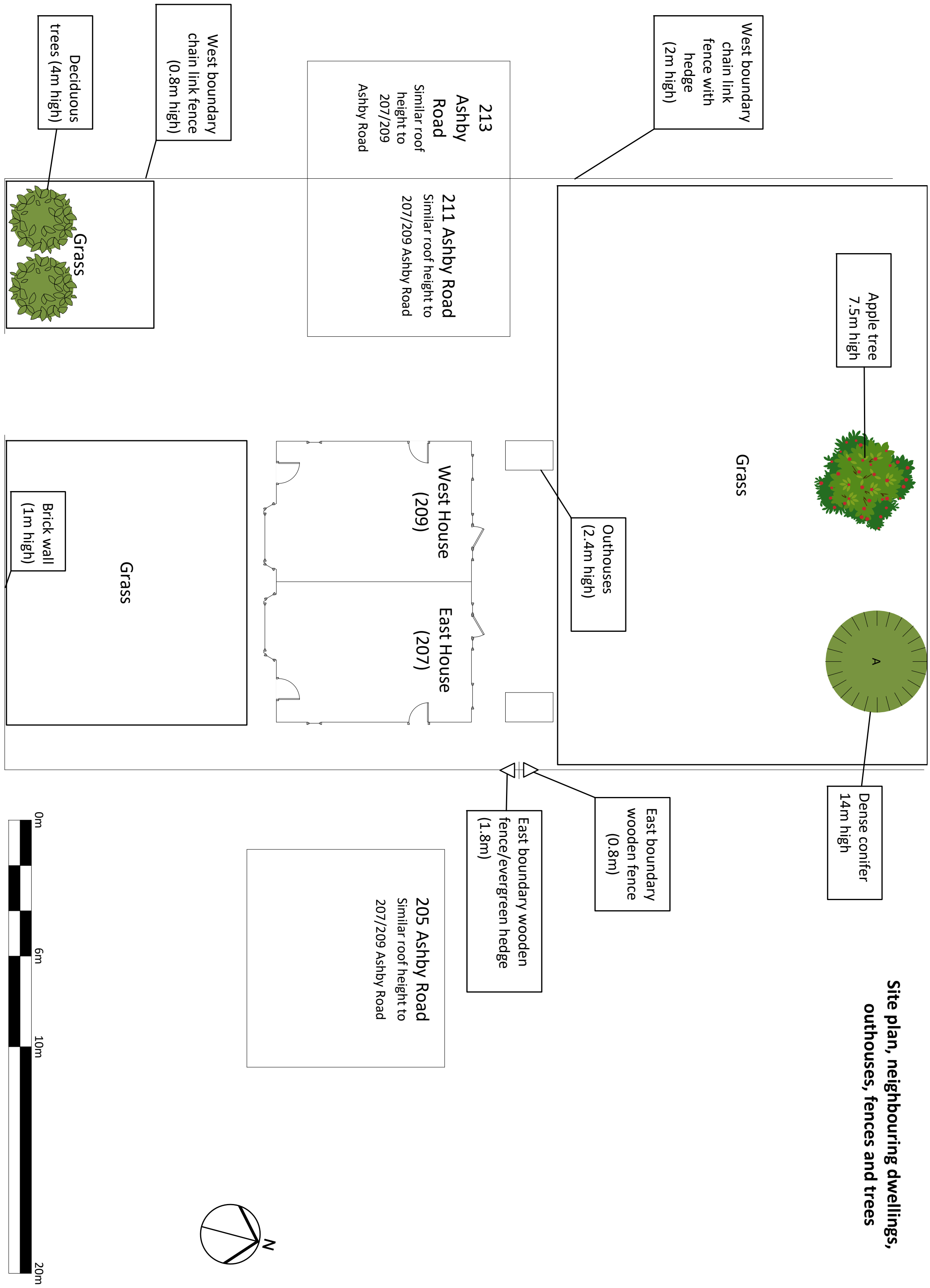


Figure 1.5: Local site plan of test houses, neighbouring houses, outhouses and trees.

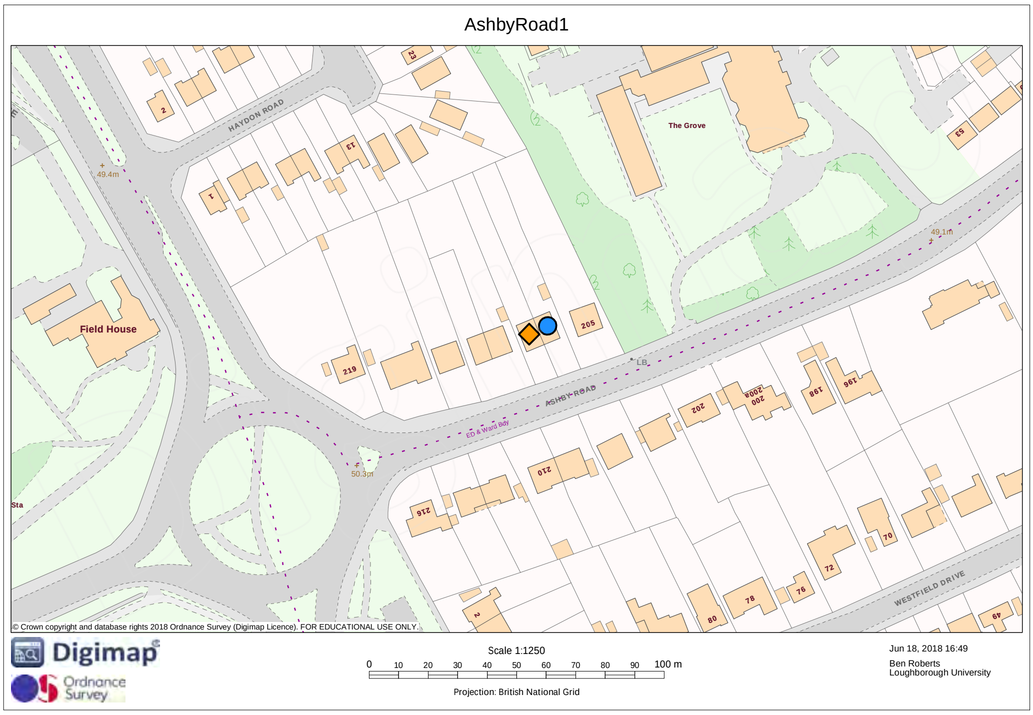


Figure 1.6: Location of the test houses and wider site in Loughborough, UK. West house (209 Ashby Road) indicated by orange diamond. East house (207 Ashby Road) indicated by blue circle.

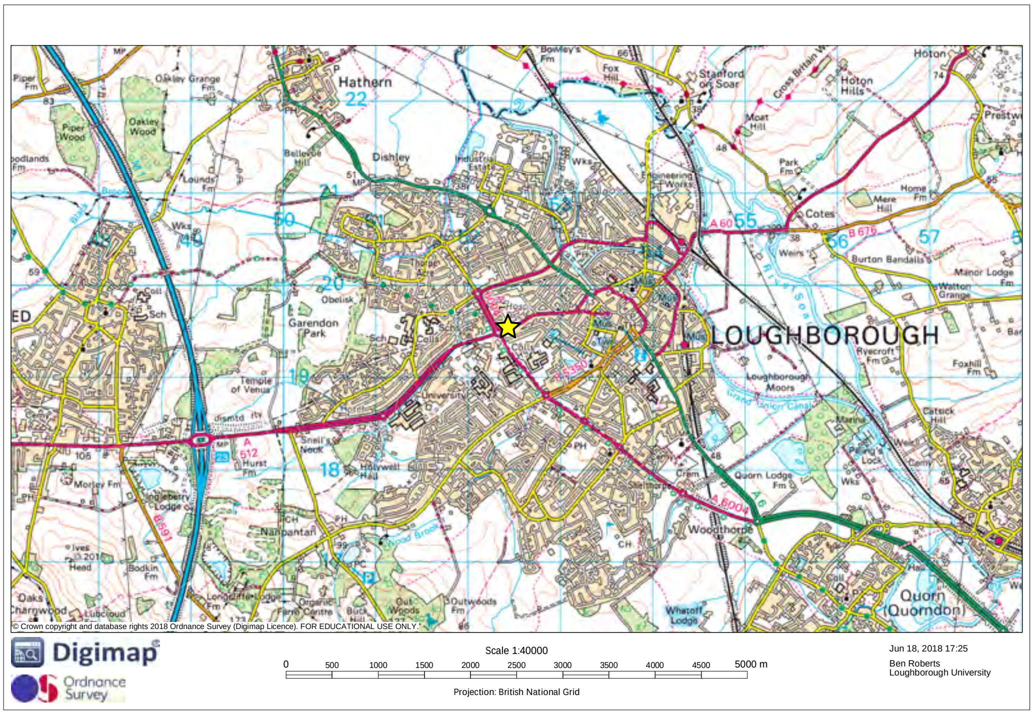


Figure 1.7: Location of test houses in Loughborough indicated by yellow star.

1.1 Geometry

Scale drawings are provided[1] at 1:50 scale at A4 size in '.dwg' '.dxf' and '.pdf' format. A total of nine files are available (table 1.1).

Table 1.1: Scale drawing file names and descriptions.

File name ('... .dwg/.dxf/.pdf')	Drawing description
'External_Ground...'	Geometry of ground floor external walls with window position and widths.
'External_First...'	Geometry of first floor external walls with window position and widths.
'Internal_Ground...'	Geometry of ground floor internal walls. Zone names specified for each room.
'Internal_First...'	Geometry of first floor internal walls. Zone names specified for each room.
'Elevation_North...'	Geometry of north elevation with window position and size.
'Elevation_South...'	Geometry of south elevation with window position and size.
'Elevation_East...'	Geometry of east elevation with window position and size.
'Elevation_West...'	Geometry of west elevation with window position and size.
'Siteplan...'	Scale drawing of test houses, surrounding buildings and trees.

1.1.1 Zone naming convention

Zones are named according to their main function and which house they are in. E.g. the living room in 207 Ashby Road would be "207_Living". (See internal floorplans).

1.1.2 Roof overhangs

The roof overhangs the external walls on all sides with a 0.27 m soffit as shown in elevation drawings. Attached to the fascia is 0.11 m wide guttering, not included in the elevation drawings.

[1] Available at: https://doi.org/10.17028/rd.lboro.8094575.

1.1.3 Ceilings

Ground floor ceiling height measured from the internal ground floor = 2.5 m.

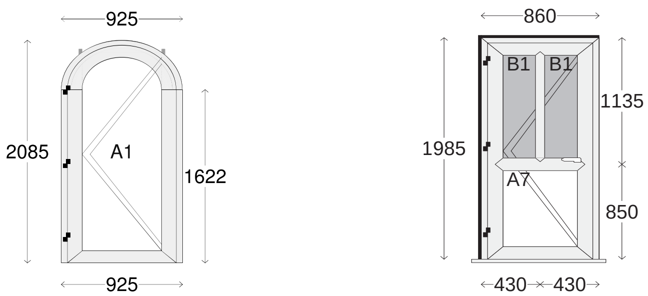
First floor ceiling height measured from the internal first floor = 2.4 m.

1.1.4 Internal doors

Internal doors measure 0.71 x 1.95 m.

1.1.5 External doors

There are external doors located on the south elevation, into the hallway; on the north elevation into the dining room; and into the kitchen on the east side in the east house (207) and the west side in the west house (209). Front door geometry is listed in figure 1.8a and table 1.2 and kitchen door geometry in figure 1.8b and table 1.3). The dining room door is detailed alongside the dining room windows in figure 1.14.



(a) Front door.

(b) East/west side kitchen door.

Figure 1.8: External door dimensions (excluding dining room).

Table 1.2: Dimensions of glazed areas of front door (refer to figure 1.8a).

Glazed area	Dimensions (mm)
A1	300 x 600

Table 1.3: Dimensions of glazed areas of kitchen door (refer to figure 1.8b).

Glazed area	Dimensions (mm)
B1	270 x 952*
A7	Unglazed

* The glazed elements in the kitchen doors were blocked with insulation.

1.2 Windows

The following section describes window reveal and sill geometry; frame dimensions; geometry of glazed elements; and opening areas. A methodology for measuring window opening area is provided in section 1.2.3 to avoid confusion. Construction and materials is listed in section 1.3. Details provided are applicable to both houses unless stated.

1.2.1 Window reveal and sill dimensions

All exterior window sill depths measure 0.085 m from the window frame to edge of the sill. Sill heights and window reveals are listed in table 1.4. Sill height is measured from the interior floor. Interior sill depth is measured from window frame to end of sill. Internal and external reveals are measured from window frame to wall edge.

Table 1.4: Interior and exterior window sill and reveal measurements.

Room	Interior sill height (m)	Interior sill depth (m)	Exterior reveal depth (m)	Interior reveal depth (m)
Living room	0.76	0.18	0	0.23
Dining room	0.9	0.22	0.035	0.2
Kitchen	1.18	0.25	0.035	0.19
Single Bedroom	0.9	0.45	0	0.22
Front double bedroom	0.75	0.105	0	0.23
Rear double bedroom	0.9	0.22	0.035	0.19
Bathroom	0.9	0.21	0.035	0.19

1.2.2 Window frames

Window frame widths are listed in table 1.5 and are the same for all windows. Frame width on sashes apply to all openable windows as indicated on the respective drawings, not only the ones listed as opening in this exercise. All window frames are 60 mm deep (thick) from the interior to exterior face.

Table 1.5: Window frame, mullion, transom and sash width.

Frame element	Width (mm)
Outerframe*	60 mm
Mullions and transoms†	66 mm
Sashes‡	75 mm

* Surrounding entire window area in contact with wall.
† Vertical and horizontal cross-members.
‡ Openable elements, top- or side-hung.

1.2.3 Window geometry and opening area

Window geometry is provided in figures 1.11-1.24 with additional information on glazed sections and opening areas provided in tables below each figure.

Window opening areas are provided for all windows that opened during testing. These were top hung windows only. Windows were either fully open or fully closed during tests, taking approximately one minute to transition between the two. All measurements of window opening area were taken when fully open. Reference points for measuring window opening areas are shown in figure 1.9. Geometric free area is measured as the actual sharp edge orifice area at the interior opening using quadrilateral area (length A to B multiplied by length A to C) in figure 1.9. The side open area is the triangular area F to E, F to D, E to D (figure 1.9). The bottom open area is the quadrilateral area (length E to G multiplied by length E to D) in figure 1.9. The throw length (E to D) is 210 mm as measured from the exterior frame to the base of the interior face of the sash.

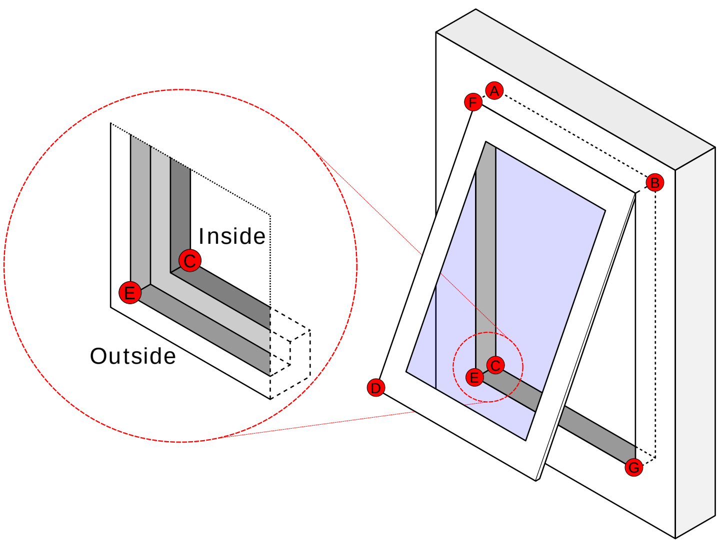


Figure 1.9: Window opening area measurement reference points. For illustrative purposes only, not to scale. Left image in red circle shows close up of frame edge.

Living room

Living room windows are arranged in a bay formation (figures 1.10 and 1.11). Glazed area dimensions are listed in figure 1.6. Bay dimensions are listed in figure 1.7. Only windows marked A1 and C1 opened during testing, but windows A4 had openable sashes with correspondingly thicker frames (figure 1.11, see table 1.5 for frame thickness). Living room window opening areas are listed in table 1.8.

(a) Outside. (b) Inside prior to curtain installation. (c) Inside with curtains and windows open.

Figure 1.10: Living room window photographs.

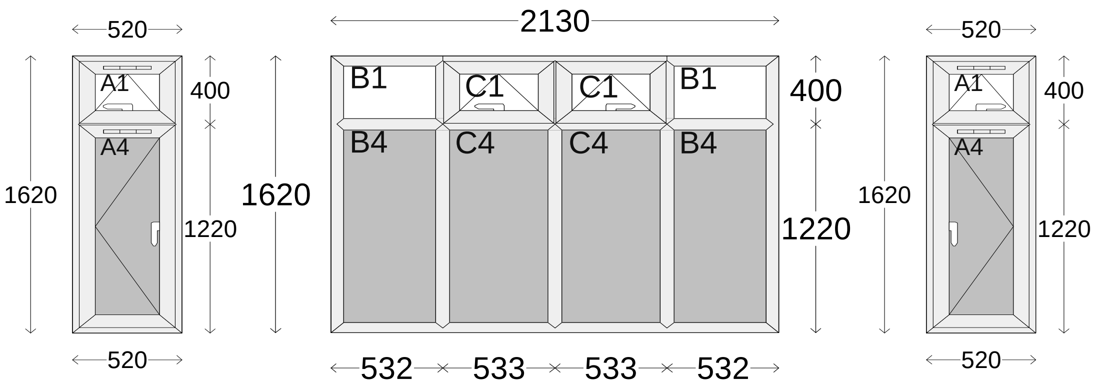


Figure 1.11: Living room window drawings and measurements in millimetres.

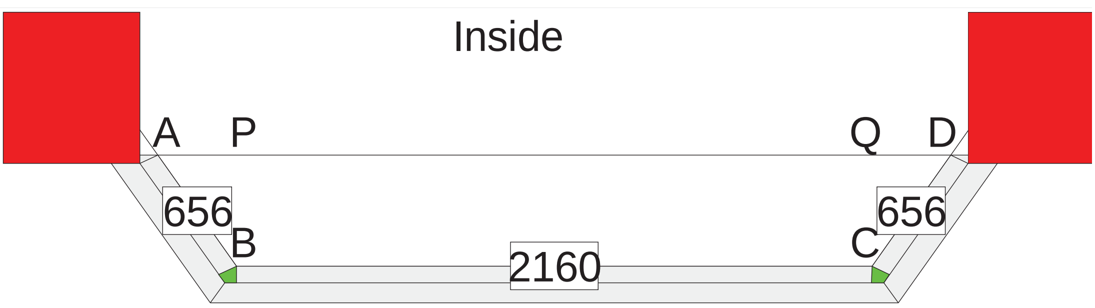


Figure 1.12: Living room bay window dimensions (mm) and reference points.

Table 1.6: Dimensions of glazed areas in living rooms (refer to figure 1.11).

Glazed area	**Dimensions (mm)**
A1 (x2)	340 x 247
A4 (x2)	340 x 1067
B1 (x2)	471 x 339
B4 (x2)	471 x 1159
C1 (x2)	407 x 247
C4 (x2)	499 x 1159

Table 1.7: Dimensions of bay window geometry in living rooms (refer to figure 1.12).

Reference point	**Length (mm) / Angle (°)**
Length A to B	535
Length B to C	2160
Length C to D	535
Angle ABC	120
Angle BCD	120

Table 1.8: Window opening areas in living rooms (refer to 1.11 for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
A1 (x2)	0.41	0.31	0.1271	0.36	0.21	0.325	0.0338	0.46	0.21	0.0966
C1 (x2)	0.475	0.31	0.14725	0.36	0.21	0.33	0.0342	0.525	0.21	0.11025

Dining room

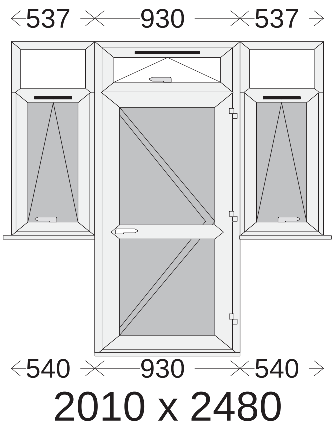
Dining room windows feature a door in the centre with an openable window above and side windows to either side (figures 1.13 and 1.14). Glazed area dimensions are listed in table 1.9. Only windows marked A1 opened in specific tests (figure 1.14b).

(a) Outside.

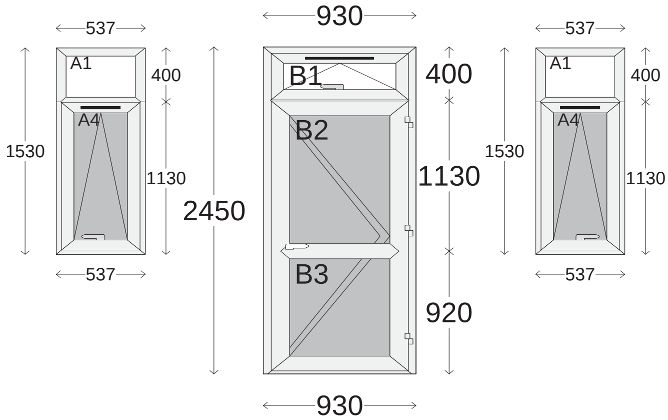
(b) Inside prior to curtain installation.

(c) Inside with curtains and window open.

Figure 1.13: Dining room window photographs.



(a) Dining room window geometry (mm).



(b) Dining room window dimensions (mm).

Figure 1.14: Dining room window drawings and measurements in millimetres.

Table 1.9: Dimensions of glazed areas in dining rooms (refer to figure 1.14).

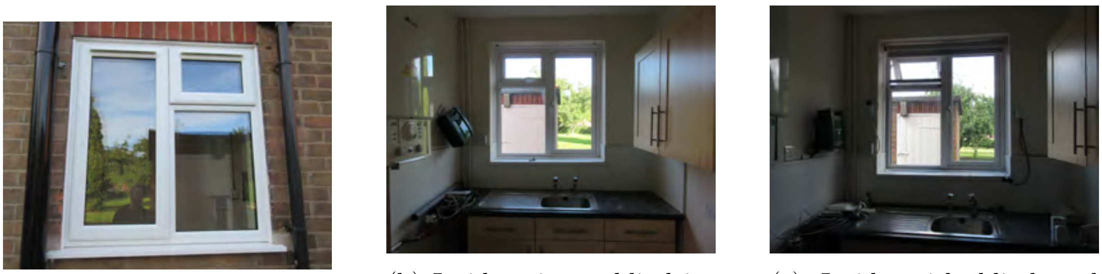
Glazed area	**Dimensions (mm)**
A1 (x2)	449 x 339
A4 (x2)	357 x 977
B1	720 x 232
B2	644 x 989
B3	644 x 762

Table 1.10: Window opening areas in dining rooms (refer to 1.14b for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
B1	0.775	0.29	0.22475	0.34	0.21	0.31	0.032	0.825	0.21	0.17325

Kitchen

Kitchen windows feature one opening top-hung window above a lower fixed window and a long window running the full height to the side. The small opening window is closest to the west wall in the West house (209 Ashby Road) and closest the east wall in the East house (207 Ashby Road) (figures 1.15 and 1.16). Glazed area dimensions are listed in table 1.11. Only windows marked A1 opened in specific tests (figure 1.16).



(a) Outside.

(b) Inside prior to blind installation.

(c) Inside with blind and window open.

Figure 1.15: Kitchen windows. West house (209 Ashby Road) windows shown. East house (207 Ashby Road) has opening on alternate side.

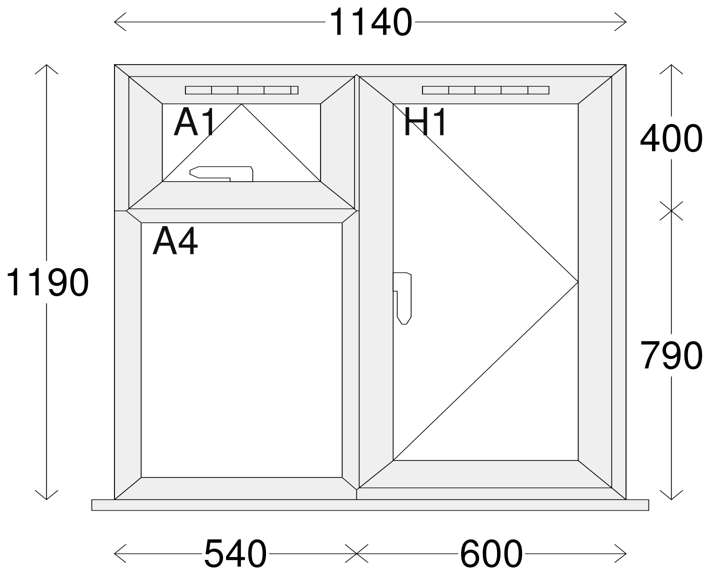


Figure 1.16: Kitchen window drawing and measurements in millimetres. Viewed from outside this represents the East house kitchen. Reverse for West house viewed from outside.

Table 1.11: Dimensions of glazed areas in kitchens (refer to figure 1.16).

Glazed area	**Dimensions (mm)**
A1	387 x 247
A4	479 x 729
H1	447 x 1010

Table 1.12: Window opening areas in kitchen (refer to 1.16 for window key and 1.9 for reference points).

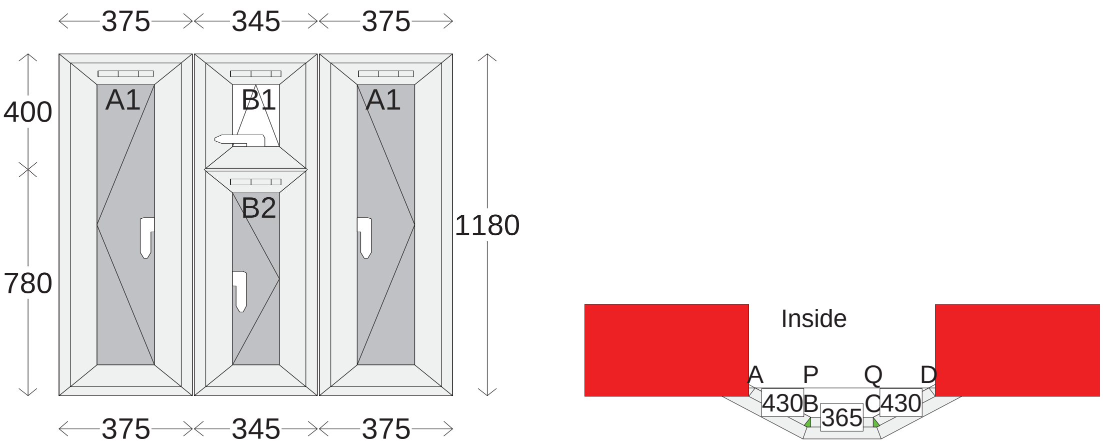
	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
A1	0.475	0.31	0.14725	0.36	0.21	0.33	0.0342	0.525	0.21	0.11025

Single bedroom

Single bedroom windows are arranged in a small bay. It features one one top-hung opening window above a lower side-hung window which has side-hung sashes to the right and left running the full height of the window (figures 1.17 and 1.18). Bay dimensions are listed in 1.14. Glazed area dimensions are listed in table 1.13. Only windows marked B1 opened in specific tests (figure 1.18).

(a) Outside. (b) Inside prior to curtain installation. (c) Inside with curtains and window open.

Figure 1.17: Single bedroom windows.



(a) Single bedroom window geometry (mm). (b) Single bedroom bay window dimensions (mm).

Figure 1.18: Single bedroom window drawings and measurements in millimetres.

Table 1.13: Dimensions of glazed areas in single bedrooms (refer to figure 1.18a).

Glazed area	Dimensions (mm)
A1 (x2)	195 x 1000
B1	165 x 247
B2	165 x 627

Table 1.14: Dimensions of bay window geometry in single bedrooms (refer to figure 1.18b).

Reference point	**Length (mm) / Angle (°)**
Length A to B	385
Length B to C	365
Length C to D	385
Angle ABC	147
Angle BCD	147

Table 1.15: Window opening areas in single bedrooms (refer to 1.18 for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
B1	0.22	0.27	0.0594	0.32	0.21	0.325	0.032	0.27	0.21	0.0567

Front double bedroom

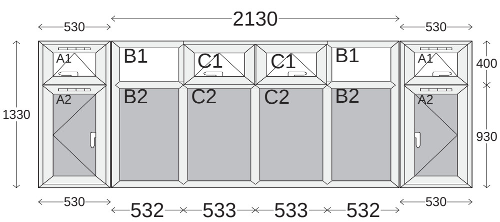
Front double bedroom windows are arranged in a bay as in the living room. Four top-hung windows open (figures 1.19 and 1.20a). Bay dimensions are listed in 1.17. Glazed area dimensions are listed in table 1.16. Only windows marked A1 and C1 opened in specific tests (figure 1.20).

(a) Outside.

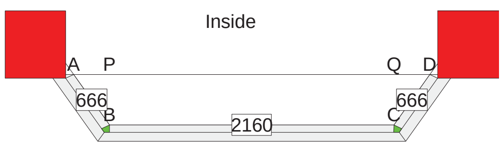
(b) Inside prior to curtain installation.

(c) Inside with curtains and windows open.

Figure 1.19: Front bedroom windows.



(a) Front double bedroom window geometry (mm).



(b) Front double bedroom bay window dimensions (mm).

Figure 1.20: Front double bedroom window drawings and measurements in millimetres.

Table 1.16: Dimensions of glazed areas in front double bedrooms (refer to figure 1.20a).

Glazed area	**Dimensions (mm)**
A1 (x2)	350 x 247
A2 (x2)	350 x 777
B1 (x2)	471 x 339
B2 (x2)	471 x 869
C1 (x2)	407 x 247
C2 (x2)	499 x 869

Table 1.17: Dimensions of bay window geometry in front double bedrooms (refer to figure 1.20b).

Reference point	**Length (mm) / Angle (°)**
Length A to B	545
Length B to C	2160
Length C to D	545
Angle ABC	120
Angle BCD	120

Table 1.18: Window opening areas in front double bedrooms (refer to 1.20a for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
A1 (x2)	0.42	0.31	0.1302	0.36	0.21	0.325	0.0338	0.47	0.21	0.0987
C1 (x2)	0.475	0.31	0.14725	0.36	0.21	0.325	0.0342	0.525	0.21	0.11025

Rear double bedroom

Rear double bedroom windows feature one top-hung opening window (figures 1.21 and 1.22). Directly below the top-hung opener is a fixed window with frames sized according to a sash (see table 1.5 for frame thickness). Glazed area dimensions are listed in table 1.19. Only windows marked B1 opened in specific tests (figure 1.22).

(a) Outside.

(b) Inside prior to curtain installation.

(c) Inside with curtains and window open.

Figure 1.21: Rear bedroom window photographs.

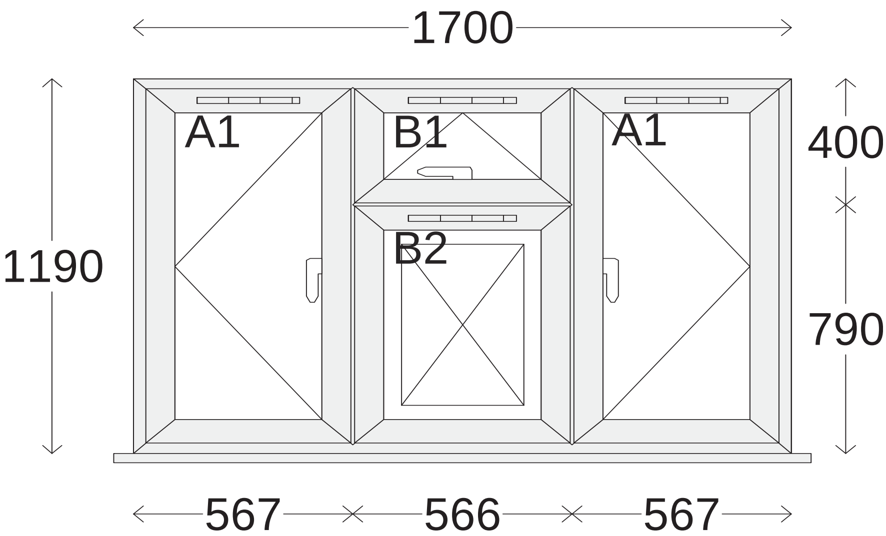


Figure 1.22: Rear double bedroom window drawing and measurements in millimetres.

Table 1.19: Dimensions of glazed areas in rear double bedrooms (refer to figure 1.20a).

Glazed area	**Dimensions (mm)**
A1 (x2)	414 x 1010
B1	440 x 247
B2	440 x 637

Table 1.20: Window opening areas in rear double bedrooms (refer to 1.22 for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
B1	0.45	0.31	0.1395	0.36	0.21	0.325	0.032	0.5	0.21	0.105

Bathroom

Bathroom windows are identical to kitchen windows. The small opening window is closest to the west wall in the West house (209 Ashby Road) and closest the east wall in the East house (207 Ashby Road) (figures 1.23 and 1.24). Glazed area dimensions are listed in table 1.21. Only windows marked A1 opened in specific tests (figure 1.24).

(a) Outside. (b) Inside prior to blind installation. (c) Inside with blind and window open.

Figure 1.23: Bathroom windows.

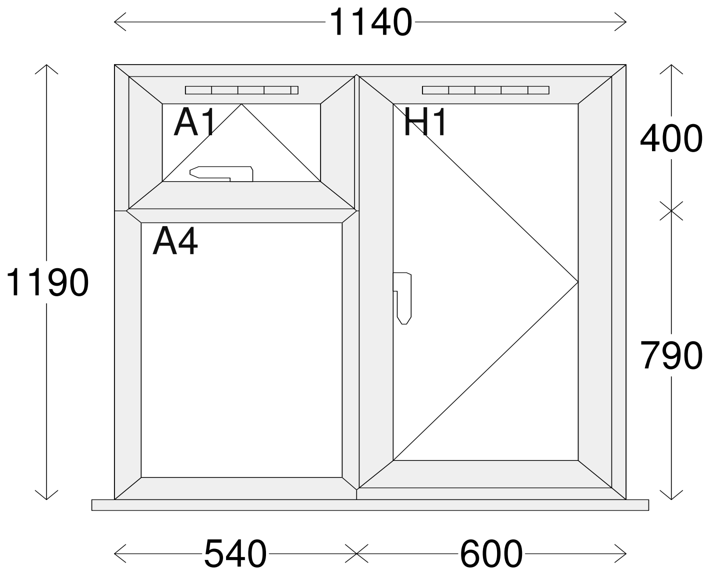


Figure 1.24: Bathroom window drawing and measurements in millimetres. Viewed from outside this represents the East house bathroom. Reverse for West house viewed from outside.

Table 1.21: Dimensions of glazed areas in bathrooms (refer to figure 1.24).

Glazed area	**Dimensions (mm)**
A1	387 x 247
A4	479 x 729
H1	447 x 1010

Table 1.22: Window opening areas in bathroom (refer to 1.24 for window key and 1.9 for reference points).

	Geometric free area			Side triangular area				Base open area		
Window	A-B (m)	A-C (m)	Area (m^2)	F-E (m)	E-D (m)	D-F (m)	Area (m^2)	E-G (m)	E-D (m)	Area (m^2)
A1	0.475	0.31	0.14725	0.36	0.21	0.33	0.0342	0.525	0.21	0.11025

1.3 Construction of each element

1.3.1 Material and thickness

Construction materials and thicknesses are provided in table 1.23. A void depth below the suspended timber floor was measured as 0.2 m^2. Borescope examination allowed an assumption of a bare earth floor beneath the subfloor void. Six air brick vents with an open area of 0.01 m^2 ventilated the subfloor.

The depth of the solid concrete kitchen floor could not be measured but was estimated by Beizaee (2016) as 0.1 m after University of the West of England (2009).

The lofts were insulated at rafter level (see table 1.23). The manufacturers listed thermal conductivity for the glass fibre mineral wool insulation is 0.044 W/mK.

Windows and glazed external doors on the east and west sides of the houses were insulated. Aluminium foil was first applied directly to the glazing. Then 50 mm thick polyisocyanurate insulation boards[2], with a low emissivity foil facing were taped across the entire frame opening. On the kitchen doors, insulation was affixed to the glazed portions only. Manufacturer's listed thermal conductivity is 0.022 W/mK. The area covered totalled 3.24 m^2 per house comprising 0.26 m^2 in the hall, 0.47 m^2 in the WC, 2 m^2 on the landing and 0.51 m^2 on the glazed portions of east/west facing kitchen external doors.

[2]Celotex GA4050.

Table 1.23: Material layers ordering and thickness. Partially adapted from Beizaee (2016).

Building element	Materials (outermost to innermost layer)	Thickness (outermost to innermost layer (m)
External cavity wall[1]	Brick, air gap, brick, plaster	0.105, 0.07, 0.105, 0.013
External bay wall	Clay tile, timber batten/air gap, vapour-permeable membrane[6], brick, plaster	0.001, 0.025, 0.00045, 0.105, 0.013
Internal partition walls	Plaster, brick, plaster	0.013, 0.105, 0.013
Party wall	Plaster, brick, air gap, brick, plaster	0.013, 0.105, 0.07, 0.105, 0.013
Suspended ground floor[2] (semi-exposed)	Timber floorboard, carpet tile	0.02, 0.005
Solid ground floor[3]	Solid cast concrete, linoleum	0.1, 0.0025
Internal floors (supporting first floor)	Plasterboard, air gap, timber floorboard, carpet tile	0.013, 0.1, 0.02, 0.005
First floor ceiling	Plasterboard, insulation[4] (between joist), insulation[3] (over joist[5])	0.013, 0.1 (between joist), 0.2 (over joist)
Pitched roof	Clay tile, air gap, vapour-permeable membrane[6] (on wooden rafters)	0.025, 0.02, 0.00045
Glazing	Glass, argon gas gap, glass	0.004, 0.02, 0.004
Window frames	uPVC[7], air gap, uPVC	0.003, 0.069 0.003
Glazing (blocked)	Glass, argon gas gap, glass, aluminium foil[8], air gap, polyisocyanurate insulation[9]	0.004, 0.02, 0.004, 0.000016, 0.01, 0.05
External door frames	uPVC[7], air gap, uPVC	0.003, 0.069 0.003
Internal doors	Wood	0.045

[1] Excluding bay window section between living room windows and front bedroom windows.
[2] Excludes kitchen floor.
[3] Kitchen floor only.
[4] 'Superglass' glass mineral wool insulation.
[5] Laid perpendicularly to ceiling joists.
[6] 'Tyvek Supro' (non-woven laminated composite of high density polyethylene and polypropylene.
[7] Unplasticised polyvinyl chloride.
[8] Foil applied to glazed windows, not glazed external doors.
[9] 'Celotex GA4050' insulation.

(a) External face of brick cavity walls.

(b) Internal view of loft space. Glass mineral wool insulation at joist level and vapour membrane at rafters. Party wall visible to rear of photograph.

(c) Evidence of tile hung area construction. Vapour membrane visible below wooden battens.

(d) Insulation blocking east and west facing windows. Sealed with aluminium tape.

Figure 1.25: Construction elements.

1.3.2 Glazing (windows and external doors)

Table 1.24: Manufacturer information on construction of glazed elements.

Outside pane	**Inside pane**	**Gas fill**	**Emissivity surface 2***	**Emissivity surface 3†**	**Pane spacer**
Float glass (4 mm)	Planitherm Total+ (4 mm)	Argon (20 mm)	0.89‡	0.05	Superspacer Premium

Glazing layer surfaces are labelled from outdoor to indoor.
* Surface 2 = inside facing surface of outside pane.
† Surface 3 = outside facing surface of inside pane.
‡ Uncoated

Table 1.25: Manufacturer information on performance of glazed elements.

Energy rating (kWh/m^2/year)	**Solar factor (gW)**	**G factor**	**Thermal transmittance (Ug)**	**Glazed fraction**
4	0.45	0.72	1.2	0.69

1.3.3 Curtains and blinds

Internal roller blinds are located in kitchens and bathrooms. The blind manufacturer was Colourtex in colour 'Ash'. All other rooms contain internal curtains. The curtain manufacturer was Edmund Bell, Venus Dim-Out in colour 'Storm 897'. There are no curtains in the hall, landing or WC due to windows being blocked with insulation. Fabric material and weight were provided by the manufacturers. Solar/optical properties were provided by the manufacturers for blind fabric. This was unavailable for curtain fabric so estimated values were used for close weave, medium colour fabric (ASHRAE 2013) (table 1.26).

Table 1.26: Roller blind and curtain fabric, solar and optical properties.

			Solar			Optical				
Type	Fabric material	Fabric weight (g/m^2)	T (%)	R (%)	A (%)	T (%)	R (%)	A (%)	SC	G_{tot}
Blind	Polyester	285	8	60	32	1	50	49	0.42	0.33
Curtain	Polyester	255	10	30	60	TBC	TBC	TBC	TBC	TBC

T = Transmittance; R = Reflectance; A = Absorptance; SC = Shading coefficient; G_{tot} = Solar transmittance corrected for double glazed, low emissivity windows.

Window covering dimensions are listed in table 1.27.

Table 1.27: Blind and curtain dimensions and distance from windows. Width measured with curtains closed at top rail. Height measured as the full drop of the fabric from the top rail. Window coverage when open is measured as the distance from the frame intersection with the wall to the edge of the blind curtain in the open position.

Room	**Width (m)**	**Height (m)**	**Fabric distance from wall (m)**	**Fabric distance from window pane (m)**	**Window coverage when open (m)**
Living	2.84	1.65	0.16	0.18	0.5*
Dining	2.12	2.46	0.08	0.28	0.34
Kitchen	1.04	1.1	N/A†	0.12	0.11‡
Single bedroom	1.32	1.36	0.11	0.65	0.25
Front double bedroom	3.08	1.4	0.03	0.09	0.4
Rear double bedroom	2	1.34	0.11	0.65	0.3
Bathroom	1.03	1.16	N/A†	0.14	0.11‡

* Large gap between curtain and wall.
† Recessed into window frame.
‡ Measured from down from top of frame.

In the living room bay window there was a large gap between the curtains and the wall (figure 1.26a), compared to the upstairs bay in the front bedroom (figure 1.26b). The living room curtain gap was identical in both houses, as was the absence of a gap in the front double bedrooms.

(a) Gap between living room curtain and wall as observed with curtains closed.

(b) Gap between front double bedroom curtain and wall as observed with curtains closed.

Figure 1.26: Comparing curtain distance from wall in the bay windows.

1.4 Infiltration and vents

The airtightness of the test houses is reported in table 1.28. See Roberts et al. (2017; 2018) for more information on testing regime.

Table 1.28: Airtightness report.

West house (209 Ashby Road)		**East house (207 Ashby Road)**	
q50 ($m^3/h/m^2$)	n50 (1/h)	q50 ($m^3/h/m^2$)	n50 (1/h)
14.7	15.3	14.9	15.6

Vents are fitted to chimney breasts, walls and trickle vents to windows. Six air bricks per house ventilate the ground floor sub-floor. No mechanical ventilation exists. All wall and chimney vents were internally sealed prior to testing using aluminium tape and therefore dimensions and locations are not provided. Sealed vent airtightness was verified using smoke sticks. All trickle vents were closed, but not sealed with tape. Trickle vent sizing and location is listed in Roberts et al. (2017). All sub-floor air bricks were left unblocked. The location of the sub-floor air bricks is provided in figure 1.27 and also included in the elevation drawings. Air brick dimensions and a photograph are given in figure 1.28.

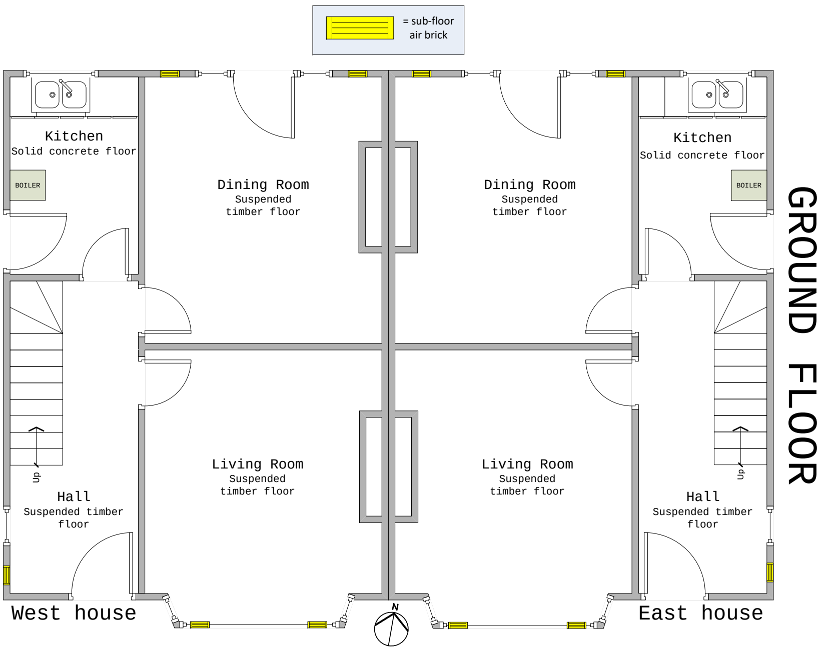
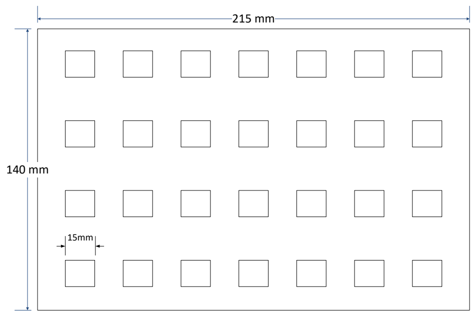


Figure 1.27: Floor plan with sub-floor air brick vent locations. Not to scale.

(a) Sub-floor air brick photograph.



(b) Dimensions of sub-floor air brick, hole placement not to scale.

Figure 1.28: Sub-floor air bricks.

1.5 Publications / Data in the public domain

The below information is available in the public domain regarding the Matched Pair test house (in order of most recent publication). Reference numbers 5-7 concern the houses before refurbishment works were carried out.

1. ROBERTS, B.M., ALLINSON, D., DIAMOND, S., ABEL, B., DAS BHAUMIK, C., KHATAMI, N. and LOMAS, K.J. (2019). Predictions of summertime overheating: Comparison of dynamic thermal models and measurements in synthetically occupied test houses. *Building Services Engineering Research and Technology.* 40 (4), 512-522. (Available at: https://doi.org/10.1177/0143624419847349).

2. ROBERTS, B.M., ALLINSON, D. and LOMAS, K.J., 2018. A matched pair of test houses with synthetic occupants to investigate summertime overheating. *Journal of Sustainable Design & Applied Research.* 6 (1), 29-38.
(Available at: https://dspace.lboro.ac.uk/2134/36275).

3. ROBERTS, B.M., ALLINSON, D. and LOMAS, K.J. (2018). Overheating in dwellings: a matched pair of test houses with synthetic occupants. Presented at the CIBSE Technical Symposium, London, UK, 12-13 April 2018.
(Available at: https://dspace.lboro.ac.uk/2134/32634).

4. ROBERTS, B.M., ALLINSON, D., LOMAS, K.J. and PORRITT, S.M. (2017). The effect of refurbishment and trickle vents on airtightness: the case of a 1930s semi-detached house. Presented at the 38th AIVC - 6th TightVent - 4th venticool Conference, Nottingham, UK, 13-14 September 2017, 369-380.
(Available at: https://dspace.lboro.ac.uk/2134/32625).

5. BEIZAEE, A. (2016). Measuring and modelling the energy demand reduction potential of using zonal space heating control in a UK home. PhD Thesis.
(Available at: https://dspace.lboro.ac.uk/2134/20326).

6. JACK, R. (2015). Building diagnostics: practical measurement of the fabric thermal performance of houses. PhD Thesis.
(Available at: https://dspace.lboro.ac.uk/2134/19274).

7. BEIZAEE, A., ALLINSON, D., LOMAS, K.J., FODA, E. and LOVEDAY, D.L. (2015). Measuring the potential of zonal space heating controls to reduce energy use in UK homes: the case of un-furbished 1930s dwellings. *Energy and Buildings.* 92, 29-44.
(Available at: https://dspace.lboro.ac.uk/2134/16776).

To the authors knowledge, no other data or publication regarding the test houses is known to be in the public domain.

Chapter 2

Descriptions of tests to be modelled

2.1 Test description

Measurement data from three testing periods were used to calibrate models for the Roberts et al. (2019) paper. Only measurement data for the second testing period (experiments Eco and Woo, see Roberts et al. 2019) are provided in this dataset[1] as these are the results that were presented in the paper. Measurement data for the first and third period may be considered for release upon request.

In test 1 identical occupant behaviour is enacted in each house to test whether the houses behave as a matched pair. Test 2 compares window opening to no window opening and test 3 compares daytime internal shading to no daytime internal shading. Tests are summarised in table 2.1 and described in detail in Roberts et al. (2019). Details on precise internal gains, window opening, internal shading and internal door use is listed in sections 2.2-2.5.

[1]Available at: https://doi.org/10.17028/rd.lboro.8094575.

2.1.1 Test 1: Matched Pair no window opening

Test 1 ran for 17 days from 21 May 2017 to 6 June 2017 (inclusive). In this testing period both houses were identically synthetically occupied with TM59 standard heat gains and occupancy patterns (section 2.2), but no window opening. Curtains, blinds and internal doors were operated as described in sections 2.4 and 2.5.

2.1.2 Test 2: Comparison of window opening

Test 2 (experiment Eco[2] and Woo[3]) ran for 21 days from 16 June 2017 to 6 July 2017 (inclusive). Both houses were identically synthetically occupied with TM59 standard heat gains and occupancy patterns (section 2.2). Curtains, blinds and internal doors were operated as described in sections 2.4 and 2.5.

The difference between the two houses was that in the West house (209) TM59 window opening rules were enacted meaning that if a room dry bulb temperature exceeded 22°C the windows in the room of temperature exceedance would open providing the room was occupied. If the temperature fell below 22°C or the room became unoccupied, the windows would close. In the East house (207) the windows never opened in any room.

2.1.3 Test 3: Comparison of internal shading

Test 3 ran for 21 days from 11 July 2017 to 31 July 2017 (inclusive). Both houses were identically synthetically occupied with TM59 standard heat gains and occupancy patterns (section 2.2). Windows and internal doors were operated as described in sections 2.3 and 2.5.

The difference between the two houses was that the East house (207) the curtains and blinds were always closed. In the West house (209), curtains and blinds were open in the day and closed when occupants were sleeping. West house (209) was operated as in test 2.

[2]Eco = **E**ast house, windows **C**losed, curtains/blinds **O**pen
[3]Woo = **W**est house, windows **O**pen, curtains/blinds **O**pen

Table 2.1: Overview of testing phases and conditions in each house. Differing element in the test is highlighted in **bold**.

		West house (209)			East house (207)		
Test Description	Test length (days)	Windows	Blinds/curtains	Internal doors	Windows	Blinds/curtains	Internal doors
1. Matched pair: no window opening	17	Always closed	Open 08:00-23:00 Closed 23:00-08:00	Closed 23:00-08:00*	As house 1	As house 1	As house 1
2. Comparison: window opening	21	Open if $\mathrm{T}_{in} \geqslant 22°\mathrm{C}^{\dagger}$	Open 08:00-23:00 Closed 23:00-08:00	Closed 23:00-08:00*	**Always closed**	As house 1	As house 1
3. Comparison: blind use	21	Open if $\mathrm{T}_{in} \geqslant 22°\mathrm{C}^{\dagger}$	Open 08:00-23:00 Closed 23:00-08:00	Closed 23:00-08:00*	As house 1	**Always closed**	As house 1

* Bedroom doors only, open at all other times. All other internal doors always open.
† Occupied rooms only.
‡ Regardless of indoor air temperature.

2.2 Internal gain profiles

Occupant heat gains for were simulated with light bulbs and heaters (see Roberts et al. 2018). The same scheduled internal gains were used in both houses and remained the same throughout all testing periods (table 2.2). In accordance with TM59, there were no differences between weekday and weekends and the houses were occupied 24 hours a day.

Lighting gains were calculated proportional to floor area with lighting loads of $2\,\mathrm{W/m^2}$ between 18:00-22:00 in living room and kitchen, and 22:00-23:00 in bedrooms as specified by CIBSE TM59. Equipment and occupant gains were sized according to CIBSE TM59's three bedroom apartment: two double bedrooms, one single bedroom and separate living room/kitchen were used.

The actual gains were not identical to TM59 specifications due to limitations in the output of heat emitters used. Actual internal gains and occupancy profiles are listed in table 2.2. It is suggested that the actual gains and times in table 2.2 are used in modelling, rather than TM59 specifications to allow comparison with measurement data.

For TM59 calculations using annual weather data and simulations, the precise TM59 gains should be used, as was the case in the Roberts et al. (2019) paper.

Please note that all times are listed in BST (GMT+1), whereas TM59 specifies GMT.

Table 2.2: Occupancy times and gains, per house.

Room	Time period (hh:mm)	Nominal gains for both houses: Source	Nominal gains for both houses: Power (W)	Mean measured gains (W): West house	Mean measured gains (W): East house
Living room	09:00-18:00	3 people 75% gain	168.75	208	211
		Equipment	60		
	18:00-22:00	3 people 75% gain	168.75	311	324
		Equipment	150		
		Lighting	26.6		
	22:00-00:00	Equipment	60	104	109
	00:00-09:00	Equipment	35	37	36
Kitchen	09:00-18:00	3 people 25% gain	56.25	134	138
		Equipment	50		
	18:00-20:00	3 people 25% gain	56.25	407	415
		Equipment	300		
		Lighting	12		
	20:00-22:00	3 people 25% gain	56.25	182	159
		Equipment	50		
		Lighting	12		
	22:00-09:00	Equipment	50	66	69
Front double bedroom	08:00-09:00	2 people 100% gain	150	184	191
		Equipment	80		
	09:00-22:00	1 person 100% gain	75	126	131
		Equipment	80		
	22:00-23:00	2 people 100% gain	150	213	219
		Equipment	80		
		Lighting	31		
	23:00-08:00	2 people 70% gain	105	118	118
		Equipment	10		
Rear double bedroom	08:00-09:00	2 people 100% gain	150	217	247
		Equipment	80		
	09:00-22:00	1 person 100% gain	75	143	159
		Equipment	80		
	22:00-23:00	2 people 100% gain	150	246	275
		Equipment	80		
		Lighting	31		
	23:00-08:00	2 people 70% gain	105	130	142
		Equipment	10		
Single bedroom	08:00-23:00	1 person 100% gain	75	141	109
		Equipment	80		
	23:00-08:00	1 person 70% gain	75	99	81

All times listed in BST (GMT+1).
[1] The total calculated occupant, equipment and lighting gain for the time period.
[2] The actual gain produced by the heat emitting devices.

2.3 Window opening

In the tests with window opening enabled, window opening was controlled following TM59 schedules whereby windows opened in occupied rooms when the room internal dry bulb temperature exceeded 22°C. The only rooms never occupied were the rear ground floor room (dining room) and the bathroom. Therefore bathroom and dining room windows never opened in any test. All other rooms had potential for window opening in response to a temperature trigger when occupied (table 2.2). In rooms where there were more than one window (living room and front double bedroom) all windows opened at the same time.

2.4 Curtain and blinds use

TM59 does not explicitly define timings for curtains/blinds to be open or closed. Therefore an assumption was made that as a baseline behaviour occupants would close the window coverings when sleeping and have them open at all other times. In the tests with curtains and blind opening enabled, curtains and blinds were closed 23:00-08:00 BST and opened at all other times, aligning with occupant sleeping schedules. In test 3, comparing the effect of internal shading, all curtains and blinds were always closed in the east house.

2.5 Internal door use

TM59 states that internal doors can be included and should be left open in the daytime and closed when the occupants are sleeping. In the test houses, internal doors in the front and rear double bedrooms and the single bedroom were closed whenever the occupants were sleeping (23:00-08:00 BST) and open at all other times, aligning with occupant sleeping schedules. All other internal doors were always open.

2.6 Weather data

For the modelling exercise reported in Roberts et al. (2019), outdoor temperature data recorded at the test house site were provided to modellers for every minute from 20 May to 31 July 2017 (inclusive). Additionally 10-minute wind data and minutely solar data were provided. In this publicly available dataset, only the weather for duration of the results reported in the paper (16 June to 6 July 2017) are provided. We may consider the provision of data from 1 May to 31 July 2017 upon request.

Weather data can be downloaded from the repository[4] from a single file containing all information: 'Weather_16Jun-6Jul_2017.xlsx'.

Annual weather files used in the TM59 calculations (DSY1 2020s, high emissions, 50% percentile at Nottingham) were provided by CIBSE and therefore cannot be made available in this dataset release.

[4]Available at: https://doi.org/10.17028/rd.lboro.8094575.

Chapter 3

Indoor temperature measurement data

Indoor dry bulb air and operative temperature data were collected at one minute intervals in the test houses, with hourly averages taken to match the hourly temperature predictions made by modellers.

The dataset provided[1] contains operative temperature data only, from 'Test 2' only (as used in experiments 'Eco' and 'Woo' in Roberts et al. (2019)). Data is provided in a single spreadsheet (MeasuredTemperature_16Jun-6Jul_2017.xlsx). This spreadsheet contains sheets of data corresponding to each of the five rooms examined in each house (totalling 10 rooms).

[1]Please note: The original 'guidance for modellers' document provided to the modellers carrying out the overheating modelling exercise in Roberts et al. (2019) did not contain details of indoor temperature measurement data, as this was delivered as part of the 'blind phase' of the exercise (i.e. without knowledge of the indoor temperature measurements).

Chapter 4

Presentation of results

Type 1 predictions[1]: Modellers should provide predictions of hourly air and operative temperature for the duration of the testing period.

Type 2 predictions: A CIBSE TM59 overheating assessment for each house using the annual DSY1 weather file and TM59 occupancy/internal gains. This should include Criterion A (Cat. I and II) for living rooms, kitchens and bedrooms), and Criterion B for bedrooms.

Details of how the following were modelled should also be provided:

1. ventilation, including chimneys and vents
2. internal heat gains
3. door and window opening and curtain operation
4. roof space and loft
5. ground floor
6. party wall
7. thermal mass
8. Any other features that have a notable impact on predictions

[1] See Roberts et al. (2019) for definition of Type 1 and Type 2 predictions.

Chapter 5

References

References below are ones that have been referred to in this document and not otherwise listed in section 1.5 'Publications...'.

ASHRAE. (2013). ASHRAE Handbook: Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers.

CIBSE (2017). TM59: Design methodology for the assessment of overheating risk in homes. The Chartered Institute of Building Services Engineers.

University of the West of England (2009). Evolution of Building Elements. The construction website. Available at: http://fet.uwe.ac.uk/conweb/house_ages/elements/index.htm. [Accessed on 20th June 2018].