



# **A Study into the use of Programmable Logic Controllers for control of lighting and heating within the home**

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## 1 Declaration

I, Shaun Farthing declare that I am the sole author of this Project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

## 2 Form of consent

I, Shaun Farthing hereby consent that my Project, submitted in candidature for the BEng (Hons) Electrical and Electronics degree, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

## 3 Abstract

The objective of this project is to create a user friendly, effective control system to allow the automation of heating and lighting systems within the home. The project direction will be focused on automation to create a more energy efficient home by limiting the energy usage from lighting and heating systems when they are not required. This project will include an overview of PLC's and their use in home automation. It will then present research into existing home automation control systems and traditional lighting and heating control. Focus then shifts to the development of the project plan. Equipment selection for this project is then compared, contrasted and selected. Associated project flow charts, software information and outcomes are displayed. Finally, all data and results are gathered and analysed.

## 4 Introduction

### 4.1 Background

#### 4.1.1 PLC

A PLC (programmable logic controller) is an industrial computer that has been designed and utilised for the control of automated devices in the fields of industrial process control, manufacturing control processes and various other processes that require automatic control. A typical PLC set up includes a range of input and output modules (IO), these consist of both analogue and digital, a central processing unit (CPU) and network connectivity unit. The PLC is a real time device that constantly monitors the state of a variety on input signals/ devices and makes calculated decisions based on a custom program that controls the state of output devices. There are 5 different PLC programming languages that form part of the International Electro technical Commission (IEC) standard 61131-3. There are 3 graphical languages; ladder diagram, function block diagram and sequential function chart, and, 2 textual languages; structured text and instruction list. The standard was produced to allow some standard rules around PLC programming languages.

#### 4.1.2 PLC in home automation

Home automation, also referred to as domotics or smart homes is a system of devices that allow a central control system to automatically control household appliances such as lighting, heating, CCTV, gates and blinds to be controlled from an automatic input or manual control from a central controller. As well as offering energy saving potential and ease of operation of household equipment, home automation systems can positively influence an elderly or disable person's quality of life by making everyday tasks easier with limited mobility. The ability to control lighting and heating systems via programmable logic controllers (PLC) lends itself to the concepts of smart homes and home automation. The concept of this is the integrating of intelligent technologies into residential spaces aiming to increase the quality of life. This emerging concept is a promising solution towards aspects of the building sector namely, energy consumption and environmental impacts. [1]

## 4.2 PLC block diagram

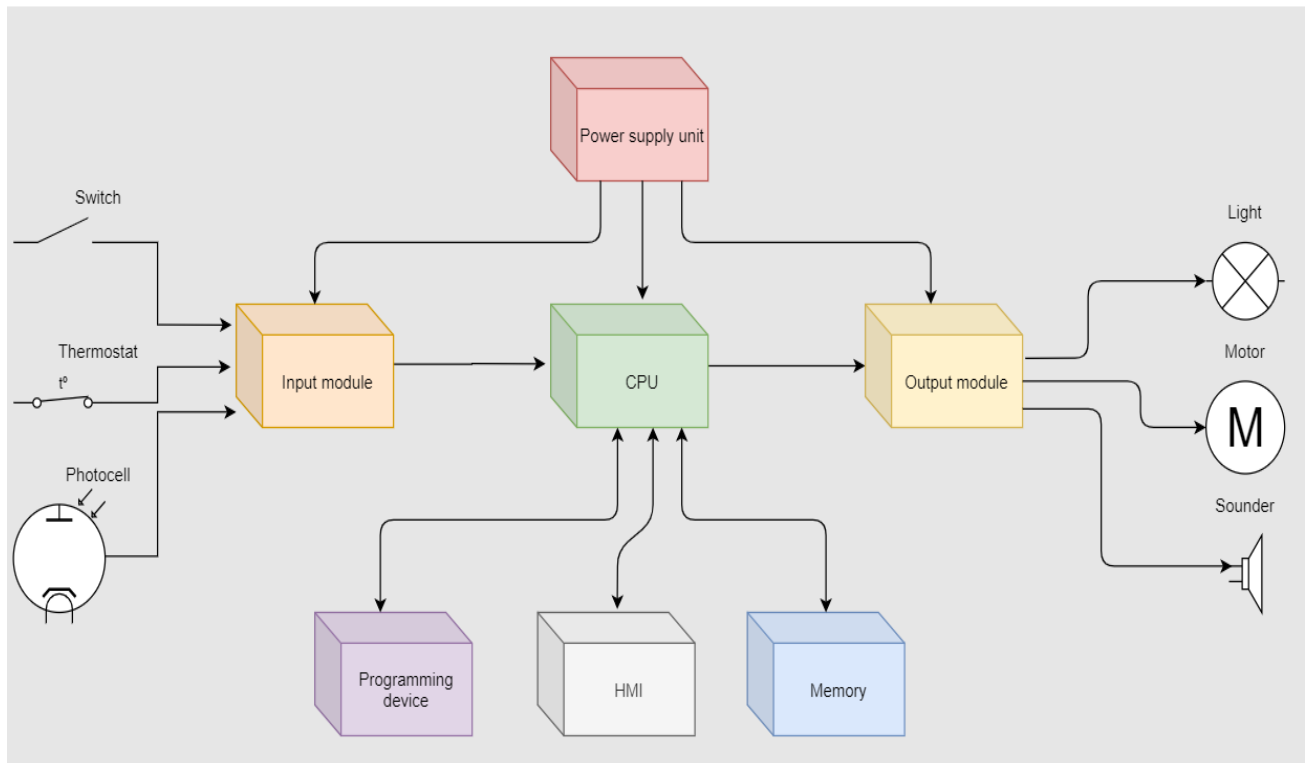


Figure 1-PLC block diagram

## 5 Aims

### 5.1 Lighting control

The aim of this project is to create a control system that automates the control and use of lighting within the home to ensure maximum efficiency and minimal energy usage. The project will incorporate a PLC to control and monitor the various inputs and outputs required, and a HMI for visual representation and manual control. The focus of the lighting control will be to monitor room occupancy and lux levels and output accordingly.

### 5.2 Heating control

The heating aspect of this project is to create a control system that automates the control and use of heating the home to ensure maximum efficiency and minimal energy usage and wastage. The project will incorporate a PLC to control the various inputs and outputs required and a HMI for visual representation and manual control. The focus of the heating control will be to monitor smaller, individual areas of the home and only heat the areas that are required.

## 6 Objectives

### 6.1 Lighting control

The objectives of the lighting control element of this project are;

- Construct a project plan/ timeline to ensure that key dates are met and to monitor that the individual project elements are achieved on time.
- Carry out research on existing lighting control systems.
- Review previous research articles and projects.
- Produce a system block diagram to highlight the different elements of the project.
- Research and compare hardware (PLC, HMI, light level sensors, motion sensors, light fittings, cabling, and enclosures), software (PLC), components (IO requirements) and other equipment required for the project.
- On completion of equipment review, procure and construct the individual elements.
- Produce a system flow chart to aid with software writing.
- Develop system to produce a working model.
- Monitor results and make amendments to improve system where possible.
- Evaluate results and findings to deem what was successful and what could be improved.
- Analyse findings of this project and compare to previous research.

## 6.2 Heating control

The objectives of the heating control element of this project are;

- Construct a project plan/ timeline to ensure that key dates are met and to monitor that the individual project elements are achieved on time.
- Carry out research on existing lighting control systems.
- Review previous research articles and projects.
- Produce a system block diagram to highlight the different elements of the project.
- Research and compare hardware (PLC, HMI, temperature sensors, heating pumps, cabling, and enclosures), software (PLC), components (IO requirements) and other equipment required for the project.
- On completion of equipment review, procure and construct the individual elements.
- Produce a system flow chart to aid with software writing.
- Develop system to produce a working model.
- Monitor results and make amendments to improve system where possible.
- Evaluate results and findings to deem what was successful and what could be improved.
- Analyse findings of this project and compare to previous research.

## 7 Project plan

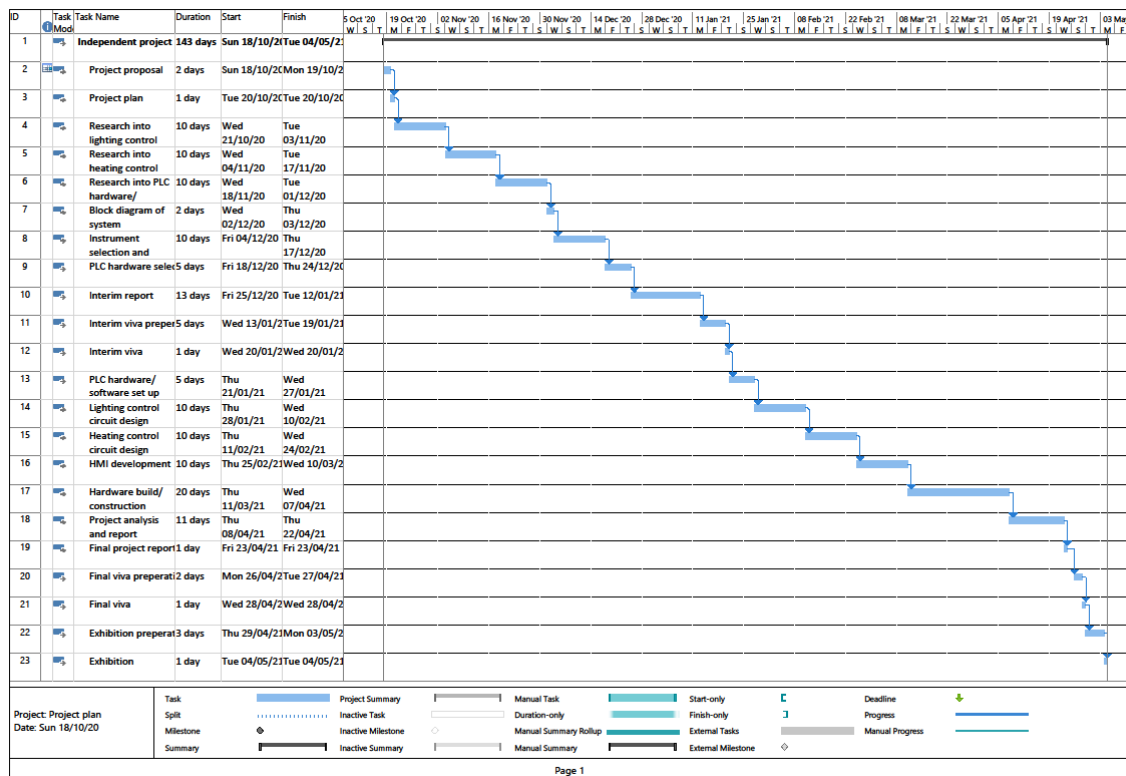


Figure 2 - Project plan

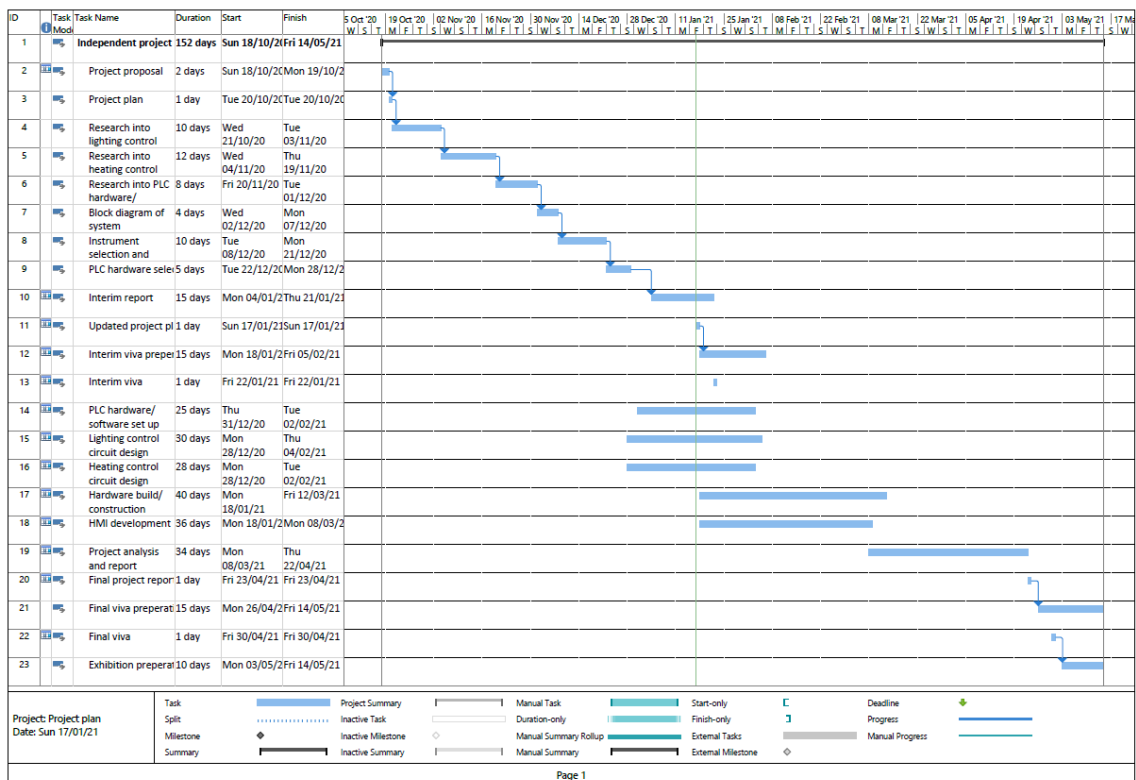


Figure 3 - Revised project plan at interim viva

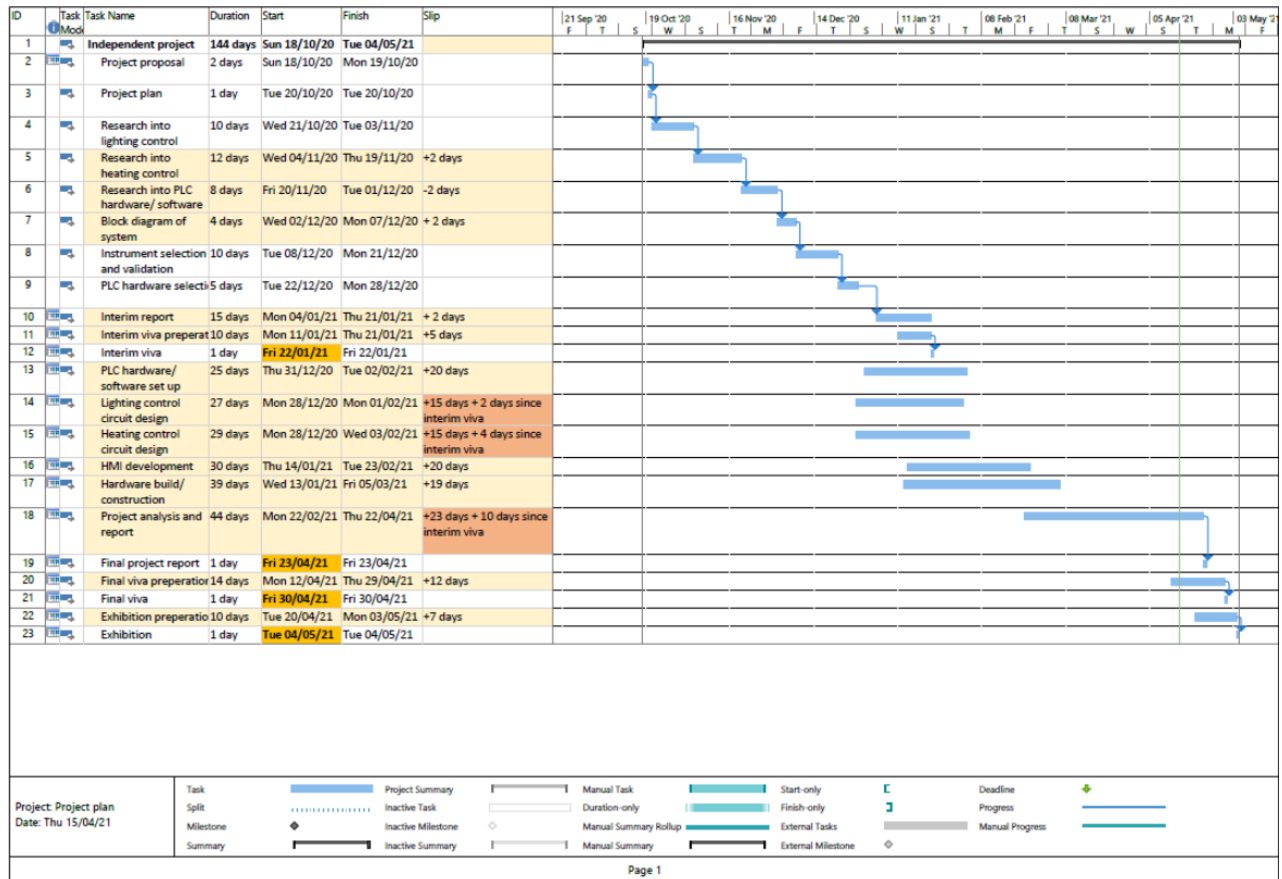


Figure 4 – Revised project plan at final viva

## 8 Research methodology

Prior to beginning my research, I referred to the 'Research onion' to determine a direction of research to ensure thorough and reliable information. The research onion proposed by Saunders et al. as detailed in the figure below displays the stages of research methodology in 6 sections. [2]

- Philosophy
- Approach
- Method
- Strategy
- Time horizons
- Data collection and analysis

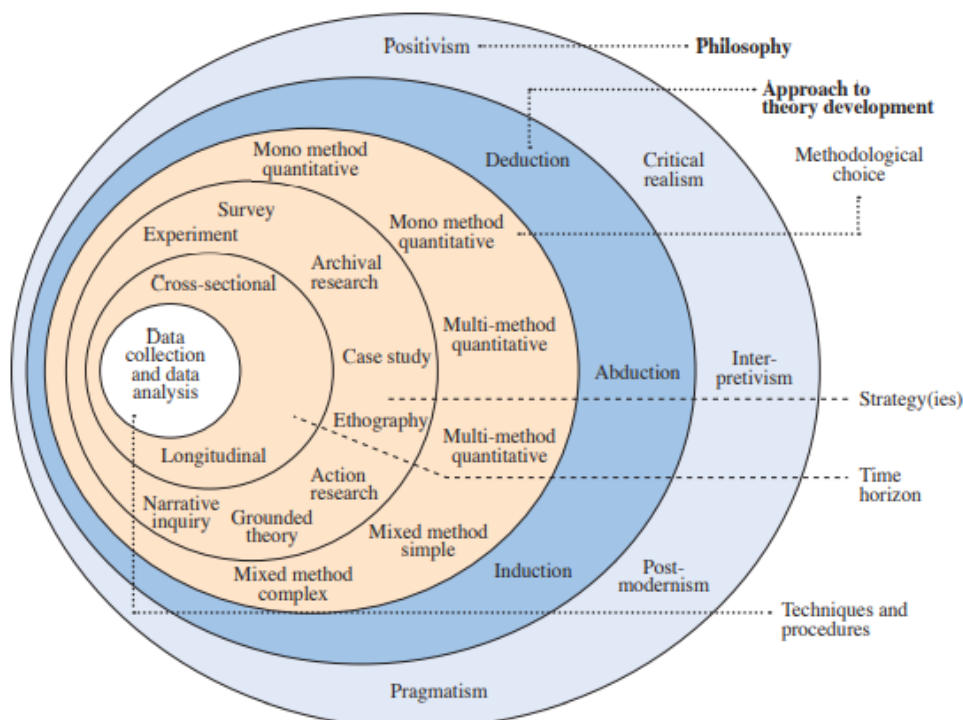


Figure 5 - Research onion

The philosophical stance I have taken with regard to this project is interpretivist. I have concluded this as the focus of interest is specific and the outcome of the research is to understand existing home automation systems. [3]

The theory development approach will be an inductive one. The existing systems will be observed and researched. The project direction will be determined as a result of theories and other systems observed during the research period. This will directly determine the project development as the project development will not progress until the research is complete. [3]

This project will incorporate a mixed method of qualitative and quantitative research methods as the research will consist of case studies and generalisations. There will be worded, system descriptions and numerical research with regard to energy usage and costs. [4]

The research strategy to be used for this project will be experimental. The research will be experimental as at this stage, we do not know whether a PLC will be capable or suitable for use in home automation.

A cross sectional time horizon will be used for this project. This is because there is a fixed completion date. Longitudinal time horizons often repeat the studies over an extended period, this will not be the case for this project. [3]

The data collected and analysed in this project will be both primary and secondary data. The secondary data will be present from existing systems, articles, books and websites that will be reviewed as part of the project development. The primary data collected and analysed will be from testing and analysing the project when it is a working prototype. [3]

## 9 Research/ literature review

### 9.1 Early home automation

Home automation really started in a physical sense with the formation of mechanization items, starting with home apparatuses. The centralization and automation of private exercises has its underlying foundations in the principal electrically-wired private structures toward the finish of the nineteenth century. The capacity to enlighten the room from a solitary switch radically changed the way we lived by making it simple and moderately safe to light vast regions for broadened periods around evening time. The following awesome progress accompanied the presentation of the home TV in the 1950s and the later presentation of the infrared remote control. The two innovations were helpful for point-to-control correspondence between gadgets however did not have a two-route trade of data. X10 was discharged in the 1970's as a standard convention for wiring houses for home automation.

1901-1920: The invention of home appliances- like refrigerators, washing machine, dishwashers, irons, toaster and garments dryers.

1966-1967: The invention of ECHO IV and Kitchen Computer- the ECHO IV was the first brilliant device. In spite of the fact that it was not industrially sold, the device could register shopping records, control the home's temperature, and turn apparatuses on and off. The "Kitchen Computer" was made for the current year. The apparatus was equipped for putting away formulas, yet didn't offer many models because of poor advertising. The cutting edge came as the Internet, which made an overall system of PCs in the 1990s. Before long, remote Internet as Wi-Fi turned into a typical apparatus in American homes.

2000's: The early 2,000's saw a further ascent in brilliant home innovation, including local tech, home systems administration, and different devices showing up available. A combination of short-range technologies created by Zen-Sys in 2005, this wireless technology creates a mesh network at the user's home and sends signals at the 900 MHz spectrum. The Z-Wave technology is capable of connecting a variety of devices to control appliances, door locks and even flood monitors. [5]

## 9.2 Lighting control systems

Lighting control systems can generally be divided into five categories; manual/ dimmer switched system, timer controlled systems, occupancy based controlled systems, natural light level based controlled systems and smart systems. Manually switched systems traditionally controlled all lighting circuits on residential and commercial buildings. This system relies on individuals to switch on/ off lighting when or when it is not required. This method can be particularly wasteful with regard to energy usage as the onus is put on the individual(s) to switch off lighting when it is not required. Timer controlled systems are set based on parameters input by an individual that allows lighting to be switched on based on timer set points. Timers can be set to switch on lighting during the hours of darkness. The negative of this is that the lighting will be switched on regardless of there being a requirement, i.e. if nobody is home, the lights will still be on. Occupancy based systems use passive infrared sensors (PIR) to determine whether a room or building is occupied. If motion is detected through infrared motion, a relay is operated and the lighting circuit is energised. This system is effective in that energy is not wasted if it is not required through occupancy. The negative aspect is that if the natural light provides sufficient light levels, the occupancy sensor will still switch on the lighting circuit if motion is detected within the area. Natural light level based systems monitor the light levels in the area using a photosensitive device. If the lux level required is achieved with natural light, the lighting system remains off, if the lux level reduces below the set point required, a relay in the photosensitive device switches and energises the lighting circuit. This system is most efficient as energy is not used when it is not required. Smart lighting systems are a relatively new concept. Smart connected devices generally use wireless transmission to send and receive signals. Some equipment will just require a Wi-Fi connection, others also require a central hub that connects to the home Wi-Fi network. The main positive of this type of system is that you are able to operate the lights from anywhere providing you have an internet connection and smart device (phone/ tablet). The negative aspect is that if you lose internet connectivity, you are unable to remotely operate the lights.

### 9.3 Heating control systems

Heating controls can generally be broken down into five different types, room thermostat, and thermostatic radiator valves (TRV's), timers, programmer and smart thermostats. Room thermostats monitor the ambient temperature of the room and adjusts the boiler accordingly. TRV's are self-regulating valves that control the flow of hot water into a radiator. Within the head of the TRV is a capsule, this capsule expands or contracts dependent on the heat in the room, the expansion or contraction on the capsule acts upon a pin the valve body allowing the valve to open or close as required. This gives more control of heating within different rooms. Timers are set by the user, they can be set so that the heating is switched on or off when the home is occupied or unoccupied respectively. The negative of this is that the heating could be on if not required, i.e. when the user's normal routine changes or temperatures are already at the required level. Programmers are very similar to timers in that the parameters are set by the user. With programmers, timers, durations and days of the week can be controlled independently. Weekdays and weekends can be set up separately as routines may change. This gives more control over a timer, but the same issue can still persist. Smart thermostats can be used in the same fashion as smart lighting, the heating can be controlled remotely from a smart device such as a smart phone. Similarly to smart lighting systems, signals are sent remotely using Wi-Fi, some system require a designated central hub. Routines can be set to allow heating to be on when required. The negative aspect is that if you lose internet connectivity, you are unable to remotely operate the heating remotely.

## 10 Existing home automation systems

There are three main types of home automation platforms currently available, these are power line home automation, wired home automation and wireless home automation.

### 10.1 Power line home automation

Powerline networking, or powerline communications, is a form of communication that uses electrical wiring to carry both data and alternating current (AC) electrical supply through existing electrical infrastructure. Powerline networking can have a range of uses. In the home it is mostly used for home automation (smart home) and internet access, but it is also used in industrial and commercial settings, for example by utility companies to carry out tasks such as remote meter readings.

The powerline is able to carry data via the superposition of a low-energy information signal to the power wave, which means they can pass through each other without being disturbed. Data is transmitted at a minimum of 3 kHz to ensure that the power wave does not interfere with the data signal. Electrical wiring in the home is able to transmit signals at a variety of frequencies. Electricity usually travels at 50/60 Hz frequencies, meaning that data can use the same wires, but at a much higher frequency so that the two do not affect each other. To install powerline networking in a home, two special adaptors are needed. The first powerline adapter would be connected to an existing wired local area network router, and the second adapter would be attached to an Ethernet-ready device such as a computer or television. When both adapters are plugged in, a network connection will be established internally through the electrical wiring between the two wall sockets, meaning that other than the power cable, no extra wires are needed to connect the device to the router. It can be used for wireless printing, playing music to remote speakers, file sharing in homes with multiple computers, connecting televisions to the internet, and gaming.

In home automation systems, powerline communications can be used for controlling lights, heating, air conditioning, cameras, and security systems. A powerline networking connection has some advantages over a wireless connection, but how well it works will still depend on the quality of the domestic electrical system. Inadequate wiring and circuit breakers in between the connected cables can negatively affect performance and cause interruptions. It can also be affected by other motorised home appliances, such as vacuum

cleaners or fans, which generate noise in the power grid and, as the wiring and associated switch work is optimised for AC power, the connectivity does not work as well. [6]

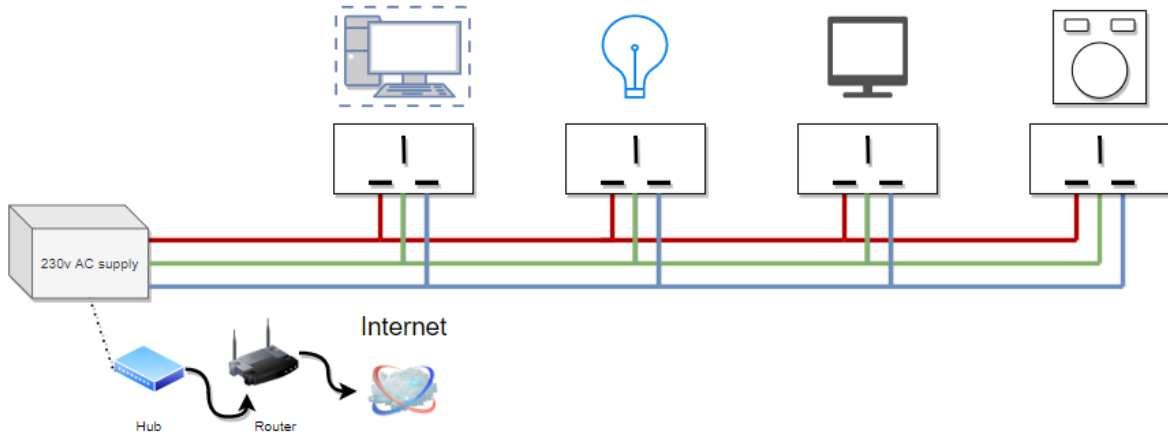


Figure 6 - Powerline network overview

## 10.2 Wired home automation system

A wired home automation system involves installing additional control and signal cables from a centralised control unit to each of the devices that you want to control. Wired systems generally use two modes of communication, serial and IP. Wired automation systems are generally more secure as they are less susceptible to hacking. They are more costly to install, as they require additional labour to install, that said, the cable required for the wiring of equipment is generally inexpensive. When installing a wired system, it is important to future proof the system to allow for additional equipment in the future or when technologies develop.

A popular wired home automation system currently available is the KNX standard. The KNX standard uses twisted pair, powerline, radio and IP wiring. The KNX system is not based on a specific hardware, it can be controlled using any controller or computer. The twisted pair bus cables are installed in parallel to the electrical power supply cabling to all devices on the network. The system uses sensors such as push buttons, thermostats and movement sensors to gather information that feeds back to the controller using the bus cabling, the controller then outputs a response through the bus cabling to the actuator (heating valve, light dimmer module and displays) which causes an action based on the sensor input.

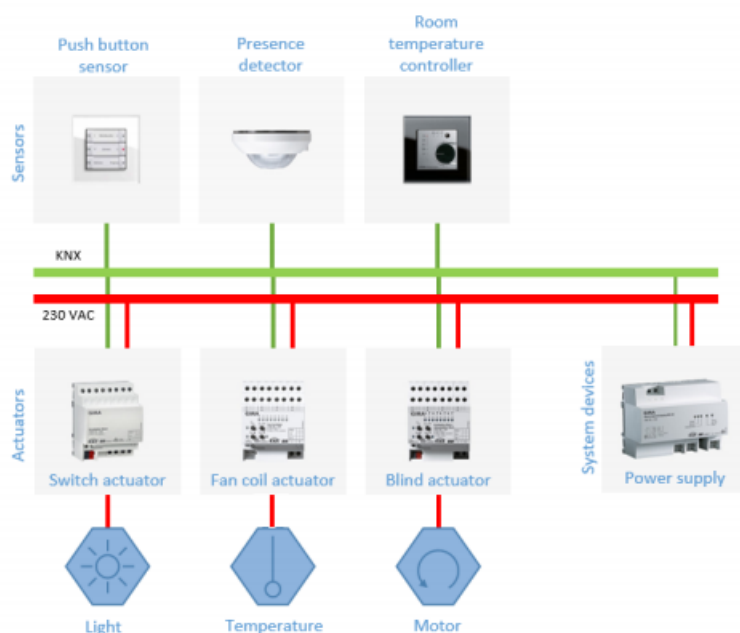


Figure 7 - KNX system overview [7]

### 10.3 Wireless home automation system

A home automation system is defined as wireless when only the control unit is connected to a wiring system. The wireless devices associated with the system communicate with the controller through the use of different wireless technologies. The devices, control unit and sometimes intermediate units have emitters and receivers built into them which allows them to communicate with other devices/ controllers. To clarify, although the system is described as 'wireless', only the communication and control is wireless, the devices and control unit will require connection to the electrical supply.

Wireless home automation systems use WHANs (Wireless Home Automation Networks). A WHAN typically comprises several types of severely constrained embedded devices, which may be battery powered and are equipped with low-power radio frequency (RF) transceivers. The use of RF communication allows flexible addition or removal of devices to or from the network and reduces installation costs since wired solutions require conduits or cable trays. [8] Several organizations and companies have developed WHAN solutions according to different architectures and principles. ZigBee, Z-Wave, INSTEON, Wavenis, and some IP-based approaches are most common. The main characteristics and requirements for WHANs are;

- The node density is potentially high, and the number of nodes may be on the order of hundreds.
- The home is typically a multipath environment due to the presence of reflective surfaces (e.g., walls, floors, and tables).
- Residential scenarios are subject to interference. Industrial, scientific, and medical (ISM) bands are particularly crowded with the presence of Wi-Fi, Bluetooth, cordless phones, and even microwave ovens.
- To facilitate end-to-end connectivity, multihop communications are required, so that intermediate nodes can retransmit data for nodes that are not within the sender's transmission range.
- Although most devices are static, the mobility of some of them and the dynamics of RF signal propagation require the network to be self-healing. The duration of connectivity gaps due to network topology changes should be low.

- The applications require WHANs to support various traffic patterns, such as point to-point (e.g., a switch transmits a command to a light), point-to-multipoint (e.g., a remote control transmits a command to a group of devices), and multipoint-to-point (e.g., several sensors report measured values to a central control).
- WHANs should offer Internet connectivity to allow remote home monitoring and management.
- Some applications (e.g., an intruder alarm system controlled by WHAN technology) require the protection of security services.
- The nodes may have a small memory capacity (e.g., a few kilobytes of RAM) and may exhibit limited processing capability (with processors running typically at tens of megahertz). Some nodes may draw their power from batteries or even some form of power harvesting. [8]

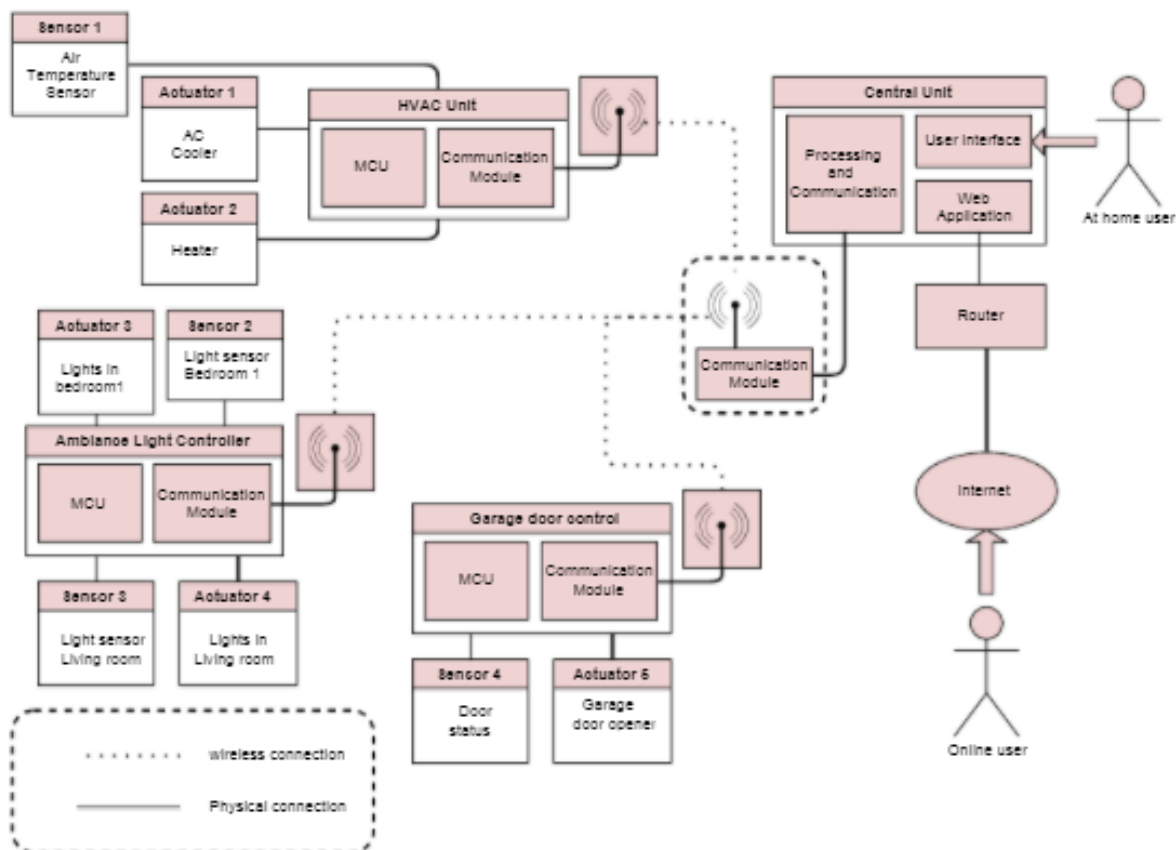


Figure 8 - Wireless home automation network framework [9]

## 11 Development

### 11.1 Hardware selection

There are multiple products available offering the same operational qualities and features. This section reviews available products and compares and contrasts to determine the most suitable for the application taking into consideration operational suitability and cost.

#### 11.1.1 PLC

| Manufacturer           | Siemens                                                                                                               | Allen Bradley                                                                                                                                                                           | Schneider                                                                                                                                                                                                                                                                                                                                                               |
|------------------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Model                  | S7-1200                                                                                                               | Micro 830                                                                                                                                                                               | TM221CE24T                                                                                                                                                                                                                                                                                                                                                              |
| Image                  |                                      |                                                                                                        |                                                                                                                                                                                                                                                                                      |
| Power supply           | 24VDC/ 300mA                                                                                                          | 24V DC/ 1.6A                                                                                                                                                                            | 20.4...28.8 V                                                                                                                                                                                                                                                                                                                                                           |
| Power consumption      | 1500mA                                                                                                                | 28 W                                                                                                                                                                                    | 14 W                                                                                                                                                                                                                                                                                                                                                                    |
| Inputs                 | DI = 14,AI = 2                                                                                                        | DI = 14, AI = expansion module                                                                                                                                                          | DI = 14,AI = 2                                                                                                                                                                                                                                                                                                                                                          |
| Outputs                | DO = 10, AO = 0                                                                                                       | DO = 10, AO = expansion module                                                                                                                                                          | DO = 10, AO = expansion module                                                                                                                                                                                                                                                                                                                                          |
| Expansion availability | Yes                                                                                                                   | Yes                                                                                                                                                                                     | Yes                                                                                                                                                                                                                                                                                                                                                                     |
| IP rating              | 20                                                                                                                    | 20                                                                                                                                                                                      | 20                                                                                                                                                                                                                                                                                                                                                                      |
| Interface type         | RJ45 x 1                                                                                                              | RJ45, RS232, USB                                                                                                                                                                        | RJ45, RS232, USB                                                                                                                                                                                                                                                                                                                                                        |
| Communication          | Profibus, Ethernet                                                                                                    | Modbus/ Ethernet                                                                                                                                                                        | Modbus/ Ethernet                                                                                                                                                                                                                                                                                                                                                        |
| Memory                 | 100KB                                                                                                                 | 20kByte                                                                                                                                                                                 | 256 kB                                                                                                                                                                                                                                                                                                                                                                  |
| Cost                   | £369.00                                                                                                               | £330.00                                                                                                                                                                                 | £547.01                                                                                                                                                                                                                                                                                                                                                                 |
| Web                    | <a href="https://www.parmley-graham.co.uk/6es7214-1ag40-0xb0">https://www.parmley-graham.co.uk/6es7214-1ag40-0xb0</a> | <a href="https://www.routeco.com/en-gb/shop/programmable-controllers/micro800/2080-lc30-24qvb">https://www.routeco.com/en-gb/shop/programmable-controllers/micro800/2080-lc30-24qvb</a> | <a href="https://www.mouser.co.uk/ProductDetail/Schneider-Electric/TM221CE24T?qs=qu071zG02iQMRnpnIPhKhA==&amp;vip=1&amp;gclid=EAlaIQobChMIzJSIoJKr7QIVi5ntCh085gUmEAQYBiABEgJGZPD_BwE">https://www.mouser.co.uk/ProductDetail/Schneider-Electric/TM221CE24T?qs=qu071zG02iQMRnpnIPhKhA==&amp;vip=1&amp;gclid=EAlaIQobChMIzJSIoJKr7QIVi5ntCh085gUmEAQYBiABEgJGZPD_BwE</a> |

## 11.1.2 HMI

|                          |                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Manufacturer</b>      | Siemens                                                                                                                                                                                                                                                                                                                                                                                 | Allen Bradley                                                                                                           | Schneider                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Model</b>             | KTP700 Basic PN<br>- 6AV2123-<br>2GB03-0AX0                                                                                                                                                                                                                                                                                                                                             | PanelView 800                                                                                                           | HMIDT Series<br>Magelis GTU Touch<br>Screen HMI                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Image</b>             |                                                                                                                                                                                                                                                                                                        |                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Power supply</b>      | 24VDC                                                                                                                                                                                                                                                                                                                                                                                   | 24VDC                                                                                                                   | 12...24 V DC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Power consumption</b> | 5.5 W                                                                                                                                                                                                                                                                                                                                                                                   | 11 W                                                                                                                    | 6.5 W                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Display size</b>      | 7"                                                                                                                                                                                                                                                                                                                                                                                      | 7"                                                                                                                      | 7"                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Touch screen</b>      | Yes                                                                                                                                                                                                                                                                                                                                                                                     | Yes                                                                                                                     | Yes                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Function keys</b>     | 8                                                                                                                                                                                                                                                                                                                                                                                       | 0                                                                                                                       | 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Resolution</b>        | 800x480 pixels                                                                                                                                                                                                                                                                                                                                                                          | 800 x 480 WVGA                                                                                                          | 800 x 480 pixels<br>WVGA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Interface type</b>    | USB                                                                                                                                                                                                                                                                                                                                                                                     | USB/ RS232/<br>RS422/ RS485                                                                                             | Serial/ USB                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Protocols</b>         | Profinet/<br>Ethernet                                                                                                                                                                                                                                                                                                                                                                   | Ethernet                                                                                                                | Ethernet                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Memory</b>            | 10MByte                                                                                                                                                                                                                                                                                                                                                                                 | 256MB                                                                                                                   | 256MB                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Cost</b>              | £606.96                                                                                                                                                                                                                                                                                                                                                                                 | £775.20                                                                                                                 | £656.88                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Web</b>               | <a href="https://www.automation24.co.uk/simatic-basic-panel-siemens-ktp700-basic-pn-6av2123-2gb03-0ax0?previewPriceListId=1&amp;gclid=EAlaIqobChMlIprs5Zer7QIVi5ntCh085gUmEAQYAyABEgJT-fD_BwE">https://www.automation24.co.uk/simatic-basic-panel-siemens-ktp700-basic-pn-6av2123-2gb03-0ax0?previewPriceListId=1&amp;gclid=EAlaIqobChMlIprs5Zer7QIVi5ntCh085gUmEAQYAyABEgJT-fD_BwE</a> | <a href="https://uk.rs-online.com/web/p/hmi-displays/8937789/">https://uk.rs-online.com/web/p/hmi-displays/8937789/</a> | <a href="https://uk.farnell.com/schneider-electric/hmidt351/hmi-touch-screen-wvga-7-7w/dp/2835425?gclid=EAlaIqobChMlIrOffiZ6r7QIVkmDmCh08Sg-1EAYYAiaABEgKJNfD_BwE&amp;gross_price=true&amp;mckv=sb5BF5H9m_dc pccrid 459820056235 plid  keyword  match  slid  product 2835425 pgrid 104445617261 ptaid aud-899162869380:pla-299936790136 &amp;CMP=KNC-GUK-SHOPPING-SMEC-Whoops-Newstructure-31Aug2020-Desktop-ME">https://uk.farnell.com/schneider-electric/hmidt351/hmi-touch-screen-wvga-7-7w/dp/2835425?gclid=EAlaIqobChMlIrOffiZ6r7QIVkmDmCh08Sg-1EAYYAiaABEgKJNfD_BwE&amp;gross_price=true&amp;mckv=sb5BF5H9m_dc pccrid 459820056235 plid  keyword  match  slid  product 2835425 pgrid 104445617261 ptaid aud-899162869380:pla-299936790136 &amp;CMP=KNC-GUK-SHOPPING-SMEC-Whoops-Newstructure-31Aug2020-Desktop-ME</a> |

## 11.1.3 Occupancy sensor

Technology types available.

| Type             | Passive infra-red sensors (PIR)                                                   | Ultrasonic sensors                                                                 | Microwave sensors                                                                   |
|------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Detection method | Heat emitted by occupants                                                         | Emit sound waves and listen for reflected sound                                    | Emit microwaves and analyse reflected waves                                         |
| Image            |  |  |  |
| Suitability      | High                                                                              | Low                                                                                | Medium                                                                              |
| Advantages       | Resistant to false triggers                                                       | Covers large area                                                                  | Suitable outdoor                                                                    |
| Disadvantages    | Shorter operating distance (within 15ft is ideal, up to 35ft)                     | Prone to false triggering                                                          | Work in intervals, require constant power                                           |
| Cost             | Medium                                                                            | High                                                                               | Low                                                                                 |

Choice from different manufacturers.

| Manufacturer      | Danlers                                                                             | Timeguard                                                                           | CP Electronics                                                                        |
|-------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Model             | CEFL PIR 24VDC occupancy Switch                                                     | SLFM360N 360° Ceiling Occupancy PIR Flush Mounting                                  | EBDSPIR-PRM-LV                                                                        |
| Image             |  |  |   |
| Power supply      | 24V DC                                                                              | 230V AC                                                                             | 12 to 24V AC / DC                                                                     |
| Switching current | 500W with LED                                                                       | 100W with LED                                                                       | 10A inductive                                                                         |
| Detection zone    | 360 degree                                                                          | 360 degree                                                                          | -                                                                                     |
| Detection range   | 7m                                                                                  | 6m                                                                                  | 7m                                                                                    |
| Time adjustment   | 10s to 40mins                                                                       | 3s to 18mins                                                                        | 1 to 30mins                                                                           |
| Photocell range   | 30 to 1000 lux                                                                      | 1 to 1000 lux                                                                       | 101 to 199 lux                                                                        |
| Cost              | £65.97                                                                              | £20.70                                                                              | £67.25                                                                                |
| Web               | <a href="https://www.bltdirect.com/danlers-">https://www.bltdirect.com/danlers-</a> | <a href="https://www.tlc-">https://www.tlc-</a>                                     | <a href="https://www.cef.co.uk/catalogue/pro">https://www.cef.co.uk/catalogue/pro</a> |

|  |                                                                                                                                                                        |                                                              |                                                                                                                                                                        |
|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | <a href="#"><u>cefl-pir-24v-occupancy-switch-2m-lead-wire-nbsp-voltage-free-output?adcid=pla&amp;gclid=EAlaIQobChMlv6rr-aGr7QIVB-7tCh0bxA1CEAQYBiABEgJSr D BwE</u></a> | <a href="#"><u>direct.co.uk/Products/SMSLFM360N.html</u></a> | <a href="#"><u>ducts/1619933-ceiling-pir-presence-absence-detector-12-24v-ac-dc?gclid=EAlaIQobChMlv6rr-aGr7QIVB-7tCh0bxA1CEAQYDCABEgLW-PD BwE&amp;gclsrc=aw.ds</u></a> |
|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 11.1.4 Lux sensor

Technology types available.

| Type             | Photodiodes                                                                          | Photo resistors (LDRs)                                                             | Phototransistor                                                                                                 |
|------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| Detection method | Semi-con device with PN junction. Accepts light input and generates electric current | Decrease in resistance when increase in light                                      | Semi-con that senses light and alters the current between the emitter and collector dependent on light received |
| Image            |     |  |                              |
| Suitability      | High                                                                                 | Low                                                                                | Medium                                                                                                          |
| Advantages       | Fast, linear response                                                                | Requires small amount of power                                                     | Relatively sensitive                                                                                            |
| Disadvantages    | Small active area                                                                    | Low response speed                                                                 | Damage at high voltages                                                                                         |
| Cost             | Medium                                                                               | Low                                                                                | High                                                                                                            |

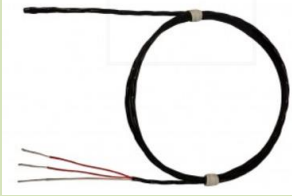
Choice from different manufacturers.

| Manufacturer | Omni instruments                                                                    | Titan products                                                                      | B and B Sensors                                                                      |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Model        | LL-E-V                                                                              | Internal Light Level Sensor                                                         | Brightness sensor with transducer                                                    |
| Image        |  |  |  |
| Power supply | 24vAC/DC                                                                            | 24vAC/DC                                                                            | 12...24 V AC/DC                                                                      |
| Output       | 0-10v                                                                               | 0-10v/ 4-20mA                                                                       | 0...10 V DC                                                                          |
| Range        | 10-2000 lux and 10-10,000 lux                                                       | 0 – 20,000 lux (selectable)                                                         | 0...100000 Lux                                                                       |
| Sensor type  | Photo diode                                                                         | Photo diode                                                                         | Photo diode                                                                          |
| Cost         | £51.71                                                                              | £35.00                                                                              | £64.55                                                                               |

|            |                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Web</b> | <a href="https://www.omniinstruments.co.uk/weather-stations-and-instruments/light-level-sensors/external-light-level-sensors.html#upsell-product-div">https://www.omniinstruments.co.uk/weather-stations-and-instruments/light-level-sensors/external-light-level-sensors.html#upsell-product-div</a> | <a href="https://titanproducts.com/product/internal-light-level-sensor-tpvllr-tpllr/">https://titanproducts.com/product/internal-light-level-sensor-tpvllr-tpllr/</a> | <a href="https://www.rapidonline.com/B-B-Sensors-LIFUE-Light-Sensor-64-3535?IncVat=1&amp;pdg=aud-378648543755:plaid-337338790750:kw337338790750:cmp-757438067:adg-44804851896:crv-207912323492:pid-64-3535:dev-c&amp;gclid=EAlaIQobChMIpr2X9a2r7QIVjqztCh0wDgMWEAQYAyABEgLSqvD_BwE">https://www.rapidonline.com/B-B-Sensors-LIFUE-Light-Sensor-64-3535?IncVat=1&amp;pdg=aud-378648543755:plaid-337338790750:kw337338790750:cmp-757438067:adg-44804851896:crv-207912323492:pid-64-3535:dev-c&amp;gclid=EAlaIQobChMIpr2X9a2r7QIVjqztCh0wDgMWEAQYAyABEgLSqvD_BwE</a> |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 11.1.5 Temperature sensor

Technology types available.

| Type             | RTD                                                                               | Thermocouple                                                                       | Thermistor                                                                          |
|------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Detection method | Increase in temp, increase in resistance                                          | Two dissimilar metal conductors forming an electrical junction                     | Resistance dependant on temp, metallic oxides into a bead                           |
| Image            |  |  |  |
| Suitability      | High                                                                              | Medium                                                                             | Low                                                                                 |
| Advantages       | Accurate                                                                          | Large temp range                                                                   | Sensitive                                                                           |
| Disadvantages    | Expensive                                                                         | Less stable                                                                        | Narrow temp range                                                                   |
| Cost             | High                                                                              | Medium                                                                             | Low                                                                                 |

Choice from different manufacturers.

| Manufacturer | Syxt Sense                                                                          | Alpha omega electronics                                                             | Titan products                                                                       |
|--------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Model        | Room temperature transmitter                                                        | P4211 Temperature transmitter with 0-10V output                                     | Room Temperature Sensor                                                              |
| Image        |  |  |  |
| Power supply | 24Vac/dc                                                                            | 15-30Vdc, max. 20mA; 24 Vac                                                         | 24Vac/dc                                                                             |
| Output       | 0-10vdc/ 4-20mA                                                                     | 0-10V                                                                               | 0-10vdc/ 4-20mA/ RTD                                                                 |
| Range        | 0...+50 degC                                                                        | -30 to +80°C                                                                        | -10 - +40°C                                                                          |
| Sensor type  | PT1000                                                                              | Pt1000                                                                              | 2 wire loop powered/ 3 wire 24v supply/ PT1000                                       |
| Cost         | £50.10                                                                              | £67.80                                                                              | £36.00                                                                               |

|            |                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                 |                                                                                                                                     |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <b>Web</b> | <a href="https://www.syxthsense.com/sensors/tehr-lu/room-air-temperature-transmitter,-0..10v/">https://www.syxthsense.com/sensors/tehr-lu/room-air-temperature-transmitter,-0..10v/</a> | <a href="https://www.alphaomega-electronics.com/en/transmitters-and-transducers/2744-p0210-temperature-transmitter-with-0-10v-output.html">https://www.alphaomega-electronics.com/en/transmitters-and-transducers/2744-p0210-temperature-transmitter-with-0-10v-output.html</a> | <a href="https://titanproducts.com/product/room-temperature-sensor/">https://titanproducts.com/product/room-temperature-sensor/</a> |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|

## 11.1.6 Power supply unit

| Manufacturer   | RS Pro                                                                                                                                        | PULS                                                                                                                                          | Schneider<br>Telemecanique                                                                                                                                                                                                                                                                                                                                                              |
|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Model          | 136-8319                                                                                                                                      | PIC120.242C                                                                                                                                   | ABL8MEM24012                                                                                                                                                                                                                                                                                                                                                                            |
| Image          |                                                              |                                                              |                                                                                                                                                                                                                                                                                                      |
| Input voltage  | 110VAC – 240VAC                                                                                                                               | AC200-240V                                                                                                                                    | 100-240V AC                                                                                                                                                                                                                                                                                                                                                                             |
| Output voltage | +24VDC                                                                                                                                        | DC24V                                                                                                                                         | 24V DC                                                                                                                                                                                                                                                                                                                                                                                  |
| Output current | 5A                                                                                                                                            | 5A                                                                                                                                            | 1.2A                                                                                                                                                                                                                                                                                                                                                                                    |
| Cost           | £36.80                                                                                                                                        | £77.35                                                                                                                                        | £71.94                                                                                                                                                                                                                                                                                                                                                                                  |
| Web            | <a href="https://uk.rs-online.com/web/p/din-rail-power-supplies/1368319/">https://uk.rs-online.com/web/p/din-rail-power-supplies/1368319/</a> | <a href="https://uk.rs-online.com/web/p/din-rail-power-supplies/1238020/">https://uk.rs-online.com/web/p/din-rail-power-supplies/1238020/</a> | <a href="https://www.cef.co.uk/catalogue/products/1439073-1-2a-24v-dc-regulated-switch-mode-power-supply-unit?gclid=EAlaIQo_bChMI6eTS9Ou-7wIVVODtCh1-VAUQEAQYBSABEgI3r_D_BwE&amp;gclsrc=aw.ds">https://www.cef.co.uk/catalogue/products/1439073-1-2a-24v-dc-regulated-switch-mode-power-supply-unit?gclid=EAlaIQo_bChMI6eTS9Ou-7wIVVODtCh1-VAUQEAQYBSABEgI3r_D_BwE&amp;gclsrc=aw.ds</a> |

## 11.1.7 Network Switch

| Manufacturer       | Weidmuller                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Schneider Electric                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Trendnet                                                                                                                                                                                                                                                                                      |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Model              | 1240890000                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | TCSESU053FN0                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | TI-PG541i                                                                                                                                                                                                                                                                                     |
| Image              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                            |
| Supply voltage     | 9.6...60V DC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 9.6...32V DC                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 100-240 V                                                                                                                                                                                                                                                                                     |
| Number of ports    | 4 RJ45, SC single mode fibre                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5 RJ45                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 5 RJ45                                                                                                                                                                                                                                                                                        |
| Data transfer rate | 10/100BaseT with RJ45                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 10Mbps, 100Mbps                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Gigabit Ethernet (10/100/1000)                                                                                                                                                                                                                                                                |
| Cost               | £167.34                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | £113.90                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | £212.91                                                                                                                                                                                                                                                                                       |
| Web                | <a href="https://uk.rs-online.com/web/p/industrial-hubs-switches/8936831/?cm_mmc=UK-PLA-DS3A-_-google-_-CSS UK EN Computing %26 Peripherals Whoop-_-Industrial+Hubs+%26+Switches+Whoop-_-8936831&amp;matchtype=&amp;aud-826607885227:pla-335756369178&amp;gclid=EAlaIQobChMlioru4-6-7wIVmK3tCh3Lww2ZEAYYASABEgL7HvD_BwE&amp;gclsrc=aw.ds">https://uk.rs-online.com/web/p/industrial-hubs-switches/8936831/?cm_mmc=UK-PLA-DS3A-_-google-_-CSS UK EN Computing %26 Peripherals Whoop-_-Industrial+Hubs+%26+Switches+Whoop-_-8936831&amp;matchtype=&amp;aud-826607885227:pla-335756369178&amp;gclid=EAlaIQobChMlioru4-6-7wIVmK3tCh3Lww2ZEAYYASABEgL7HvD_BwE&amp;gclsrc=aw.ds</a> | <a href="https://gb.wiautomation.com/schneider-electric/industrial-communication/TCSESU053FN0?utm_source=shopping_free&amp;utm_medium=organic&amp;utm_content=GB117144&amp;gclid=EAlaIQobChMluPvz9O2-7wIVEO7tCh1VGAQVEAQYASABEgL-XvD_BwE">https://gb.wiautomation.com/schneider-electric/industrial-communication/TCSESU053FN0?utm_source=shopping_free&amp;utm_medium=organic&amp;utm_content=GB117144&amp;gclid=EAlaIQobChMluPvz9O2-7wIVEO7tCh1VGAQVEAQYASABEgL-XvD_BwE</a> | <a href="https://www.cablemonkey.co.uk/switches/72652-trendnet-ti-pg541i-0710931160581.html?search_query=din+rail+ethernet+switch&amp;results=58">https://www.cablemonkey.co.uk/switches/72652-trendnet-ti-pg541i-0710931160581.html?search_query=din+rail+ethernet+switch&amp;results=58</a> |

## 11.1.8 Enclosure

|                      |                                                                                                                                                                                                                                                       |                                                                                                                     |                                                                                                                     |
|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| <b>Manufacturer</b>  | Eldon                                                                                                                                                                                                                                                 | RS Pro                                                                                                              | Schneider                                                                                                           |
| <b>Model</b>         | ASR0404021                                                                                                                                                                                                                                            | Monoblock industrial enclosure 1927115                                                                              | Spacial S3D NSYS3D4420P                                                                                             |
| <b>Image</b>         |                                                                                                                                                                      |                                    |                                   |
| <b>Material</b>      | 304 stainless steel                                                                                                                                                                                                                                   | GRP                                                                                                                 | Steel                                                                                                               |
| <b>External size</b> | 400x400x210                                                                                                                                                                                                                                           | 400x400x200                                                                                                         | 400x400x200                                                                                                         |
| <b>IP rating</b>     | IP66                                                                                                                                                                                                                                                  | IP66                                                                                                                | IP66                                                                                                                |
| <b>Cost</b>          | £243.50                                                                                                                                                                                                                                               | £182.75                                                                                                             | £97.20                                                                                                              |
| <b>Web</b>           | <a href="https://www.cse-distributors.co.uk/product/asr0404021-eldon-304-grade-ip66-stainless-steel-enclosure-400x400x210mm/">https://www.cse-distributors.co.uk/product/asr0404021-eldon-304-grade-ip66-stainless-steel-enclosure-400x400x210mm/</a> | <a href="https://uk.rs-online.com/web/p/wall-boxes/1927115/">https://uk.rs-online.com/web/p/wall-boxes/1927115/</a> | <a href="https://uk.rs-online.com/web/p/wall-boxes/7018411/">https://uk.rs-online.com/web/p/wall-boxes/7018411/</a> |

## 11.2 Hardware/ component review

The components that have been selected based on technological and operational suitability are highlighted in green above. As the products compared at this stage are all capable of providing suitable operational requirements, the selection ultimately came down to the most cost effective and readily available equipment.

There are additional components used within the project that have not been compared and contrasted with other manufacturers options, this is because they are simple components within the enclosure or equipment that will not be installed if the prototype was to be used in a real world scenario. This equipment is specifically the junction boxes that house the pilot lights used to simulate the heater and lights, the pilot lights themselves, terminals, trunking, cable identification equipment and cable. All these components will appear in the project bill of materials.

## 12 System block diagram

The image below details the hardware overview required to produce the system.

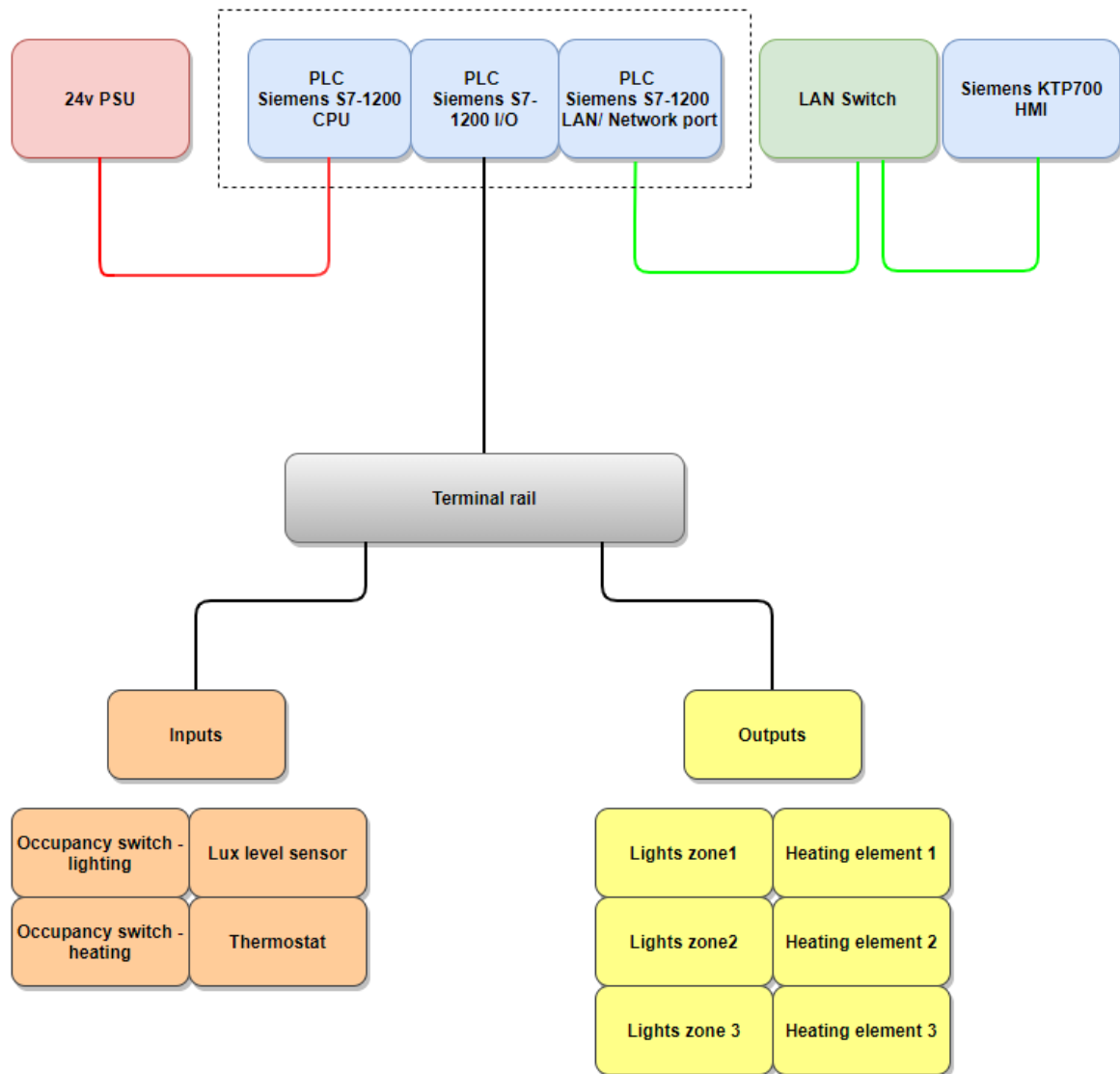


Figure 9 - System block diagram

### 13 Process flow chart

The image below details the stages of the process and the outcomes at that stage dependent on the input.

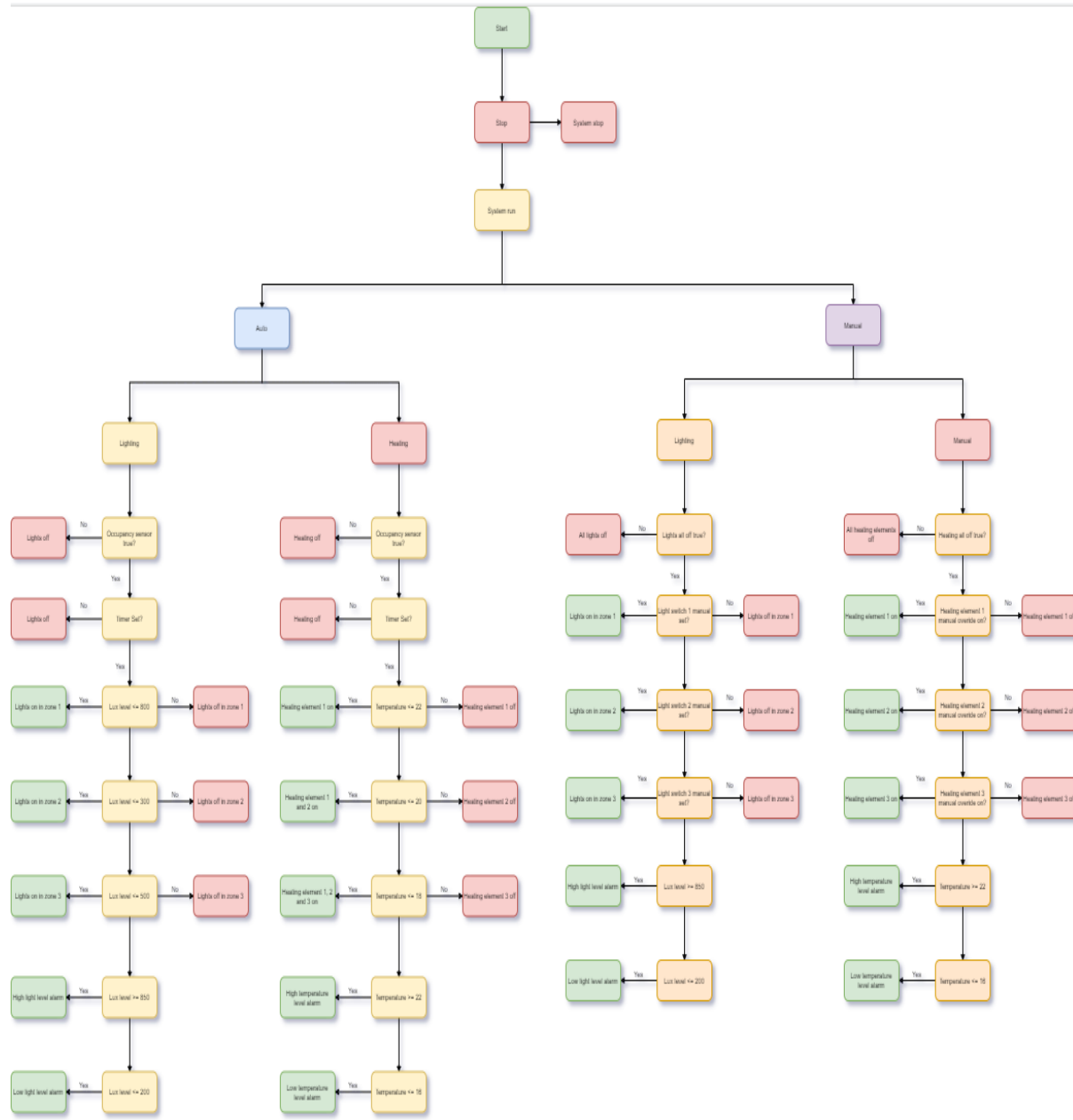


Figure 10 - System flow chart

## 14 Software

The following section details the software development. The images are of each individual network that has been developed with a brief description of the functionality of the pictured network.

The function block in this network allows the Siemens software to interact with the Factory IO software that was used for testing.

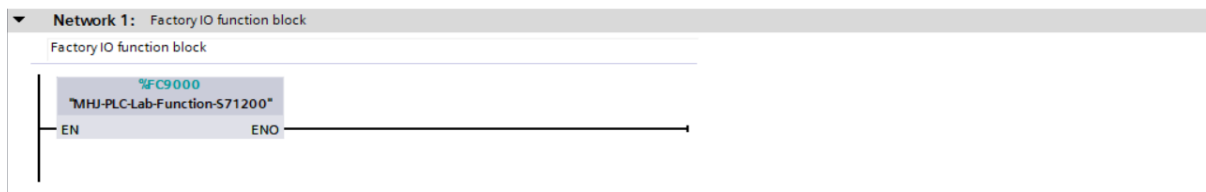


Figure 11 - Network 1

Network 2 is a start/ stop circuit used to run the program.

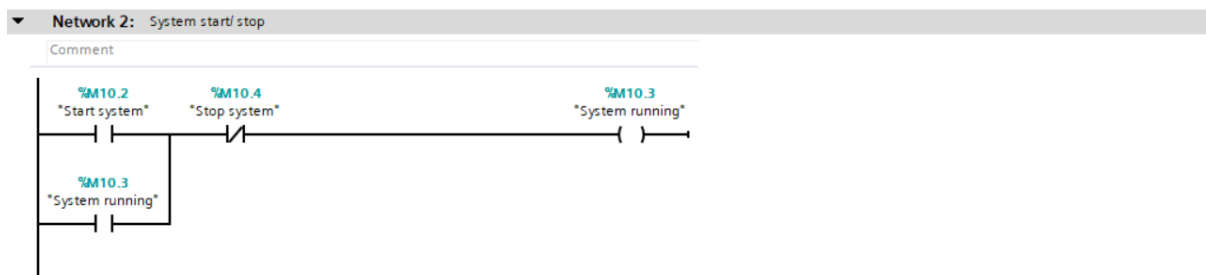


Figure 12 - Network 2

Network 3 allows the user to select between the 'auto' or 'manual' program function.

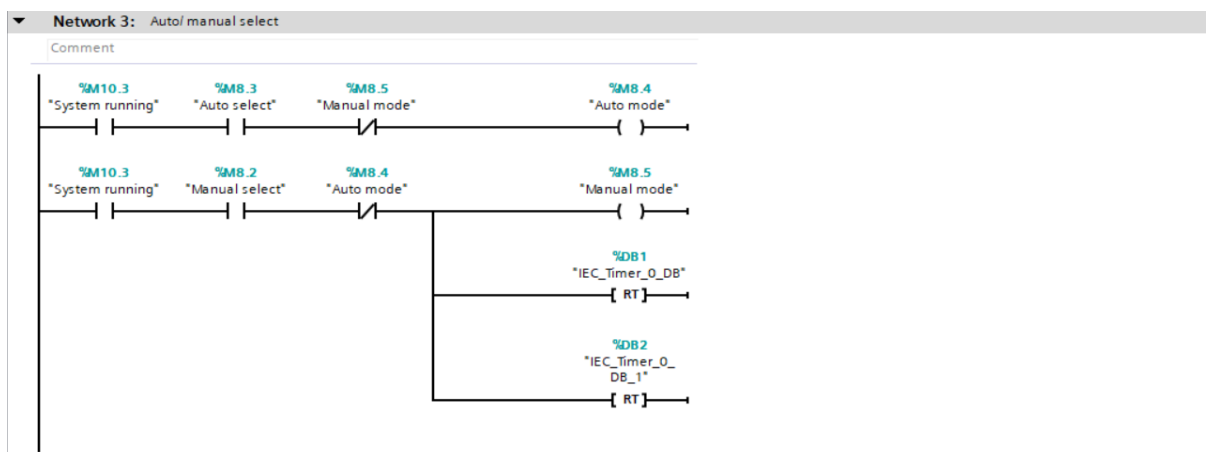


Figure 13 - Network 3

Network 4 contains the timer for the lighting circuits, providing 'auto mode' and 'occupancy lighting' are set, the timer will start and energise the 'light on' output for 30 seconds.

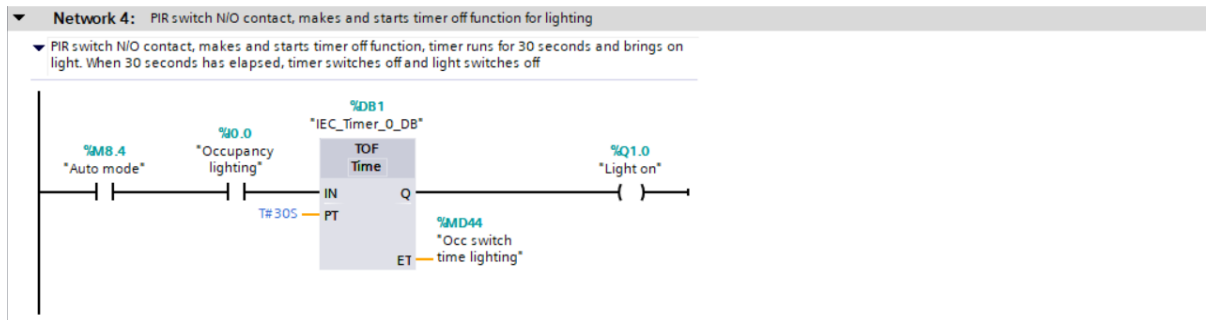


Figure 14 - Network 4

Network 5 uses the 'light on' output from network 4 to set 'light timer on' output.

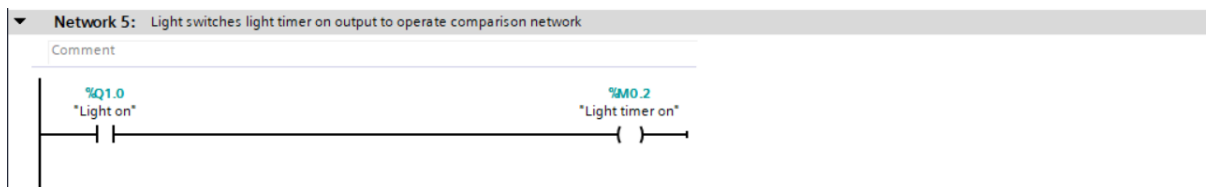


Figure 15 - Network 5

Network 6 contains the conversion function block for the lighting circuit. This function block converts the integer data value to a real value. The division function is then used to allow the value to be divided by 32767, which is the standard full scale analogue input value.

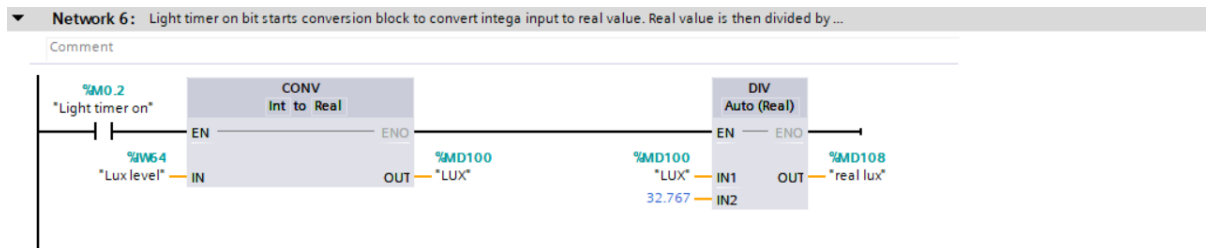


Figure 16 - Network 6

Network 7 contains the math function 'greater than or equal too.' This is so that if the 'lighting timer' is set and the 'real lux' value is less than or equal to 800, the light in zone 1 will energise. This network also contains a 'light 1 manual output' contact, this contact can be set when in 'manual mode' to allow lights to be switched on regardless of lux level or whether the zone is occupied.

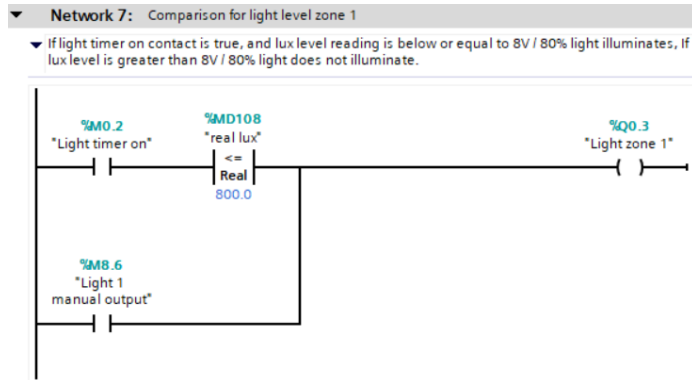


Figure 17 - Network 7

Network 8 contains the math function 'greater than or equal too.' This is so that if the 'lighting timer' is set and the 'real lux' value is less than or equal to 300, the light in zone 2 will energise. This network also contains a 'light 2 manual output' contact, this contact can be set when in 'manual mode' to allow lights to be switched on regardless of lux level or whether the zone is occupied.

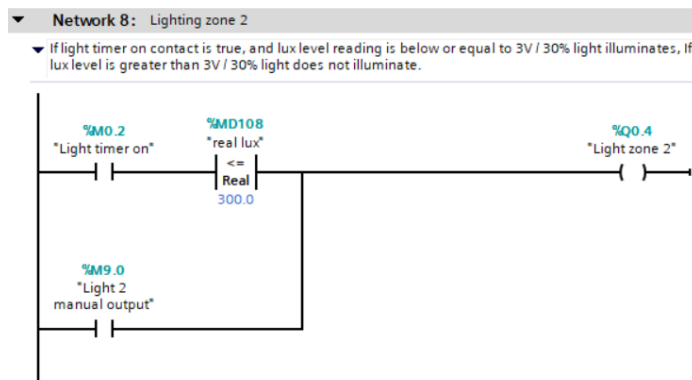


Figure 18 - Network 8

Network 9 contains the math function 'greater than or equal too.' This is so that if the 'lighting timer' is set and the 'real lux' value is less than or equal to 500, the light in zone 3 will energise. This network also contains a 'light 3 manual output' contact, this contact can be set when in 'manual mode' to allow lights to be switched on regardless of lux level or whether the zone is occupied.

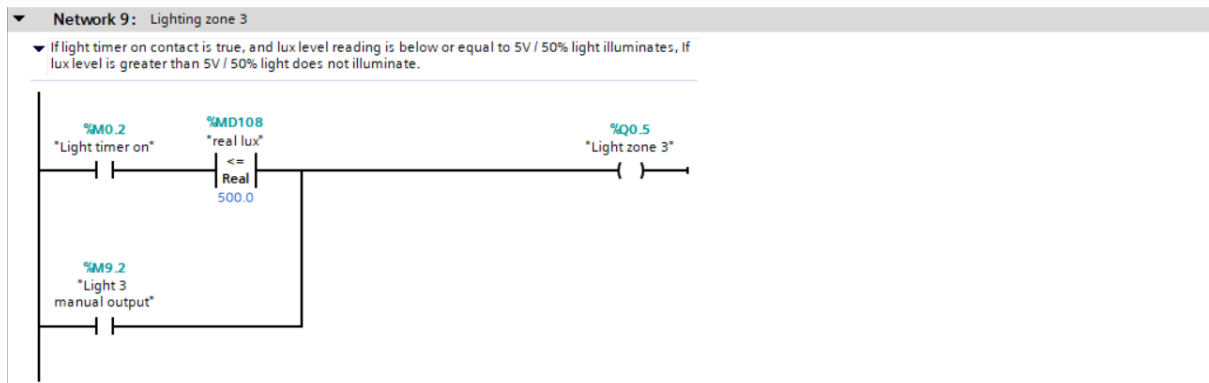


Figure 19 - Network 9

Network 10 contains the timer for the heating circuits, providing 'auto mode' and 'occupancy heating' are set, the timer will start and energise the 'heating timer on' output for 60 seconds.

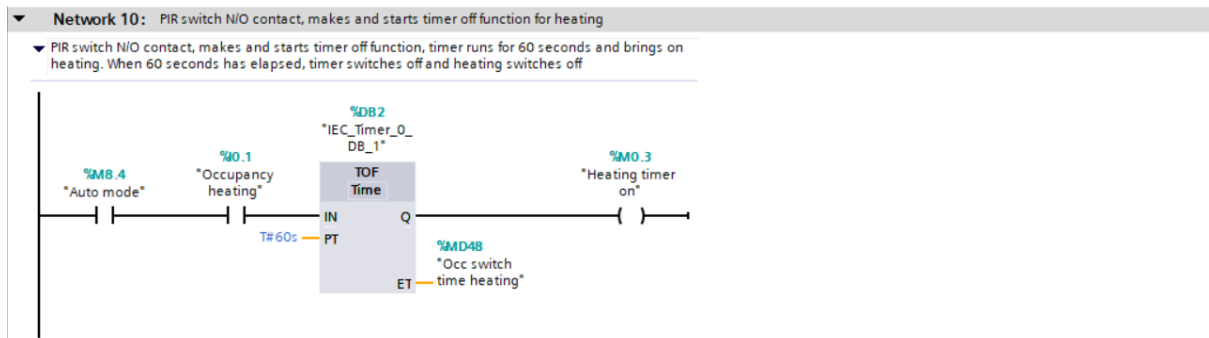


Figure 20 - Network 10

Network 11 contains the conversion function block for the heating circuit. This function block converts the integer data value to a real value. The division function is then used to allow the value to be divided by 32767, which is the standard full scale analogue input value.

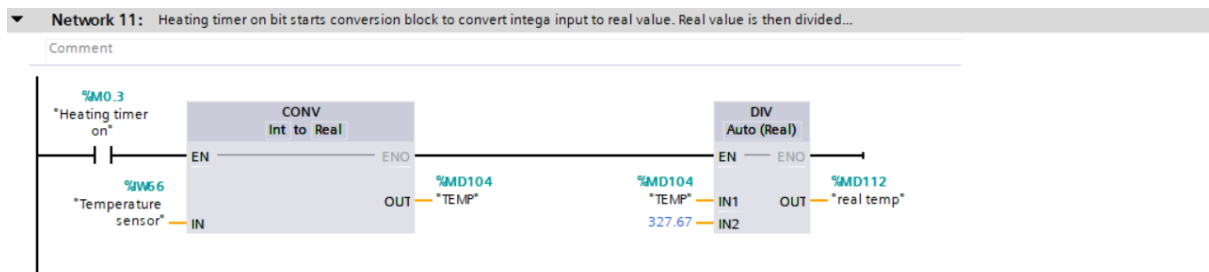


Figure 21 - Network 11

Network 12 contains the math function 'less than or equal too.' This is so that if the 'heating timer on' contact is set and the 'real temp' value is less than or equal to 22, then, heating element 1 will energise. This network also contains a 'heating element 1 manual output' contact, this contact can be set when in 'manual mode' to allow heating to be switched on regardless of temperature or whether that area is occupied.

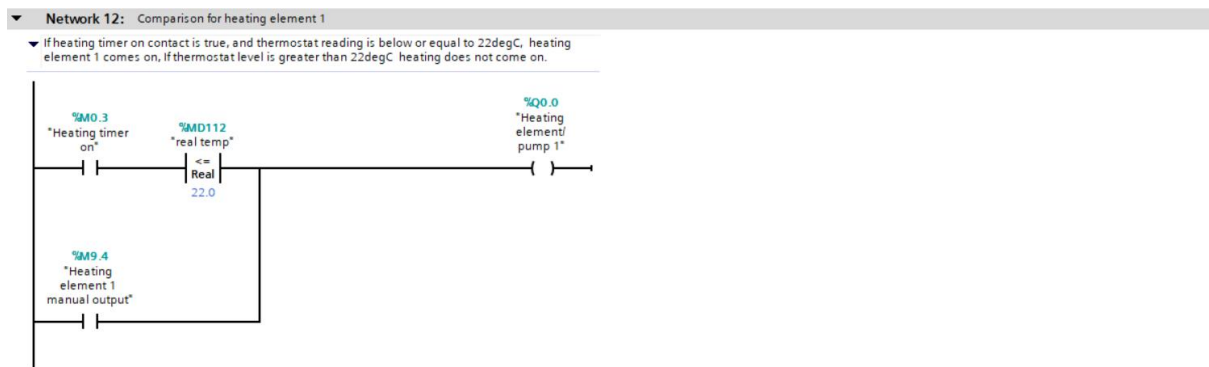


Figure 22 - Network 12

Network 13 contains the math function 'less than or equal too.' This is so that if the 'heating timer on' contact is set, 'heating element 1' is set and the 'real temp' value is less than or equal to 20, then, heating element 2 will energise. This network also contains a 'heating element 2 manual output' contact, this contact can be set when in 'manual mode' to allow heating to be switched on regardless of temperature or whether that area is occupied.

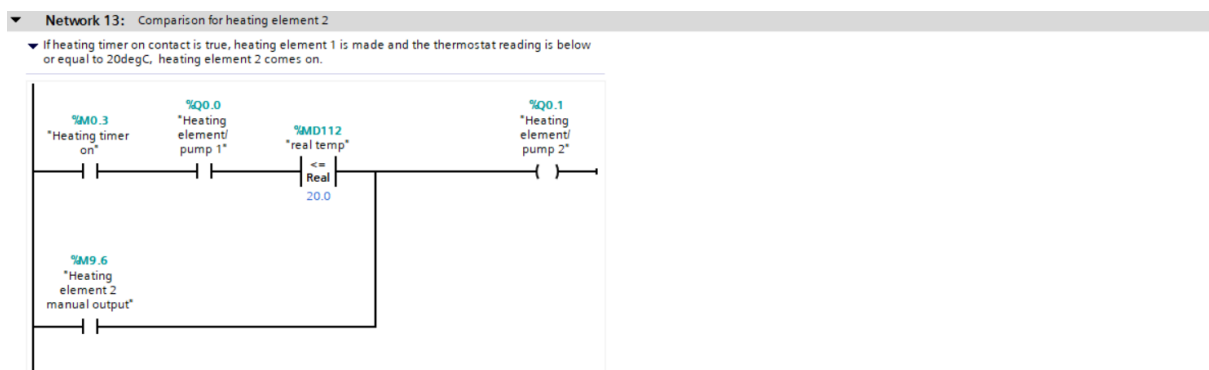


Figure 23 - Network 13

Network 14 contains the math function 'less than or equal too.' This is so that if the 'heating timer on' contact is set, 'heating element 1' is set, 'heating element 2' is set and the 'real temp' value is less than or equal to 18, then, heating element 3 will energise. This network also contains a 'heating element 3 manual output' contact, this contact can be set when in

'manual mode' to allow heating to be switched on regardless of temperature or whether that area is occupied.

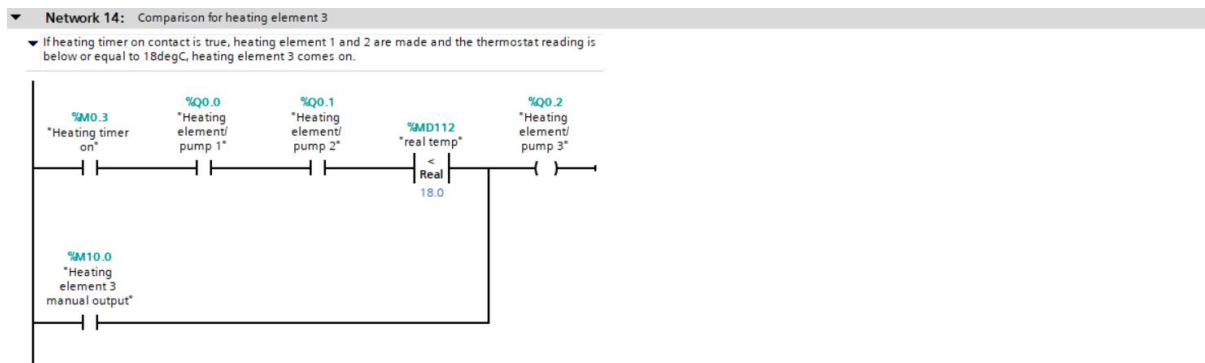


Figure 24 - Network 14

Network 15 contains the controls for the lighting in manual mode. If 'manual mode' is set and 'lights all off' is true 'light switch 1 manual', 'light switch 2 manual', and 'light switch 3 manual' can be set using the HMI to operate the respective lighting zones. If 'lights all off' is set, all lights will be de-energised.

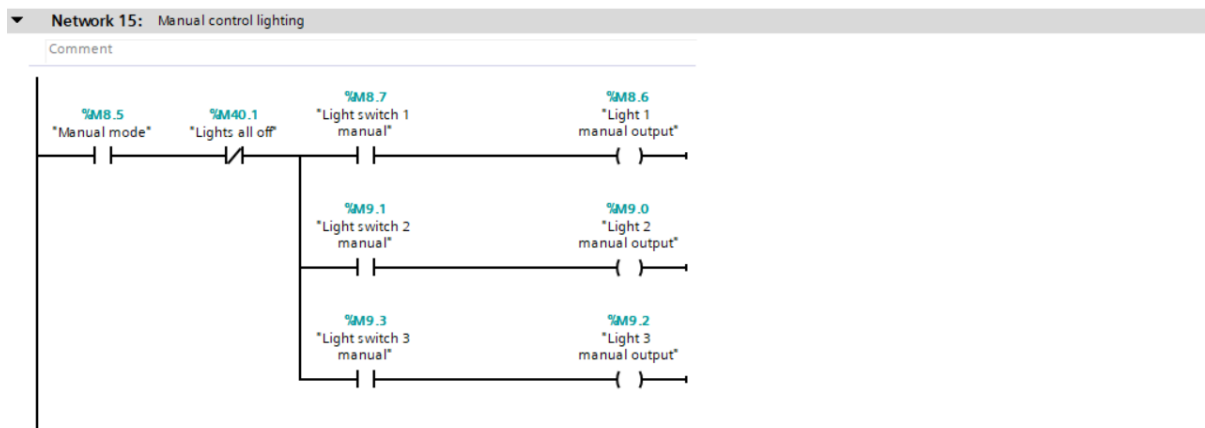


Figure 25 - Network 15

Network 16 contains the controls for the heating in manual mode. If 'manual mode' is set and 'heating all off' is true 'heating element 1 manual override', 'heating element 2 manual override', and 'heating element 3 manual override' can be set using the HMI to operate the respective heating elements. If 'heating all off' is set, all heating elements will be de-energised.

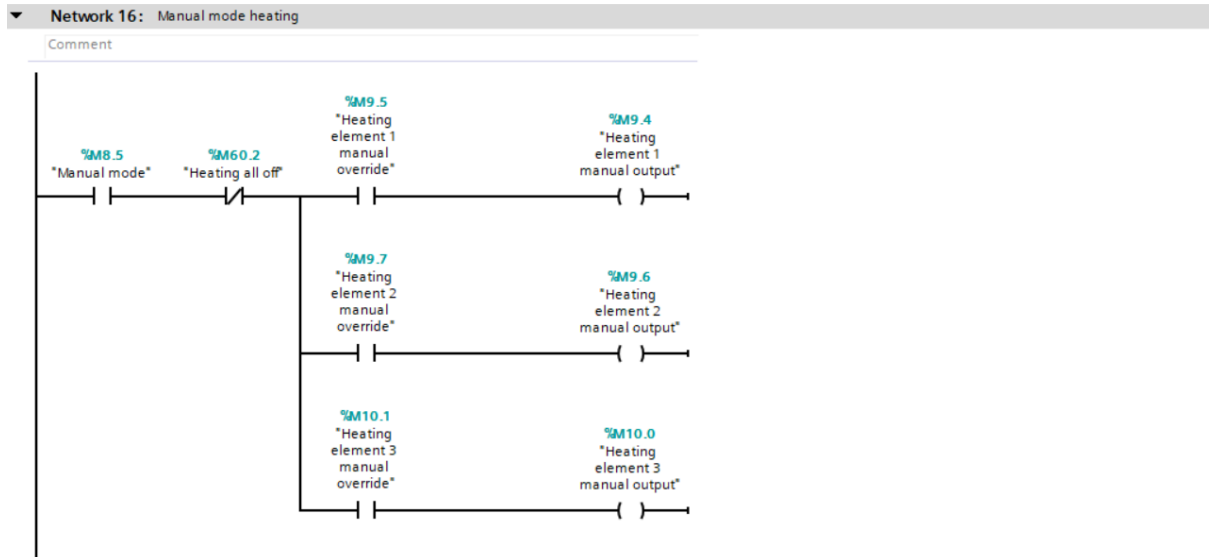


Figure 26 - Network 16

Network 17 uses a comparator function to set an alarm contact. If the 'real lux' level is equal to or greater than 850, the 'high light level' alarm will illuminate.

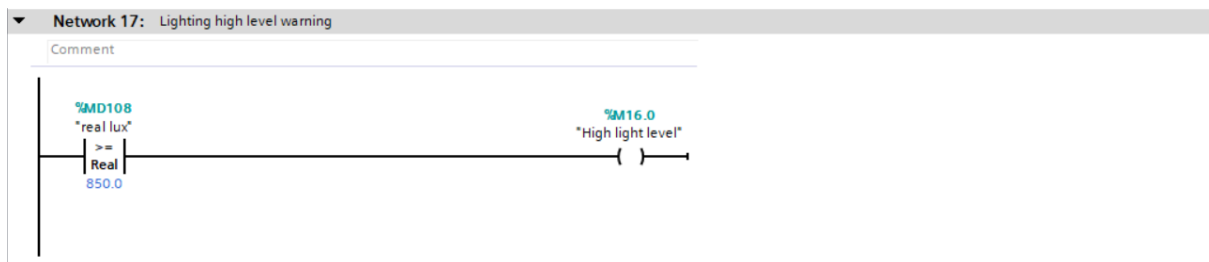


Figure 27 - Network 17

Network 18 uses a comparator function to set an alarm contact. If the 'real temp' level is equal to or greater than 24, the 'high temperature level' alarm will illuminate.

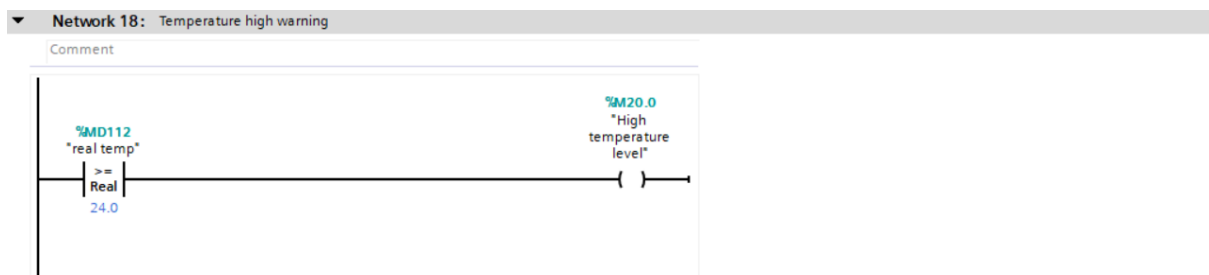


Figure 28 - Network 18

Network 19 uses a comparator function to set an alarm contact. If the 'real temp' level is equal to or less than 16, the 'low temperature level' alarm will illuminate.

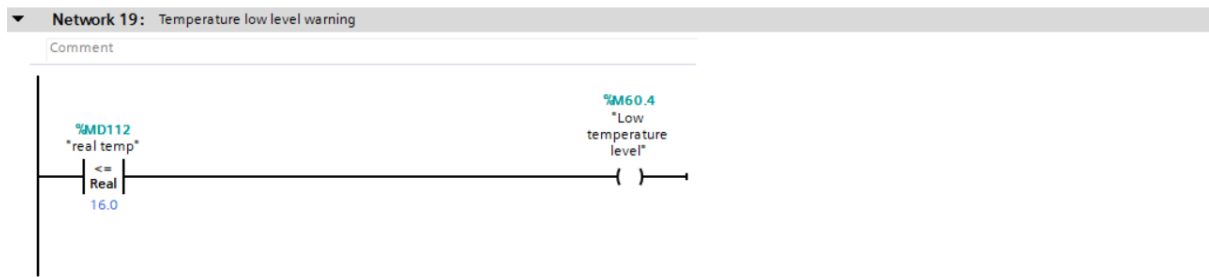


Figure 29 - Network 19

Network 20 uses a comparator function to set an alarm contact. If the 'real lux' level is equal to or less than 200, the 'low light level' alarm will illuminate.

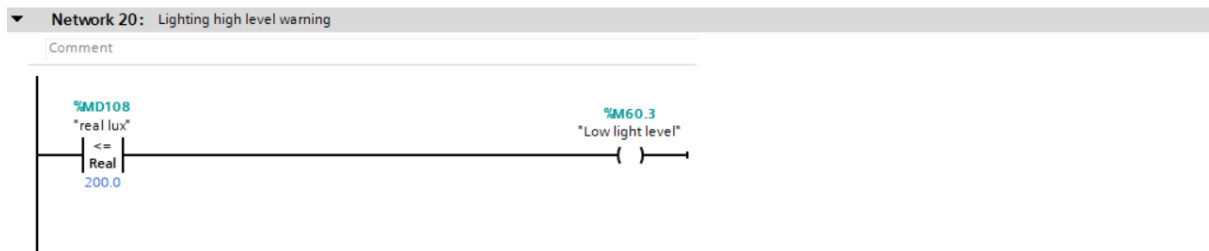


Figure 30 - Network 20

## 15 Software testing

During the PLC software development stage, Factory IO was used to help prove the logic and functionality of the PLC software. The Siemens software has an associated simulation package which integrates with the Factory IO software through a function block. The IO tags set within the Siemens software can be transferred to the factory IO, when run in simulation mode, objects selected within Factory IO can be controlled using the PLC program. Below are some images showing the Factory IO software.

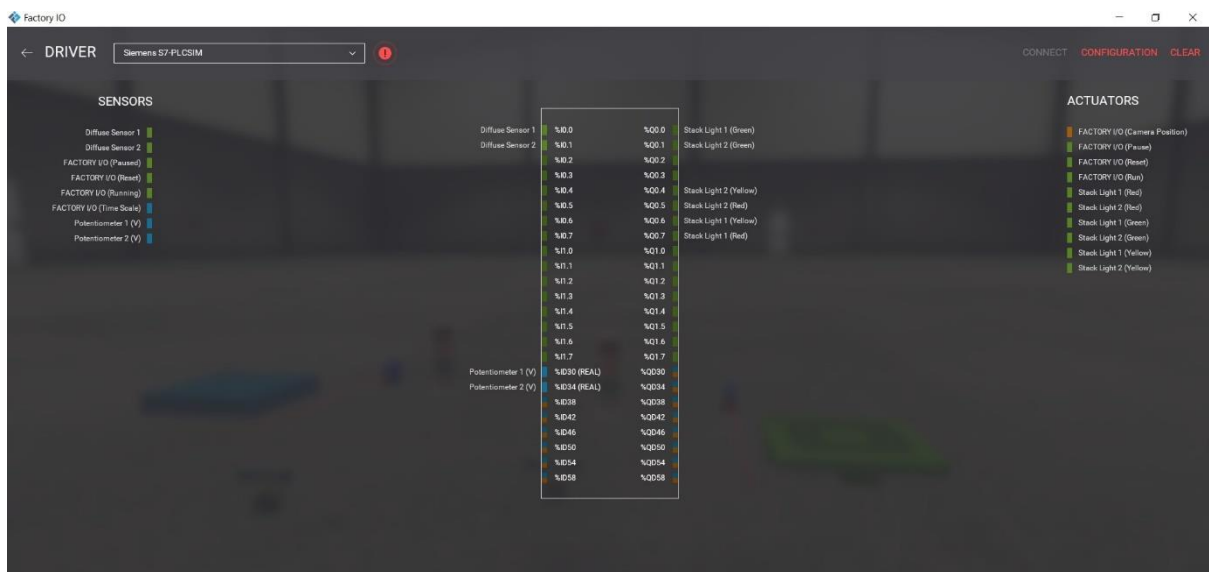


Figure 31 - Factory IO tags



Figure 32 - Factory IO components

Although the Factory IO software doesn't contain the exact components required for the project, it contains components that could be used to replicate the required. Laser sensors were used to replicate the occupancy sensor and provide a digital input signal to the PLC when the beam was broken, potentiometers were used to replicate the analogue input signals from the thermostat and lux sensor and stack lights were used to replicate the heating and lighting digital outputs.

Using this software, it was possible to test the functionality of the PLC logic relatively quickly and effectively.

## 16 Layout

Image below shows control panel external layout.

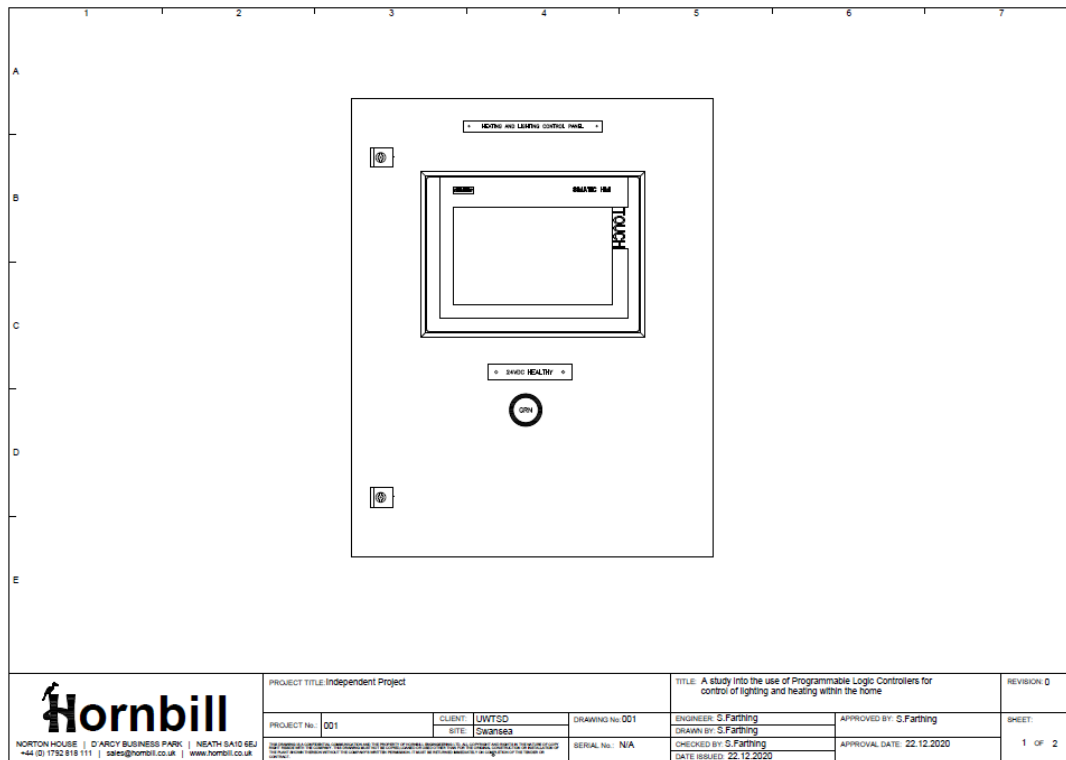


Figure 33 - Panel external layout

Image below shows panel internal back plate layout.

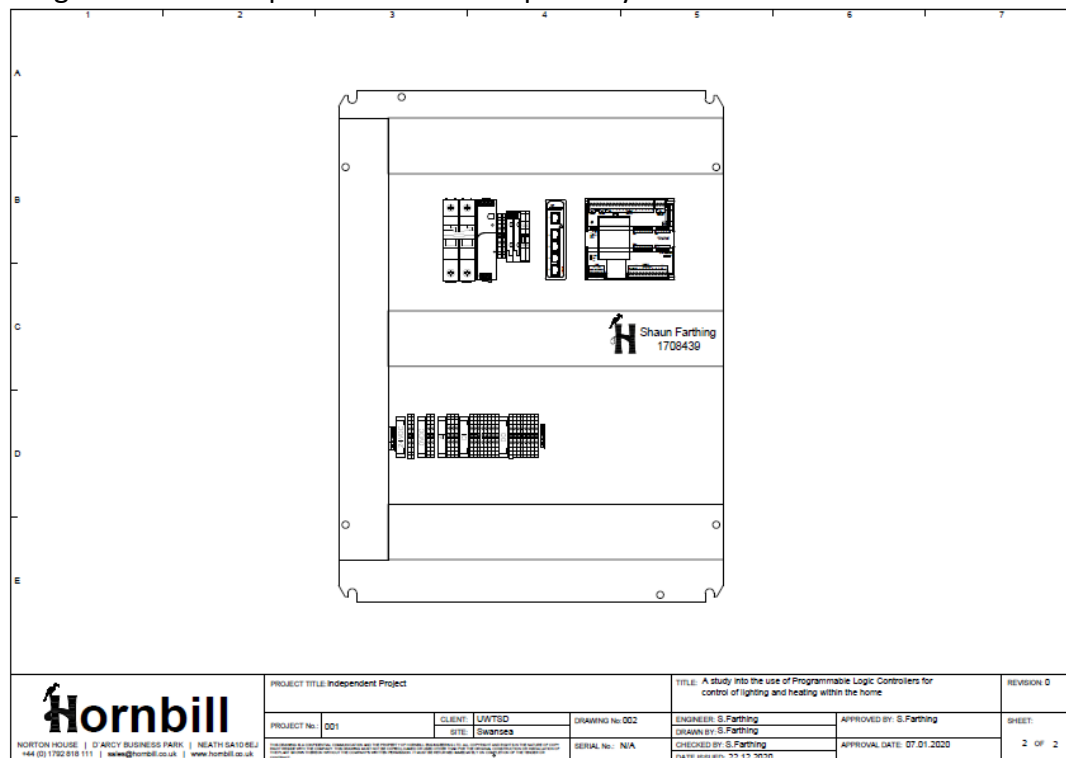


Figure 34 - Internal back plate layout

Image below shows lighting system inputs layout.

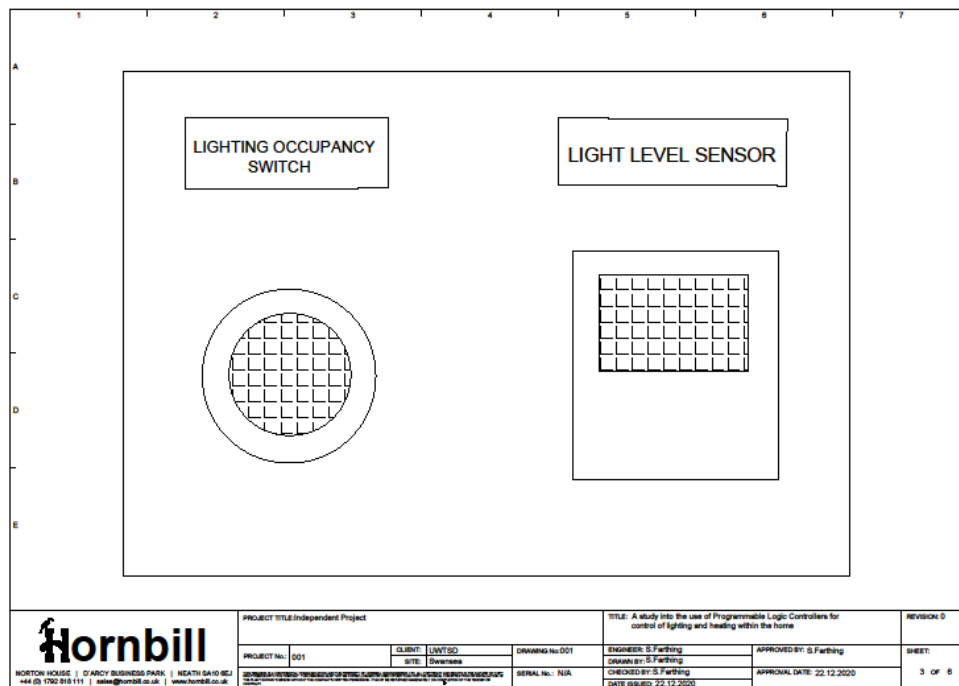


Figure 35 - Lighting inputs

Image below shows heating system inputs.

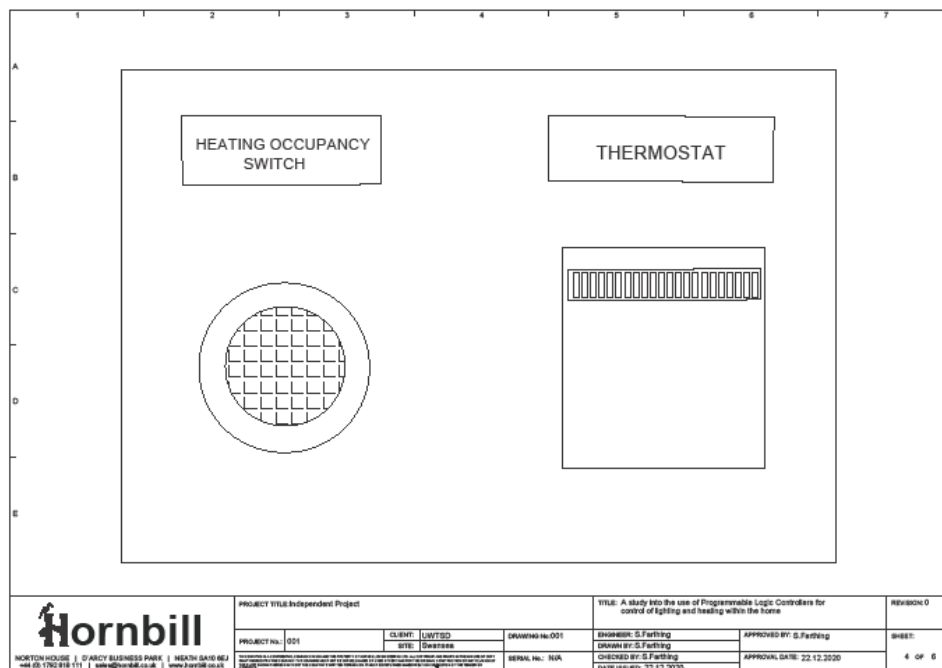


Figure 36 - Heating inputs

Image below shows lighting system outputs.

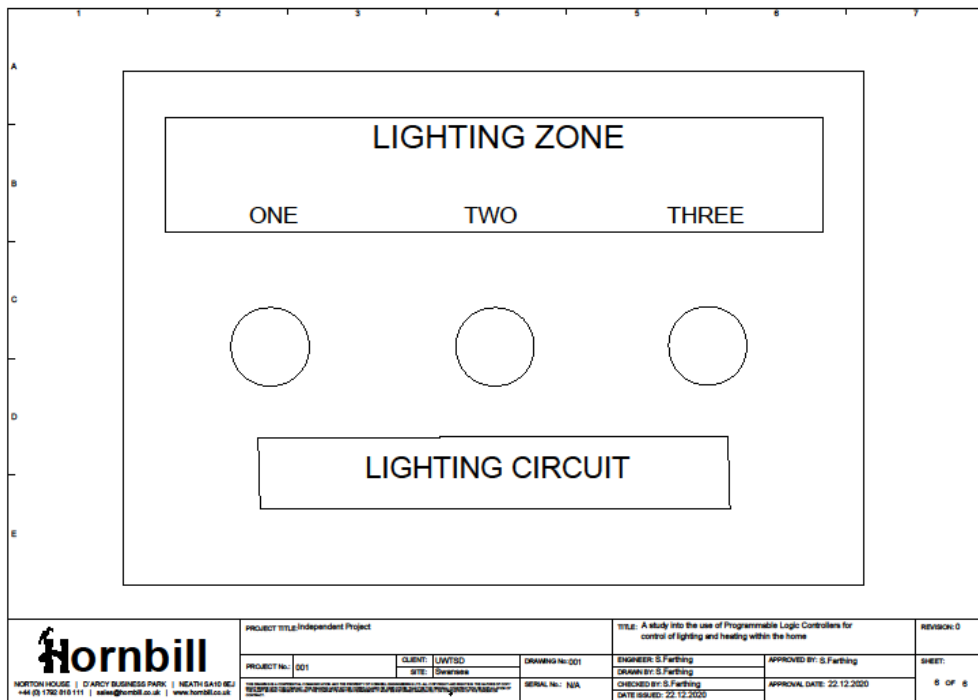


Figure 37 - Lighting outputs

Image below shows heating system outputs.

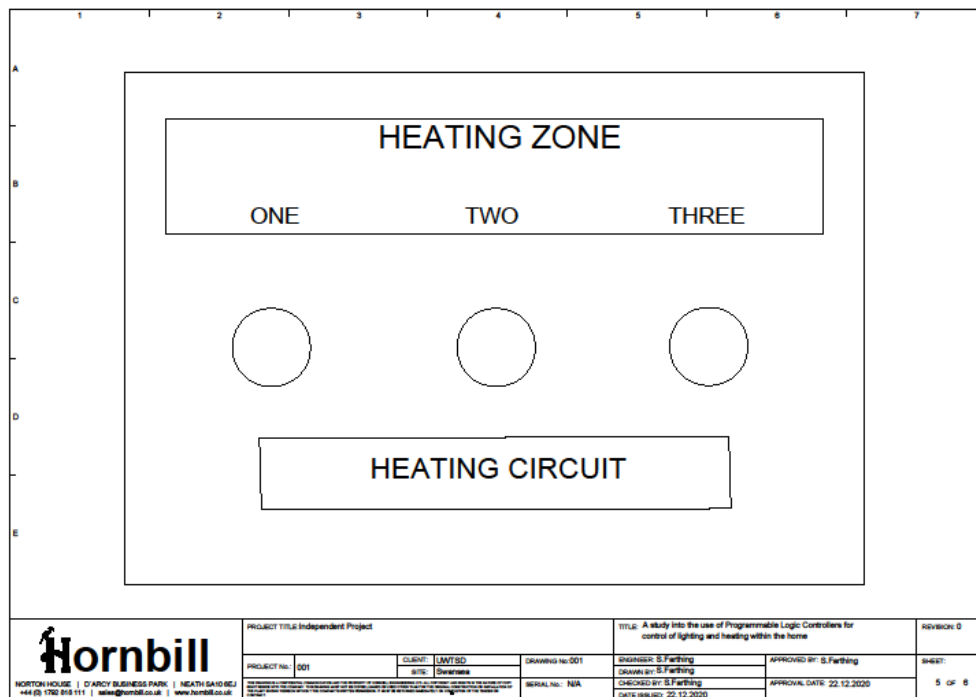


Figure 38 - Heating outputs

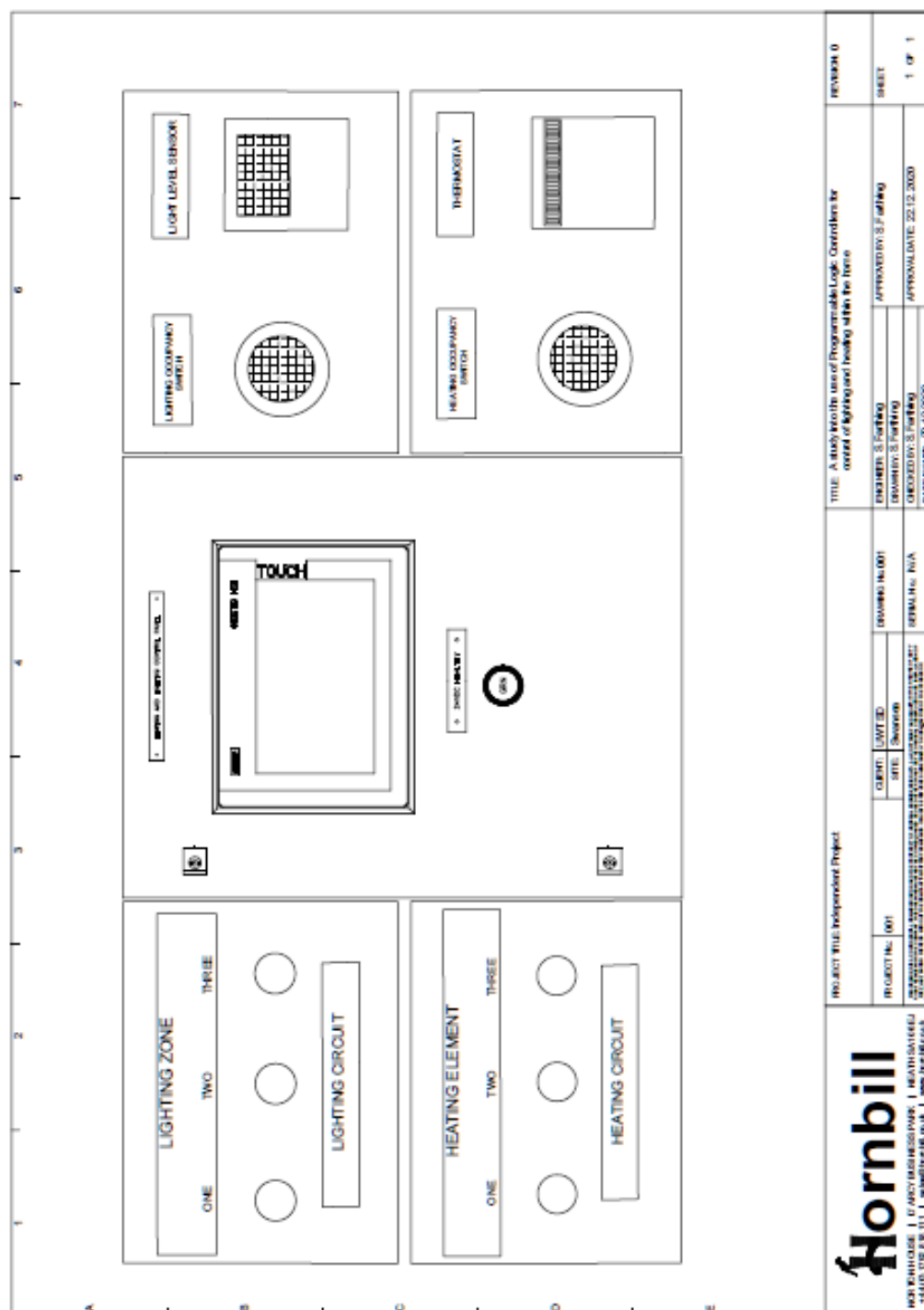


*Figure 39 - Full external layout*

## 17 Panel schematics

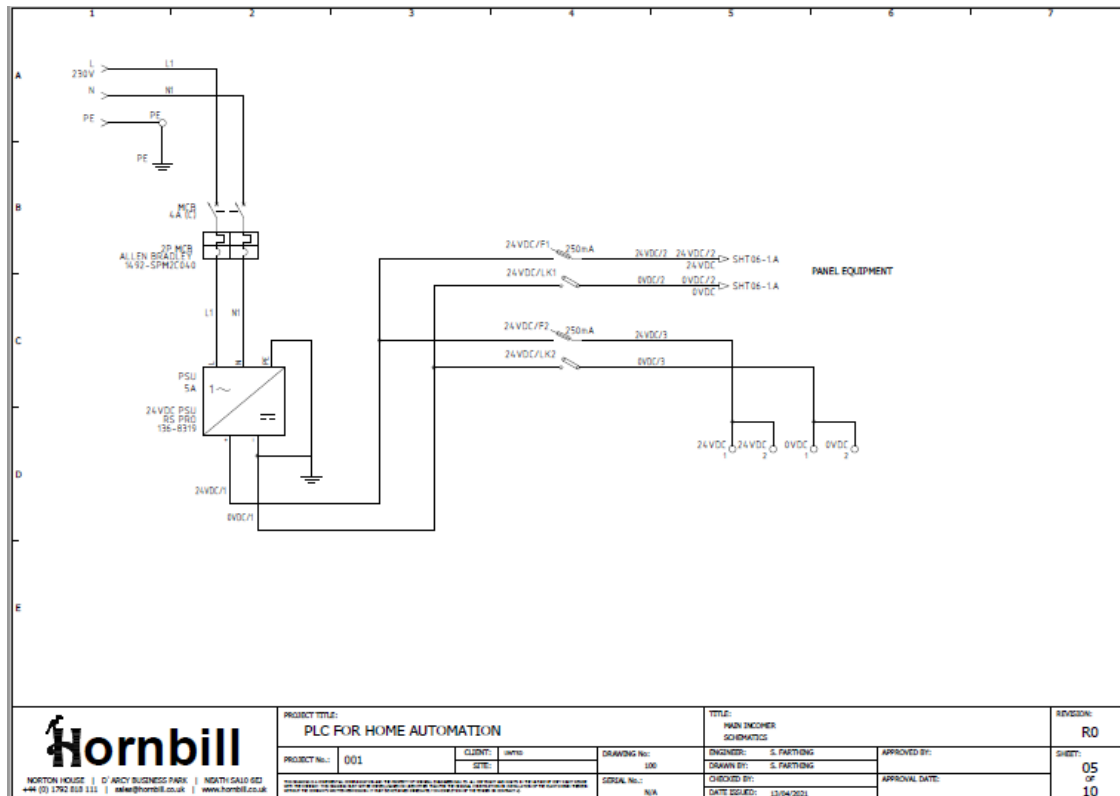


Figure 40 - Power supply

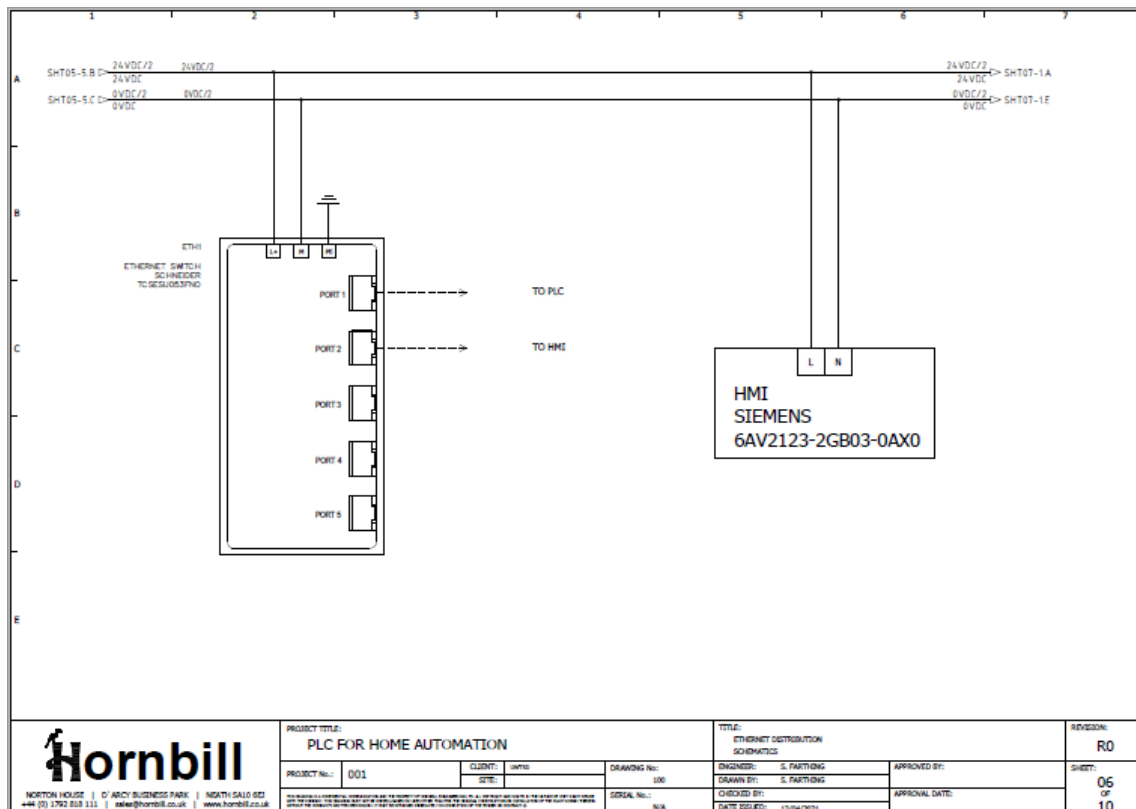


Figure 41 - Ethernet connectivity

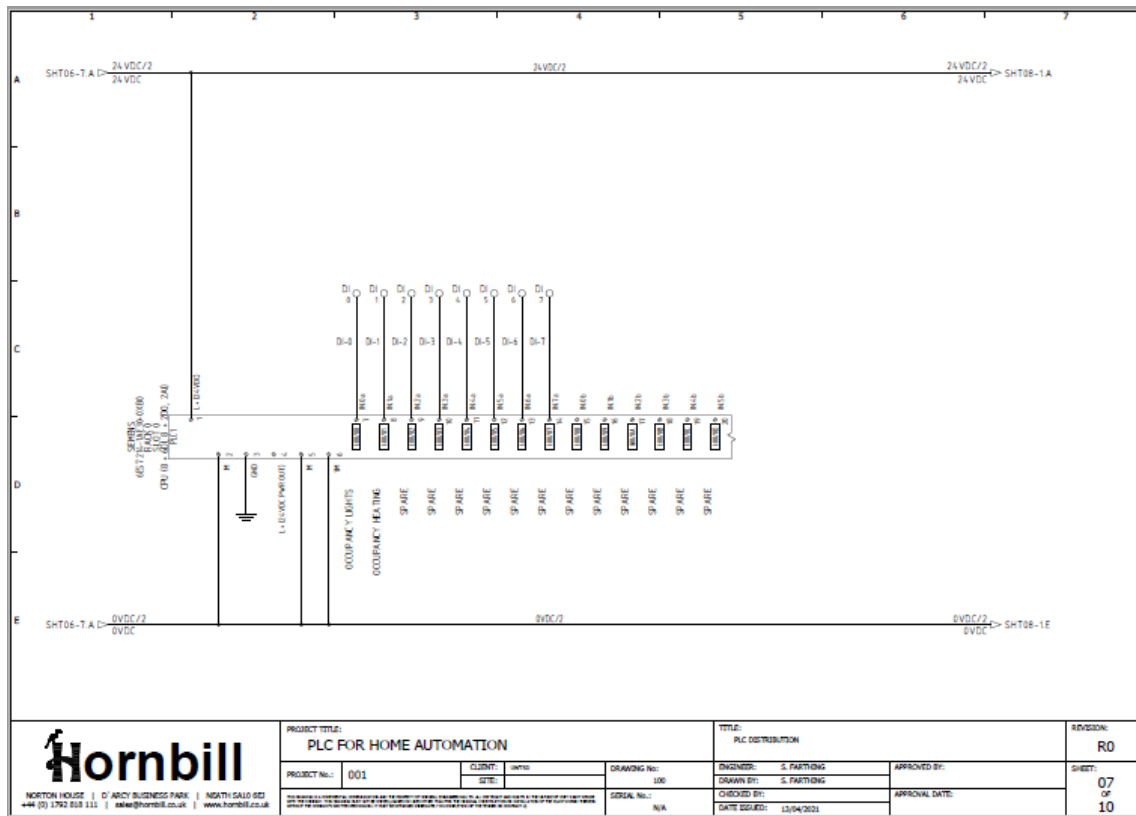


Figure 42 - Digital inputs

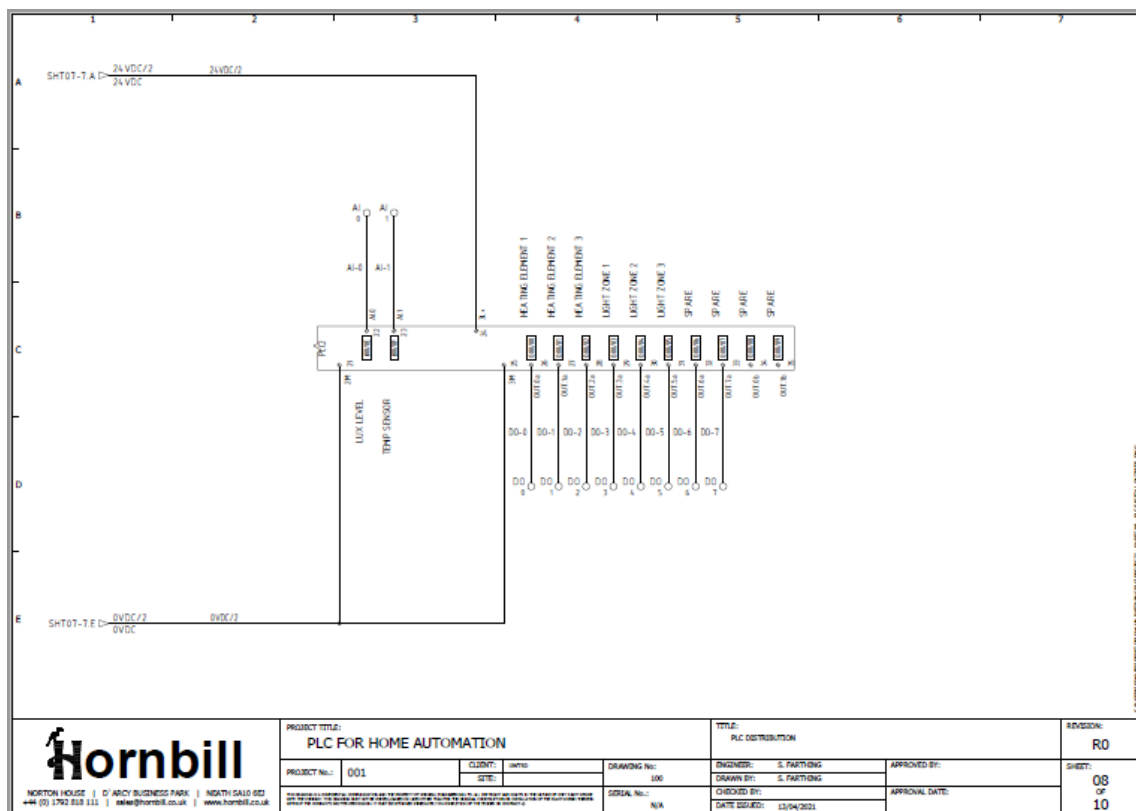


Figure 43 - Analogue inputs and digital outputs

## 18 HMI layouts

The images below show the HMI screen layouts. The displays and functions on each screen allow the user to be able to monitor the state of the individual circuits, monitor how far through a process the sequence is, select auto or manual modes, control the circuits in manual mode and display any warning alarms. Each screen also has push buttons to allow navigation to other screens.

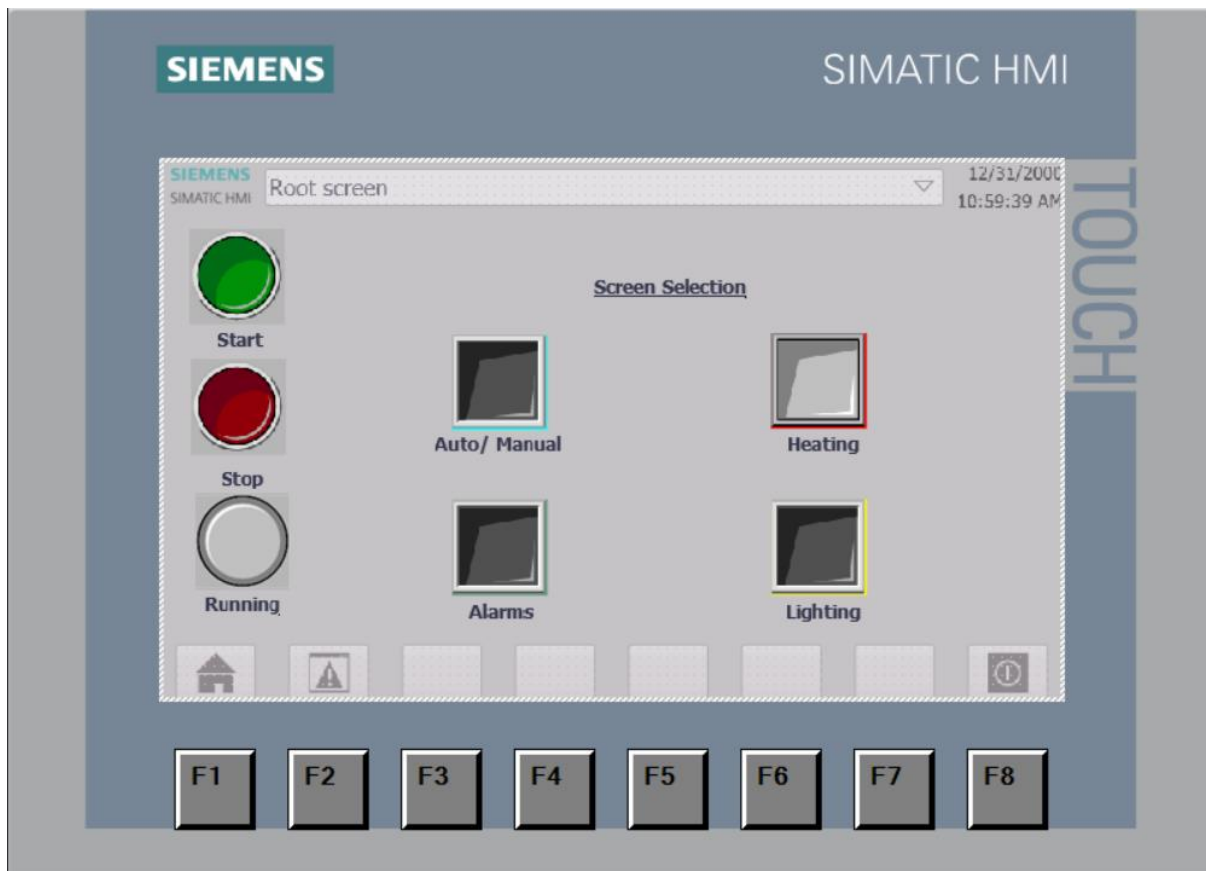


Figure 44 - Root/home screen

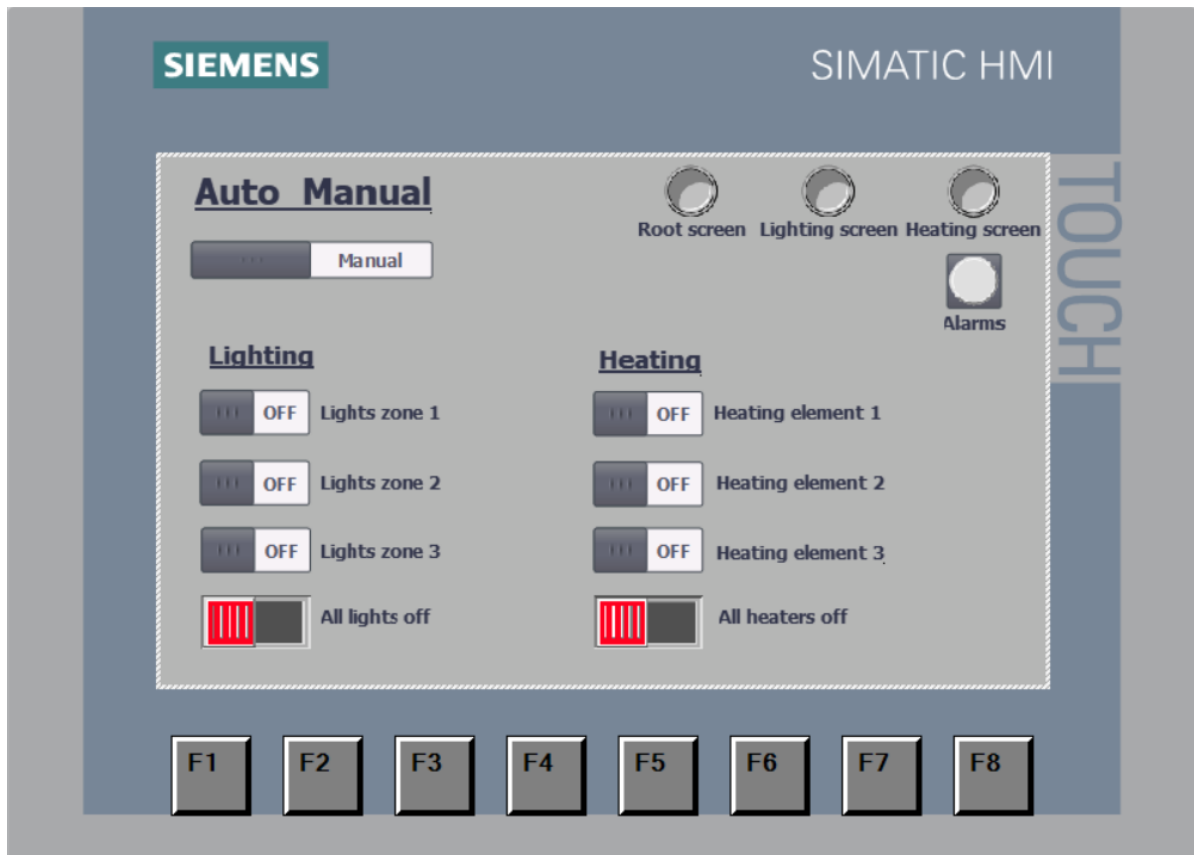


Figure 45 - Auto/manual selection and control screen

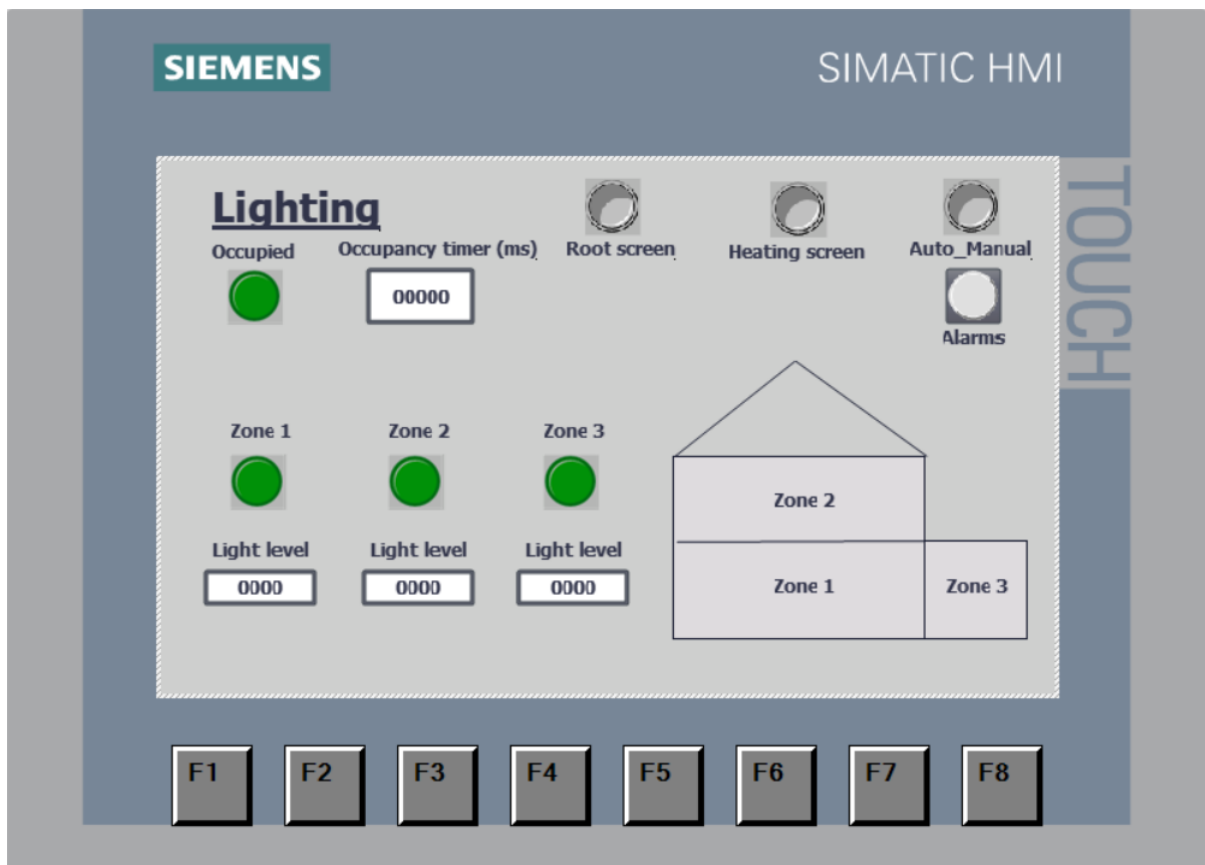


Figure 46 - Lighting screen

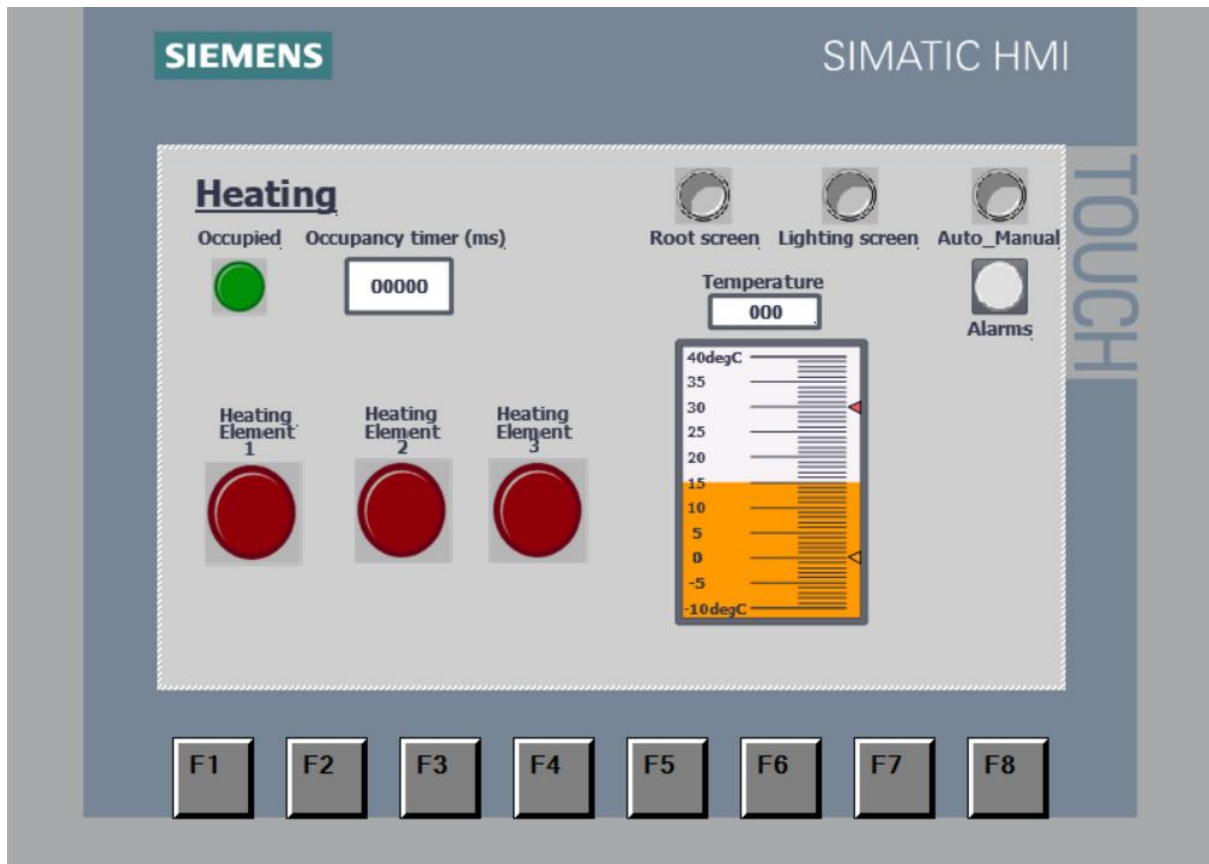


Figure 47 - Heating screen

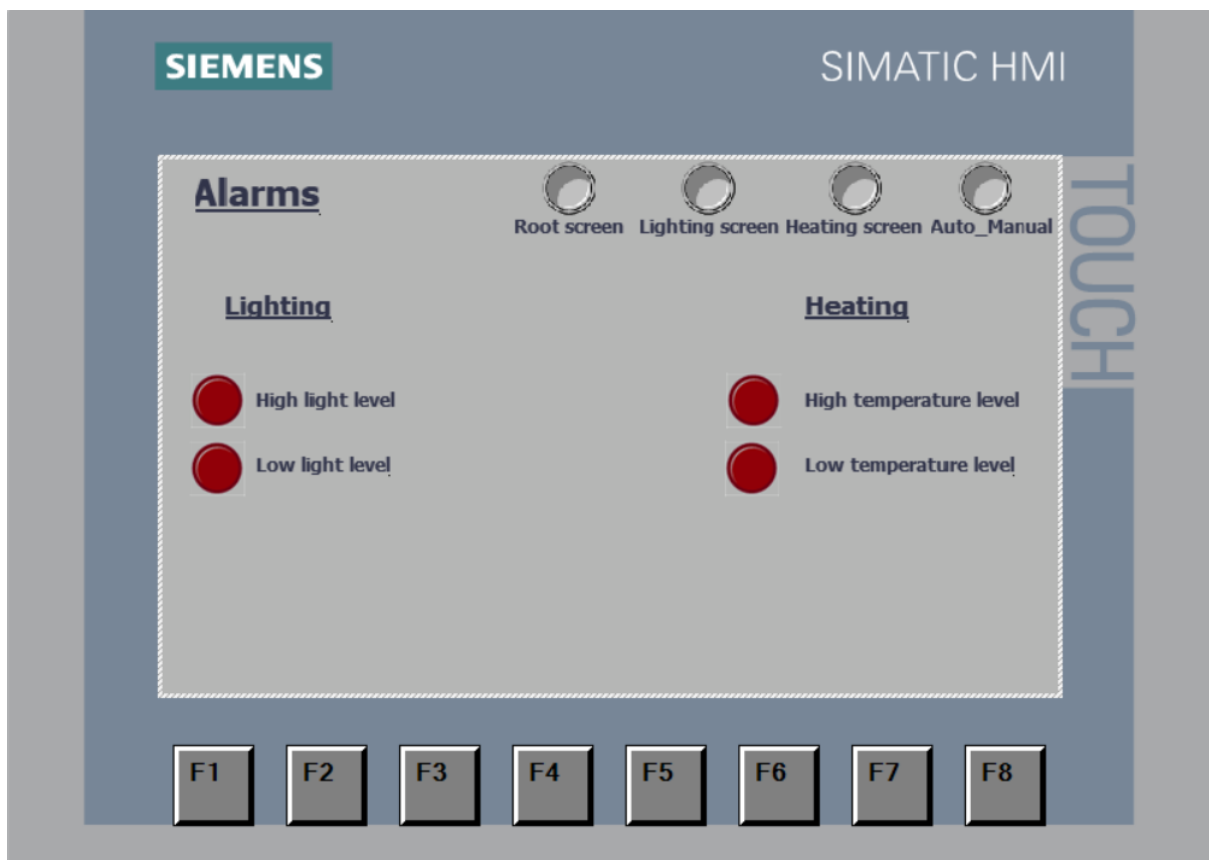


Figure 48 - Alarm display screen

## 19 Tags and addresses

|    | Name                            | Tag table         | Data type | Address | Retain | Acces...                            | Writa...                            | Visibl...                           | Comment |
|----|---------------------------------|-------------------|-----------|---------|--------|-------------------------------------|-------------------------------------|-------------------------------------|---------|
| 1  | Occupancy lighting              | Default tag table | Bool      | %I0.0   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 2  | Light on                        | Default tag table | Bool      | %Q1.0   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 3  | Norm value                      | Default tag table | Real      | %MD0    |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 4  | Scaled value                    | Default tag table | Real      | %MD4    |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 5  | Occupancy heating               | Default tag table | Bool      | %I0.1   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 6  | Heating element/ pump 1         | Default tag table | Bool      | %Q0.0   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 7  | Norm temp                       | Default tag table | Real      | %MD36   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 8  | Scaled temp                     | Default tag table | Real      | %MD40   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 9  | Occ switch time lighting        | Default tag table | Time      | %MD44   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 10 | Light timer on                  | Default tag table | Bool      | %M0.2   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 11 | Occ switch time heating         | Default tag table | Time      | %MD48   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 12 | Heating timer on                | Default tag table | Bool      | %M0.3   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 13 | Heating element/ pump 2         | Default tag table | Bool      | %Q0.1   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 14 | Heating element/ pump 3         | Default tag table | Bool      | %Q0.2   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 15 | Light zone 2                    | Default tag table | Bool      | %Q0.4   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 16 | Light zone 3                    | Default tag table | Bool      | %Q0.5   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 17 | Light zone 1                    | Default tag table | Bool      | %Q0.3   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 18 | Auto_Manual                     | Default tag table | Bool      | %M8.1   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 19 | Manual select                   | Default tag table | Bool      | %M8.2   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 20 | Auto select                     | Default tag table | Bool      | %M8.3   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 21 | Auto mode                       | Default tag table | Bool      | %M8.4   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 22 | Manual mode                     | Default tag table | Bool      | %M8.5   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 23 | Light 1 manual output           | Default tag table | Bool      | %M8.6   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 24 | Light switch 1 manual           | Default tag table | Bool      | %M8.7   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 25 | Light 2 manual output           | Default tag table | Bool      | %M9.0   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 26 | Light switch 2 manual           | Default tag table | Bool      | %M9.1   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 27 | Light 3 manual output           | Default tag table | Bool      | %M9.2   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 28 | Light switch 3 manual           | Default tag table | Bool      | %M9.3   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 29 | Heating element 1 manual out... | Default tag table | Bool      | %M9.4   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 30 | Heating element 1 manual ove... | Default tag table | Bool      | %M9.5   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 31 | Heating element 2 manual out... | Default tag table | Bool      | %M9.6   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 32 | Heating element 2 manual ove... | Default tag table | Bool      | %M9.7   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 33 | Heating element 3 manual out... | Default tag table | Bool      | %M10.0  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 34 | Heating element 3 manual ove... | Default tag table | Bool      | %M10.1  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 35 | Start system                    | Default tag table | Bool      | %M10.2  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 36 | System running                  | Default tag table | Bool      | %M10.3  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 37 | Stop system                     | Default tag table | Bool      | %M10.4  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 38 | Lux level                       | Default tag table | Word      | %IW64   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 39 | Temperature sensor              | Default tag table | Word      | %IW66   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 40 | LUX                             | Default tag table | Real      | %MD100  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 41 | TEMP                            | Default tag table | Real      | %MD104  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 42 | real lux                        | Default tag table | Real      | %MD108  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 43 | real temp                       | Default tag table | Real      | %MD112  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 44 | Graph temp                      | Default tag table | Real      | %MD12   |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 45 | High light level                | Default tag table | Bool      | %M16.0  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 46 | High temperature level          | Default tag table | Bool      | %M20.0  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 47 | Lights all off                  | Default tag table | Bool      | %M40.1  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 48 | Heating all off                 | Default tag table | Bool      | %M60.2  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 49 | Low light level                 | Default tag table | Bool      | %M60.3  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 50 | Low temperature level           | Default tag table | Bool      | %M60.4  |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |
| 51 | <Add new>                       |                   |           |         |        | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |         |

Figure 49 - PLC tag table

shaun1 - HMI\_1 [KTP700 Basic PN] - HMI tags

| Name                          | Tag table         | Data type | Connection       | PLC name | PLC tag                   | Address |
|-------------------------------|-------------------|-----------|------------------|----------|---------------------------|---------|
| Auto mode                     | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Auto mode*               |         |
| Auto select                   | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Auto select*             |         |
| Auto_Manual                   | Default tag table | Bool      | HMI_Connectio... | PLC_1    | Auto_Manual               |         |
| Heating all off               | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating all off*         |         |
| Heating element 1             | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element/ pump .. |         |
| Heating element 1 manual ove. | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element 1 man... |         |
| Heating element 2             | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element/ pump .. |         |
| Heating element 2 manual ove. | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element 2 man... |         |
| Heating element 3             | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element/ pump .. |         |
| Heating element 3 manual ove. | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element 3 man... |         |
| Heating on                    | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Heating element/ pump .. |         |
| High light level              | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *High light level*        |         |
| High temp level               | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *High temperature level*  |         |
| Input temp                    | Default tag table | Word      | HMI_Connectio... | PLC_1    | *Temperature sensor*      |         |
| Light level                   | Default tag table | Real      | HMI_Connectio... | PLC_1    | *real lux*                |         |
| Light on                      | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light on*                |         |
| Light switch 1 manual         | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light switch 1 manual*   |         |
| Light switch 2 manual         | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light switch 2 manual*   |         |
| Light switch 3 manual         | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light switch 3 manual*   |         |
| Light zone 1                  | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light zone 1*            |         |
| Light zone 2                  | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light zone 2*            |         |
| Light zone 3                  | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Light zone 3*            |         |
| Lights all off                | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Lights all off*          |         |
| Low light level               | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Low light level*         |         |
| Low temperature level         | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Low temperature level*   |         |
| Manual mode                   | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Manual mode*             |         |
| Manual select                 | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Manual select*           |         |

shaun1 - HMI\_1 [KTP700 Basic PN] - HMI tags

| Name                     | Tag table         | Data type | Connection       | PLC name | PLC tag                    | Address |
|--------------------------|-------------------|-----------|------------------|----------|----------------------------|---------|
| Occupancy heating        | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Occupancy heating*        |         |
| Occupancy lighting       | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Occupancy lighting*       |         |
| Occupancy timer heating  | Default tag table | Time      | HMI_Connectio... | PLC_1    | *Occ switch time heating*  |         |
| Occupancy timer lighting | Default tag table | Time      | HMI_Connectio... | PLC_1    | *Occ switch time lighting* |         |
| Start system             | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Start system*             |         |
| Stop system              | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *Stop system*              |         |
| System running           | Default tag table | Bool      | HMI_Connectio... | PLC_1    | *System running*           |         |
| Tag_ScreenNumber         | Default tag table | UInt      | <Internal tag>   |          | <Undefined>                |         |
| Teperature level         | Default tag table | Real      | HMI_Connectio... | PLC_1    | *real temp*                |         |
| <Add new>                |                   |           |                  |          |                            |         |

Figure 50 - HMI tags

## 20 PLC system network overview

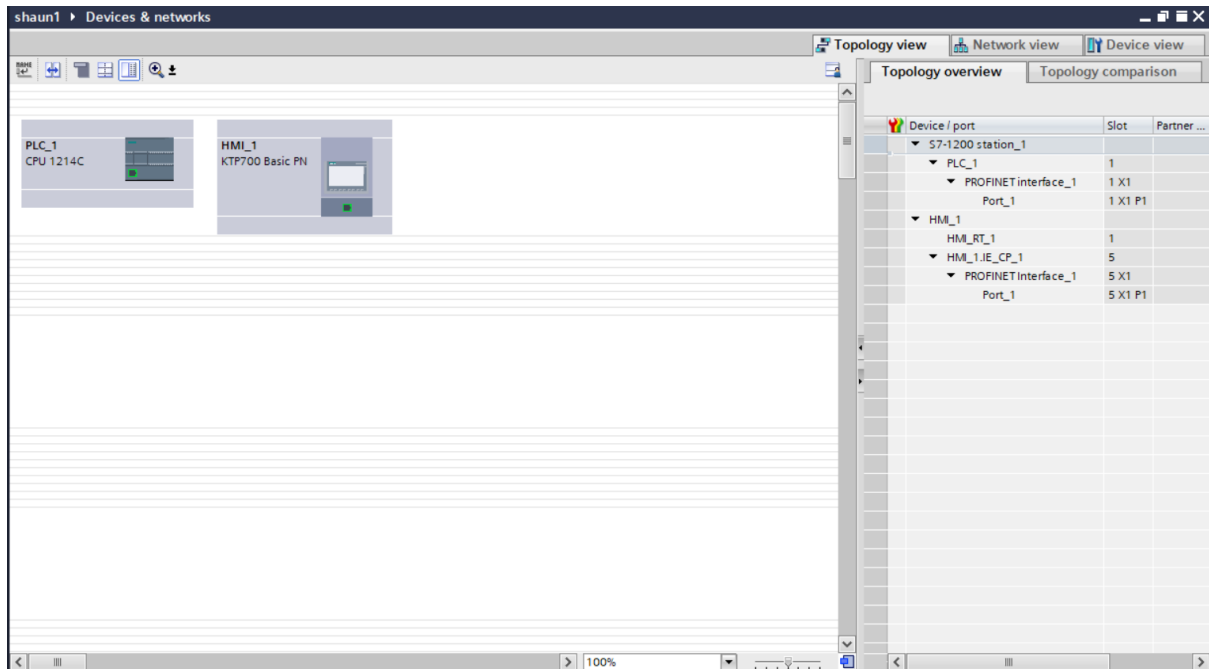


Figure 51 - Topology view

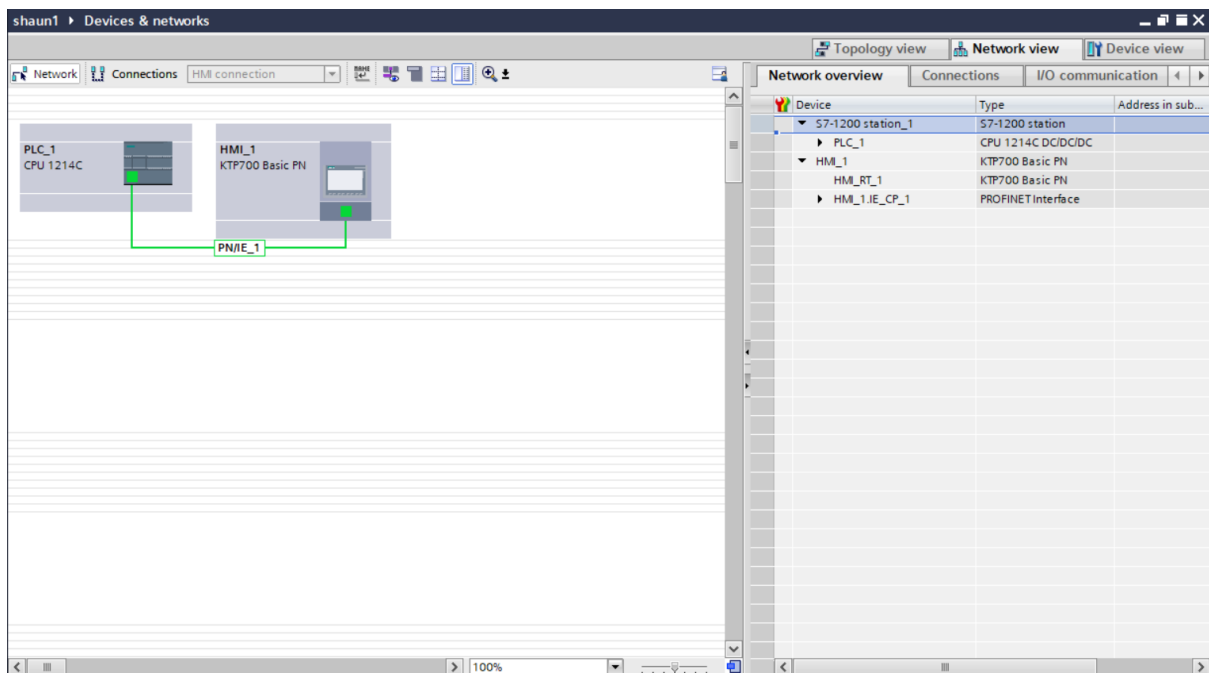


Figure 52 - Network view

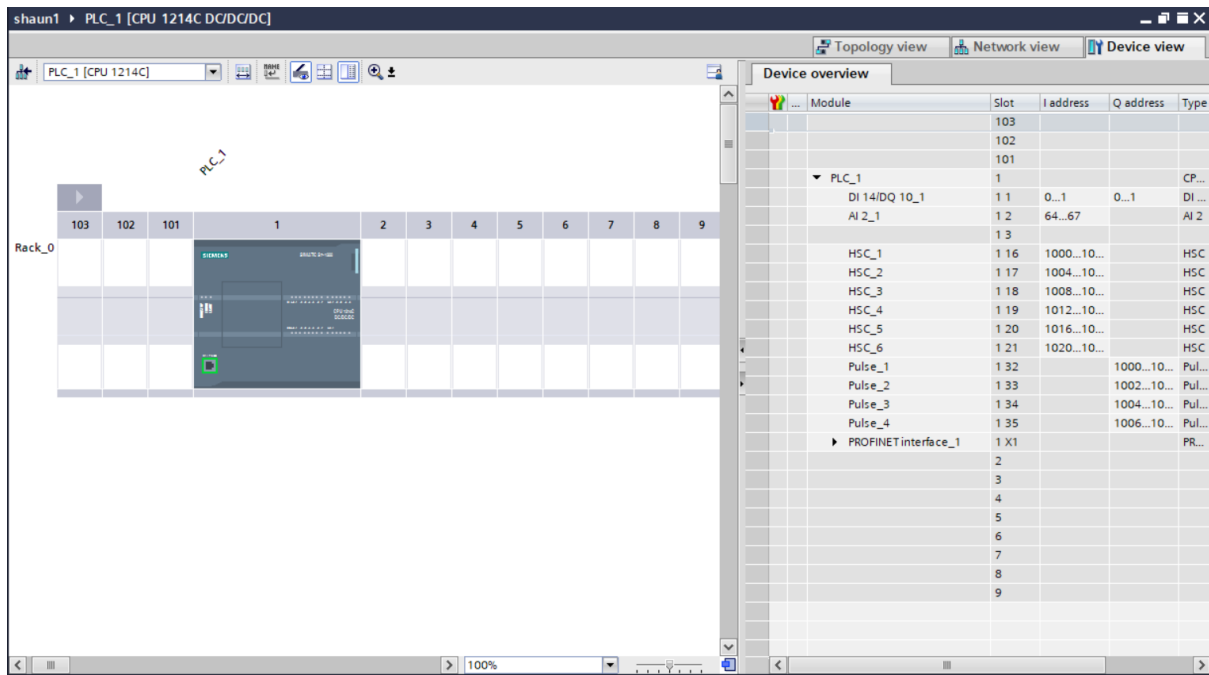


Figure 53 - Device view

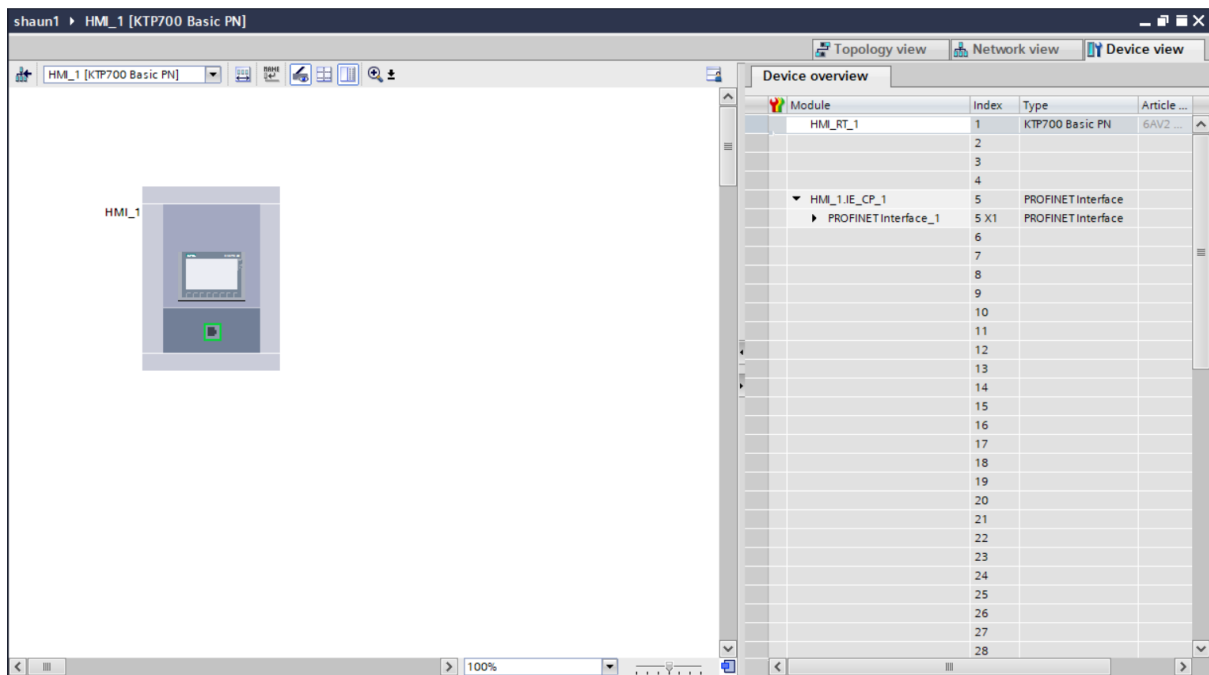


Figure 54 - Device view HMI

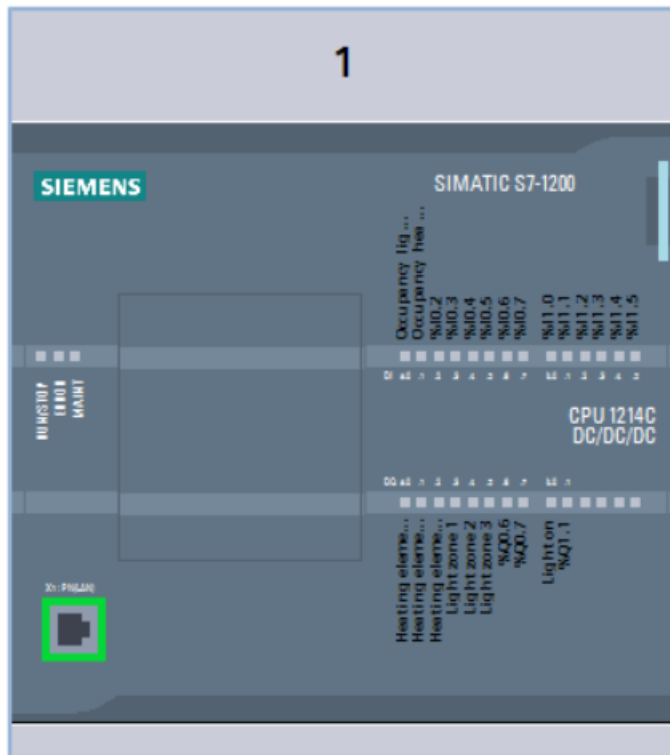


Figure 55 - PLC device view IO detail

## 21 Project build testing

To test the sensor functionality of the occupancy sensors, the panel was energised, when the sensor is set, the occupancy sensor has 24v across the positive and negative terminals. When, the timer expires, the sensor de-energises and has 0v across the cores. On the HMI the 'occupied' light is illuminated when the occupancy sensor is set.



Figure 56 - Occupancy sensor test

To function test the analogue inputs, when the panel was energised, the voltage was recorded between the signal wire (to AI on PLC) and the 0v wire. The voltage output of the individual item is the 0-10v signal, the value will be dependent on the brightness or temperature in the area. The readings are also depicted on the HMI as a temperature and light levels.



Lighting

Heating



Figure 57 - Analogue input testing

To test the digital outputs, each of the individual heater and light outputs were set, when the respective output was energised, there was 24v across that pilot light, when the output was de-energised, there was 0v. The pilot lights also energised when the outputs were set. The individual heating elements and lights were also depicted on the HMI.



Figure 58 - Digital output testing

Whilst testing the digital outputs, the alarms were tested to ensure they illuminated when they went either high level or low level. Excessive light was applied for high light level, the lux sensor was covered to achieve low level. The high temperature was in alarm due to the heating in the house being on, the low temperature was achieved by placing frozen food on the RTD.

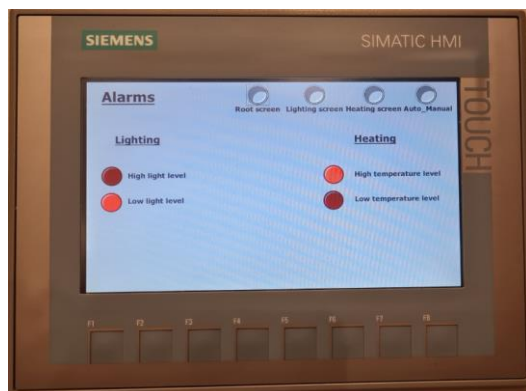


Figure 59 - Alarm testing

## 22 Design

This project incorporated a PLC over other methods of control such as a microcontroller for a number of reasons. The amount of interfaces and the ability to continually reconfigure or add additional inputs or outputs during the lifetime of the product was a factor. As equipment in the home is constantly evolving and changing, having a product that can be altered to adapt changes was important and crucial to the longevity of use.

The PLC also has the ability to have multiple interfaces to actuators or display equipment such as HMI's. The intention of this project is so that it can be used in the home, having an interface where information can be displayed and controls for the operation of household equipment can be located so that it is interactive and easy to use was important. This is more easily achieved using a PLC. Also, the ability to add additional actuators or sensing devices as the home develops is more easily adaptable and achievable using a PLC.

PLCs are also less susceptible to environmental factors, electrical noise and rough handling as they are designed for industrial environments whereas microcontrollers are designed to be embedded into other hardware. PLCs are also favourable for real time operation, they are able to produce outputs in a very short time frame after evaluating an input, this is crucial for use in the home. PLCs are also relatively simple to troubleshoot should there be any issues with the programme as they can generally be displayed on the HMI, with a microcontroller troubleshooting will require a good knowledge of electrical and electronic circuitry.

Although there are many positives to using a PLC for this application, they are very costly to purchase, they require occasional maintenance, they will require specialist support if faults develop.

## 23 Analysis

The average UK household uses around 3,731 kWh/year of electricity. This figure does not factor in heating, if electric heating is used, this figure will grow substantially. A household's energy profile can be defined as low, medium or high. These categories values are low = 1,800kWh, medium = 2,900kWh and high = 4,300kWh. [10]

In the South Wales area, the average cost per kWh of electricity is 15.07p. [11] This equates to an annual bill of £559.65.

The main energy consumers within the home using approx... 63% of the electricity are cold appliances such as fridges and freezers, approx... 10% is used by wet appliances such as washing machines and dishwashers while approx... 7% is used by cookers and microwaves. [10] Other than installing energy efficient appliances or limiting the amount the appliances are used, we are unable to save electricity with these appliances, we must use them when required.

With regard to lighting and heating, we have control of when these are required, what quantity they are required in and for what duration they are required.

For this project, to make an estimate of the potential savings, I have monitored the energy use for lighting within my home. The graph below shows the quantity, different type of lamps installed and in what areas of the house.

### 23.1 Lighting use

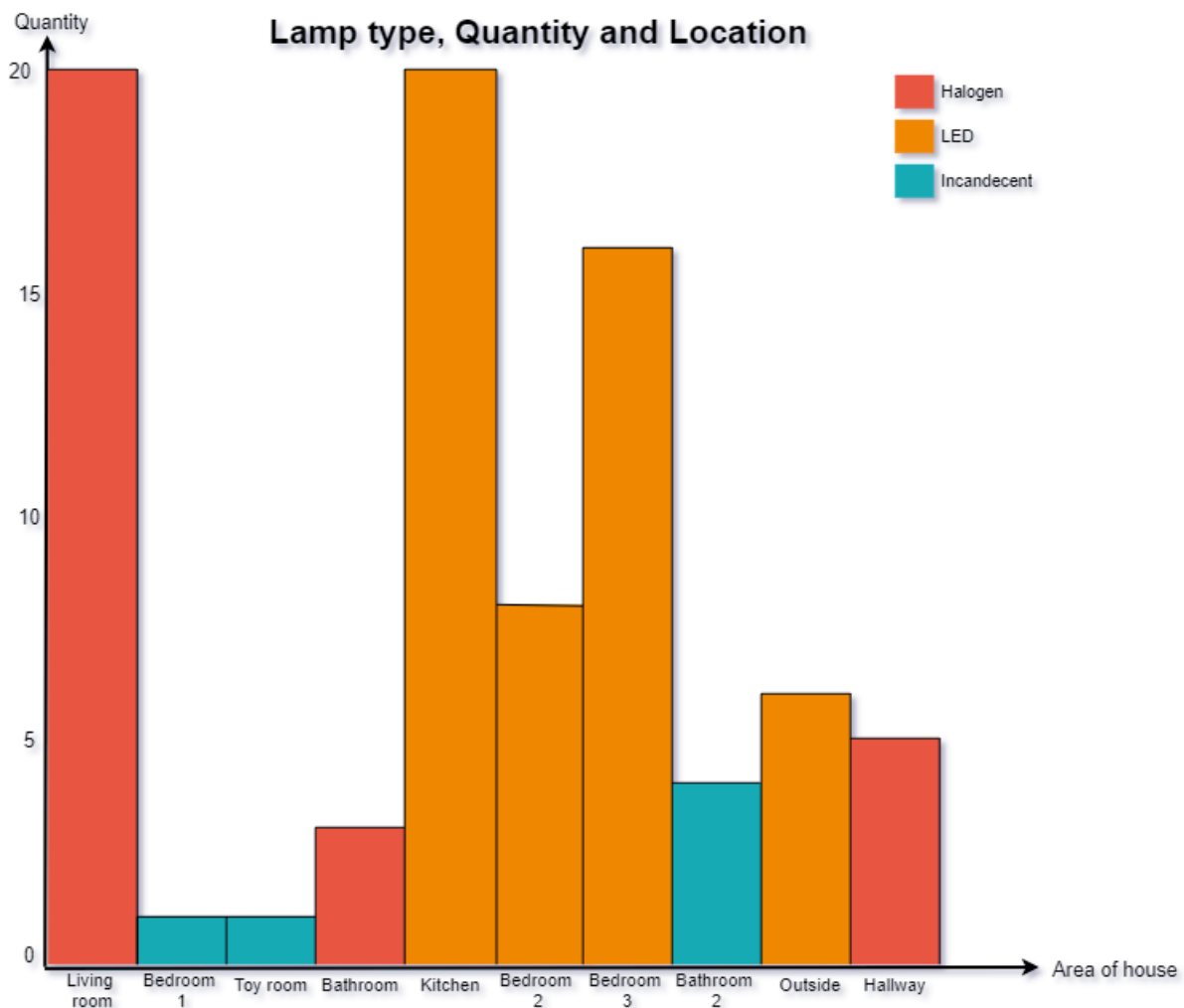


Figure 60 - Lamp type, quantity & location graph

Whilst documenting the quantity and types of lamps I have installed, I also made note of the wattage of each of these lamps, and I have detailed these on the table below.

| Area of house and lamp W | Qty lamps | Watt per lamp |
|--------------------------|-----------|---------------|
| Living room – 28W each   | 20        | 28            |
| Bedroom – 40W            | 1         | 40            |
| Toy room – 40W           | 1         | 40            |
| Bathroom 1 – 18W each    | 3         | 18            |
| Kitchen – 3W each        | 20        | 3             |
| Bedroom 2 – 3W each      | 8         | 3             |
| Bedroom 3 – 3W each      | 16        | 3             |
| Bathroom 2 – 18W each    | 4         | 18            |
| Outside – 5W each        | 6         | 5             |
| Hallway – 18W each       | 5         | 18            |

Table 1 - Quantity & wattage of installed lamps

To understand the quantity of energy being consumed by lighting in my home, I monitored the time the lights in each area of the house were used per hour, I have listed this information in the table below.

| Area of house | 12AM | 1AM | 2AM | 3AM | 4AM | 5AM | 6AM | 7AM | 8AM | 9AM | 10AM | 11AM |
|---------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| Living room   | 0    | 0   | 0   | 0   | 0   | 0   | 15  | 0   | 10  | 30  | 0    | 0    |
| Bedroom 1     | 0    | 0   | 0   | 0   | 0   | 10  | 0   | 0   | 10  | 45  | 0    | 0    |
| Toy room      | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 15  | 0   | 10   | 0    |
| Bathroom 1    | 5    | 0   | 0   | 0   | 5   | 20  | 5   | 0   | 30  | 10  | 0    | 5    |
| Kitchen       | 0    | 0   | 0   | 0   | 0   | 0   | 10  | 0   | 0   | 45  | 0    | 10   |
| Bedroom 2     | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 5   | 30  | 10  | 0    | 0    |
| Bedroom 3     | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 5   | 0   | 0    | 0    |
| Bathroom 2    | 0    | 0   | 0   | 0   | 0   | 5   | 5   | 0   | 10  | 5   | 0    | 5    |
| Outside       | 60   | 60  | 60  | 60  | 60  | 60  | 60  | 0   | 0   | 0   | 0    | 0    |
| Hallway       | 60   | 60  | 60  | 60  | 60  | 60  | 0   | 0   | 0   | 0   | 0    | 0    |

| Area of house | 12PM | 1PM | 2PM | 3PM | 4PM | 5PM | 6PM | 7PM | 8PM | 9PM | 10PM | 11PM |
|---------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| Living room   | 0    | 15  | 0   | 0   | 60  | 60  | 60  | 30  | 0   | 10  | 10   | 0    |
| Bedroom 1     | 0    | 0   | 0   | 0   | 15  | 0   | 15  | 0   | 0   | 0   | 15   | 0    |
| Toy room      | 15   | 0   | 0   | 0   | 20  | 25  | 20  | 0   | 5   | 0   | 0    | 0    |
| Bathroom 1    | 0    | 5   | 0   | 5   | 0   | 10  | 0   | 15  | 0   | 0   | 15   | 0    |
| Kitchen       | 45   | 50  | 10  | 0   | 5   | 60  | 60  | 45  | 10  | 5   | 10   | 0    |
| Bedroom 2     | 0    | 0   | 0   | 0   | 0   | 60  | 60  | 60  | 5   | 0   | 0    | 0    |
| Bedroom 3     | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0    | 5    |
| Bathroom 2    | 0    | 5   | 5   | 0   | 0   | 10  | 5   | 5   | 0   | 5   | 5    | 5    |
| Outside       | 0    | 0   | 0   | 0   | 0   | 0   | 60  | 60  | 60  | 60  | 60   | 60   |
| Hallway       | 0    | 0   | 0   | 0   | 5   | 5   | 60  | 60  | 60  | 60  | 60   | 60   |

| Area of house | Total times (mins) |
|---------------|--------------------|
| Living room   | 300                |
| Bedroom 1     | 110                |
| Toy room      | 110                |
| Bathroom 1    | 130                |
| Kitchen       | 365                |
| Bedroom 2     | 230                |
| Bedroom 3     | 10                 |
| Bathroom 2    | 75                 |
| Outside       | 780                |
| Hallway       | 730                |

Table 2 - Lighting use time over 24hrs

After calculating the total times the individual lights in different areas of the house were used, I then calculated the total watts used during this period. This was achieved by multiplying the quantity of lamps by the watt rating of the lamps by the time on during the 24 hour period.

| Area of house and lamp W | Qty lamps | Watt per lamp | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Total W used in 24hrs |
|--------------------------|-----------|---------------|--------------------------|---------------------------|-----------------------|
| Living room – 28W each   | 20        | 28            | 300                      | 5                         | 2800                  |
| Bedroom 1 – 40W          | 1         | 40            | 110                      | 1.83                      | 73.2                  |
| Toy room – 40W           | 1         | 40            | 110                      | 1.83                      | 73.2                  |
| Bathroom 1 – 18W each    | 3         | 18            | 130                      | 2.16                      | 116.64                |
| Kitchen – 3W each        | 20        | 3             | 365                      | 6.08                      | 364.8                 |
| Bedroom 2 – 3W each      | 8         | 3             | 230                      | 3.83                      | 91.92                 |
| Bedroom 3 – 3W each      | 16        | 3             | 10                       | 0.16                      | 7.68                  |
| Bathroom 2 – 18W each    | 4         | 18            | 75                       | 1.25                      | 90                    |
| Outside – 5W each        | 6         | 5             | 780                      | 13                        | 390                   |
| Hallway – 18W each       | 5         | 18            | 730                      | 12.16                     | 1094.4                |
|                          |           |               |                          |                           | 5101.84               |

Table 3 - Total watts used by lighting in 24hr period

To determine the cost over this period, the watts used were divided by 1000 to convert the value to kW. This was then divided by 24 to produce the kWh value. This value was then multiplied by the current unit cost rate for electricity (17p) to supply the cost per the 24 hour period monitored. Providing the lights are on for the same duration every day, this value is then multiplied by 365 to give the annual cost.

|                                        |         |
|----------------------------------------|---------|
| Total watts used in 24hr               | 5101.84 |
|                                        |         |
| Total kW in 24hr period (5101.84/1000) | 5.1     |
|                                        |         |
| Cost per 24hr period @ 17p/kWh         | £0.87   |
|                                        |         |
| Annual cost = £0.87*365                | £317.55 |

Table 4 - Annual lighting cost

## 23.2 Heating use

To analyse the electricity use by the heating system, I documented the quantities and locations of heaters installed in the house.

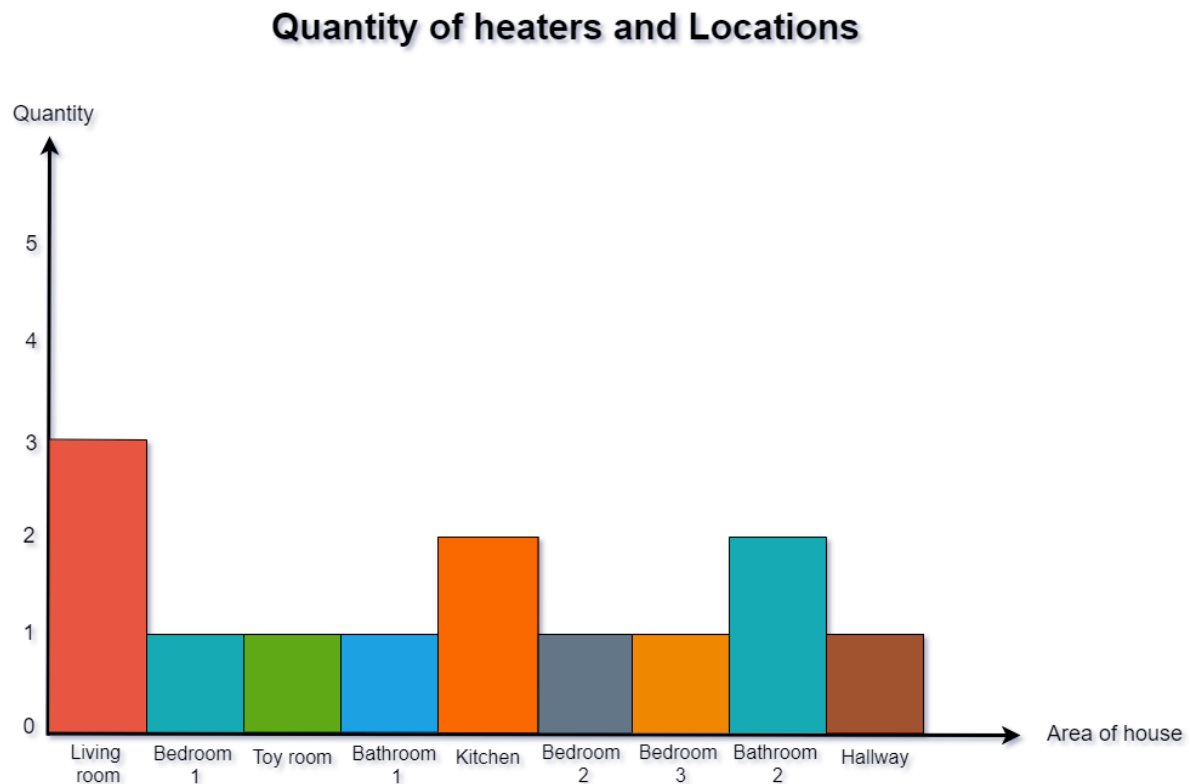


Figure 61 - Heater size & location

I then recorded the size of each of the heater mentioned in the graph above.

| Area of house and wattage | Qty heaters | Watts per heater |
|---------------------------|-------------|------------------|
| Living room – 2kW each    | 3           | 2000             |
| Bedroom 1 – 1700W         | 1           | 1700             |
| Toy room – 1700W          | 1           | 1700             |
| Bathroom 1 – 1700W        | 1           | 1700             |
| Kitchen – 2kW each        | 2           | 2000             |
| Bedroom 2 – 2kW           | 1           | 2000             |
| Bedroom 3 – 1700W         | 1           | 1700             |
| Bathroom 2 – 900W each    | 2           | 900              |
| Hallway – 2kW             | 1           | 2000             |

Table 5 - Quantity & wattage of installed heaters

To fully understand the quantity of energy being consumed by heating in my home, I monitored the times the heaters in each area of the house were used per hour, I have listed this information in the table below.

| Area of house | 12AM | 1AM | 2AM | 3AM | 4AM | 5AM | 6AM | 7AM | 8AM | 9AM | 10AM | 11AM |
|---------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| Living room   | 0    | 0   | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 15  | 15   | 0    |
| Bedroom 1     | 0    | 0   | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 15  | 0    | 0    |
| Toy room      | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 30  | 30  | 10   | 0    |
| Bathroom 1    | 0    | 0   | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 15  | 0    | 0    |
| Kitchen       | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 30  | 30  | 15  | 0    | 0    |
| Bedroom 2     | 0    | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 30  | 15  | 0    | 0    |
| Bedroom 3     | 0    | 0   | 0   | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 0    | 0    |
| Bathroom 2    | 0    | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 30  | 30  | 0    | 0    |
| Hallway       | 0    | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 15  | 15  | 0    | 0    |

| Area of house | 12PM | 1PM | 2PM | 3PM | 4PM | 5PM | 6PM | 7PM | 8PM | 9PM | 10PM | 11PM |
|---------------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| Living room   | 0    | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 30  | 15  | 0    | 0    |
| Bedroom 1     | 0    | 0   | 0   | 0   | 0   | 0   | 15  | 30  | 30  | 0   | 0    | 0    |
| Toy room      | 0    | 0   | 0   | 0   | 30  | 30  | 30  | 15  | 0   | 0   | 0    | 0    |
| Bathroom 1    | 0    | 0   | 0   | 0   | 0   | 30  | 45  | 15  | 0   | 0   | 0    | 0    |
| Kitchen       | 0    | 0   | 0   | 0   | 0   | 30  | 45  | 30  | 15  | 0   | 0    | 0    |
| Bedroom 2     | 0    | 0   | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 30  | 15   | 0    |
| Bedroom 3     | 0    | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 30  | 0   | 0    | 0    |
| Bathroom 2    | 0    | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 0   | 0   | 0    | 0    |
| Hallway       | 0    | 0   | 0   | 0   | 0   | 30  | 30  | 30  | 15  | 15  | 15   | 10   |

| Area of house | Total times (mins) |
|---------------|--------------------|
| Living room   | 240                |
| Bedroom 1     | 165                |
| Toy room      | 175                |
| Bathroom 1    | 195                |
| Kitchen       | 195                |
| Bedroom 2     | 255                |
| Bedroom 3     | 210                |
| Bathroom 2    | 225                |
| Hallway       | 250                |

Table 6 - Heating use over 24hrs

As with the lighting, after calculating the total times the individual heaters in different areas of the house were used, I then calculated the total watts used during this period. This was achieved by multiplying the quantity of heaters by the wattage rating of the heaters by the time on during the 24 hour period.

| Area of house and wattage | Qty heaters | Watts per heater | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Total W used in 24hrs |
|---------------------------|-------------|------------------|--------------------------|---------------------------|-----------------------|
| Living room – 2kW each    | 3           | 2000             | 240                      | 4.00                      | 24000.00              |
| Bedroom 1 – 1700W         | 1           | 1700             | 165                      | 2.75                      | 4675.00               |
| Toy room – 1700W          | 1           | 1700             | 175                      | 2.92                      | 4958.33               |
| Bathroom 1 – 1700W        | 1           | 1700             | 195                      | 3.25                      | 5525.00               |
| Kitchen – 2kW each        | 2           | 2000             | 195                      | 3.25                      | 13000.00              |
| Bedroom 2 – 2kW           | 1           | 2000             | 255                      | 4.25                      | 8500.00               |
| Bedroom 3 – 1700W         | 1           | 1700             | 210                      | 3.50                      | 5950.00               |
| Bathroom 2 – 900W each    | 2           | 900              | 225                      | 3.75                      | 6750.00               |
| Hallway – 2kW             | 1           | 2000             | 250                      | 4.17                      | 8333.33               |
|                           |             |                  |                          |                           | 81691.67              |

*Table 7 - Total watts used by heating in 24hr period*

Again, as with the lighting, to determine the cost over this period, the watts used were divided by 1000 to convert the value to kW. This was then divided by 24 to produce the kWh value. This value was then multiplied by the current unit cost rate for electricity (17p) to supply the cost per the 24 hour period monitored. Providing the heating is on for the same duration every day, this value is then multiplied by 365 to give the annual cost.

|                                      |           |
|--------------------------------------|-----------|
| Total watts used in 24hr             | 81691.67  |
|                                      |           |
| Total kW in 24hr period (99525/1000) | 81.691667 |
|                                      |           |
| Cost per 24hr period @ 17p/kWh       | £13.89    |
|                                      |           |
| Annual cost = £13.89*365             | £5,068.97 |

*Table 8 - Annual heating cost*

### 23.3 Analysis review

These usage values were recorded in February, the day was relatively dark and the outside ambient temperature was low. To achieve a more accurate and realistic usage of both lighting and heating consumption, the monitoring should be carried out regularly throughout the year, this would give a better understanding of how the electricity usage fluctuates with the increased amounts of natural light and increased ambient temperature that the summer months generally provide. This would alter the amount the lighting and heating that is used.

It should also be noted that I recorded these values on a 'weekday' where the normal routine is that the house is unoccupied during the day. During the 'weekend' the house would be occupied more frequently during the day, this may lead to increased lighting and heating use. Therefore, monitoring of usage should be a sample during both occupied and unoccupied situations.

Although the data recorded is true for this period, it is not necessarily as accurate as longer term sampling would provide.

## 24 Comparison to traditional control methods

To understand the potential, estimated cost saving, I tried to use the prototype build project to compare when the outputs were energised in comparison to when the lighting and heating was used in my house. This was just a visual check and I did not document whether the outputs on the project were de-energised because of the lux level input or the thermostat input or whether it was because of the occupancy sensors not being set. I altered the occupancy timer of both the heating and lighting circuits to switch off after 5 minutes if no movement was detected. The trial for the prototype use was not carried out at the same time as the existing lighting and heating use documented time. This was carried out over multiple days as I was unable to use the prototype in multiple locations at one time. I also refrained from using the existing lighting and heating during this time to give more realistic test results.

### 24.1 Lighting use comparison

The table below details the times that the lights were on in each area using conventional switching (yellow columns) compared to the time the lights were on using the project control panel (red columns)

|               | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype |
|---------------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|
| Area of house | 12AM     | 12AM      | 1AM      | 1AM       | 2AM      | 2AM       | 3AM      | 3AM       | 4AM      | 4AM       | 5AM      | 5AM       | 6AM      | 6AM       | 7AM      | 7AM       | 8AM      | 8AM       | 9AM      | 9AM       | 10AM     | 10AM      | 11AM     | 11AM      |
| Living room   | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 15       | 5         | 0        | 0         | 10       | 5         | 30       | 10        | 0        | 0         | 0        | 0         |
| Bedroom 1     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 10       | 5         | 0        | 0         | 0        | 0         | 10       | 5         | 45       | 20        | 0        | 0         | 0        | 0         |
| Toy room      | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 15       | 5         | 0        | 0         | 10       | 0         | 0        | 0         |
| Bathroom 1    | 5        | 5         | 0        | 0         | 0        | 0         | 0        | 0         | 5        | 5         | 20       | 10        | 5        | 5         | 0        | 0         | 30       | 15        | 10       | 10        | 0        | 0         | 5        | 0         |
| Kitchen       | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 10       | 5         | 0        | 0         | 0        | 0         | 45       | 0         | 0        | 0         | 10       | 0         |
| Bedroom 2     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 5        | 5         | 30       | 10        | 10       | 5         | 0        | 0         | 0        | 0         |
| Bedroom 3     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 5         | 5        | 5         | 0        | 0         | 0        | 0         | 0        | 0         |
| Bathroom 2    | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 5        | 5         | 5        | 5         | 0        | 0         | 10       | 5         | 5        | 0         | 0        | 0         | 5        | 0         |
| Outside       | 60       | 5         | 60       | 0         | 60       | 0         | 60       | 0         | 60       | 5         | 60       | 0         | 60       | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         |
| Hallway       | 60       | 10        | 60       | 0         | 60       | 0         | 60       | 0         | 60       | 0         | 60       | 0         | 0        | 10        | 0        | 10        | 0        | 10        | 0        | 10        | 0        | 10        | 0        | 10        |

|               | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype | Existing | Prototype |
|---------------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|----------|-----------|
| Area of house | 12PM     | 12PM      | 1PM      | 1PM       | 2PM      | 2PM       | 3PM      | 3PM       | 4PM      | 4PM       | 5PM      | 5PM       | 6PM      | 6PM       | 7PM      | 7PM       | 8PM      | 8PM       | 9PM      | 9PM       | 10PM     | 10PM      | 11PM     | 11PM      |
| Living room   | 0        | 0         | 15       | 0         | 0        | 0         | 0        | 0         | 60       | 15        | 60       | 20        | 60       | 30        | 30       | 10        | 0        | 5         | 10       | 5         | 10       | 5         | 0        | 5         |
| Bedroom 1     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 15       | 5         | 0        | 0         | 15       | 5         | 0        | 5         | 0        | 0         | 0        | 0         | 15       | 0         | 0        | 0         |
| Toy room      | 15       | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 20       | 0         | 25       | 20        | 20       | 5         | 0        | 5         | 5        | 0         | 0        | 0         | 0        | 0         | 0        | 0         |
| Bathroom 1    | 0        | 0         | 5        | 5         | 0        | 0         | 5        | 0         | 0        | 10        | 5        | 0         | 0        | 15        | 10       | 0         | 5        | 0         | 5        | 15        | 10       | 0         | 0        | 0         |
| Kitchen       | 45       | 10        | 50       | 10        | 10       | 5         | 0        | 0         | 5        | 5         | 60       | 30        | 60       | 20        | 45       | 20        | 10       | 5         | 5        | 5         | 10       | 5         | 0        | 0         |
| Bedroom 2     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 60       | 20        | 60       | 40        | 60       | 30        | 5        | 5         | 0        | 0         | 0        | 0         | 0        | 0         |
| Bedroom 3     | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 5         | 5        | 5         |
| Bathroom 2    | 0        | 5         | 5        | 5         | 5        | 5         | 0        | 0         | 0        | 0         | 10       | 5         | 5        | 5         | 5        | 5         | 0        | 0         | 5        | 5         | 5        | 10        | 5        | 5         |
| Outside       | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 0        | 0         | 60       | 15        | 60       | 10        | 60       | 0         | 60       | 5         | 60       | 5         | 60       | 0         |
| Hallway       | 0        | 10        | 0        | 10        | 0        | 10        | 0        | 0         | 10       | 10        | 5        | 10        | 60       | 15        | 60       | 20        | 5        | 0         | 60       | 10        | 60       | 10        | 60       | 0         |

| Area of house | Total times (mins) Existing | Total times (mins) Project | % difference |
|---------------|-----------------------------|----------------------------|--------------|
| Living room   | 300                         | 115                        | -61.67%      |
| Bedroom 1     | 110                         | 45                         | -59.09%      |
| Toy room      | 110                         | 35                         | -68.18%      |
| Bathroom 1    | 130                         | 90                         | -30.77%      |
| Kitchen       | 365                         | 120                        | -67.12%      |
| Bedroom 2     | 230                         | 115                        | -50.00%      |
| Bedroom 3     | 10                          | 15                         | 50.00%       |
| Bathroom 2    | 75                          | 65                         | -13.33%      |
| Outside       | 780                         | 45                         | -94.23%      |
| Hallway       | 680                         | 175                        | -74.26%      |

Table 9 - Lighting use comparison

As the table above shows, the decrease in usage is vast. For the majority of areas within the house, usage has decreased by over 50%.

The table below totalises the energy saving for lighting in the whole of the house. On average, the total wattage used has decreased by 65%.

| Area of house and lamp W | Qty lamps | Watt per lamp | Existing                 |                           | Prototype                |                           | Existing              |                       | % difference |
|--------------------------|-----------|---------------|--------------------------|---------------------------|--------------------------|---------------------------|-----------------------|-----------------------|--------------|
|                          |           |               | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Total W used in 24hrs | Total W used in 24hrs |              |
| Living room – 28W each   | 20        | 28            | 300                      | 5                         | 115                      | 1.92                      | 2800                  | 1073.33               | -61.67%      |
| Bedroom 1 – 40W          | 1         | 40            | 110                      | 1.83                      | 45                       | 0.75                      | 73.2                  | 30.00                 | -59.02%      |
| Toy room – 40W           | 1         | 40            | 110                      | 1.83                      | 35                       | 0.58                      | 73.2                  | 23.33                 | -68.12%      |
| Bathroom 1 – 18W each    | 3         | 18            | 130                      | 2.16                      | 90                       | 1.50                      | 116.64                | 81.00                 | -30.56%      |
| Kitchen – 3W each        | 20        | 3             | 365                      | 6.08                      | 120                      | 2.00                      | 364.8                 | 120.00                | -67.11%      |
| Bedroom 2 – 3W each      | 8         | 3             | 230                      | 3.83                      | 115                      | 1.92                      | 91.92                 | 46.00                 | -49.96%      |
| Bedroom 3 – 3W each      | 16        | 3             | 10                       | 0.16                      | 15                       | 0.25                      | 7.68                  | 12.00                 | 56.25%       |
| Bathroom 2 – 18W each    | 4         | 18            | 75                       | 1.25                      | 65                       | 1.08                      | 90                    | 78.00                 | -13.33%      |
| Outside – 5W each        | 6         | 5             | 780                      | 13                        | 45                       | 0.75                      | 390                   | 22.50                 | -94.23%      |
| Hallway – 18W each       | 5         | 18            | 730                      | 12.16                     | 175                      | 2.92                      | 1094.4                | 262.50                | -76.01%      |
|                          |           |               |                          |                           |                          |                           | 5101.84               | 1748.67               | -65.72%      |

Table 10 - Lighting, difference in consumption

The table below details the energy usage and associated costs based on the existing system and usage recorded over the 24hr monitoring period.

|                                        |         |
|----------------------------------------|---------|
| Total watts used in 24hr               | 5101.84 |
|                                        |         |
| Total kW in 24hr period (5101.84/1000) | 5.1     |
|                                        |         |
| Cost per 24hr period @ 17p/kWh         | £0.87   |
|                                        |         |
| Annual cost = £0.87*365                | £317.55 |

Table 11 - Existing lighting annual costs

The table below details the energy usage and associated costs based on the data gathered using the prototype project control panel. The energy usage is considerably reduced and therefore so are the costs associated.

|                                        |         |
|----------------------------------------|---------|
| Total watts used in 24hr               | 1748.67 |
| Total kW in 24hr period (1748.67/1000) | 1.75    |
| Cost per 24hr period @ 17p/kWh         | £0.30   |
| Annual cost = £0.30*365                | £108.50 |

Table 12 - Estimated annual lighting cost using prototype

The table below details the potential percentage of energy saved, total kWh consumption difference and the total cost saving over a year.

|                          |         |
|--------------------------|---------|
| Total percentage saving  | -66%    |
| Total kWh reduction      | 3.35    |
| Total annual cost saving | £209.05 |

Table 13 - Estimated lighting saving

## 24.2 Heating use comparison

The table below details the times that the heaters were on in each area using conventional heating controls (timer), this is displayed in the yellow columns, compared to the time the heaters were on using the project control panel (red columns).

| Area of house | Existing 12AM | Prototype 12AM | Existing 1AM | Prototype 1AM | Existing 2AM | Prototype 2AM | Existing 3AM | Prototype 3AM | Existing 4AM | Prototype 4AM | Existing 5AM | Prototype 5AM | Existing 6AM | Prototype 6AM | Existing 7AM | Prototype 7AM | Existing 8AM | Prototype 8AM | Existing 9AM | Prototype 9AM | Existing 10AM | Prototype 10AM | Existing 11AM | Prototype 11AM |
|---------------|---------------|----------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|---------------|----------------|---------------|----------------|
| Living room   | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 10            | 30           | 20            | 30           | 20            | 15           | 5             | 15            | 5              | 0             | 0              |
| Bedroom 1     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 10            | 30           | 20            | 30           | 15            | 15           | 5             | 0             | 5              | 0             | 0              |
| Toy room      | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 15            | 30           | 15            | 10            | 5              | 0             | 0              |
| Bathroom 1    | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 20            | 30           | 20            | 30           | 20            | 15           | 5             | 0             | 5              | 0             | 0              |
| Kitchen       | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 20            | 30           | 25            | 15           | 15            | 0             | 5              | 0             | 0              |
| Bedroom 2     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 0             | 30           | 20            | 30           | 20            | 30           | 10            | 15           | 5             | 0             | 0              | 0             | 0              |
| Bedroom 3     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 20            | 30           | 10            | 30           | 20            | 0             | 0              | 0             | 0              |
| Bathroom 2    | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 0             | 30           | 10            | 30           | 30            | 30           | 20            | 30           | 25            | 0             | 0              | 0             | 0              |
| Hallway       | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 0             | 30           | 10            | 30           | 10            | 15           | 10            | 15           | 5             | 0             | 5              | 0             | 0              |

| Area of house | Existing 12PM | Prototype 12PM | Existing 1PM | Prototype 1PM | Existing 2PM | Prototype 2PM | Existing 3PM | Prototype 3PM | Existing 4PM | Prototype 4PM | Existing 5PM | Prototype 5PM | Existing 6PM | Prototype 6PM | Existing 7PM | Prototype 7PM | Existing 8PM | Prototype 8PM | Existing 9PM | Prototype 9PM | Existing 10PM | Prototype 10PM | Existing 11PM | Prototype 11PM |
|---------------|---------------|----------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|--------------|---------------|---------------|----------------|---------------|----------------|
| Living room   | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 30            | 30           | 40            | 30           | 40            | 30           | 30            | 15           | 15            | 0             | 15             | 0             | 5              |
| Bedroom 1     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 15           | 5             | 30           | 5             | 30           | 15            | 0            | 5             | 0             | 5              | 0             | 5              |
| Toy room      | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 0             | 30           | 30            | 30           | 20            | 15           | 15            | 0            | 5             | 0            | 5             | 0             | 0              | 0             | 0              |
| Bathroom 1    | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 15            | 45           | 30            | 15           | 5             | 0            | 5             | 0            | 5             | 0             | 5              | 0             | 5              |
| Kitchen       | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 15            | 45           | 45            | 30           | 40            | 15           | 20            | 0            | 5             | 0             | 5              | 0             | 5              |
| Bedroom 2     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 15            | 30           | 20            | 30           | 25            | 30           | 20            | 15            | 10             | 0             | 5              |
| Bedroom 3     | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 15            | 30           | 20            | 30           | 20            | 30           | 15            | 0            | 5             | 0             | 5              | 0             | 5              |
| Bathroom 2    | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 10            | 30           | 10            | 30           | 15            | 0            | 5             | 0            | 5             | 0             | 10             | 0             | 5              |
| Hallway       | 0             | 0              | 0            | 0             | 0            | 0             | 0            | 0             | 0            | 0             | 30           | 25            | 30           | 25            | 30           | 20            | 15           | 10            | 15           | 5             | 15            | 5              | 10            | 5              |

| Area of house | Total times (mins) Existing | Total times (mins) Project | % difference |
|---------------|-----------------------------|----------------------------|--------------|
| Living room   | 240                         | 235                        | -2.08%       |
| Bedroom 1     | 165                         | 95                         | -42.42%      |
| Toy room      | 175                         | 110                        | -37.14%      |
| Bathroom 1    | 195                         | 140                        | -28.21%      |
| Kitchen       | 195                         | 200                        | 2.56%        |
| Bedroom 2     | 255                         | 150                        | -41.18%      |
| Bedroom 3     | 210                         | 135                        | -35.71%      |
| Bathroom 2    | 225                         | 145                        | -35.56%      |
| Hallway       | 250                         | 135                        | -46.00%      |

Table 14 - Heating use comparison

As the table details above, and as we saw with the lighting usage, the potential energy and cost saving is substantial. Generally, all areas of the house show a reduction in energy use, the majority indicate a potential reduction of between 30 and 40%.

The table below totalises the energy saving for heating in the whole of the house. On average, the total wattage used has decreased by 21%.

| Area of house and wattage | Qty heaters | Watt per heater | Existing                 |                           | Prototype                |                           | Existing              |                       | % difference |
|---------------------------|-------------|-----------------|--------------------------|---------------------------|--------------------------|---------------------------|-----------------------|-----------------------|--------------|
|                           |             |                 | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Time on per 24hrs (mins) | Time on per 24hrs (hours) | Total W used in 24hrs | Total W used in 24hrs |              |
| Living room – 2kW each    | 3           | 2000            | 240                      | 4.00                      | 235                      | 3.92                      | 24000.00              | 23500.00              | -2.08%       |
| Bedroom 1 – 1700W         | 1           | 1700            | 165                      | 2.75                      | 95                       | 1.58                      | 4675.00               | 2691.67               | -42.42%      |
| Toy room – 1700W          | 1           | 1700            | 175                      | 2.92                      | 110                      | 1.83                      | 4958.33               | 3116.67               | -37.14%      |
| Bathroom 1 – 1700W        | 1           | 1700            | 195                      | 3.25                      | 140                      | 2.33                      | 5525.00               | 3966.67               | -28.21%      |
| Kitchen – 2kW each        | 2           | 2000            | 195                      | 3.25                      | 200                      | 3.33                      | 13000.00              | 13333.33              | 2.56%        |
| Bedroom 2 – 2kW           | 1           | 2000            | 255                      | 4.25                      | 150                      | 2.50                      | 8500.00               | 5000.00               | -41.18%      |
| Bedroom 3 – 1700W         | 1           | 1700            | 210                      | 3.50                      | 135                      | 2.25                      | 5950.00               | 3825.00               | -35.71%      |
| Bathroom 2 – 900W each    | 2           | 900             | 225                      | 3.75                      | 145                      | 2.42                      | 6750.00               | 4350.00               | -35.56%      |
| Hallway – 2kW             | 1           | 2000            | 250                      | 4.17                      | 135                      | 2.25                      | 8333.33               | 4500.00               | -46.00%      |
|                           |             |                 |                          |                           |                          |                           | 81691.67              | 64283.33              | -21.31%      |

Table 15 - Heating, difference in consumption

The table below details the energy usage and associated costs based on the existing system and usage recorded over the 24hr monitoring period.

|                                         |           |
|-----------------------------------------|-----------|
| Total watts used in 24hr                | 81691.67  |
|                                         |           |
| Total kW in 24hr period (81691.67/1000) | 81.69     |
|                                         |           |
| Cost per 24hr period @ 17p/kWh          | £13.89    |
|                                         |           |
| Annual cost = £13.89*365                | £5,068.97 |

Table 16 - Existing heating annual costs

The table below details the energy usage and associated costs based on the data gathered using the prototype project control panel. The energy usage is considerably reduced and therefore so are the costs associated.

|                                         |           |
|-----------------------------------------|-----------|
| Total watts used in 24hr                | 64283.33  |
|                                         |           |
| Total kW in 24hr period (64283.33/1000) | 64.28     |
|                                         |           |
| Cost per 24hr period @ 17p/kWh          | £10.93    |
|                                         |           |
| Annual cost = £0.30*365                 | £3,988.78 |

*Table 17 - Estimated annual heating cost using prototype*

The table below details the potential percentage of energy saved, total kWh consumption difference and the total cost saving over a year.

|                          |           |
|--------------------------|-----------|
| Total percentage saving  | -21%      |
|                          |           |
| Total kWh reduction      | 17.41     |
|                          |           |
| Total annual cost saving | £1,080.19 |

*Table 18 - Estimated heating saving*

These comparisons were carried out over a short time period, during winter, on a weekday. To be able to estimate a more accurate potential saving, a substantial amount of monitoring and analysing would be required. To determine real savings, the system would need to switch relay outputs on the 230v household circuits rather than just switching pilot lights. Although, I feel that what has been found, gives a good indication that there would be energy and costs savings if this project was to be used in a real work scenario.

## 25 Design review

A PLC was incorporated for use in this project as they are reliable, robust and can be configured to control the inputs and outputs required for this project. They are also capable of expansion, which would allow for future system growth. This project is based around reading and computing the environment in terms of 'light level in an area' and 'temperature of an area', and also whether an area is occupied and then applying an output signal to a heater or light dependent on the input signal. A PLC's primary function is to monitor the state of input signals from devices and make calculated decisions based on a custom program that controls the state of output devices, the goal to be achieved with this project lends itself perfectly to a PLC. A PLC also has the ability to connect to a HMI (Human machine interface), this is desirable as it allows the user to be able to manually control the outputs when required. I feel the HMI is a positive addition to the project, although, there are multiple screens that require scrolling through for different operations, I feel an improvement to this would be to have a larger HMI with all controls and displays on one page making it easier for the user.

Traditionally, heating control is by using timers, allowing the occupants to pre-set a timer based on when the home is likely to be occupied and require heating. Lighting is typically controlled by manual switches that require the occupants to switch on or off as and when required. The issue with this, is that if the heating is on, and the occupant's routine changes and they don't require the heating to be on, it still is, and using energy that doesn't need to be used. As with the lighting, it's easy to forget to switch lights off when they are not required. This is the predominantly why for this project I have decided to use two forms of monitoring to enable the heating and lighting to be energised. The occupancy sensors are the first requirement, if these are not set, the area is not occupied and therefore do not require lighting or heating. Secondly, if the areas are occupied, the thermostat and lux sensor monitor whether lighting or heating is actually required, if there is sufficient light and/ or heat, the systems remain de-energised. Monitoring in this way will ensure that energy is only being used when required. I feel that this is an appropriate, valid and reliable solution as this method does not require user interaction. A disadvantage of this system is that if an area is occupied, but the occupant is relatively still, the occupancy sensor may de-energise causing the lights/ heating to switch off, I feel that this would be inconvenient but

with though at the installation stage with correct or multiple sensors I feel that the positives outweigh the negatives.

The hardware selected for this project is manufactured by reputable manufacturers, this was a conscious decision as, if the system was to be installed in a real life scenario, the products selected will be supported for years to come, and this is an important point as when the system expands additional compatible equipment may be required. This is particularly important with the Siemens PLC hardware and software. The other equipment such as occupancy sensors, thermostats and lux levels sensors can be replaced for alternative manufacturers as they are standalone devices, providing they offer the correct supply parameters and output characteristics.

The structure in which the software has been developed is relatively simple. A new network has been created for each step, I feel that if the prototype was successful, there may be an option to produce larger function blocks that could incorporate multiple steps in one function. Due to my knowledge limitations with software development, I used individual networks, I do feel that this method would allow for easier future alterations and fault locating should it be required, but, for efficiency a function block would be more suitable for future projects.

With regard to the prototype project build, I feel that the enclosure to house the components used may be a bit 'industrial' and heavy, if I was able to revisit the layout, I would not have used a metal enclosure, this would have been a lighter plastic material, the metal enclosure does give good mechanical protection but may not be required in a domestic setting. I would also alter the layout of the components, I feel that the input sensors should be on umbilical's to allow for easier and more accurate testing. As they are currently installed, they are low level, next to the HMI, the light level and temperatures monitored at this level may not be as accurate as when they would be installed during actual application.

## 26 Implementation

Whilst implementing the project, there were a few difficulties and issues that became apparent. The Siemens S7-1200 has only two analogue inputs as standard, although there is an analogue input expansion module available, due to cost, I was unable to obtain one. For the purpose of trialling the project, I used one lux level sensor and one temperature sensor, it would have been ideal to be able to use one lux level sensor and one temperature sensor per zone/ area to be monitored.

The analogue input module on the S7-1200 CPU 1214C DC/DC/DC, 6ES7214-1AG40-0XB0, only accepts voltage inputs. Whilst procuring the components for my build, I purchased a 0-20mA output lux level sensor, as this was a current output, the input card interoperate the input correctly. To rectify this, I had to use a 500 ohm resistor across the circuit to produce the 0-10v signal. To work the resistor value, basic ohms law was used,  $R = 10V / 0.020A = 500$  ohms.  $V = I * R = 0 * 500 = 0V$ .  $V = I * R = 0.020 * 500 = 10V$ .

The positioning of the input sensors were also poorly placed, on reflection, the inputs, both AI and DI should have been remote from the control panel to allow them to be placed in a more suitable and realistic position.

The testing of suitability of the project was also limited due to not integrating it into the lighting and heating circuits in the house. The project switches pilot lights to replicate heating elements or lights, it would have been more realistic and accurate to have switched relays and connected the actual lighting and heating circuits to the relays. This would have then led to more accurate energy saving quantities.

As the project only used 24vdc, I was unable to install an energy meter for real energy usage, again, as above, if the project had been installed on 230v circuits, an energy monitor/ logging device could have been integrated and generated real time energy usage.

The project was tested by placing it in the different areas of the house and visually monitoring and recording how long lighting and heating outputs were energised for within

hour time frames, although I feel this was fairly accurate, as it was my interpretation and recoding of times, there could have been times where I induced an error through mistakes or miss-recordings.

## 27 Bill of materials

| Component                    | Manufacturer    | Part.No                               | Quantity | Unit cost  | Total cost |
|------------------------------|-----------------|---------------------------------------|----------|------------|------------|
| Enclosure                    | Schneider       | Spacial S3D NSYS3D4420P               | 1        | £97.20     | £97.20     |
| Din rail                     | Weidmuller      | 514510000                             | 1        | £19.90     | £19.90     |
| Trunking (25x80)             | Betaduct        | 10430024                              | 150      | £0.16      | £24.15     |
| 4A, 2 pole MCB               | Allen Bradley   | 1492 SP                               | 1        | £41.52     | £41.52     |
| 230v-24vdc power supply      | RS Pro          | 136-8319                              | 1        | £36.80     | £36.80     |
| PLC                          | Siemens         | S7-1200 CPU1214C DC/DC/DC             | 1        | £369.00    | £369.00    |
| HMI                          | Siemens         | KTP700 Basic panel 6AV2123-2GB03-0AX0 | 1        | £606.96    | £606.96    |
| Network switch               | Schneider       | TCSESU053FN0                          | 1        | £113.90    | £113.90    |
| Earth terminal               | Weidmuller      | WPE2.5                                | 2        | £2.30      | £4.60      |
| Fused terminal               | Weidmuller      | ASK1                                  | 2        | £4.80      | £9.60      |
| Fuses                        | Niglon          | FAS1                                  | 2        | £0.90      | £1.80      |
| Lever disconnect terminal    | Weidmuller      | WTR2.5                                | 2        | £2.13      | £4.26      |
| Terminal                     | Weidmuller      | WDU2.5                                | 22       | £0.64      | £14.08     |
| End plates                   | Weidmuller      | WAP2.5/10                             | 8        | £0.37      | £2.96      |
| End stops                    | Weidmuller      | EW35                                  | 6        | £0.73      | £4.38      |
| Ident stands                 | Weidmuller      | SCHT 5                                | 5        | £1.27      | £6.35      |
| Black cable                  | Pro power       | CB15111                               | 20       | £0.11      | £2.20      |
| Dark blue cable              | Multicomp pro   | PP001196                              | 20       | £0.11      | £2.20      |
| Light blue cable             | Pro power       | CB20572                               | 20       | £0.11      | £2.20      |
| Green/ yellow cable          | Pro power       | CB15119                               | 20       | £0.11      | £2.20      |
| Core IDs                     | Weidmuller      | TMI-20                                | 100      | £0.62      | £62.00     |
| Core ID sleeves              | Weidmuller      | TM201/20                              | 100      | £0.04      | £4.40      |
| Ferrules                     | Engex           | 641001                                | 100      | £0.03      | £2.58      |
| Network cables               | Magicpatch      | 003-3NB4-005-05C                      | 3        | £0.75      | £2.25      |
| 20mm Brass bush              | Niglon          | MS20                                  | 4        | £0.34      | £1.36      |
| 20mm locknut                 | Niglon          | SLN20G                                | 4        | £0.16      | £0.64      |
| 20mm Compression gland       | MCG             | M20GB                                 | 1        | £0.75      | £0.75      |
| RJ45 bulkhead connector      | Amphenol        | RDP-5SPFFH-TCU7001                    | 1        | £9.20      | £9.20      |
| 240x190x90 plastic enclosure | Gewiz           | GW44208                               | 4        | £7.97      | £31.88     |
| Red pilot lights             | Schneider       | XB4BVB4                               | 3        | £15.80     | £47.40     |
| Yellow pilot lights          | Schneider       | XB4BVB5                               | 3        | £15.58     | £46.74     |
| Green pilot light            | Schneider       | XB4BVB3                               | 1        | £15.94     | £15.94     |
| Occupancy sensors            | Danlers         | CEFLPIR24VDC                          | 2        | £65.97     | £131.94    |
| Thermostat                   | Titan products  | Room temperature sensor               | 4        | £36.00     | £144.00    |
| Lux level sensor             | Titan products  | Internal light level sensor           | 4        | £35.00     | £140.00    |
| Connector block              | TE Connectivity | 1-1776293-2                           | 1        | £9.60      | £9.60      |
| Fixings                      | -               | -                                     | 1        | £5.00      | £5.00      |
| 41x41 steel channel          | Unistrut        | P1000T                                | 1500     | £0.01      | £7.50      |
| Internal angle brackets      | Univolt         | UV CF34                               | 2        | £1.85      | £3.70      |
| 3 core flex cable            | TLCO            | CA 1.5F3                              | 1        | £1.00      | £1.00      |
| 13A plug                     | Knightsbridge   | AA PT13/3                             | 1        | £0.82      | £0.82      |
|                              |                 |                                       |          |            | £0.00      |
|                              |                 |                                       |          | Build cost | £2,034.96  |

## 28 Evaluation

At the beginning of my project, I outlined a number of aims and objectives that I hoped to achieve through the project process.

I firstly constructed a project plan to aid in managing my time and ensure that I met key milestones dates. I feel that the project plan worked well as it made me focus on the individual elements that I needed to achieve. The project timeline did alter slightly, some elements took longer than I had anticipated but other aspects were slightly quicker.

I then needed to research existing lighting and heating systems, although I feel the research was in depth and successful, I would have liked to explore other options of lighting and heating control. I feel that there are other systems available where energy may be stored should it not be required. Due to time constraints and work load I was unable to research this further.

To understand the components required to produce a prototype, I created a system block diagram. The block diagram outlined the individual hardware to ensure the system operates as planned. I found this helpful as it helped me to visual what I needed to procure. Although this was helpful, I did not originally include a network switch to aid me to connect a HMI to the PLC.

When the hardware requirement was listed, I researched the individual elements to see what manufacturers and technology types were most suitable for my project. I listed the options that were compatible, then chose the most suitable of the options based on cost and availability.

To help develop the software, I produced a flow chart that shows the steps of the system and when they need to appear. The description of the action to be undertaken helped me to visualise the requirement and made producing the individual networks achievable. As I started writing the software, and testing it using Factory IO, it was apparent that details had been missed and needed altering, I found this very time consuming, but, if I hadn't produced a flow chart, more details would have been missed and ultimately, the software development would have taken longer.

I then drew layouts of what I wanted to build and started to develop the physical project. Generally, items installed were where I had originally planned to put them, although, the internal layout of the control panel was changed slightly as I had missed some components

off the drawing. The panel operates as required, although I would have laid some components out differently if I was going to do the project again.

I then analysed the project by comparing how the project panel outputs time use compared to the time that lighting and heating was used in my home. The results are documented in the analysis section of this report. I feel that the results could have been more accurate if the system was connected to the 230v circuits, with energy meters installed to gather a true picture of energy use and energy saving. I was only able to monitor the time that lights and heating outputs were energised on the panels visually and documenting the times they were on.

Despite this, I feel that the project was a success. The analysis shows how much energy conventional lighting and heating control uses and loses through waste. Lighting and heating is often left on when not required, this project reduces the potential of this happening. I feel that the project has been worthwhile. I feel that the aims and objectives have been met. The biggest change I would apply for a future project would be to ensure it could be used on the 230v household circuits to ensure analysis is true and accurate.

## 29 Conclusions, recommendations and further opportunities

In conclusion, I feel that I have achieved the aims and objectives that I had set out to accomplish at the start of this project. I feel that the research carried out was sufficient and gave a good overview of the types of lighting and heating control methods that are available. I do feel that I could have ventured down other avenues during the research period, I would have like to have looked at energy storage in automated systems and how they could have been incorporated into each other.

The design aspect of the project I feel I should have thought out more. Initially I just wanted to get components mounted and working, I think I was too eager to achieve this and didn't plan the testing and analysing period in enough detail. If I had thought this through more, I feel I could have mounted components in more appropriate areas for testing and then I would have achieved more accurate results. Other than components being placed in better positions, I think the actual build was successful, it is functioning and operates how it is supposed to.

With regard to potential future opportunities and expansion to the project, I think that there are many possibilities, I think that this project has just scraped the surface of what could be achieved using a PLC for home automation purposes. There could be opportunity to control blinds and curtains, this could be done automatically using light sensors. Access gates, doors or garages could also be operated using beam sensors to automatically open these on detection of motion. Swimming pool maintenance such as heating, pumping and cleaning could be incorporated into PLC control, also monitoring of pH levels could be viewed. Home security such as door sensors can be wired through a PLC to operate an alarm and log operation. Socket outlets could also be switched remotely using the HMI, this would allow for appliances to be switched off from a central point. The most convenient and practical opportunity would be to control all these features remotely. Siemens have now released a new generation PLC called the LOGO! The Siemens LOGO! Can connect to the KNX standard bus for building systems which would allow convenient control from a smartphone, PC or tablet. [12]

Further future developments that I feel would be beneficial is energy monitoring, this could be thorough current transformers on circuits, this can be used to see when energy use is high and therefore highlight when attention needs to be focused on how to reduce that

usage. Finally, as this entire system relies on the power, I feel a good future development would be a battery back/ UPS. This would have to be sized depending on the load of individual houses. The system could switch to the battery back up on mains failure, this would allow for essential items within the home to maintain operation in the case of power failure.

## 30 Reflection

The reason I decided to focus on incorporating a PLC into home automation for this project is because I have a keen interest in industrial process control. I'm fortunate in my employment as an electrical / instrument technician to be able to work in industrial settings such as power stations, refineries and other industrial sites where PLC's are at the heart of the process controls. Unfortunately, in my work area, I am involved with the instrumentation, infrastructure and cabling up to the point of connection to the PLC but I do not get the opportunity to be involved with the PLC software development. This project gave me a great opportunity to develop my knowledge in this area. The reason I chose to incorporate this device for use in the home is that I have recently renovated my home and I am keen to install 'smart' and automated devices into my home. I feel that the PLC is a reliable, robust piece of equipment that lends itself well to this function. Through the project, this is still my belief, maybe not with the model of PLC I used for this project, but there are other PLC's now available that work with the KNX standard bus that many other home automation devices use.

The project gave me opportunities to use software such as the TIA portal, this has given me a great insight to software engineering and has actually prompted me to develop this knowledge further through some specific PLC training courses. I was also able to use the AutoCAD programme to produce drawings for the project, this is something that I hadn't used before, it was enjoyable to gain some experience with this and develop my skills further.

I had also had limited exposure to using the Microsoft Project programme, planning my project using this was also very insightful. I found it surprising how much time individual elements of the project took. In particular, I found the back ground research and literature review took a lot of time, and, I could have spent far longer than I did researching systems, I found that there are many avenues to venture in this topic.

The biggest disappointment for me is that I didn't incorporate the project into my home wiring, I really feel that this would have given accurate analysis results. It is my intention to continue with the project and incorporate the project into my home.

At this stage, I feel that the project has been successful, I feel that a PLC can most certainly be used for home automation. The most pleasing aspect for me is that I have been able to

spend time developing the Siemens software, I have enjoyed this aspect and hope to further develop my knowledge in this area in the future.

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## 33 Project files

Project files have been submitted in separate documents.