Department of Mechanical and Aerospace Engineering

**Investigating the West Whitlawburn Housing District Heating System Extension to East Whitlawburn Housing**

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Abstract

Currently, CCG Construction and Manufacturing Group has been appointed to build 300 new homes as part of Cambuslang's East Whitlawburn £42m housing-led Regeneration Project in Glasgow, Scotland. It is expected to get under way in late summer 2019, with the first delivery of new homes planned for March 2021.

West Whitlawburn Housing Co-operative Ltd have has a biomass district heating system which serves 543 residential properties, a community center and office in Cambuslang. The system heats water through a wood chip fueled 740kw (685kw continuous output) boiler, which is then pumped around the district heating network to provide space heat and hot water. The boiler operates in a 50,000-liter thermal store. There are 3 gas fired back up boilers for times of peak demand.

There are plans of expanding this district heating system from West Whitlawburn Housing Co-operative Ltd to East Whitlawburn housing to serve these new homes. This thesis aims to investigate the heating energy required to meet the space heating and hot water demands of the new residents at east Whitlawburn housing. With the heating demand known, the requirements needed for the district heating system to meet this demand can be ascertained.

# ACKNOWLEDGEMENTS

I would like to thank my supervisor Mr. Graeme Flett, for his support and dedication throughout the completion of this thesis. Also, I want to thank Andrew Lyden, for his time and help, in acquiring and understanding the data.

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# Nomenclature and Abbreviations

| | |
|---|---|
| West Whitlawburn housing cooperation | WWHC |
| East Whitlawburn housing | EWH |
| Energy Performance Rating | EPC |
| Chartered Institution of Building Services Engineers | CIBSE |
| Kilowatt | kW |
| Kilogram | kg |
| Kilowatt-hour | kWh |

# 1. INTRODUCTION

The West Whitlawburn Housing Co-operative is considering the potential benefits that could be achieved by the extension of their district heating system to the newly commissioned 300 homes of the East Whitlawburn Housing. This scheme is as a result of the partnership between South Lanarkshire Council and West Whitlawburn Housing Co-operative, who has chosen the Co-operative as its preferred Social Landlord.

The South Lanarkshire Council has decided to demolish the East Whitlawburn estate and build new houses on the site to serve 300 residents. This was as a result of falling demand, high percentage of residents leaving and the unpopularity of the housing stock in East Whitlawburn. Cambuslang's East Whitlawburn £42m housing-led Regeneration Project was given to CCG Construction and Manufacturing Group, a Cambuslang based contractor to carry out the demolition and new build plan.

Extension of the district heating is important, because prior to the biomass district heating system, the residents of West Whitlawburn Housing Cooperative relied on electricity for hot water and heating, this was supplied via electric storage and panels heaters in the individual dwellings. This was an expensive endeavor and due to the build construction types of the multi-story and low-rise tenement flats gas heating could not be installed. This resulted to fuel poverty as Cambuslang one of the most deprived areas in Scotland. The district heating system now provides the residents with an affordable, sustainable, and community-controlled energy to their homes. Considering this, it would be beneficial for the new houses to be connect to West Whitlawburn Housings Cooperatives district heating network.

## 1.1 Project Outline

### Aims and Objectives

The overall aim of this thesis is to determine the performance of West Whitlawburn Housing district heating system when the heating demand of East Whitlawburn is added to it. To achieve this aim, the following objectives will be met:

- Determining the maximum demand for hot water and space heating at West Whitlawburn Housing.
- Analyzing the performance of the district heating system with the maximum heating demand.
- Ascertaining the maximum demand for hot water and space heating at East Whitlawburn Housing.

## 1.2 Scope

The thesis is based on the heat metered data from West Whitlawburn Housing Cooperation for the period of June 2016 to July 2017. This data was used to obtain heating demand for 300 residential properties of East Whitlawburn Housing. Excel was used to create models which was used to analyze the performance of the district heating system for both West Whitlawburn Housing Cooperation and 300 buildings of East Whitlawburn Housing. This enabled a conclusion to be drawn on the performance of the district heating system when both estates are combined.

## 1.3 West Whitlawburn Housing Cooperation District Heating System

The Energy Centre houses the plant where water is heated through a Viessman Pyrotec biomass (wood chip) boiler fueled at 740kW (685kW continuous output), 3 back up 1,300kW Vitoplex gas boiler to provide top up heat for times of peak demand and during the biomass boiler maintenance period, all working in conjunction with a 50,000-liter thermal store. The thermal store runs at a high temperature of 85°C and low temperature of 70°C, it allows the heat generated by the biomass boiler to meet daily peaks in demand which are in excess of the boilers capacity and to optimize the performance of the boiler by reducing cycling. The distribution network which comprises of both buried and building pipework of 1,204m (2,408m including return) pumps the heat generated from the energy center by the district heating system to the residence buildings in West Whitlawburn Housing Cooperation.

## 1.4 Mode of Operation

By design, filling and emptying of the thermal store is dependent on its mean temperature. Figure 1 shows a 9-hour period of the thermal storage mean temperature and the biomass flow rate. The boiler switches off when the biomass output exceeds the load of the boiler and the thermal storage reaches a temperature of 85°C. When the thermal store drops to the mean temperature of 70°C, the biomass then turns back on, returning the thermal storage temperature to 85°C. This mode of operation allows the district load to be separated from the biomass boiler load, letting the biomass to operate at a fixed point, feeding both the district load and thermal storage.

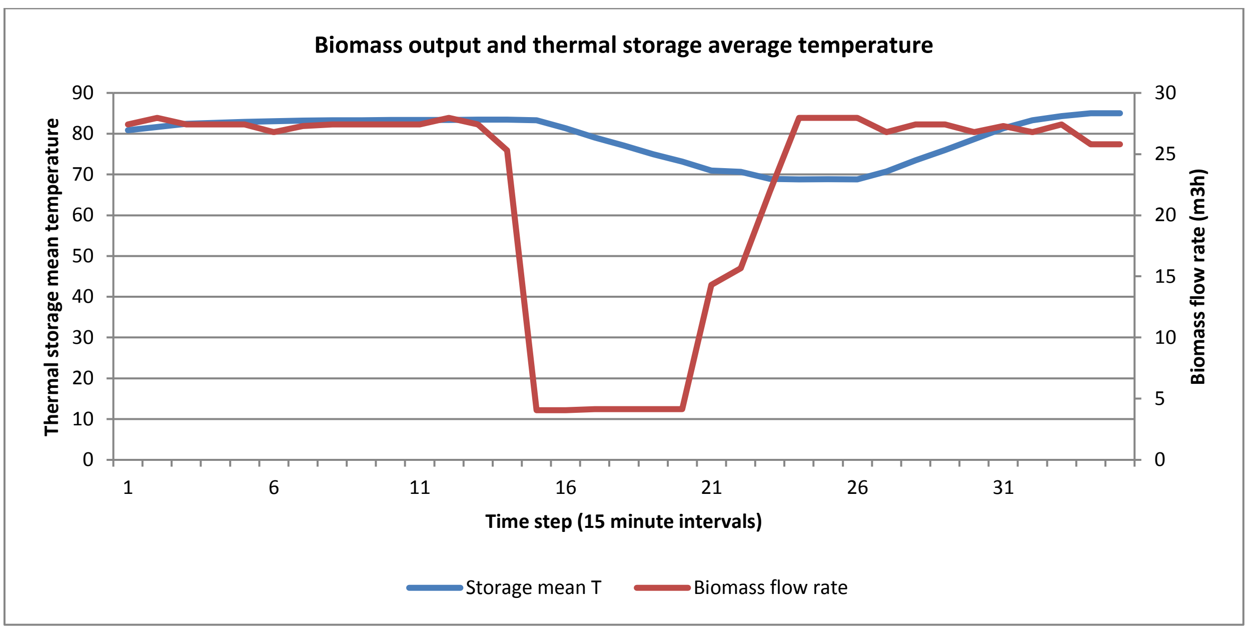


*Figure 1: Biomass and thermal storage operation*

When the biomass boiler does not keep up with the energy demand then the backup gas boiler picks up to support the system. Figure 2 shows a 96-hour period of the thermal storage mean temperature, gas output and the biomass output. The thermal store drops to mean temperature of 70°C, but the biomass is slow to pickup, which causes the backup gas boiler to pick up preventing the thermal store from being depleted. This allows the biomass to catch up to the energy demand. This configuration keeps the system resilient, maintaining the separation of the district load with the biomass boiler.

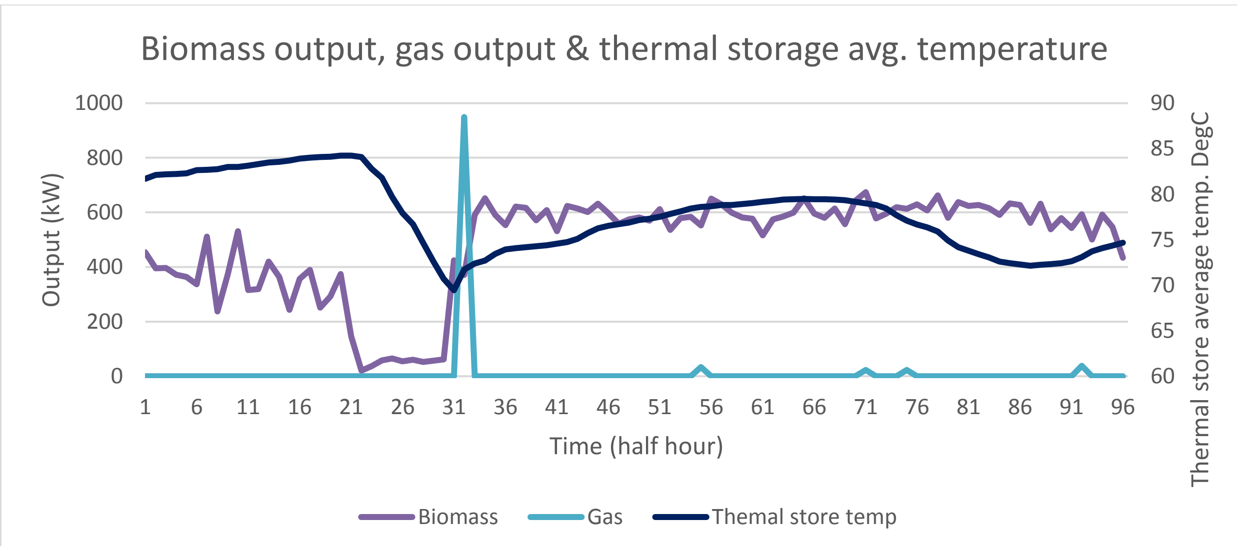


*Figure 2: Biomass, gas and thermal storage operation*

# 2. LITERATURE REVIEW

## 2.1 Fuel Poverty

In the UK, if your home is not connected to the mains gas, the use of electricity for heating is an option as all homes have access to the electric grid. But this is an expensive option, especially for lower income earners. It's like burning money, when you consider the cost of electricity is 10-15p/kWh and the cost of gas is just 3.5-4p/kWh. An average energy bill in a gas central heated home is approximately £1300, which is 70% gas with remainder being electricity. Now, of the 70% gas, 85% of this is for heating with the remainder hot water meaning that approximately £775 goes towards heating (The Greenage, 2015).

According to the Scottish index of multiple deprivation (SIMD), South Lanarkshire in which the Whitlawburn community is located, is listed amongst top 10 of the most deprived areas in Scotland (National Statistics publication for Scotland, 2016). This means the people who live in that area, experience conditions which limit their opportunities in life, this is examined according to employment, income, education, health, access, housing and crime. Figures published by the Scottish Government reveal figures of 26% of household across Lanarkshire are in fuel poverty because more than 10% of their household income is spent on fuel (Kenealy, 2017). This means some families struggle to heat their homes and most times must decide if they want to eat or stay warm.

In England, Fuel poverty is measured using the low income high cost indicator (LIHC), which states that a household is in fuel poverty if: they have required fuel costs that are above average (the national median) or were they to spend that amount, they would be left with a residual income below the official poverty line. The household Income, household energy requirements and fuel prices are 3 determining factors to ascertain if a household is fuel poor (Gov.uk, 2019). The proportion of households in England in fuel poverty was estimated to have decreased by 0.2

percentage points from 2016 to 10.9 per cent in 2017 (approximately 2.53 million households) (Department of Business, Energy & Industrial Strategy, 2019). Diagram required check bachlan

## 2.2 Energy Performance Certificate (EPC)

A factor that responsible the high cost of heating residences is due to the energy performance of the property. The energy performance in the building determines how much the occupant will spend annually on energy bills, which includes space heating, hot water and lighting. The energy performance in a building is measured through an EPC survey, and an EPC rating is given depending on the property's energy efficiency from A to G, with A as 'Very Efficient' and G, as 'Not Very Efficient'. The EPC contains information regarding a property's energy use, typical energy costs and recommendations on how to reduce energy consumption (Davidson, 2018). The property's EPC rating will depend on the amount of energy used per $m^2$ and the level of carbon dioxide emissions (given in tons per year) (Evergreen Energy Ltd, 2019). The EPC is valid for 10 years and after that period the homeowner will require another survey.

The age of a property is often indicative of its energy performance, which is due to building regulations being slack and the importance of energy efficiency not understood (Bouquet, 2017). But now there are stricter regulations, as it is now a requirement for any properties rented, leased or sold out to have a minimum energy performance rating of E on their Energy Performance Certificate (EPC) (Residential Landlords Association Ltd, 2019). Older buildings are less energy efficient than newer ones, hence they require energy efficiency improvements. This was what done by the West Whitlawburn housing cooperative. They invested £22.4 million to improve the energy efficiency of their buildings, this included insulation, cladding, new windows, reroofing and enclosing the exposed balconies in six high rise blocks. The property now has an average EPC rating of C.

Considering this, the new 300 residential property at East Whitlawburn will have a higher EPC rating than West Whitlawburn, making their energy consumption cheaper than the former. This is because the build construction types of newer buildings are geared towards energy efficiency, due to the newer building regulations. According to (Home Builders Federation, 2017), retrofitting existing homes with components to make it more energy efficient can be very costly, time consuming and disruptive and, in some cases, can be unfeasible considering structural constraints. When compared to a new build home which is already compliant with the regulatory regime that housebuilders work within. According to Figure 3, EPC data 2017 second quarter, 84.4% of new builds are rated A-B for energy efficiency while just 2.2% of existing properties manage to fall into A-B categories. Based on government data, homes built in the year to June 2017 use an average of 103kWh/$m^2$ compared with an average for existing properties of 294kWh/$m^2$.

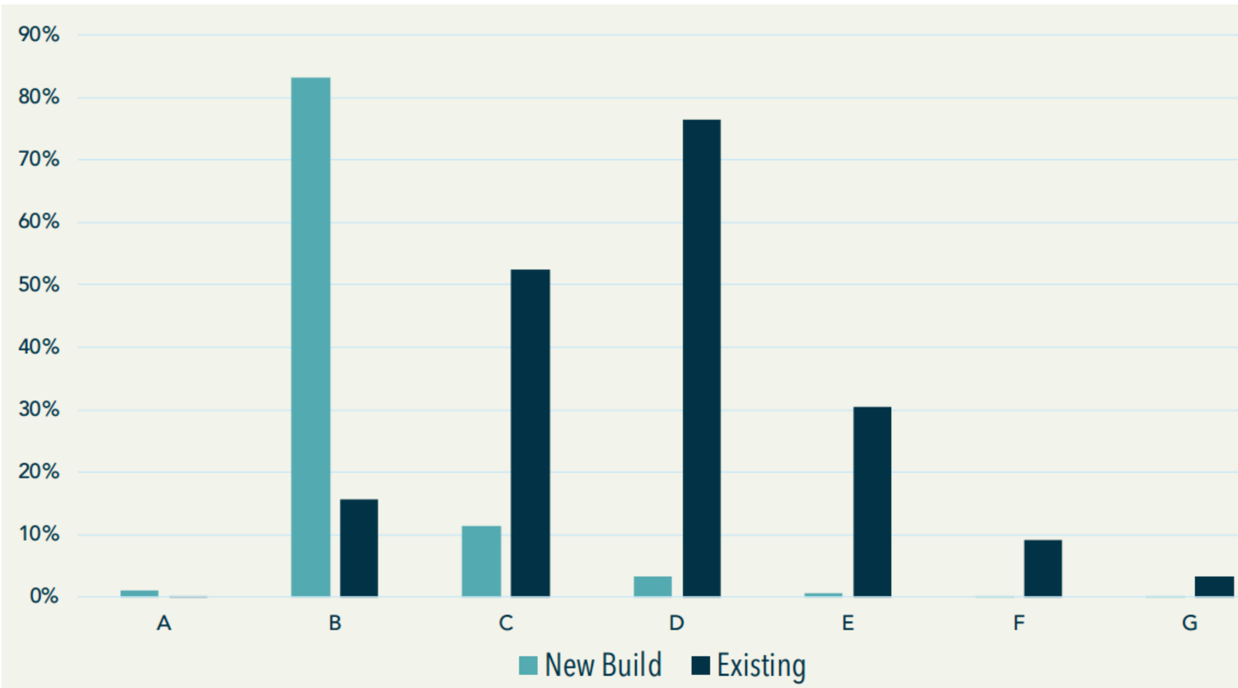

*Figure 3: Proportion of homes in each energy performance rating category, Q2 2017(Home Builders Federation, 2017)*

## 2.3 District Heating Sizing

### 2.3.1 Load Profile

Boiler sizing requires knowledge of the buildings heat load profile, making a distinction between the base load and peak load. A load profile is a graph of the variation in the energy load versus time. A load profile will vary according to residents, weather temperature and season of the year or month. There are several ways of creating a load profile, it can be determined by knowledge of the previous boiler energy output or electricity usage from a meter, preferably from the winter months. Most companies have a dynamic building simulation tool they use with data or CEN standard EN ISO 13790: Energy performance of buildings – Calculation of energy use for space heating and cooling can be used on a winter design day external temperature profile (Palmer et al, 2014). Figure 4 shows the load profile of a day.

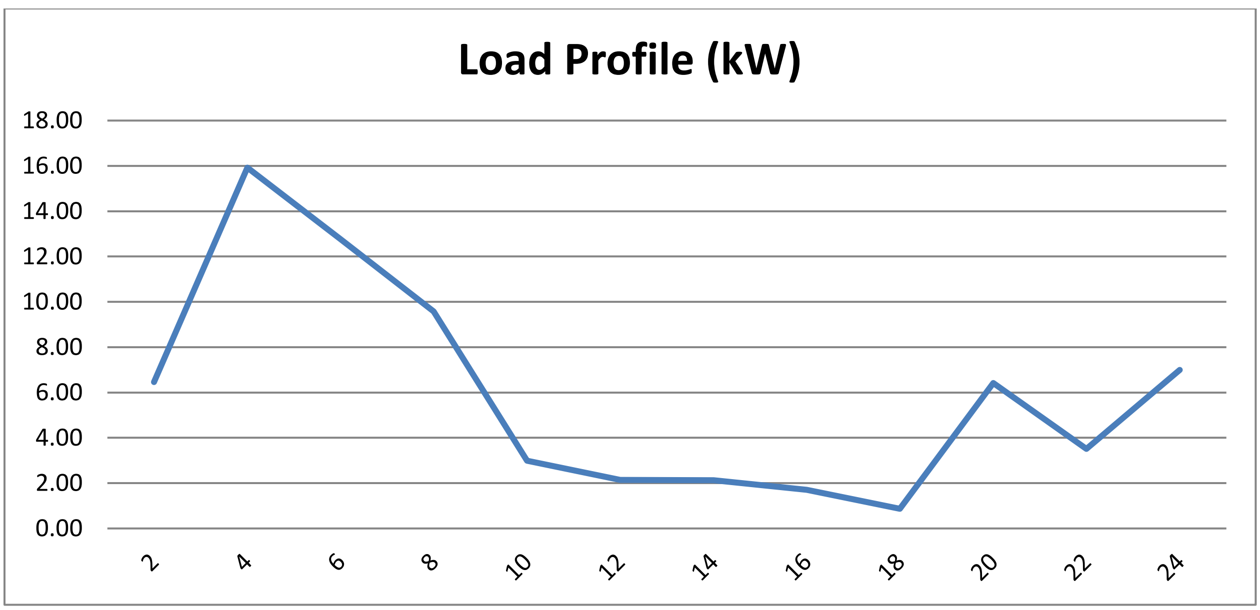


*Figure 4: A 24-hour load profile*

### 2.3.2 Biomass boiler sizing

Biomass boilers are usually sized to meet only a proportion of the peak load, this is because a biomass boiler sized at 100% of heat required would spend most of the operating time at low loads (Intelligent Energy Europe, 2019). This occurrence leads to short cycling and happens when the boiler is oversized, meaning it quickly satisfies the heating demand, shuts off for a short period before starting the process again as seen in figure 5.

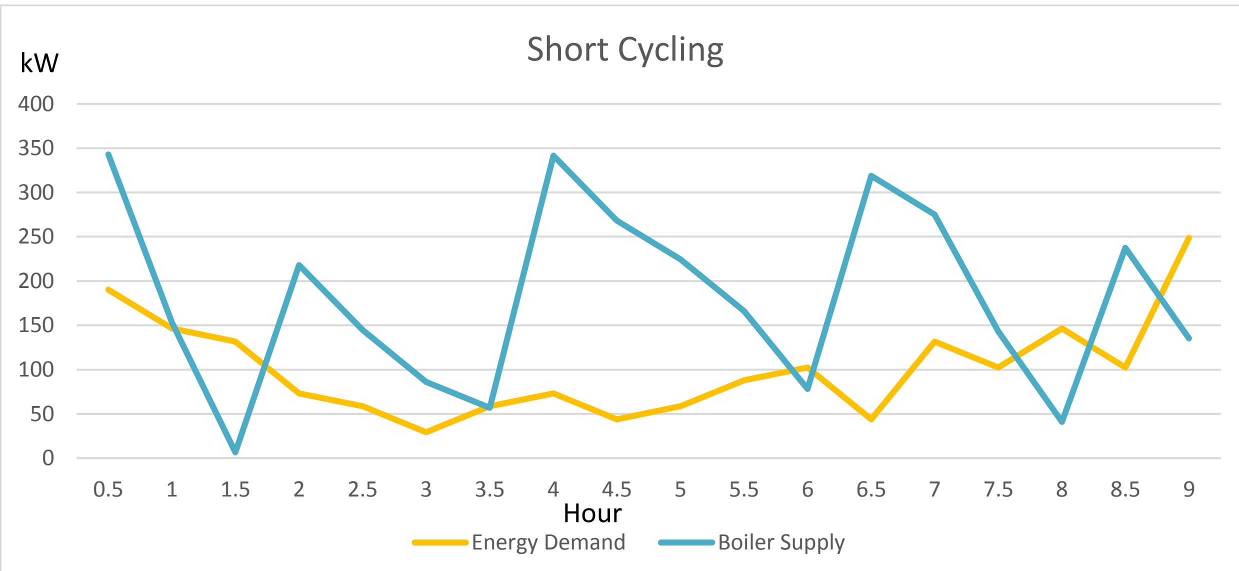


*Figure 5: Short cycling of an oversized boiler*

This continuous process can shorten the life of the boiler and is not suitable especially for biomass boilers, because unlike a fossil-fuel boiler, its turn-down ratio is lower. The biomass boilers turndown ratio is typically between 2:1 and 3.5:1 (Palmer et al, 2014). Biomass boilers are typically used in combination with another boiler or thermal storage or a combination of both, which allows the heat generated to satisfy peak loads that are in excess of the biomass boilers capacity and to optimize the performance of the boiler by reducing cycling. The thermal storage collects heat energy from the biomass boiler during the base load periods, and during the peak load periods, releases it in combination with the biomass boiler.

According to (Palmer et al, 2014), the primary way of sizing a biomass boiler and thermal store combination, is to design the system using a smaller boiler in relation to the peak load while the system is in continuous operation. The shape and duration of the daily heat load profile determines the extent to which the boiler size can be reduced in relation to peak load. The size of thermal storage for the boiler is then ascertained by the shape of the heat load profile. Biomass boilers work most efficiently when they can run at close to their operating capacity for extended periods, therefore the need for a thermal store and are not sized to meet the demand profile exactly but reduced. Unlike fossil fuel boiler which are usually oversized as they are sized to meet a demand profile with all loads starting simultaneously, as they have quicker start up time compared to biomass which must charge the store first.

An undersized thermal store will not be able to provide any flexibility or system protection. A short load profile will result in a low biomass utilization factor, if the boiler is sized half the peak load. Heating systems are usually oversized rather than undersized, because once the building is occupied, variables might change resulting to insufficient heat energy supply. Therefore, it is preferable to have more heat available than not enough because once a system has reached its maximum output, additional heat cannot be generated. An oversized system can be modulated or adjusted to serve the required load, but there is no way to adjust an undersized system to meet peak loads.

## 2.4. Potential issues of the network expansion

With WWHC being in-charge of managing the new buildings at EWH, connecting to their district heating system could be beneficial to the residents due to low energy bills. But there are potential issues that may arise by this connection and require consideration before this project can be commissioned.

### 2.4.1 Build Type

The building at WWHC was commissioned in 1968 (Fandom, 2019) and as such was subject to the heating regulations at that time, which was of a low quality compared to recent regulations. Recent regulations are made to combat climate change and promote the use of renewable energy, while at the era of constructing WWHC buildings focus was on just keeping residents warm. This build type is unsuitable to modern standards and WWHC had to spend a substantial amount to retrofit the structure. The WWHC buildings meets standard regulation and averages an EPC rating of C. WWHC uses a 3rd generation district heating system which suits their build type, considering the district heating system generation was introduced during the 1970s (Gudmundsson, 2016). The 3rd generation district heating systems use high pressure water at temperatures below 100 ◦C (Gudmundsson, 2016). The network at WWHC is fed by a 740 (685) kW biomass boiler, operated at 85°C and return at 70°C.

The new buildings at EWH will have a build type that reflects the current building heating regulations and will have an EPC rating of either A or B. This presents a potential issue; the new build types are suitable to 4th generation district heating as it's meant to compliment recent regulations. Compared to the 3rd generation, the temperature levels have been reduced to increase the energy efficiency of the system, with temperatures of 70 °C and lower (Millar, et al., 2019). The modern build type has better energy efficiency than older buildings, which needs higher temperature because of increased heat losses. Connecting EWH to WWHC district heating system will result in higher return temperatures to the system, which will distort the equilibrium of the system. This can be detrimental especially during summer months when the load profile is at the base load, and eventually will shorten the life of the district heating system.

### 2.4.2 System flexibility

When the district heating system was being designed, a load profile was created using the base load and peak load, to determine the heat demand of the residents WWHC. This load profile ascertained the size of the district heating system. The size of the biomass boiler and the heat store are interlinked, and as such the biomass boiler size determines the size of the thermal storage. The thermal storage is important as it serves as a peak lopping and load smoothing device. Providing the system with flexibility which ensures stability and efficiency by charging during base load periods and discharging heat along with the biomass boiler during peak loads.

The biomass boiler at WWHC is rated at 740kw but operates at 685kw, hence is not operating at full capacity thermal store.  If the biomass boiler could be resized to fit EWH demand, it would require purchasing a new thermal store, as the thermal store was sized to the previous load profile. Operating with the same thermal store would create an unstable system resulting in heat demands not being satisfied.

## 2.5 East Whitlawburn housing heating options

The energy and sustainability consultants, Carbon Futures is working with CCG Construction and Manufacturing Group to develop a sustainable, energy-efficient strategy for the East Whitlawburn housing regeneration project (Carbon Futures, 2018). This means the houses are constructed with the mindset of promoting renewable energy technology to keep in line with the policy and regulations of the Government. If feasibility of the district heating system expansion is not possible, there are other renewable energy options available. Considering the build type is energy efficient, renewable energy incentives and schemes, and that Cambuslang is a deprived area in Scotland, there are few heating and hot options that can be taken advantage of by the residents.

- Air source heat pumps (ASHPs) – will be suitable for a low energy demand building, since air source heat pumps are most efficient when producing heat at a lower temperature. An air source heat pump extracts heat from the outside air and transfers this heat to the heating and hot water circuits of the house.
- Gas condensing boiler for mains gas – Main gas is a very popular source for hot water and heat in the UK because it is cost effective. About 78% homes in Scotland are connected to mains gas (Morrison & Moyes, 2018). Condensing boilers work by converting water vapor condensation into heat, which can be used for heating and hot water.
- Solar thermal systems – solar panels are fitted to the roof or hanged from a wall, which collect heat from the sun and use it to heat up water in the solar cylinder. Immersion heaters can be employed as a back-up to heat the water further to a desired temperature.

# 3. METHODOLOGY

## 3.1 Data

The primary source of data used for investigation in this thesis was the West Whitlawburn housing cooperative. Through which heat energy consumption metered reading was provided for an entire year, July 2016 to June 2017, encompassing the seasons of Scotland, summer, autumn, winter and spring respectively. While all the Energy Performance Certificates (EPC) for each building was sourced from the Scottish EPC register.

This data was sourced from a PhD research student of the University of Strathclyde, Andrew Lyden. The block level reads data has the month end metered reading of the heat energy produced by both the biomass and gas boiler of the district heating system, and what was inputted and consumed by every building in the cooperative. The smart meter data for Arran tower, which is one of the 72 flat high-rise building in the cooperative. This data is more detailed as it shows a half hour time-step of heat energy consumed by each flat for every month over a year. Show figures or recommend appendix to view referred to data

This was useful as the smart data of Arran tower was interpolated to represent the heat energy demand for WWHC, illustrating its half hour time-step. The 72 flat high-rise building holds 49 residents and West Whitlawburn serves 543 residents. Equation 1 shows calculation used to obtain the WWHC energy demand data for each time-step.

*Equation 1:*

$$WWHC\ energy\ demand = \frac{\text{No of WWHC residents} \times \text{Arran tower energy demand}}{\text{No of Arran tower residents}}$$

## 3.3 Data Analysis

### 3.3.1 Space Heating and Hot Water

The period of peak demand will determine the optimal performance of the district heating system. This required the month of peak demand for WWHC to be used, which is January. With the opted month data, the specific heat demand for space heating and hot water had to be shown. The month of least demand, August was selected as during summer months it is assumed that only heat demand for hot water is required. August demand was then subtracted from January demand, which now specified what the demand for hot water and space heating was. The data was edited to remove negative values but still retains its original total sum. This became the demand profile for the model. The heat demand profile is the principle input to the model, which will determine how the district heating system will run. It should be noted that this demand profile is obtained from the total heat sold data, which is from the smart meter in each dwelling at Arran tower which logs energy usage at half an hour time-step. This demand data will be influenced by the number of habits, resident's economic situation, levels of occupancy and larger households in each flat of the residents of Arran tower. Figure 6 shows the demand profile of 24 hours.

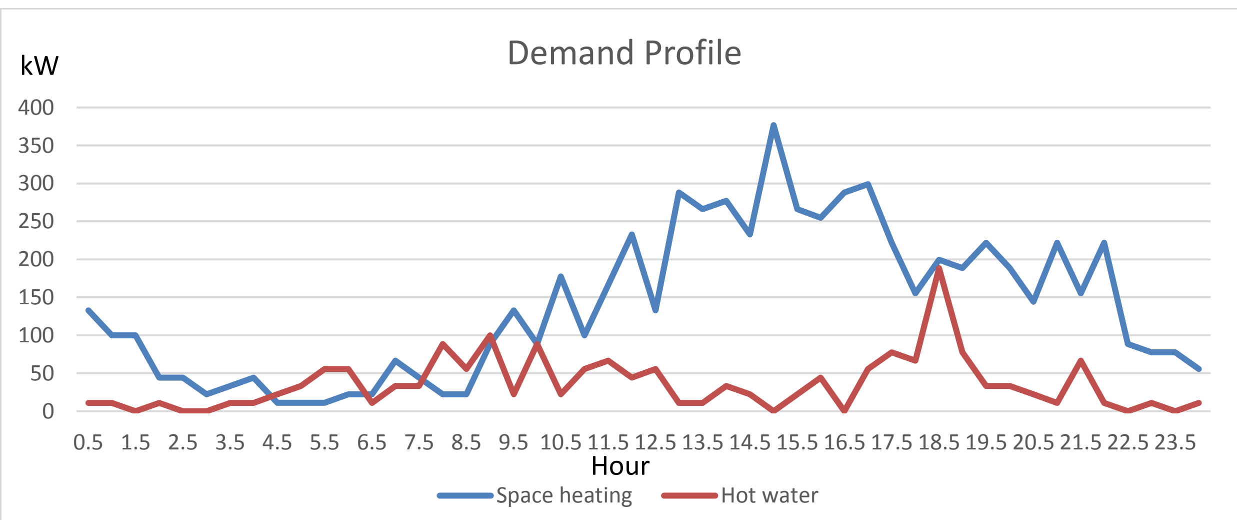


*Figure 6: 24-hour demand profile*

### 3.3.2 District Heating System Energy Output

From chapter 1.3, we can determine the energy output of the district heating system. The energy of the biomass boiler, gas boiler and thermal store energy capacity can be calculated from the numbers given. In the model, the maximum value for the thermal store is reached when it is fully charged. Gas boilers are flexible and, in the model, out of the 3, only 1 is used as back up for the district heating system. The biomass boiler is used at the maximum sized capacity in the model.

*Equation 2:*

$$E_s = \frac{V \times \rho \times C_P \times (T_1 - T_2)}{3600}$$

Where:

$E_s = Energy\ capacity\ of\ thermal\ store\ (kWh)$

$V = Volume\ of\ thermal\ store\ (l)$

$\rho = Density\ of\ water\ (kg/l)$

$C_P = Specific\ heat\ of\ water\ (kJ/kg°C)$

$T_1 = Upper\ operating\ temperature\ (°C)$

$T_2 = Lower\ operating\ temperature\ (°C)$

*Equation 3:*

$$E_x = P \times t$$

Where:

$E_b = Energy\ capacity\ of\ biomass\ boiler\ (kWh)$

$E_g = Energy\ capacity\ of\ gas\ boiler\ (kWh)$

$P = Power\ of\ boiler\ (kW)$

$t = Hours\ (h)$

### 3.3.3 Network Losses

Network losses is considered as a load in the model as it consumes a portion of the heat energy produced. The value for network losses is obtained from the block level reads data, which was computed using ratio. A ratio is a relationship between two numbers indicating how many times the first number contains the second. The value used in the model is the ratio of network losses to the total heat sold for January. This ratio value was then multiplied by the total energy demand (heat sold) for January in the model, which gives a value for network losses for each timestep.

*Equation 4:*

$$r_n = \frac{Q_l}{Q_s}$$

Where:

$r_n = Ratio$

$Q_l = Network\ losses\ \ (kWh)$

$Q_s = Total\ heat\ sold\ (kWh)$

### 3.3.4 Heat demand and network losses data for East Whitlawburn

The value calculated for East Whitlawburn heat is based on the government data which showed that energy usage for new homes averaged 103kWh/$m^2$ for new built while existing properties of 294kWh/$m^2$. The EPC value for West Whitlawburn housing cooperation averaged a rating of C after the retrofitting to improve its energy efficiency. A ratio was found between the two values of new properties and existing one's averages, which was put into the model to modify the data for WWHC space heating and hot water values.

The network losses of East Whitlawburn are expected to be lower than West Whitlawburn. The Chartered Institution of Building Services Engineers (CIBSE) Code of Practice recommends that on insulation "total annual heat loss from the network up to the point of connection to each building when fully built out should not exceed 10% of the sum of the estimated annual heat consumption of all of the buildings connected." And With respect to in building distribution advises that "With appropriate design the heat loss within the building should be less than 15%." Based on this an assumed value of 15% was used to determine the network losses.

*Equation 5:*

$$r_e = \frac{P_n}{P_e}$$

Where:

$r_e = Ratio$

$P_n = New\ properties\ \ (kWh/m^2)$

$P_e = Existing\ properties\ (kWh/m^2)$

## 3.5 The Model

This is required to create a representation of the data acquired, which enables the investigation between the interaction of the heat energy demands and the district heating system to be carried out. This model which is created with Microsoft excel can be applied to the demands of both West Whitlawburn housing cooperation and the new buildings of East Whitlawburn housing. The if and ifs function are used to run a logic which determines how district heating satisfies the energy demand as it was designed. This model enables the observation of the operation of district heating system, which allows a conclusion to be drawn.

### 3.2.1 Determining the maximum demand for hot water and space heating at West Whitlawburn Housing

Determining the maximum demand would require use of the month of when demand was highest. This was the January, but the demand data needed to reflect the space heating and hot water demand for January. To determine the hot water demand would require the use of the month when demand was lowest. This is because at that time, it is assumed that there will be no demand for space heating. This period is during the summer months and the lowest was august. The difference between both January and August will be assumed as the hot water demand for January.

### 3.2.2 Analyzing the performance of the district heating system with the maximum heating demand

Analyzing the performance of the district heating system with the maximum heating demand would require an interaction of the system with the maximum load. Space heating and hot water demand has been determined but is not the only demand to consider. There were network losses during the operation of the system. Heat was lost from the energy center to the point of connection to each building and during the distribution of within the building. Network loss is also a load and therefore this will be known as heat loss load.

This must be ascertained, if the maximum heating demand is to be found. Using the monthly meter reading data, heat loss was determined by subtracting the total energy produced from the energy center with the heat sold (demand). The network loss was then taken from January using the monthly meter reading data. A ratio of network losses to heat sold was taken and put into the model by multiplying the ratio with total demand. This gave a value which represented the heat loss load. Adding space heating, hot water and heat loss load gives the maximum heating demand.

The configuration and operation of the system is required for an analysis of the performance when interacting with the maximum heating demand. The thermal store will be fully charged at the start of the model and as the maximum demand extracts heat from the system at each half hour time-step, the boiler will be charged by the biomass boiler to keep up with the demand. When the biomass boiler is overwhelmed the backup gas boiler in start up to support the system. There will be sensors in the system to activate the biomass boiler to top-up the thermal store and the gas boiler to back-up the biomass boiler, keeping the system resilient. Observation of the interaction between the district heating system with maximum demand will help draw a conclusion of the performance of the West Whitlawburn district heating system.

### 3.2.3 Ascertaining the maximum demand for hot water and space heating at East Whitlawburn Housing

To ascertain the maximum demand for hot water and space heating for East Whitlawburn required the use of Energy Performance Certificate (EPC) rating. East Whitlawburn has no EPC rating as it has not yet been built but West Whitlawburn housing cooperation does. The EPC rating of WWHC was ascertain and then compared to the EPC rating of a newly built house. The EPC of WWHC will be lower as it was commissioned in the late 1960’s and was subject to the building regulations of that time, which is not of high standard of recent times. WWHC had to be retrofitted to have an average EPC rating of C. The rating was in line with the government data which stated that new buildings EPC are higher. Hence the ratio of energy usage new buildings to old buildings was used to ascertain the space heating and hot water demand. The data of WWHC was used to obtain a value for EWH heat energy demand, by interpolating to get a figure for EWH and multiplying that value with the ratio of energy usage new buildings to old buildings. The heat loss load for EWH was calculated by multiplying its total energy demand with an assumed value. Adding the heat energy demand and heat loss load will give the maximum heating demand for EWH.

Having the maximum heating demand for WWHC and EWH will enable the performance of the district heating system when put under that load to be ascertained.

# 4. RESULTS AND DISCUSSION

## 4.1 Maximum demand for West Whitlawburn housing cooperative

Determining the maximum heat demand for West Whitlawburn housing cooperative (WWHC) involved choosing the highest demand month for WWHC, which was during the winter month. January was chosen because of it had the highest peak demand with a total of 25818 kW used and seen in Figure 8, when compared to the other winter months of December, Figure 7 and February, Figure 9.

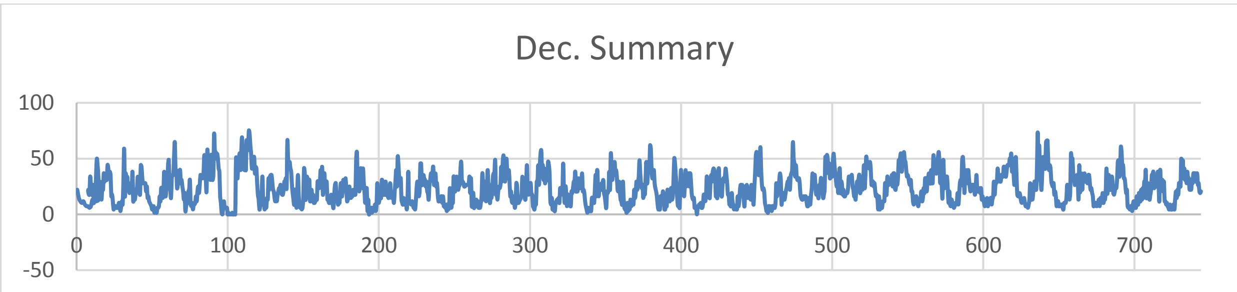


*Figure 7: December demand profile*

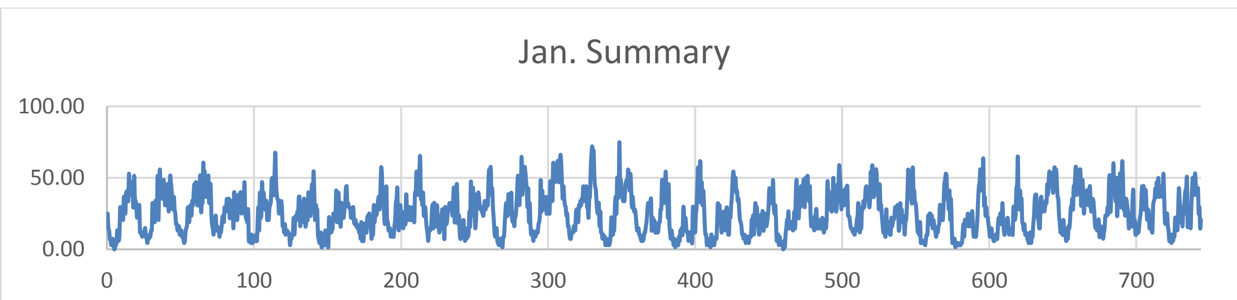


*Figure 8: January demand profile*

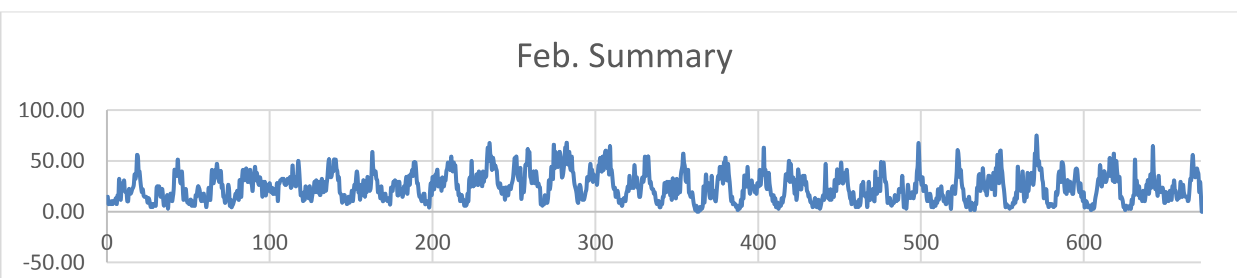


*Figure 9: February demand profile*

These were the demand months of Arran tower which house 49 residents, when compared to the 543 residents of Whitlawburn residents required for the model. An interpolation was then carried out to determine the demand for Whitlawburn January demand as seen in Figure 10, with a total of 286106 kW.

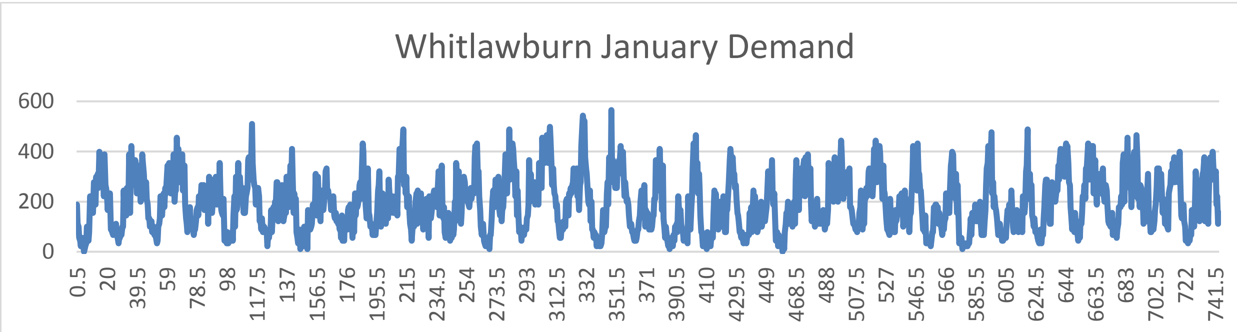

*Figure 10: January demand profile for WWHC*

The heat demand is made up of both space heating and hot water demand, obtaining that required the months of least demand, which is the summer months as it is assumed that demand for space heating would be non-existent and all the demand data would refer to hot water demand. The months of July, Figure 11 and August, Figure 12 was analyzed as June 2017 data was unavailable. August has the lowest base demand with a total of 5658 kW.

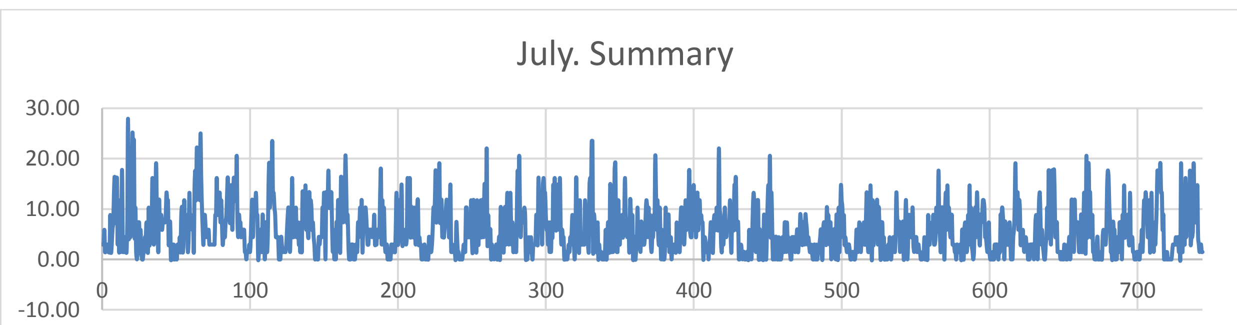

*Figure 11: July demand profile*

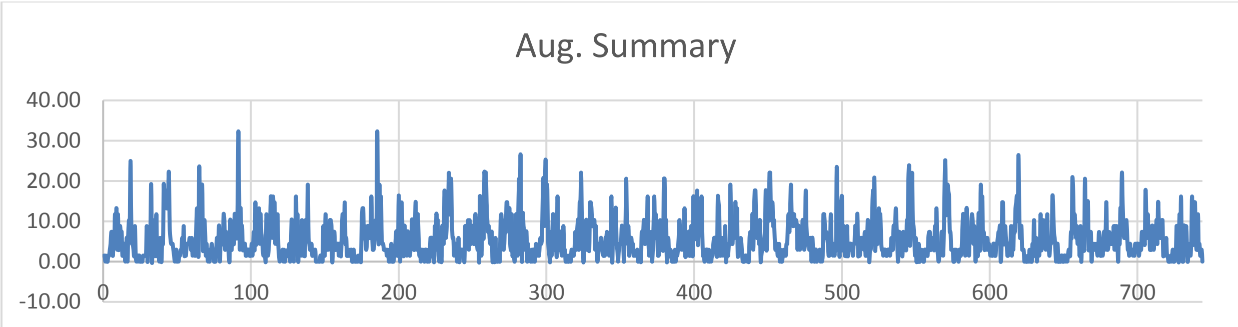

*Figure 12: August demand profile*

This was interpolated to get the demand for Whitlawburn August demand as seen in Figure 13, with a total of 62700 kW.

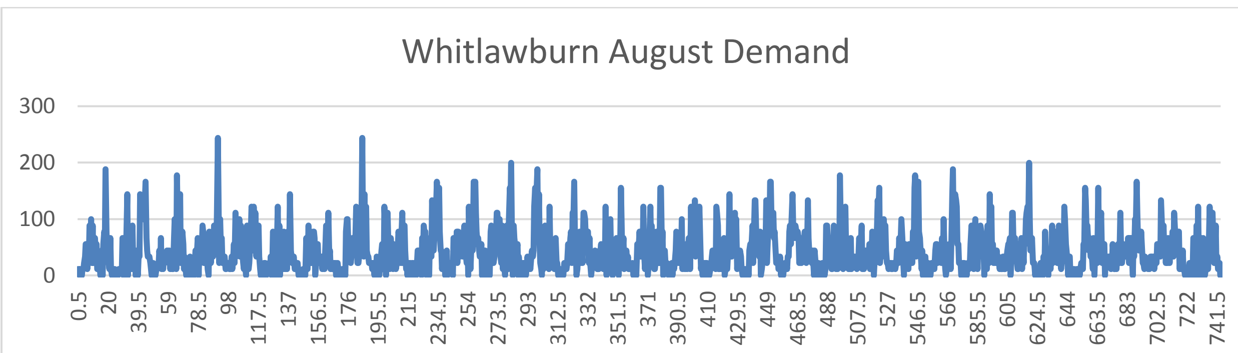

*Figure 13: August demand profile for WWHC*

August energy demand was subtracted from January, this resulted in the defining the space heating demand and the hot water demand. The Data was then cleaned to remove negative values, retaining its original total. Figure 14 shows the space heating demand, while Whitlawburn August demand was as the hot water demand.

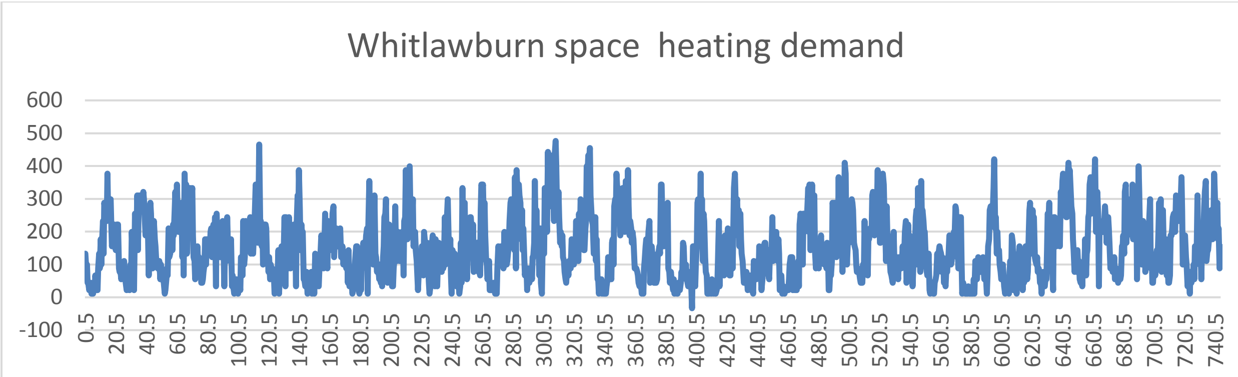


*Figure 14: January space heating demand profile for WWHC*

## 4.2 Performance analysis of West Whitlawburn district heating system

Analyzing the performance required data for the network losses in the system and configuration of the district heating system. Network losses was computed from block level meter read data for January. This was extracted using the ratio of network losses to heat sold (energy demand) for January, which gave a value of approximated to 0.32. This value was multiplied by the total energy demand for January. This gave a value for each time-step for network losses as shown in Figure 15.

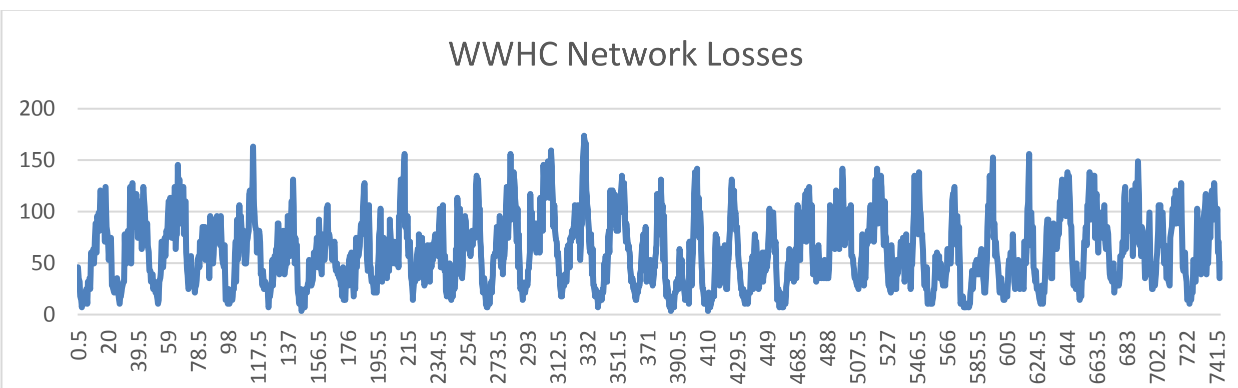


*Figure 15: Network Losses Profile for WWHC district heating system*

The If and Ifs function in excel was used to create a logic that would replicate the behavior of the system. This logic would be used to analyze the performance of the system. There are three scenarios that can come out from this analysis, either the system is undersized, oversized or properly sized. Analysis show the system was properly sized as there was minimum cycling from the biomass boiler, the thermal store kept the demand load separated from the biomass boiler load and the gas boiler came up few times to maintain the systems integrity. Figure 16 shows the first day of operation in the model, starting when the thermal store was at its maximum of 872kwh.

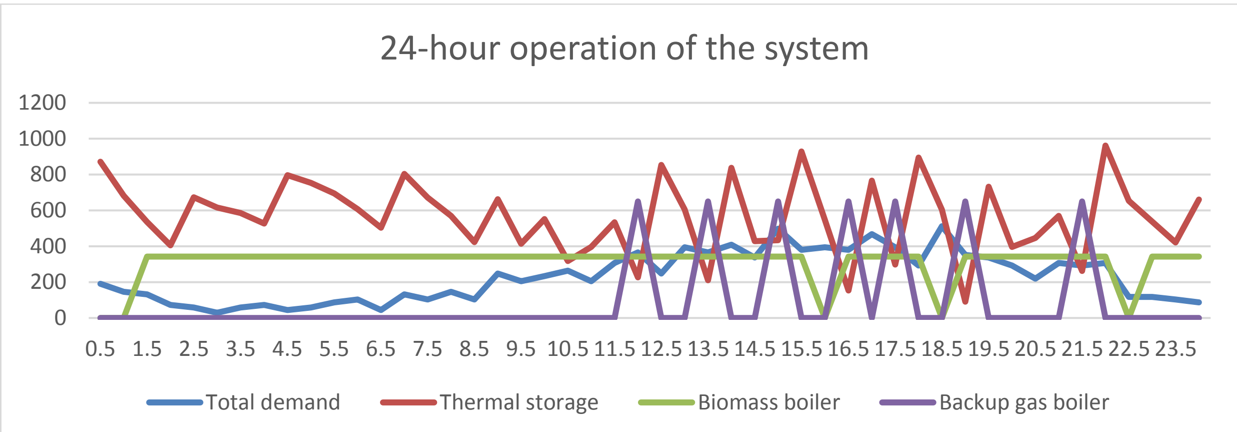


*Figure 16: District heat operation for 24 hours*

## 4.3 Maximum demand for East Whitlawburn Housing

The data for West Whitlawburn housing cooperative was used to obtain the values for East Whitlawburn housing. The difference in the buildings will be their energy performance, which can be ascertained with an energy performance certificate (EPC) rating. The value of West Whitlawburn housing cooperation was checked from the EPC registry and averaged an EPC rating of C, which validated the data from the HBF report. The ratio based on the HBF report which showed that energy usage for new homes averaged 103kWh/m$^2$ for new built while existing properties of averaged 294kWh/m$^2$ was used. The ratio of average energy usage of new properties to average usage of existing properties gave a value approximated to 0.35. This value was multiplied with the interpolated value for space heating and hot water demand for WWHC to create the East Whitlawburn heating demand. As seen in Figure 17 for space heating and Figure 18 for hot water demand, the EWH heating demand is lower than WWHC due to improvements in build type and building regulations.

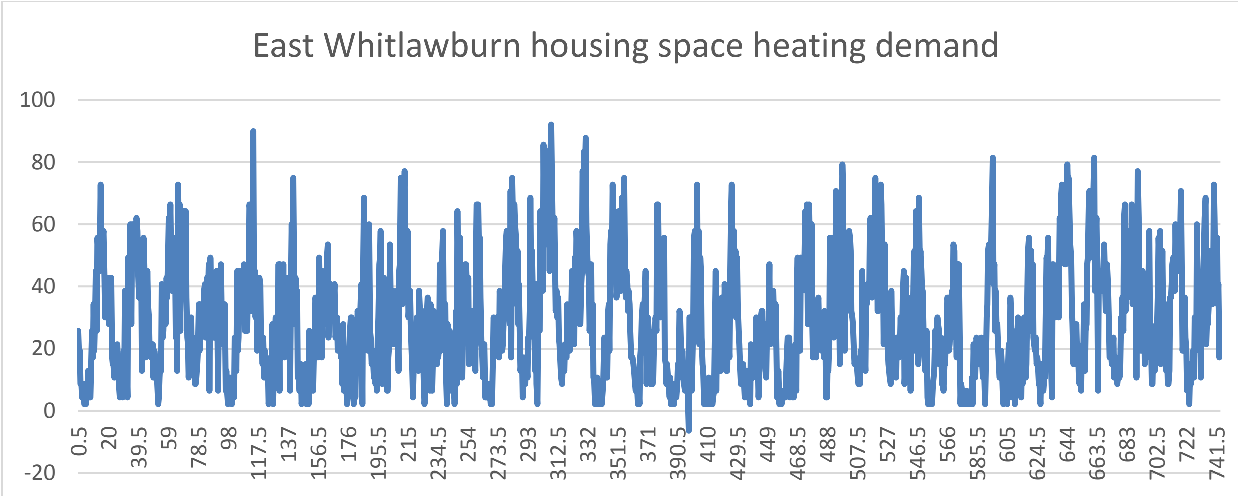

Figure 17: Space heating demand profile for EWH

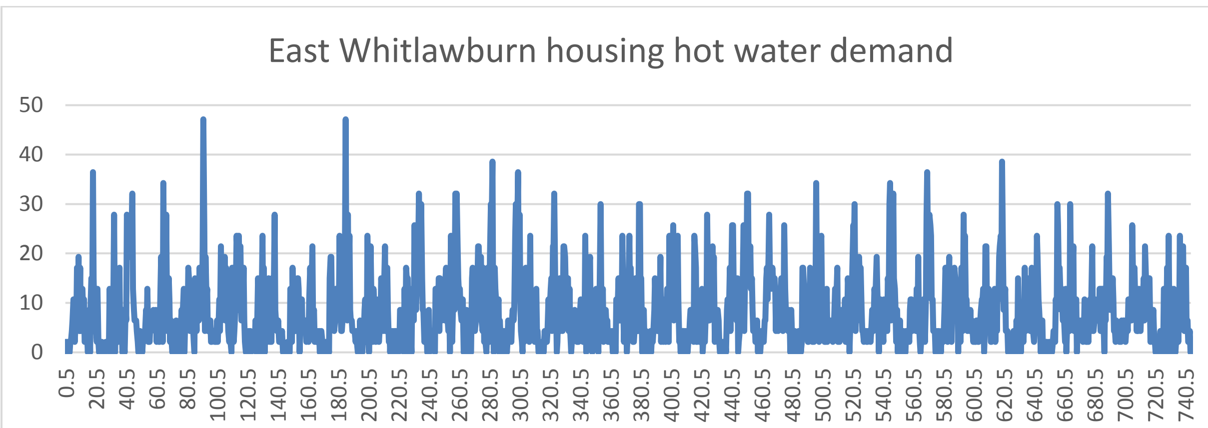

Figure 18: Hot water demand profile for EWH

The network losses were calculated by using an assumed value of 15% to multiply EWH heating demand. This value was assumed to be ratio of network losses to heat demand. The value was determined because it is assumed that EWH housing will have better network insulation than WWHC. Figure 19 shows that EWH network losses were improved over WWHC.

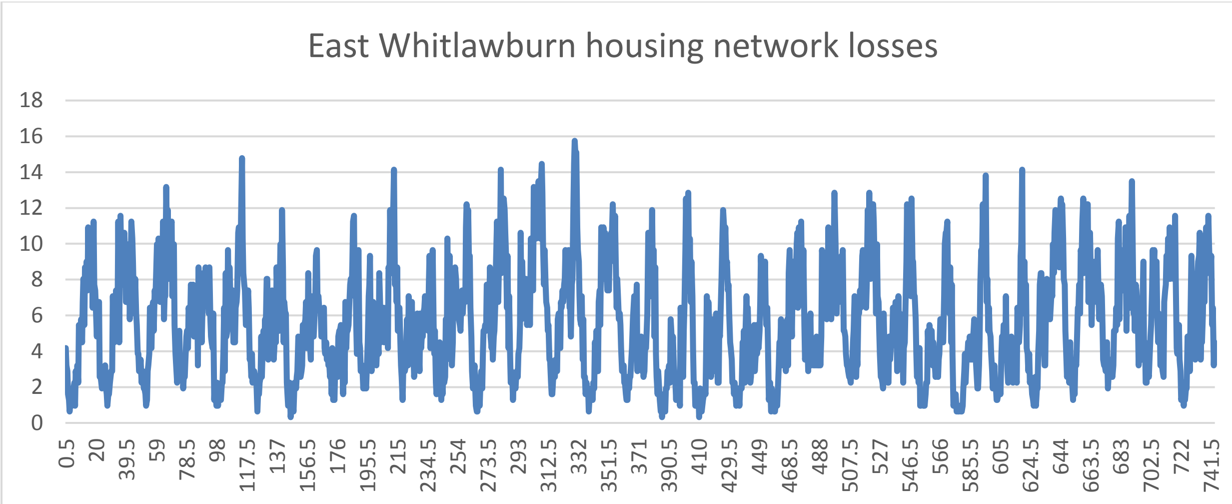


*Figure 19: Network losses profile of EWH*

## 4.4 Performance analysis of district heating system with West Whitlawburn and East Whitlawburn energy demand

Analyzing the performance of the district heating system was the aim of this paper and it has been achieved. From the model the system had a few negative values, when the load was at its peak. The extra energy demand from EWH put strain on the system but that can be countered with use of the second gas boiler as the negative values weren't too high or often. The biomass boiler does not need to be replaced but should be resized to accommodate the extra load. This means a new thermal store will be needed to separate the district load from the biomass boiler load. Figure 20 shows the first day of operation in the model, with both WWHC and EWH heating load.

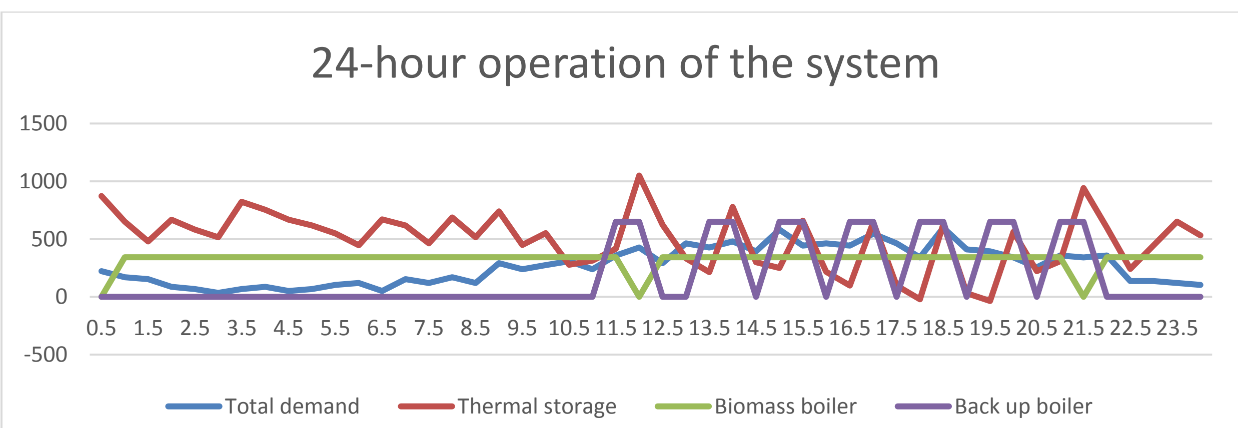


*Figure 20: District heat operation for 24 hours with the extra load*

# 5. CONCLUSION

The maximum demand for hot water and space heat at West Whitlawburn housing was by interpolating Arran towers data. This data enabled the analysis of the performance of the district heating system which was found to be sized properly. The maximum demand for East Whitlawburn housing was determined with the data of West Whitlawburn housing, which was interpolated to consider the number of residents. Then the data was then adjusted using a ratio reflecting what the heat demand will be by the EPC rating of newer buildings. With the data for heat demand obtained, the district heating system was analyzed to determine its performance under both housings heavy load. It was discovered that the boiler would have to be resized slightly to fit the of fit the demand of both West Whitlawburn housing cooperative and East Whitlawburn housing.

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