Energize Worcester: Identification and Analysis of Heating Behaviors in Student HMOs

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Abstract

Sponsored by Worcester Bosch and The University of Worcester, the Energize Worcester Project evaluated the home heating behavior of student tenants in in houses near the St John's Campus. The team surveyed tenants, interviewed landlords, analyzed boiler logging data to supplement our research into what factors affect students' energy consumption. We found that smart technology can be used to effectively manage heating systems as well as aid the tenants in navigating difficulties surrounding common billing methods. From these findings, we recommend that the University and landlords educate students on energy-conscious heating habits and landlords explore alternative billing methods to incentivize tenants to curb heating use.

Acknowledgments

We would like to thank our sponsors at the Worcester Bosch Group: Richard Forrester, Paul Greer, and Ewan Sutherland. We appreciate their guidance, assistance, and the time they spent speaking with us. Their input was a valuable contribution to our understanding of the intricacies of the boiler and logging data.

We also greatly appreciate the support of Katy Boom, the University of Worcester's Director of Sustainability. We began this project with plenty of questions and her continual guidance provided us with clear direction and purpose. Additionally, we would like to acknowledge Tim Hewes-Belton and Kate Gynn of the Worcester Students' Union for giving us their time and knowledge through our interview.

We owe much of the success of our data analysis to the two landlords and the representative of the letting agency who generously lent their time and perspectives to the project. Their input was crucial to our understanding of the billing for utilities and education of tenants. Each of the tenants who participated in our survey contributed to our understanding of their perspectives on the heating system in their houses, and for this, we are also grateful.

We would like to thank Dominic Golding, our project advisor, for helping us through every step of our progress throughout the past few months. His personal investment in the success of the project and his commitment to the academic growth of each member of the team were instrumental in our success.

Executive Summary

The United Kingdom's housing stock is among the least thermally efficient in Europe, and high energy demand continues to be a problem in the country's domestic sector. Many older homes' style of construction limits the effective implementation of conventional energy-saving measures. While the UK's government and home heating industry are making strides to improve the country's domestic energy profile through legislature and energy-efficient home heating solutions, respectively, much work remains to be done in order to achieve significant progress.

Increased insulation, Smart thermostats, and other technologies can improve comfort and reduce energy consumption, but responsible heating behavior of residents is also a central element. This behavioral factor is magnified in student HMOs (Houses in Multiple Occupation), where a single heating system must satisfy the demands of multiple individuals with different schedules and different levels of energy consciousness. The Energize Worcester project, created in 2013 at the University of Worcester and funded through the National Union of Students Green Fund, aims to improve the quality of student living by educating students on sustainability, particularly with regard to responsible heating practices.

Phase II of the project began in 2015 when the University of Worcester partnered with the boiler manufacturer Worcester Bosch to equip five student HMOs around the university's Saint John's campus with new Greenstar boilers and Bosch's smart thermostat, the Wave. Since this time, Bosch has been logging usage data from these boilers. Past Energize Worcester projects have ascertained attitudes and perspectives on energy use in HMOs from tenants, landlords, and the university's student body at large, to draw conclusions about students' investment in energy-conscious heating behavior. The present iteration of the project is the first that has had complete access to the logging data for the entirety of the heating season and is thus uniquely equipped to assess the relationship between students' expressed heating behaviors and the corresponding behavior data from the Worcester Bosch boilers.

Methods

The goal of our project was to examine the patterns in expressed and observed heating behavior in student Houses in Multiple Occupation (HMOs) around the University of Worcester and provide recommendations to improve energy management in HMOs. To gather data in support of this goal, we developed the following three research objectives:

- Review previous patterns in attitudes, behavior, and energy use in HMOs
- Review current patterns in attitudes, behavior, and energy use in HMOs
- Identify stakeholder perspectives on better ways to manage energy use in student HMOs, including the role of ‘smart’ controls

To complete our first objective, we reviewed the raw data and analysis completed by previous Energize Worcester projects. This information supplemented our own background research and guided the development of our tenant surveys and stakeholder interviews.

We used these surveys in conjunction with the Worcester Bosch logging data to investigate the current patterns in tenant heating habits. The surveys asked primarily about the tenants' experience with the Wave smart thermostat, their hot water use, and their tendencies towards energy consciousness. To make sense of the raw logging data we were provided, we designed a program that combined, parsed, and visualized the data into easy-to-understand charts. With our charts and responses, we were able to find discrepancies, or the lack thereof, between expressed and observed heating behavior.

We implemented the interviews to identify the perspectives of certain stakeholders on the energy use in the student HMOs, specifically those of the pertinent landlords and members of the Worcester Students' Union who work directly with student accommodations. In these conversations, we furthered our understanding of the social situation surrounding student housing. In particular, the landlord interviews allowed us to investigate the HMOs in ways that are not suited to tenant surveys.

Conclusions and Recommendations

Through analysis of survey data, logging data, and material from our literature review, we reached several notable conclusions about both our study subjects and the research tools we were afforded. Based on these findings, we have provided several recommendations for stakeholder actions to improve the completeness of future research in this arena, the energy impact of HMO rental schemes, and student tenant heating management. The key findings from our research, and our corresponding recommendations, are as follows:

- **Conclusion 1: The Worcester Bosch logging data were not intended for behavioral analysis.** The logging data collected from the sample of HMOs were intended primarily as a diagnostic tool to monitor the operation of the boilers themselves, they were not intended to monitor resident behaviors. While we were able to draw useful conclusions from these data, the quantitative observations that could be made were valuable but somewhat limited.
- **Recommendation 1: Worcester Bosch consider installing additional sensors to monitor internal HMO temperature, real-time thermostat settings, and localized weather temperatures**. Worcester Bosch currently logs nine variables for use in Energize Worcester projects. While these variables are useful for diagnostic boiler maintenance, they are not sufficient for the behavioral analysis we aimed to perform. Access to data from these additional variables would facilitate more complete data analysis in future projects.
- **Conclusion 2: Proper education encourages energy-conscious behavior**
    - **Conclusion 2.1: Use of the Wave encourages energy-conscious behavior.** Our survey and logging data indicate that tenants active use of the Wave smart thermostat can make a dramatic difference in a house's energy use. The houses in our sample set which demonstrated the most energy-conscious behavior reported that they used the Wave's features to manage their boiler. Conversely, houses in which neither tenants nor the landlord claimed to use the Wave demonstrated a lack of energy-conscious behavior.

- **Conclusion 2.2: Education encourages smart thermostat use.** Through our surveys of students and landlords, we learned that student tenants are more likely to use the Wave's 'smart' features if they are directly taught how the system works. In those houses where the landlord took the time to explain the Wave and heating system the tenants demonstrated more energy-conscious behavior. Tenants whose landlords did not take such measures reported limited knowledge and use of their Wave thermostat.

- **Recommendation 2: Properly educate students/tenants**
  - **Recommendation 2.1: The University of Worcester educates its students on how to effectively manage their energy use.** We found that the Worcester Students' Union's primary role in student off-campus housing is assisting students in finding comfortable homes; they are less focused on educating students on energy-conscious behavior. For many students moving off-campus, it is likely their first time having complete control over their energy consumption. An effective education scheme would enhance student awareness of energy consumption and conservation and help them increase their comfort and reduce their living costs.
  - **Recommendation 2.2: Landlords spend the time to properly show the student tenants how to manage their heating system.** We observed that the tenants in one HMO managed their heating use much better than their counterparts in the other HMOs. We attributed this to their landlord thoroughly teaching them about the features of their Bosch heating system and the Wave app. Other landlords either just told their tenants the Wave's app existed or did nothing at all. Educating the tenants on how to use their heating system would give them effective agency to manage their heating use on their own.

- **Conclusion 3: Billing methods play a significant role in how tenants use their heat.** Our interviews with landlords, Worcester Students Union staff, and a local letting agent led us to conclude that the recent shift in rental billing formats has impacted students' personal investment in their heat use. According to our research, utilities-inclusive rent

and capped energy expenses standardize and homogenize rent payments, effectively simplifying rent plans, but this removes students' incentive to monitor and adjust their use of energy for heating and hot water.

- **Recommendation 3: Landlords investigate options to financially incentivize tenants to be more energy-conscious.** In our research, we concluded that inclusive bills and capped energy expenses lead to tenants' lack of incentive to monitor their energy use or adopt more responsible heating habits because they do not see the monetary cost of their behavior. The addition of financial incentives to promote energy-conscious behavior or the removal of billing methods that hinder energy-awareness may convince the tenants to manage their heating effectively.

Authorship

Title	Primary Author	Secondary Author	Primary Editor	Secondary Editor
Abstract	TA		All	
Acknowledgements	JP		All	
Executive Summary	AK, TA	JP	AK, TA	RW
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Table of Contents	JP		—	—
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Background	AK		All	
Emissions & Energy	RW	AK	TA	AK
Government Programs	RW		AK	TA
City of Worcester	AK		AK	TA
Worcester Bosch	TA	JP	AK	
University of Worcester	TA	RW	AK	TA
Traditional and Smart Thermostats	JP	AK	AK	TA
Methods	AK		All	
Objective 1	JP		All	
Investigation of Past Perspectives	JP		AK	TA
Objective 2	RW		All	
Analysis of Bosch Logging Data	JP		TA	AK
Identification of Current Perspectives	RW	TA	AK	
Objective 3	TA		All	
Worcester Students' Union	TA	RW	AK	TA
Landlord Perspectives	TA		AK	TA
Findings	AK		All	

The Boiler Data	JP	RW	TA	AK
Use of The Wave	TA	RW	RW, TA	AK
Education is Correlated	RW		AK	TA
Billing Methods	TA		All	
Conclusions and Recommendations	All		All	

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Introduction

The UK's housing stock is generally considered the least thermally efficient in all of Europe. Many of the existing homes date back to the Victorian era, and their style of construction limits the effective implementation of conventional energy-saving measures. In 2017, the UK's domestic sector was responsible for approximately 28% of the country's total energy consumption. While the energy demand of this sector may change with year-to-year temperature fluctuations, there has been little measurable success to reduce overall energy use. Nevertheless, the home heating industry is making strides to improve the efficiency of boilers and make heating systems more flexible to consumer needs as part of an ongoing effort to reduce energy consumption and CO2 emissions (Department for Business, Energy, and Industrial Strategy, 2018).

In 2015, the University of Worcester partnered with Worcester Bosch, a leading boiler manufacturer, to equip new smart heating technology and data loggers in five off-campus student HMOs (Houses in Multiple Occupation). HMOs are typically family homes that have been modified to house between three and eight tenants. These homes are particularly energy inefficient; a study by the National Union of Students (NUS) found that 49% of students described their HMOs as drafty and cold as a result of poor heating and/or insulation (National Union of Students, 2018). Nevertheless, students are notorious for not managing their energy use; boilers are often left to continually heat an empty home, and tenants tend to open windows to cool off instead of lowering the thermostat.

Our project reviewed both previous and current patterns in attitudes, behavior, and energy use in HMOs and identified stakeholder perspectives on better ways to manage energy use in these homes. Students working on past Energize Worcester projects interviewed past HMO tenants, but no project has had the opportunity to compare tenant behavior to a full heating season's worth of logging data, which was the focus of our project. A notable conclusion from years past is that the study might benefit from an increased number of HMOs by including those with different thermostats or heaters. Previous researchers have also said that, due to the current mentality of most college-aged students, there is little incentive for them to learn how to more efficiently manage their heat, especially if there is no financial benefit for them. They suggested

finding a different solution rather than trying to change the mindset of university students, as they are unlikely to change their habits.

To understand our project stakeholders' opinions on home heating, we interviewed landlords and members of the Student Union and surveyed student tenants. The interviews with the landlords and members of the Student Union helped us learn what steps were being taken to ensure the energy efficiency of HMOs. We cross-referenced tenant surveys with the logging data to identify differences between the tenants' perceived and actual energy use in their HMO. Based on our findings, we make several recommendations for future implementation of the project.

Background

In this section, we review the current state of energy consumption in the United Kingdom, particularly in the privately rented domestic sector. The UK's housing stock is notoriously inefficient, and its government has developed programs to combat the poor energy efficiency of its houses. Despite modest improvements in domestic energy consumption, much remains to be done. The University of Worcester and Worcester Bosch conduct the Energize Worcester project every year to evaluate heating systems in student homes.

Emissions and Energy in the United Kingdom

High energy consumption in the United Kingdom remains a persistent issue in the country's path to environmental sustainability. The Department for Business, Energy reported that in the UK, greenhouse gas emissions decreased 2.6% from 2016 to 2017 and are 43% lower than they were in 1990, largely because fuel transitioned from coal to gas during that period. The same report stated that the residential sector "accounted for 17 per cent of all carbon dioxide emissions" at 64.1 metric tons in 2017, a 4.3% drop from 2016. However, this is likely due to the fact that the average temperature was higher in 2017 than in 2016, reducing overall heat demand. Despite this recent decrease in domestic energy use, the energy profile of the country leaves room for progress.

Among UK homes, an estimated 11.1% are considered "fuel poor" (Department for Business, Energy & Industrial Strategy, 2018). Fuel poverty is when people cannot reasonably afford to keep their homes warm. Figure 1 shows that, from 2003 to 2016, more than 10% of homes consistently fell under "fuel poor" status. According to Mattioli and Marsden (2017, p. 115), the driving force of fuel poverty stems from income, energy prices, and energy efficiency. If the price of energy were to increase sufficiently, then a household's effective income would decrease, exposing the possibility of inadequate temperature in the living space. Homes linked to high rates of fuel poverty tend to be "larger, older, poorly insulated and/or not connected to the gas grid" (Mattioli and Marsden, 2017, p. 115); 36% of houses in the UK have solid-wall construction, and cannot accommodate the cavity-wall-style insulation that is common in contemporary structures (Solid Wall Insulation, n.d.). These poorly insulated homes do not retain heat effectively and are accordingly more expensive to keep warm.

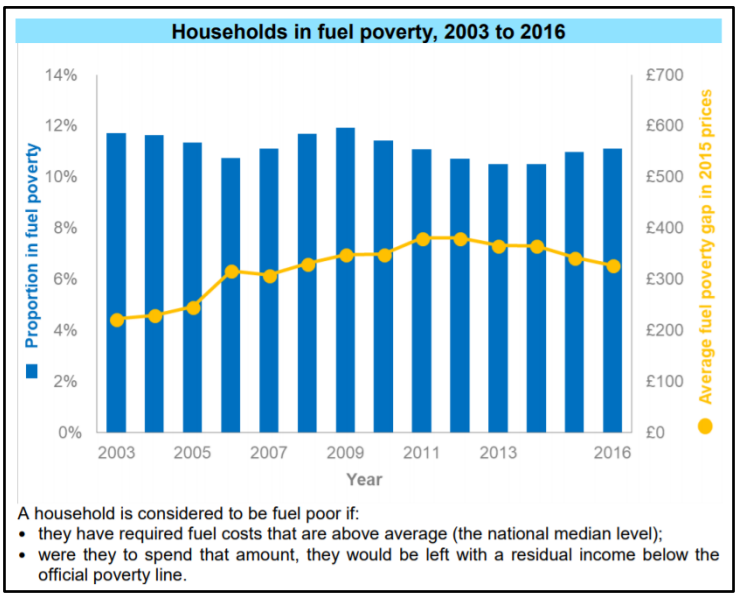

Figure 1: Fuel Poverty Trends in the UK (Department for Business, Energy & Industrial Strategy, 2018)

Government Programs

In order to combat the issues of fuel poverty and high energy use, the United Kingdom has focused on improving the energy efficiency of its housing stock. The government ultimately hopes to make all properties reach the Energy Performance Certificate (EPC) rating of C by 2030. The EPC rating is an A-G rated scale, with A being the most efficient and G the least. The Energy Act of 2011 made it illegal to lease homes with an EPC of F or G. It is still legal to buy and sell these properties, but the residents must be the owners themselves, rather than members of the general public (Trotta, 2018). In order to attain this standard, the government implemented several programs and policies.

One such program, which was previously government funded and is now privatized, is the United Kingdom's Green Deal. The Green Deal allows homeowners to borrow money to invest into making their home more energy efficient. The loaner then repays the loan using what they saved due to the increased efficiency of their homes. People can take out up to the total amount they will save, while the rest of the expenses for the improvements are paid out of pocket. Typically, the loans would have an interest rate of 9.3% APR and last for the lifetime of the upgrade. This program is ideally a win-win: homes become more energy efficient, and the lenders make money on the interest. However, the program saw only a 0.6% conversion rate from assessed homes to live Green Deal plans. It is believed that the high interest rate and

ineffective marketing contributed greatly to the Deal's failure (“The Green Deal in 2018,” 2019).

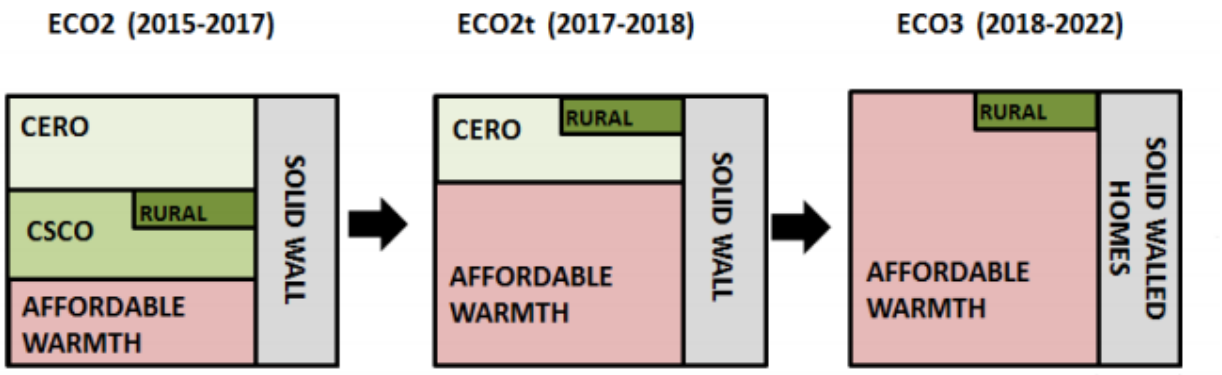

Figure 2: Evolution of the ECO Scheme (Department for Business, March 2018)

Among the most notable of the UK's policies is the Energy Company Obligation (ECO) scheme. This program, also known as the Affordable Warmth scheme, is available to property owners and tenants of privately-owned properties who have an annual household income of less than £20,000. Local city councils determine who is eligible for services like boiler replacement and improved insulation, and then allocate funds to those who need them. As Figure 2 indicates, ECO was updated in 2018 and renewed through March of 2022. The ECO scheme was used to fund the Carbon Emission Reduction Obligation (CERO), which subsidized insulation for wall cavities and in some cases provided financial assistance to make homes more energy efficient (The Environment Centre, 2019). It also funded the Carbon Savings Community Obligation (CSCO), a program designed to provide insulation for low income households, with 15% of their resources going to rural areas (Goodfellow and Dight, 2018). Currently, all of the funds from the ECO3 scheme are being spent on Affordable Warmth, as opposed to being split between Affordable Warmth, CERO, and CSCO, as was the case from 2015-2018 (Figure 2). The ECO3 scheme is now only available to homeowners; landlords are no longer considered eligible. Furthermore, ECO3 will replace a boiler only if the boiler or heating system is broken.

The Warm Home Discount Scheme is also funded at the national level. Between the months of September 2018 and March 2019, homeowners can qualify for a one-time £140 discount on their electricity and gas bills if they meet certain requirements. These requirements include having the "Guarantee Credit element of Pension Credit” or having low income (“GOV.UK,” n.d.).

Other programs include the Winter Fuel Payment (WFP) and the Cold Weather Payment

(CWP). The Winter Fuel Payment entitles the senior population living in the United Kingdom to receive up to £300 in payments toward heating. This program is targeted towards the elderly; those born before September 23rd, 1938 receive 50-100% more in payments than those who were born up to 1953. The CWP is a £25 benefit, paid out for qualifying people when the average temperature is "recorded as, or forecast to be, zero degrees Celsius or below for 7 consecutive days". This policy is effective from November to March, the coldest months, when homeowners need the money most. The CWP is for those living in poverty, with qualifying criteria including income support, income-based Jobseeker's Allowance, and income-related Employment and Support Allowance. These programs show the United Kingdom's dedication to improving the standard of living in the nation by giving those who most need the financial support to stay warm ("GOV.UK," n.d.).

Despite the many policies aiding the general population, some demographics do not benefit equally from governmental support. Perhaps the least recognized is the student population in Houses in Multiple Occupation (HMOs). An HMO is "a house or flat in which three or more persons forming two or more households share one or more basic amenities such as a bathroom, toilet and/or kitchen facilities" (Matthews, 2017, p. 3). Residents of HMOs have historically been of vulnerable economic status. A 2014 report on the state of HMOs shows that the most common tenants are "students, … homeless people, persons newly released from prison, young people leaving the care system, and people with mental health or substance misuse problems" (Viitanen and Weatherall, 2014, p. 25).

Due to the nature of their typical occupants, HMOs are generally thought to be underrepresented in energy consumption survey data and are "among the most likely to refuse to participate in official surveys" (Viitanen and Weatherall, 2014, p. 16). Accordingly, it is very difficult to create a clear profile of HMO heating, exclusive of very broad statistics concerning UK housing as a whole. High rates of energy use in the privately rented sector are intrinsically a concern because it is difficult to control energy consumption in houses occupied by a group of unrelated people with different standards of comfort, schedules, and commitments to energy conservation.

Students in HMOs are particularly susceptible to the shortcomings of their household; most students are categorized as fuel poor under the widely accepted definition of the term,

simply because their income often consists of nothing more than a part-time job, money from their parents, and loans. In a study conducted by the National Union of Students, 38% of students reported that they had found themselves uncomfortably cold in their living accommodation at some point; separately, 42% found their home to be “poorly insulated and/or draughty” (National Union of Students, 2019). In 2018, Morrison and Genovese surveyed 286 students and found that 74% wished that their accommodation was either slightly or much warmer. Students are just as vulnerable to inefficient heating as the rest of the UK population, yet there are very few government-sponsored programs geared towards helping them. A major reason for this is that students are viewed to have “lifestyles fueled by alcohol” (Morrison and Genovese, 2018). It is hard to mobilize a movement promoting the better living conditions for students when they have this reputation of irresponsibility. Landlords are also unlikely to help the situation because of the issue of split incentives. Split incentives are when those paying the energy bills are not the same as those making the decisions to improve the property. In cases of split incentives, the landlord is not inclined to upgrade their property when the only benefactors are the tenants. This, paired with the limited research done on student HMOs, leaves a significant gap in the understanding the UK's domestic energy situation.

City of Worcester

With its large student population, Worcester provides an excellent opportunity to study student HMOs. As of January 1, 2019, there are 775 “live” HMO licenses in Worcester, not including housing directly provided by educational institutions. In 2014, HMOs represented approximately 2.4% of the total residences in the city (Worcester City Council, 2014, p. 12). Students make up a fairly large portion of city HMO occupants as a result of the University of Worcester's housing requirements. Beyond its on-campus housing, the university maintains connections with a number of local landlords. Students can find accredited landlords through the university's StudentPad website, a service available exclusively to enrolled students (University of Worcester, 2019).

Within the scope of HMOs endorsed by the university, housing units are held to a set of standards that satisfy both the university and the city of Worcester. Endorsed housing must, in keeping with national policy, have an EPC rating of at least E in order to be legally let. Additionally, tenants are entitled to personal control of heating, and the heating system of the

building must perform to a specific temperature threshold (Matthews, 2017, p. 14).

While Worcester HMOs are ostensibly held to standards of upkeep and operation, the homes are still often perceived as cold and damp (K. Boom, Personal Communication). To address this, the Worcester City Council manages its own programs to improve the city's housing stock. One local project, Warmer Worcestershire, battles fuel poverty by offering information on grants for insulation, thermal mapping of any house, and advice for homeowners on how to improve their homes (Worcester City Council, n.d.). The Council also recommends the program Act on Energy, which offers homeowners free energy assessments (Act on Energy, n.d.).

Several independent groups work to promote energy efficiency in Worcester's privately rented housing stock and are active stakeholders in our project: The Worcester City Council wants housing within their city to be as comfortable and energy efficient as possible, the Worcester Bosch Group hopes to understand the effectiveness of their new technologies, and the University of Worcester wants the best for their students. Our recommendations will help identify issues surrounding a relatively untested demographic, perhaps leading to updated regulations and future studies.

Worcester Bosch

The Worcester Bosch Group is the leading boiler manufacturer and installer in Worcester. It provides the boilers and smart systems that heat the five HMOs that this project investigates. The integration of Bosch smart tools, such as the Wave and EasyControl, is a relatively new practice, so it is important that their performance is evaluated within each home to improve the overall product (K. Boom, Personal Communication).

Before the Energize Worcester (EW) project, Worcester Bosch had plenty of information on single family homes and their heating behavior. Through EW, however, the company intends to shed light on the situation within student HMOs. In family homes, there are often only one or two decision-makers, determined simply by who pays the bills. In student HMOs, the dynamic is completely different; each tenant has as much say in controlling the heat as their roommates. When Bosch and the University of Worcester teamed up for the EW project, they offered to install upgraded boilers along with Bosch's smart thermostat, the Wave, in five off-campus student HMOs. In doing so, Worcester Bosch hopes to understand the bigger picture within these

living arrangements in order to provide better personalized service and to evaluate the impact of their smart technologies (Worcester Bosch, 2018).

University of Worcester

The University of Worcester is one of the UK's most progressive universities, demonstrating values of equality, representation, innovative teaching techniques, and dedication to its social and natural community (University of Worcester, 2019). It is particularly interested in ensuring that its students live in comfortable, energy efficient housing during their time in Worcester. The university stays in contact with local landlords, providing advice on how to gain accreditation through the City Council. Accredited landlords who partner with the university are advertised through StudentPad. However, the advice given to landlords and students is cuffed by insufficient knowledge surrounding HMOs (University of Worcester, 2016).

Recent years have seen the National Union of Students overseeing its own research on student housing. In 2017, the NUS conducted the second phase of its Homes Fit for Study project which used online surveys across the UK's private rented sector to identify students' experiences with energy efficiency in their homes. The findings note that the majority of tenants were satisfied with their living arrangements. However, results from the focus group indicate that this high rate could be a result of low expectations for the accommodation. A hefty 68% of respondents would often use other means to supplement their warmth throughout the day, such as extra layers and blankets. With generally low expectations going into their lease, tenants may be less inclined to improve their living conditions through more energy efficient practices, such as lowering the thermostat when the house is unoccupied (National Union of Students, 2018).

According to Tim Hewes-Belton (Student Engagement Manager, University of Worcester Students' Union, March 27th, 2019) and Kate Gynn (Academic and Welfare Advisor, University of Worcester Students' Union, March 27th, 2019), housing is a major problem for students in the United Kingdom. To help students enter the housing market, the Worcester Students' Union emphasizes helping students find quality homes that will keep them warm and comfortable, with less emphasis on finding homes which are tailored for efficient heating. The university conducts a housing fair every year, targeted at first year students. The fair introduces students to accredited landlords and to the university's online student housing tool, StudentPad.

Mr. Hewes Belton stated that “We are in a demographic dip. There are fewer eighteen-year-olds, which means that there are fewer students” (Tim Hewes-Belton, Personal Communication, March 27th, 2019). This recent decline in student numbers has decreased demand for off-campus housing, so landlords have shifted from exclusive to inclusive rents as a way to attract students. As of 2018, nearly 30% of student tenants through the UK were given inclusive bills, which allow them to ignore the financial cost of excessive heating (National Union of Students, 2018). Including heating caps and utility expenses in monthly bills allows for students to use as much heat as they want, with no extra costs, until the cap is exceeded. However, landlords often find that enforcing the cap is worth neither their time nor efforts for small overages. When tenants do not reach the cap, which is the case the majority of the time, they are not reimbursed for the energy they did not use. However, when they go over, they are not charged extra (unless it is an extreme example of excessive use). Ultimately, this billing method costs the students more in utility expenses because they often pay for energy they do not use. Unfortunately, a lack of on-campus housing forces most second- and third-year students to live off-campus and into these expensive and vulnerable situations (Katy Boom, University of Worcester Director of Sustainability, 2019).

The university supplements the work done by the Students' Union with its own Energize Worcester project. Our team's case studies in the five student HMOs will provide the university and the landlords with additional information on how to maintain and improve housing within this demographic. Phase II of Energize Worcester began in 2015 and has since seen continuous funding from NUS Students' Green Fund. Over the years, this project has addressed the relationship between tenants and landlords, the role that technology plays in the student HMOs, and how tenants' habits and perceptions shape their energy consumption.

Past projects have all presented their own findings based on their own research. However, it is in their consistency across each report that their recommendations gain a great deal of credibility. Many previous projects identified unmotivated and uninformed tenants as a prevalent issue; the tenants knew little of the smart thermostat features and often expressed no interest in learning. There was also frequent mention of general misunderstanding between tenants and landlords. Tenants care about staying warm and keeping peace in the household (i.e., no arguing about or tinkering with the thermostat), while landlords want to improve the energy

consumption of their property. Landlords often get frustrated when their residents seem indifferent to changing bad habits or utilizing the tools they are given.

All six of the previous IQP teams noted that an educational campaign, led by the University of Worcester and their accredited landlords, would benefit all parties involved. Postings can be kept on the properties highlighting effective boiler use and meetings can be held to give each party a better understanding of the other and to develop working relationships. The projects also mentioned that separating rent and energy bills will entice tenants to curb any excessive heating tendencies. This is an unlikely course of action, however, because landlords who provide combined bills are more appealing to students. In one bill, they can estimate the average monthly utility cost and simply add it to the rent. Since this is an average, there is little worry of under- or over-charging residents; month-to-month, the errors will balance each other out, so students have no incentive to care.

Traditional and Smart Thermostats

Conventional thermostats, which usually comprise a simplistic control scheme and regulate indoor temperature to a constant value, are common as they are cheap, simple to install, and, for the most part, easy to understand. Thermostats may have additional features, though users are sometimes reluctant to utilize them because they are often perceived as unintuitive. According to one UC Davis study, 40% of survey respondents who owned programmable thermostats did not use their devices' advanced features, and 33% even had the features overridden (Pritoni, Meier, Aragon, Perry, & Peffer, 2015). While programmable thermostats are the de facto standard for heating control, an increasing public interest in internet-capable 'smart' devices has led to a more prominent market role for smart thermostats.

Internet connectivity significantly extends the scope of thermostats' functionality; it allows artificial intelligence to analyze when residents are home or away, and recognize a daily pattern so that it can shut off right before the house is vacated, and turn on right before someone returns. This gives homeowners, landlords, and even utility companies very useful tools to manage energy use in homes. In 2013, Nest Labs (before they were purchased by Google) announced a new feature, Rush Hour Rewards, that allows utility companies to manage a home's Nest thermostat during peak energy consumption hours to save both energy and money (Nest, n.d.).

The first smart thermostat produced by Worcester Bosch, “the Wave,” was released in 2014 and is sparsely used or understood by the students living in houses equipped with one (K. Boom, Personal Communication). A lot of problems stem from the Wave's interface. The better the interface is designed, the easier it is to learn and use. A better interface would therefore make it easier to effectively operate.

Worcester Bosch claims that the Wave should increase the efficiency of a heating system by and average of 4% (Worcester Bosch Group, 2018). However, this system was designed for use in single-family homes, not in properties with multiple decision makers. With the characteristically high foot traffic in student HMOs and the sporadic schedules of their occupants, a normal smart thermostat with only one temperature setting for an entire home is not necessarily suited to this environment. If one tenant is too hot because the rest of the house is set to please their roommates, they may open a window to let in cold air. This is an energy inefficient response, but a common one.

Differing heating preferences between residents of a single house can be addressed, in part, by the implementation of a zoned heating system. Thermostatic Radiator Valves (TRVs) are used to control the flow of hot water to be supplied to individual radiators in a house’s heating system. Such solutions are common in most modern homes, and they are a mandatory feature in Worcester HMOs (Matthews, 2017, p. 14). Older models of TRVs are usually operated manually, independent of the house’s thermostat. Thus, the effectiveness of many current ‘smart’ thermostats can be limited by their inability to simultaneously manage different heating conditions and demands in different rooms of a house and the holistic demands of the house itself. The Wave lacks this connectivity, and cannot always suit the needs of multiple decision makers. Zoned heating capability was added in Worcester Bosch’s second smart thermostat, “EasyControl”, which has not yet been installed in the HMOs.

There are many variables that make students in HMOs a unique demographic. The UK government prioritizes supporting the elderly and poor over them, the housing market takes advantage of their relative inexperience in renting, and appliance companies struggle to optimize their products for them. Outside of the few studies the National Union of Students has published, the student HMO is a largely under-researched population. Through Energize Worcester, it is our hope to shed light on this situation and to provide an understanding necessary to mend the

vulnerability of these students.

Methods

The goal of our project was to examine the patterns in expressed and observed heating behavior in student Houses in Multiple Occupation (HMOs) around the University of Worcester and provide recommendations to improve energy management in HMOs. In order to achieve this goal, we developed the following three research objectives:

1. Review previous patterns in attitudes, behavior, and energy use in HMOs.
2. Review current patterns in attitudes, behavior, and energy use in HMOs.
3. Identify stakeholder perspectives on better ways to manage energy use in student HMOs, including the role of 'smart' controls.

In this chapter, we describe our methods for gathering and analyzing data to support these objectives and discuss the relevance of the accumulated data in the scope of our overall goal. The specific tasks associated with the fulfillment of each objective are detailed in Figure 3.

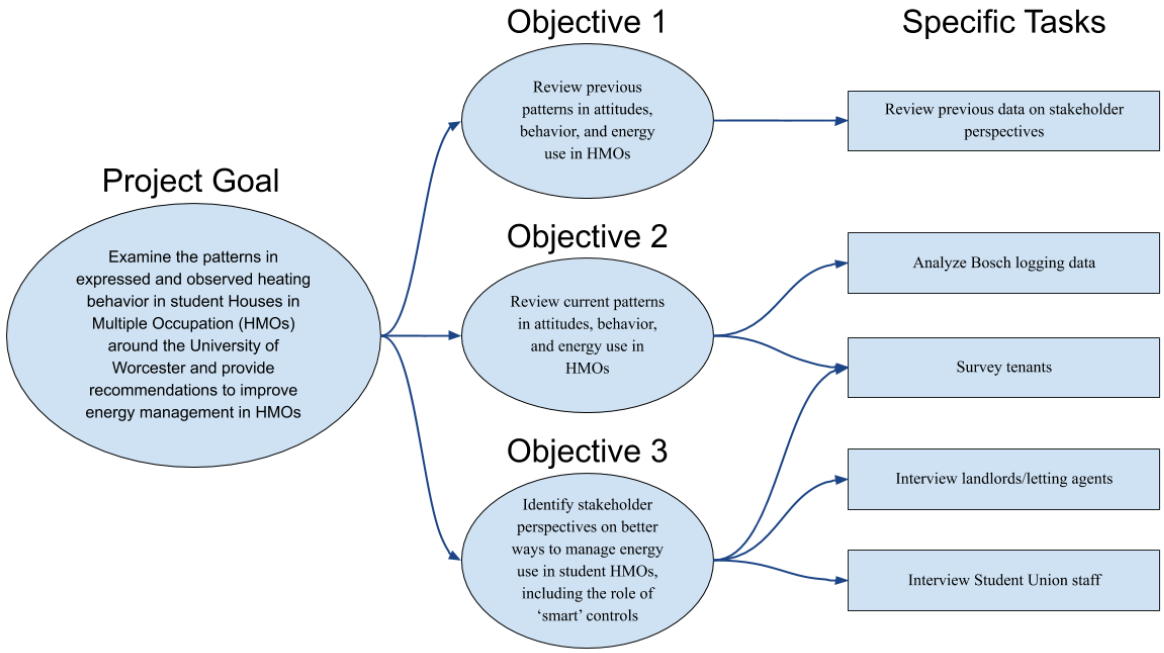

Figure 3: Project Goal, Objectives, and Tasks Flowchart

Objective 1: Review Past Patterns in HMO Energy Use

Six projects related to Energize Worcester have been conducted by Worcester Polytechnic Institute (WPI) teams over the past four years. As the seventh iteration of the project, our team had access to a wealth of data and perspectives from years past on energy use, attitudes, and behaviors. In particular, we reviewed stakeholder perspectives from previous interviews and surveys.

Investigation of Past Perspectives

The previous WPI teams performed numerous interviews and surveys of tenants, landlords, and the other stakeholders involved in Energize Worcester. One project interviewed the tenants in the HMOs about their Wave heating system and compared these responses to logging data (Guerrero, Grant, McAteer, & Caplin, 2017). The December, 2018 team focused on all University of Worcester students instead of the tenants of the five HMOs. They surveyed the general student body about their perception of home heating and smart heating systems. (Westwater, Pinette, Donald, & Lussier, 2018). The university maintains all the raw results from these projects. We reviewed past findings and data to give us a better understanding of the situations and to direct the development of our interview scripts.

Objective 2: Review Current Patterns in HMO Energy Use

Data from past studies lent context and guidance to our own project. We also aimed to learn about the current conditions of energy use in the designated HMOs through the collection of stakeholder perspectives and behavioral data from the Worcester Bosch logging data. This information helped us to identify what future actions may be taken to improve the project.

Analysis of Bosch Logging Data

For several years, Worcester Bosch has logged boiler usage data from five student HMOs near the University of Worcester Saint John's campus, storing them in in Comma-Separated Value (CSV) files in five-day intervals. We leveraged these data to ascertain the heating behaviors demonstrated by the student tenants of these properties. For unknown reasons, the data logger one of the houses was inactive during this past heating season, so we were unable to analyze this boiler in the manner described in this section. Worcester Bosch maintains a

visualization tool for the analysis of the data, but they could not share it with us because the tool is proprietary. Instead, we designed a command-line prompt via Python in order to facilitate the combination and analysis of the data and to present it as an interactive chart that can be embedded on a website. The logging data tracks nine parameters:

- Time, logged in ten-second increments;
- Primary Temperature Setpoint (the temperature ℃ at which the boiler is set to heat radiator water), logged when it is adjusted;
- Primary Temperature (the temperature ℃ at which the Boiler heats radiator water), logged when it changes;
- Hot Water Output Temperature Setpoint (the temperature ℃ at which the boiler is set to heat house water), logged in ten-second increments;
- Hot Water Output Temperature (the temperature ℃ at which the boiler is outputting house water), logged in ten-second increments;
- Actual Power, logged when it changes;
- Power Setpoint, logged when it changes;
- Hot Water Active, logged when it changes; and
- Central Heating Active, logged when it changes.

A new data point is stored every ten seconds for several parameters, so around 8,300 entries are logged daily at each property. To simplify the data for the generation of charts, the program only keeps: Time, Primary Temperature, Hot Water Output Temperature, Hot Water Active and Central Heating Active. We omitted the rest of the data, which was unused in our charts, to decrease our file sizes and make the data files easier to manipulate and analyze. The tool produces six charts which cover four different time frames selected based on the university's academic calendar for the year. We also generate a chart for the heating season, which we consider to span from the end of September to the end of March. An additional chart compares data from the hottest week (February 24th - March 2nd, 10℃ - 19℃) and coldest week (January 27th - February 2nd, 2℃ - 6℃) of the heating season. We picked these weeks with the assumption that the high and low temperature extremes would correspond to clear differences in the heating behavior of the tenants and provide clear data patterns. Every chart also plots the

average primary temperature over a 15-minute timespan, with the exception of the hot and cold week comparison, which average every 3 minutes.

Using our visualization tool, we analyzed the relationship between outside temperature and boiler activity. Our ultimate goal for the data analysis was to identify differences between tenants' expressed and observed heating behavior by comparing the logging data to the tenant surveys (see *Identification of Current Perspectives*). To communicate the results of our visualization tool, we made a website[1] on which all of the charts can be viewed. A feature of the website is the ability to select two HMOs and compare HMOs in one of the six chart designs side-by-side. This website allows readers of this report and other interested parties to interact with the data with much greater resolution than would be feasible with a static image.

Identification of Current Perspectives

In order to to obtain students' expressed heating behavior, we developed an anonymous online survey, which asked tenants a variety of questions about the ways they manage their heat and hot water use (see final survey instrument in Appendix C). We pilot tested these survey questions by taking the survey ourselves and adjusted questions which lacked substance and specificity. The university provided us with the addresses of the five HMOs, but we did not have the contact information of the tenants, so we visited the homes between 5 p.m. and 7 p.m. on weekdays to obtain their email addresses. Since it was a new academic year and turnover in student off-campus housing is quite rapid, not all of the current tenants had previously been interviewed. We emailed the tenants a link to our online survey and asked them to forward it to their housemates, for whom we did not have contact information. We periodically contacted the tenants to remind them to fill out the survey if they had not already, however we were wary of reminding them too often so as not to harass them.

We reviewed and coded the survey responses so that each HMO's results were grouped together and anonymized as "HMO 1" through "HMO 5". This way we could compare the responses between the housemates and between the HMOs themselves. Table 1 outlines the number of survey responses we received from each household.

[1] Energize Worcester Website: https://energizeworcester.wp.worc.ac.uk/code/

Table 1: Number of tenants and survey responses by HMO

HMO #	Number of Tenants	Number of Survey Responses
1	4	1
2	3	3
3	4	0
4	4	1
5	3	1
TOTAL	**18**	**6**

Objective 3: Identification of Stakeholder Perspectives

In addition to our analysis of tenants' heating behaviors, we sought to identify stakeholder perspectives on energy use and 'smart' controls. To do this, we conducted interviews with various stakeholders, including local landlords and letting agency[2] representatives, and advocates for the Worcester Students' Union. We did not take measures to collect data from the tenants beyond those described in Objective 2.

We developed our interview scripts based on our review of previous Energize projects and conversations with our sponsor liaisons: Katy Boom at the University of Worcester and Richard Forrester at Worcester Bosch. We designed the interview questions to be open-ended so as to invite free discussion. We began each interview with a preamble (see Appendix B) that described the nature of our research and informed the interviewee of their right to review any material we used in our report in advance of publication.

[2] Letting Agencies facilitate the contract negotiations between landlords and tenants. They provide optional services to both the tenants and landlords such as Rent Collection and Property Management (Maunder, 2018).

Worcester Students' Union

We interviewed two members of the Worcester Students' Union: Kate Gynn (Academic and Welfare Advisor) and Tim Hewes-Belton (Student Engagement Manager). We were particularly interested in these two staff members because their roles within the Union pertain directly to housing. We emailed them to schedule an interview to be held in a conference room at the Students' Union. Rather than asking specific questions, we decided it was best to have a list of talking points we could use to direct conversation (Appendix E). The interview focused on how the Students' Union, both nationally and within Worcester, were invested in off-campus student accommodations. The interview touched on current clubs, programs, and events the Union run to inform students of the housing market and of their responsibilities as tenants.

Landlord Perspectives

We obtained contact information of landlords of the five HMOs through the university. We contacted the landlords to set up a convenient time and place for the interview and sent our interview script (see Appendix D) ahead of time to give them the chance to think about the questions and their answers prior to the interview. These questions asked about their relationship with the tenants and their feelings regarding the heat use within the HMOs. In our interviews, two members of our team spoke with each landlord, one acting as a speaker and the other as a scribe. Each interview lasted between 15 and 25 minutes. Similar to our tenant surveys, we reviewed and coded the interviews in order to make them easier to analyze. We also compared the perspectives from the interviews with the views expressed within the surveys. We conducted interviews with three landlords in all, including a representative from the letting agency that manages HMO 5. The landlords of HMO 1 and HMO 2 were interviewed over the phone and the letting agency interview took place at the company’s Worcester office.

In our investigation of the patterns in expressed and observed heating behavior and attitudes in student HMOs, we drew from several data sources: the research conducted by our predecessors, which included in-depth interviews with landlords and students; the logging data collected before and during the term of our research, which allowed us to develop a visualization tool for the data and compare patterns in boiler use; our own surveys of student HMO tenants, aimed at identifying the current perspectives students have regarding their heating use; interviews with landlords, either corroborating or contradicting the information given by

students; and interviews with two members of the Worcester Students Union from whom we hoped to learn how the organization helps students mediate their energy use. The unique perspectives and observed behavior relating to heat management, when examined concomitantly, serve to provide a unified account of heating patterns in houses in multiple occupation.

Findings

Building upon data from past Energize Worcester projects, we surveyed tenants from four of the five HMOs and conducted interviews with three of the properties' landlords. We also benefited from interviews with Worcester Students' Union staff, which served to augment our literature review. Our analysis of behaviors from the Worcester Bosch logging data, when paired with tenant and landlord attitudes ascertained from interviews and surveys, yielded several pertinent findings. We found that the Bosch logging data used to make these conclusions were not sufficient to provide a complete perspective of the heat management in each property; the data was designed for diagnostic purposes and is removed from tenant interactions with the house's thermostat. Tenants' use of the Wave smart thermostat's advanced features, in the context of this study, is intimately linked with identifiably energy-conscious heating behaviors in their home. Students' consciousness of their energy use can be severely limited by a utilities-inclusive bill format, which maintains separation between students' lifestyles and their influence on heating demands.

The Boiler Data Are Not Optimal for Behavioral Analysis

The boiler logging data from Worcester Bosch were intended primarily for a diagnostic tool to monitor the operation of the boilers themselves, and the parameters recorded are tailored to that purpose rather than to user interaction with the heating system. This limited the conclusions that we could draw from the data. As we compiled the entire heating season's data for the four other HMOs, we struggled to assemble the charts with the Worcester Bosch logging data because we were not sure of the most useful ways to represent the data. Bosch provided us with the nine variables referenced in the Methods section, but many of them were not used in our analysis; our visualization tool only showed the primary temperature of the boiler (PrimT) and the hot water outlet temperature (HW outlet).

We did not focus on the power output data because it is optimized for monitoring boiler performance rather than behavioral patterns. The boiler's power draw can be influenced by many factors, many of which are specific to the house in which the boiler in installed; physical differences between each of the five properties prevented a direct comparison of their power data because power demand is not a product of heating habits alone. For our purposes, the Actual

Power variable can do little more than identify when the boiler is active, and this is something we can discern in greater detail with the primary temperature and the hot water temperature.

The hot water data provided us with an easy way to identify times when the tenants were not home, as the hot water would be low or off while they were gone. However, we originally intended to use these data to analyze whether tenants were using their hot water in an energy conscious manner. It was difficult to discern behavior based on when the hot water outlet was turned on and the temperature of the hot water output. Ideally, we would have been able to identify when tenants showered and cleaned their dishes, and we would have compared the responses from our survey in order to compare expressed and observed behavior. Figure 4 shows an example of the hot water use for an arbitrary HMO in our study. The vertical orange lines (Hot Water Active) in this chart represent when the hot water was reported to be in use and the blue line (Hot Water Outlet) follows the temperature of the boiler's hot water outlet. Ostensibly, all increases in HW Outlet correspond to a HW Active spike. However, there are instances where the hot water's temperature increases but it is not flagged as "active". We were unable to account for these discrepancies, and this confusion made it difficult to draw reliable conclusions about the tenants' hot water behavior. However, we are unsure if this was an issue in the logging data, or the code we wrote to generate the charts.

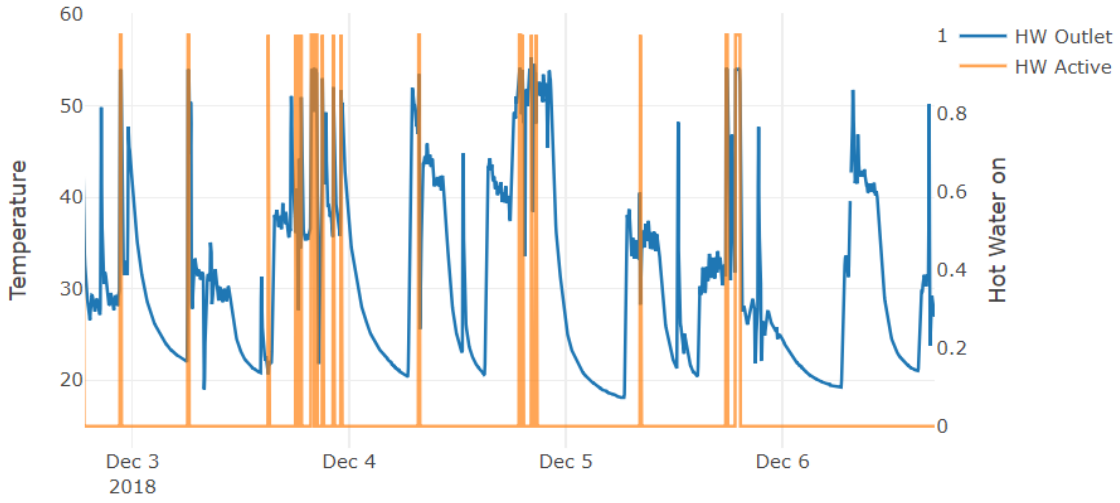

Figure 4: Example of Hot Water Use

The Central Heating Active variable was not helpful in determining heating behaviors. Like Hot Water Active, it merely supplemented the primary temperature variable of the inside

the boiler. Whenever the temperature of the house drops below the thermostat set temperature, the boiler turns on and the Central Heating Active variable signals that this has occurred. Since the logging data track the activity of the boiler and not the thermostat, we could not determine whether any boiler activations were the result of tenants raising the thermostat or the house falling below the set temperature.

This left just the primary temperature of the boiler and the hot water outlet temperatures that were useful to display as a time series. These are the only variables that were useful in recognizing patterns in behavior because, when put together, they suggest whether or not the boiler is active and whether activity is due to central heating or hot water use. All that we could determine from this is whether or not the tenants appeared to be home at certain times and whether or not the tenants periodically lowered their heat use in order to conserve energy.

Use of The Wave Correlates with Energy Consciousness

The composite logging, survey, and interview data show that use of the Wave can make a dramatic difference in energy use. According to the Bosch logging data, the tenants of HMO 1 and 2 were the only ones that adopted a clearly discernible routine throughout the heating season; the heat would be turned off or lowered when the tenants were gone for a day or more, lowered overnight, and adjusted accordingly depending on the outside temperature. In both homes, the Wave was used to control the heat. Our surveys and landlord interviews supplement our claim that effective use of the Wave is a common variable in all energy-conscious HMOs.

The easiest way to understand energy conscious behavior is with a counterexample; what does energy use look like when it is not being consciously monitored and controlled? It can best be viewed in the case of HMO 4. Figure 5 represents the primary temperature and hot water temperature of the boiler in HMO 4 during the coldest week of the year. We are confident that the tenants were in the house during this time because of the hot water data, which flatlines for long stretches of time, but periodically spikes. These brief spikes are likely caused by a tenant using the hot water. The boiler's primary temperature levels off around 67°C for much of the week. The chart indicates that the boiler was active for four days straight at the end of the week. While we do not claim that these tenants always neglect to manage their energy, as we do not have sufficient survey data or a landlord interview to help draw any reliable conclusions, this

particular week is a good counterexample to the energy conscious behavior we found in HMO 1 (discussed below).

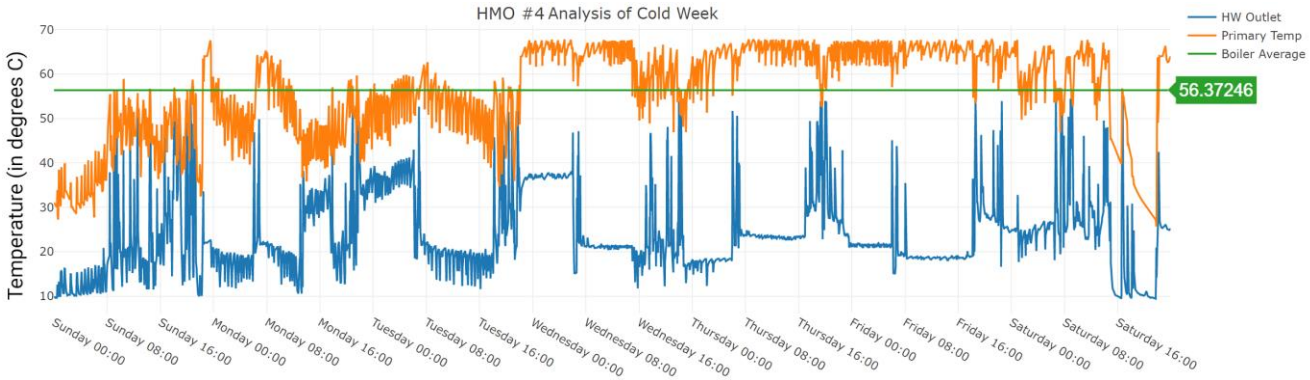

Figure 5: HMO 4 Cold Week

Figure 6 was a strong indicator that the tenants in HMO 1 were mindful of their energy use. This chart shows the primary temperature and hot water temperature of the house over Christmas holiday. The lack of activity during this period is consistent with responsible heating behavior; we did not expect the tenants to be home during the break, and Figure 6 confirms that expectation because there was no hot water use during that period. Because both the hot water and the boiler are inactive during this period, we believe that the tenants in HMO 1 were diligent enough to turn their heating system off over the holiday. We also see the system resuming activity at the beginning of January, which is when the tenants returned.

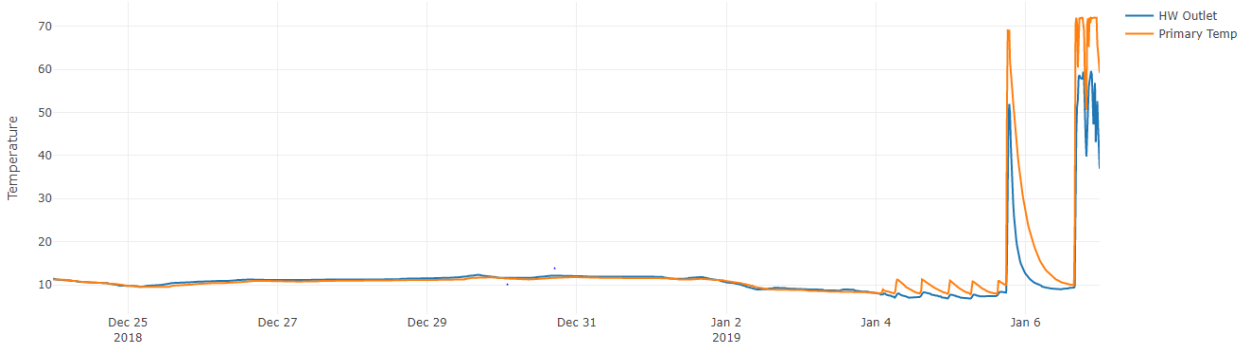

Figure 6: HMO 1 Christmas Holiday

Figure 7 provides further evidence of energy-conscious behavior in HMO 1. The chart shows the primary temperature and the hot water outlet temperature of the heating system during the coldest week of the heating season. The data presented indicate that the Wave's features are being used to precisely control the activation of the heating system. As the boiler is activated,

either to supply hot water or heat the radiators, the boiler's primary internal temperature—represented by the orange line—peaks to 72°C. When this line plateaus, the boiler is actively heating at a constant, maximum temperature. In the cases where the primary temperature drops considerably, the thermostat has either been lowered or the boiler has become inactive. Results from our surveys and interviews suggest that these drops correspond to when the tenants leave the property for an extended period of time or when they go to bed for the night. The data retrieved from HMO 1 are full of swells and dips that occur at similar times of day throughout the week, which implies that the residents of this property adhere to an energy-conscious heating routine. As indicated in Figure 7, the boiler becomes active at 8:00AM every day, and other isolated periods of boiler activation later in each day are likely reflective of tenant presence in the home. While we cannot say exactly how much energy this behavior saves the house, we can say that the student tenants in HMO 1 have firm control of their heating system, in part because of their effective use the Wave's mobile features.

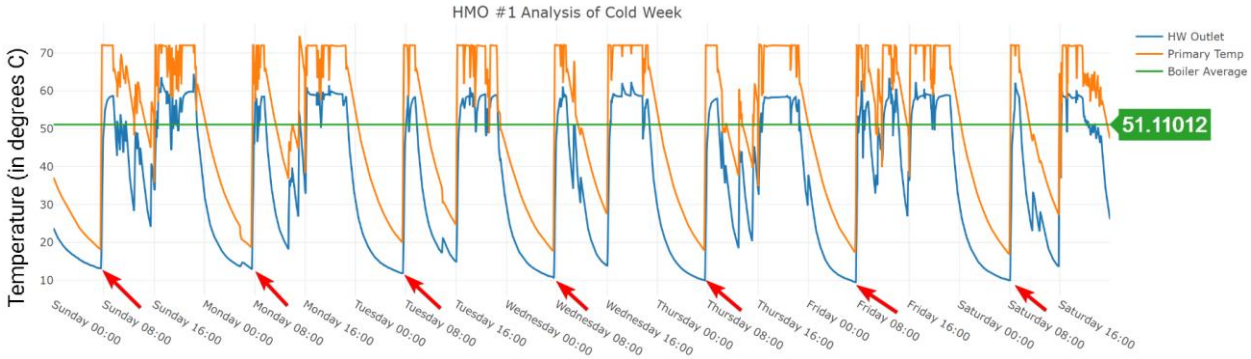

Figure 7: Boiler Temperatures for HMO 1 During the Coldest Week

In our interview with the landlord of HMO 1, we found that all of the tenants understood and used the Wave's features. At the beginning of their tenancy, the landlord spoke with the tenants to discuss how to effectively use the Wave heating system. The landlord even stated that the residents were "better with the app than I am," despite the fact that they had only been using it for half a year. Although our survey only garnered one response from this HMO, the respondent said that they used the Mobile Temperature Adjustment and Data Visualization features, which are both available on the Bosch Control phone app. Despite the lack of survey participation, we expect that the landlord is correct in saying that most, if not all, of the tenants use the Wave. It is very unlikely that a lone tenant would be able to so effectively adjust the

heating system in line with their housemates schedules. This supports the claim that tenants' engagement in effective heat management correlates to their use of the Wave.

Using similar data analyses, we discovered that HMO 2's heating system was also managed effectively. Figure 8 shows HMO 2's boiler to be inactive over Christmas holiday, when we assume the house was vacant. At the beginning of January, we once again see the tenants returning to the house, reflected in the reactivation of the heating system.

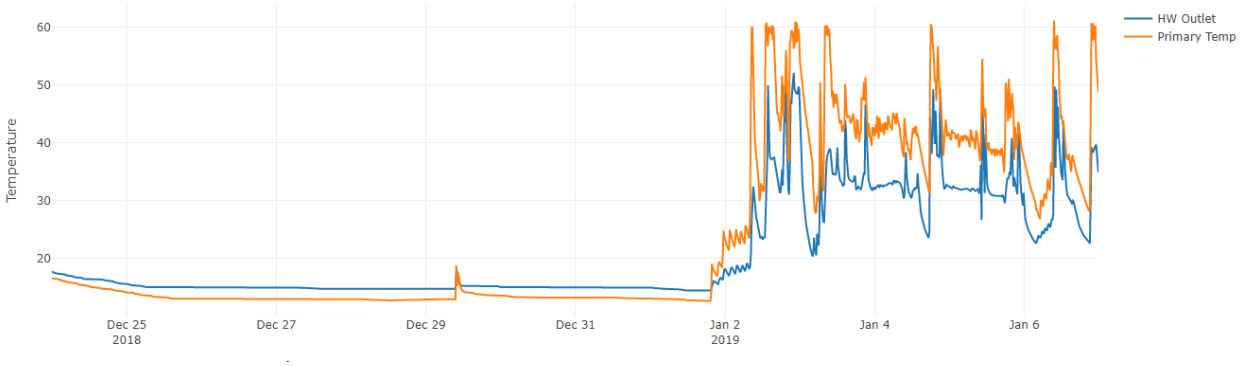

Figure 8: HMO 2 Christmas Break

Still, the logging data from HMO 1 and HMO 2 exhibit slightly different behaviors. Figure 9, which shows the primary temperature and hot water outlet temperature of HMO 2 during the same cold week as in Figure 7, exhibits slightly different behavior; the data retrieved from HMO 2 are more 'noisy' than in HMO 1, and do not exhibit the same level of discernable periodicity. This chart lacks the smooth dips associated with an inactive boiler and instead oscillates around a constant temperature, which itself fluctuates from time to time. This indicates that the thermostat is merely lowered, so the boiler remains active throughout the week. While this would lead us to believe that the heating system in HMO 2 consumes more energy than the one in HMO 1, we have to take into consideration that the highest the primary temperature reached here is only 62°C, which is a full 10° less than the 72°C of HMO 1. Richard Forrester of Worcester Bosch suggested that a boiler at a lower primary temperature setpoint[3] would be active for a longer period of time but could be more energy efficient than one that is on for shorter periods of time at a higher temperature.

[3] Each boiler leaves the factory with a default primary temperature setpoint, which can be adjusted by a user once installed in a home.

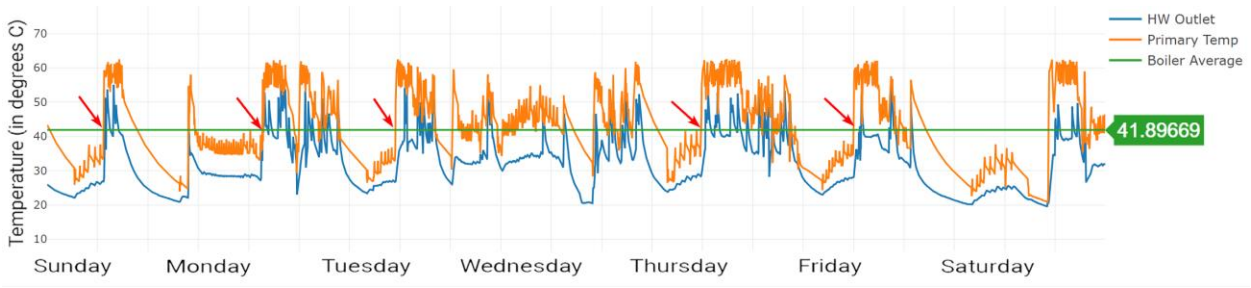

Figure 9: Boiler Temperatures for HMO 2 during the Coldest Week

Despite the uncertainty of its relative energy efficiency, the boiler in HMO 2 still appears to be utilized in a manner which reflects tenants' comings and goings, which suggests energy consciousness. While the system is not completely inactive when the tenants leave, as was the case in HMO 1, it is still lowered significantly. All three tenants responded to the survey and surprisingly they indicated that they do not know about any of the Wave's features and rarely make conscious decisions in managing their energy use in the house. While we were initially confused by how these survey results could lead to such a well-managed heating system, it was explained once the landlord of the HMO revealed to us that they were remotely controlling the house's heat.

In our interview, the landlord appeared to be worried about the environmental impact of the tenants' excessive heating, saying that "...they use far too much [heat]. It's not so much about the money, it's about wastage…". While the tenants do not pay attention to their own energy consumption, which is reflected in our surveys, the landlord ensures that the system is being used effectively by remotely adjusting the thermostat's temperature setting accordingly when the house is vacant. This intervention results in the apparently energy-conscious pattern we see in the logging data. The landlord believes that the Wave is an amazing accessory to the HMO's heating system, and avers that "if everyone were to engage with [the system] properly, then there are no limits" to its energy management potential. This HMO is yet another example of the Wave being used to effectively manage heating and energy consumption in an HMO.

The influence of the use of the Wave on energy demand is most clearly demonstrated in the juxtaposition of HMO 1 and HMO 4. In our interview with the landlord of HMO 1, we learned that their tenants not only understood the how to effectively use the Wave app after they were taught how to operate it, but they also used it on a regular basis. While they did not control the thermostat's Holiday Programme feature, which designates certain dates to automatically adjust

the temperature, the tenants did use the app's remote temperature control to raise and lower the heat and its Mobile Data Visualization tool to monitor their monthly energy consumption. Unlike the respondent from HMO 1, the respondent from HMO 4 had no knowledge of the smart thermostat features and seemed to be less energy-conscious. When asked whether or not the tenants consciously tried to save energy by reducing heat and hot water consumption, the respondent from HMO 4 said that they sometimes did so, while the respondent of HMO 1 said that they always did so.

These behaviors are directly reflected in the HMO logging data. Figure 10 shows the primary boiler temperatures for HMO 1 (left) and HMO 4 (right) during the coldest week of the 2018-19 heating season, from January 27th to February 2nd, and the hottest week, from February 24th to March 3rd. HMO 1 shows the typical daily peaks and troughs in the usage of the boiler in both the hottest week and coldest week of the heating season. The boiler is inactive for a significant portion of each day in both weeks. On the other hand, HMO 4's heating system lacks this periodicity and only ever seems to turn off completely one time during the hot week, which suggests neither the tenants nor landlord are monitoring and controlling energy use. We should also point out that the average primary temperature of the boilers throughout the hot week were fairly similar, although the average in HMO4 was marginally higher in the cold week and lower in the hot week. Average boiler temperature, however, is not a good measure of total energy use.

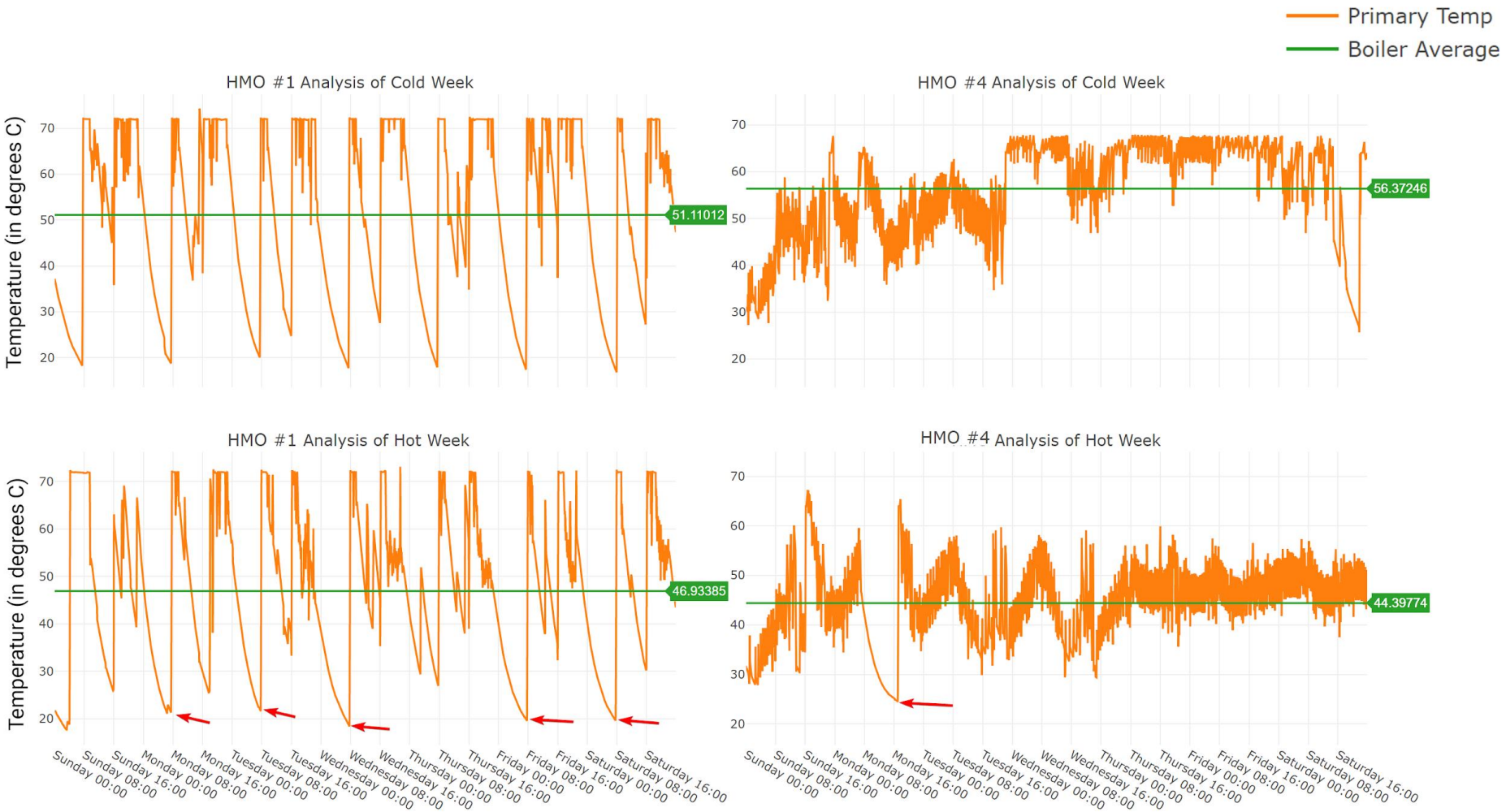

Figure 10: Boiler temperatures for HMO 1 (left) and HMO 4 (right) during the hottest and coldest weeks of the 2018-19 heating season

Smart Thermostat Use Correlates with Education

The student surveys show each student tenants' apathy toward the smart thermostat system in the HMOs. Figure 11 shows the collective answers from the six respondents from four of the HMOs where they were asked whether they used, did not use, or did not know about the features of the Wave. Only the sole respondent from HMO 1 indicated that they use any of the features of the Wave. However, it is unlikely that one tenant would be able to manage the heat around their housemates' schedules so effectively; it is likely that the other tenants in HMO 1 use the app to manage the heat as well. The remaining five respondents from the other HMOs either stated that they did not use the features or did not know about them.

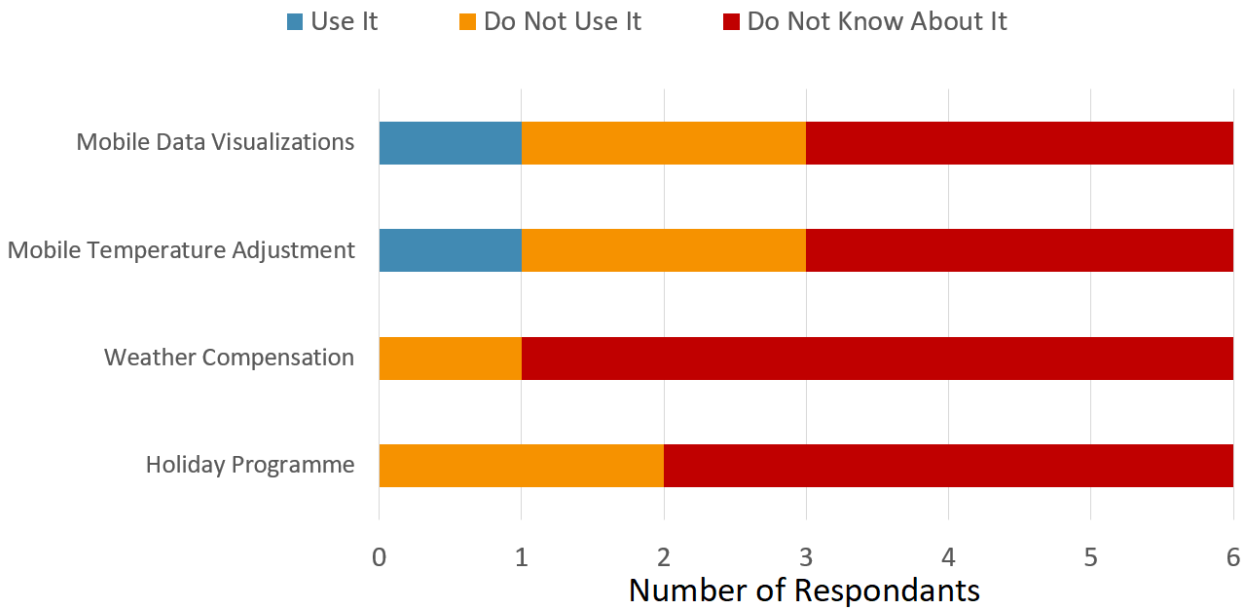

Figure 11: Student Tenants' Knowledge and Use of the Wave's features

Whether or not the tenants use the Wave seems to be correlated with the approach the landlord uses when speaking with the tenants. Table 2 overviews how the landlords' education methods, or lack thereof, influence the behavior of the tenants in each HMO. HMO 1 epitomizes the results of an effective education scheme. The landlord took the time to show the students how to use the app and its specific features, and the students took the time to apply this teaching to their energy management. These students recognize the value of the app because the landlord showed them specific features that would reduce their overall energy use, and thus helped them manage the boiler to reduce heating costs.

Table 2: Summary of HMOs

HMO #	Landlord's Actions	Tenants Use the App?	Managed Energy Use?
1	Showed tenants how to use the app	Yes	Yes
2	Told the tenants about the app	No	Yes
3	N/A	N/A	Yes
4	N/A	No	No
5	Did not tell tenants about the app	No	Offline Logger

However, unless the respondents in the HMOs were specifically taught how to use the smart thermostat features, they did not use them. The landlord of HMO 2 simply told their tenants that the Wave app existed, and the tenants did not use the app. Of the three respondents from this house, two of the three tenants were not aware of any of the features of the Wave, showing that simply telling the students the app exists is not enough to convince them to use it. The only reason the logging data from this house reflected energy-conscious behavior was because the landlord uses the app themselves to control heating system. The landlord of HMO 5, at best, provided the residents with a guidebook on managing a general heating system; the landlord was unsure of whether or not this was the case. The respondent from this HMO stated that they do not use any of the Wave's features and that they never took actions to be energy-conscious. We were unable to identify whether the heating behavior in this house was energy-conscious because the data logger was offline in this house, however it is clear by looking at the other HMOs that the education about the Wave corresponds to its use.

Billing Methods Play a Significant Role in How Tenants Use Their Heat

From our landlord interviews and background research, we found that billing methods play a significant role in how tenants use their heat. Specifically, when the amount of energy consumed is not reflected clearly in the monthly bill, tenants pay less attention to how

much energy they use. Given capped utilities and inclusive bills, tenants do not explicitly see the cost of their previous month's energy consumption, so they have no financial incentive to restrict their heating behavior. In fact, the caps are often calculated to provide a large amount of leeway in what is expected of the house to spend, meaning the tenants would pay for energy they do not even use.

In our interviews with the landlords of both HMO 1 and HMO 2, the interviewee revealed that past tenants would often spend up to the capped energy expense. In HMO 1, the current tenants actually use the Wave's Mobile Data Visualization to monitor their heat use throughout the month; their landlord said that "they'll go up to [the cap], but not sort of above. They are more conscious when using the app, in turning [the boiler] on and turning it off". This means that these tenants are willing to use their heat enough to reach near the cap and will use the app to ensure they do not go over.

The landlord of HMO 2 believes that the cap they implement is rather generous, yet the tenants still use their heat excessively. This is in part because they are paying for the energy anyway, so they might as well use it. Including the utilities in the rent also lends itself to the neglect the tenants show their energy use. Without some indication of how their heating habits affect their utilities cost, the tenants do not worry about limiting their consumption.

Conclusions and Recommendations

Through analysis of survey data, logging data, and material from our literature review, we reached several notable conclusions about both our study subjects and the research tools we were afforded. Based on these findings, we have provided several recommendations for stakeholder actions to improve the completeness of future research in this arena, the energy impact of HMO rental schemes, and student tenant heating management. The key findings from our research, and our corresponding recommendations, are as follows:

- **Conclusion 1: The Worcester Bosch logging data were not intended for behavioral analysis.** The logging data collected from the sample of HMOs were intended primarily as a diagnostic tool to monitor the operation of the boilers themselves, they were not intended to monitor resident behaviors. While we were able to draw useful conclusions

from these data, the quantitative observations that could be made were valuable but somewhat limited.

- **Recommendation 1: Worcester Bosch consider installing additional sensors to monitor internal HMO temperature, real-time thermostat settings, and localized weather temperatures**. Worcester Bosch currently logs nine variables for use in Energize Worcester projects. While these variables are useful for diagnostic boiler maintenance, they are not sufficient for the behavioral analysis we aimed to perform. Access to data from these additional variables would facilitate more complete data analysis in future projects.
- **Conclusion 2: Proper education encourages energy-conscious behavior**
    - **Conclusion 2.1: Use of the Wave encourages energy-conscious behavior.** Our survey and logging data indicate that tenants active use of the Wave smart thermostat can make a dramatic difference in a house's energy use. The houses in our sample set which demonstrated the most energy-conscious behavior reported that they used the Wave's features to manage their boiler. Conversely, houses in which neither tenants nor the landlord claimed to use the Wave demonstrated a lack of energy-conscious behavior.
    - **Conclusion 2.2: Education encourages smart thermostat use.** Through our surveys of students and landlords, we learned that student tenants are more likely to use the Wave's 'smart' features if they are directly taught how the system works. In those houses where the landlord took the time to explain the Wave and heating system the tenants demonstrated more energy-conscious behavior. Tenants whose landlords did not take such measures reported limited knowledge and use of their Wave thermostat.
- **Recommendation 2: Properly educate students/tenants**
    - **Recommendation 2.1: The University of Worcester educates its students on how to effectively manage their energy use.** We found that the Worcester Students' Union's primary role in student off-campus housing is assisting students

in finding comfortable homes; they are less focused on educating students on energy-conscious behavior. For many students moving off-campus, it is likely their first time having complete control over their energy consumption. An effective education scheme would enhance student awareness of energy consumption and conservation and help them increase their comfort and reduce their living costs.

    - **Recommendation 2.2: Landlords spend the time to properly show the student tenants how to manage their heating system.** We observed that the tenants in one HMO managed their heating use much better than their counterparts in the other HMOs. We attributed this to their landlord thoroughly teaching them about the features of their Bosch heating system and the Wave app. Other landlords either just told their tenants the Wave's app existed or did nothing at all. Educating the tenants on how to use their heating system would give them effective agency to manage their heating use on their own.

- **Conclusion 3: Billing methods play a significant role in how tenants use their heat.** Our interviews with landlords, Worcester Students Union staff, and a local letting agent led us to conclude that the recent shift in rental billing formats has impacted students' personal investment in their heat use. According to our research, utilities-inclusive rent and capped energy expenses standardize and homogenize rent payments, effectively simplifying rent plans, but this removes students' incentive to monitor and adjust their use of energy for heating and hot water.

- **Recommendation 3: Landlords investigate options to financially incentivize tenants to be more energy-conscious.** In our research, we concluded that inclusive bills and capped energy expenses lead to tenants' lack of incentive to monitor their energy use or adopt more responsible heating habits because they do not see the monetary cost of their behavior. The addition of financial incentives to promote energy-conscious behavior or the removal of billing methods that hinder energy-awareness may convince the tenants to manage their heating effectively.

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Appendix A: Sponsor Description

The Worcester Bosch Group, founded in 1962, is a mid-sized company of over 1,600 employees (Boiler Guide, 2014) headquartered on the outskirts of Worcester, United Kingdom. Its principal focus is the manufacture, sale, and installation of gas and oil heating products, including boilers, hot water cylinders, heat pumps, and solar water heating systems, as well as controls and accessories. Worcester Bosch's parent company, Bosch Thermotechnology, Ltd., has a broader range of products, including refrigerators, dishwashers, coffee pots, stoves, and lawn mowers/trimmers (Bosch Garden Tools, 2019). In addition, they have smart software for many of their devices available on the app store.

Figure 1: Map of Worcester, with the Worcester Bosch Group offices highlighted (Google, n.d.)

The Worcester Bosch Group is committed to providing reliable products, on-time deliveries, and customer consultation. They are also dedicated to improving the community of Worcester by mentoring students, performing charity work, providing books to local primary schools, and financially supporting both the arts and the Chamber of Commerce. They were chosen by "Which?" boiler report for the "Best Buy" from 2012-2016 (Worcester Bosch Group, n.d.), indicating the impact of their mission. This is further evidenced by the company's popularity among consumers; 2 million Worcester combination boilers are currently in use, and a Trustpilot user survey rated these boilers 9.1 out of 10 with 8756 reviews (Worcester Bosch Group, n.d.).

Customer service is taken very seriously by the Worcester Bosch Group. Their website provides various means of easy-to-use customer service, which includes both a call center and a 24-hour online support system. They keep their boiler-use manuals, a list of accredited installers, and a library of YouTube video tutorials for "Home Heating Tips" online. If a customer has an issue with their boiler, they can use the company's website as a guide to fix it themself, or to schedule a professional fix (Worcester Bosch Group, n.d.).

In recent years, the Worcester Bosch Group has made efforts to support environmentally sustainable practices. They give out awards to engineers, architects, and even children for different competitions relating to energy efficiency as part of their Environment 2020 initiative. Children have the ability to enter the Children's Art Competition to raise awareness of energy efficiency. This artwork, and most importantly, the process of creating the artwork, is designed to get the children to think about the environment. The Bosch Group has even published a children's book promoting the use of renewable resources. Professionals compete in the Installation Competition, in which the product installer who has the most positive impact on the environment wins an "Installation of the Year Award". This award goes out to installers of an array of boilers and heat pumps. An additional award is reserved for installers of combinations of an various Worcester products. (Worcester Bosch Group, n.d.).

Figure 2: A picture of a Worcester Bosch Group Combi Boiler (The Hamilton Group, n.d.)

The Worcester Bosch Group are most known for their boilers, claiming to be "The UK's Most Loved Boiler Brand" for gas and oil boilers in 2018 (Worcester Bosch Group, n.d.). Their website guides consumers to the optimal boiler for their home, asking them for the type of home they have, how many bedrooms, how many bathrooms, and where within the home the boiler would be placed. Consumers are then directed to a bespoke heating solution. A common recommendation is the combination, or "combi", boiler which exposes cold water to coils of very hot water to heat it up quickly, providing an on-demand hot water supply, as opposed to having a standing tank full of hot water that could run out and be inefficient if not insulated correctly.

Bosch has a long history leading to their appliance dominance in Worcester. In 1886, Robert Bosch founded the "Workshop for Precision Mechanics and Electrical Engineering" in Stuttgart, Germany (Worcester Bosch Group, n.d.). By the 1900's Bosch was one of the few reliable installers and providers of ignition magnetos for engines requiring a spark-ignition. During the 1960's, Bosch became more and more globalized, with self-managed groups in all areas of the globe, dealing in a wider variety of electric appliances. However, it would take Bosch nearly 30 years to expand into Worcester. Worcester

Engineering was formed in 1962, and by 1963 was a leading supplier of oil-first central heating equipment. After a fire destroyed their main factory in 1983, they rebuilt and began serious research on a rising technology, the combination boiler, which had been making periodic waves in the UK since 1971. When Bosch came to Worcester in 1992 after two years of negotiations with Worcester Heating Systems (the new name was decided upon following their entry into the London Stock Market). With increased funding and a strict refocus on home boiler appliances, Worcester Bosch integrated Smart technology with the 2014 launch of "the Wave", their first smart thermostat. Consumers could now control the temperature of their homes remotely with the use of a smartphone app. In 2019, the Wave was replaced by "EasyControl", a similar but more dynamic product that advanced the use of smart technology (Worcester Bosch Group, n.d.).

With the introduction of the Wave, Worcester Bosch aimed to remove some of the difficulty typically inherent in the management and understanding of thermostat controls, and make it "smart" and have it manage the heat in a more efficient way. However, according to a previous IQP, the team reported that use of the Wave was very inconsistent and that students were not motivated to learn a new control system, smart or traditional. In spring of 2018, Worcester Bosch introduced the "Bosch EasyControl" which is the successor to "the Wave." (Professional Heating & Plumbing, 2018) The EasyControl at first glance appears to be much more intelligent and has a much better user experience and interface, making it easier for their average consumer to understand how to use it. The EasyControl has not been installed in any of the five HMO's to which we have access; however, they will be installed in the summer of 2019. The EasyControl also appears to be a much more in-depth project, with videos on YouTube that explain the product in much more detail, and with other accessories such as the "smart radiator thermostats" or "Smart TRVs" that allow the EasyControl to individually manage the heat outputted by a radiator. Also, the EasyControl supports Amazon's Alexa platform and

Figure 3: The Bosch EasyControl system (Professional Heating and Plumbing, 2018)

will be adding more compatibility in the future, showing the dedication that Worcester Bosch has to this product, and to making it more user friendly.

Our project is relevant to the Bosch Group's mission, as its aim is the more efficient usage of the company’s boilers by college students living in HMO's, and investigating how new ‘smart’ controls could improve efficiency. Understanding how tenants interact with Bosch heating and boiler systems, and assessing their demand for hot water and heat, will assist the Bosch Group in developing controls that are more conducive to consistent and responsible device usage and, ultimately, improved efficiency in homes.

Appendix B: Interview Preamble for Landlords, Students' Union, and Letting Agencies

We are students from Worcester Polytechnic Institute in the United States. We are conducting research on energy use in student off-campus housing in collaboration with the University of Worcester and Worcester Bosch. We appreciate you taking the time to share your opinions. Your participation in this interview is completely voluntary; you may refrain from answering any question, and may end the interview at any time. Should we use any information from this interview in our final report, we will give you an opportunity to review the materials prior to publication. May we quote you by name, or would you prefer to remain anonymous? Is it alright if we record the interview today? We will only use the recording to verify our notes and any quotations we might use. May we proceed?

Appendix C: Tenants Survey

Student Heating Survey

We are students from Worcester Polytechnic Institute in the United States. We are conducting research on energy use in student off-campus housing, in collaboration with the University of Worcester and Worcester Bosch. Your property is part of a pilot study organized by Worcester Bosch and the university, and was provided with a smart thermostat and a boiler a few years ago. We appreciate you taking the time to share your opinions. Your participation in this survey is completely voluntary. Your responses will remain anonymous and the survey will take less than 15 minutes.

1. **What year are you in the University of Worcester?**
   Mark only one oval.
   - ◯ First year
   - ◯ Second year
   - ◯ Third Year
   - ◯ Other: _____

2. **What course are you studying at the University?**
   _____

3. **How many people live at this property?**
   Mark only one oval.

1	2	3	4	5	6
◯	◯	◯	◯	◯	◯

4. **When did you move in to this household (month, year)?**
   _____

5. **Who is your landlord?**
   _____

6. **Does your rent include heat and hot water or do you pay for those separately?**
Mark only one oval.

- ◯ Rent includes heat and hot water
- ◯ We pay for heat and hot water separately from our rent

Now we would like to ask some questions about the temperature in your home:

7. **Did you consider your house to have been an overall comfortable temperature this past winter?**
Mark only one oval.

- ◯ Yes
- ◯ No

8. **Please indicate how comfortable the temperature was in each room.**
Mark only one oval per row.

	Very Uncomfortable	Somewhat Uncomfortable	Neutral	Somewhat Comfortable	Comfortable	N/A
Kitchen	◯	◯	◯	◯	◯	◯
Bathroom	◯	◯	◯	◯	◯	◯
Living Room	◯	◯	◯	◯	◯	◯
Your Bedroom	◯	◯	◯	◯	◯	◯

9. **What measures would you take if you were too cold in any of the following rooms?**
Check all that apply.

	Put On More Layers	Turn Up the House's Thermostat	Adjust the Room's Individual Radiator	Nothing	Other
Your Bedroom	☐	☐	☐	☐	☐
Other Living Areas	☐	☐	☐	☐	☐

10. **If you selected "Other" in the previous question, what are these additional measures that you take?**

11. **Which of these measures would be your first response?**
Mark only one oval per row.

	Put On More Layers	Turn Up the House's Thermostat	Adjust the Room's Individual Radiator	Nothing	Other (from above)
Your Bedroom	◯	◯	◯	◯	◯
Other Living Areas	◯	◯	◯	◯	◯

12. **What measures would you take if you were too warm in any of the following rooms?**
Check all that apply.

	Remove Layers	Turn Down the House's Thermostat	Adjust the Room's Individual Radiator	Open a Window	Nothing	Other
Your Bedroom	☐	☐	☐	☐	☐	☐
Other Living Areas	☐	☐	☐	☐	☐	☐

13. **If you selected "Other" in the previous question, what are these additional measures that you take?**

_____

_____

_____

_____

_____

14. **Which of these measures would be your first response?**
Mark only one oval per row.

	Remove Layers	Turn Down the House's Thermostat	Adjust the Room's Individual Radiator	Open a Window	Nothing	Other (from above)
Your Bedroom	◯	◯	◯	◯	◯	◯
Other Living Areas	◯	◯	◯	◯	◯	◯

Now we would like to ask you some questions about the thermostat that Worcester Bosch installed, called the Wave.

15. **Which, if any, of these Wave features do you use?**
Mark only one oval per row.

	Use It	Do Not Use It	Do Not Know About It
Holiday Programme (Set dates for your boiler to automatically control the heat while the house is vacant)	◯	◯	◯
Weather Compensation (The boiler uses the outside temperature to maintain a comfortable home climate)	◯	◯	◯
Mobile Temperature Adjustment ("Bosch Control" Phone App)	◯	◯	◯
Mobile Data Visualizations	◯	◯	◯

16. **If you were home alone, to what temperature would you set the thermostat (degrees Celsius)?**

_____

17. **Do you and/or your housemates ever disagree about your thermostat's temperature setting? (i.e. one person wants to lower the temperature while someone else wants to raise it)**
Mark only one oval.

◯ Yes
◯ No

18. **If you answered yes to the previous question, how are these disagreements typically settled?**

_____

_____

_____

_____

_____

19. **Please indicate below how frequently you adjust the thermostat when you are going to be away from the house for a given period of time.**
Mark only one oval per row.

	Never Adjust Thermostat	Sometimes	Always Adjust Thermostat
A Few Hours	◯	◯	◯
Full Day	◯	◯	◯
Weekend	◯	◯	◯
Longer	◯	◯	◯

Now we would like to ask you some questions about your hot water use:

20. **Please indicate all of the times that you and your housemates typically shower (tick all that apply if you shower more than once a day).**
Check all that apply.

	Morning	Afternoon	Night	Variable
You	☐	☐	☐	☐
Housemate 1	☐	☐	☐	☐
Housemate 2	☐	☐	☐	☐
Housemate 3	☐	☐	☐	☐

21. **Approximately how long, in minutes, do your showers typically last?**

_____

22. **Do you have a washing machine in your house?**
Mark only one oval.

◯ Yes
◯ No

23. **Approximately how many times a week do you and your housemates use the washing machine?**

_____

24. **How often do you and your housemates generally wash dishes?**
Mark only one oval per row.

	After Each Meal	Daily	Weekly	Not at All
You	◯	◯	◯	◯
Housemate 1	◯	◯	◯	◯
Housemate 2	◯	◯	◯	◯
Housemate 3	◯	◯	◯	◯

25. **Please indicate how consciously you and your housemates try to save energy by controlling your heat and hot water consumption.**
Mark only one oval per row.

	Never	Sometimes	Always	Unsure
You	◯	◯	◯	◯
Housemate 1	◯	◯	◯	◯
Housemate 2	◯	◯	◯	◯
Housemate 3	◯	◯	◯	◯

Thank you for taking the time to complete this questionnaire. If you have any questions, please feel free to contact us at j.pinzer@worc.ac.uk

Appendix D: Landlords Interview Script

We'd like to start off by asking about your general role as a landlord.

- We understand you are the landlord for the student HMO at *Address*, how long have you owned that property?
- How long have you been renting it to students?
- How many other properties do you manage?
    - How many of these properties house students?
- What are the differences between managing the student HMOs vs other properties?

Now we would like to ask some questions about energy use and management in student HMOs in particular.

- Does the rent at *Address* include utilities?
    - Is this the case at your other properties?
    - Have you always included utilities in the rent at *Address*?
        - If not, when did your approach change and why?
    - Have you implemented a capped energy expense?
        - If so, why?
    - Did you notice any change in energy use at this property after you moved to these billing methods?
- When you rent to students, do you discuss how they should manage their heat and hot water use? What do you discuss?
- When did she have this convo? Maybe beginning of the tenancy?
- As you know, Worcester Bosch installed a new boiler and smart thermostat (called the Wave) in your HMO at *Address*.
    - Have you noticed any change in the utility costs since that installation?
    - I thought she
    - Why do you think costs have/have not changed?
    - Do you manage any other properties that don't have this sort of heating system?

    - If so, what differences have you noticed between properties with and without smart systems?
- Have you used the Wave app on your phone?
    - What do you use it for?
- What do you think would encourage students to better manage their heat and hot water use?
    - Do you explain to the current tenants how to use the boiler and Wave thermostat?
    - Do you see any limitations of the energy management system in the student HMO? What are they?
- Do you have any concerns about how tenants manage their heating?
    - Is there an ideal way you'd have your tenants manage their heat?
- How significant a role do you think a tenants' heating behavior plays in the house's overall energy use (keeping in mind other factors such as the HMO's physical properties and the heating system technology)?
- It is common for students to open windows to get fresh air into a room or to mediate the temperature in their room without worrying about the thermostat. Have you noticed this sort of behavior with your student tenants?
- How do you try to minimize heat loss in your properties?
- Are you familiar with Thermostatic Radiator Valves?
- Are there TRVs installed in this property or any property you manage?
    - If yes, do TRVs generally help reduce heating costs in the properties you manage?
    - If no, any plans to install them in the HMOs?
- Are there any other observations you have noticed regarding your tenants' heating and hot water use?

Appendix E: Letting Agency Interview Script

We'd like to start off by asking about your general role as a letting agent.

- What is *Agency*'s role in managing the property at *Address*? Does the agency handle items such as:
    - Recruiting student tenants
    - Handling general repairs based on tenant complaints (e.g., boiler)
    - Paying utility bills, collecting rent, etc.
- How long has *Agency* been managing this property?
- How many other properties does *Agency* manage?
- How many of these properties house students?
- What would you say are the differences between managing the student HMOs and other properties?

Now we would like to ask some questions about energy use and management in student HMOs in particular.

- Does the rent at *Address* include utilities?
    - What are the advantages and disadvantages of doing this?
    - Have you always included utilities in the rent?
    - Have you implemented a capped energy expense?
        - If so, why?
    - Did you notice any change in energy use at *Address* after you moved to inclusive rents?
- When you rent to students, do you or the landlord discuss how they should manage their heat and hot water use? What do you discuss?
- As you may know, Worcester Bosch installed a new boiler and smart thermostat (called the Wave) in the HMO at *Address*.
    - Do you manage any other properties that have smart thermostats?
    - If so, what differences have you noticed between properties with and without smart systems?

- What do you think would encourage students to better manage their heat and hot water use?
    - Have you or the landlord explained to the current tenants at *Address* how to use the boiler and Wave thermostat?
    - Do you see any limitations of the energy management system in the student HMO? What are they?
- Do you have any concerns about how tenants manage their heating?
    - Is there an ideal way you'd have your tenants manage their heat?
- How significant a role do you think a tenants' heating behavior plays in the house's overall energy use (keeping in mind other factors such as the HMO's physical properties and the heating system technology)?
- Are there any other observations you have made regarding your tenants' heating and hot water use?
- It is common for students to open windows to get fresh air into a room or to mediate the temperature in their room without worrying about the thermostat. Have you noticed this sort of behavior with your student tenants?
- How do you try to minimize heat loss in your properties?
- Are you familiar with TRVs?
- Are there TRVs installed in this property or any property you manage?
    - If yes, do TRVs generally help reduce heating costs in the properties you manage?
    - If no, any plans to install them in the HMOs?

Appendix F: Student Union Interview Script

- General introduction
    - What is your role within the Worcester Students Union?
    - How long have you been in this role / a leading member of the WSU?
- Programs Currently in Place Regarding Heating/Housing
    - What information is there for students for heating homes efficiently?
        - What are programs or Clubs they have to give students information?
    - How do you handle conflict resolution between landlords and tenants?
- Studies done by the Student Union
    - How much has the Worcester Students Union looked into cold homes around the University?
    - What are your key takeaways from the Homes Fit for Study Report?
- Future Plans
    - Are there currently plans to educate students on the impact of (in)efficient heating?
    - Are there plans to expand or improve the role the Worcester Students' Union plays in finding good housing for students?