Programme Area: Smart Systems and Heat

Project: WP1 Integrated Electrical Heat

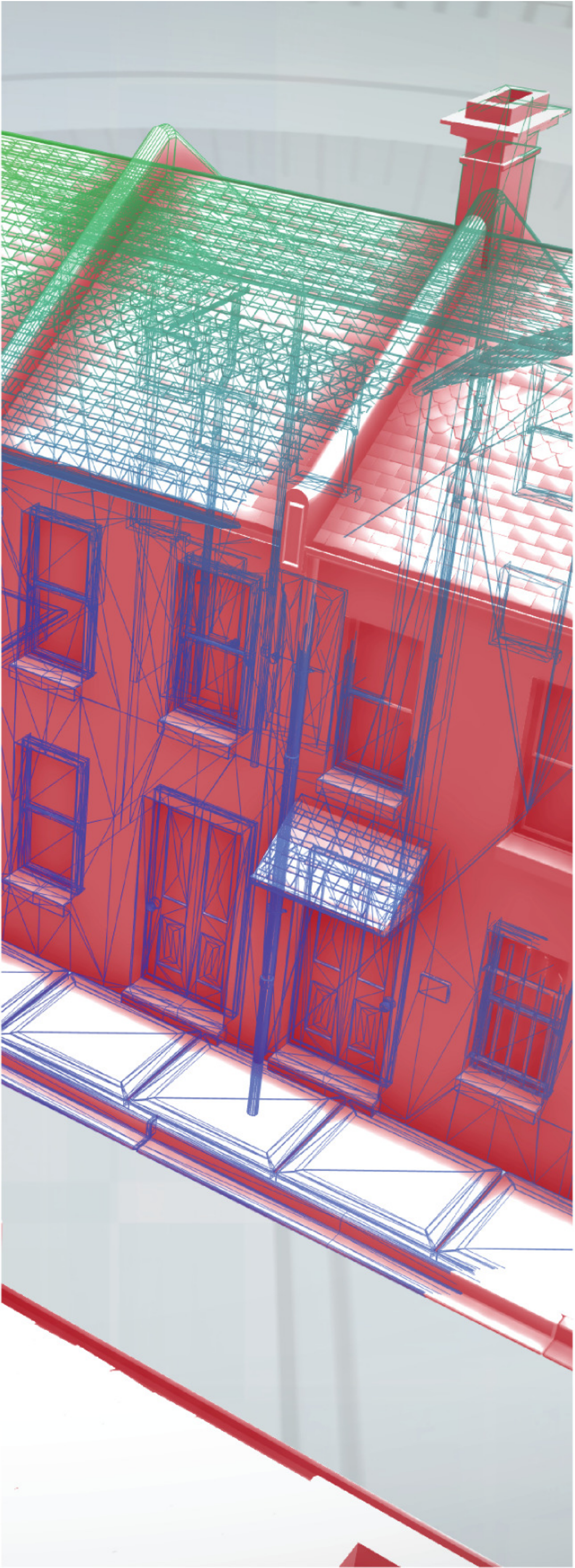
# Title: Building and Heating Systems Definition


## Abstract:

This deliverable provides a description of the Building and Heating System Definition which was used to support the analysis work done for BEIS for their input to IEA Annex 42.


## Context:

The Integrated Electric Heating Project provided a modelling tool to evaluate the opportunities and challenges for electric heating to meet UK household requirements. The tool will be used to create and evaluate upgrade pathways for a small number of housing archetypes informed by detailed information gathered from dwelling participating in the recent Home Energy Management System trial.



# Smart Systems and Heat Phase 1

## Integrated Electric Heat

## Buildings and Heating Systems Definition

**ESC Project Number ESC00045**

**ETI Project Number SS9003**

**Version V1.0**



Delivered by Catapult Energy Systems

## Energy Technologies Institute Smart Systems and Heat Programme

“Creating future-proof and economic local heating solutions for the UK”

- Connecting together – the understanding of consumer needs and behaviour with the development and integration of technologies and new business models into…
- Delivering enhanced knowledge amongst industry and public sector
- Resulting in industry and investor confidence to implement from 2020 which enables a UK heat transition

The Energy Systems Catapult will deliver Phase One of the SSH programme as a supplier to the ETI following the transition of the SSH programme team to the Catapult. From 2017 the Catapult will be responsible for delivery of Phase Two of the programme independently of the ETI.

## Disclaimer

# Building and Heating Systems Definition

## Supporting simulations for BEIS response to IEA Annex 42

**14/03/2017**

# Contents

# 1 Introduction

The document defines the buildings and heating systems to be investigated in the Integrated Electric Heating project.

Table 1 is taken from the User Requirement Specification (URS) document. It gives a high-level overview of the buildings to be investigated. This document will expand on this to give all of the required information to define the buildings within the tool-kit. See Appendix A for details of the selection process which resulted in the buildings listed in Table 1.

None of the homes defined have been extended since they were originally built. However, the construction of each reflects the likely upgrades that would have been applied to them. As an example, most homes which were built with unfilled cavities have subsequently had cavity wall insulation installed. This is reflected in the details of each building in the following sections.

| Building Type | Building Age | Proportion of Stock[1] | | Building Size (m$^2$)[2] | Number of bedrooms |
|---|---|---|---|---|---|
| **Mid-terrace** | Pre-1919 | 8.2 | | 85 | 2 |
| **Semi-detached** | 1919-1944 | 7.7 | | 90 | 3 |
| **Semi-detached** | 1945-1964 | 9.0 | | 70 | 2 |
| **Detached** | 1965-1980 | 5.3 | | 200 | 4 |
| **Detached** | Post 1990 | 4.4 | | 115 | 3 |
| **Flat** | Post 1990 | 4.0 | | 50 | 1 |

Table 1: Building types

# 2 Buildings

This section details the building layouts and the constructions to be investigated in the Integrated Electric Heating project. The layouts also indicate a building orientation which, although fixed in the initial investigation, can be varied later.

## 2.1 Material Properties

Table 2 and Table 3 show the properties of the building materials and windows referenced in this document.

[1] The proportion of the housing stock listed in this table relates only to the building type and building age, not the size and number of bedrooms.

[2] Building size is the useable floor area of the home (excludes stairways, cupboards, etc.).

| Material | Density (kg/m³) | Thermal Conductivity (W/m.K) | Specific Heat Capacity (J/kgK) | Reference |
|---|---|---|---|---|
| **Brick (exposed)** | 1700 | 0.77 | 900 | CIBSE Guide A3 |
| **Brick (unexposed)** | 1700 | 0.56 | 900 | CIBSE Guide A3 |
| **Air gap (10mm)** | 1.225 | 0.07 | 1 | DECC/BRE |
| **Air gap (25mm)** | 1.225 | 0.14 | 1 | DECC/BRE |
| **Air gap (60mm)** | 1.225 | 0.33 | 1 | DECC/BRE |
| **Plaster** | 900 | 0.57 | 850 | CIBSE Guide A3 |
| **Mineral wool insulation** | 20 | 0.036 | 1210 | CIBSE Guide A3 |
| **Wooden floorboards** | 500 | 0.12 | 2500 | CIBSE Guide A3 |
| **Carpet** | 200 | 0.084 | 1200 | CIBSE Guide A3 |
| **Lightweight concrete block** | 1400 | 0.46 | 1000 | Cemex ReadyBlock |
| **Wall insulation board** | 35 | 0.02 | 1400 | Kingspan Kooltherm K8 cavity board |
| **Concrete Slab** | 2300 | 0.8 | 750 | CIBSE Guide A3 |
| **Concrete slab insulation** | 35 | 0.02 | 1400 | Kingspan Kooltherm K3 Floorboard |
| **Blown wall insulation** | 200 | 0.034 | 670 | Knauf Supafil cavity wall insulation |

Table 2: Material properties used in this document

| Window Type | Installed | U-value (W/m²K) | g-value |
|---|---|---|---|
| Single glazing | Any | 4.8 | 0.85 |
| Double glazing (before 2002) | England & Wales: before 2002<br>Scotland: before 2003<br>N. Ireland: before 2006 | 2.8 | 0.76 |
| Double glazing (2002 or later) | England & Wales: 2002 or later<br>Scotland: 2003 or later<br>N. Ireland: 2006 or later | 2.0 | 0.72 |
| Secondary glazing | Any | 2.4 | 0.76 |
| Triple glazing | Any | 1.8 | 0.68 |

Table 3: U-Values and g-values of different window types used in this document. Source: SAP[3]

## 2.2 Pre-1919 Mid-Terrace

Pre-1919 mid terrace properties are very prevalent in the UK housing stock. The majority are built with solid brick external walls which have not, subsequently, had any wall insulation applied. Although the majority were originally built with wooden sash windows with single glazing and no loft insulation, most have been upgraded to some degree. This will be reflected in the definition of the building to be used during modelling.

[3] 'Table S14: Window Characteristics', The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2012 edition, Version 9.92.

A wide range of building sizes can be defined as 'pre-1919 mid terrace', it has therefore been necessary to select an example and base the investigation around this. In this case, the example chosen is a 2-bedroom building with a useable floor area of 85m². Justification for this can be found in Appendix A.

### 2.2.1 Building Details

Figure 1 shows the layout of the pre-1919 mid terrace to be investigated. Room dimensions are shown and can also be seen in Table 4. Windows are numbered one to six and are detailed in Table 5. Table 6 shows the constructions of the different wall types highlighted in Figure 1 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

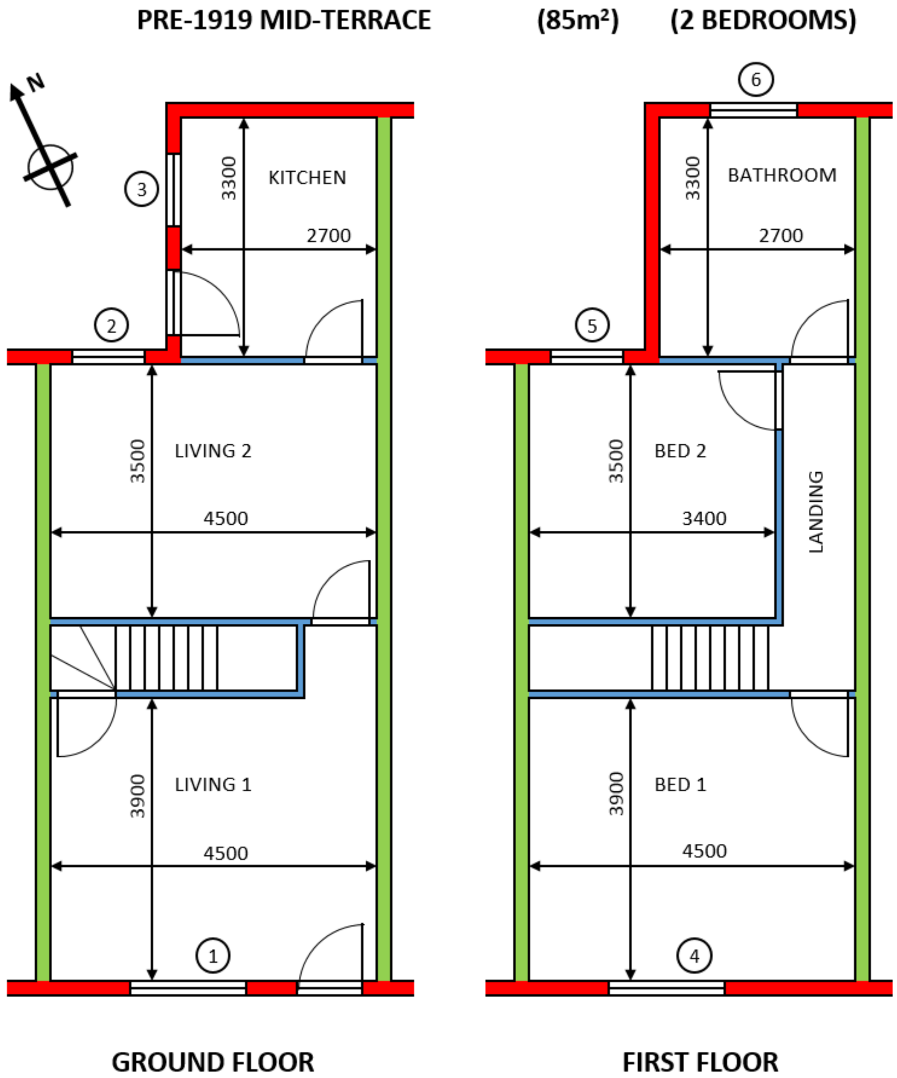



Figure 1: Pre-1919 mid terrace – building layout. Window references are numbers in circles; red walls are exernal, blue walls are internal and green walls are party.

| Room | Width (m) | Length (m) | Area (m$^2$) | Height (m) |
|---|---|---|---|---|
| **Living 1** | 3.9 | 4.5 | 17.6 | 2.6 |
| **Living 2** | 3.5 | 4.5 | 15.8 | 2.6 |
| **Kitchen** | 3.3 | 2.7 | 8.9 | 2.6 |
| **Bed 1** | 3.9 | 4.5 | 17.6 | 2.6 |
| **Bed 2** | 3.5 | 3.4 | 11.9 | 2.6 |
| **Landing** | 4.5 | 1.0 | 4.5 | 2.6 |
| **Bathroom** | 3.3 | 2.7 | 8.9 | 2.6 |
| | | **Total** | **85** | |

Table 4: Pre-1919 mid terrace – room dimensions

| Window | Area (m$^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 1.95 | 1.5 | Double glazing (before 2002) |
| **2** | 1.44 | 1.6 | Double glazing (before 2002) |
| **3** | 1.21 | 1.1 | Double glazing (before 2002) |
| **4** | 1.82 | 1.4 | Double glazing (before 2002) |
| **5** | 1.44 | 1.6 | Double glazing (before 2002) |
| **6** | 1.26 | 1.4 | Double glazing (before 2002) |

Table 5: Pre-1919 mid terrace - window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| External wall | 1 | 102.5 | Brick (exposed) |
| | 2 | 10 | Air Gap (10mm)[4] |
| | 3 | 102.5 | Brick (unexposed) |
| | 4 | 13 | Plaster |
| Internal wall | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 13 | Plaster |
| Party wall | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 10 | Air Gap (10mm) |
| | 4 | 102.5 | Brick (unexposed) |
| | 5 | 13 | Plaster |
| External ceiling | 1 | 15 | Plaster |
| | 2 | 150 | Mineral Wool Insulation |
| | 3 | 1000 | Air Gap |
| | 4 | 3 | Slate roof |
| Internal floor/ceiling | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 200 | Air Gap |
| | 4 | 15 | Plaster |
| Ground floor | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 600 | Air Gap |
| | 4 | N/A | Ground |

Table 6: Pre-1919 mid terrace - wall constructions

## 2.3 1919-1944 Semi-Detached

The second building type selected for investigation in this project is defined as '1919-1944 semi-detached'. Within the UK housing stock, there are a variety of construction types associated with this building type; Solid brick, unfilled cavity and filled cavity are the most widespread. For the purpose of this investigation, a building with unfilled cavity walls will be defined.

A wide range of building sizes can be defined as '1919-1944 semi-detached', it has therefore been necessary to select an example and base the investigation around this. In this case, the example chosen is a 3-bedroom building with a useable floor area of 90m$^2$. Again, see Appendix A for justification.

[4] This gap has been introduced to solid walls to reflect the findings of a report by BRE for DECC, "In-Situ Measurements of Wall U-Values in English Housing"

### 2.3.1 Building Details

Figure 2 shows the layout of the 1919-1944 semi-detached building to be investigated. Room dimensions are shown and can also be seen in Table 7. Windows are numbered one to ten and are detailed in Table 8. Table 9 shows the constructions of the different wall types highlighted in Figure 2 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

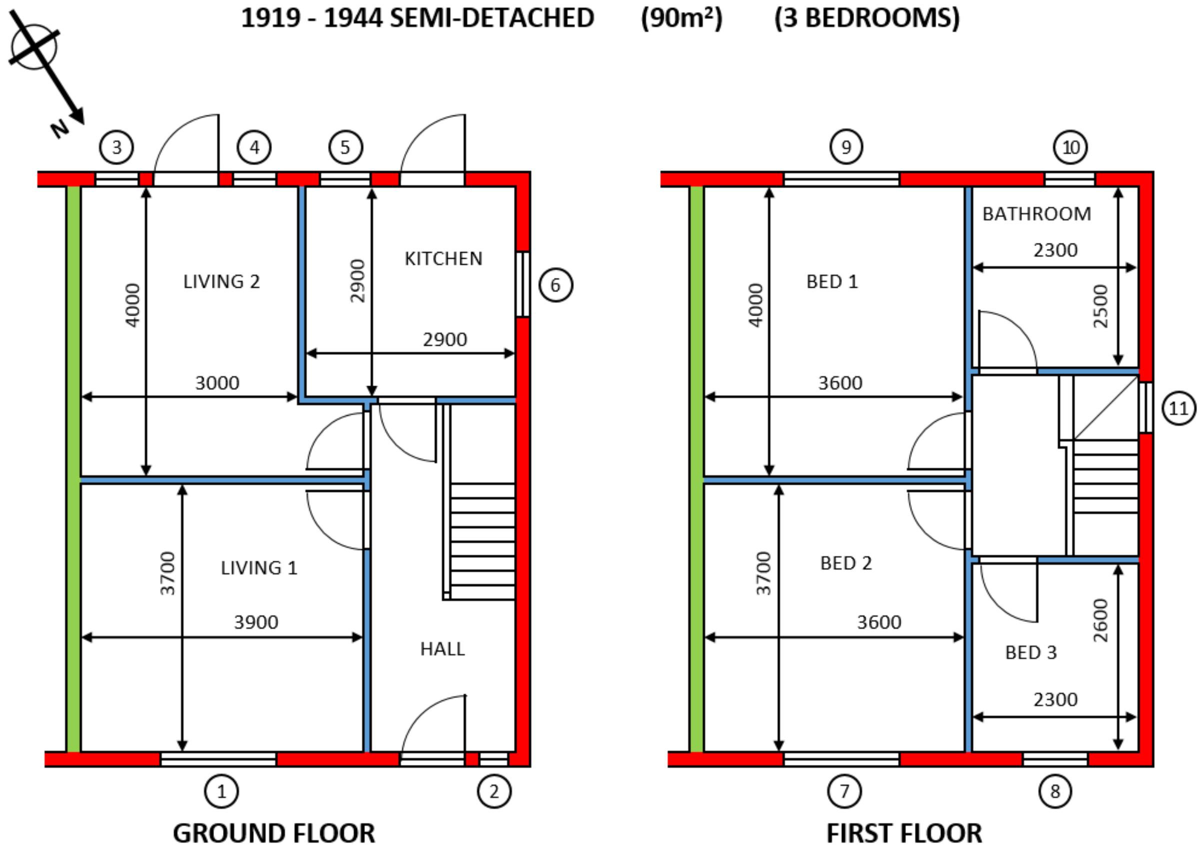



Figure 2: 1919-1944 semi-detached – building layout. Window references are numbers in circles; red walls are external, blue walls are internal and green walls are party.

| Room | Width (m) | Length (m) | Area (m²) | Height (m) |
|---|---|---|---|---|
| **Living 1** | 3.7 | 3.9 | 14.4 | 2.5 |
| **Living 2** | 4.0 | 3.0 | 12.0 | 2.5 |
| **Kitchen** | 2.9 | 2.9 | 8.4 | 2.5 |
| **Hall** | 4.8 | 2.0 | 9.6 | 2.5 |
| **Bed 1** | 4.0 | 3.6 | 14.4 | 2.5 |
| **Bed 2** | 3.7 | 3.6 | 13.3 | 2.5 |
| **Bed 3** | 2.6 | 2.3 | 6.0 | 2.5 |
| **Landing** | 2.6 | 2.3 | 6.0 | 2.5 |
| **Bathroom** | 2.5 | 2.3 | 5.8 | 2.5 |
| | | **Total** | **90** | |

Table 7: 1919-1944 semi-detached – room dimensions

| Window | Area ($m^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 2.60 | 1.3 | Double glazing (before 2002) |
| **2** | 0.48 | 1.2 | Double glazing (before 2002) |
| **3** | 0.91 | 1.3 | Double glazing (before 2002) |
| **4** | 0.91 | 1.3 | Double glazing (before 2002) |
| **5** | 0.96 | 1.2 | Double glazing (before 2002) |
| **6** | 1.32 | 1.2 | Double glazing (before 2002) |
| **7** | 2.21 | 1.3 | Double glazing (before 2002) |
| **8** | 1.56 | 1.3 | Double glazing (before 2002) |
| **9** | 2.21 | 1.3 | Double glazing (before 2002) |
| **10** | 0.96 | 1.2 | Double glazing (before 2002) |
| **11** | 0.60 | 1.2 | Double glazing (before 2002) |

Table 8: 1919-1944 semi-detached – window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| External wall | 1 | 102.5 | Brick (exposed) |
| | 2 | 60 | Air Gap (60mm) |
| | 3 | 102.5 | Brick (unexposed) |
| | 4 | 13 | Plaster |
| Internal wall | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 13 | Plaster |
| Party wall | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 10 | Air Gap (10mm) |
| | 4 | 102.5 | Brick (unexposed) |
| | 5 | 13 | Plaster |
| External ceiling | 1 | 15 | Plaster |
| | 2 | 150 | Mineral Wool Insulation |
| | 3 | 1000 | Air Gap |
| | 4 | 5 | Tile roof |
| Internal floor/ceiling | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 200 | Air Gap |
| | 4 | 15 | Plaster |
| Ground floor | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 600 | Air Gap |
| | 4 | N/A | Ground |

Table 9: 1919-1945 semi-detached – wall constructions

## 2.4 1945-1964 Semi-Detached

The third building type selected for investigation in this project is defined as '1945-1964 semi-detached'. Within the UK housing stock, there are two main construction types associated with this building type; unfilled cavity and filled cavity. For the purpose of this investigation, a building with filled cavity walls will be defined. This reflects the fact that a majority of these properties (although not built with filled cavities) have had cavity wall insulation retrospectively injected. In terms of building size, the example chosen is a 2-bedroom building with a useable floor area of 70m$^2$. See Appendix A for justification.

### 2.4.1 Building Details

Figure 3 shows the layout of the 1945-1964 semi-detached building to be investigated. Room dimensions are shown and can also be seen in Table 10. Windows are numbered one to nine and are detailed in Table 11. Table 12 shows the constructions of the different wall types highlighted in Figure 3 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

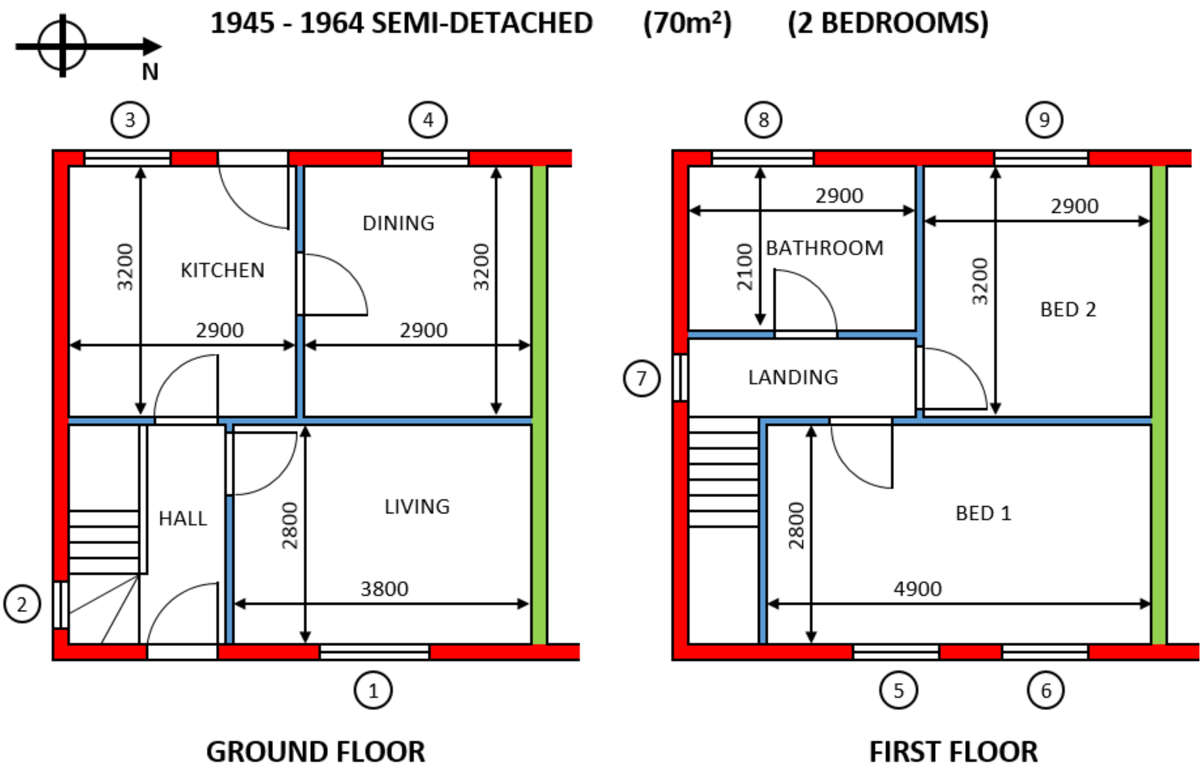



Figure 3: 1945-1964 semi-detached – building layout. Window references are numbers in circles; red walls are external, blue walls are internal and green walls are party.

| Room | Width (m) | Length (m) | Area ($m^2$) | Height (m) |
|---|---|---|---|---|
| **Living 1** | 2.8 | 3.8 | 10.6 | 2.5 |
| **Living 2** | 3.2 | 2.9 | 9.3 | 2.5 |
| **Kitchen** | 3.2 | 2.9 | 9.3 | 2.5 |
| **Hall** | 2.8 | 2.0 | 5.6 | 2.5 |
| **Bed 1** | 2.8 | 4.9 | 13.7 | 2.3 |
| **Bed 2** | 3.2 | 2.9 | 9.3 | 2.3 |
| **Landing** | 1.0 | 2.9 | 2.9 | 2.3 |
| | 0.9 | 2.9 | 2.6 | 2.3 |
| **Bathroom** | 2.1 | 2.9 | 6.1 | 2.3 |
| | | **Total** | **70** | |

Table 10: 1945-1964 semi-detached – room dimensions

| Window | Area ($m^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 2.16 | 1.2 | Double glazing (before 2002) |
| **2** | 0.55 | 1.1 | Double glazing (before 2002) |
| **3** | 1.21 | 1.1 | Double glazing (before 2002) |
| **4** | 2.16 | 1.2 | Double glazing (before 2002) |
| **5** | 0.70 | 1.0 | Double glazing (before 2002) |
| **6** | 0.70 | 1.0 | Double glazing (before 2002) |
| **7** | 0.50 | 1.0 | Double glazing (before 2002) |
| **8** | 1.10 | 1.0 | Double glazing (before 2002) |
| **9** | 1.80 | 1.0 | Double glazing (before 2002) |

Table 11: 1945-1964 semi-detached - window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| **External wall** | 1 | 102.5 | Brick (exposed) |
| | 2 | 60 | Blown cavity wall insulation |
| | 3 | 102.5 | Brick (unexposed) |
| | 4 | 13 | Plaster |
| **Internal wall** | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 13 | Plaster |
| **Party wall** | 1 | 13 | Plaster |
| | 2 | 102.5 | Brick (unexposed) |
| | 3 | 10 | Air Gap (10mm) |
| | 4 | 102.5 | Brick (unexposed) |
| | 5 | 13 | Plaster |
| **External ceiling** | 1 | 15 | Plaster |
| | 2 | 150 | Mineral Wool Insulation |
| | 3 | 1000 | Air Gap |
| | 4 | 5 | Tile roof |
| **Internal floor/ceiling** | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 200 | Air Gap |
| | 4 | 15 | Plaster |
| **Ground floor** | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 600 | Air Gap |
| | 4 | N/A | Ground |

Table 12: 1945-1964 semi-detached - wall constructions

## 2.5 1965-1980 Detached

The fourth building type selected for investigation in this project is defined as '1965-1980 detached'. Within the UK housing stock, there are two main construction types associated with this building type; unfilled cavity and filled cavity. For the purpose of this investigation, a building with filled cavity walls will be defined. This reflects the fact that a majority of these properties (although not build with filled cavities) have had cavity wall insulation retrospectively injected. In terms of building size, the example chosen is a large 4-bedroom building with a useable floor area of 200m$^2$. See Appendix A for justification.

### 2.5.1 Building Details

Figure 4 shows the layout of the 1965-1980 detached building to be investigated. Room dimensions are shown and can also be seen in Table 13. Windows are numbered one to 17 and are detailed in Table 14. Table 15 shows the constructions of the different wall types highlighted in Figure 4 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

**1965 - 1980 DETACHED (200m²) (4 BEDROOMS)**

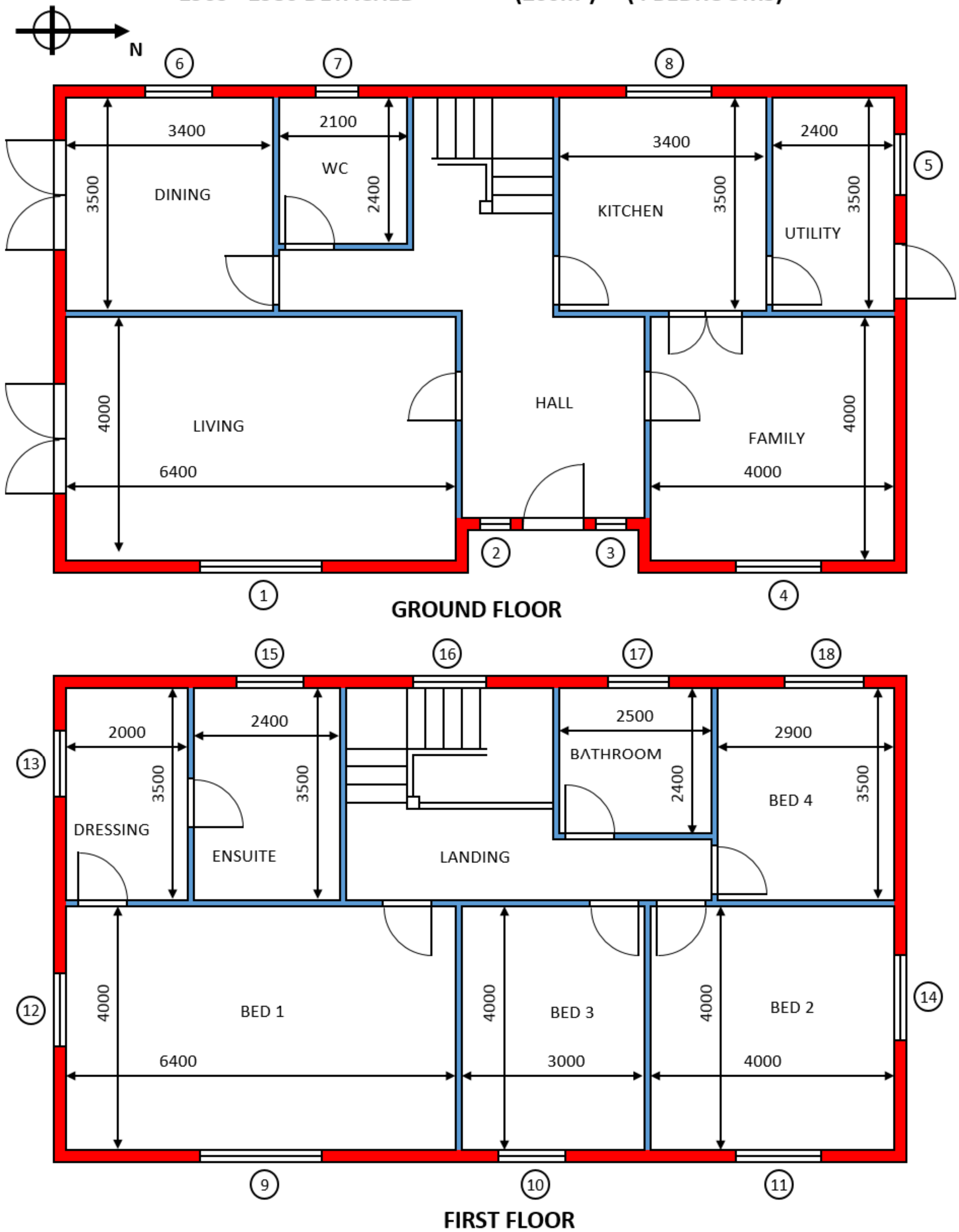



Figure 4: 1965-1980 detached – building layout. Window references are numbers in circles; red walls are external and blue walls are internal.

| Room | Width (m) | Length (m) | Area ($m^2$) | Height (m) |
|---|---|---|---|---|
| **Living 1** | 4.0 | 6.4 | 25.6 | 2.5 |
| **Living 2** | 4.0 | 4.0 | 16.0 | 2.5 |
| **Kitchen** | 3.5 | 3.4 | 11.9 | 2.5 |
| **Utility** | 3.5 | 2.4 | 8.4 | 2.5 |
| **WC** | 2.4 | 2.1 | 5.0 | 2.5 |
| **Dining** | 3.5 | 3.4 | 11.9 | 2.5 |
| **Hall** | 3.3 | 3.0 | 9.9 | 2.5 |
| | 3.5 | 2.3 | 8.1 | |
| | 1.0 | 2.2 | 2.2 | |
| **Bed 1** | 4.0 | 6.4 | 25.6 | 2.5 |
| **Bed 2** | 4.0 | 4.0 | 16.0 | 2.5 |
| **Bed 3** | 4.0 | 3.0 | 12.0 | 2.5 |
| **Bed 4** | 3.5 | 2.9 | 10.2 | 2.5 |
| **Bathroom** | 2.4 | 2.5 | 6.0 | 2.5 |
| **Ensuite** | 3.5 | 2.4 | 8.4 | 2.5 |
| **Dressing** | 3.5 | 2.0 | 7.0 | 2.5 |
| **Landing** | 3.5 | 3.4 | 11.9 | 2.5 |
| | 1.0 | 2.4 | 2.4 | 2.5 |
| | | **Total** | **200** | |

Table 13: 1965-1980 Detached – Room Dimensions

| Window | Area ($m^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 3.90 | 1.3 | Double glazing (before 2002) |
| **2** | 0.60 | 1.2 | Double glazing (before 2002) |
| **3** | 0.60 | 1.2 | Double glazing (before 2002) |
| **4** | 3.25 | 1.3 | Double glazing (before 2002) |
| **5** | 1.65 | 1.1 | Double glazing (before 2002) |
| **6** | 3.51 | 1.3 | Double glazing (before 2002) |
| **7** | 0.88 | 1.1 | Double glazing (before 2002) |
| **8** | 2.97 | 1.1 | Double glazing (before 2002) |
| **9** | 3.25 | 1.3 | Double glazing (before 2002) |
| **10** | 2.73 | 1.3 | Double glazing (before 2002) |
| **11** | 3.25 | 1.3 | Double glazing (before 2002) |
| **12** | 2.34 | 1.3 | Double glazing (before 2002) |
| **13** | 2.34 | 1.3 | Double glazing (before 2002) |
| **14** | 2.34 | 1.3 | Double glazing (before 2002) |
| **15** | 1.65 | 1.1 | Double glazing (before 2002) |
| **16** | 3.00 | 1.5 | Double glazing (before 2002) |
| **17** | 1.65 | 1.1 | Double glazing (before 2002) |
| **18** | 1.95 | 1.3 | Double glazing (before 2002) |

Table 14: 1965-1980 detached - window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| **External wall** | 1 | 102.5 | Brick (exposed) |
| | 2 | 100 | Blown cavity wall insulation |
| | 3 | 100 | Lightweight concrete block |
| | 4 | 13 | Plaster |
| **Internal wall** | 1 | 13 | Plaster |
| | 2 | 100 | Lightweight concrete block |
| | 3 | 13 | Plaster |
| **External ceiling** | 1 | 15 | Plaster |
| | 2 | 150 | Mineral Wool Insulation |
| | 3 | 1000 | Air Gap |
| | 4 | 5 | Tile roof |
| **Internal floor/ceiling** | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 200 | Air Gap |
| | 4 | 15 | Plaster |
| **Ground floor** | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 600 | Air Gap |
| | 4 | N/A | Ground |

Table 15: 1965-1980 detached - wall constructions

## 2.6 Post 1990 Detached

The fifth building type selected for investigation in this project is defined as 'Post 1990 detached'. This building type is typically constructed using filled cavity walls. In terms of building size, the example chosen is a large 3-bedroom home with a useable floor area of 115m$^2$. See Appendix A for justification.

### 2.6.1 Building Details

Figure 5 shows the layout of the Post 1990 detached home to be investigated. Room dimensions are shown and can also be seen in Table 16. Windows are numbered one to 13 and are detailed in Table 17. Table 18 shows the constructions of the different wall types highlighted in Figure 5 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

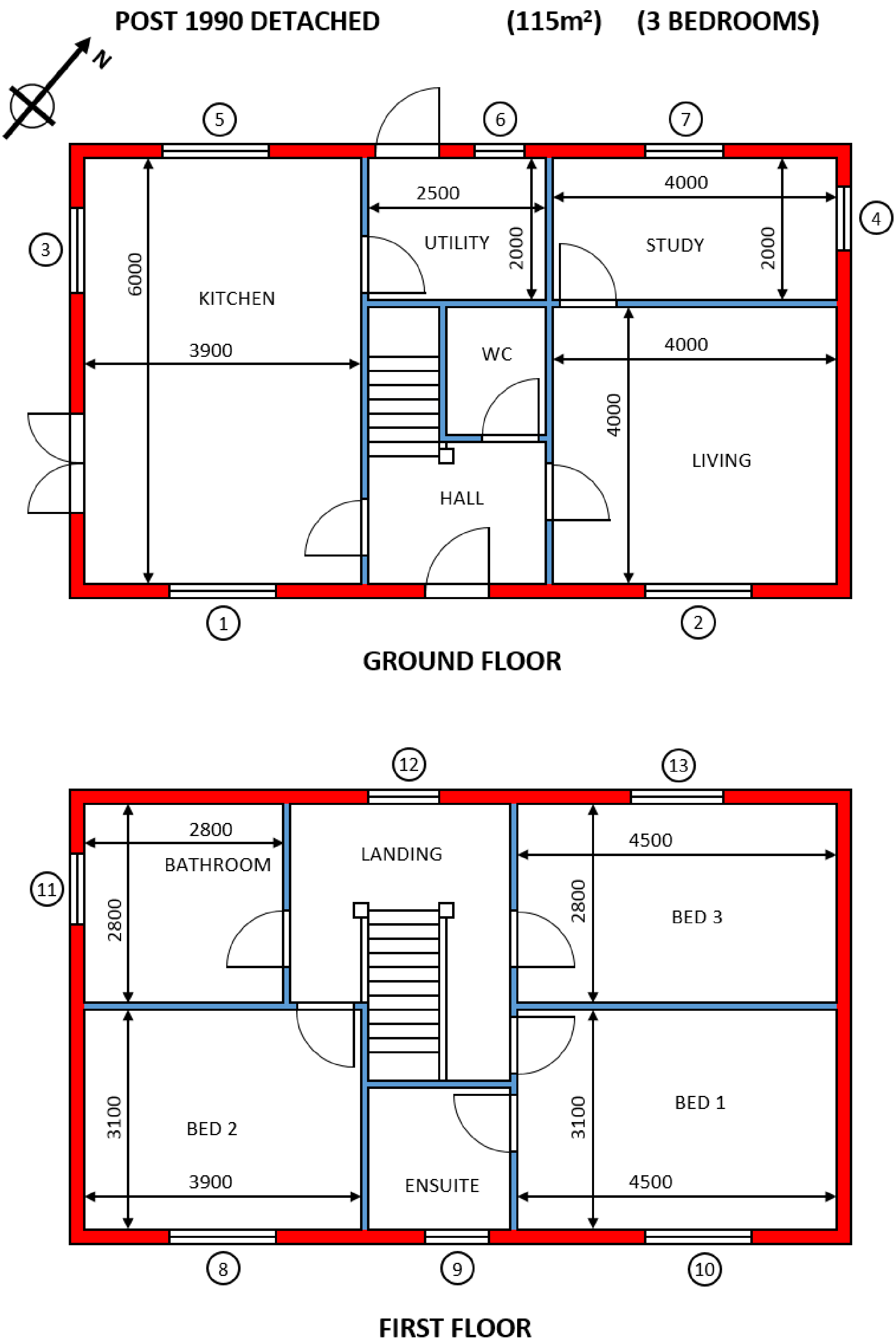



Figure 5: Post 1990 detached – building layout. Window references are numbers in circles; red walls are external and blue walls are internal.

| Room | Width (m) | Length (m) | Area ($m^2$) | Height (m) |
|---|---|---|---|---|
| **Living** | 4.0 | 4.0 | 16.0 | 2.4 |
| **Kitchen** | 6.0 | 3.9 | 23.4 | 2.4 |
| **Utility** | 2.0 | 2.5 | 5.0 | 2.4 |
| **WC** | 1.8 | 1.5 | 2.7 | 2.4 |
| **Study** | 2.0 | 4.0 | 8.0 | 2.4 |
| **Hall** | 2.0 | 2.5 | 5.0 | 2.4 |
| **Bed 1** | 3.1 | 4.5 | 14.0 | 2.4 |
| **Bed 2** | 3.1 | 3.9 | 12.1 | 2.4 |
| **Bed 3** | 2.8 | 4.5 | 12.6 | 2.4 |
| **Bathroom** | 2.8 | 2.8 | 7.8 | 2.4 |
| **Ensuite** | 2.0 | 2.0 | 4.0 | 2.4 |
| **Landing** | 2.0 | 2.5 | 5.0 | 2.4 |
| | | **Total** | **115** | |

Table 16: Post 1990 detached – room dimensions

| Window | Area ($m^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 1.54 | 1.4 | **Double Glazing (2002 or later)** |
| **2** | 1.54 | 1.4 | **Double Glazing (2002 or later)** |
| **3** | 1.21 | 1.1 | **Double Glazing (2002 or later)** |
| **4** | 1.54 | 1.4 | **Double Glazing (2002 or later)** |
| **5** | 1.21 | 1.1 | **Double Glazing (2002 or later)** |
| **6** | 0.88 | 1.1 | **Double Glazing (2002 or later)** |
| **7** | 1.54 | 1.4 | **Double Glazing (2002 or later)** |
| **8** | 1.43 | 1.3 | **Double Glazing (2002 or later)** |
| **9** | 0.75 | 1.0 | **Double Glazing (2002 or later)** |
| **10** | 1.43 | 1.3 | **Double Glazing (2002 or later)** |
| **11** | 1.43 | 1.3 | **Double Glazing (2002 or later)** |
| **12** | 1.43 | 1.3 | **Double Glazing (2002 or later)** |
| **13** | 1.43 | 1.3 | **Double Glazing (2002 or later)** |

Table 17: Post 1990 detached - window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| **External wall** | 1 | 102.5 | Brick (exposed) |
| | 2 | 25 | Air Gap (25mm) |
| | 3 | 75 | Cavity wall insulation board |
| | 4 | 100 | Lightweight concrete block |
| | 5 | 13 | Plaster |
| **Internal wall** | 1 | 13 | Plaster |
| | 2 | 100 | Lightweight concrete block |
| | 3 | 13 | Plaster |
| **External ceiling** | 1 | 15 | Plaster |
| | 2 | 270 | Mineral Wool Insulation |
| | 3 | 1000 | Air |
| | 4 | 5 | Tile roof |
| **Internal floor/ceiling** | 1 | 5 | Carpet |
| | 2 | 20 | Wooden Floorboards |
| | 3 | 200 | Air |
| | 4 | 15 | Plaster |
| **Ground floor** | 1 | 5 | Carpet |
| | 2 | 100 | Concrete slab |
| | 3 | 125 | Concrete floor insulation |
| | 4 | N/A | Ground |

Table 18: Post 1990 detached - wall constructions

## 2.7 Post 1990 Flat

The final building type selected for investigation in this project is defined as a ‘post 1990 flat’ with 1 bedroom and a floor area of 50m$^2$.

### 2.7.1 Building Details

Figure 6 shows the layout of the post 1990 flat to be investigated. Room dimensions are shown and can also be seen in Table 19. The two windows are numbered and are detailed in Table 20.

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| **External wall** | 1 | 102.5 | Brick |
| | 2 | 25 | Air Gap |
| | 3 | 75 | Cavity wall insulation board |
| | 4 | 100 | Lightweight concrete block |
| | 5 | 13 | Plaster |
| **Internal wall** | 1 | 13 | Plaster |
| | 2 | 100 | Lightweight concrete block |
| | 3 | 13 | Plaster |
| **Party wall** | 1 | 13 | Plaster |
| | 2 | 200 | Lightweight concrete block |
| | 5 | 13 | Plaster |
| **Ceiling** | 1 | 15 | Plaster |
| | 2 | 200 | Concrete slab |
| | 3 | 5 | Carpet |
| **Floor** | 1 | 5 | Carpet |
| | 2 | 200 | Concrete slab |
| | 4 | 15 | Plaster |

Table **21** shows the constructions of the different wall types highlighted in Figure 6 and the ceilings, floors and roof. The material properties associated with these constructions can be found in Table 2.

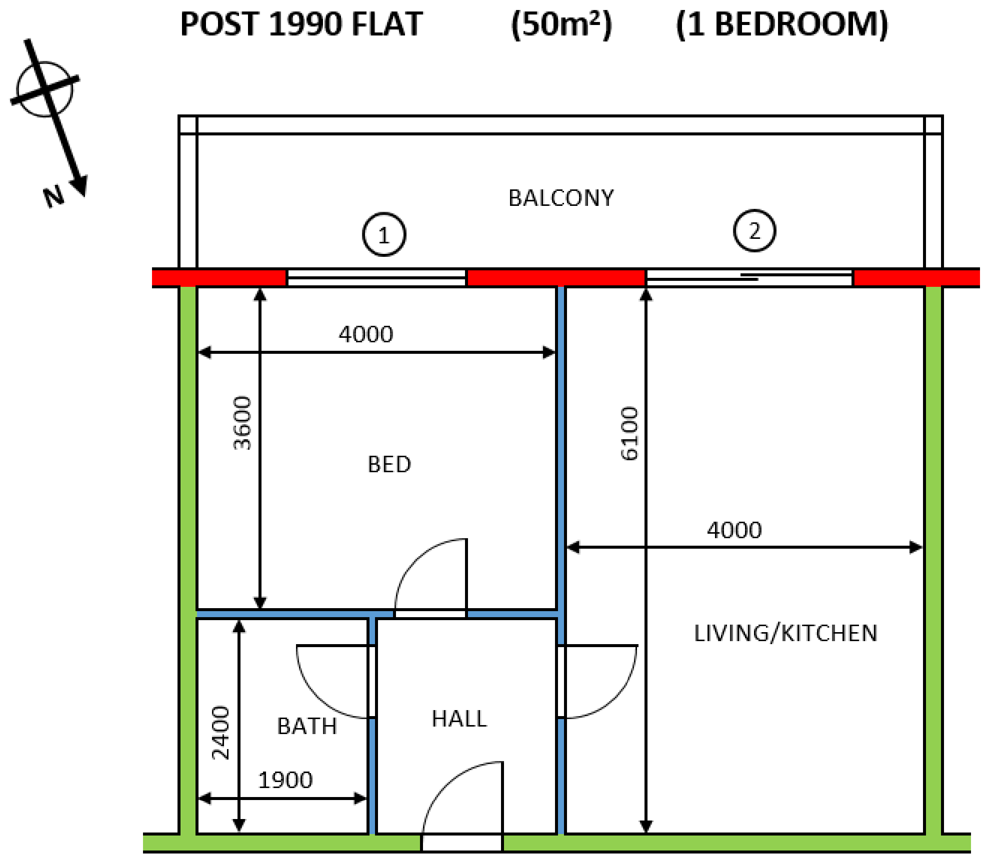



Figure 6: Post 1990 Flat – building layout. Window references are numbers in circles; red walls are external, blue walls are internal and green walls are party.

| Room | Width (m) | Length (m) | Area ($m^2$) | Height (m) |
|---|---|---|---|---|
| **Living/kitchen** | 6.1 | 4.0 | 24.4 | 2.4 |
| **Hall** | 2.5 | 2.0 | 5.0 | 2.4 |
| **Bed** | 3.6 | 4.0 | 14.4 | 2.4 |
| **Bathroom** | 2.5 | 2.5 | 6.3 | 2.4 |
| | | **Total** | **50** | |

Table 19: Post 1990 flat – room dimensions

| Window | Area ($m^2$) | Height (m) | Type |
|---|---|---|---|
| **1** | 3.0 | 1.5 | **Double Glazing (2002 or later)** |
| **2** | 4.4 | 2.2 | **Double Glazing (2002 or later)** |

Table 20: Post 1990 flat - window details

| Wall Type | Layer | Thickness (mm) | Material |
|---|---|---|---|
| **External wall** | 1 | 102.5 | Brick |
| | 2 | 25 | Air Gap |
| | 3 | 75 | Cavity wall insulation board |
| | 4 | 100 | Lightweight concrete block |
| | 5 | 13 | Plaster |
| **Internal wall** | 1 | 13 | Plaster |
| | 2 | 100 | Lightweight concrete block |
| | 3 | 13 | Plaster |
| **Party wall** | 1 | 13 | Plaster |
| | 2 | 200 | Lightweight concrete block |
| | 5 | 13 | Plaster |
| **Ceiling** | 1 | 15 | Plaster |
| | 2 | 200 | Concrete slab |
| | 3 | 5 | Carpet |
| **Floor** | 1 | 5 | Carpet |
| | 2 | 200 | Concrete slab |
| | 4 | 15 | Plaster |

Table 21: Post 1990 flat - wall constructions

# 3 Heating Systems

This section discusses the heating systems that will be investigated during the project. Four different systems are described and underlying control strategies are proposed for each. The control strategies are proposed in addition to the higher-level control strategies discussed in the URS – such as predictive control; the latter will (where appropriate) provide signals to the heating system controller. The systems discussed in this section are:

- Gas fired condensing combination (combi) boiler.
- Gas fired condensing system boiler.
- Air-to-water Air Source Heat Pump (ASHP).
- Hybrid system with an air-to-water ASHP and gas fired condensing combi boiler.
- Hybrid system with an air-to-water ASHP and gas fired condensing system boiler.

Hybrid heating systems containing both a gas boiler and an ASHP are seen as a possible transition heating technology for the existing housing in the UK, which is why they have been selected as the basis of this investigation. They also have the added benefit of allowing the specification of the heating systems at the two extremes of just an ASHP, and just a gas boiler (either combination or system). Including gas boilers on their own will enable the user to determine a baseline performance, since this is the type of heating system installed in the majority of UK homes.

At the end of this section, the most appropriate systems for each of the buildings described in section 2 are proposed as benchmark systems. These systems can then be substituted to determine the effect on overall performance as discussed in the URS.

## 3.1 Gas Fired Condensing Combi-Boiler

The combi-boiler is of a condensing type and is fitted with a fully modulating gas valve to ensure the gas/air mix is right for all operating conditions. The pre-mix gas fired burner gives it the ability to control down to 20% of maximum output – typically 4 to 20kW for a wall hung version.

The system schematic is shown in Figure 7.

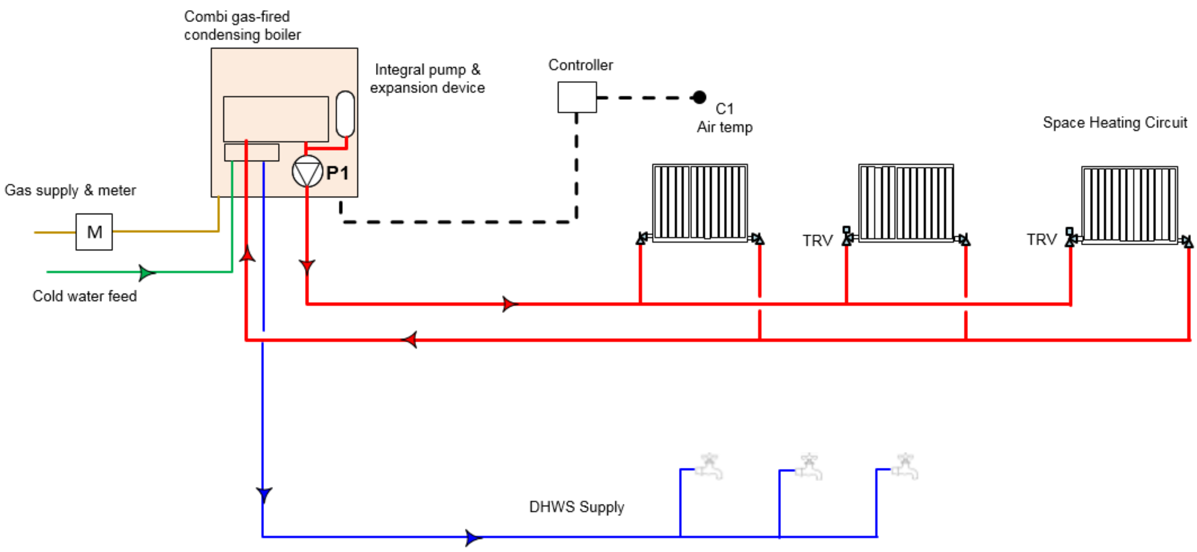



Figure 7: Gas fired condensing combi-boiler schematic

There is a single heating circuit fed from the integral circulating pump within the boiler. The radiators are fitted with Thermostatic Radiator Valves (TRVs) for local room control with one radiator left with simple isolation and lock shield valves to always provide an open circuit for water to circulate to avoid the pump operating against a closed head. This radiator is typically in the same room as the air temperature sensor C1.

Domestic Hot Water (DHW) is provided instantaneously by the boiler with an integral heat exchanger which has limited flow rate and results in a large gas demand ~ 30kW.

### 3.1.1 Control Strategies

The simplest control strategy for gas fired boilers is constant temperature control. In this, the boiler flow temperature is manually set on the boiler's control interface and, when running, the gas burner modulates to maintain that value [e.g. 70℃].

The controller provides means of scheduling the heating on and off times and introducing an occupied space temperature [e.g. 21℃] and setback temperature set point [e.g. 16℃] which are compared against temperature C1. The controller gives an enable signal to the boiler that then starts constant volume pump P1 which circulates water to the space heating circuit. The boiler then starts when flow is proven and controls to its flow water set point. The boiler will maintain the flow temperature set manually on the boiler controller. Individual room temperatures are maintained by the local TRVs on the radiators.

When DHW draw off is detected, the boiler will change over the space heating circuit flow to an internal auxiliary heat exchanger for on-demand preparation of hot water. For clarity, DHW demand is prioritised over space heating demand in this system.

One enhancement which can be made over the control strategy outlined above is to introduce weather compensation. Here, the control of the space heating flow temperature is compensated against outside air temperature. This can be achieved by either re-setting the boiler water flow temperature set point remotely, which is available on some boilers, or by introducing an additional pump and a three-way valve to recirculate some of the return water as shown in Figure 8. These two approaches achieve the same result, therefore, for simplicity of implementation, the first will be modelled Figure 9 shows a typical weather compensation curve which relates the heating circuit water flow temperature (C3 set point) to the outdoor air temperature. An outdoor air temperature sensor or access to weather data is also required. Using weather compensation will optimize the condensing boiler efficiency ensuring the low return water temperatures required to condense flue gases.

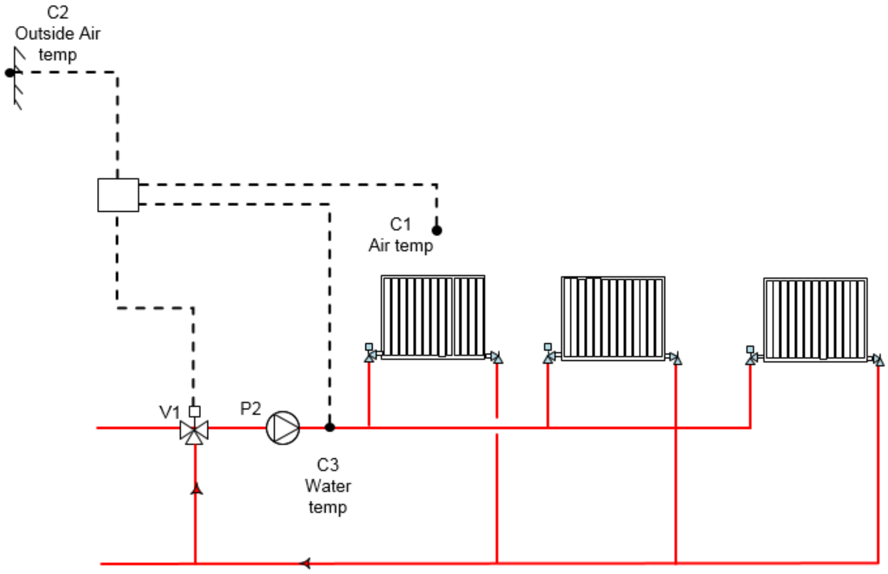



Figure 8: Schematic of heating circuit with weather compensation

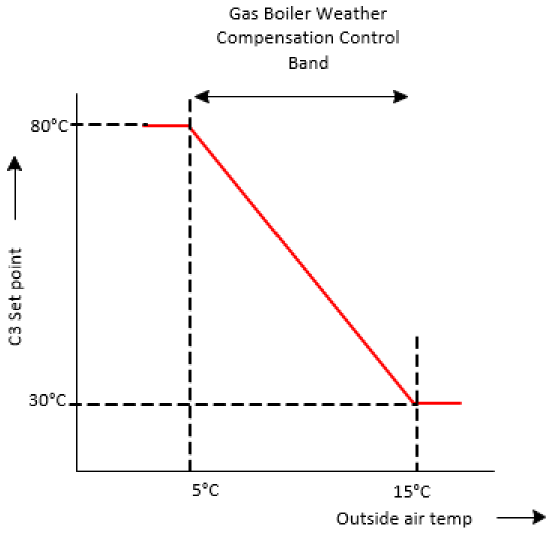



Figure 9: Weather compensation curve for heating circuit

## 3.2 Gas Fired Condensing 'System' Boiler

The 'System' boiler is similar in construction to the 'Combi' boiler but differs in that it does not possess the integral auxiliary DHW heat exchanger. DHW is, instead, delivered through a storage tank. A system schematic is shown in Figure 10.

As with the Combi boiler, the System boiler is fitted with a fully modulating gas valve to ensure the gas air mix is right for all operating conditions. The pre-mix gas fired burner gives it the ability to control turn down to 20% of maximum output – typically 4 to 20kW.

As shown in Figure 10, a single heating circuit is fed from the integral circulating pump within the boiler and the DHW is generated by a hot water heating coil in the storage tank.

The radiators are fitted with direct acting TRVs one radiator is always left with only a manual value to allow an open path for water circulation if all the other TRVs have modulated closed. Again, this radiator is typically in the same room as the air temperature sensor C1.

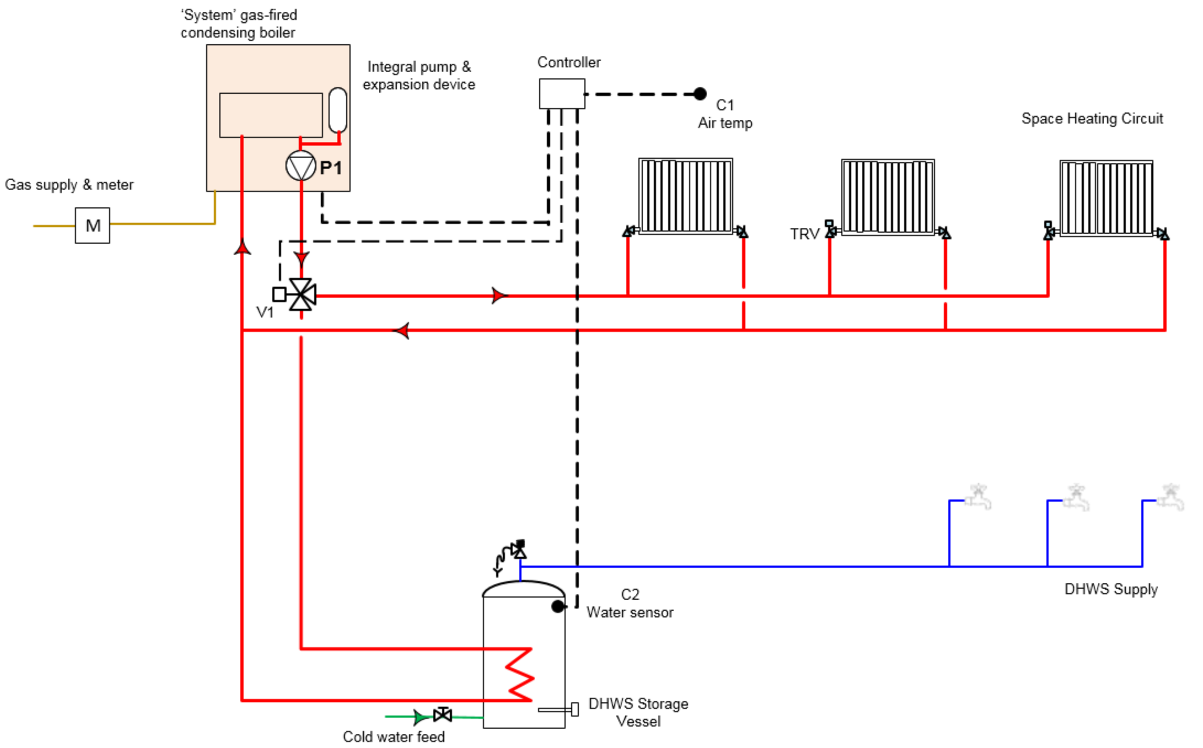



Figure 10: Gas fired condensing system boiler schematic

### 3.2.1 Control Strategies

The control for the heating circuit is the same for this system as it is for the system described in section **Error! Reference source not found.**. The main difference with this system is that the controller allows the time scheduling of water preparation, and a three-way valve (V1) and DHW storage tank are introduced. When the controller's schedule allows, and the water temperature sensor C2 sees a temperature lower than a set-point, V1 directs the boiler's water flow to the coil within the DHW storage tank to heat the water within it.

As with the system described in section **Error! Reference source not found.**, weather compensation can be introduced to optimise the heating circuit.

## 3.3 Air-To-Water Air Source Heat Pump

An air source heat pump is used for space heating and is supplemented by an immersion heater in the DHW storage tank to assist in DHW production.

A system schematic is shown in Figure 11. This shows the ASHP effectively replacing the system condensing gas fired boiler discussed in section 3.2. The main additional components are the buffer vessel, which is connected in parallel to the ASHP, and the immersion heater in the DHW storage tank. A buffer vessel[5] is included to add water content to the heating system to minimize the cycling of the heat pump – the compressor usually should be limited to no more than 6 compressor starts per hour to avoid premature failure.

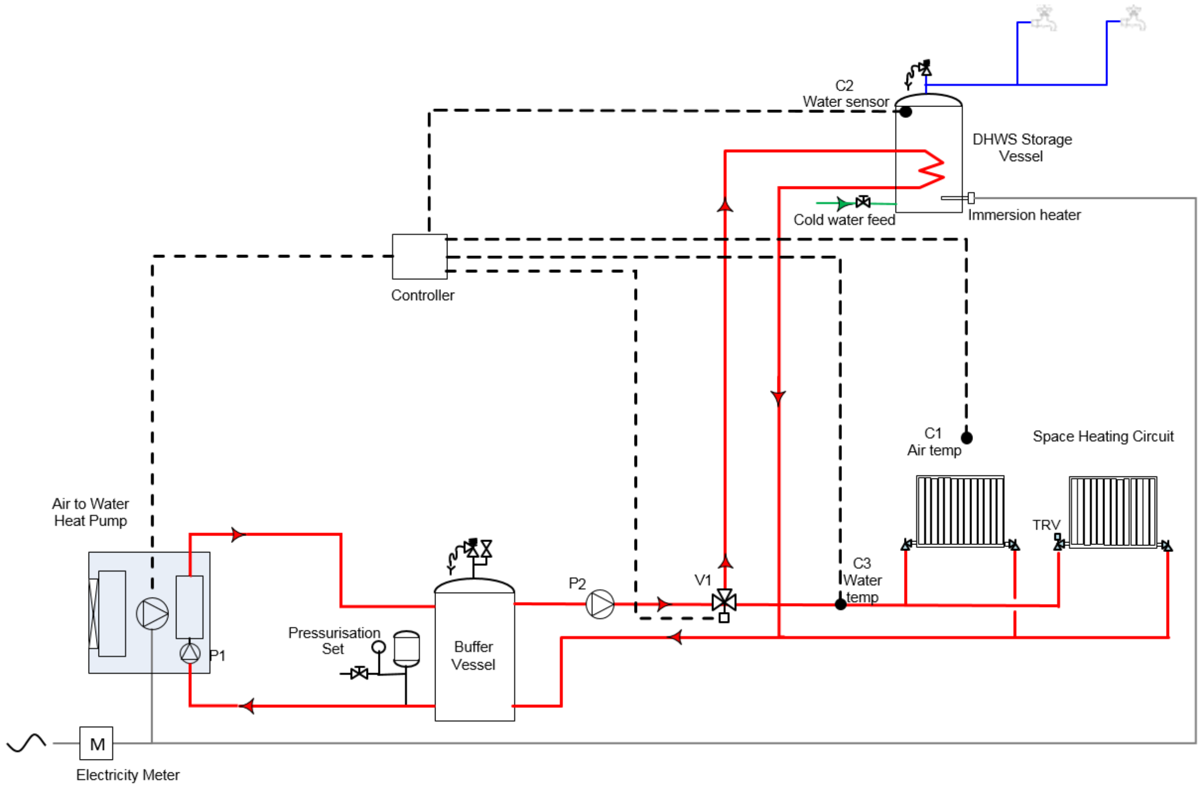



Figure 11: Air-to-water ASHP system schematic

### 3.3.1 Control Strategy

The control strategy for this system is, in many ways, similar to that covered in section 3.2.1 for the gas fired condensing system boiler. The main exceptions are the details behind the

[5] "EN 15450:2007 Heating systems in buildings – Design of heat pump heating systems", recommends sizing of buffer vessels: 12 to 35 litres/kW

production of DHW, and mechanisms to take advantage of the introduction of the buffer tank.

As discussed above, the buffer tank is introduced to provide a disconnect between the production of hot water in the heat pump and its use in the space heating circuit and DHW system. This allows the number of heat pump compressor starts to be minimised, and an element of thermal storage to be introduced to the space heating circuit. The implication of this to the control strategy is that an additional circulation pump (P2) needs to be controlled when there is a call for space heating or DHW production.

The difference with the DHW production on this system over the gas fired condensing system boiler is a result of the lower water flow temperature from an ASHP. This means that in order to achieve a sufficient water temperature in the DHW storage tank, an electric immersion heater is required to boost the temperature. Increasing the temperature within the DHW storage tank both allows for a greater storage density and minimises the risk of Legionella.

As with the control strategies already discussed – and by the same means – weather compensation can be introduced to the space heating circuit to optimise the system. This is in addition to the wider system control strategies presented in the URS.

## 3.4 Hybrid Heating System with ASHP and Combi Gas Fired Boiler

This system utilizes the heat pump as the primary source of heat so its configuration is similar to that discussed in section 3.3 above, with heat pump primary circuit buffer vessel and secondary space heating circuit. The system is supplemented with high grade heat derived from the Combi boiler. This can be injected through valve V1 if the space heating demand is higher than the capacity of the heat pump and also provides DHW in the same way as the system described in section 3.1. The system schematic is shown in Figure 12.

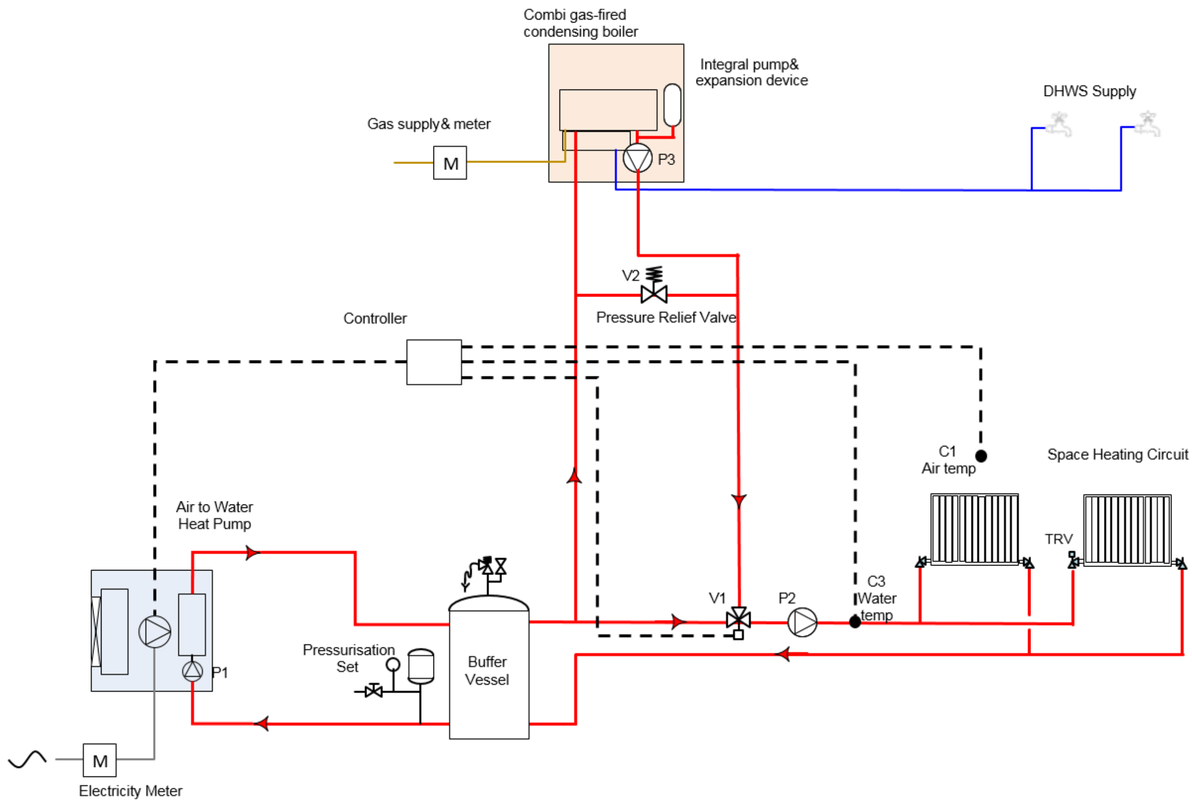



Figure 12: Schematic of hybrid heating system with ASHP and combi gas fired boiler

### 3.4.1 Control Strategy

Control is similar to that described in section 3.3.1 in that the controller will enable the heat pump if there is a demand for heat from sensor C1 - space heating [e.g. 21°C]. The DHW is now independent and under the control of the Combi Boiler flow sensor.

The heat pump will operate to maintain the set point at C3 [e.g. 50°C]. Once the space temperature at C1 (which is located in a representative space in the dwelling) is satisfied, the heat pump is disabled. The Combi boiler will be on-line to satisfy any hot water demand triggered by opening of a draw-off.

In cold weather the output from the heat pump will reduce due to the increased pressure lift that the compressor must work through and the need for defrost cycles as ice builds on the surface of the outdoor unit. Supplementary heating is then necessary to top-up the shortfall in heat output. The second stage of heating is then enabled modulating valve V1 and activating the gas boiler with the initiation of pump P3. Valve V1 will modulate to maintain the set point at C3.

As with the control strategies already discussed weather compensation can be introduced to the space heating circuit to optimise the system.

As well as heating capacity being a driver for supplementing the heat from the heat pump with the gas boiler, other factors may induce a switch of heat source. The control strategy may be set to minimise operating costs or $CO_2$ production, for example. In the case of minimising operating cost, the cost to deliver a unit of heat from each source is calculated.

The cost of heat from the heat pump would vary as a function of electricity tariff and the effect of external temperature on operating efficiency. This may lead to the gas boiler providing all of the space heating and the heat pump switching off.

## 3.5 Hybrid Heating System with ASHP and System Gas Fired Boiler

The ASHP system with a gas fired 'System' boiler is similar in configuration to that discussed in section 3.4. In this instance, the gas System boiler provides the supplementary heat to the space heating circuit (as in section 3.4) and also serves a conventional DHW storage vessel (as in section 3.2). The system hydraulics are thus more complex as shown in Figure 13.

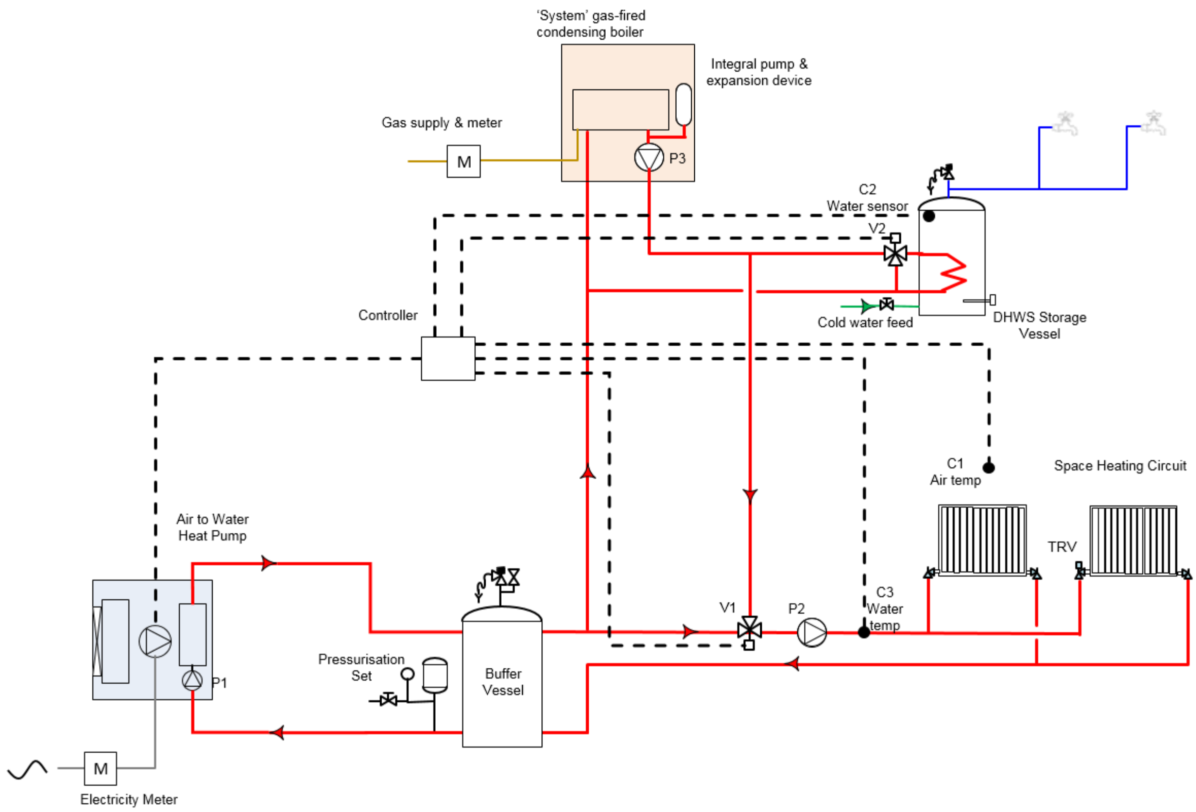



Figure 13: Schematic of hybrid heating system with ASHP and system gas fired boiler

### 3.5.1 Control Strategy

For this system, the control strategy for the space heating circuit is the same as that for the system described in section 3.4. For DHW heating, the control strategy is the same as that detailed for the system in section 3.2.

## 3.6 Mapping of heating systems to properties

This section suggests both the base/benchmark heating systems installed in each property, and the most appropriate alternative which will be investigated. These are based on the expected peak and average winter loads on the system, as well as on the overall objectives of the Integrated Electric Heating project. This is outlined in Table 22, where Option A and Option B are the two most appropriate alternatives to the Base/Benchmark system.

| Building Type | Building Age | Base/Benchmark system | Option 'A'[6] | Option 'B' |
|---|---|---|---|---|
| **Mid-terrace** | Pre-1919 | Gas fired condensing combi boiler | ASHP | ASHP with combi gas fired boiler |
| **Semi-detached** | 1919-1944 | Gas fired condensing combi boiler | ASHP | ASHP with combi gas fired boiler |
| **Semi-detached** | 1945-1964 | Gas fired condensing combi boiler | ASHP | ASHP with combi gas fired boiler |
| **Detached** | 1965-1980 | Gas fired condensing system boiler | ASHP | ASHP with system gas fired boiler |
| **Detached** | Post 1990 | Gas fired condensing system boiler | ASHP | ASHP with system gas fired boiler |
| **Flat** | Post 1990 | Gas fired condensing combi boiler | ASHP | ASHP with combi gas fired boiler |

Table 22: Mapping of properties to heating systems

[6] An ASHP could be appropriate for all properties as long as the system is sized correctly for the space heating and hot water loads.

# 4 Document Control

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**Revision History**

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