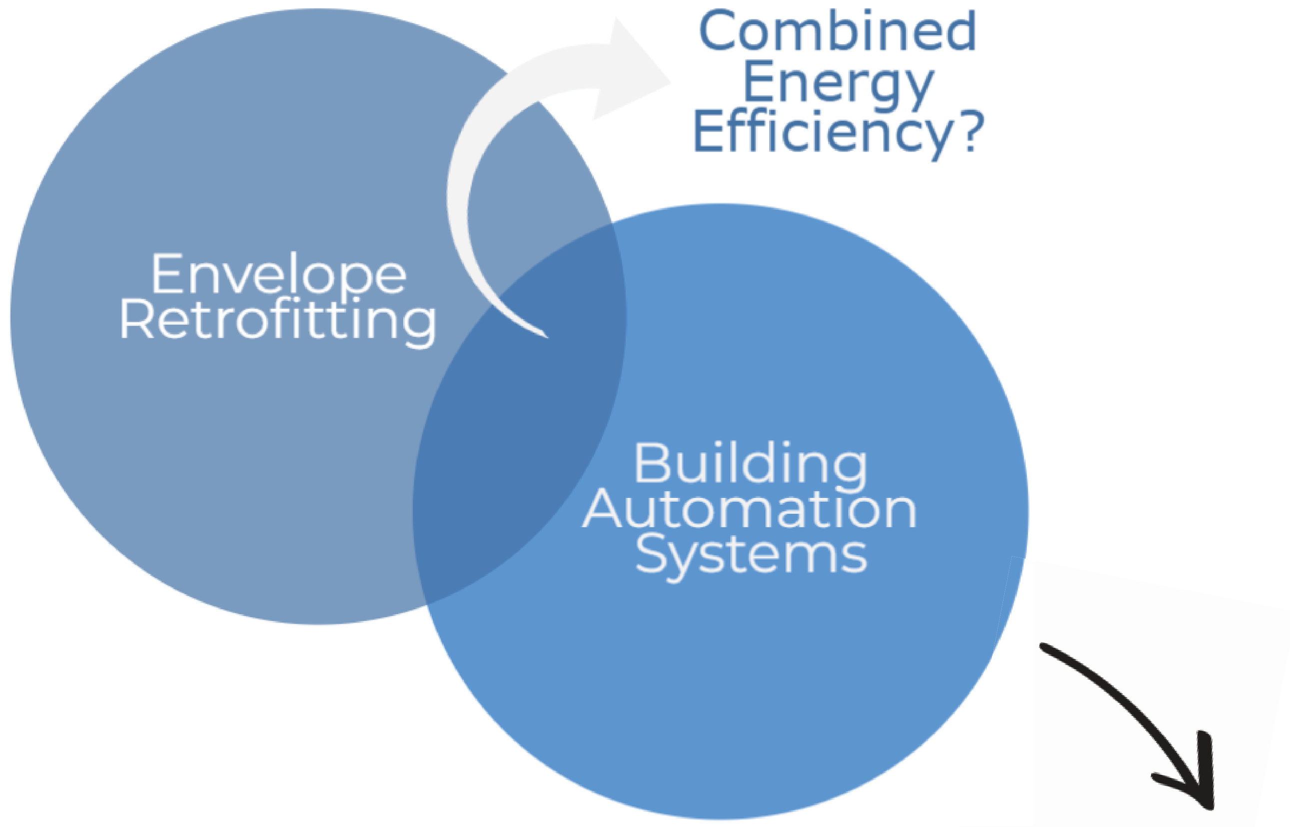
# INTRODUCTION

This study will be investigating the potential energy savings that are achievable for homeowners that are looking to retrofit if they implement building automation systems (BAS) into their retrofitting plans.

I will be conducting research into the use of BAS both with an envelope retrofit, and without an envelope retrofit to determine if BAS maximises energy savings when retrofitting a home. The research will be carried out using an energy simulation software, IDA Indoor Climate and Energy (IDA ICE).

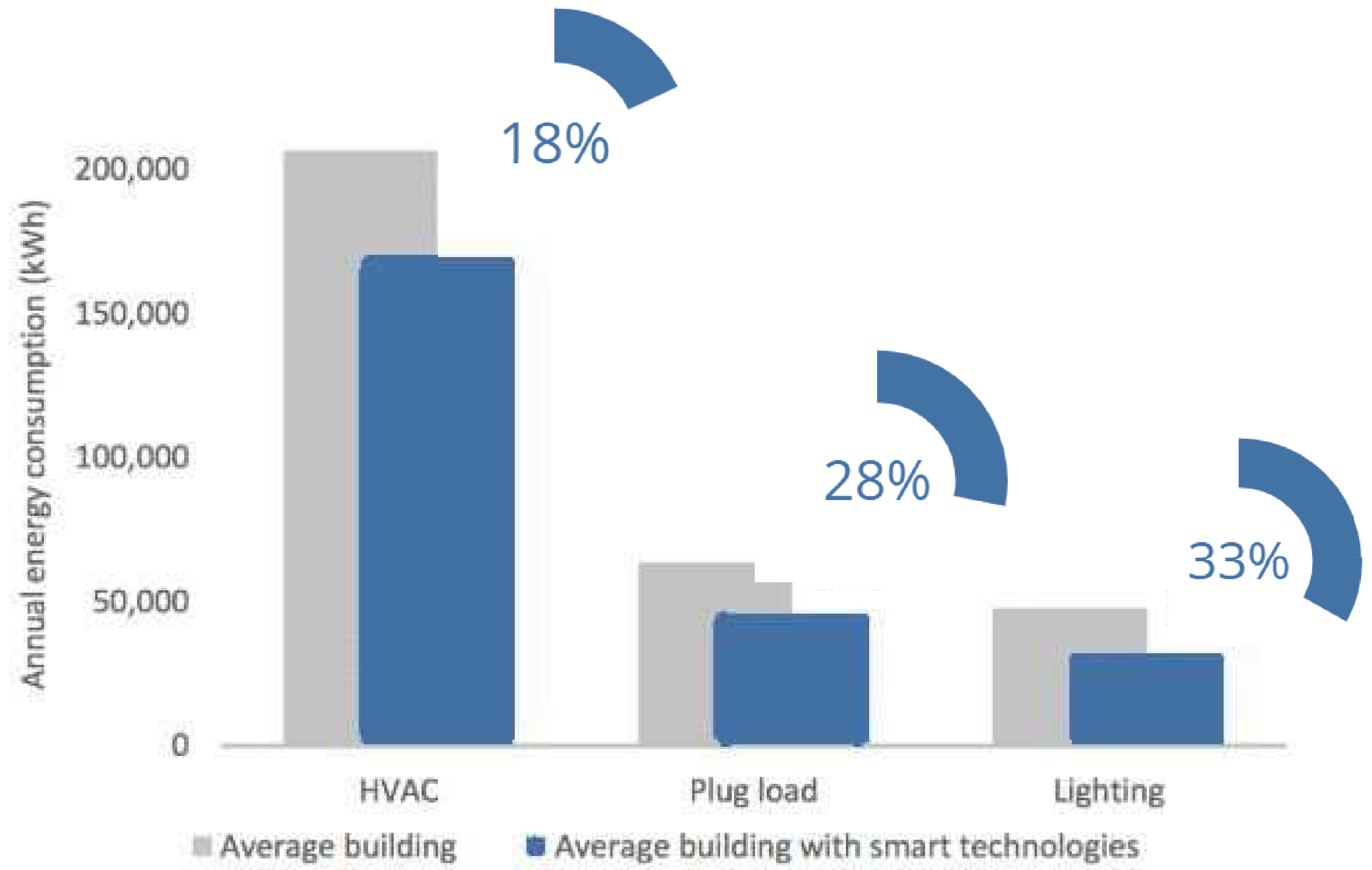



What are building automation systems?

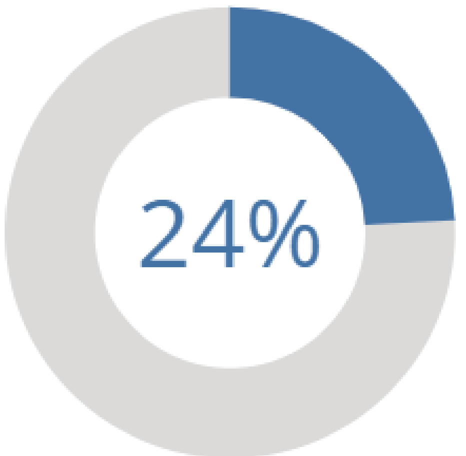
'Building automation systems' refers to any system inside a building that connects and automates certain functions, generally connected via the WiFi.

- Daylight and motion sensors, smart thermostats
- Smart boilers, heat pumps, smart radiator valves

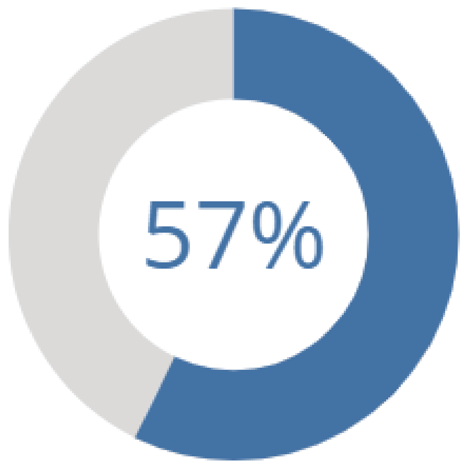
# INITIAL KEY FINDINGS




The ACEEE (American Council for Energy-Efficient Economy) estimates that smart building technologies can save the average office 18% in HVAC, 28% in plug load, and 33% in lighting energy.




Energy reduction from BAS alone




Energy reduction when BAS is combined with an envelope retrofit

*Figures taken from Doctoral Thesis: Combining building automation control systems with envelope retrofitting to improve the energy performance of cold climate housing*
*Laurina C. Felius, 2020*

# AIM

To investigate how building automation systems can impact the energy output of an Irish home, and to analyse to what degree a combination with envelope retrofitting can complement the systems installed.

The study also aims to determine if future retrofits should incorporate BAS to create more energy efficient homes, and then to recommend that new builds should incorporate BAS to ensure homeowners are using less energy.

# OBJECTIVES

- Produce a BIM model of an existing semi-detached Irish home to use as a case study for this research.
- Survey and measure existing buildings elements in the case study building to ensure accuracy in the parameters inputted to IDA ICE.
- Validate the IDA ICE software, based on measured data, through an energy bill comparison.
- Develop a retrofit of the existing envelope to current building regulations to determine the impact on the annual energy output (kWh) of the case study building.
- Construct a building automation system to simulate in IDA ICE, and to combine with the previously developed envelope retrofit to determine the impact on the annual energy output (kWh).

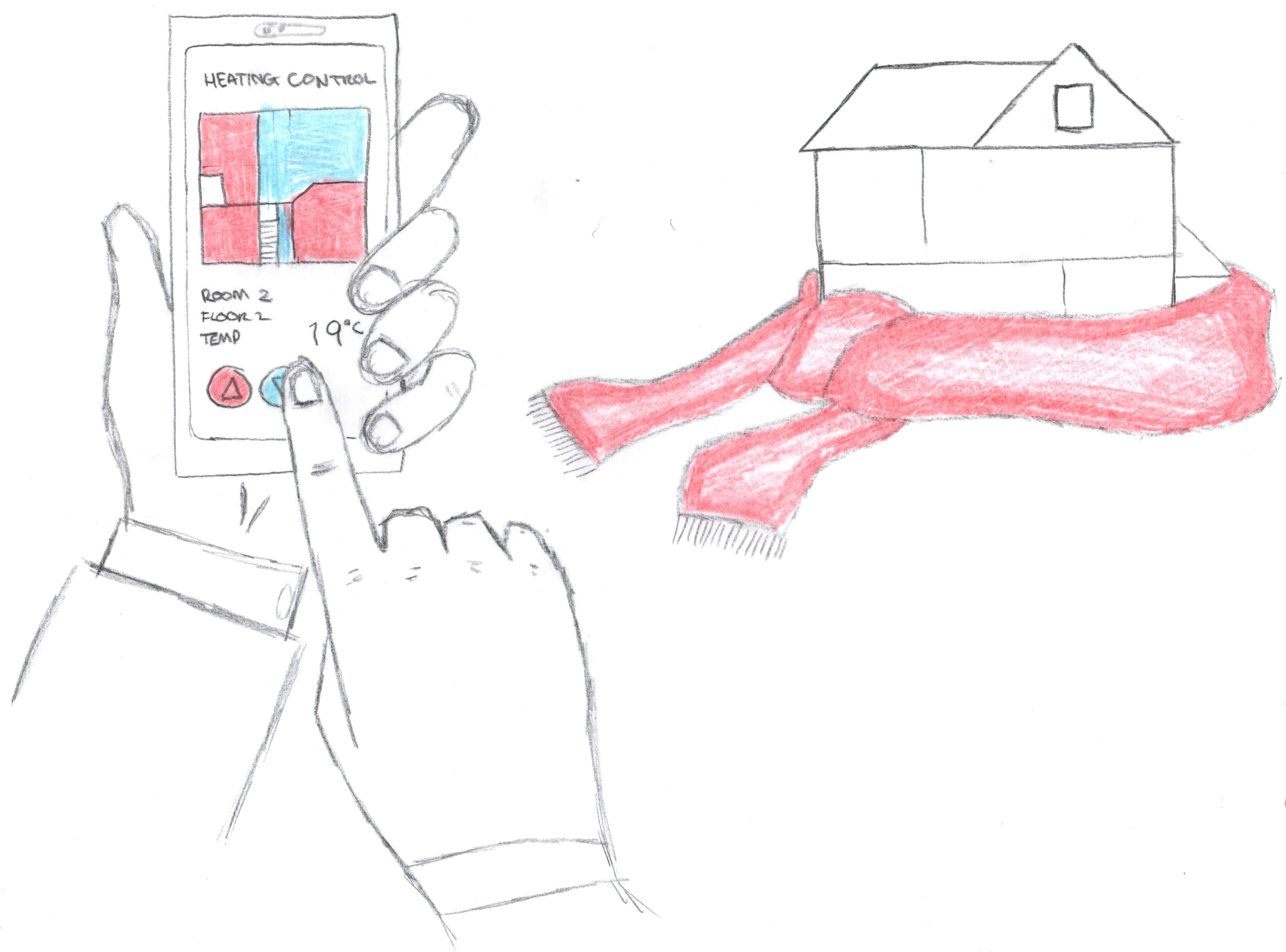
# MOTIVATION

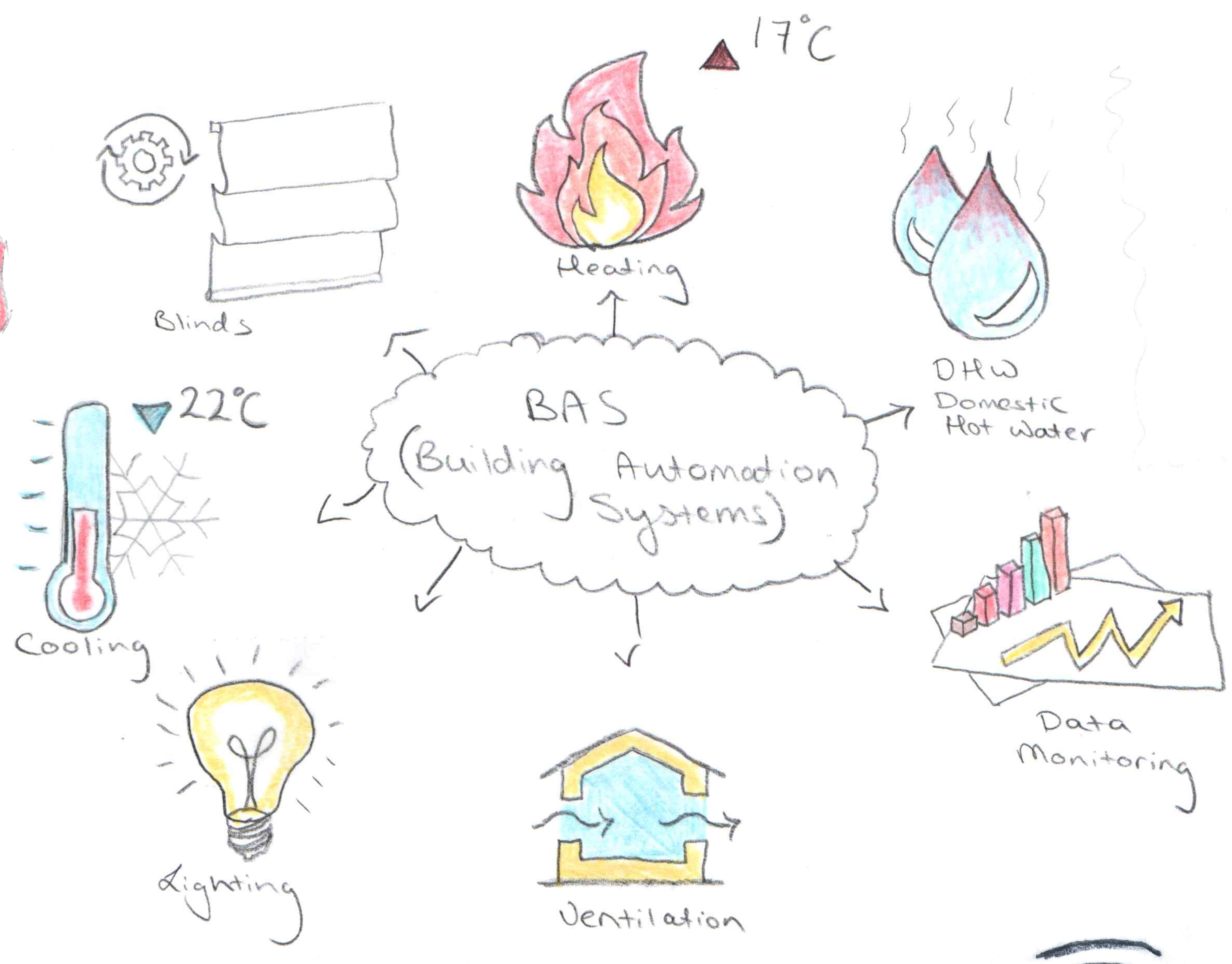
The motivation for this topic derived from my experience working in an office over the last year. I saw automation becoming a trend in everyday office life. From simple Revit tasks to people automating their daily timesheet, I was curious as to if this trend was implemented anywhere in the construction industry.

Through thesis topic research, I found building automation systems, and learned that the Irish government had released plans to retrofit 500,000 homes by 2030, and I thought building automation could play a key role in the energy efficiency of retrofitting.

# HOW DO BUILDING AUTOMATION SYSTEMS IMPACT THE ENERGY OUTPUT OF IRISH HOMES?

## DEFINING BUILDING AUTOMATION SYSTEMS

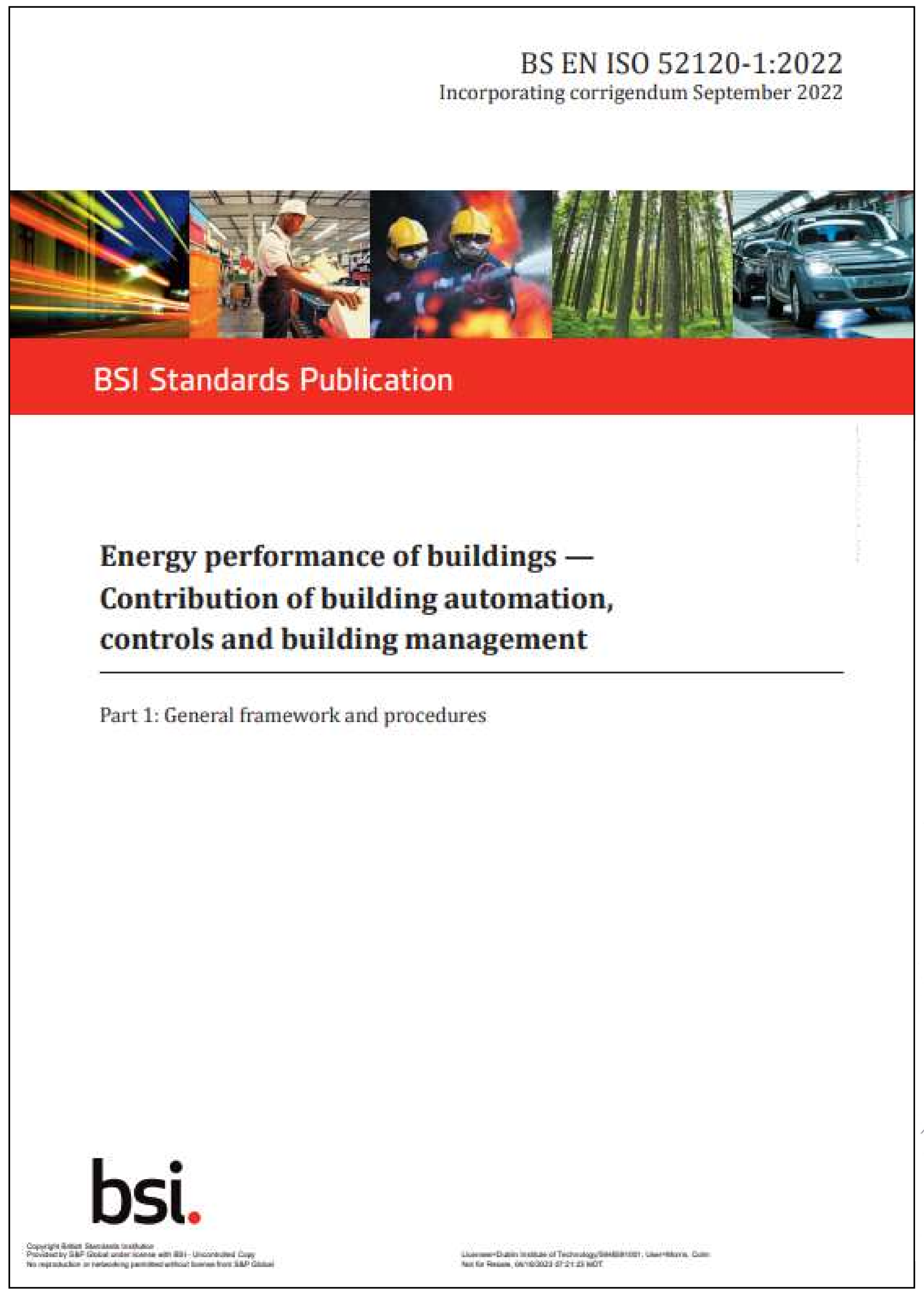



BS EN ISO 52120-1:2022 outlines 7 elements of BAS.

In the document, there are also 'BAS efficiency classes', which determine the intelligence of each of the aspects installed based on certain criteria.

This document was used in this study to specify the functions of the implemented BAS and to justify a number of decisions made throughout.



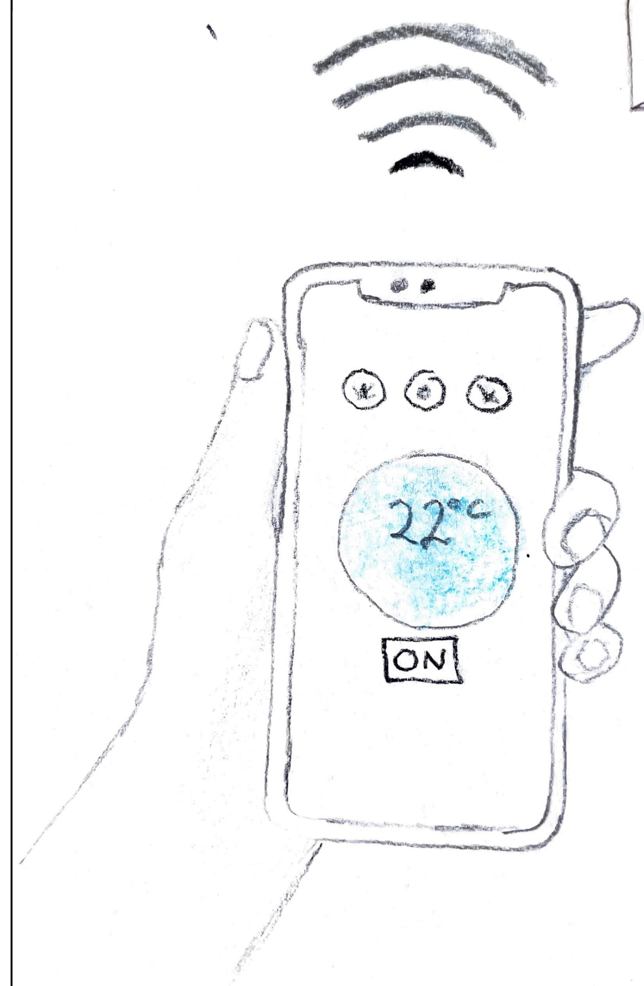
BS EN ISO 52120-1:2022
Incorporating corrigendum September 2022

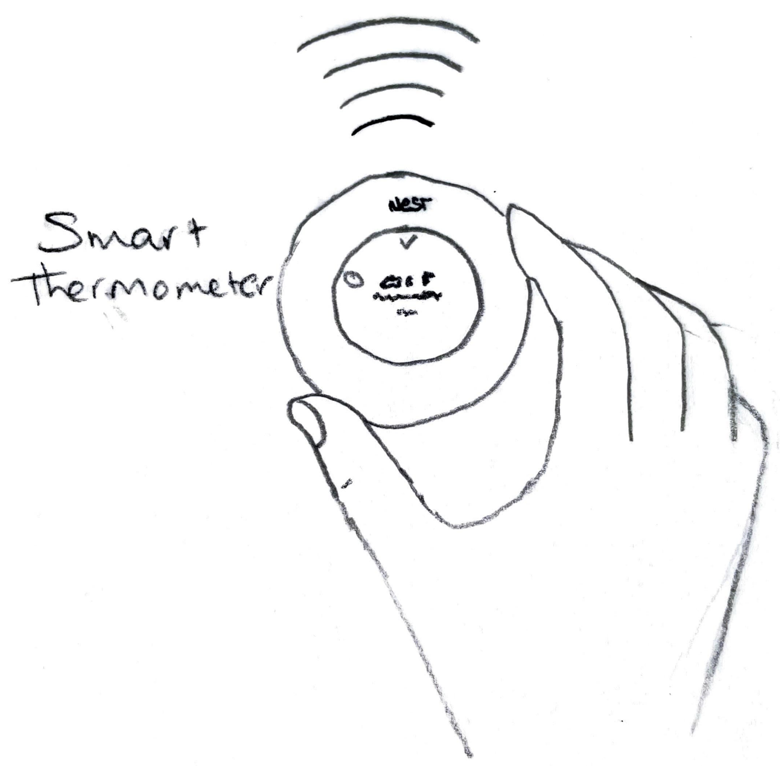
BSI Standards Publication

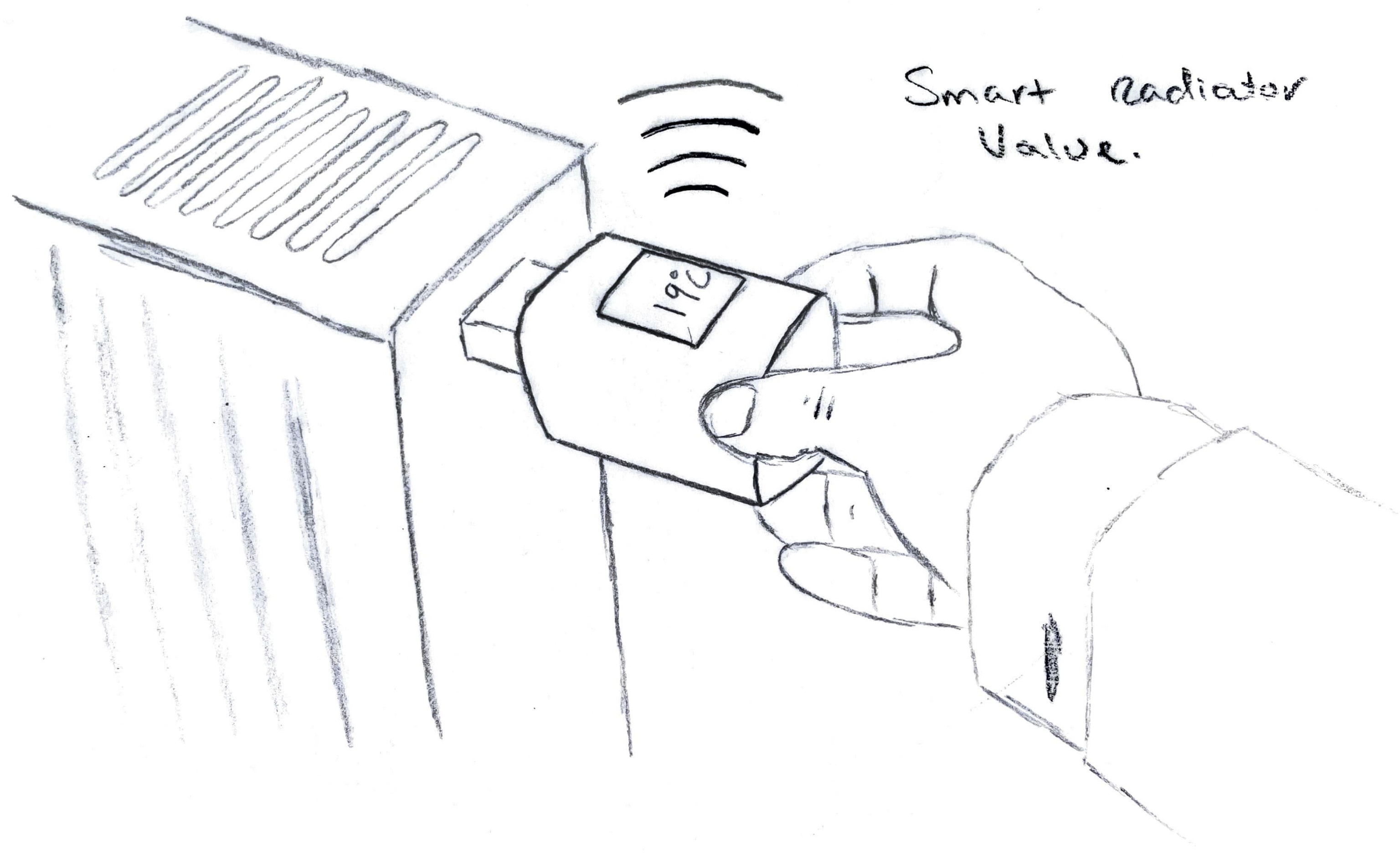
**Energy performance of buildings — Contribution of building automation, controls and building management**

Part 1: General framework and procedures

bsi.


## PROJECT SCOPE

### Included

Automatic heating

Automatic lighting

Automated blinds

Automatic cooling (Hypothetical)

Automatic ventilation (Hypothetical)

### Not Included

Domestic hot water
- Smart hot water systems monitor occupant behaviour and patterns, and adjust accordingly. In IDA ICE, modelling this is extremely advanced.

Data monitoring
- This is an element of BAS, but is not a physical element. This study is only assessing physical elements.

This research will not investigate how IDA ICE utilises the data supplied to the software to calculate it's results.

### Limitations

Only one climate was investigated

Only one occupancy schedule was investigated

Only one building typology was investigated

## CASE STUDIES


*Source: Self Build*

### Mark McCall's Automated Home
### Co. Down

Automatic sensored lighting, automatic blinds, automatic heating. Automatic DHW system that raises hot water to 55°C at 6am to make use of the cheaper night time rate

System does not depend on WiFi. Loxone uses their own mini-server built into the house.

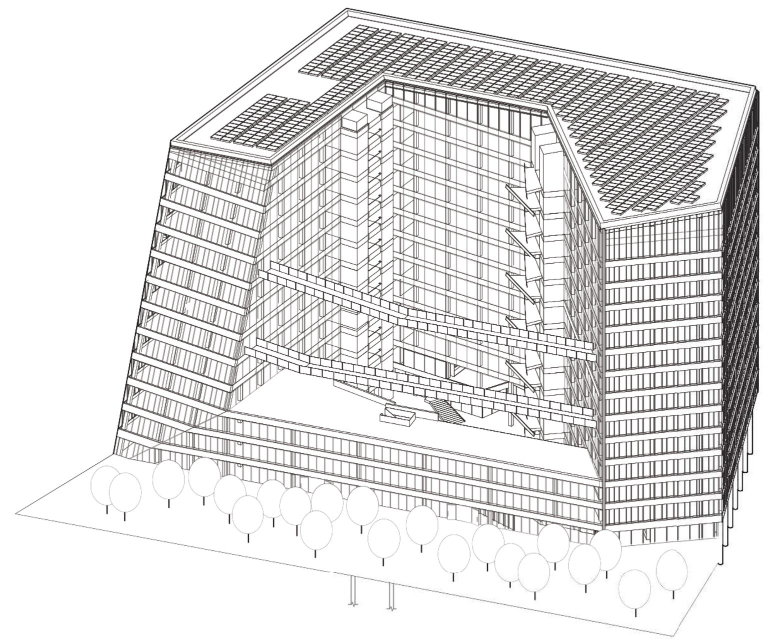
System can pull-in weather forecasts and use that information to adjust the heat pump automatically to compensate for likely solar gain during the day.

Mark's home uses 54kWh/m², compared to BER A & B rated homes using 89kWh/m²

*(Census 2016)*

*54kWh/m²*

*89kWh/m²*
*for typical BER A & B dwellings*



*Source: PLP Architecture*

### The EDGE Building
### Amsterdam

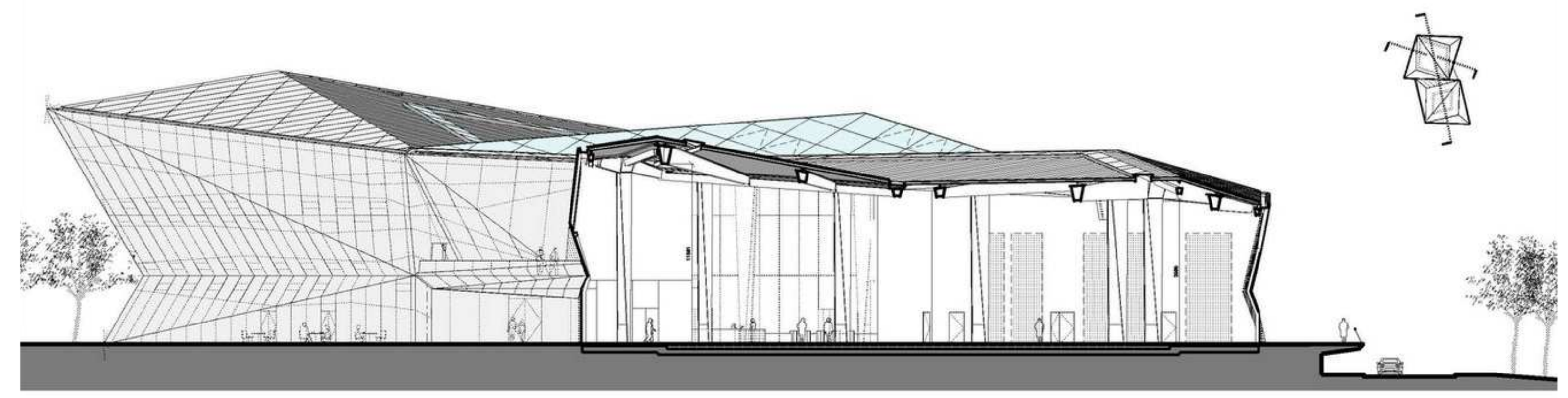
The world's smartest office building with a BREEAM sustainability score of 98.36%

Over 28000 sensors installed around the building (motion, light, temperature, humidity, infrared)

The building has an app for employees which is used to monitor employee data (preferred room temperatures, coffee preference, car driven for parking). On days when fewer employees are expected, an entire section of the building may shut down, saving energy on heating, cooling, lighting and cleaning.

The EDGE uses 72kWh/m², compared to 233kWh/m² for typical non-residential buildings, due to it's automation systems.

*72kWh/m²*



*Source: Wilkonson Eyre Architects*

### The Crystal
### London

Achieved a BREEAM sustainability score of 86.92%

Sensors on it's roof to incorporate rainwater harvesting, where rainwater is converted to potable water.

Has effective sensors that automatically adjust lights based on time of day and occupancy.

The Crystal uses 83kWh/m² due to the implemented automation systems.

*83kWh/m²*

*223kWh/m²*
*for typical non-residential buildings*

## DESKTOP RESEARCH / LITERATURE REVIEW

Information modelling for urban building energy simulations - A taxonomic review
(Avichal Malholtra, Julian Bischof, Alexandru Nichersu)
2022

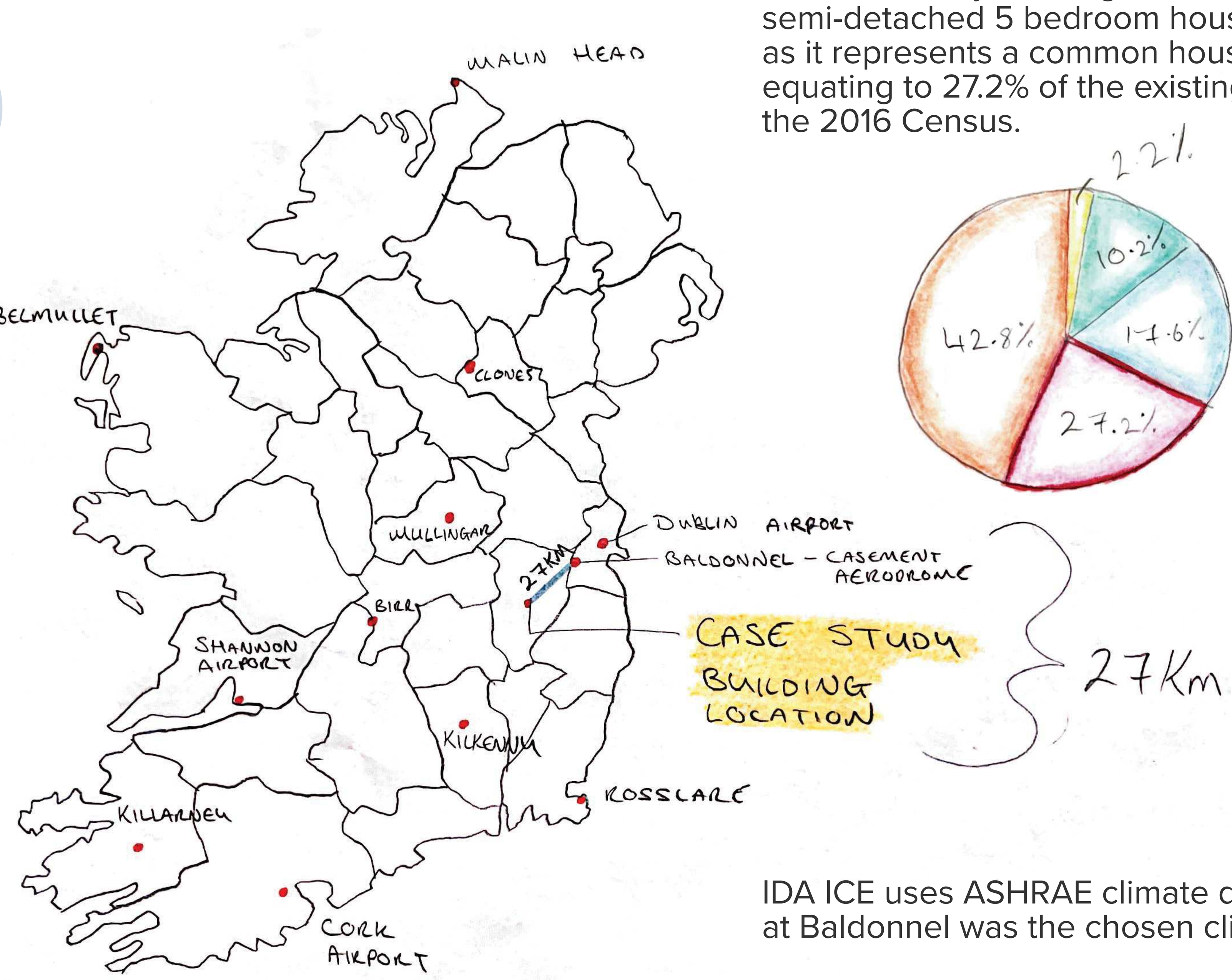
A validation of IDA ICE was conducted as part of this research.

The literature review part of this study presented a publication where a sample of UBEM (Urban Building Energy Modelling) studies were analysed for reproducibility and validation techniques.

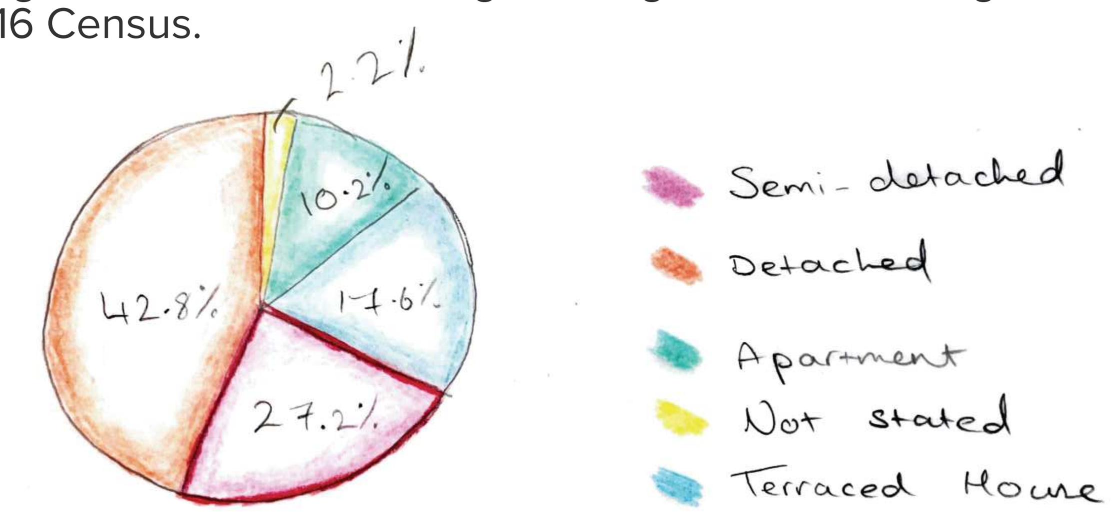
The study found that ~95% of reviewed publications cannot be reproduced. This is either due to the unavailability of input data and/or the impossibility to reproduce the simulation workflow.

Reproducibility of studies is important for UBEM studies to allow for future researchers to bring research further.

A validation based on measured data provides confidence in results, and ensures reproducibility of the study.



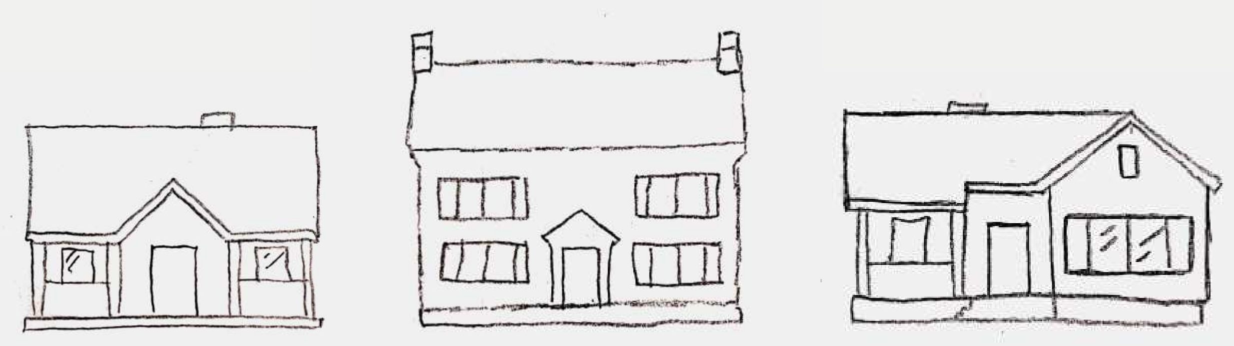

The case study building chosen for this study is an existing semi-detached 5 bedroom house. This typology was chosen as it represents a common housing typology in Ireland, equating to 27.2% of the existing housing stock, according to the 2016 Census.




IDA ICE uses ASHRAE climate data. Casement Aerodrome at Baldonnel was the chosen climate file for this study.

| Why IDA ICE? | |
|---|---|
| IDA ICE - | Most widely used in previously completed research surrounding BAS implementation into buildings. |
| Design Builder - | There were a number of reviews saying Design Builder can be quite slow, can crash a lot and is not very user-friendly. |
| Energy Plus - | There were a number of reviews saying the software is 'partially free', and is quite difficult to use for beginners. |
| eQuest - | Was not compatible with Revit or AutoCAD. |
| IES VE - | No BAS implementation into energy simulations. |

## METHODOLOGY BREAKDOWN



### *SOFTWARE SELECTION*

BAS implementation was necessary when choosing a software for this study. Multiple softwares were considered in the planning of this research, and were ruled out based on licensing issues, poor reviews and BAS implementation issues.

### *BUILDING TYPOLOGY SELECTION*

A common building typology was selected based on the existing building stock outlined in the 2016 Census

Semi-detached houses account for 27% of the existing building stock

IDA ICE

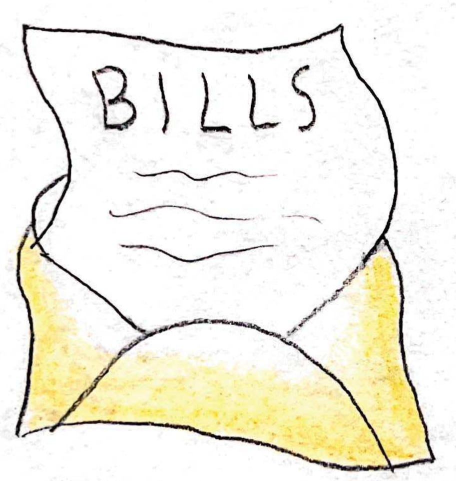
IES

### *BUILDING SURVEYING & DATA COLLECTION*

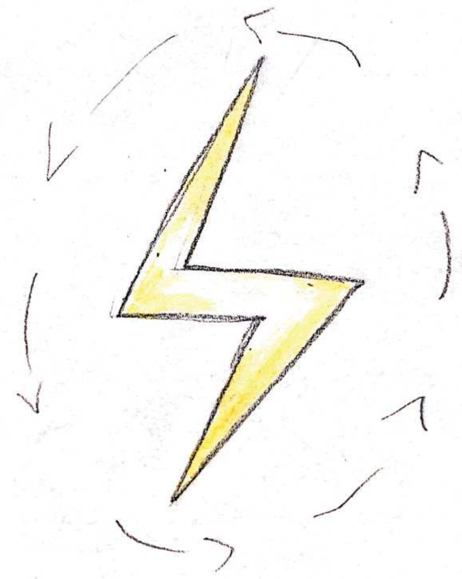
Due to the validation, based on measured data, required as outlined in the literature review, a survey of the case study building was done to ensure accuracy in IDA ICE results.

An analysis was conducted on the various systems in the building and the existing envelope. Temperature was measured to provide setpoints for the simulations.

## PRELIMINARY TESTING / DATA COLLECTION

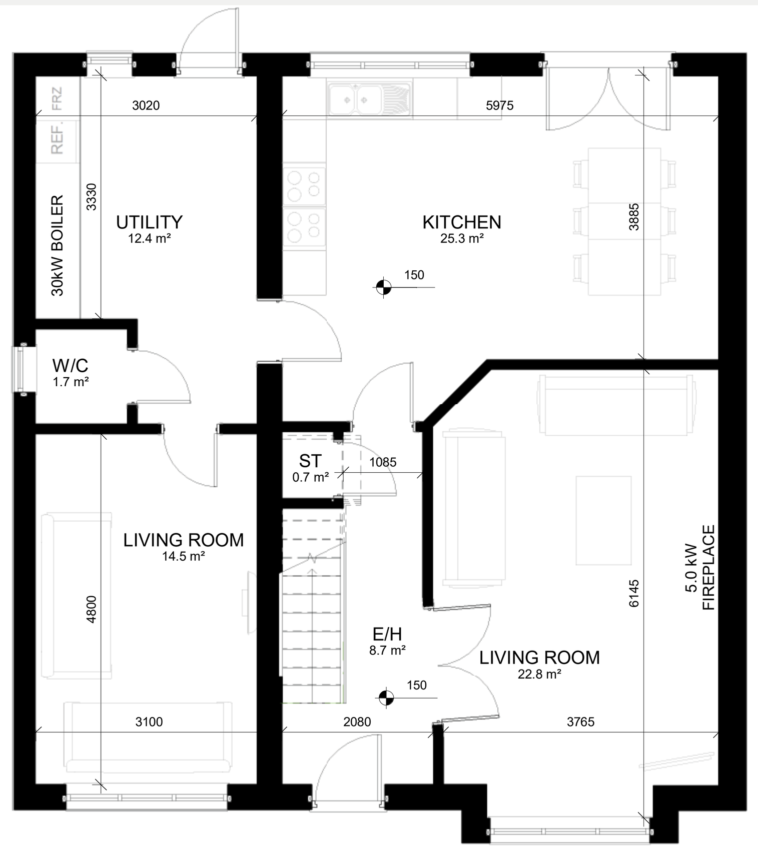



kWh as Shown on Gas Bills



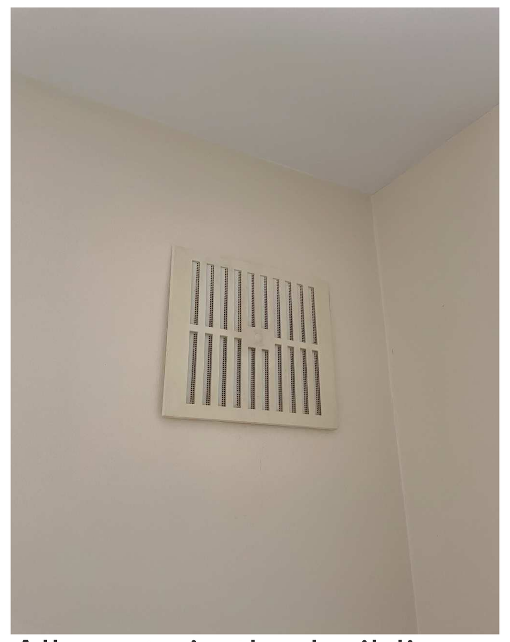
Basic IDA ICE simulation

Case Study Building
Semi-detached,
5 Bedroom
Co. Kildare



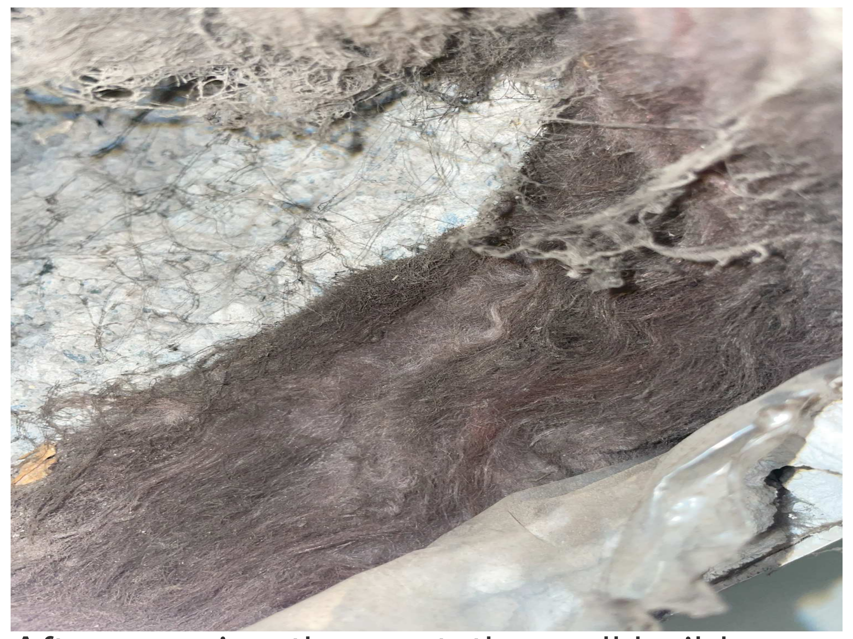

Ground Floor Plan


First Floor Plan



All vents in the building were opened and examined

There was only one accessible vent in the house



After opening the vent, the wall buildup was shown and measured

5 Gas burners (hobs) totalling 12.4kW

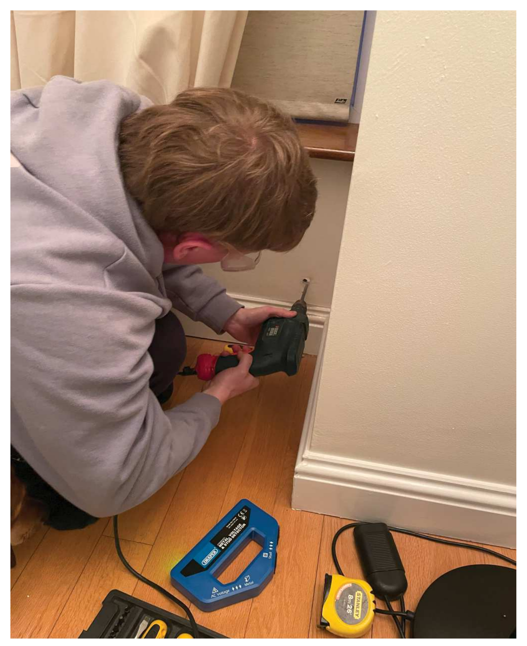
2.5 kW(min) -
5.0kW(max)
Valor gas fireplace

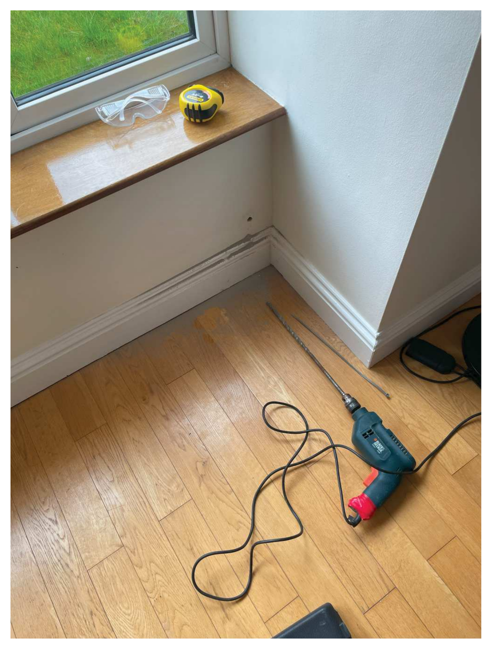
30kW Ariston Gas boiler
97.8% Efficiency
Heats radiators & DHW


Domestic hot water thermostat controlling supply temperature @ 65°C

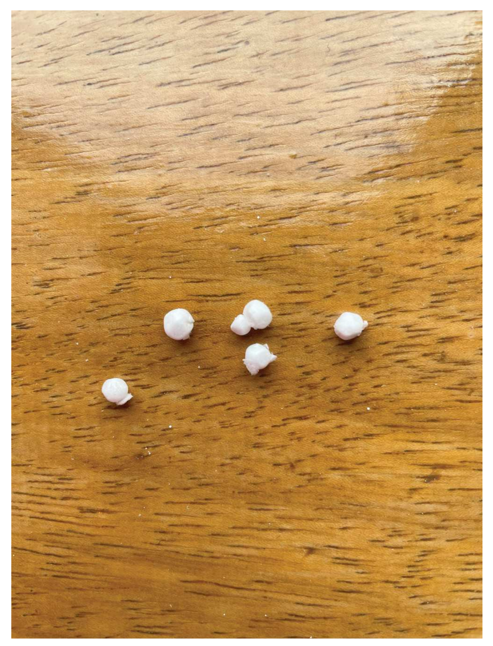
DHW Tank

Safety: Protective Glasses and Electrical cable detector were used to ensure safety while drilling into the wall.



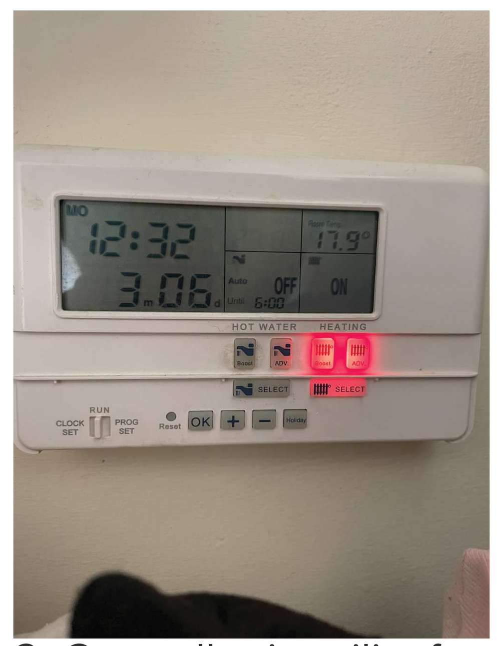


A hole was drilled using a 300mm drill bit. Care was taken not to drill into the external brickwork.



Clothes hanger end used for taking the measurements inside wall, inserted into wall, hooked onto various materials with measurements taken.
Polystyrene insulation was pulled out of the wall in


1. Thermometer in hallway to control heating, set to 18°C




2. Controller in utility for heating and hot water, reading 17.9°C

3. Temperature in the hallway, at the same time, reading 22.0°C

Due to the thermometer being broken, the temperature was taken in every room, for a week each, over the space of 2 months.

*REVIT MODEL CREATION*

A revit model was created based on a previous planning application.

The revit model was used to produce AutoCAD plans which were kept readily available to be imported to IDA ICE.

IDA ICE

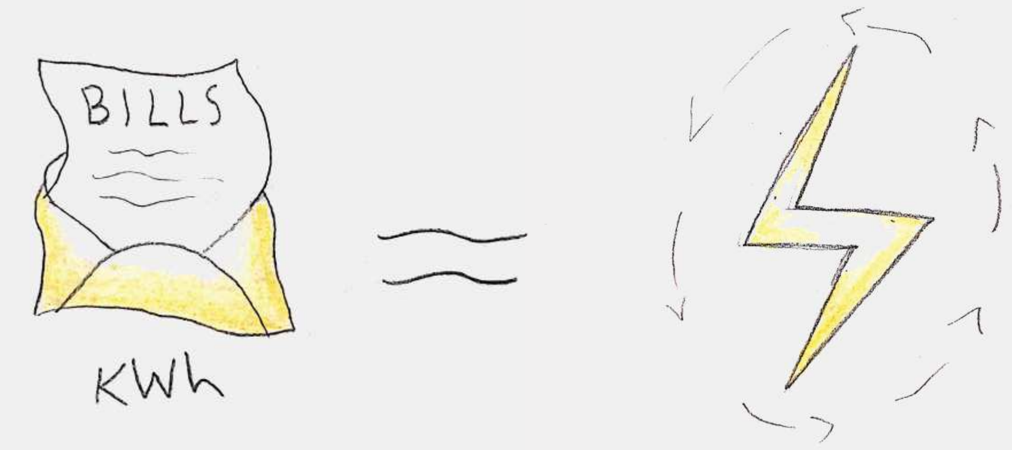
*VALIDATION METHOD*

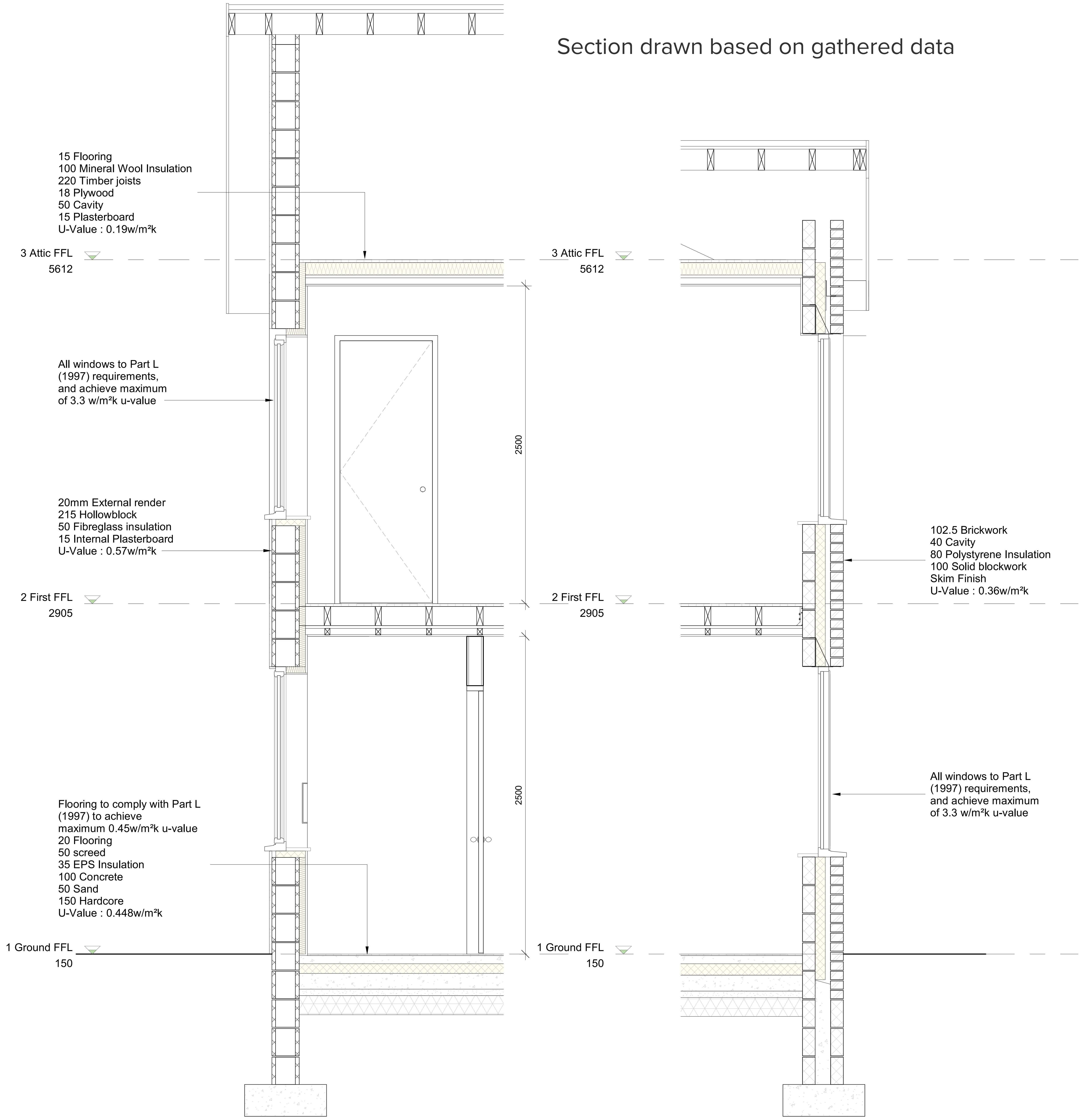
A validation method was carried out, both to validate IDA ICE and to create confidence in simulated results produced by IDA ICE. The validation created a safe virtual space to test ideas surrounding BAS implementation. The validation method compared existing energy bills to a basic simulation without BAS on IDA ICE.

AUTODESK Revit 2023

*IDA ICE MODEL CREATION*

A base model was created on IDA ICE, using the AutoCAD plans as a reference. The model was initially created without any BAS implementation.



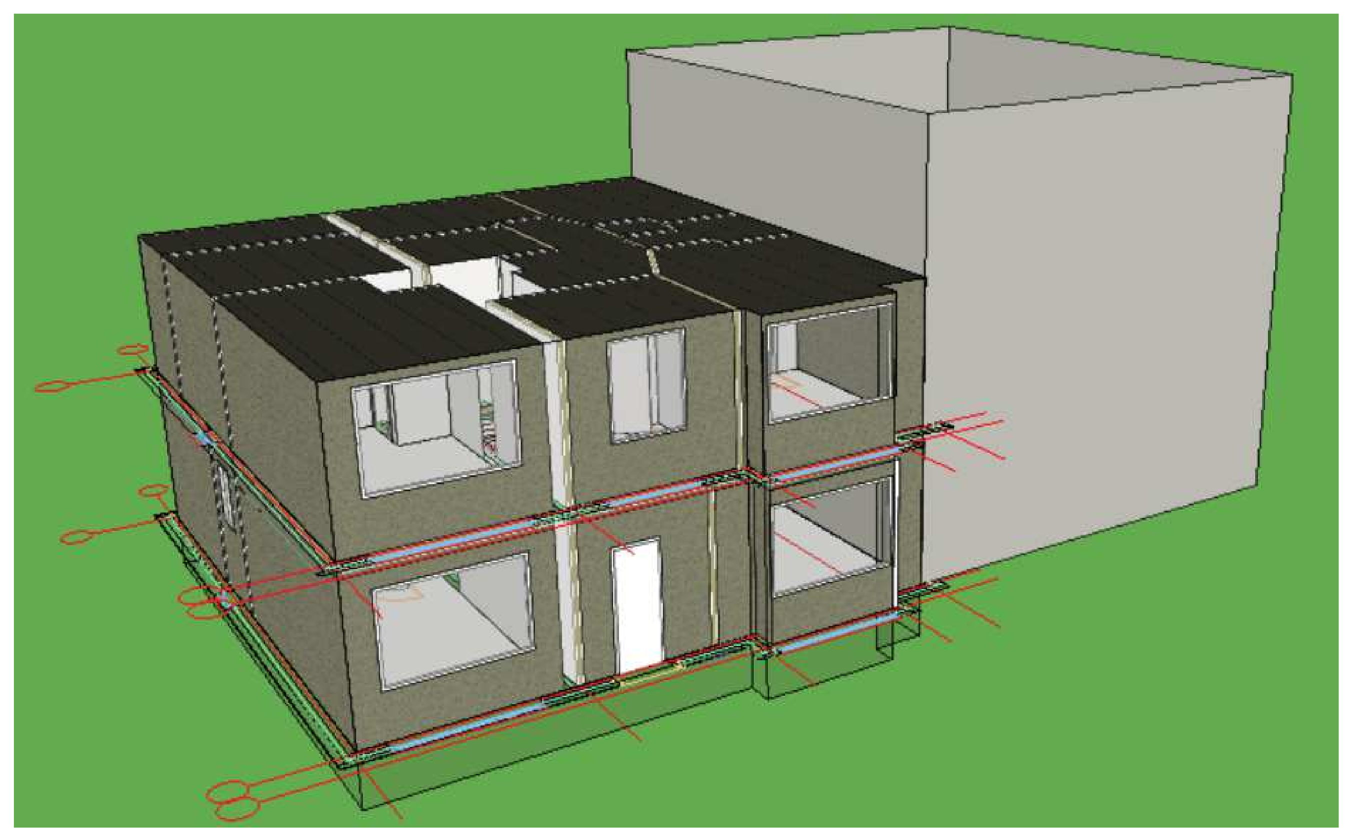

Section drawn based on gathered data

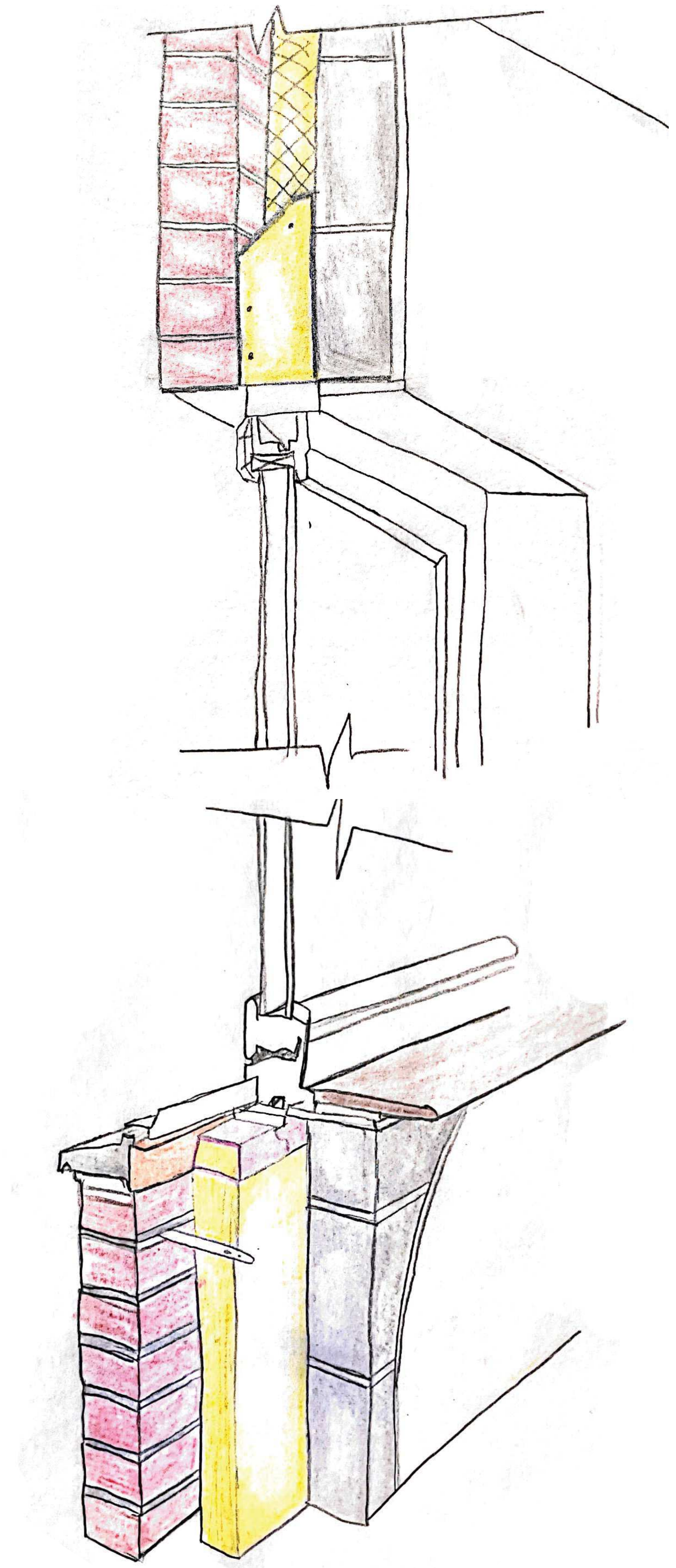
## TESTING

Produce a BIM model of an existing semi-detached Irish home to use as a case study for this research.

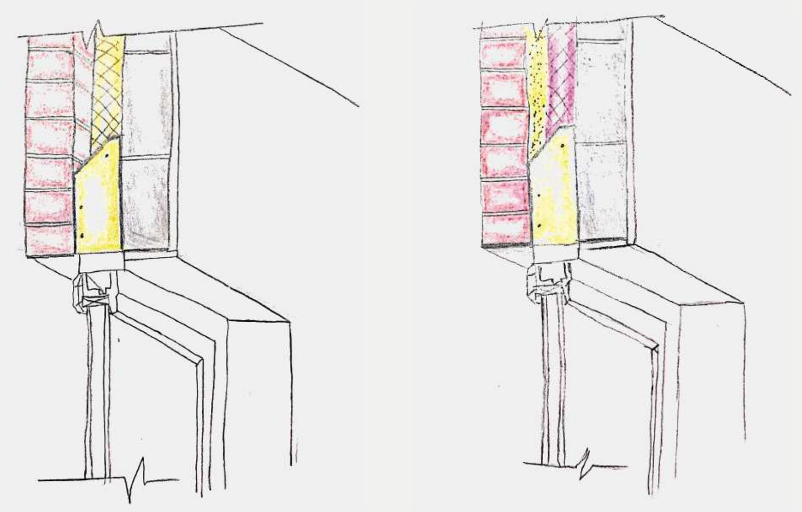
R → IDA ICE

Model created in IDA ICE



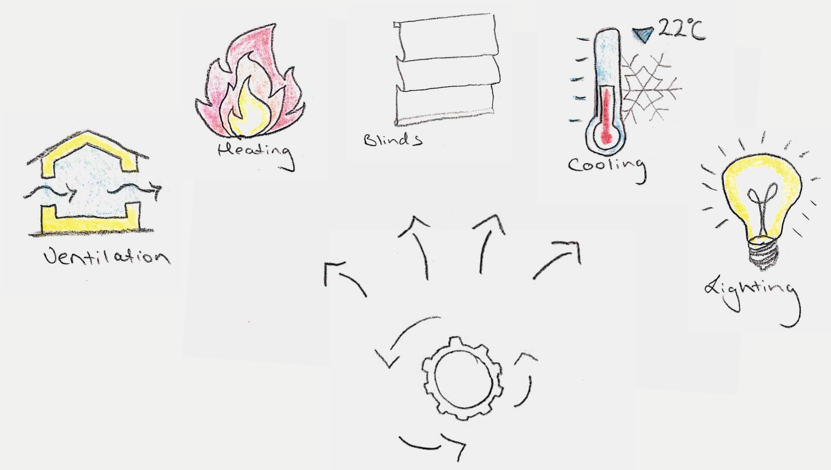


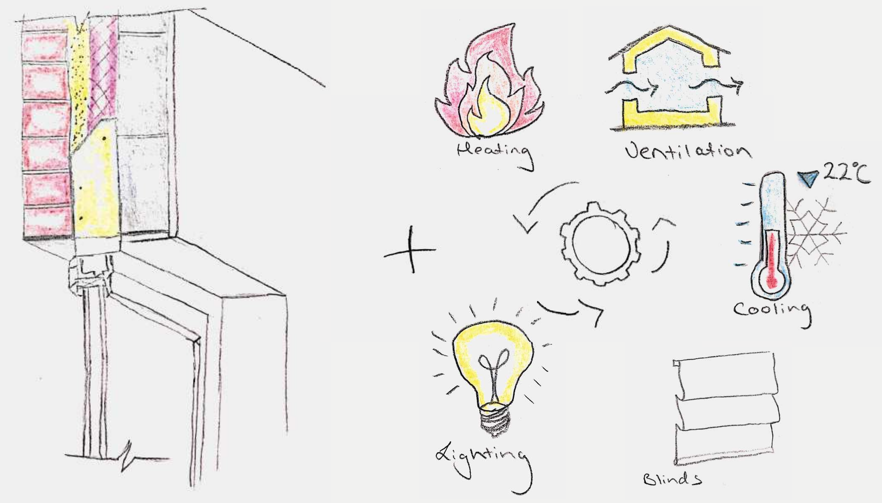
3D Sketched Detailed Section of Existing Cavity Wall



## IDA ICE MODEL DEVELOPMENT - 2

BAS was implemented and simulated combined with the envelope retrofit. Systems implemented were based on the criteria laid out in BS EN ISO 52120-1:2022 to achieve an 'A' class system.



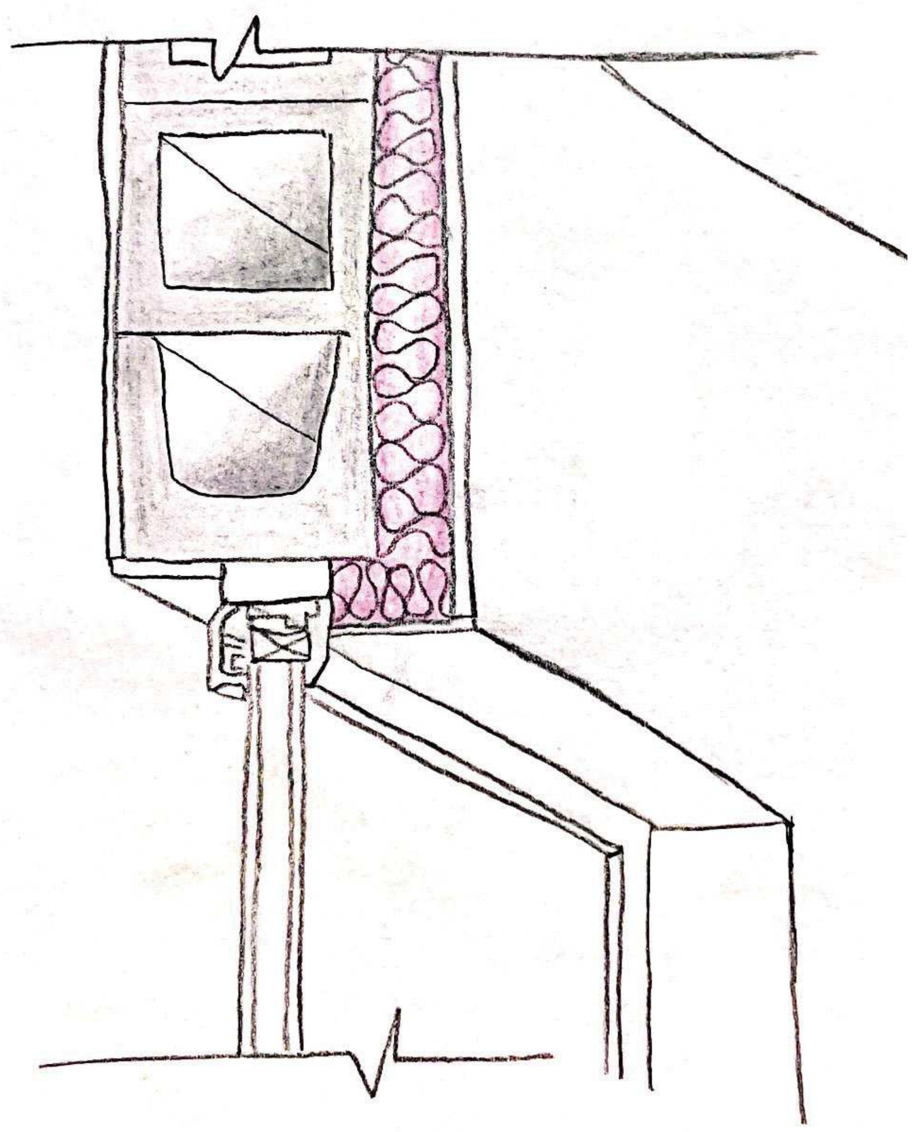



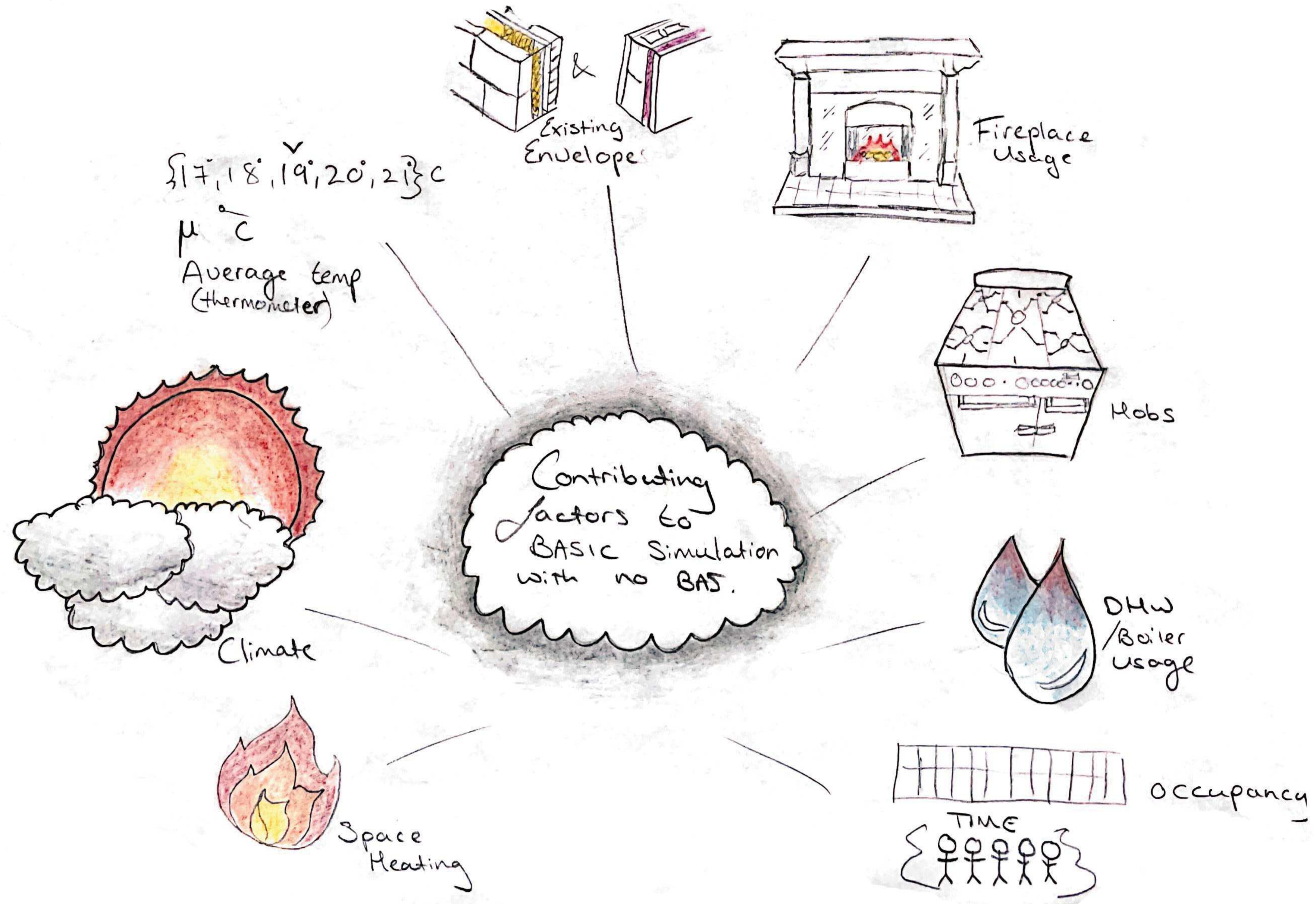

## IDA ICE MODEL DEVELOPMENT - 1

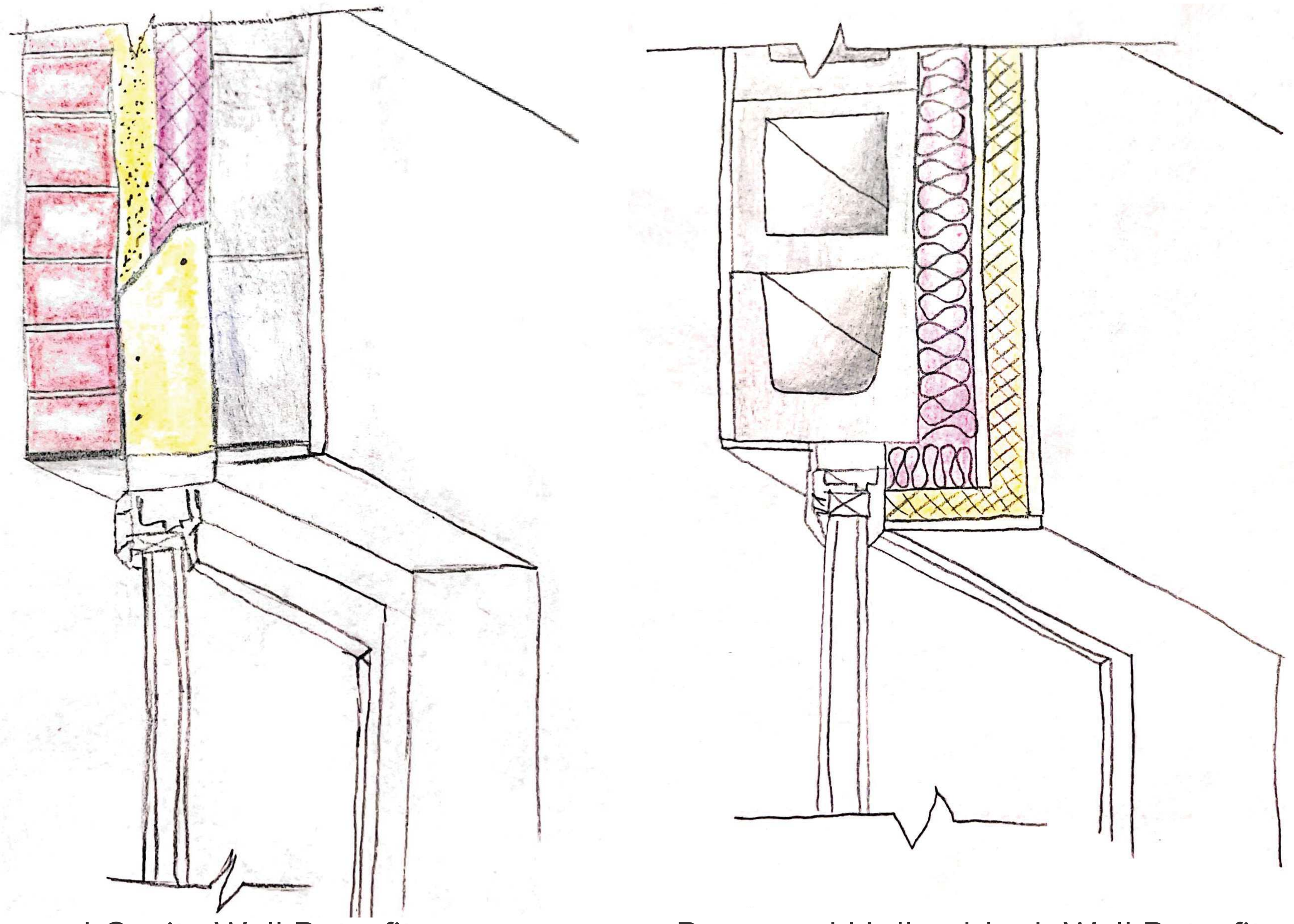
The thermal envelope of the IDA ICE model was developed to meet current building regulations as laid out in TGD Part L.

## IDA ICE MODEL DEVELOPMENT - 3

The multiple elements of BAS were isolated into separate files in IDA ICE and tested individually to evaluate the exact energy reductions attainable from the individual systems.





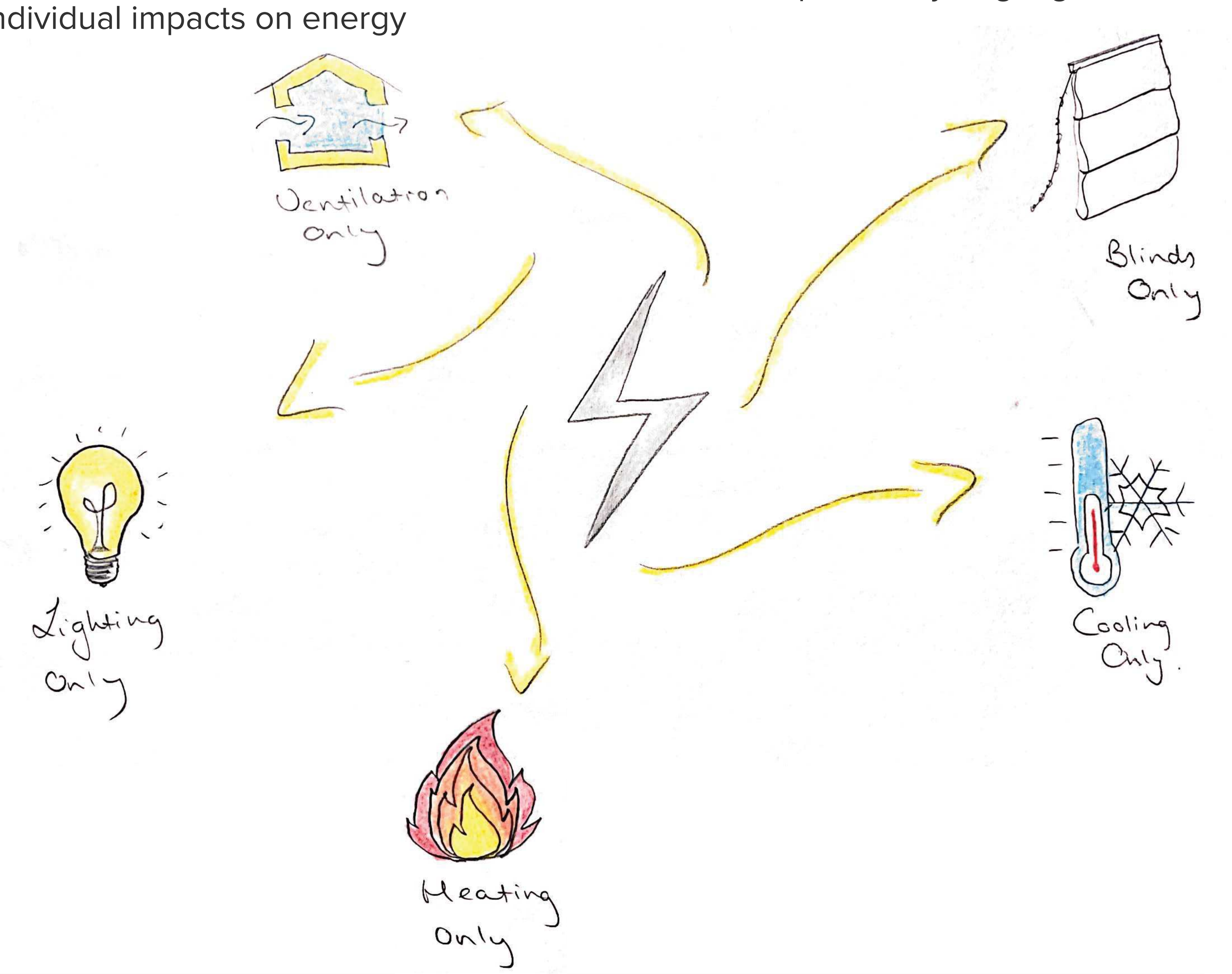



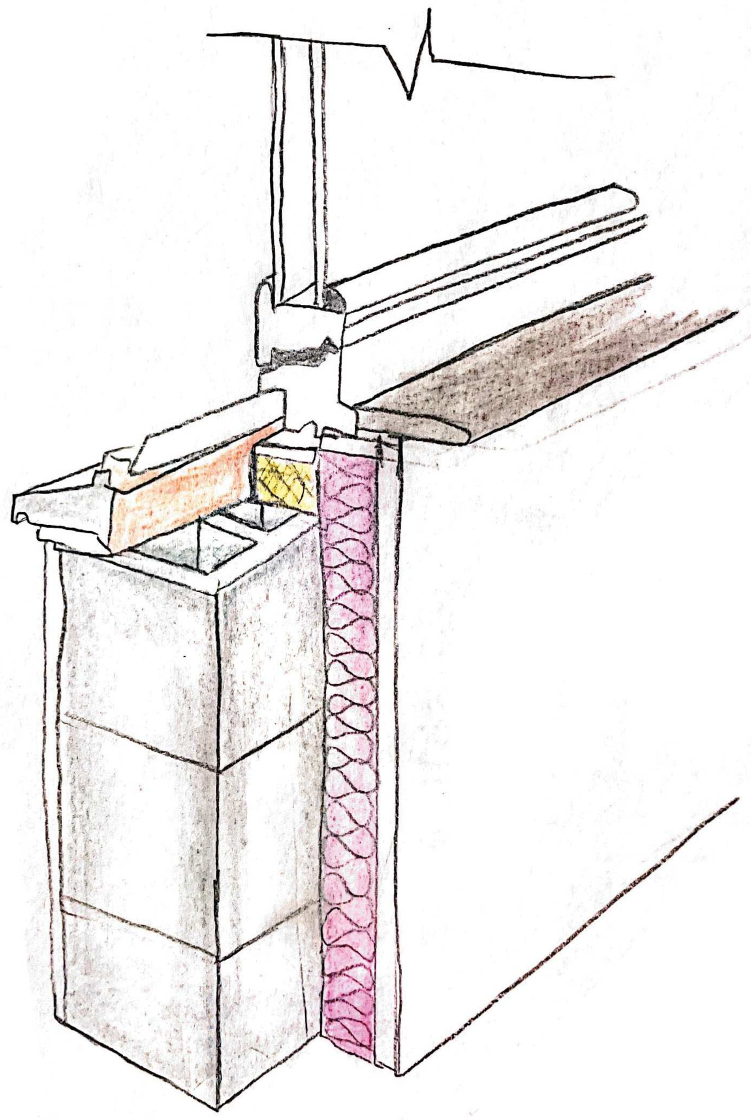
Proposed Cavity Wall Retrofit

Proposed Hollowblock Wall Retrofit

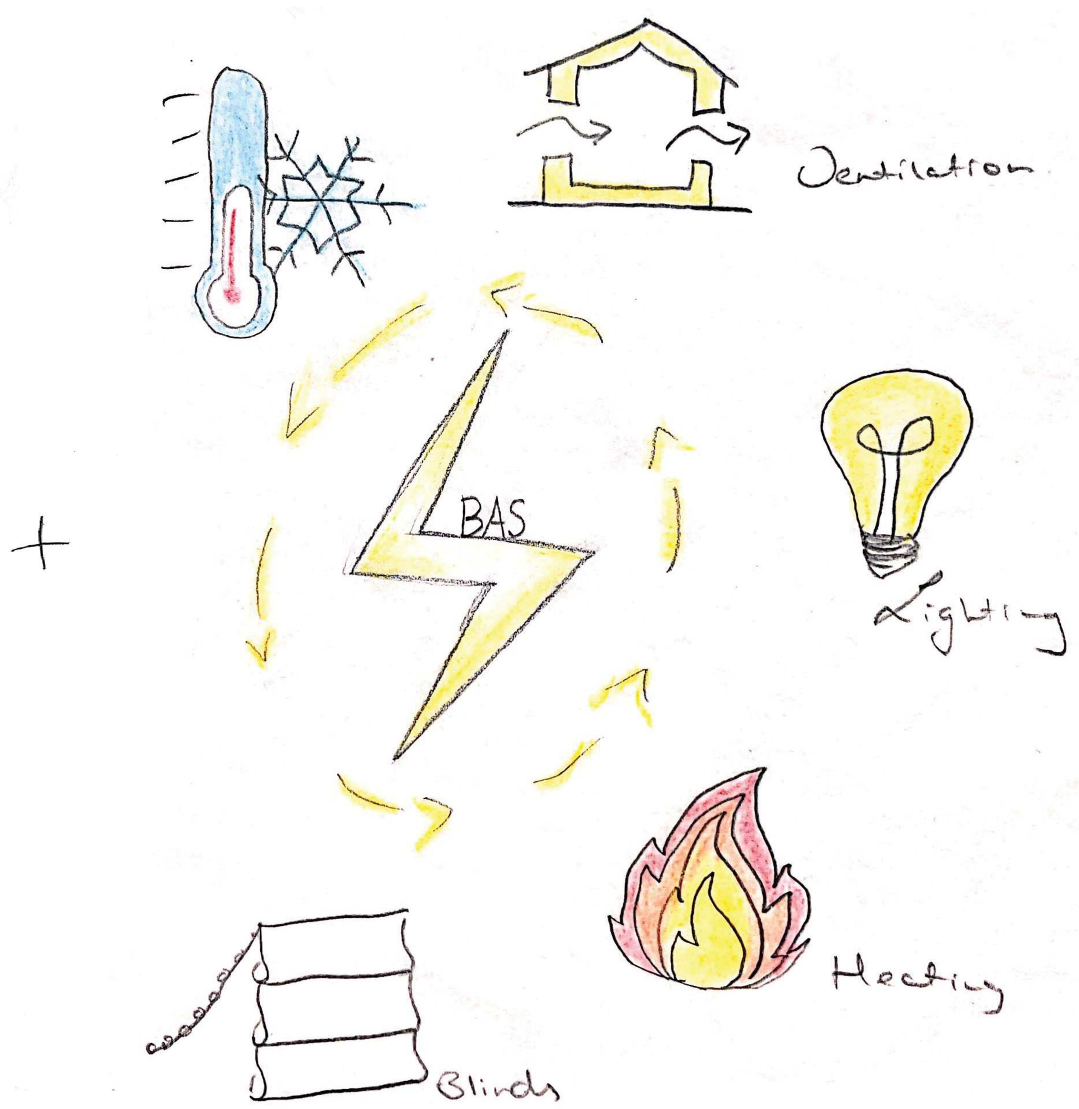
The impact of an envelope retrofit alone was assessed independently of BAS.

Various elements of BAS were isolated and tested independently to gauge the individual impacts on energy



3D Sketched Detailed Section of Existing Hollowblock Wall




The IDA ICE model was initially created to resemble the existing building.

The existing envelope and all of the building systems were recreated in IDA ICE, alongside a chosen climate file and occupancy/usage schedules.

The model was then developed 3 separate times, each time producing a new output.

The total of 4 outputs are as follows;

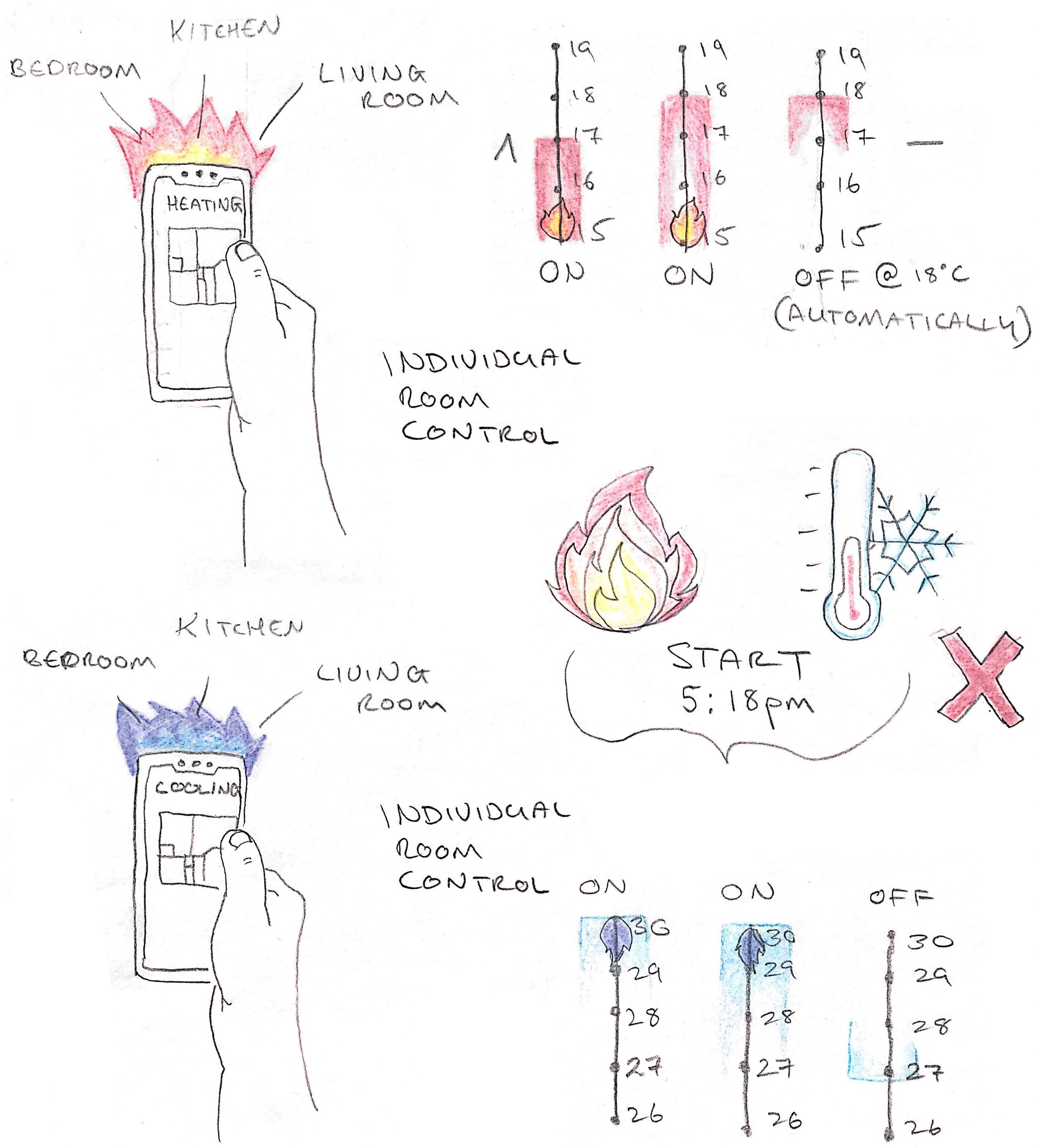
- Basic simulation (Existing building)
- Envelope retrofit alone
- BAS + Envelope Retrofit
- BAS Alone (elements tested separately)

To ensure accuracy in results, certain aspects of the simulations were kept at a constant throughout the entire process.

- Room occupancy schedules were kept at a constant throughout all simulations.
- Equipment (fireplace, hobs, boiler) usage schedules were kept at a constant throughout the entire process.

# TESTING - CONTINUED

All controls created in IDA ICE were based on the criteria outlined in BS EN 52120 to achieve an 'A' BAS efficiency class.

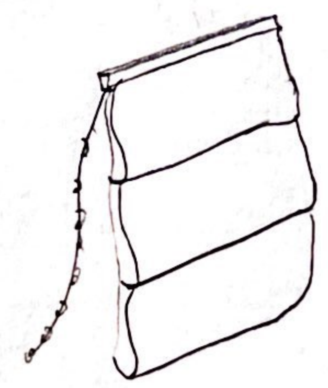



Heating and cooling follow the same criteria in BS EN 52120. To achieve an 'A' BAS efficiency class, the following are necessary;

- Individual room control
- Automatic intermittent control, with demand evaluation
- Total interlock between heating and cooling that warrants no simultaneous operation.

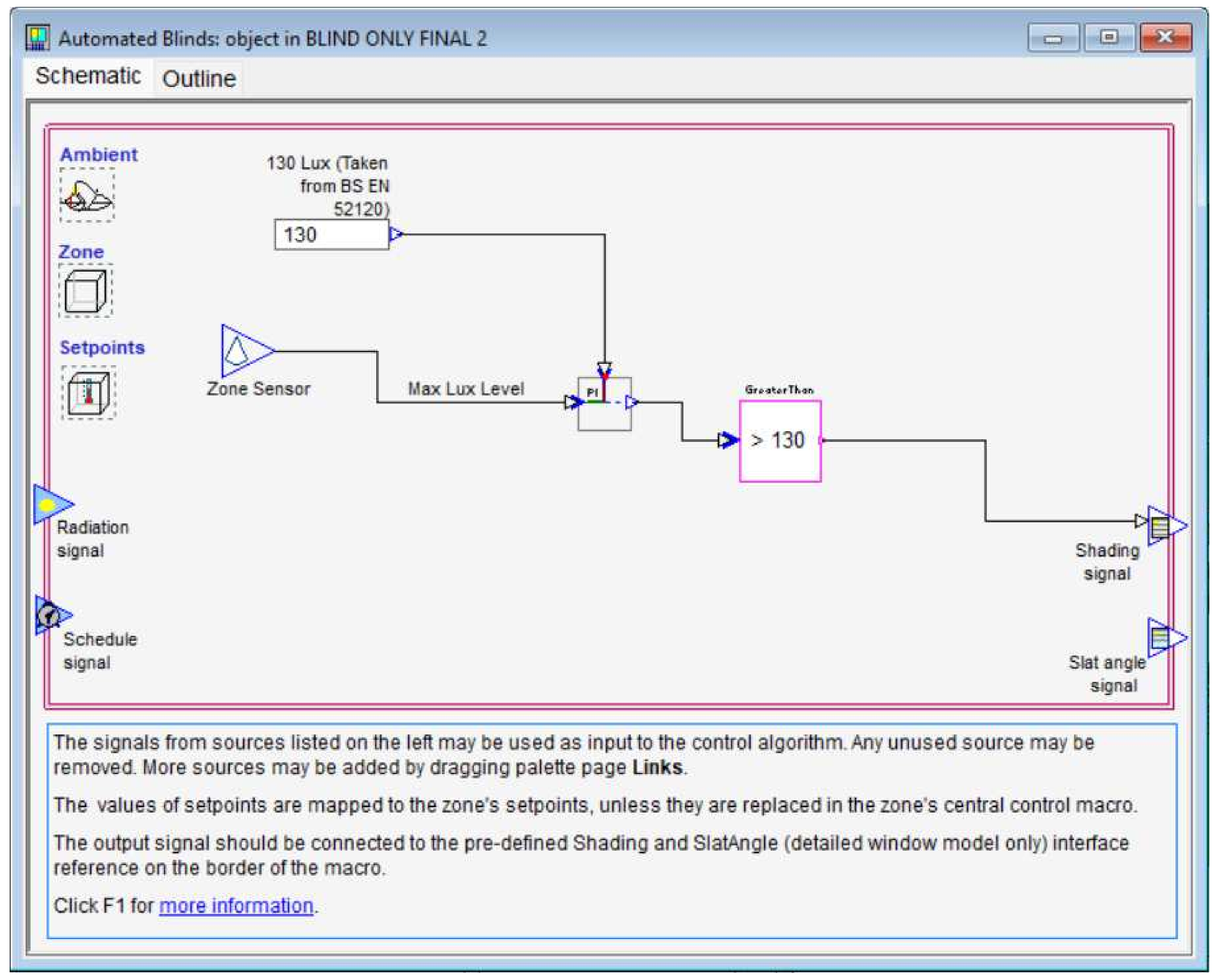
Automated blinds were implemented and assessed for their energy impact, due blinds being one of the seven elements of BAS.

The case study building only has black-out blinds. For the implementation of BAS, the blinds were set to 'Always Drawn' in IDA ICE, and only opened when the illuminance level in the room exceeded 130 w/m² (130w/m² taken from BS EN 52120).



BS EN 52120 outlines that there are two different motivations for blind control: solar protection to avoid overheating and to avoid glaring.
For automatic blinds to achieve an 'A' BAS efficiency class, the following are necessary;

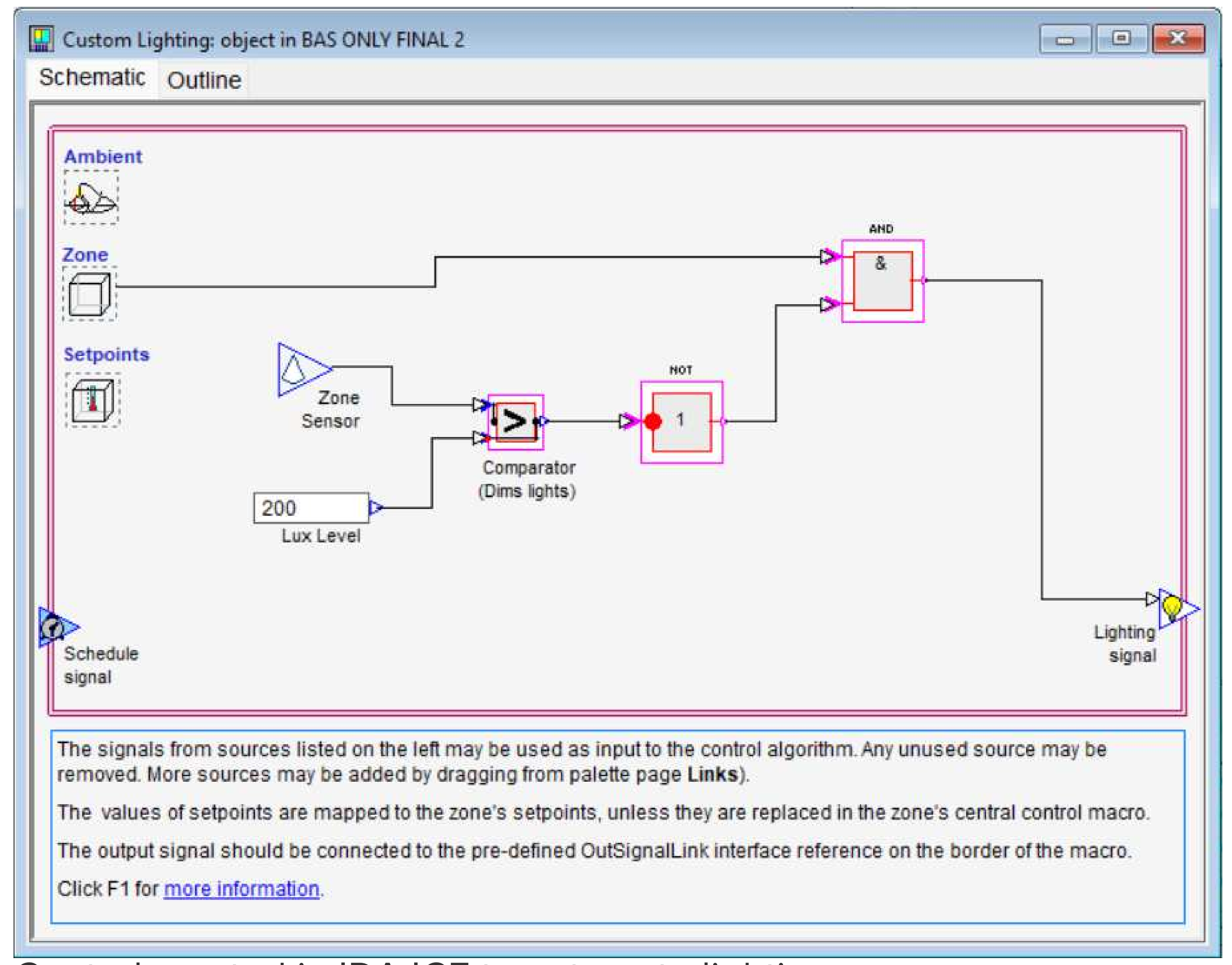
- Combined light/blind/HVAC control: to optimise energy use for HVAC, blind and lighting for occupied and non-occupied rooms.




Automatic lighting was implemented and assessed for the energy impact

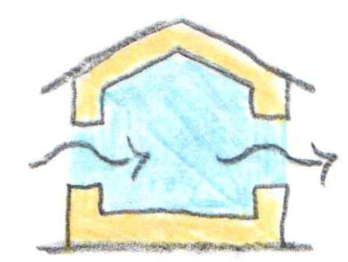
BS EN 52120 outlines two criteria to achieve an 'A' BAS efficiency class.

- Automatic occupancy detection
- Automatic dimming of lights according to current illuminance levels.



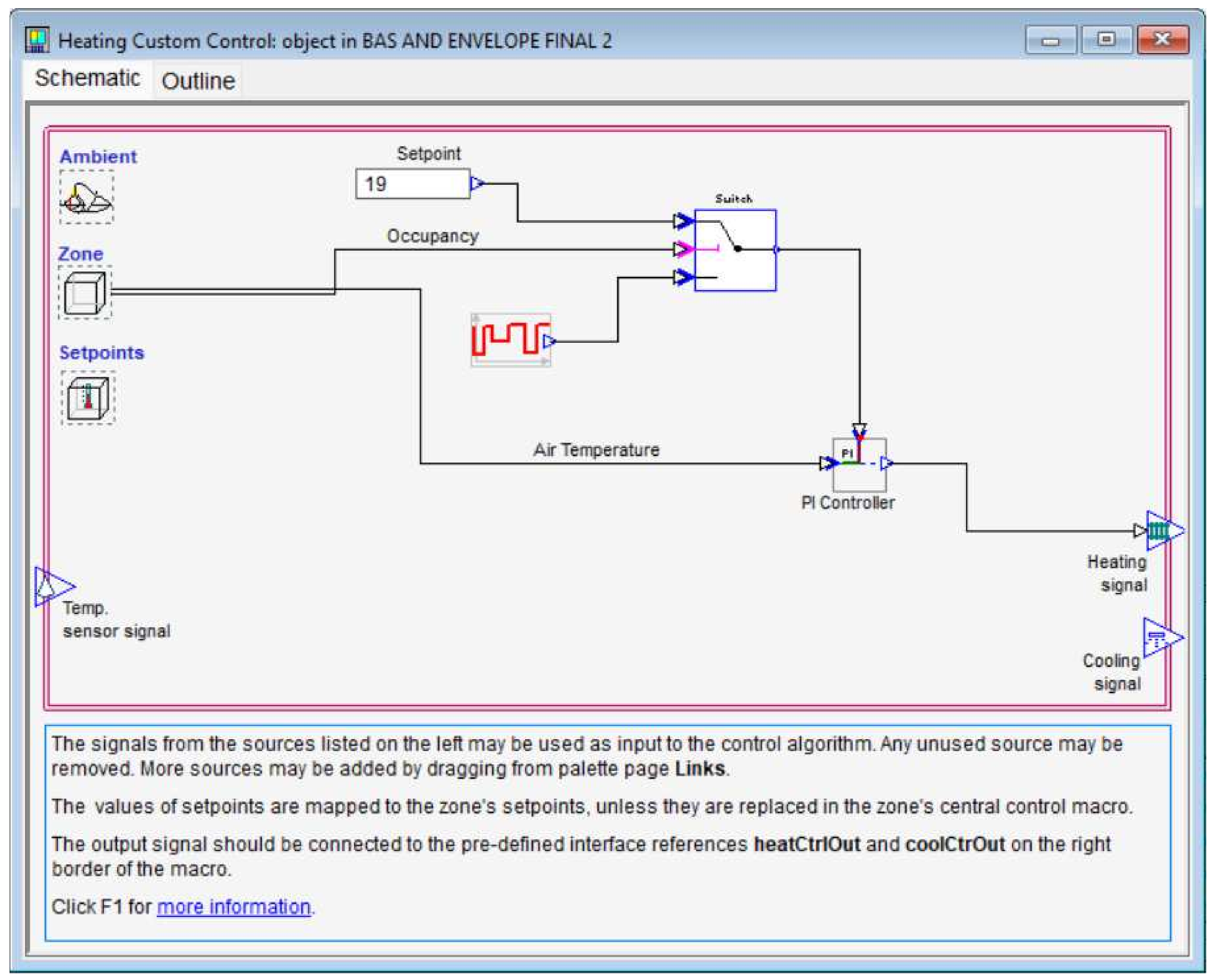

Control created in IDA ICE to automate lighting.

Automatic ventilation was hypothetically implemented and virtually tested to evaluate the impact on energy.

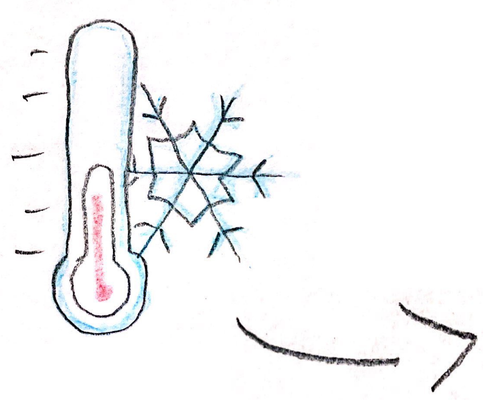


An 'A' BAS efficiency class is achieved for ventilation through;

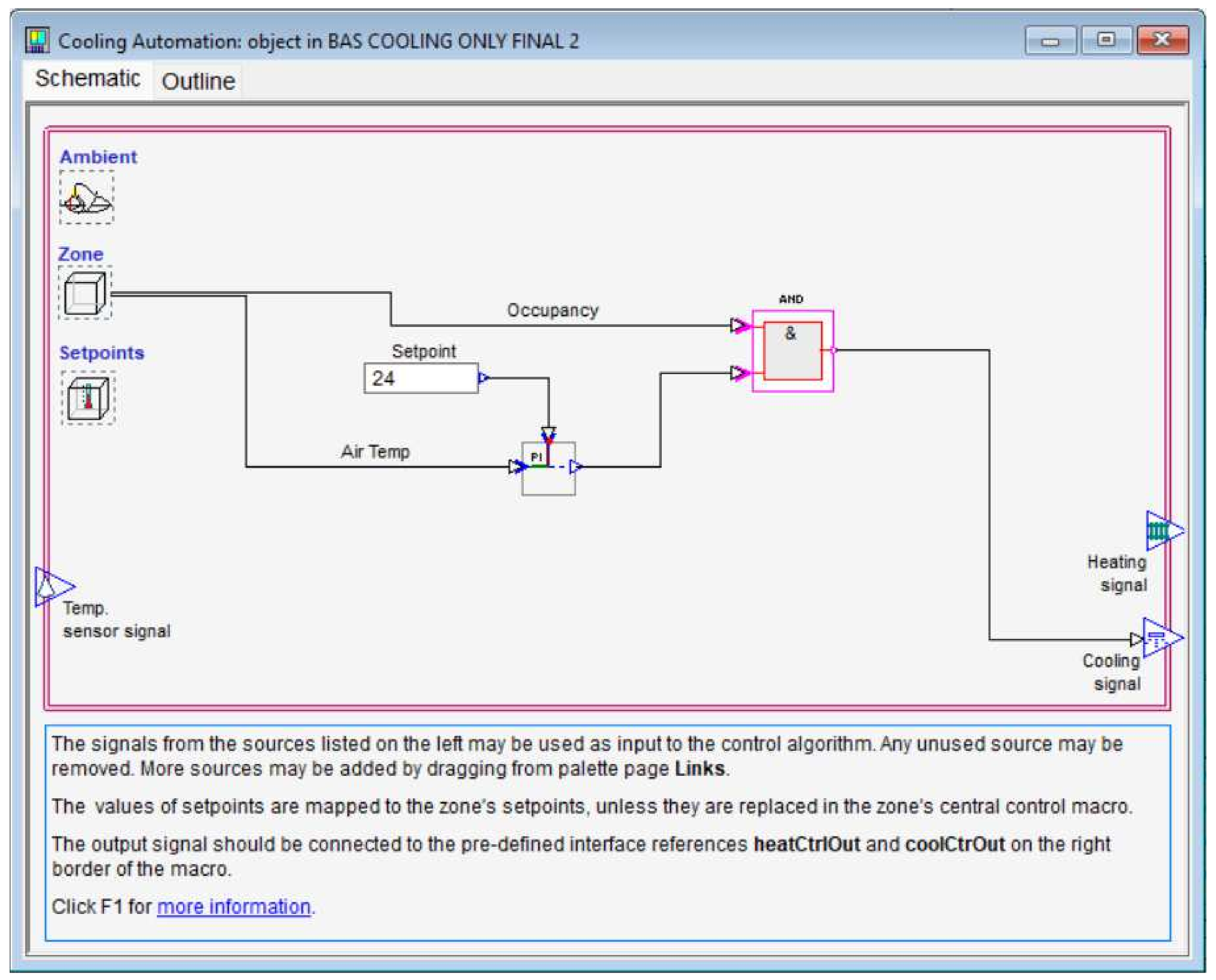
- Optimised control of the air temperature
- Demand control of the air flow rate
- Direct air quality control
- Night time cooling

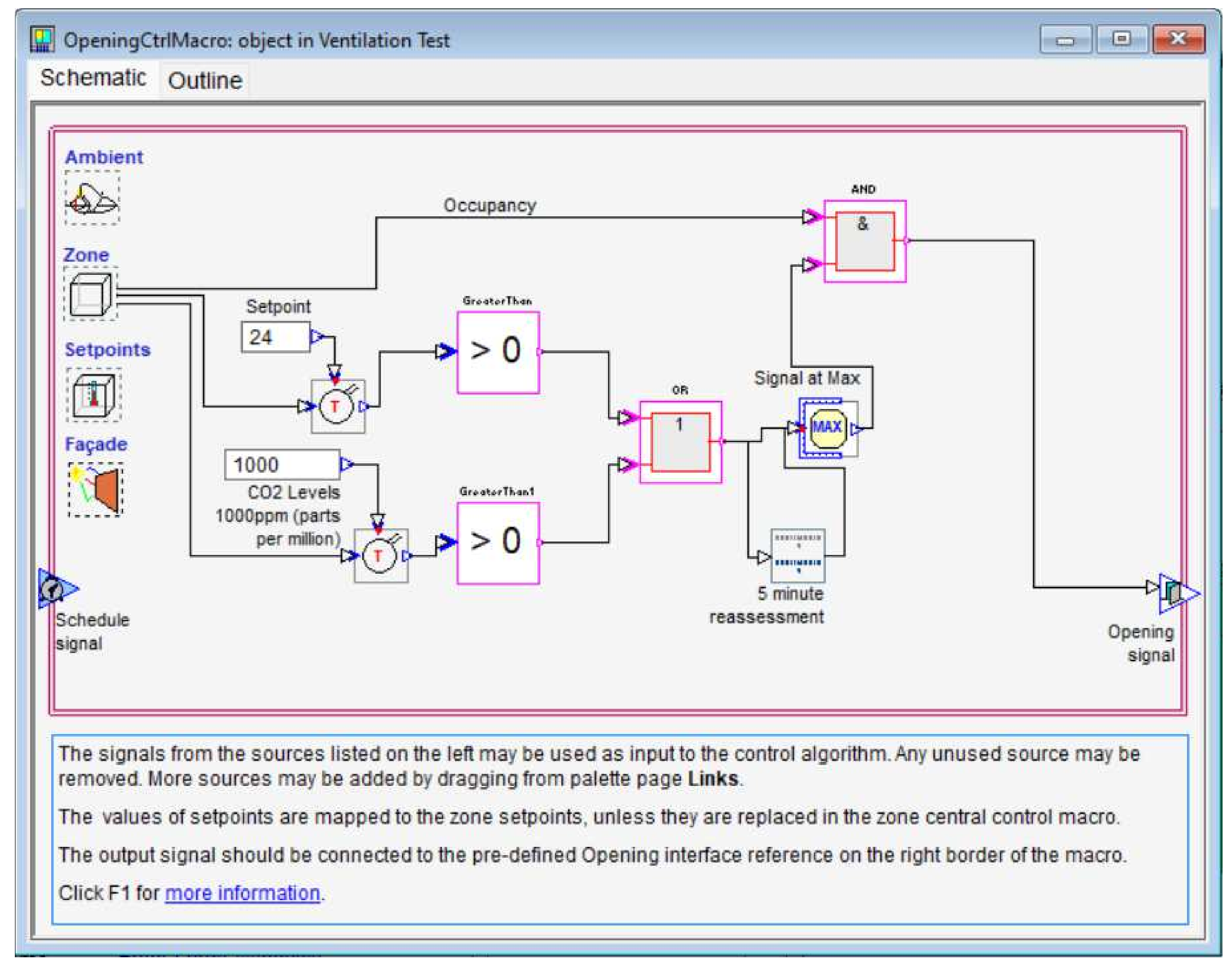



Heating control used to automate heating in IDA ICE



Cooling control used to automate cooling in IDA ICE
Cooling was hypothetically tested in this study.



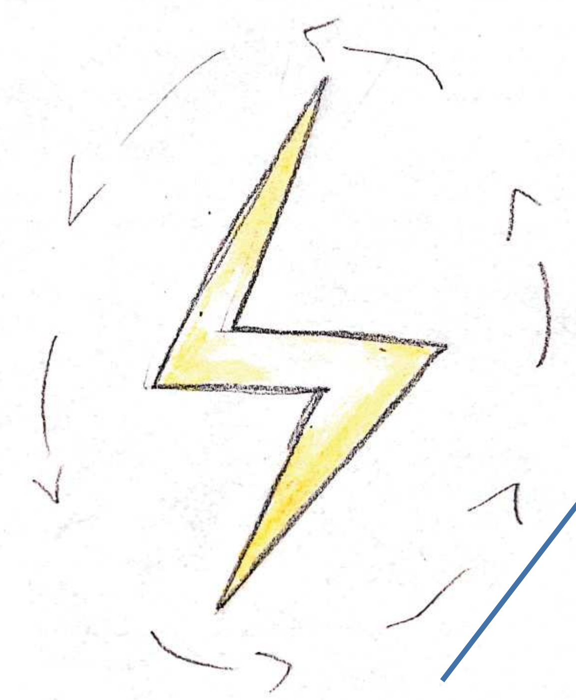



# RESULTS

## IDA ICE Validation

Gas Bills

| 2020 | 2021 | 2022 |
| --- | --- | --- |
| 17367kWh | 14482kWh | 11944kWh |



IDA ICE Result - Basic Simulation

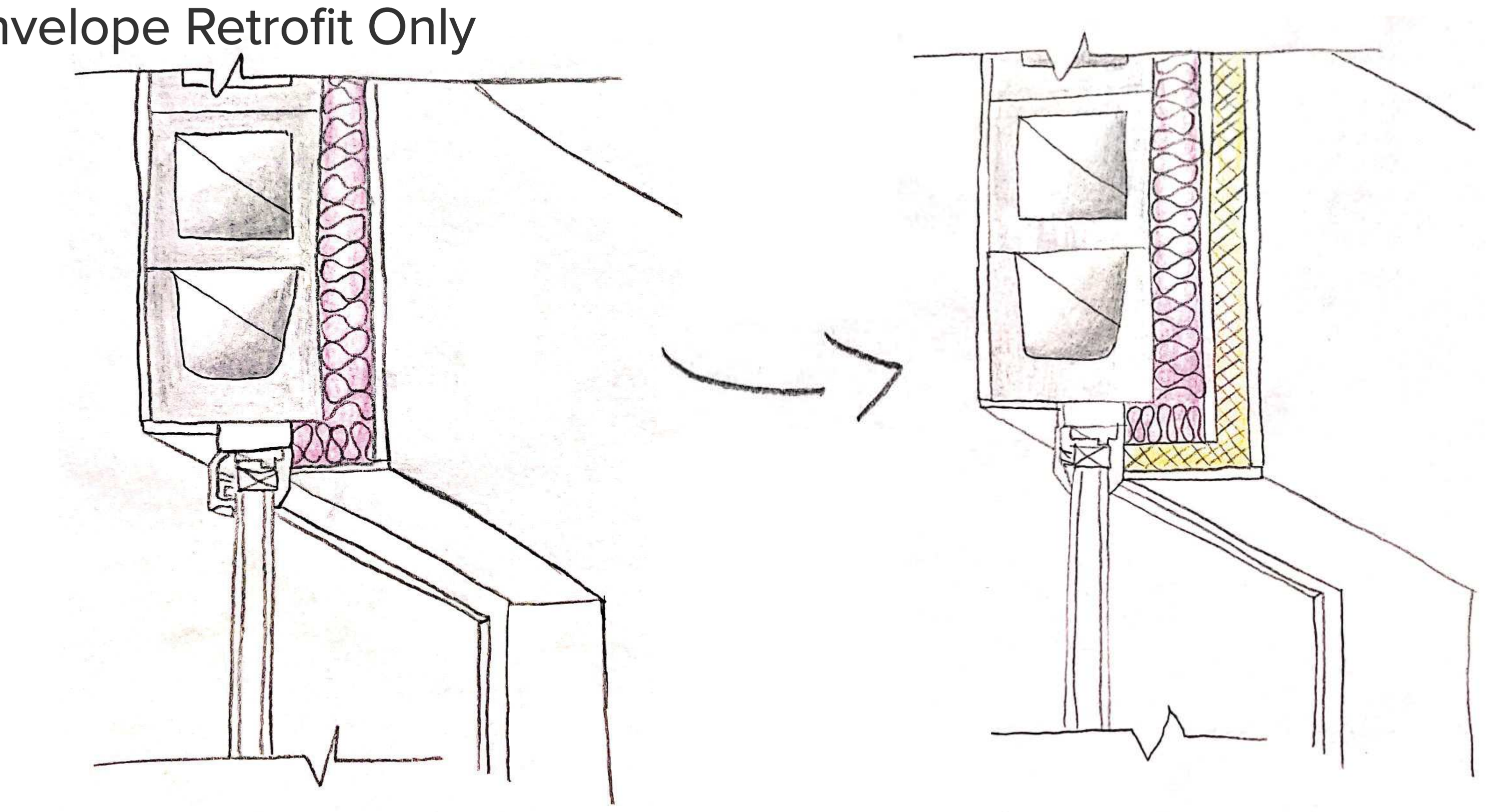
*14544kWh*

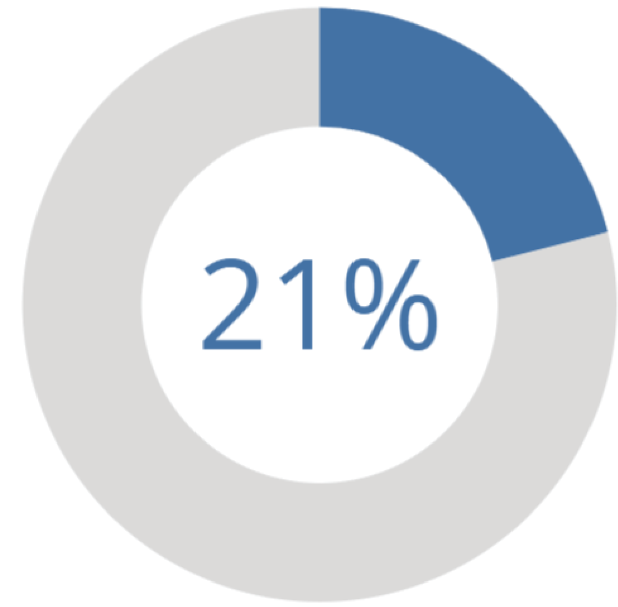
Average of 3 years - 14598kWh

The basic simulation without any BAS implementation yielded a result of 14544kWh for 2022.

This result was used as a base line for the rest of the simulations.

## Envelope Retrofit Only



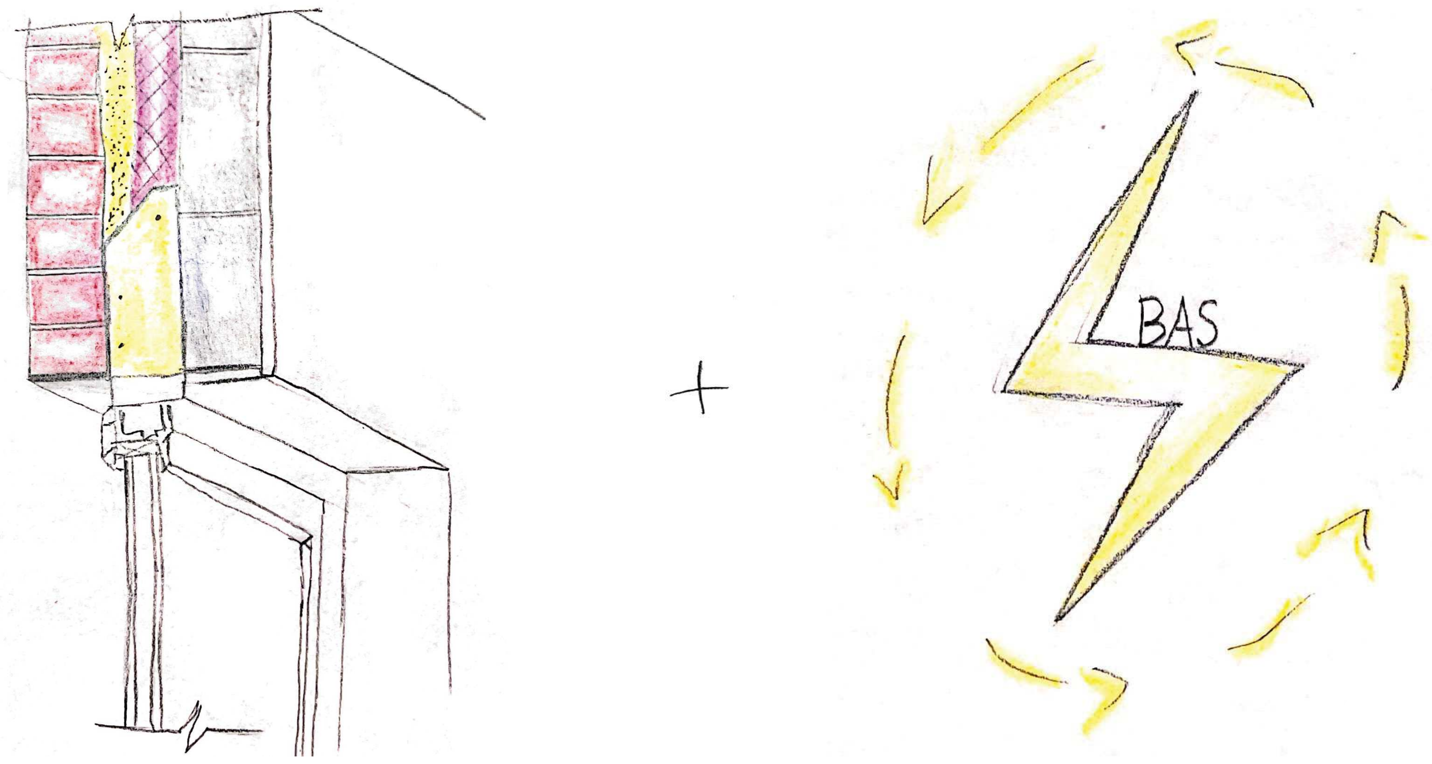


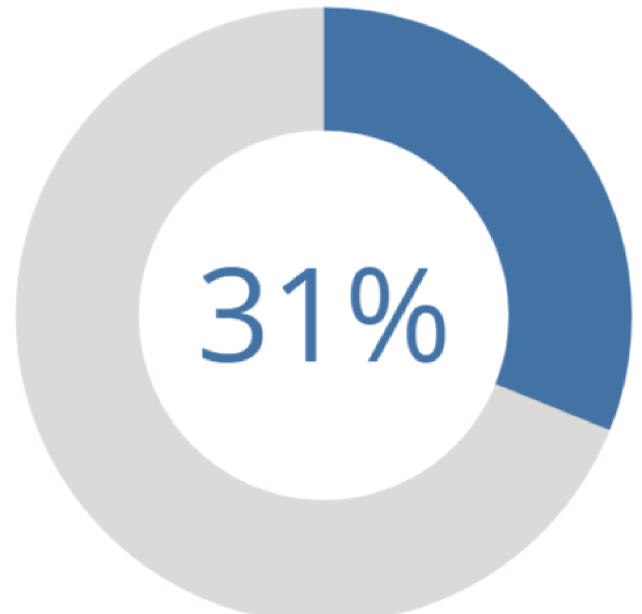

IDA ICE Result - Envelope Retrofit only

*11446kWh*

*Overall Gas Usage*

## Envelope Retrofit + BAS Implementation



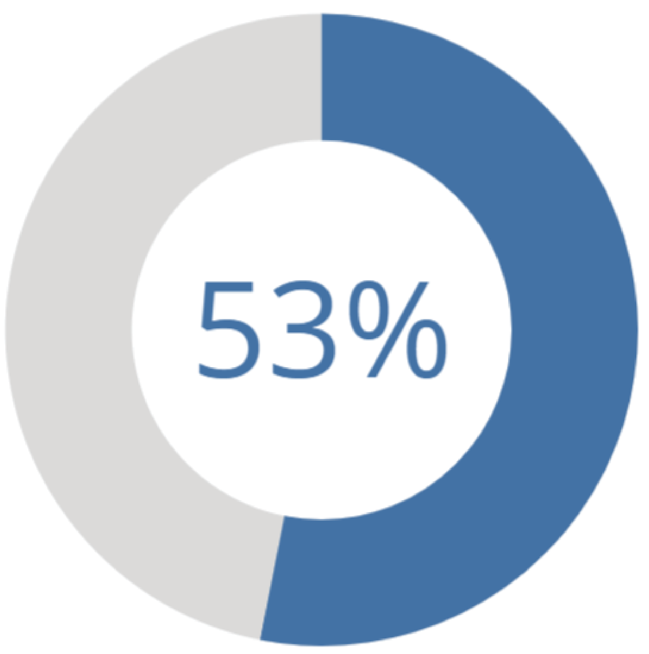




IDA ICE Result - Envelope Retrofit only

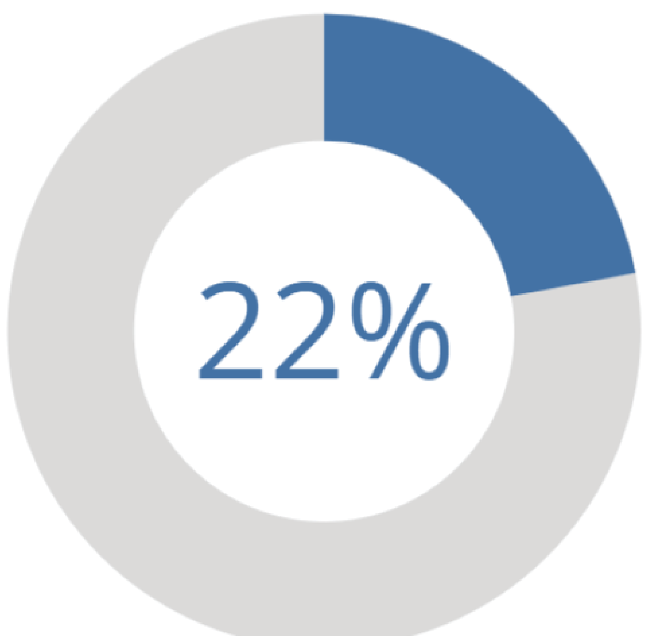
*10042kWh*

*Overall Gas Usage*

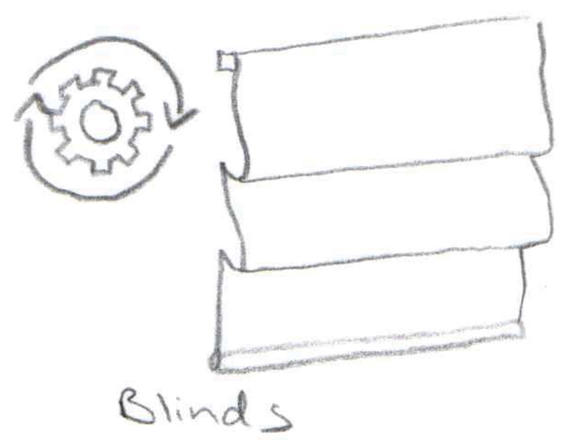
## BAS Isolation

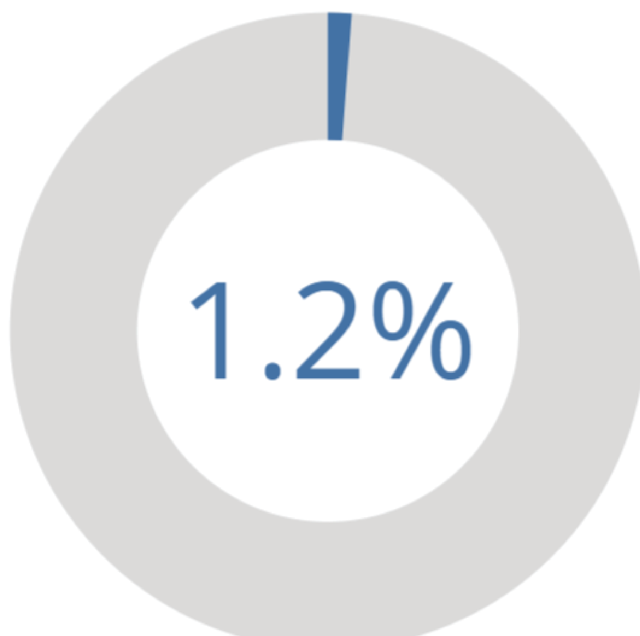




*Electricity used to power lighting from 1010kWh to 474kWh*

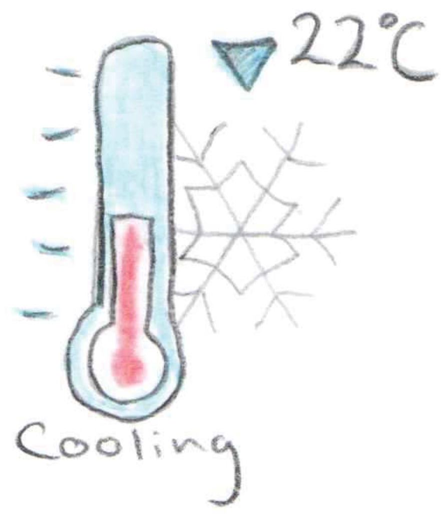



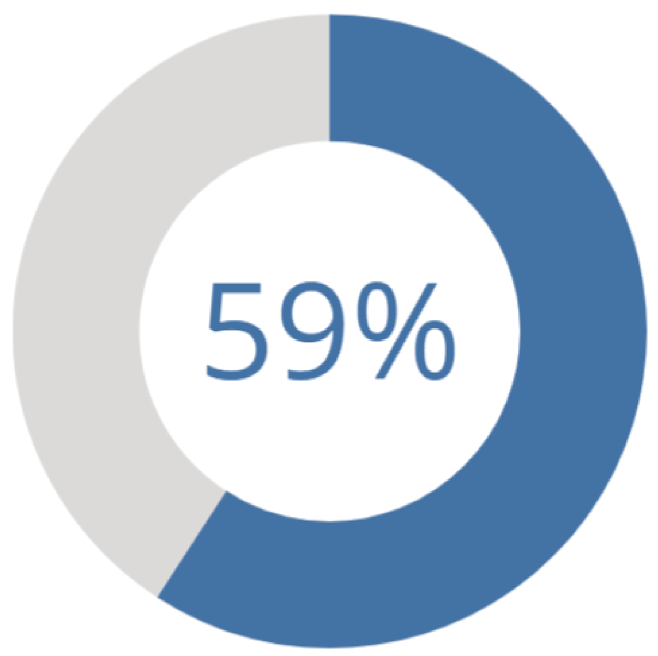

*Overall gas usage from 14544kWh to 11345kWh*



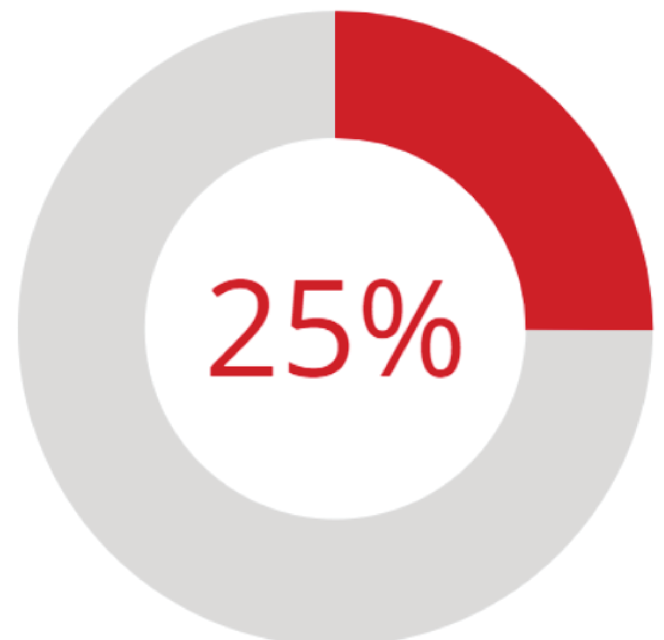

*Overall gas usage from 14544kWh to 14373kWh*




*Electricity used to power cooling from 922kWh to 381kWh*

Hypothetical


*Overall gas usage from 14544kWh to 18177*

# RESULTS ANALYSIS

## Validation

The IDA ICE validation consisted of a basic simulation, without any BAS implementation, and a comparison of the result to previous gas bills. This process yielded a result of 14544kWh.

There was disparity in the kWh as shown in the gas bills which were analysed. The disparity may have been due to the following;

- 2020 (17367kWh) : COVID-19 Global Pandemic, National lockdown lead to the population staying indoors, which may be why the kWh for 2020 is quite high.

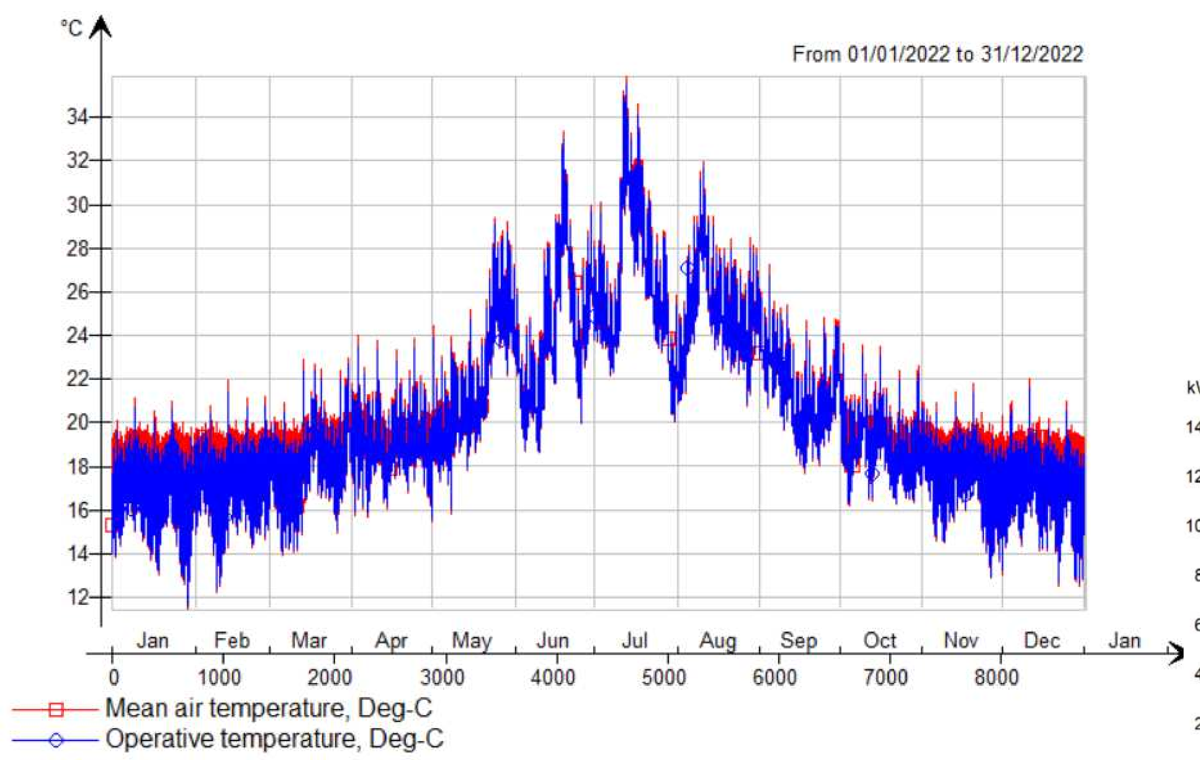
- 2022 (11944kWh) : Russia invades Ukraine, leading to a rise in gas prices. Due to the rise in gas prices, there was more caution around gas usage.

A thermometer was used in this study to establish heating setpoints for the simulations. Setpoints in this study refer to the temperature at which automated heating will automatically cut off.

In the basic simulation, the setpoint (19°C) was used to mimic human behaviour, where humans will turn on the heating if it gets cold.

The boiler was set to turn on 4 times everyday from November 1st to March 31st, in 1 hour blocks (6am, 10am, 2pm, 6pm). If the temperature was above 19°C at the start of any of these 1 hour blocks, the boiler did not heat the radiators. This means the radiators would have turned on 3-4 times everyday in December/January, when the temperature is consistently below 19°C, and would have only turned on once or twice in the warmer months, due to the house temperature being above 19°C. The graphs below shows how the setpoint impacted the results.

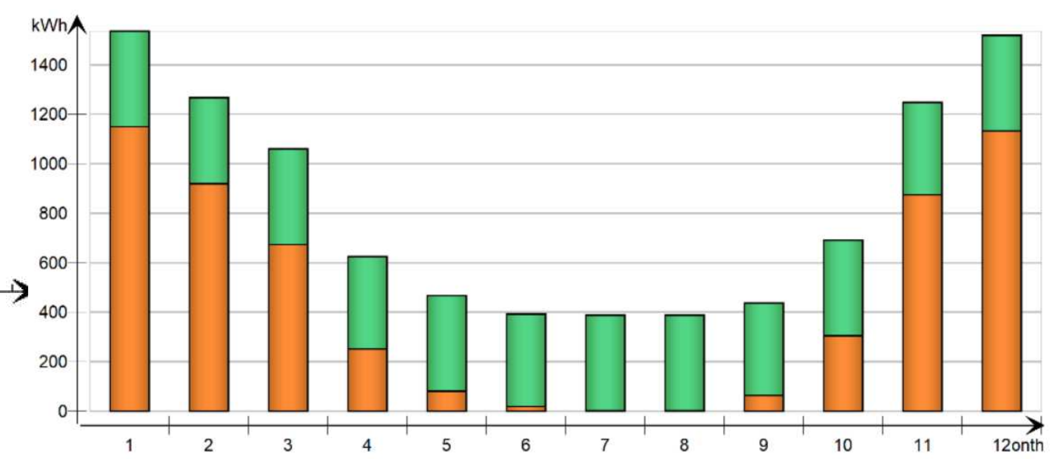
These results show that using the temperature setpoint to mimic human behaviour around heating habits was correct.




Temperature in utility room during year

**kWh (sensible and latent)**

| Month | Zone heating | Zone cooling | AHU heating | AHU cooling | Dom. hot water |
|---|---|---|---|---|---|
| 1 | 1150.0 | 0.0 | 0.0 | 0.0 | 385.8 |
| 2 | 920.1 | 0.0 | 0.0 | 0.0 | 348.5 |
| 3 | 674.2 | 0.0 | 0.0 | 0.0 | 385.8 |
| 4 | 252.6 | 0.0 | 0.0 | 0.0 | 373.4 |
| 5 | 80.6 | 0.0 | 0.0 | 0.0 | 385.8 |
| 6 | 19.3 | 0.0 | 0.0 | 0.0 | 373.4 |
| 7 | 3.2 | 0.0 | 0.0 | 0.0 | 385.8 |
| 8 | 2.2 | 0.0 | 0.0 | 0.0 | 385.8 |
| 9 | 63.7 | 0.0 | 0.0 | 0.0 | 373.4 |
| 10 | 304.3 | 0.0 | 0.0 | 0.0 | 385.8 |
| 11 | 875.2 | 0.0 | 0.0 | 0.0 | 373.4 |
| 12 | 1133.0 | 0.0 | 0.0 | 0.0 | 385.8 |
| Total | 5478.4 | 0.0 | 0.0 | 0.0 | 4542.7 |




kWh used in Building Throughout year

## Envelope Retrofit

The IDA ICE simulation yielded that an envelope retrofit to TGD L standards returned a 21% decrease in energy. The setpoint in this simulation was also set to 19°C, mimicking human behaviour in the same way as the basic simulation. This lead to the higher performing envelope taking pressure off the heating system.

The zone heating significantly reduced in expended energy, dropping from 5186kWh to 2289kWh to heat all rooms for the year.

Inspection of results show that the upgraded windows were the most effective retrofitting measure. Retrofitting the wall made minimal difference, potentially due to this study only retrofitting to TGD L's alteration of material guidelines.

**All zones**

**kWh (sensible only)**

| Month | Envelope & Thermal bridges | Internal Walls and Masses | Window & Solar | Mech. supply air | Infiltration & Openings | Occupants | Equipment | Lighting | Local heating units | Local cooling units | Net losses |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1241.0 | -26.1 | -465.7 | 0.0 | -4.4 | 73.1 | 463.7 | 86.8 | 1092.5 | 0.0 | 21.6 |
| 2 | -1104.6 | -20.2 | -317.7 | 0.0 | -3.9 | 65.5 | 414.6 | 77.6 | 872.1 | 0.0 | 17.1 |
| 3 | -1131.1 | -32.3 | -53.6 | 0.0 | -3.8 | 72.7 | 416.2 | 85.3 | 635.5 | 0.0 | 12.1 |
| 4 | -977.4 | -0.1 | 179.1 | 0.0 | -3.0 | 72.7 | 404.4 | 83.1 | 236.8 | 0.0 | 3.7 |
| 5 | -997.9 | -54.2 | 396.5 | 0.0 | -3.2 | 77.1 | 424.6 | 85.5 | 74.8 | 0.0 | 0.3 |
| 6 | -921.2 | -18.2 | 368.9 | 0.0 | -3.0 | 71.8 | 404.2 | 82.0 | 17.9 | 0.0 | -0.8 |
| 7 | -949.8 | 25.7 | 341.8 | 0.0 | -3.4 | 70.6 | 424.8 | 85.9 | 3.0 | 0.0 | -1.2 |
| 8 | -898.5 | -25.4 | 347.9 | 0.0 | -2.6 | 78.0 | 416.2 | 84.9 | 2.0 | 0.0 | -1.2 |
| 9 | -780.2 | 8.8 | 152.7 | 0.0 | -2.0 | 73.3 | 404.3 | 82.3 | 59.2 | 0.0 | 0.0 |
| 10 | -867.5 | 13.8 | -24.3 | 0.0 | -2.2 | 74.7 | 424.9 | 86.7 | 286.9 | 0.0 | 4.8 |
| 11 | -1077.8 | 2.7 | -325.8 | 0.0 | -3.6 | 69.8 | 404.2 | 82.7 | 828.7 | 0.0 | 16.2 |
| 12 | -1218.2 | -11.1 | -480.1 | 0.0 | -4.1 | 72.4 | 455.6 | 86.0 | 1076.7 | 0.0 | 21.3 |
| Total | -12165.3 | -136.6 | 119.6 | 0.0 | -39.5 | 871.8 | 5057.7 | 1008.8 | 5186.0 | 0.0 | 93.9 |
| During heating (MIXED h) | -6061.4 | 1806.8 | -1512.2 | 0.0 | 423.8 | 465.5 | 50.0 | 440.0 | 4225.3 | 0.0 | 72.5 |
| During cooling (MIXED h) | -4923.4 | -1637.0 | 1438.4 | 0.0 | -523.0 | 310.6 | 4891.1 | 449.8 | 39.7 | 0.0 | -1.3 |
| Rest of time | -1180.5 | -306.4 | 193.4 | 0.0 | 59.7 | 95.7 | 116.6 | 119.0 | 921.0 | 0.0 | 22.7 |

Basic simulation, without envelope or system retrofit.

**All zones**

**kWh (sensible only)**

| Month | Envelope & Thermal bridges | Internal Walls and Masses | Window & Solar | Mech. supply air | Infiltration & Openings | Occupants | Equipment | Lighting | Local heating units | Local cooling units | Net losses |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1028.9 | -22.9 | -159.7 | 0.0 | -5.6 | 74.5 | 463.4 | 86.5 | 580.7 | 0.0 | 11.0 |
| 2 | -918.6 | -20.8 | -38.3 | 0.0 | -5.1 | 66.6 | 414.6 | 77.4 | 415.6 | 0.0 | 7.6 |
| 3 | -987.2 | -39.1 | 232.0 | 0.0 | -5.5 | 74.2 | 416.7 | 85.0 | 221.5 | 0.0 | 3.4 |
| 4 | -976.5 | -0.7 | 396.4 | 0.0 | -6.2 | 75.4 | 404.3 | 83.2 | 23.9 | 0.0 | -0.7 |
| 5 | -1093.2 | -74.3 | 597.9 | 0.0 | -7.1 | 69.2 | 424.5 | 85.7 | 3.6 | 0.0 | -1.2 |
| 6 | -1057.0 | -13.4 | 538.6 | 0.0 | -7.2 | 54.4 | 404.4 | 82.2 | -0.0 | 0.0 | -1.2 |
| 7 | -1093.9 | 32.1 | 515.7 | 0.0 | -8.0 | 39.6 | 424.9 | 86.5 | 0.0 | 0.0 | -1.2 |
| 8 | -1034.7 | -28.1 | 507.1 | 0.0 | -6.5 | 63.3 | 416.4 | 85.0 | 0.0 | 0.0 | -1.2 |
| 9 | -869.1 | 22.2 | 286.8 | 0.0 | -5.2 | 76.9 | 404.3 | 82.6 | 0.2 | 0.0 | -1.2 |
| 10 | -837.9 | 23.1 | 161.4 | 0.0 | -4.7 | 76.5 | 425.0 | 86.5 | 66.8 | 0.0 | 0.1 |
| 11 | -908.5 | 12.1 | -56.1 | 0.0 | -4.9 | 71.1 | 404.3 | 82.6 | 389.6 | 0.0 | 6.9 |
| 12 | -1014.5 | -12.8 | -182.7 | 0.0 | -5.3 | 73.7 | 455.6 | 85.7 | 587.4 | 0.0 | 11.1 |
| Total | -11820.0 | -122.7 | 2799.1 | 0.0 | -71.1 | 815.4 | 5058.4 | 1008.8 | 2289.1 | 0.0 | 33.5 |
| During heating (MIXED h) | -2809.4 | 1078.7 | -371.0 | 0.0 | 200.2 | 304.4 | 3.2 | 230.0 | 1272.8 | 0.0 | 14.3 |
| During cooling (MIXED h) | -7822.0 | -1035.3 | 3021.3 | 0.0 | -316.3 | 422.8 | 5032.5 | 678.4 | 42.0 | 0.0 | -0.6 |
| Rest of time | -1188.6 | -166.1 | 148.8 | 0.0 | 45.0 | 88.2 | 22.7 | 100.4 | 974.3 | 0.0 | 19.8 |

Envelope retrofit simulation

## Envelope & BAS Retrofit

Combining an envelope retrofit with BAS yielded a lesser result than expected, of 31%. Previous studies on the impact of BAS on energy when combined with an envelope retrofit had acquired 57% in energy reductions. The lesser energy reductions in this study may have been due

## BAS Isolated into elements, Impact on energy?

Heating and lighting yielded the largest energy reductions in the final simulations.

Cooling was significantly higher than expected, which may have been due to the climate in which the simulations were completed. A setpoint of 24°C was chosen, which means without automation, if the building's mean temperature rose above 24°C, the cooling would turn on for an hour in the building. The smart cooling system would rectified this issue, leading to increased energy reductions from cooling.

Automated blinds did contribute greatly to positive energy reductions.

Automatic ventilation lead to significantly more energy being used throughout the year. A traditional MHVR which produces warm, fresh air may be a more attractive option.

# FUTURE WORKS

The scope of this project identified some key limitations to this research. In the event of future research being conducted on the energy impact of implementing BAS as a retrofitting measure, the following may be worthwhile to investigate.

This study only investigated one building typology. It is indicated in some studies that smaller buildings/apartments gain larger energy reductions from the implementation of

Additional years worth of gas bills may have effected the average kWh of the case study building. A larger sample of gas bills may have provided a slightly different result.

This study retrofitting to TGD L's requirements for alteration of materials. Retrofitting to NZEB/Passive House standards may provide different results.

# CONCLUSION

BAS is an attractive retrofitting measure, however, may mostly be utilised for the accompanied convenience of installing the systems.

Retrofitting walls to alteration of use guidelines in TGD L may not be the most effective retrofitting measure, however, retrofitting windows to these guidelines is highly effective.

Automation of heating and lighting significantly reduce energy, and would contribute positively to reducing the energy output of Irish homes.

Automatic cooling and ventilation may not be entirely effective in Ireland, due to the climate.

Automatic blinds can minorly reduce the energy output of Irish homes.

Colm Morris
C19446164
Supervisor - Tim O'Leary