Energize Worcester Phase II: Perceived vs. Actual Heating Behaviors

An Interactive Qualifying Project Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE In partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

This project was a continuation of Energize Worcester, a program sponsored by the University of Worcester. Energize Worcester is an initiative that aims to increase sustainability in student houses of multiple occupation (HMOs) by focusing on thermal efficiency specifically. The goal of our project was to identify differences between the perceived and actual heating behavior of students through the use of student interviews and smart heating data loggers, respectively. Our two datasets identified a few key points. The use of the 'Wave' smart heating system is inconsistent, there are external factors that affect the usage of the system, and student education and motivation to use the system is low. We recommend that future research teams investigate what factors have the greatest influence on student heating behaviors.

Executive Summary

Introduction

The United Kingdom is greatly affected by inefficient use of energy in the country's homes. Overall, there are about 26 million homes in the UK, and around 21 million of them have a poor level of energy efficiency, as stated by the Energy Performance Certificate (EPC) guidelines. The homes in the UK are the least thermally efficient of all Western Europe (*The cold man of europe,* 2015). About a third of the homes in The UK - 6.6 million - have an EPC of E, F or G, which are the lowest ratings possible. Living in homes as inefficient as these, it makes heating the home for an affordable price difficult (*The cold man of europe,* 2015). This in turn has led to arising complaints of people's comfortable living habits across the UK.

Many complaints come from tenants in homes from the private sector. The majority of private sector homes have some of the worst EPC ratings of all homes in the UK; they are known as houses of multiple occupancy, or HMOs (*The cold man of europe,* 2015). With the expansion of the University of Worcester in recent years, the higher education institution needed to expand housing for all years of students; this resulted in HMOs being used for first year housing. However, students have expressed uncomfortable living situations in these HMOs, which lead to the university intervening.

In order to help improve this, the University of Worcester has given initiative to a new project to increase sustainability in homes in the city of Worcester, called Energize Worcester. It started in 2013 and focused on recycling, along with saving energy in general. Over the past few years, it has developed into a project that mainly aims at heating usage in homes; the University of Worcester has narrowed the focus of Energize Worcester to student HMOs.

Energize Worcester has been working with local students and landlords to improve living conditions and reduce energy use in student-rented HMOs. In past projects, data was collected about student homes and their attitudes about heating; most recently, the students were surveyed on their attitudes towards smart heating devices. As a result of this, smart heating controls were installed in five HMOs over the summer of 2017. Energize Worcester collaborated with Worcester-Bosch to install more efficient, 'Wave' smart heating boilers in these homes.

The goal of our project was to identify how students perceive their heating habits compared to actual behavioral data gathered from Worcester-Bosch smart heating loggers. In order to complete this goal, we carried out the following objectives:

- Collected data on tenants' perception of their energy use habits
- Gathered behavioral data from the Wave heating systems
- Analyzed and compared the two datasets
- Identified possible points of intervention that will require future research

Methodology

We drew the population of our study from students living in the HMOs around the St. John's University of Worcester campus. More specifically, the population was the students from the five HMOs with Wave smart heating controls installed. Each house contained three or four tenants, making our overall population 19 students.

We decided that the best way to understand how students perceive their heating habits is to directly talk to them in person, so interviews is the approach we took. We broke up into pairs, and went to each house, interviewing each student that accepted in a two-on-one fashion. Each interview took about 15 minutes. The question set that we used was a mix of questions from previous groups, some of our own, and questions that relate directly to the Worcester-Bosch Wave heating system.

In order to obtain the actual heating behavior of the same students, we retrieved the Wave system's data from each home. This data shows important metrics such as the amount of power used by the boiler, and at what times the actual heat turns on throughout a span of time. After data collection, we compared metrics between the interview results dataset and the Wave data logger set. Although only a few factors could be directly compared between the two pieces of data, other conclusions were drawn from qualitative data as well as the Wave quantitative data.

Findings

We were able to draw the following conclusions based on our findings.

1. **The split incentive plays a large role in saving energy:** In one of the HMOs that we collected data from, the tenants pay for utilities separately from the rent each month. This

was the only house where the tenants actually seemed like they were consciously trying to use less heat, and two out of the three tenants use the Wave system a decent amount. When comparing what they said to the actual data logger files, the tenants were telling the truth. This one house had much less overall energy use due to heat per day than any of the other HMOs.

2. **The education level of smart heating is low; motivation to learn is also low:** As a part of our interview questions, we asked specific questions about the level each tenant believed they understood the Wave system. About 69% of the students believed they knew the system decently well, but then did not know the answers to most other Wave questions that followed. In addition to that, we asked if the students were interested in learning more about managing their energy expenditure, and almost 70% of them said they did not want any more information. The motivation to learn the smart heating system is severely low.

3. **Students do not seem to be using the Wave system:** Our interview results showed that students change the thermostat temperature less than once a day and less than once a week. This was also the same for the background programme of the Wave thermostat; it was changed less than once per day and per week. In addition, from the data logger files, it seems that the temperature is generally set to the same thing all of the time, leading us to believe the system is set once and not touched afterwards very much.

4. **External factors play a larger role than anticipated:** Based on the two datasets that we obtained and compared, we realized that we do not have enough information to draw conclusions; our dataset is incomplete. There seem to be random days that follow a similar trend, but then there are days where the heating usage is completely different. For example, we measured two different consecutive days in November where the weather and outside temperature was almost identical. We noticed that the heat was used less on the colder day, and was running the whole time on the warmer day. This could be due to students opening windows with the heat on, therefore making it run for a longer time.

5. **It is difficult to understand whether the problem is technical, behavioral, or both:** Building off of the previous finding, on days where it seems that the heating is used more than it should be, there are many factors that could be the source of this. These reasons could consist of behavioral issues, or technical issues. Some behavioral issues that may

exist in tenants are habits such as leaving doors/windows open, or turning up the thermostat to a high temperature and forgetting about it. On the technical side, some of the heating usage could be higher than anticipated due to the physical aspects of the HMO. For instance, if the windows are single glazed, they will lose more heat than double glazed.

Recommendations

There are many different ways that this project may be continued. Some ways include using a similar approach to ours, and others are alternative ways to measure different pieces of potentially useful data.

1. **Expand the Wave sample size:** One of the ways to gain a better understanding of how students use the Wave system specifically is to increase the sample size. This may not be possible due to funding reasons, but the installation of more Worcester-Bosch boilers in more HMOs could show other findings that we could not reach with such a small sample size.

2. **Equip data loggers to traditional heating systems:** Another possible way to gain a different supplementary dataset could be to install data loggers on older Worcester-Bosch boilers. This would bring in a new dataset for comparison to smart heating loggers, and could potentially show interesting results between the two different groups of tenants.

3. **Analyze homes with other smart heaters:** Similar to the other recommendations but including a slightly different population, future groups could look into HMOs in the area with different types of smart heating systems. For example, Nest is a competing type of smart heating thermostat that could be compared with the Wave thermostat. There may be ways to compare the two datasets to see if the type of smart heating is factor or not.

4. **Increase the use of the Wave system:** Finding a way to get students to use the Wave system is another avenue that this project can be taken. Since the technology is so new right now to the students, educational sessions could be conducted to show the tenants how they can use the Wave app and other features of the system to be more efficient.

5. **Continue old Energize Worcester projects:** Continuing in the same direction as previous Energize Worcester projects would help to maintain the ongoing research efforts started by these prior project teams. By returning to the unmodified questionnaire and

conducting bulk interviews on various HMOs, the future project teams would contribute to the existing database of survey responses.

6. **Address the points of interventions that our project suggests:** Using what we have found in this study can be good for groundwork for a new study. Finding what exactly causes the inconsistent usage of the Wave system would be useful for the future of Energize Worcester. If there was an answer to why the heat is used so inefficiently one day and not the next day, more concrete conclusions could be drawn, which could lead to a final answer to how to increase HMO heating efficiency.

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1. Introduction

Sustainability, in relation to energy and thermal efficiency, has been a topic of concern for the United Kingdom since the early 2000s. Physical limitations of buildings are a major factor that contribute to wasted energy; many antiquated housing structures suffer from inefficient heating methods and significant heat loss from poor insulation. This is particularly pertinent in the United Kingdom, where the "properties are among the least thermally efficient in Western Europe" (*The cold man of europe,* 2015). The majority of private sector homes, such as houses of multiple occupation, or HMOs, have some of the worst EPC ratings of all homes in the UK (*The cold man of europe,* 2015). With the expansion of the University of Worcester in recent years, the higher education institution needed to expand housing for all years of students; this resulted in HMOs being used for first year housing.

One of the main concerns with students living in HMOs pertains to how inefficient they are. From the physical aspect, the EPC ratings are low, but the behavioral aspects of tenants can significantly increase the amount of energy a property wastes as well. For instance, in student housing where there are many tenants, bad heating habits are commonplace. Many students are uneducated about their heating systems, do not care about how often the heat is on, have no motivation to try to change their ways, or have a combination of the three (White et al, 2017). Between the physical limitations of HMOs and the tenants living in them, these homes can be exceptionally wasteful.

As an effort to try to understand why student-rented HMOs are so inefficient, a project called Energize Worcester was created at the University of Worcester. It focuses on the research of off campus student home heating efficiency, and possible ways to intervene. This initiative targets students living in HMOs that surround the St. John's Campus of the university. The program started in 2013, and was originally based around recycling and saving energy in a broader sense. Within the past few years, the aim of Energize Worcester gradually changed to better address the sustainability needs of the Worcester community; the focus shifted to heating usage and how to save energy in relation to thermal efficiency.

In the past, previous Energize Worcester projects have collected data on students' behavior, landlords' behavior, and the housing that students live in. These projects concluded that while improvements to the buildings are likely needed to make them energy efficient, the deeper underlying problem is actually rooted in behavioral factors. Many tenants do not understand how to use their heating systems, do not wish to change their poor energy consumption habits, or simply do not feel motivated to improve energy efficiency, while many landlords do not wish to spend the money to improve their properties (White et al, 2017). The goals of the landlord and tenant are perpetually differing as well, due to a phenomenon referred to as the split incentive dynamic. This is defined as the party who is paying for utilities is the only one with any kind of incentive to improve efficiency (White et al, 2017). In situations where the landlord includes utilities in the rent price, students are careless about their energy use, since they are not facing any consequences in doing so. This situation becomes further complicated by the fact that there is little to no communication between landlords and tenants (White et al, 2017).

Worcester, UK apartments waste a lot of energy due to poor choices made by tenants. As previous research shows, tenants have wasteful habits and consume vast amounts of energy while largely misusing their heating systems (White et al, 2017). Landlords are much more knowledgeable of energy consumption, thermostatic controls, and utility costs, than their student tenants. The spring 2017 team concluded that students are particularly uneducated on thermostatic controls (White et al, 2017). Most of the heating systems in these homes are outdated; many landlords are starting to retrofit their properties with more efficient systems. In late spring of 2017, Energize Worcester partnered with Worcester-Bosch to implement newer heating systems in a select group of student homes. This resulted in the installation of Worcester-Bosch's award winning smart boilers in five student HMOs. Our group is the first to have access to these new smart 'Wave' heating systems.

The purpose of this project was to identify key factors that affect efficient energy use in these homes. The first step was to understand how students perceive their heating habits in HMOs with smart heating controls. Once the perceived behavior data was collected, the next step was to gather actual behavioural data from the Worcester-Bosch 'Wave' smart heating data loggers. With these two different types of data, we compared students' perceptions of their

energy efficiency to the data that showed their actual heating habits, and identified possible points of intervention.

        This report unfolds as follows. In the next chapter, the Literature Review provides useful background information which frames our research and demonstrates the conditions that made our project necessary. The Methodology explains how we actually conducted our research project. Following this, the Findings chapter highlights the key pieces of data we collected by applying our methodology, and explains what implications these pieces of data have on our research. Lastly, the Conclusion chapter describes the key takeaways from the findings, and from those, recommends potential directions to take future Energize Worcester projects.

2. Literature Review

In this section, we discuss sustainability in the UK, Energize Worcester, tenant behaviour, traditional as well as smart heating systems, and policies for more efficient usage of heating technology. We first explain the United Kingdom's increase in energy consumption as well as its perspective towards sustainability. We then detail the history of Energize Worcester and examine the social and behavioural problems that led to its creation. We later focus on the current heating technologies and the student's behaviors and habits towards it. In addition, we discuss the landlord's outlook on the issue of inefficient heating, and how they are trying to implement smart heating technologies with Worcester-Bosch to settle this problem. Finally, we state possible methods and policies put in place to support efficient heating habits.

2.1 Energy Consumption in the United Kingdom

Energy consumption in the United Kingdom has been a major problem in the previous decades due to high consumption of oil and due to CO_2 emissions. As of 2016, the TPES (Total world Primary Energy Supply) was estimated to be equivalent to over 13 Billion tonnes of oil, and has more than doubled since the 1970s. The UK specifically produced approximately 200.9 mtoe (million tonnes of oil equivalent) worth of oil, natural gas and coal combined (Cuce & Riffat, 2016). With that said, the UK has seen a decrease in production of most of its fossil fuels over past decades: coal production has fallen 80% since 1973, oil production fell 30% since 1999, and the entire energy production of the UK has fallen by over 11% since 2000 (Cuce & Riffat, 2016). Up until 2011, energy consumption from gas had been increasing until its peak of 48%. After this all time high, it has slowly been decreasing due to higher gas prices (United Kingdom Government, 2015). Overall, the United Kingdom's energy consumption has been decreasing in the past few years, and the nation is actively monitoring and seeking ways to continue this trend.

2.2 United Kingdom Sustainability Initiatives

The United Kingdom's energy consumption has decreased over time because of the sustainability measures that have been put in place within the last decade; the government in the

UK has been considering going "green" for about 6 years. (Carrington, 2011). This initiative started with a report on the government's plan for sustainability, stating that the UK will try to put the green incentive in the center of the country's lifestyle (Department for Environment, 2011). This report even went as far as to say that it will start drastically changing people's lives instantaneously.

Aside from the ambitious goals from the report, the United Kingdom has actually made significant progress with becoming "greener". Between the years 2000 and 2015, renewable energy has increased by a factor of 8 (United Kingdom Government, 2015). In addition to that, as of mid-2017, renewable energy has made up 29.8% of total nation's energy (United Kingdom Government, 2015). Some of these new energies include offshore wind, solar PV, landfill gas, and many other bioenergies.

2.2.1 Behaviour Change in the United Kingdom

In order to push towards a more sustainable lifestyle, the United Kingdom has introduced campaigns intended to help change human behavior for the better. One of these campaigns, called the "Green Deal", was launched in autumn of 2012 and is "intended to help householders to revolutionise the energy efficiency of British properties" (Bichard & Thurairajah, 2013). It was created so that delivery partners will need to implement a strategy that makes residents want to accept the Green Deal offer. Once this offer is accepted, the program is intended to be a method to motivate and educate residents on their energy use habits, and persuade them to understand and act upon them (Bichard & Thurairajah, 2013).

Another program aimed at behaviour change is called "Resilient Homes". This program took a slightly different approach by using neighborhoods as their population. The method was used in a neighborhood near Manchester as a trial test. During this trial, the first phase of the report concluded that a non-cash based incentive program could work for attitude change (Bichard & Thurairajah, 2013).

2.2.2 Sustainability Measures at HEIs

Many HEIs in the United Kingdom have been working towards more sustainable practices as well. The University of Oxford has been focusing on more sustainable travel arrangements for students, including improved bicycle paths, electric student vans, and

encouraging more simple bus travel. For instance, in 2016, the university started implementing the first electric Oxon Bikes in the city's bike share system. It was also reported that "...74% of staff and students travel using a sustainable mode of transport" (University of Oxford, 2017). Aside from travel, the university has lowered their carbon intensity by 23% since 2005, installed their 1000th solar photovoltaic panel in 2016, and saved £50,000 through the university's reuse program, WARPit (University of Oxford, 2017). Many other HEIs in the United Kingdom have implemented sustainable practices on their campuses as well. One of which being the University of Worcester.

2.3 University of Worcester Sustainability Efforts

The University of Worcester focuses on promoting principles of sustainability in a few different ways; they teach students, conduct research to find innovative new ways to be more efficient, and have various activities/campaigns that the university has pioneered (The University of Worcester, 2016b). In addition, the University of Worcester has been ranked 5th out of 150 UK universities for being green in the 2016 People & Planet University League. Some of the factors that helped the university achieve this ranking pertain to biodiversity on campus and education on sustainability. Many other organizations such as Higher Education Academy Green Academy, FairTrade, and Green Gown have recognized the university for their impeccable efforts towards a green EcoCampus Platinum status (The University of Worcester, 2016).

Annually, the University of Worcester produces a sustainability report which outlines every activity and their general performance from the past year. According to the report from 2015, more and more students are joining in on the initiative to be greener; the National Union of Students leads a campaign to change the behavior of students in order to save energy in student residence halls. From 2014 to the beginning of 2016, the energy use in the student resident halls decreased by 10% from the previous two years -- a whopping 49,745 kWh. This is the equivalent of £4,975 and 27 tons of CO_2 (University of Worcester, 2016).

Carbon emissions are another big part of the annual sustainability report; The University Board keeps a close eye on finding new ways to reduce the carbon footprint, and actively updates its Carbon Management Strategy. Despite the initiatives made to reduce the carbon levels, the report states that gas emissions had increased by 11% from 2014 to 2015. On the other hand, electricity emissions decreased by 9% in the same time frame. Overall, when comparing

the levels from 2015 to those of their baseline levels from 2008, emissions have been reduced by 32% (*Change Today, Protect Tomorrow,* 2016). Although some years waver and different levels rise again, this carbon management strategy is just another factor that shows the University of Worcester is seriously devoted to a greener, better campus.

2.4 Energize Worcester

Energize Worcester was founded by the University of Worcester and driven by students as an initiative to increase the thermal efficiency of student rented houses. It was originally a program within the University of Worcester by the name of "Student Switch Off." This program started off with recycling and saving energy in a broader scale. The University took this program, reworked and built off of it in order to create Energize Worcester (Frick et al, 2014). Energize Worcester focused on student behavior toward reducing energy consumption in their homes. The EW teams found that students primarily waste heating energy, and tried to figure out ways for students to reduce their wasteful habits. As Energize Worcester evolved, its focus has shifted towards not only the students, but now also the HMOs in which they live. To accomplish this, the initiative needed further funding, which they received from the National Union of Students (NUS). Specifically, this funding came from the NUS's Student Green Fund, which allowed Energize Worcester to continue its work in bettering the thermal efficiency of Worcester's outdated homes (Frick et al, 2014).

Energize Worcester's direction has been frequently improving in order to make the greatest impact on the people who live in Worcester, as well as the environment. By collaborating with additional stakeholder Worcester-Bosch, Energize Worcester was able to renovate numerous HMOs with newer technology to be more thermally efficient. This improvement was the installation of smart heater technology, which brought the entire home into a more modern era (White et al, 2017). These pieces of technology, when utilized, allow the students and landlords to see the usage of energy and track it in order to make themselves more efficient (Worcester, bosch, 2014). Energize Worcester is still evolving as a project in order to accomplish its goals of sustainability and cost effectiveness.

2.5 Past Energize Worcester Findings

The work done by previous Energize Worcester groups has identified a number of factors that can influence how students use their heating. Financial factors, students' motivation and education levels, and students' relationships with their landlords were the most predominant factors identified.

2.5.1 Financial Factors

Students seem to be even less educated on their heating bills because utilities are included in their rent (White et al, 2017). The University of Worcester pays landlords a fixed amount weekly to cover energy charges of students and does not pay more than this amount. The survey also showed that 61.5% of students that responded had a ceiling charge for their utility bills, but none of the students have ever hit it (White et al, 2017).

A circumstance that commonly arises in these type of HMOs is "split incentive". This issue can be described as either the landlord or the tenants lacking a financial incentive to have optimal energy efficiency in their homes (White et al, 2017). In this scenario, the party who is responsible for the cost of utilities is more likely to implement solutions to improve energy efficiency, because it benefits them financially to do so. In the case where tenants have to pay proportionally to the amount of energy they use, the tenants tend to develop energy saving behaviors, whereas if the landlords are the ones paying the utility bills they are likely to invest in energy saving building improvements (Braconnier et al, 2016). However if the financial incentive is not sufficient people generally will not be motivated to address this issue without some sort of additional incentive. This lack of motivation to save energy is clearly demonstrated in the survey results of the 2017 Energize Worcester project (White et al, 2017).

2.5.2 Motivation & Education

Many students in the area that are living in these HMOs may want to try and be more sustainable, but do not have the motivation to do so. According to a past Energize Worcester IQP project, an in-home survey was conducted to find out how motivated students were to reducing their energy consumption and decrease environmental impact. The group surveyed 39 students, and "...51.3% did not make any conscious attempts to reduce energy consumption in their homes

since they began the tenancy" (White et al, 2017). Of the same 39 students, 38.5% of them rarely or never turn down their heat in there HMO even if they leave the property for a few days.

One of the metrics the survey measured was whether students believed they, personally, needed more education on the subject of energy management; only 51.3% responded firmly that they did. However, when students were asked whether they thought their flat mates needed this help, 66.6% responded that they did (White et al, 2017). This statistic directly correlates with the study done with students in the Unite Group Plc; students blamed their wasteful habits on their fellow tenants (Chaplin & Wyton, 2014).

Aside from the students, the landlords do not seem to have motivation either. Based on the results from the Private Landlord Survey of over 1000 interviews, landlords in the private rented sector are the least engaged when it comes to sustainability issues. The study showed that "38% of private landlords do not have an Energy Performance Certificate for their property and do not plan to get one. Of the landlords that do have one, 70% do not plan to make any changes to their property as a result" (Hope & Booth, 2014). The landlords will not directly benefit from home improvements, so there is no motivation to do them (Hope & Booth, 2014).

2.5.3 Relationship Between Landlords and Students

The University of Worcester went through a period of time where it needed more housing for students, which resulted in the university turning to HMOs owned by local landlords. Due to this factor, the students would communicate with the school rather than with the landlord directly, which created a relationship gap. The previous Energize Worcester project concluded that a large percentage of students had little to no communication with their landlords. This is a particularly significant issue because the majority of students surveyed were not confident about how they were supposed to use their heating systems due to a lack of information from the landlords (White et al, 2017).

2.6 Houses of Multiple Occupancy

The houses that are the focus of Energize Worcester are HMOs surrounding St. John's Campus. The official definition of a HMO according to the Worcester City Council is a 'House in Multiple Occupation'. To delve even deeper, it states that HMO is "...a housing classification, for a house (or flat) with 3 or more tenants, forming 2 or more households" (The Strategy and

Private Sector Housing Team, 2015). Houses of multiple occupancy must follow energy regulation requirements that are set by the United Kingdom's government. As of April 1, 2018, all properties in the private rented sector will need to have a minimum energy performance rating of E on an Energy Performance Certificate (EPC) (Residential Landlords Association, 2017). Privately rented homes, such as homes in this sector, are the worst performing tenure type; only 8% receiving a rating between A to C (Hope & Booth, 2014).

Students who attend the University of Worcester are avid pursuers of these HMOs. A few years ago, the growth of the university caused it to start leasing HMOs in order to accommodate first year students with housing (The University of Worcester, 2016a). The University of Worcester explains the choices to students for living off campus; it states what to look for in terms of safety, explains how students can rent from landlords, and what their agreements entail (University of Worcester, 2009). Since a growing number of first year students are placed in HMOs each year, it has become a topic of concern to increase energy efficiency in them.

2.7 Smart Heating Controls

Within the last five years, the concept of a "smart home" has formed. These types of homes consist of smart thermostats, smart boilers, multi-zonal heating support, smart learning, and much more. These smart homes are mostly software based, controlling most aspects of the home, for example, door locks, lights, cameras, and heating/cooling systems in each area of the house, through a smartphone.

Worcester-Bosch has been actively trying to help this efficient heating wave by installing their award winning Greenstar boilers in student homes (Worcester, bosch, 2014). Their plan is to install central heating systems that warm the whole building while returning the heat to the boiler instead of letting it go to waste. Worcester-Bosch is minimising the impact on the environment by installing these high efficiency products that will significantly cut each building's CO_2 emissions. In addition, Worcester-Bosch claims that their award winning boiler technology heats homes with maximum efficiency, having optimum savings in fuel costs (Worcester, bosch, 2014). Worcester-Bosch installed their smart heating technology during the summer of 2017 in five student HMOs. The students in these buildings haven't experienced a winter with these smart heaters yet, so there has not yet been any research done to study their behaviours using the smart heating controls.

The Worcester Wave smart heaters installed by Worcester-Bosch come equipped sensors to continually monitor multiple usage statistics for the heating systems. The metrics which the Worcester Wave can use include: primary temperature within the boiler, target temperature set, boiler power use, when the central heating is active, plus many others. In addition to that, reports can be downloaded from these smart heater's data loggers which detail these factors as they change over time. This data can be shown in CSV files, or graphically (Worcester, bosch, 2014). Several analysis methods, such as pattern recognition, could be applied to this data to potentially provide a very rich understanding student's actual heating habits.

2.8 Conclusion

The University of Worcester is working to be as green and sustainable as possible in every aspects of their students' daily lives. From these efforts, the university is well above the national average for energy efficiency. To continue this high level of sustainability, the university has a direct interest in the living situations of the students. The students are either not as concerned with their own energy efficiency or don't understand what they could to improve on this matter. Both the university and landlords are working to give the students the tools to become more efficient over their heating. These tools, the Worcester-Bosch Wave smart heaters, give the landlords and students the ability to adjust the heating remotely and allows them to easily track the energy usage of the home. This smart heating technology is believed to bridge the gap between efficiency and comfort, assisting students to be able to use their home heating more effectively. Using this technology to easily review the heating habits of the students, we can find the inefficiencies throughout their daily habits. For this reason, our goal is to produce a methodology that assists Energize Worcester in identifying how students perceive their heating habits comparing actual behavioral data gathered from Worcester-Bosch smart heating loggers.

3. Methodology

We identified ways to improve student use of heating systems efficiently in HMOs by analyzing the student's perceptions of their own heating habits and comparing those perceptions against actual behavior gathered from smart heating data loggers. The students' perceptions of their own heating usage helped us to identify the students' overall motivation towards maintaining an energy efficient home while away at university. We gathered students' perceived energy usage from the residents of five separate HMOs that have each been outfitted with Worcester-Bosch Wave smart heating systems. We gathered this data by individually interviewing each occupant of these five HMOs. After we completed every interview that the students consented to doing with us, we remotely retrieved the data from their smart heaters with the help of Worcester-Bosch engineers. Analyzing these two datasets showed how efficient the students actually are versus their perceptions. In order to carry out this process, we completed the following objectives:

- Collect data on tenants' perception of their energy use habits
- Gather behavioral data from the Wave heating systems
- Analyze and compare the two datasets
- Identify possible points of intervention that will require future research

3.1 Population

This project focused on students that live in privately rented HMOs around the University of Worcester's St. John's Campus. The entire study focused solely on HMOs that have had Worcester-Bosch smart heaters implemented during the summer of 2017. Of the five rented homes that we studied, there were between three and four students in each one, with a total of nineteen students overall.

3.2 Interviews

In order to initiate the interviews, we walked up to each HMO in pairs and asked each resident if they would take part in a fifteen minute interview in order to study the behaviours and perceptions of their heating habits. If they accepted, we first asked them to sign a consent form

stating that they were comfortable with us interviewing them about their heating habits. Then, we asked them a list of questions using the BOS questionnaire software. These questions were selected from a combination of the spring 17' IQP's questions, and new questions specific to the Wave heating system.

The questions used were devised with the help of the University of Worcester in order to maintain their interests and the integrity of the data that they have already accumulated. We asked questions on when they use their smart boilers, if they know how to use the smart boilers, and how conscious they are on using/wasting energy with their boilers. Each interview was done with two members of our group speaking to a single resident at a time. Having two of us there ensured the safety of the interview, and by keeping the other residents out of the room while conducting interviews, it maintained the independence of the answers. We had one person conduct the interview on their phone, which was logged into the BOS system with the survey open. We submitted the data to conclude the interviews and thanked the students for their participation before we left.

3.3 Worcester-Bosch Data

With the help of the Worcester-Bosch engineers, we were emailed the data from the Wave smart heaters that were downloaded remotely. The purpose of this dataset was to see the actual heating behaviors of students over a period of time. This data came to us in a numeric and a graphic format, and we separated it into sub-datasets based on each HMO. This data is comprised of many different metrics that relate to how the smart boiler has performed over several weeks. The relevant metrics we looked at are:

- Primary Temperature
- Primary Temperature Setpoint
- Hot Water Outlet Temperature
- Hot Water Temperature Setpoint
- Central Heating Active
- Hot Water Active
- Actual Power

By using a combination of these metrics, we were able to compare certain pieces of the interview responses directly to the data logger files.

3.4 Data Analysis

With the two different datasets, we compared a few common metrics between the interview responses and the data logger results. Specifically, we measured: how often the temperature setpoint is changed over the course of a weekday, as well as over a week, how often the background timing programme is changed over the course of a weekday, as well as over a week, times during a normal weekday when heating is used the most and the least, and the average temperature of the thermostat.

With all of these different measuring metrics, we were able to see how the actual heating behaviors of the students change on a day by day basis as well as how their habits change as the temperature drops in November to December. The data helped show us which days of the week the most energy was used and where possible behavioral changes can be made to be more energy efficient.

To gain a deeper understanding of the actual behavior, we developed a Java program that analyzes the data logger files. More specifically, the program asks for a folder with all of the data files for one HMO. It then reads the excel sheet for each day, and calculates the total energy use for the time period. In addition to that, it graphs the energy use per day with four different line plots (one line for each time of day: morning, afternoon, evening, and night) on the same chart. An example of what the program outputs can be seen in Figure 1.
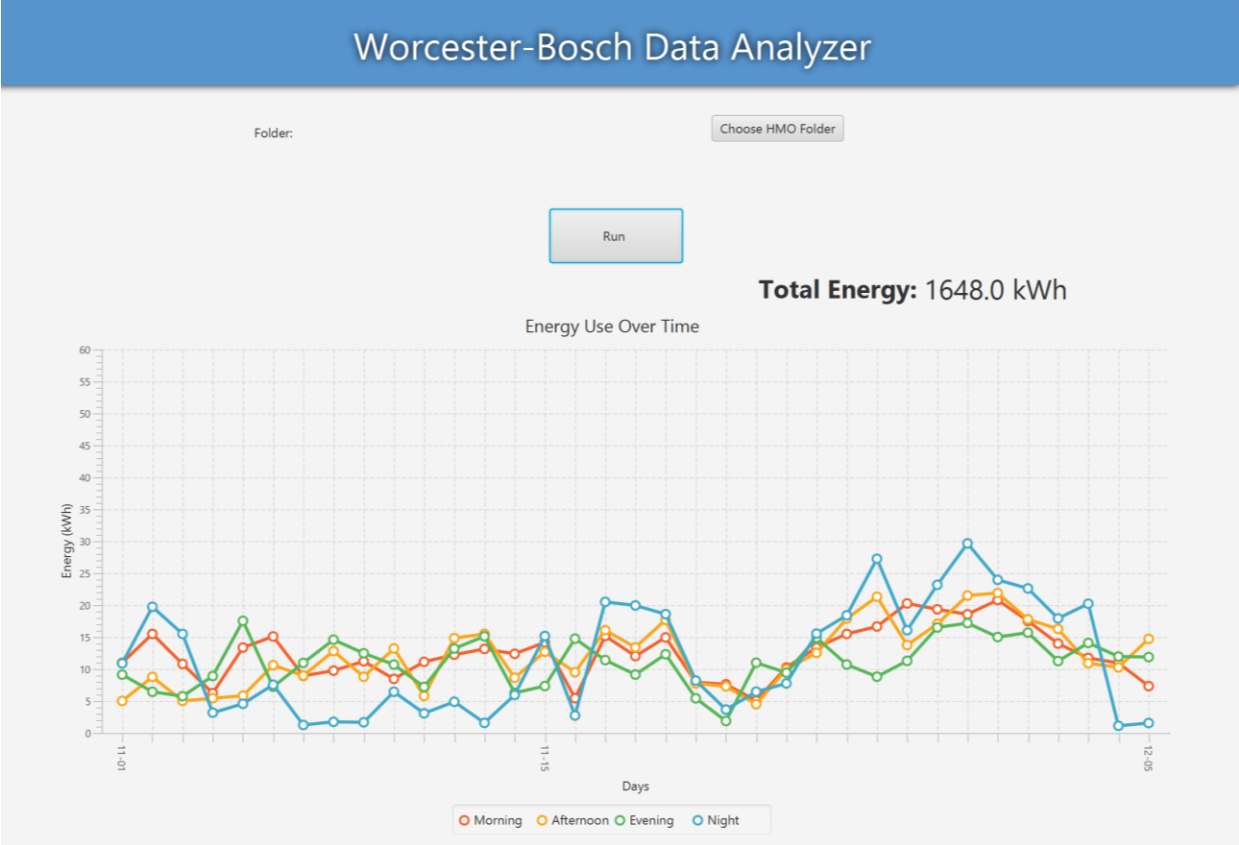
Figure 1: Java program to analyze energy use over time

3.5 Summary

We started our approach by obtaining the addresses of the 5 HMOs with Worcester-Bosch smart heaters, and contacted the students about conducting interviews with them. We then started our perceived data collection phase by going to each house and conducted interviews with every student that agreed to participate; there were 19 students total between the 5 homes. After going to each student's HMOs, we only acquired 14 students' surveys out of the total 19.

After we gathered the students' perceptions of how they use their heat, we met with a Worcester-Bosch engineer to retrieve the data files for the HMOs. We decided on which metrics were needed with him, and he sent us the files so that we could analyze the trends.

The final phase was to analyze the two different datasets and compare the set of metrics to see if the students were actually doing what they believe they were. Once we compared all of the data house by house, we identified areas where students can improve their behavior to increase heating efficiency.

4. Findings

By collecting data on the perceived behavior of students using interview methods, we were able to compare and contrast this information to the actual heating behaviors of the smart heating data loggers. After finding correlations to these datasets, we extrapolated our conclusions and recommendations for the following Energize Worcester teams.

4.1 Perceived Behavior

When it comes to student interviews, we ended up with two primary areas of information: the students' understanding and opinions of the smart heating technology, and the students' perceptions of their own household's heating behavior. The former category gave us insight into how generally motivated students are to use the smart heating technology, as well as act in a way which saves energy. The latter category gave us specific information on how students believe they use their heating in a format that was directly compared to the information collected from data loggers.

In terms of student opinions and understanding with regard to the heating system, students tend to be not well informed and have little to no motivation to change. According to the interview results we gathered, it has become apparent that most students simply cannot be bothered to use the system to improve the efficiency of their home's heat use. This is most clearly demonstrated by the fact that 42.9% of respondents do not believe the temperature in their household is adjusted at all during a typical week, and the remaining respondents claim that their households adjust the temperature setting two times or less over the course of a typical week. This implies that any distinct difference in the residents' daily behavior will be the main cause of the boiler working more or less efficiently. Also, from this infrequent use, we concluded that the students do not consciously attempt to use the Wave system to manage their energy use. This conclusion is further solidified by the fact that all but one of the respondents claimed they did not actively use the Wave system to manage their energy use.

The reason for the minimal use of the system could be due to a lack of understanding of the Wave systems features, or simply due to a lack of desire to use these known features. Students appear to feel confident in their knowledge of the Wave system's features, with 78.6% of respondents reporting their understanding of the Wave system to be a 5 or above (on a scale

from 1-10, with 10 being expert on the Wave system). This confidence in their understanding of the system doesn't even stop there, with 71.4% stating that they felt nobody in their flat needed any more information on the use of the Wave system. However, this may not accurately reflect their actual level of understanding, as most students seem to hardly use the system. Of those who do, very few use the most advanced and efficient features. Only 28.6% of students have ever adjusted the background programming, and only 35.7% of students have even used the system to check what the temperature in the house was set to. Even worse, only about 21.4% of students living in these HMOs fitted with smart heaters check if the heat is off when nobody is home.

A total of 57.1% of students claim to have used either the phone app or wall mount to change the temperature at some point, however, only one person that we interviewed has used both. Even though not every student uses the system's features, it is clear that they know that the system can help them with their energy usage. Every single student interviewed said either, "Possibly", "probably", or "yes", when asked if the Wave system would be able to save them energy and live a more efficient lifestyle. It is unclear if students rarely use their heaters because they are confused by the system, or if they simply do not view their heating as something important enough to deal with. Only 28.6% say they actually adjust the temperature when they are uncomfortable, and only 21.4% of respondents have bothered to have any kind of conversation with their flatmates about heating whatsoever. This blatant lack in motivation may be due to the fact that none of the students have ever had to pay a fee for exceeding a heating cap, and only three being responsible for their own energy bill. This lack of responsibility may be a large reason for the lack of interest in heating.

Using a specific set of metrics, many of our findings from the interviews can be quantified and compared to the data from the Wave data loggers. When comparing the perceived and actual heating behavior of the students' households, the following metrics were extracted from the interviews:

1. Average temperature
2. Frequency the thermostat is adjusted (weekly and daily)
3. Frequency the background timer is adjusted (weekly and daily)
4. Times of highest and lowest energy use

Students' expectations for their average temperature setpoints ranged from 17 to 23 degrees Celsius, with most responses being very close to the average 19.9 degrees Celsius. The

data actually backs the students' claims to not actively try to be energy efficient. They tend to not change the thermostat even with the increased access from the smart heaters; this method can most accurately be described as 'setting it and forgetting it'. As a result of this, in the warmer months the heater tends to only be used when the students are home and actively using the water or heat.

However, when the students progressed into the colder months the heater maintained the home at a constant temperature. The boilers tended to be continuously running and only increase in usage the times the residents were home. This difference caused a drastic increase in overall energy usage.

4.2 Actual Behavior

Using data downloaded from the data loggers, we determined that the students are very inconsistent in their daily and weekly lives, making it impossible to determine a trend with only thirty five days of data. The graphs below show multiple metrics that graph different parts of the students' lifestyles. The data that we found the most important to view is the "actual power" metric. This can be seen in the red lines on the graph. The independent variable on this metric is time in seconds across a day while the dependent variable for this metric is measured in kilowatt hours (kWh). Each graph is a snapshot into the energy usage of a single household on a single day.

4.2.1 Daily Behaviour Matters More Than Weather
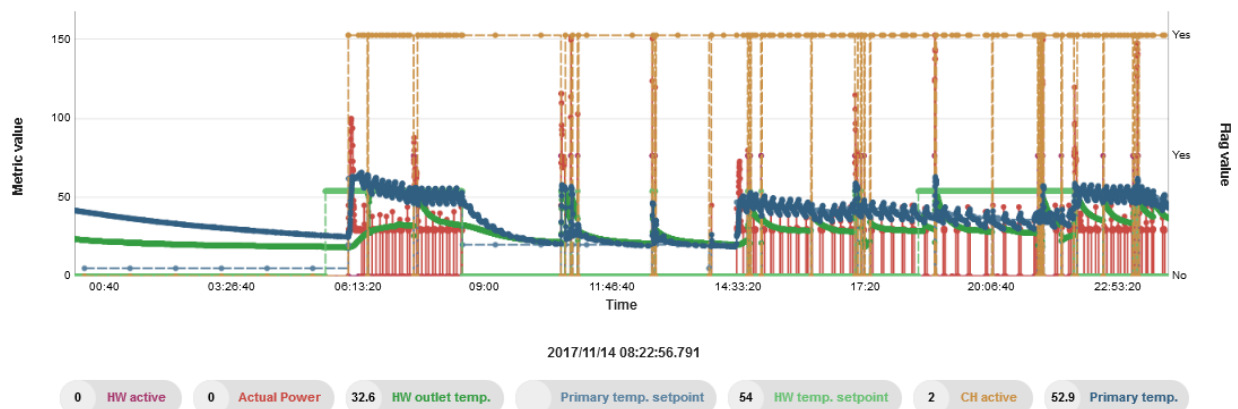
Figure 2: House A on November 14th 2017, Tuesday
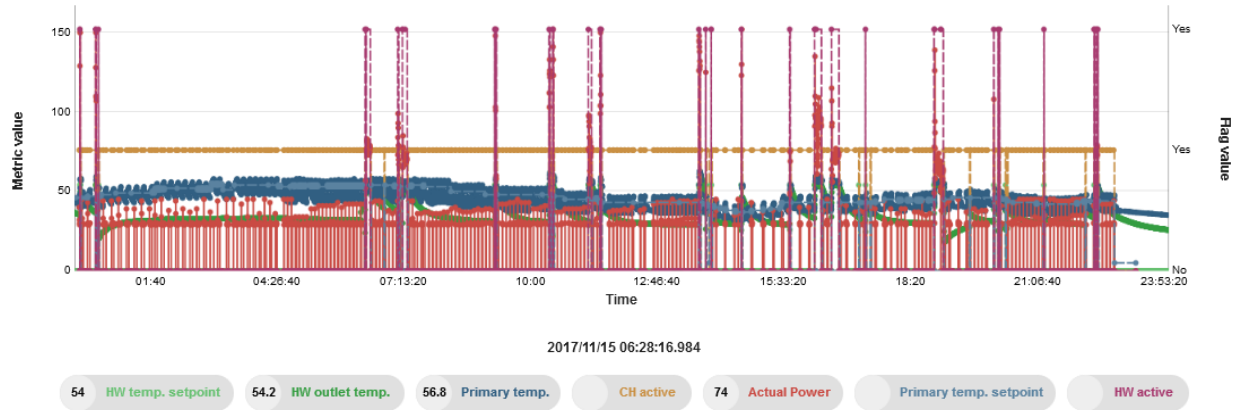
Figure 3: House A on November 15th 2017, Wednesday

These two days of data show the drastic difference in usage of energy throughout the house on a day by day basis. On November 14th, 2017 the temperature as given by Accuweather showed a high of twelve degrees Celsius and a low of five degrees Celsius. Whereas the same weather site showed that on November 15th, 2017 the temperature was a high of twelve degrees Celsius and a low of nine degrees Celsius. The day with the higher average temperature used a staggering amount of energy compared to the colder day prior. These two days show how drastically the heating in an HMO can change. One would first assume that this is due to the weather. However, this is clearly not the reason, because logic dictates that you would need more energy to maintain a temperature on a colder day. So, this leads us to believe that the difference in energy usage from a day-to-day standpoint is more directly associated with the weekly or daily schedule of the tenants rather than the weather itself.

4.2.2 There is No Clear Weekly Schedule

We compared the data on the same days of the week, to see if there would be any heating patterns on the students' weekly schedules. We first thought that students would have similar energy usage patterns during the same days of the week, yet the data shows otherwise. Something as simple as doing their wash or cooking more in a single week caused the data to be wildly inconsistent.
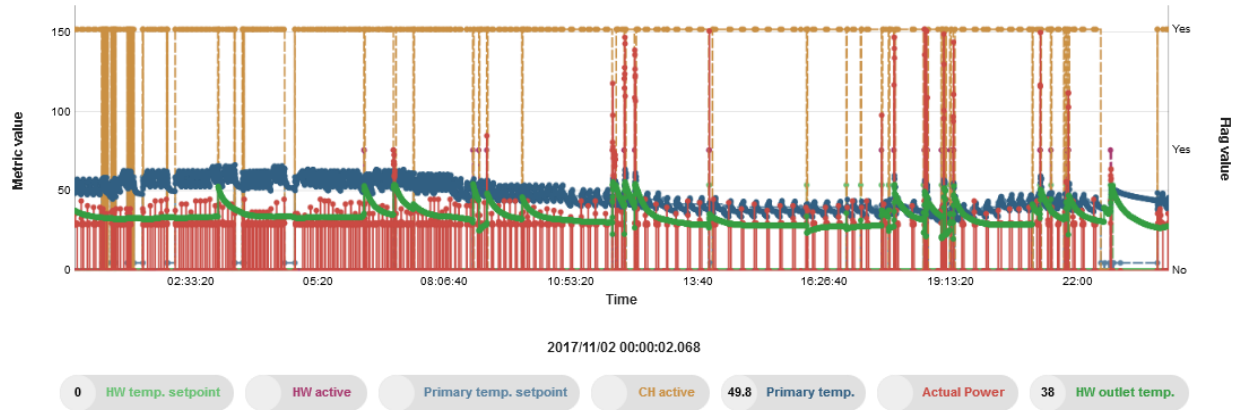
Figure 4: House A on November 2nd 2017, Thursday

Figure 5: House A on November 9th 2017, Thursday

It is impossible for us to tell if these inconsistencies are from external factors or from the genuine habits of the students. Figure 4, November 2nd 2017, a Thursday, the data shows that the majority of energy was used in the morning with a reduction of energy as the day went on. Whereas the very next week's data, November 9th 2017, also a Thursday, the data shows two spikes of energy with the majority of energy used towards the end of the day. These are two graphs of the same day of the week but on different weeks, they should have a similar pattern but clearly do not. Since we cannot measure this data based on the consistency of a single household we are much better off comparing the trends of energy usage between different households.

4.2.3 HMOs With Similar Payment Arrangements Act Similarly

There is a chance that this first house (Figures 1-5) may be an outlier. There is a chance that the residents of house A are just particularly bad with their heating and that the normal

household is more consistent and not as bad with their heating. To check this claim, we compared house A to house B. These are two different HMOs that are owned by two different landlords. One of the few things that relate these two households is that the residents do not have to pay for their own utilities. This means that the water, gas, oil, and electricity are all covered in their rent and the landlord has to deal with the direct costs of their usage.

2017/12/02 00:00

| 56.7 Primary temp. | HW active | Actual Power | Primary temp. setpoint | CH active | 35.3 HW outlet temp. | 0 HW temp. setpoint |
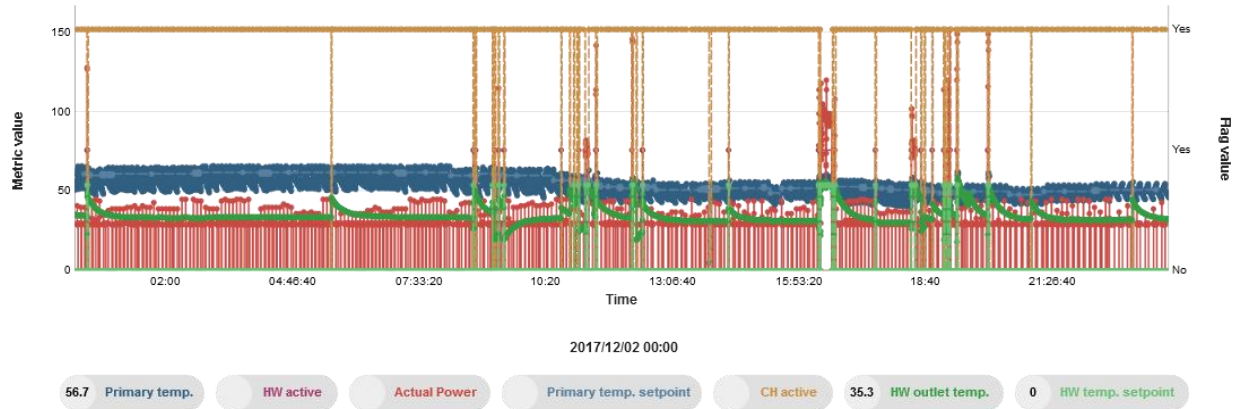
Figure 6: House A on December 2nd 2017, Saturday

2017/12/02 02:14:26.101

| 55 HW temp. setpoint | Primary temp. setpoint | 45.2 Primary temp. | CH active | 38.6 HW outlet temp. |

| Actual Power | HW active |

Figure 7: House B on December 2nd 2017, Saturday

These graphs show very different levels of kilowatt hours on each spike from the power. However the sum total of the power that the heater uses is near identical. However, the graphs are very clear about the consistent energy being imputed into the system. It appears that this consistent input of energy is being used to maintain a constant temperature within the home. So, even with the ability to easily turn off the heater whenever the residents want, they still just allow

it to run and maintain a constant temperature. Simply put, the students do not appear to use the smart heater in any way more than a traditional thermostat.

4.2.4 HMOs With a Financial Incentive Act More Responsibly

What may motivate some of the residents of the HMOs is the money associated with paying their own bills. We interviewed one home that paid their own utility bills and they told us that they are extremely conscious of how much heat they use. We were skeptical at first because most students say that they are more efficient than they actually are. To test what these students told us, we looked at the logger files for their house over the course of the month.
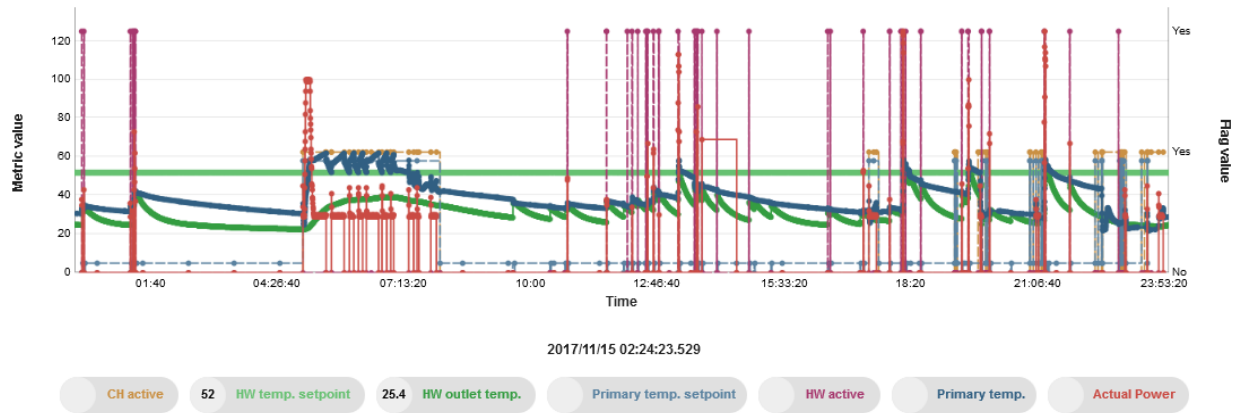
Figure 8: Home C on November 15th, 2017, Wednesday

Figure 9: Home D on November 15th, 2017, Wednesday

We took the same day from above (Section 4.2.1, Figure 3) and compared an HMO with utilities paid by the tenants (Figure 8, Home C), with another HMO that has utilities included (Figure 9, Home D). As Figures 8 and 9 show, the amount of actual power used throughout each

day is much more overall in Home D, the home with utilities paid by the landlord. It is interesting but not surprising that Home C has such low energy use over the course of most days.

In addition to the usage of the single day, we plotted the total usage for each HMO from November 1 to December 5, and calculated the total energy use for the time period. As the two graphs (Figures 10 and 11) show, the total energy use for Home D is three times the amount as Home C.
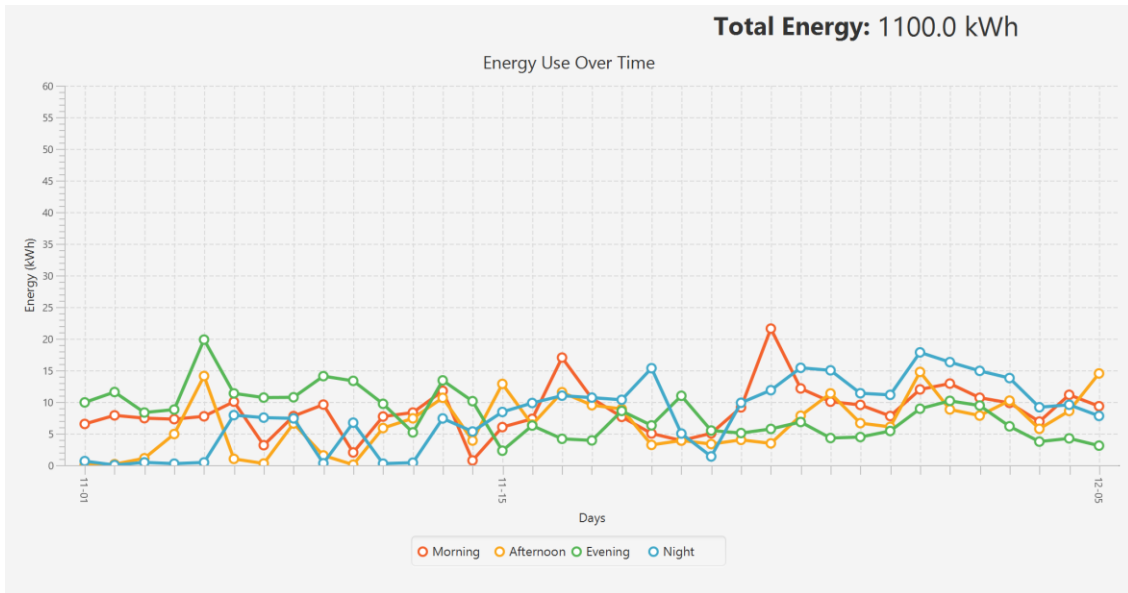
Figure 10: Home C's energy use over time
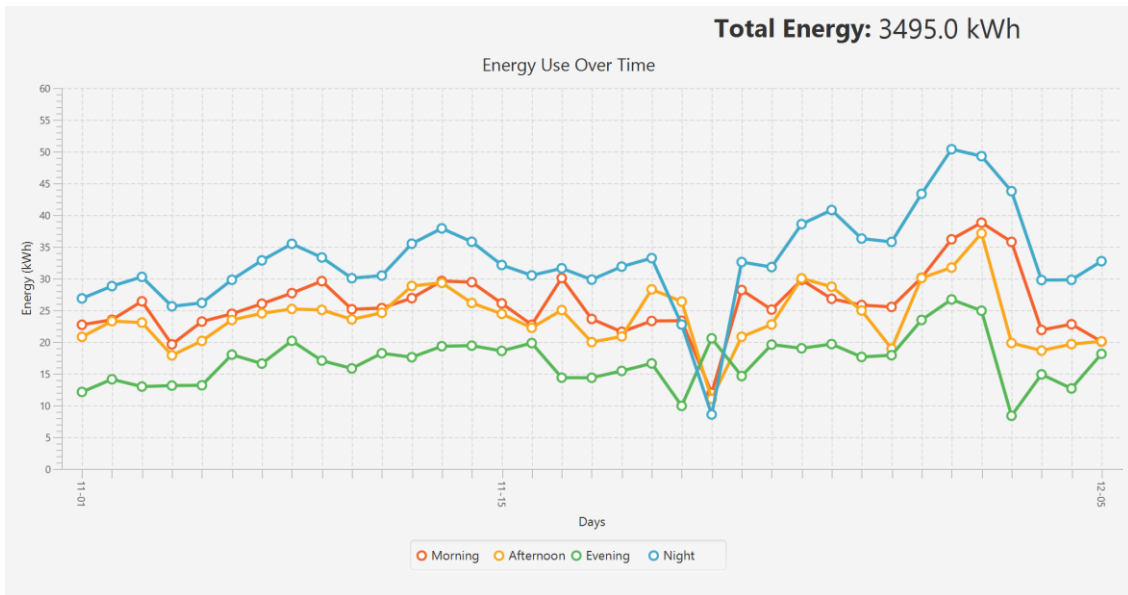
Figure 11: Home D's energy use over time

Due to the fact that the tenants in Home C are paying for their heating, it makes sense that they would be conscious of their behavior. Home C has 3 tenants total, and two of the tenants took control of the Wave system and actively use the app as well as the wall mount to adjust the settings. The third tenant did not know anything about the heat habits or the Wave system; he claimed that his other two tenants took control of it.

4.2.5 Presence of External Factors: Technical, Behavioral, or Both

As mentioned above, we observed the use of the system to vary wildly day by day, and this does not appear to be in correlation to any metric present in our data. When compared to daily temperature data for the month of November, there was no specific use pattern that consistently matched up with the outdoor temperature. Additionally, there was little commonality between the same days of the week, which allows us to infer that the changes in use are not heavily dependent of students' schedules either. The only trend we were able to identify was the lack of any observable trends, from which we must conclude that some external unobserved factors had a significant influence on our data. These external factors could be technical, such as quirks with how the house retains heat, or they could be behavioral, such as students inconsistently leaving windows open. In this qualitative graph of Home B, it's depicted how sporadic the heating energy is being used over time.
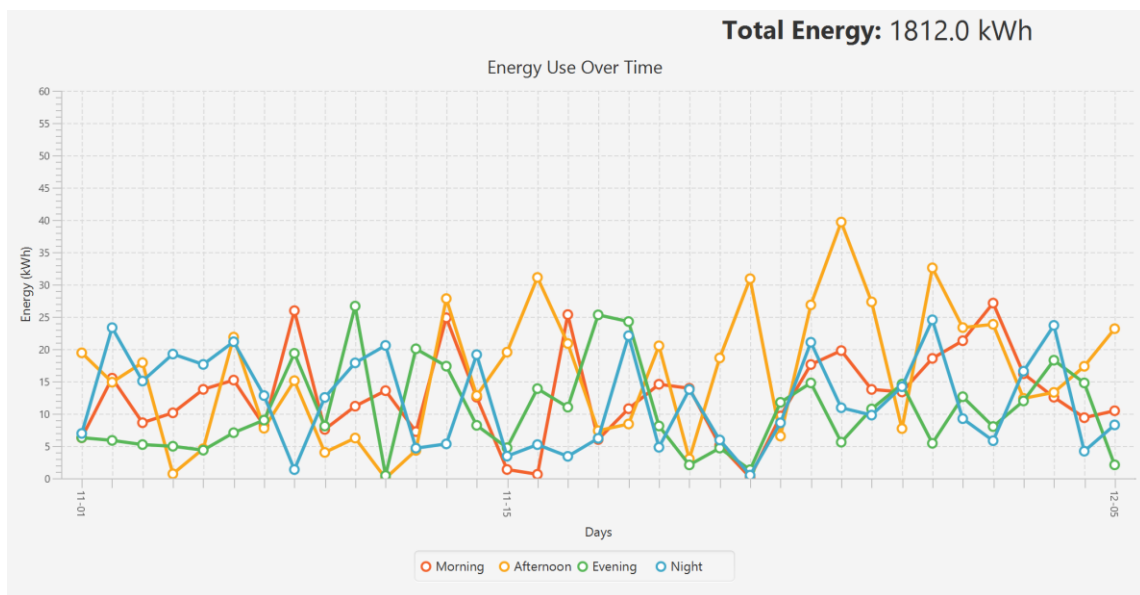
Figure 12: Home B, energy use over time

4.3 Summary

Overall, it seems that there is not a general trend in heating habits between day to day use in the studied HMOs. After studying consecutive days in one week, and then checking those same set of days in the following weeks, we could not find a pattern with the student schedules. We believe this is caused by external factors that cannot be seen by the datasets we obtained.

We found that most students do not use the Wave system to manage their energy, and do not have the motivation to start using it. There is one exception to this though; in the home where the tenants pay for utilities, some of the tenants have taken charge and are motivated to use the heating less. The tenants in the rest of the four HMOs simply do not care enough to learn the system and use it efficiently.

5. Conclusion and Recommendations

5.1 Summary of Key Findings

By analyzing the perceptions and the actual behavior of students over the course of about a month, our team was able to formulate the following key claims:

- The split-incentive plays a large role in saving energy
- The education level of smart heating is low; motivation to learn is also low
- Usage of the Wave system seems to be sporadic
- Unobserved factors play a larger role than anticipated
- The problem can be technical, behavioral, or a mix of both

We found that the perceived behaviors of the students only matched some of the actual behavioral data provided by the Worcester-Bosch smart heating data loggers. Students described in their interviews how they use their heating primarily in the mornings and evenings and not as much during midday or in the nighttime. The smart heating data loggers in the houses recorded similar data to the students' perceptions. However, all of the houses we investigated used the heating all day with no break for the heater. Due to this, we believe that the students are not well educated about their heating systems.

The data we analyzed fluctuated so extensively that is it is difficult to find a consistent trend throughout the 35 days taken in this study. This lack of trend makes it impossible to find a solidified result in student behaviors. It is clear that external factors have to be considered; for instance, if students leave their windows open, take irregular showers, cook irregularly, or infrequently wash their clothes, the data will be skewed. Due to all of these irregularities, we do not specifically know if the problem is behavioral, technical, or both.

Even though all of the students' behaviors were sporadic, we compared the energy usage from student homes that pay for their heating to the student homes that do not. The results showed that students who pay for their utilities use sufficiently less energy and are far more conscious about their heating. If every student was as motivated to save energy as a student that pays for their electricity, then the HMOs would be drastically more efficient.

5.2 Recommendations

The following recommendations pertain to the continuation of our research by applying our methodology to different populations, or using the conclusions from our findings to take future research in new directions. Any of these directions can lead to the development of data that will help Worcester-Bosch gather data on their heaters in real world scenarios and the University of Worcester to gather data on their students.

Going forward, replicating our study on more students living in Wave equipped HMOs would be useful for verifying our results with a more statistically viable sample size. Future EW teams can also find additional datasets for comparison, rather than just comparing the Wave smart heaters' data against the students' perceptions of their own habits. Our recommendation is equipping traditionally heated HMOs with sensors that are able to log the same parameters as the Wave's onboard data loggers. By conducting an experiment with the same methodology on these houses with traditional heaters, it would allow direct comparison of the actual behaviors of students in HMOs with and without smart heaters. This experiment may also be possible on the HMOs with alternative smart heaters installed. Prior EW surveys have revealed several HMOs equipped with smart thermostats such as the Nest. The drawback to this method is that data logging on the same level as the Wave may not be fully or consistently available on these systems.

In terms of moving the research in new directions, future research teams also have several options. Research into what factors resulted in such low use of the Wave system, and how to address them would reveal some very valuable information, and would likely be of great interest to Worcester-Bosch. In addition, future research could try to identify what factors external to our research were the cause for the wildly inconsistent use of energy, in turn revealing which factors can be addressed to effectively reduce student energy use. Another avenue that this project could go down returns to the path of the Energize Worcester IQP in D-term of 2016. This would involve returning to the unmodified questionnaire and conducting bulk interviews in a similar fashion to the prior EW projects.

5.2.1 Expand the Sample Size of HMOs with Wave Systems

Continuing this project's research on more students living Wave-equipped-HMOs is one particular direction future researchers should consider. Using an expanded sample of students would help to verify our findings and provide a more statistically significant dataset for future research groups to draw conclusions from. The sample size of the students in smart homes can potentially be increased through one of two ways. Further donation and outfitting of smart heaters into more HMOs would be the most effective way to bolster the sample size, but it may prove to be prohibitively expensive. Another option is to aggregate yearly data, which will build up the sample over time when new sets of students move into the current set of smart homes.

5.2.2 Equip Traditional Heaters with Data Loggers

Since the data that we received from Worcester-Bosch was very helpful in determining the actual behavior of students that had the Worcester-Bosch smart data loggers. We figured it would be a good idea to attach data loggers to traditional heaters to determine their definite behaviors rather than relying on less accurate student surveys. This would also provide an understanding of how student's perception of their heating habits compares to their actual behavior, specifically for students in HMOs with traditional heating. If the equipped data loggers monitor the same metrics as the Wave data loggers, HMOs with smart and traditional heating can be directly compared using these metrics to observe the effect smart heaters have on student behavior.

5.2.3 Homes with Other Smart Heaters

We recommend surveying other HMOs with smart heaters because it would differentiate the information from just the Worcester-Bosch smart heaters. The only other smart heaters that we know of in the Worcester area is the Nest learning heating systems. These Nest systems have some properties that the Worcester-Bosch systems don't have. This is why our sponsor Katy Boom wanted to gather data from students that live in these Nest HMOs to compare the similarities and differences to the data that we gathered from the Worcester-Bosch HMOs.

5.2.4 Increase Use of Wave System

Our survey data concludes that the majority of the students do not know how to use the wave system. When asking the students how often they used the application for their smartphone, some weren't aware of this feature and were very surprised to learn that it existed. Several other students were aware that the Wave system had additional features, but they were not motivated to look up what they were or learn how to use them. If students could be educated and motivated to use this system effectively, they may be more efficient in using their smart heating system, and have less wasteful energy habits. We recommend educating the students that have smart heating systems in their homes on how to use the Wave System (especially the Wave App) and observing if energy efficiency improves.

5.2.5 Identify External Factors

Our data showed the energy use of students varied greatly day to day. Surprisingly, these changes in use patterns did not appear to be the result of outdoor temperature or the tenants' schedules for any given day of the week. From this, it was concluded that some factor outside of what we were capable of observing strongly influences the students' use of the system in a difficult to predict way. This might be due to technical factors (such as inconsistent heat retention in homes) or behavioral factors (such as students occasionally leaving windows open), but these factors could not be determined from the data at hand. We recommend further research be conducted into what factors could be the cause of this wildly inconsistent heat use.

5.2.6 Continue the Old Energize Worcester Projects

Continuing in the same direction as previous Energize Worcester projects would help to maintain the ongoing research efforts started by these prior project teams. By returning to the unmodified questionnaire and conducting bulk interviews on various HMOs, the future project teams would contribute to the existing database of survey responses. This database has extensive information on the attitudes of Worcester HMO residents as they relate to energy use.

5.3 Conclusion

After further analyzing the perceived behavior of the students and comparing it to the actual behavior, it seems that the students are correct in some cases, but completely inaccurate in other instances. There are many factors that affect the actual behavioral data, which makes it hard to conclude what is exactly causing the problem.

Something as simple as whether they decided to cook one day will throw off the data with such a small sample size. If heat from the oven caused the entire house to warm, the heater would not have to work as hard to maintain the constant temperature of the home. From our end, with the boiler data, it will look like the residents are being more efficient, when in reality it had nothing to do with the boiler and everything to do with the inconsistent actions of the tenants in their small homes.

In conclusion, very specific factors are being put into play when trying to accurately compare the perceived data of the students to the actual information from the smart data loggers. Our data that we acquired from the students was not sufficient enough to depict a conclusion from the data of the smart heating loggers because of all of the external factors stated before; more research must be conducted on this subject.

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Appendix A - Interview Questions

Shown below are the set of interview questions used to gain an understanding of students perceived energy use habits. Most of these questions were adapted from previous energize questionnaire questions and the Worcester Wave questions provided by Carolyn Roberts.

General Instructions

Please utilise this questionnaire as a basis for a discussion, and capture the results of the discussion on a digital recording, in addition to completing all the questions below. Interview respondents separately, not in groups. Reassure the respondent that their identity will be protected, that if they do not wish to answer any or all questions, they are free to do that, but that their assistance would help the researchers to identify key aspects of the influences on people's ability to manage their household energy consumption successfully. Non-participation would have no influence on their university studies, and nor will information be shared with anyone else, including their landlord. The findings of the research may enable participants to be more comfortable in their houses, and to spend less on energy.

DETAILS OF PROPERTY (can be completed mainly by the interviewer)

1. Address
2. Number of bedrooms in property
3. Number of other rooms including kitchen, but not conservatory, bathrooms or hallways
4. Number of storeys, including (part) basement if used as a living area

GENERAL DETAILS ABOUT RESPONDENT

5. Name of respondent
6. Gender male/female/other/prefer not to say
7. Email address of respondent
8. Age of respondent
9. Course being followed by respondent

DETAILS OF HEATING SYSTEM AS UNDERSTOOD AND OPERATED BY THE RESPONDENT

10. Who <u>actually</u> controls the timing and temperature of the heating?
    - i) You, on behalf of the group of tenants
    - ii) another of the tenants on behalf of the group of tenants
    - iii) the landlord
    - iv) some or all of the above
    - v) No one really controls the heating
    - vi) I don't know
11. Does someone regularly or frequently adjust the thermostat (say daily, or several times a week) to alter the set temperature?

12. Has your household made any conscious attempts to reduce its energy consumption in the house since you began the tenancy? Say a little more…..
13. What times, specifically, do you find that your heating is used the most?
14. What times, specifically, do you find that your heating is used the least?
15. In colder months of the year, do you personally find the temperature <u>in your room</u> generally too warm, sufficiently warm, tolerably cold or too cold?
16. In colder months of the year, do you personally find the temperature <u>in common living areas</u> generally too warm, sufficiently warm, tolerably cold or too cold?
17. Have you had discussions amongst your house's tenants about the control of the heating in your house? Say a little more about this…
18. How do you decide what temperature is appropriate in your house? Say a little more about this…
19. What temperature do you find that your thermostat is usually set to?
20. If you personally feel uncomfortably cold in the house, what would your typical response be?
    i)   Turn up the heating
    ii)   Put on more clothing
    iii)   Go to another place to study or relax (bed, library, gym, pub….)
    iv)   Ignore it, and suffer in silence
    v)   Other (please specify)….
21. Do you feel that you or the other tenants need more information or training about managing energy in your house?

DETAILS OF THE TENANCY

22. Does the rental you personally pay include part or all of utility bills, including
    i)   gas
    ii)   electricity
    iii)   other fuels
    iv)   water
    v)   telephone
    vi)   Broadband/WiFi
    vii)   I don't know?
            (tick all that apply)
23. If the rental includes only part of the utility bills, or has a ceiling charge on utility bills (e.g. beyond £10 per month, then the tenants must pay excess charges), explain this….
24. During your tenancy, have you ever paid excess energy charges to the landlord?

WAVE QUESTIONS
25. On a scale 1-10, where 1 is 'not at all', and 10 is 'expert', how well do you think you understand the use of the Wave system?

Answers to questions 27 and 28 should be completed using the matrix below. Please read the questions carefully to ensure that you understand the differences between them. Question 27 refers to the wall mounted element of the Wave, and Question 28 to the phone app.

		Q27 Wall mounted display part of Wave system	**Q28 Using Wave phone app**
i)	Have you personally <u>ever</u> set or changed the background programme of timing and temperature on your heating system? (e.g. the times when the system comes on and off automatically, or the temperatures of the different periods)	Yes/No/Don't know	Yes/No/Don't know
ii)	How many times, typically, have you or other people in your house set or changed the background programme of the heating system in a weekday?		
iii)	How many times, typically, have you or other people in your house set or changed the background programme of the heating system in a week, including the weekend?		
iv)	Have you personally <u>ever</u> adjusted the thermostat controlling the temperature of the house (including switching heating on or off)?	Yes/No/Don't know	Yes/No/Don't know
v)	How many times, typically, have you or other people in your house adjusted the thermostat controlling the temperature of the house (including switching heating on or off) in a weekday?		
vi)	How many times, typically, have you or other people in your house adjusted the thermostat controlling the temperature of the house (including switching heating on or off), in a week including the weekend?		

29. Do you personally ensure that the heating is switched off when there is no one in the house?
   Always/sometimes/occasionally/never
30. Do you or your group of tenants actively use the Wave system to try to manage your energy expenditure? Please say a little more about how you use.
   Yes/no

31. Do you think that the Wave system **is** assisting you to manage your house's energy system? Please say a little more about this.

      Yes/no

32. Do you consult the Wave system for information on actual temperatures in your house? Please say a little more about this.

      Yes/no

33. Would you object to your landlord adjusting the settings on your Wave system, for instance to turn the heating down or off during holidays? Please say a little more about this.

      Yes/slightly/not really/no

34. Have you personally used the Wave to control your hot water heating system? Please say a little more about this.

      Yes/no/not really

35. Do you think that the Wave system is a useful way of reducing energy use in houses with groups of tenants? Please say a little more about this.

      Yes/probably/possibly/unlikely/no

36. Other general observations on the Wave energy management system.

DETAILS OF THE INTERVIEW

- Would the respondent be willing to be interviewed again, in a few month's time?
- Date of interview
- Time of completion of interview
- Would you be willing to participate in a focus group in the next few weeks?

Appendix B - Interview Consent Form

Researchers – Professor Carolyn Roberts, Gresham Professor of Environment; Katy Boom, Director of Sustainability, University of Worcester, Henwick Grove, Worcester WR2 2AJ. k.boom@worc.ac.uk 01905 855243. This study follows the principles of the University of Worcester ethical guidelines, but is being undertaken by Worcester Students' Union.

Information to potential participants of this study

You are being invited to take part in a research study, which will help you to manage your expenditure on domestic energy, and be more comfortable in your rented accommodation. Your participation will also assist the researchers, and help the University to maintain its position is a leader in sustainable practice in the UK. We would be very grateful for your assistance, but before you decide whether to help, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

This research is being undertaken to understand the role of technological innovation (smart boiler controls, other apps) to manage and control domestic heating, by developing new opportunities for energy management. The study involves both young people living in shared rental property, and the landlords of these homes. Pilot work has already been undertaken in 2015 and 2016. This new phase of the study will be conducted in semesters 1 and 2 this academic year, and most work will be complete by June 2017. Participation would not be time consuming for you. Focus group and short interviews, or on-line surveys, often undertaken by other students, will be arranged at convenient times. The research is being undertaken in conjunction with a group of landlords in Worcester, and with Worcester-Bosch, who make boilers and control systems. A small number of student rental properties will also have new boilers and state-of-the art remote control systems installed this winter, which will offer tenants additional controls on comfort and expenditure.

Your participation in this study will help us examine how temperatures are set in houses, what arrangements are considered optimal by groups of tenants, and how responsibility for energy consumption and conservation is shared between occupants and landlords. Information from this research, anonymised, may be used in conference presentations and/or in publicised research papers. *It is up to you to decide whether or not to take part.* If you do decide to take part you will be asked to sign the consent form on the reverse of this information. You would still be free to withdraw at any time and without giving a reason. Choosing either to take part or not take part in the study will have no impact on your housing arrangements or your university studies.

All information collected about you will be kept strictly confidential. The information is not highly sensitive however, data on line will be stored in a password protected UW server, and hard copies kept securely in a locked office. Data will be destroyed after 3 years. A random generated code will be used, quotes will be anonymized.

Thank you for taking the time to read this information, and the questions overleaf.

Please Initial Box

1. I confirm that I have read and understand the information for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.

3. I agree to take part in the above study.

4. I agree to the interview / focus group / consultation being audio recorded

5. I agree to the use of anonymised quotes in publications

_____   _____   _____

Name of Participant   Date   Signature

_____   _____   _____

Researcher   Date   Signature

Appendix C - Data Analyzer Code

**NOTE: All files have to be converted to excel files before being run through the program (CSV→XLS).

Main.java

```java
package WB;

import javafx.application.Application;
import javafx.fxml.FXMLLoader;
import javafx.scene.Parent;
import javafx.scene.Scene;
import javafx.stage.Stage;

public class Main extends Application {

    public static Stage primaryStage;

    @Override
    public void start(Stage stage) throws Exception{
        Parent root = FXMLLoader.load(getClass().getResource("ControlPanel.fxml"));
        stage.setTitle("Worcester-Bosch Data Analyzer");
        stage.setScene(new Scene(root, 1170, 850));
        stage.show();
        primaryStage = stage;
    }

    public static void main(String[] args) {
        launch(args);
    }
}
```

Controller.java

```java
package WB;

import javafx.fxml.FXML;
import javafx.scene.chart.LineChart;
import javafx.scene.chart.XYChart;
import javafx.scene.control.Label;
import javafx.stage.DirectoryChooser;
import org.apache.poi.openxml4j.exceptions.InvalidFormatException;
import org.apache.poi.ss.usermodel.*;

import java.io.*;
import java.util.*;

public class Controller {
    //JavaFX elements
```

```java
    @FXML private Label folderLbl;
    @FXML private LineChart<String, Double> chart;
    @FXML private Label totalPwrLbl;
    private File selectedDirectory;

    //List of workbooks
    private List<Workbook> workbooks = new LinkedList<Workbook>();
    private ArrayList<Row> rows;

    //DataFormatter
    private DataFormatter df = new DataFormatter();

    //TreeMaps for time of day
    TreeMap<String, Double> morning = new TreeMap<String, Double>();
    TreeMap<String, Double> day = new TreeMap<String, Double>();
    TreeMap<String, Double> evening = new TreeMap<String, Double>();
    TreeMap<String, Double> night = new TreeMap<String, Double>();
    TreeMap<String, Double> fullday = new TreeMap<String, Double>();

    /*
     * Populates the charts using the treemaps
     */
    public void populateCharts() {

        XYChart.Series<String, Double> series1 = new XYChart.Series<String, Double>();
        for (Map.Entry entry: morning.entrySet()) {
            System.out.println(entry.getKey());
            series1.getData().add(new XYChart.Data<String,
Double>((String)entry.getKey(), (Double)entry.getValue()));
        }
        XYChart.Series<String, Double> series2 = new XYChart.Series<String, Double>();
        for (Map.Entry entry: day.entrySet()) {
            series2.getData().add(new XYChart.Data<String,
Double>((String)entry.getKey(), (Double)entry.getValue()));
        }
        XYChart.Series<String, Double> series3 = new XYChart.Series<String, Double>();
        for (Map.Entry entry: evening.entrySet()) {
            series3.getData().add(new XYChart.Data<String,
Double>((String)entry.getKey(), (Double)entry.getValue()));
        }
        XYChart.Series<String, Double> series4 = new XYChart.Series<String, Double>();
        for (Map.Entry entry: night.entrySet()) {
            series4.getData().add(new XYChart.Data<String,
Double>((String)entry.getKey(), (Double)entry.getValue()));
        }
        XYChart.Series<String, Double> series5 = new XYChart.Series<String, Double>();
        for (Map.Entry entry: fullday.entrySet()) {
            series5.getData().add(new XYChart.Data<String,
Double>((String)entry.getKey(), (Double)entry.getValue()));
        }
        series1.setName("Morning");
        series2.setName("Afternoon");
        series3.setName("Evening");
        series4.setName("Night");
```

```java
        chart.getData().add(series1);
        chart.getData().add(series2);
        chart.getData().add(series3);
        chart.getData().add(series4);
    }

    /*
     * Method to handle opening folder
     */
    @FXML
    public void openFolderBtnClick() {
        DirectoryChooser dirChooser = new DirectoryChooser();
        selectedDirectory = dirChooser.showDialog(Main.primaryStage);
        folderLbl.setText(selectedDirectory.getName());

        if (selectedDirectory == null){
            folderLbl.setText("No directory selected");
        }else{
            folderLbl.setText(selectedDirectory.getAbsolutePath());
        }
        try {
            populateFileList(selectedDirectory);
        } catch (IOException e) {}
    }

    /*
     * Adds all of the values up for an HMO for total power
     */
    public void calcTotalPower() {
        double total = 0;
        for (Map.Entry entry: fullday.entrySet()) {
            total = total + (Double)entry.getValue();
        }
        totalPwrLbl.setText(Double.toString(Math.round(total)) + " kWh");
    }

    /*
     * Creates a workbook object and adds it to list
     */
    public void populateFileList(File selectedDirectory) throws FileNotFoundException,
IOException {

        //Add all files and create workbooks
        String[] allFiles = selectedDirectory.list();
        String path = selectedDirectory + "\\";

        for (String s: allFiles) {
            InputStream inp = new FileInputStream(path + s);
            Workbook wb = null;
            try {
                wb = WorkbookFactory.create(inp);
            } catch (InvalidFormatException e) {}
            workbooks.add(wb);
        }
```

```java
    }

    /*
     * Finds the ActPow column and calls function for calculation
     */
    public void findPowerColumn() {
        int actPowerColNum = 0;
        //for each workbook(day)
        for (Workbook wb: workbooks) {
            Sheet sheet = wb.getSheetAt(0);
            //find the actualpwr column
            for (Cell c: sheet.getRow(0)) {
                if (c.getStringCellValue().equals("ActPow")) {
                    actPowerColNum = c.getColumnIndex();
                }
            }
            //call function to iterate over power column for each day
            calcPowerPerDay(wb, actPowerColNum, "morning");
            calcPowerPerDay(wb, actPowerColNum, "evening");
            calcPowerPerDay(wb, actPowerColNum, "day");
            calcPowerPerDay(wb, actPowerColNum, "night");
            calcPowerPerDay(wb, actPowerColNum, "fullday");
        }
        populateCharts();
        calcTotalPower();
    }

    /*
     * Calculates the power for a given time of day
     * @param wb workbook object
     * @param columnIndex the index of power column
     * @param tod string for time of day
     */
    public void calcPowerPerDay(Workbook wb, int columnIndex, String tod) {
        System.out.println("wb: " + wb.toString());
        String cellValue = "";
        String date = "";
        double prevNum = 0;
        double num = 0;
        double total = 0;

        //call function to get row range
        ArrayList<Row> rowRange = null;
        rowRange = getRowsByTimeOfDay(wb, tod);

        for (Row r: rowRange) {
            cellValue = df.formatCellValue(r.getCell(columnIndex));
            if (!cellValue.equals("ActPow")) {
                //Take into account for blank cells and 0 cells
                if (cellValue.length() > 0 && !cellValue.equals("0")) {
                    //get the value from the ActPow column
                    num = Double.parseDouble(cellValue);
                    //Store the num
                    prevNum = num;
                //if the cell is 0, heating has turned off, prevNum set to 0
```

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```java
            } else if (cellValue.equals("0")) {
                prevNum = 0;
            //if blank cell, heat is on, use prevNum
            } else {
                //use previous number
                num = prevNum;
            }
        }
        //convert to energy
        num = num / 100 * 24 / 360;
        total = total + num;
    }
    //format date for only time
    date = wb.getSheetAt(0).getRow(1).getCell(0).getStringCellValue().substring(5,
10);

    //add to treemaps
    if (tod.equals("night")) {
        night.put(date, total);
    } else if (tod.equals("morning")) {
        morning.put(date, total);
    } else if (tod.equals("day")) {
        day.put(date, total);
    } else if (tod.equals("evening")) {
        evening.put(date, total);
    } else if (tod.equals("fullday")) {
        fullday.put(date, total);
    }
}

/*
 * Defines times of day and gets rows
 * @param wb workbook object
 * @param tod string for time of day
 * @return ArrayList of rows
 */
public ArrayList<Row> getRowsByTimeOfDay(Workbook wb, String tod) {
    rows = new ArrayList<Row>();
    int minHour = 0;
    int maxHour = 0;
    String trimmedTime;
    int trimmedHour;

    if (tod.equals("night")) {
        minHour = 22;
        maxHour = 6;
    } else if (tod.equals("morning")) {
        minHour = 6;
        maxHour = 12;
    } else if (tod.equals("day")) {
        minHour = 12;
        maxHour = 18;
    } else if (tod.equals("evening")) {
        minHour = 18;
        maxHour = 22;
```

```java
        }

        for (Row r: wb.getSheetAt(0)) {
            //2017-11-01T00:01:24.834Z
            if (!df.formatCellValue(r.getCell(0)).equals("Time")) {
                trimmedTime = df.formatCellValue(r.getCell(0)).substring(11, 16);
                trimmedHour = Integer.parseInt(trimmedTime.substring(0, 2));
                //night time is special case
                if (tod.equals("night")) {
                    if ((trimmedHour >= 22 && trimmedHour <= 23) || (trimmedHour >= 0
&& trimmedHour < 6)) {
                        rows.add(r);
                    }
                } else if (tod.equals("fullday")) {
                        rows.add(r);
                } else {
                    if ((trimmedHour < maxHour) && (trimmedHour >= minHour)) {
                        rows.add(r);
                    }
                }
            }
        }
        return rows;
    }

    /*
     * Calls first function on button click
     */
    @FXML
    public void runBtnClick() {
        findPowerColumn();
    }

}
```

ControlPanel.fxml

```xml
<?xml version="1.0" encoding="UTF-8"?>

<?import javafx.scene.effect.*?>
<?import javafx.scene.shape.*?>
<?import javafx.scene.chart.*?>
<?import javafx.scene.text.*?>
<?import javafx.scene.control.*?>
<?import javafx.scene.layout.*?>

<Pane maxHeight="-Infinity" maxWidth="-Infinity" minHeight="-Infinity" minWidth="-
Infinity" prefHeight="850.0" prefWidth="1170.0" xmlns="http://javafx.com/javafx/8"
xmlns:fx="http://javafx.com/fxml/1" fx:controller="WB.Controller">
  <children>
     <Button fx:id="chooseFolderBtn" layoutX="675.0" layoutY="109.0"
mnemonicParsing="false" onAction="#openFolderBtnClick" text="Choose HMO Folder" />
     <Label layoutX="246.0" layoutY="117.0" text="Folder:" />
```

```xml
        <Label fx:id="folderLbl" layoutX="336.0" layoutY="109.0" prefHeight="35.0"
prefWidth="328.0" />
        <Button fx:id="runBtn" layoutX="523.0" layoutY="197.0" mnemonicParsing="false"
onAction="#runBtnClick" prefHeight="51.0" prefWidth="125.0" text="Run " />
        <LineChart fx:id="chart" alternativeColumnFillVisible="true" layoutX="45.0"
layoutY="290.0" prefHeight="500.0" prefWidth="1073.0" title="Energy Use Over Time">
          <xAxis>
            <CategoryAxis label="Days" side="BOTTOM" fx:id="x" />
          </xAxis>
          <yAxis>
            <NumberAxis fx:id="y" autoRanging="false" label="Energy (kWh)" side="LEFT"
upperBound="60.0" />
          </yAxis>
        </LineChart>
        <Rectangle arcHeight="5.0" arcWidth="5.0" fill="#5794cd" height="81.0"
stroke="TRANSPARENT" strokeType="INSIDE" width="1170.0">
          <effect>
            <DropShadow />
          </effect>
        </Rectangle>
        <Label layoutX="339.0" layoutY="19.0" text="Worcester-Bosch Data Analyzer"
textFill="WHITE">
          <font>
            <Font size="35.0" />
          </font>
          <effect>
            <DropShadow />
          </effect>
        </Label>
        <Label fx:id="totalPwrLbl" layoutX="874.0" layoutY="251.0" prefHeight="43.0"
prefWidth="275.0">
          <font>
            <Font size="26.0" />
          </font>
        </Label>
        <Label layoutX="719.0" layoutY="255.0" prefHeight="35.0" prefWidth="218.0"
text="Total Energy:">
          <font>
            <Font name="System Bold" size="24.0" />
          </font>
        </Label>
    </children>
</Pane>
```