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Placement topic:

Building performance and energy consumption

http://www.worcester.ac.uk

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List of abbreviations:

AEH: AE Houseman

BSM: Building Management System

EBB: Elizabeth Barrett Browning

DHW: Domestic Hot Water

DEC: Display Energy Certificate

LED: Light-Emitting Diode

I. Acknowledgments

At the end of my two-year degree in Thermal Engineering and Energy, I was required to do a twelve-week work placement. I had the opportunity to do this in England and decided to apply to various universities. Completing my work placement abroad was a great opportunity and I have found it very interesting.

Firstly, I wish to thank my English teacher, Karine Nadler, for helping me to find my work placement abroad, which was precisely what I was looking for.

Next, I would like to thank my work placement supervisor Katy Boom, Director of Sustainability at the University of Worcester, for her guidance.

I would like to thank the Estates team: Tom Mimnagh, Andy Lewis, David Mourby, David Norman, Nicole Green and Richard Owens for helping me throughout my internship.

I am grateful to Odette Fielding for taking time to explain the consumption of the Riverside building. Generally, the University as an organization has been supportive throughout my placement.

II. Introduction

I'm a second year student in Thermal and Energy Engineering at Belfort University and currently completing a twelve-week internship. The work placement comes at the end of the second year of a two-year degree in Thermal Engineering and Energy and is great opportunity to apply our skills in a real-life working environment. Thanks to Karine Nadler, I found an internship in England at the University of Worcester. I was based in the Facilities office, Hines Building and was supervised by Katy Boom. I carried out my placement from 4th April 2016 to 24th June 2016. During these 12-weeks, I worked from 08:45 AM to 04:45 PM.

The University of Worcester is the only institution of higher education serving the English counties of Worcestershire and Herefordshire. It is a British public university based in Worcester. With a history dating back to 1946, the institution was granted university status in September 2005. During the academic year 2014/2015 there were 10,065 students. The University has built several buildings in order to improve student life, including the Hive, a library which uses renewable energy, and the Arena, which offers unique services to local sport clubs in the community as well as elite and professional athletes. Since 2006, the number of people applying to study at the University of Worcester has more than doubled - a rate of growth much higher than the national average. Worcester has become sought after for several reasons:

- Highly relevant, very professional courses
- Excellent, inspiring teaching
- A truly friendly, inclusive approach with excellent student report
- An outstanding record of graduate employment
- A beautiful home in historic Worcester

Within the university, there are a great number of buildings. There are both academic and residential buildings. During my work placement, I was based in Facilities, Hines Building. There are several sub-departments within the Facilities office: Accommodation, Conferencing, Campus Services and Estates. Personally, I work in the later. I have six colleagues:

- Tom Mimnagh: Building Services Manager
- Andy Lewis: Projects Manager
- David Norman: Projects Manager
- David Mourby: Contracts & Compliance Coordinator
- Nicole Green: Facilities Administrative Assistant
- Richard Owens: Business and Administration Apprentice

Nowadays, sustainability is a huge issue affecting numerous industries. Many of these seek a positive image by demonstrating a responsible attitude towards the environment. The University of Worcester is looking to be as sustainable as possible.

It is apparent that sustainability now greatly influences the way we think and behave. Indeed, it's a key factor in the recruitment of students, hence why the University is trying to reduce its carbon footprint. People like to live environmentally friendly.

If we look at the carbon footprint, we can see it is divided into three parts:

- Direct emissions which we can control, relative to the consumption of boilers, exchangers
- Emissions due to the electricity supply
- Other emissions which are a consequence of staff activity or student activity

The latter is the most significant.

In 2014/15, the University of Worcester produced 21,013 tonnes of carbon dioxide The University aims to reduce these emissions by 40% by 2020.

The University has several targets which aim to improve the Display Energy Certificate (DEC) for all buildings:

- September 2014: all buildings should have a minimum of D for the DEC rating,
- September 2017: all buildings should have a minimum of C for the DEC rating,
- September 2020: 60% of the buildings should have a minimum of B for the DEC rating,
- All new buildings build should have the class B minimum.

My task is to examine consumption of buildings using the above targets as a guide. That's why I will study electricity consumption, gas consumption water consumption and solar production during my work placement. The University has different type of buildings. Indeed there are both residential and academic buildings, so each building will have a different consumption. However, my report focuses more specifically on residential buildings. My project is entitled 'Buildings performance and energy consumption.'

III. Gas consumption

In order to understand gas consumption, it is important to know which system is in use in each building. I visited all of the University's plant rooms to gain an understanding of their plant and equipment. Building sizes vary so I expected different installations, but I have seen similar things in different buildings. It is unusual because there should be a specific installation for each building to reflect these differences.

For all residential buildings there are combined boilers, so these are condensing boilers. This means that boilers are used for both heating and for Domestic Hot Water (DHW). These boilers are more efficient because they recover heat lost in fumes. If there is an important volume to heat, condensing boilers are more efficient. Moreover, this type of boiler is more environmentally friendly.

Usually a house needs between 25 and 60 W/m³. The lower value is for a house with good insulation and the higher value is in the event of poor insulation. But in this situation, the boilers are also used for DHW, meaning the value should be reconsidered.

1. Different heating installations

a. Installation which is most widely used

I am going to begin with the most common installation. This can be found in Abberley, Ankerdine, Berrow, Malvern, Sarah Siddons, Teme, Vesta Tilley, William Morris, Windrush and Wulfstan. These residential buildings have two boilers with a power of 65 kW. Although these buildings are different sizes (see Table 1), they have the same installation. We need to examine these buildings as it may be that their boilers are oversized.

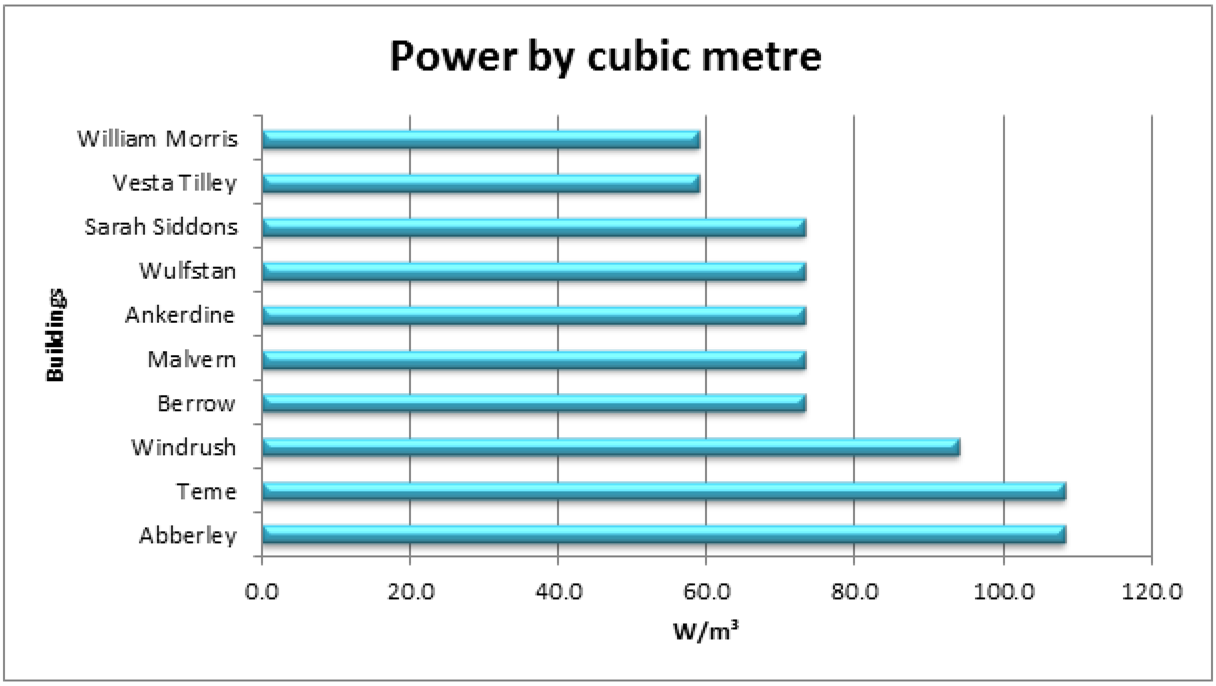
Table 1: Specifications of buildings (1)

	Surface (m^2)	Height (m)	Volume (m^3)	Number of boilers	Power of one boiler (kW)	Total power (kW)	W/m^3
Abberley	521.8	2.3	1,200.14	2	65	130	108.3
Teme	521.8	2.3	1,200.14	2	65	130	108.3
Windrush	601.2	2.3	1,382.76	2	65	130	94.0
Berrow	772.4	2.3	1,776.52	2	65	130	73.2
Malvern	772.4	2.3	1,776.52	2	65	130	73.2
Ankerdine	772.4	2.3	1,776.52	2	65	130	73.2
Wulfstan	772.4	2.3	1,776.52	2	65	130	73.2
Sarah Siddons	772.4	2.3	1,776.52	2	65	130	73.2
Vesta Tilley	958.8	2.3	2,205.24	2	65	130	59.0
William Morris	958.8	2.3	2,205.24	2	65	130	59.0

Let's look at Abberley and Vesta Tilley for example. These two buildings are not the same size. Vesta Tilley is nearly twice the size of Abberley; however they have the same gas installation.
If we compare the power by cubic metre (Table 1) we can see that: Vesta Tilley has 59 W/m^3 and Abberley has 108.3 W/m^3. The difference between the two is significant.

In this table, we see the power by cubic metre for ten buildings. All buildings were built in 1995 so I suppose that they have the same insulation. That's why I think that heating systems are not adapted for each building.

On this graph, we can see a clearer representation of the power by cubic metre for each building and how it differs (Graph 1):



Graph 1: Power by cubic metre for buildings

I'm going to assume that 59 W/m³ is sufficient for a building. Though I am not sure if it is a good base, this figure is coherent. Maybe these boilers are also oversized, but it can give an order of magnitude.
On average, a building needs 40 W/m³, but in this case, we also use the boiler for DHW. That's why we need to increase this number but it needs adjusted with room's number (Table 2).

Table 2: Number of bed spaces

	Abberley	Teme	Windrush	Berrow	Malvern	Ankerdine	Wulfstan	Sarah Siddons	Vesta Tilley	William Morris
Bed spaces	24	24	24	36	36	36	36	36	40	40

We can note that buildings with the most bed spaces have the smallest power by cubic metre: it's Vesta Tilley and William Morris. This detail shows that the same heating installation in each building of different volume is not the most economical with regards to energy.

I wanted to analyse water consumption in each building but the data seemed to be erroneous. I used Dynamat to obtain results. Dynamat is software which the University uses to track the energy consumption in all of its buildings. There are meters in each building for gas, electricity, water and solar production. All of these are connected with the software and we can see the consumption measured per hour. It is an essential tool for utility cost saving and environmental responsibility.

I have obtained the below results from Dynamat (Table 3):

Table 3: Water consumption

	Water used (m³/an)
Abberley	1,560.00
Ankerdine	649.00
Berrow	1,029.34
Malvern	524.20
Sarah Siddons	595.33
Teme	587.81
Vesta Tilley	966.87
William Morris	752.22
Windrush	410.80
Wulfstan	671.56

This data is from the Academic Year 2014 - 2015

We note that buildings which have the highest water consumption are not the largest buildings. Abberley and Teme have the same surface area and an identical number of rooms; however Abberley consumes nearly three times as much. I don't know if the meters are showing the correct data here. During my work placement, I have studied Dynamat and have noticed that there appears to be erroneous data on this software. That's why I am not going to take this data into consideration.

I assume that Vesta Tilley and William Morris have the correct heating installation. Indeed, these buildings are the largest with the largest number of rooms yet they use a low value of W/m³. I'm going to calculate the power that buildings need by taking 59 W/m³ as a reference (value for Vesta Tilley and William Morris.)

Calculation concerning Abberley and Teme:

Please find below a dimensional calculation:

[W] = [W/m³] * [m³] → 59 * 1,200.14 = 70,808.3 W ≈ 70.8 kW

As a result of this calculation, we can determine that the boilers in Abberley and Teme are oversized. If we consider that a building needs around 59 W/m^3, Abberley and Teme should have a heating system with a power of around 70 kW. However, the heating installation in these buildings has a power of 130 kW, so it is clear that there is too much power here.

Calculation concerning Windrush:

[W] = [W/m³] * [m³] → 59 * 1,382.76 = 81,582.84 W ≈ 81.6 kW

Like Abberley and Teme, the heating system is oversized. Inside this building, there is an installation with a power of 130 kW. If we consider that a building needs 59 W/ m³, the current installation is too powerful for the requirements of Windrush.

Calculation concerning Berrow, Malvern, Ankerdine, Wulfstan and Sarah Siddons:

[W] = [W/m³] * [m³] → 59 * 1,776.52 = 104,814.7 W ≈ 104.8 kW

In this case the size of the boilers is necessary because the buildings are of a larger size. For these buildings it is not necessary to change the boilers as it would likely be a pointless investment. For this reason, it is more important to concentrate on the aforementioned heating systems.

From the previous calculations, we note that heating systems are generally oversized, particularly inside three buildings: Abberley, Teme and Windrush. However, we have taken two buildings to act as a base (Vesta Tilley and William Morris) and this may not be a good base. These buildings could have oversized boilers, which would mean that the other buildings need less power in the plant room. These calculations give an order of magnitude concerning the sizing of the heating installation.

b. Second installation

Now I'm going to analyse Avon & Ledbury and Evesham & Pershore. They do not have the same installation (Table 4) but the power of one boiler is identical. This is why I have chosen to make a comparison.

Table 4: Specifications of buildings (2)

	Surface (m^2)	Height (m)	Volume (m^3)	Number of boilers	Power of one boiler (W)	Total power (W)	W/m^3
Evesham & Pershore	1,219.50	2.35	2,865.83	2	100,000	200,000	69.8
Avon & Ledbury	3,949.10	2.35	9,280.39	6	100,000	600,000	64.7

We can see that the buildings have nearly the same power by cubic metre. However, taking the previous value of 59 W/m^3 is not possible. These buildings are old with poor insulation, notably simple glazing. They were built in 1988 which would explain their bad performance. Therefore, these buildings need more power by cubic metre due to their low efficiency.

Furthermore, we can see that the power by cubic metre is less important in these buildings than it was for Abberley or Teme, for example. Although Avon & Ledbury and Evesham & Pershore are old buildings, their heating installation is better dimensioned. This strengthens the argument that the boilers in Abberley, Teme or Windrush are oversized.

c. Last installation

The last installation concerns AE Housman (AEH) and Elizabeth Barrett Browning (EBB). They are the University's newest residential halls. Please find data concerning both buildings in Table 5.

Table 5: Specifications of buildings (3)

	Surface (m^2)	Height (m)	Volume (m^3)	Number of boilers	Power of one boiler (W)	Total power (W)	W/m^3
EB Browning	2,588.00	2.29	5,926.52	4	65,000	260,000	43.9
AE Housman	2,588.00	2.29	5,926.52	4	65,000	260,000	43.9

For these buildings, it is apparent that the power by cubic metre is the lowest of all. The plausible explanation for this is their recent construction. These buildings should certainly have a better insulation than the other buildings.

However, I haven't take 43.9 W/ m^3 as a reference because these buildings are newer, so it would not be judicious to take this as a base. AEH and EBB must be considered separately from the other buildings.

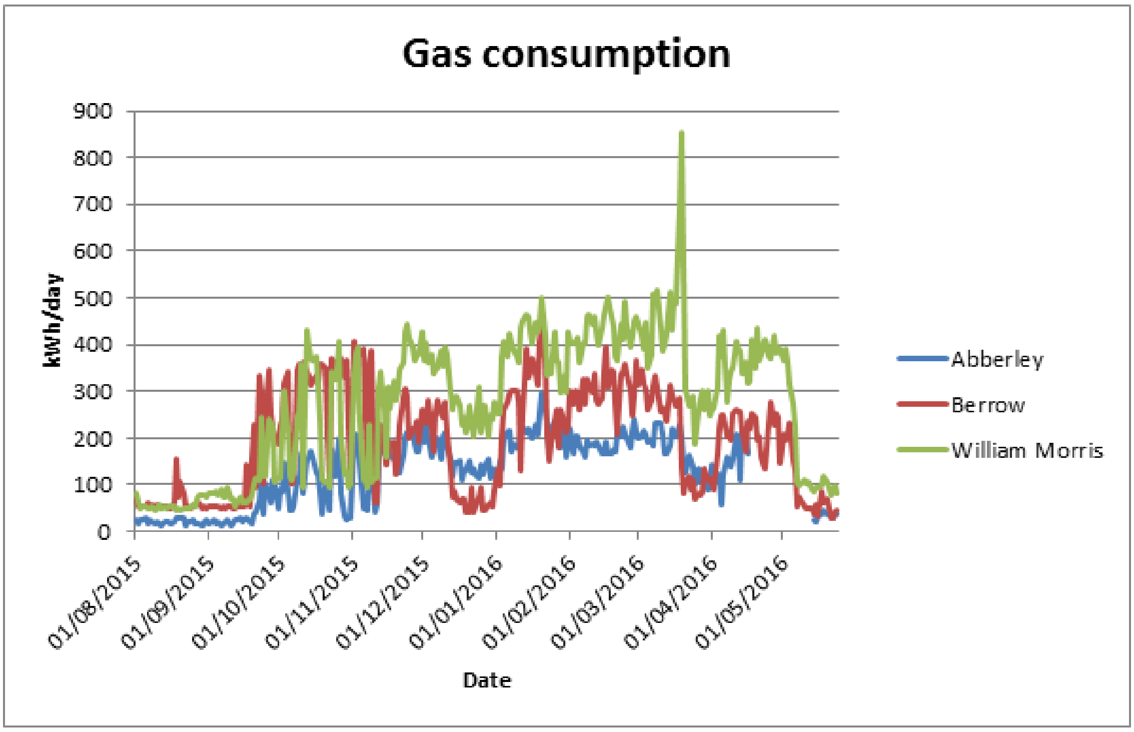
2. Recommendations

If we buy a boiler with high power, it will be more expensive. This is why it is important to evaluate requirements for a house. Moreover, if the boiler is oversized, it works harder during a shorter time. That creates an over-consumption which leads to accelerated ageing of the equipment. The yield will be lower because the boiler operates with a medium or a low level of productivity. This is often the result of an incomplete combustion. To have a productive heating system it is important to purge radiators regularly.

However, it would be unwise to change the boilers at this stage as, if there are planned works concerning insulation, it will be necessary to review the data. Having a good thermal insulation will reduce the need for heating. Therefore, if the insulation is improved, boilers would be too powerful for the accommodation. Moreover, there are new boilers in each building, which is why we cannot yet envisage their replacement. If boilers are changed in the future, it will be necessary to reduce the power of some of them; however, two boilers will need to be retained in each building. Indeed, in the case where one boiler is deficient, the accommodations will still need heating and DHW. It would be sensible to install two boilers with a power of 40 kW for Abberley and Teme, for example.

3. Comparison between three buildings concerning the gas consumption

To support my theory that some boilers are oversized, I made a comparison about the gas consumption for three buildings. To do this, I have used Dynamat and produced a graph.
If we compare the gas consumption in buildings of different sizes, we can see that the requirement for heating is different (Graph 2). For this comparison, I have chosen three buildings: Abberley (521.8 m^2), Berrow (772.4 m^2) and William Morris (958.8 m^2).



Graph 2: Gas consumption in Abberley, Berrow and William Morris (01/08/2015 – 26/06/2016)

Thanks to this graph, we are able to see the problem with the heating system, namely that some of the boilers are oversized. However, there are new boilers in each residence so we can't change the boilers at this stage. The University has bought condensing boilers, they are performing but they have too much power for some of the buildings, which is an issue.

Solar panels, installed on some of the buildings, are helping to produce DHW. This installation reduces the gas consumption of eight buildings.

IV. A renewable energy: solar installation

In order to reduce the carbon footprint and the consumption in accommodation buildings, the university installed solar panels on the roof of several residential buildings. It's the case for Abberley, Ankerdine, Malvern, Teme, Sarah Siddons, Windrush, AEH and EBB. Solar energy is good because it is inexhaustible and it doesn't pollute the environment.

1. Generalities

To locate buildings, please find below a map (Figure 1) of residences on the St John's Campus. On this map, we can see solar panels on each roof and their orientation, thanks to the compass.

The two largest buildings, EBB and AEH, have solar panels on their roof; however solar panels don't work in EBB. It could be judicious to repair this installation considering the size of the building; it needs a lot of DHW.

If we examine the other buildings, we can see that smaller buildings have solar panels, like Abberley, Teme or Windrush. It could be interesting to put solar panels on larger buildings like Vesta Tilley or William Morris. For the size of each building, we can refer to tables 2, 3 and 4. These installations allow a reduction in bills and the University's carbon footprint.

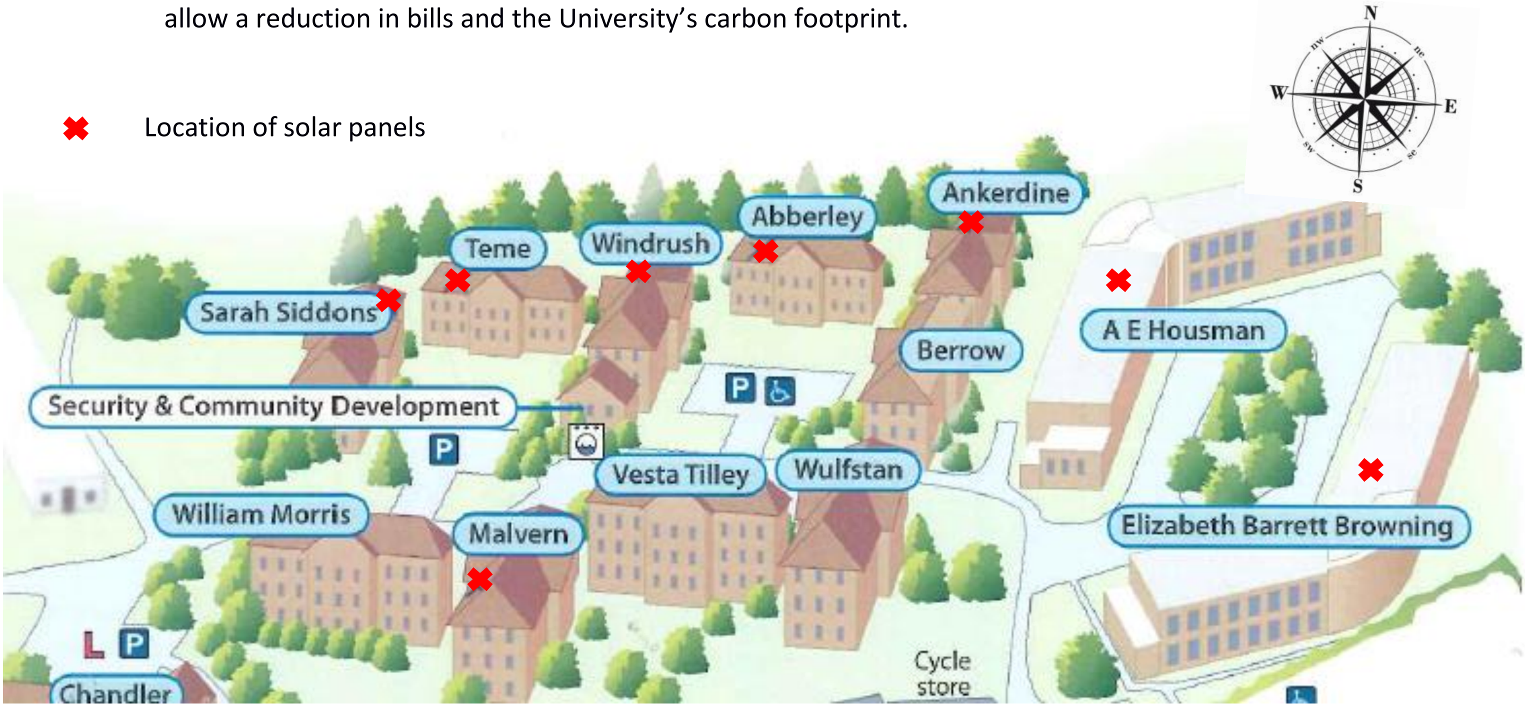


Figure 1: Student accommodations map

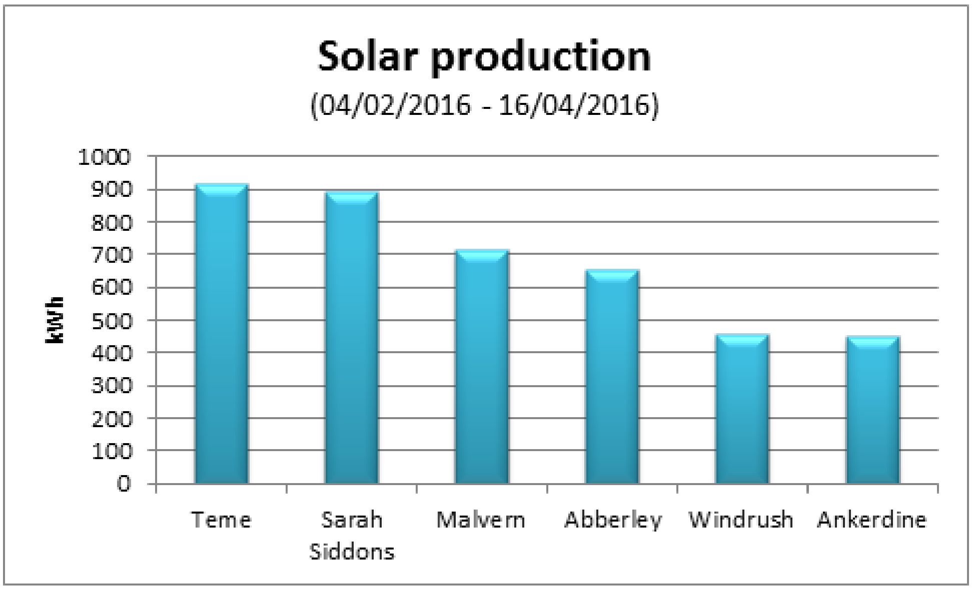
However it is worth nothing that all panels do not have the same orientation. As a result of building structure, we are unable to put all solar panels in a south-facing direction; this is in fact the best direction as you can see in Table 6.

Table 6: Which orientation for solar panels?

		Inclination						
		0	15	25	35	50	70	90
Orientation	East	88%	87%	85%	83%	77%	65%	50%
	South-East	88%	93%	95%	95%	92%	81%	64%
	South	88%	96%	99%	100%	98%	87%	68%
	South-West	88%	93%	95%	95%	92%	81%	64%
	West	88%	87%	85%	82%	76%	65%	50%

2. Survey

I'm going to look at the solar production in six buildings. Please find below a graph and a table regrouping this data (graph 3 and table 7).



Graph 3: Solar production for six buildings

I retrieved the above data from Dynamat.

Table 7: Specifications of solar panels

	Teme	Sarah Siddons	Malvern	Abberley	Windrush	Ankerdine
Number of solar panels	6	8	8	6	7	8
Orientation	South	East	West	South	West	West

Normally, the most productive buildings will be those with the highest number of solar panels, but this is not the case here. Teme is the most productive although it has only six solar panels. We have the same installation on Abberley; however we don't have the same yield. The same problem exists with Ankerdine and Malvern. I am unable to explain this difference, though it may result from incorrect installation. It may be useful to improve the installation in order to have a better yield.

As a result of this installation, boilers in plant room operate less effectively. Solar panels are used to provide hot water which would assist DHW boilers, so this emphasises the fact that boilers are oversized in some buildings. However, it would be interesting to install solar panels on buildings with a high demand for heating and DHW. It may be advantageous to improve the consumption of Vesta Tilley and William Morris. Placing solar panels in these buildings would indeed reduce their consumption. They also benefit from the best possible orientation (south-facing).

In Vesta Tilley and William Morris, the DHW is heated solely by boilers. Without this installation, these buildings would need more power by cubic metre. Consequently, the value I have used as a reference 59 W/m^3 could be too high. This proves that previous calculations concerning the size of the heating system are coherent, though could be too high. In spite of this, the order of magnitude is correct.

V. Thermal insulation

One of the University's targets is to improve the energy efficiency of all buildings by September 2017. All buildings should have a minimum DEC rating of C. If we look at the DEC (Table 8) for each residence, we can see that buildings are not yet as energy efficient as they could be. To acquire a better DEC rating, improving the insulation would be a good start. Though it is easier to build an efficient building, it can be more difficult to improve the insulation of an existing building.

Table 8: DEC for each building

Buildings	DEC	Energy score	Energy previous score
Abberley	D	76	76
AE Housman	D	81	76
Ankerdine	D	76	76
Avon	D	78	76
Berrow	D	76	76
Elizabeth Barret Browning	C	58	76
Evesham & Pershore	D	78	76
Ledbury	D	78	76
Malvern	D	76	76
Sarah Siddons	D	76	76
Teme	D	76	76
Vesta Tilley	D	76	76
William Morris	D	76	76
Windrush	D	76	80
Wulfstan	D	76	76

In the University's case, improving insulation could be tricky. We cannot add an external insulation due to the aesthetics of the facade and if we were to apply an internal insulation, it would reduce the size of the room.

However, we can identify if the roofing is well insulated because it represents 30% of thermal losses. In reality, roofs are often accountable for major heat loss within a building. Please see Figure 2 for examples of losses within a house. It is also possible to replace all simple glazing with double glazing as windows represent 15% of thermal losses.

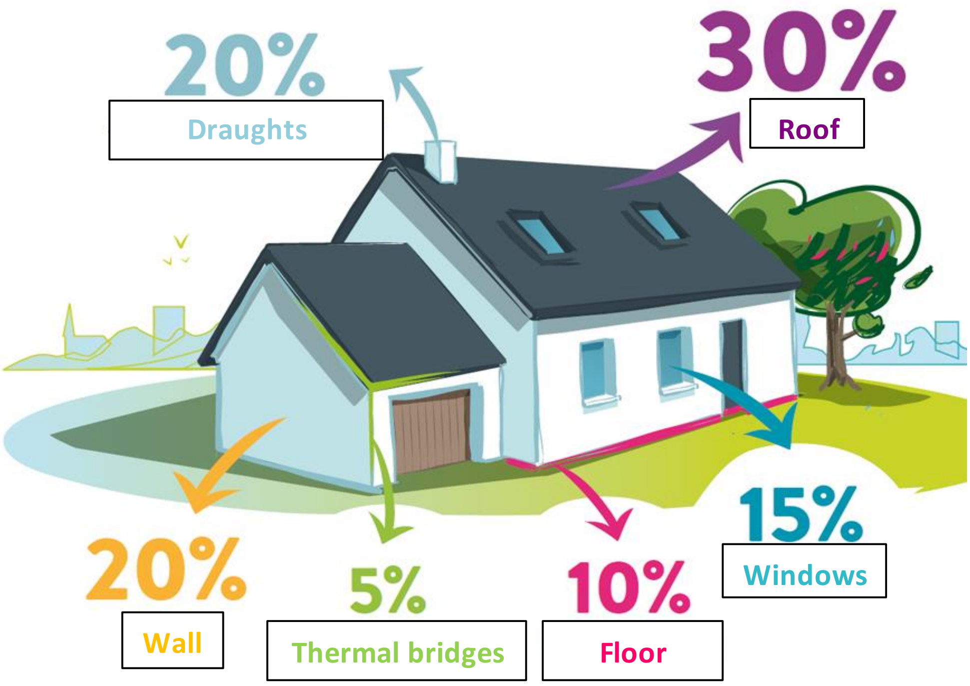


Figure 2: Thermal losses in a house

http://www.diogo.fr/actualites/actu/278/isoler-sa-maison-les-conseils-drsquoun-constructeur

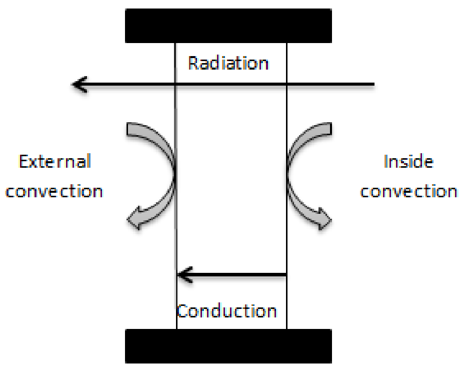


Figure 3: Heat transfer concerning a window

On figure 3, we can see the different types of heat transfer at a window. With reference to a window, the simple glazing isn't efficient. There is too much exchange between inside temperature and outside temperature. It is more beneficial to install double glazing. Please find below two images showing the difference between simple glazing and double glazing (Figure 4).

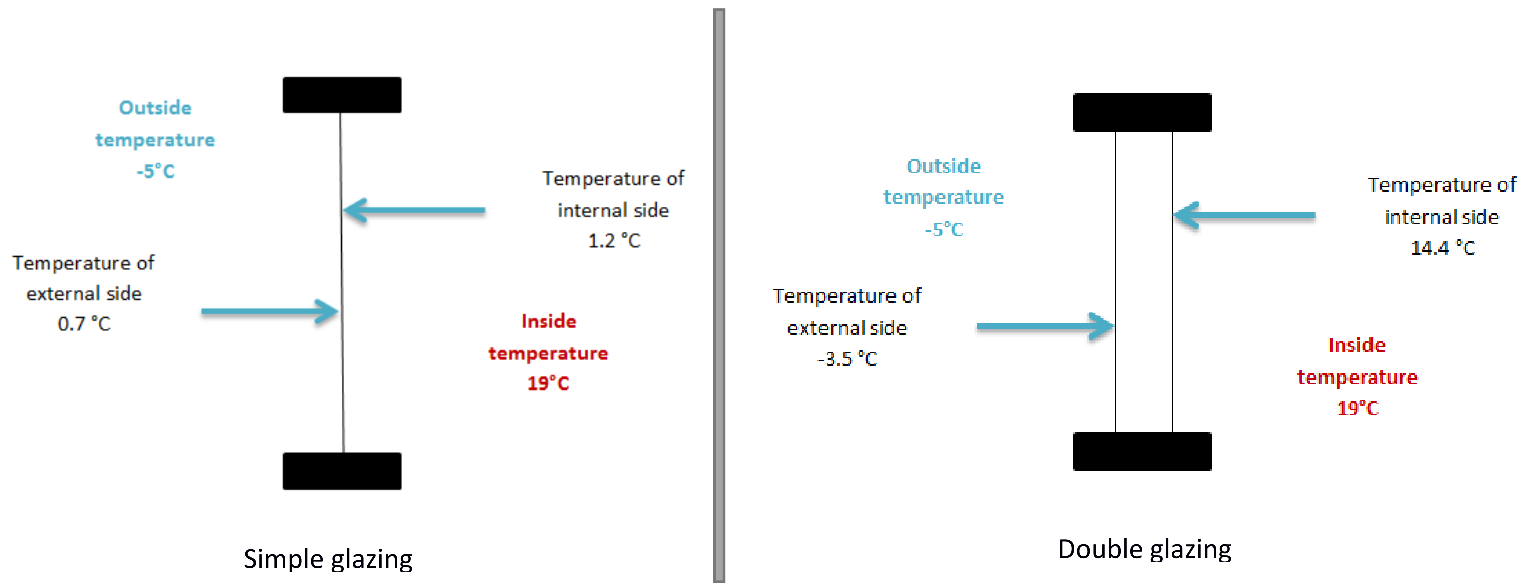


Figure 4: Difference between simple glazing and double glazing

http://conseils-thermiques.org/contenu/triple_vitrage.php

This image demonstrates the poor performance of simple glazing. During winter, the room would feel uncomfortable due to the inefficiency of the glazing. In comparison, double glazing is much more efficient. There is gas between the two layers of glass which improves the insulation and in turn, makes the room a more comfortable environment.

On account of the above information, we can recommend double glazing. It is worth noting that triple glazing would not be useful for these buildings, this would instead be used for a passive house.

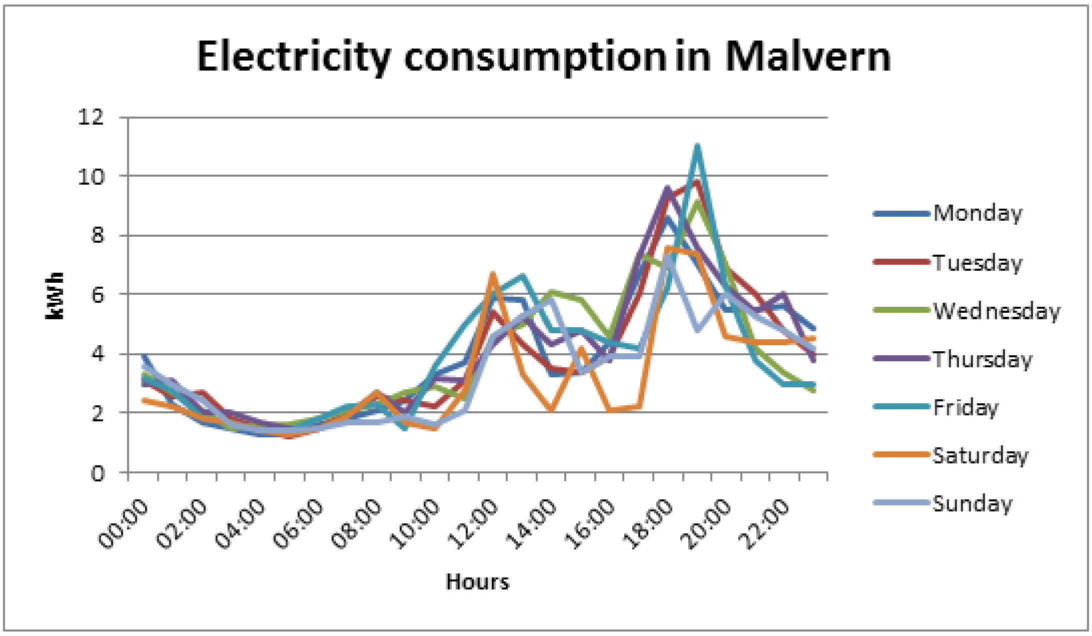
Carbon emissions and bills are also generated by the consumption of electricity. It could be interesting to study it in order to have a better understanding of this consumption. Thanks to that, the University will be able to improve the electricity consumption.

VI. Electricity consumption

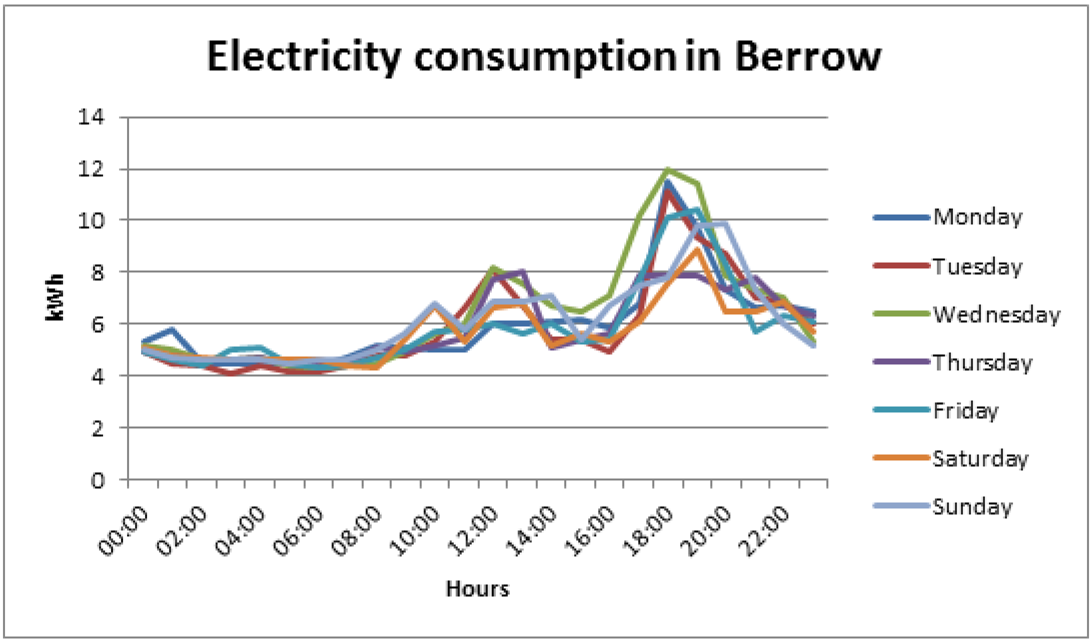
In order to understand the electricity consumption, I need to know the daily consumption for each building. I have collected a week's worth of data for the residences for analysis. I am unable to study the consumption of electricity for each week of the year. Therefore, I have chosen a typical week as an example (7th March 2016 to 13th March 2016.). To clarify, this week falls during a semester so it will give a representative result.

1. Consumption of electricity in buildings during one week

Thanks to Dynamat I was able to collect data regarding electricity consumption for each residential building. Please see below two examples of this graph (graphs 4 and 5).



Graph 4: Electricity consumption in Malvern



Graph 5: Electricity consumption in Berrow

These two graphs show the base load for electricity in Malvern and Berrow. I have chosen these buildings because they have an identical volume as well as the same number of kitchens and bedrooms. However, it is clear that the buildings do not have the same base load:

- Base load in Malvern : 1.5 kWh
- Base load in Berrow: 4.5 kWh

Thanks to previous data, we can see that the base load for each building is different. Nevertheless these two buildings have the same size (772.4 m²) that's why a difference like that is surprising. Inexplicably, Berrow has a higher consumption of electricity than Malvern. Normally during the night we wouldn't expect to use electricity. Here we can see electricity is being used during the night, this is due to the refrigerators and the freezers running. In each building there is the same number of rooms and kitchens so we can expect a similar consumption.

Therefore, checking household appliances can be useful. In a freezer, air humidity condenses and then it freezes on the sides and shelves, producing frost. Progressively, a layer of ice forms and this limits the transfer of thermal energy. The ice creates a thermal insulator, so the system needs more energy to maintain the inside temperature. A freezer not defrosted can increase its electricity consumption from 30% to 40%.

Please find below a table regrouping the base load for each residence (Table 9). On these graphs, buildings are colour-coded based on their size. This shows that it would be useful to have a near-identical base load.

Table 9: Base load for residences

	Base load (kWh)
Abberley	1
Teme	1.3
Windrush	1.5
Berrow	4.5
Malvern	1.4
Ankerdine	2
Wulfstan	2
Sarah Siddons	0.5
Vesta Tilley	5
William Morris	2.4
Pershore	2.5
Evesham	1.5
EB Browning	12
AE Housman	12

For calculate the base load and trace graphs, I have used Dvnamat.

This table enables us to compare the consumption between buildings of a similar size and purpose. We can see that each building has different electricity consumption. Checking the fridges and freezers in each student flat is an important task. This should explain the difference in consumption.

If we look at the rest of the day (as per Graphs 1 and 2), there are two peaks: one at 12:00 PM and a more significant peak at 06:30 PM. These peaks make sense because they correspond to the time when students would typically arrive home. During this time, students would probably be eating their evening meal. There are similar peaks for each residential.

For AEH and EBB halls, it is evident that the base load for electricity is high. But it is explainable because these large buildings contain ninety-one rooms and twelve kitchens. Furthermore, they contain a high number of automatic doors and two lifts. Please see in the appendices graphs for the lifts in AEH and EBB. The graphs demonstrate consumption during a typical week. As we can see on each graph, they are similar but they do not have the same base load for lifts. There is a slight difference:

- AEH base load = 0.045 kWh
- EBB base load = 0.07 kWh

Concerning electricity in general, the only thing that we can do is make sure that freezers are defrosted regularly in order to avoid excessive consumption. We can also try to change student behaviour but this would be more difficult. Generally, students are not concerned with their energy usage nor are they not interested in their carbon footprint. Consequently, this means reducing electricity consumption is often complex. Electricity consumption is hard to improve as most equipment uses electricity. Moreover, consumption can be reduced by replacing lighting with LEDs (Light-Emitting Diodes). It will be necessary to carry out a new calculation for the base load in each building after these improvements have taken place.

Using LEDs can be a good way of reducing bills and carbon footprint. Please find below a survey about this.

2. Example of LED installation

During my work-placement, lighting has been replaced in the Student Union Pear Tree Café. The previous lights have been replaced with LEDs to reduce the electricity consumption. I have done a survey about it in order to establish the savings made in electricity and carbon footprint.

Design brief:

- 17 lights have been replaced
- The older lights have a power of 64 W
- LEDs have a power of 35 W
- Lights are switched on 16 hours per day, every weekday
- 15 hours during which the lights are switched on are at peak times
- 1 hour during which the lights are switched on is at off-peak time
- For the old fittings, there are two bulbs in each light and we need to replace them every year
- One bulb cost £2.30

- The cost to replace light fittings is approximately £2.30*17*2 = £78.20
- LEDs guaranteed for 5 years
- Carbon footprint: 1 kWh → 0.46219 kg of CO_2

With all this information, we can note that the lights are switched on the majority of the time (16 hours per day). This is why it is important to have economic fittings.

In table 10, we can find the details for the new fittings.

Table 10: New installation cost

	Number	Price	Total
35 W LED downlight dimmable	14	£88.69	£1,241.66
35 W LED downlight Emergency	3	£123.07	£369.21
Power switch	1	£136.38	£136.38
		Total cost	**£1,747.25**

Please find my results regrouped in table 11.

Table 11: Electricity use, cost and carbon footprint

	Power used for one day (W)	Power used for one week (W)	Power used for one year (kW)	Cost for one year	Carbon footprint for one year (kg/CO2/year)
Old installation	17,408	121,856	6,353.92	£713.41	2,936.72
New installation	9,520	66,640	3,474.8	£347.38	1,606.02

If we calculate the savings for one year we find:

713.41 – 347.38 = 366.03
2,936.72 – 1,606.02 = 1,330.70

Saving per year:	£366.03 1,330.70 kg of CO_2

Savings in kg of CO_2 are really interesting because the University is hoping to have the most sustainable reputation possible. Thanks to this example, we can see that electricity consumption releases a lot of CO_2 in the atmosphere. Indeed, the previous calculation shows that we can reduce the carbon footprint. Using LEDs is a good way to reduce this.

It is also interesting to consider the payback of this installation:

- The cost of the new installation is £1,747.25
- Each year the savings are £366.03

$$\rightarrow \quad \frac{1747.25}{366.03} = 4.77 \text{ years}$$

The payback of this investment will be in 4 years and 9 months. During this period, we can note that we do not need to buy new LEDs because they are guaranteed for five years. On average, the LEDs have a life of 50,000 hours. If we consider that they work 16 hours per day, they work 5,840 hours per year so this equates to 29,200 hours during five years. Normally, we would need to change a standard light after 8 months and 6 months.

It is beneficial to swap standard lights with LEDs because it is more profitable. If we did not change the lights, the cost of installation would be similar but we would not have a payback. To place LEDs is a good investment for the University because they have a long life and they consume less electricity.

VII. One particular case: Riverside Building

During my internship, I focused primarily on residences but I also studied academic buildings. Riverside is a building used for lectures and sports. This building is principally controlled by a system called Building Management System (BMS.) This building is difficult to manage because it has several usages. Indeed, the need for heating is not the same in a seminar room as in a hall activity. There are currently several systems in this building: heating systems, air conditioners, ventilations, RAD heating system and a heat plate exchanger.

1. Problems observed

As I mentioned previously, each room has a particular function. Although a BMS is used, the building is not heating correctly. We can note several problems:

- We can’t switch on or switch off the heating/cooling system manually,
- We can’t adjust the temperature of each room,
- The system inside the building doesn’t display the correct hour, so the heating doesn’t work during useful hours while the building is in use
- The temperature is much higher upstairs, but it’s cold downstairs.

Because of these problems, it is necessary to improve the management of the building in order to ensure better comfort.

2. Requirements

In order to ward off these problems, we can change some parameters on the BMS system.

For the lecture rooms, the requirements will be:

- Day and times set to automatically switch on at 08:00 and switch off at 21:00. However it must have the flexibility of being manually controlled by a person in the lecture theatre at any given time,
- Summer – Heating is generally off but A C might be required dependent on weather,
- Winter – Heating required to come on at 08:00 and go off at 21:00,
- Temperature range to be set between 16 – 28 degrees Celsius.

For sports halls, the requirements will be:

- The room to be heated before the students start their routines (to help prevent injury) and once occupants' muscles have warmed up , the heating is turned down.
- Heating required to come on at 08:00 and go off at 21:00,
- Temperature range to be set between 16 – 28 degrees Celsius,
- The ability to keep space cool in summer and warm in winter. The flexibility for control of heating/cooling system on/off as required.

These improvements will allow better comfort in each room. Moreover, Riverside is a recent construction with a C for the DEC rating. Improving heating issues would be beneficial to the building.

VIII. Conclusion

I observed that the University is really involved in sustainability. Currently, it's become unavoidable in order to recruit students. There are already several projects intending to project the University as a friendly organisation. I have seen two presentations concerning sustainability. During one presentation, I observed that the University allows an important role for waste management. Waste sorting is a good way of being sustainable.

The newest buildings, AEH and EBB, are the best performing blocks of accommodation. They were built in 2009 and it would be difficult to further improve them because they already have good thermal insulation, double glazing and a good heating system. In addition, the bathroom lights have been replaced recently with LEDs. This allows a reduction in bills and carbon footprint. These buildings are performant and comfortable for students. There are solar installations on both roofs; however the solar doesn't work in EBB. If the University was to repair this, this could reduce the gas consumption and consequently the carbon footprint. These buildings also have a good installation which is the rainwater harvesting. This is a good way of saving water; indeed each building has 91 bedrooms so the University could reduce bills if it used the water from the rainwater harvesting to flush toilets. To finish with AEH and EBB, the only thing that the University can do is to repair two existing installations: the solar panels on EBB and rainwater harvesting for both.

More generally concerning buildings, the University could continue the LEDs replacement programme (thanks to the survey concerning the Students' Union's Pear Tree Café, we can see that LEDs are environmentally-friendly). Some buildings still have simple glazing and it is not performant. It could be a good investment to replace all simple glazing with double glazing. This improvement will bring additional comfort for occupants.
In order to reduce carbon emissions, the University could develop more renewable energy such as solar panels, photovoltaic panels and biomass. To install renewable energies is expensive but it provides an environmentally-friendly solution, and could prove to be a valuable payback in years to come. That's why it's very interesting. The University already invests in renewable energy. It installs solar panels, photovoltaic panels and rainwater harvesting. Thanks to Dynamat, we can see that solar energy helps to reduce gas consumption or electricity consumption.

At the University, we can observe that most students open their windows during cold days. That is owing to a problem with the heating. That's why the University could install new fittings. It could be interesting to place several thermostats in accommodation block in order to control the temperature with the BMS system. This system is a good way of saving energy and reducing the carbon footprint. Students can control the temperature of their room thanks to a dial but, the majority of the time; they don't turn off the heating when they leave. To have an automatic temperature control could be useful for accommodation block. This could lead to reducing the gas consumption. It could be interesting to install a heat recovery system in order to re-use the heat lost through the ceiling. Heat pumps could also be a good option in order to reduce the energy consumption.

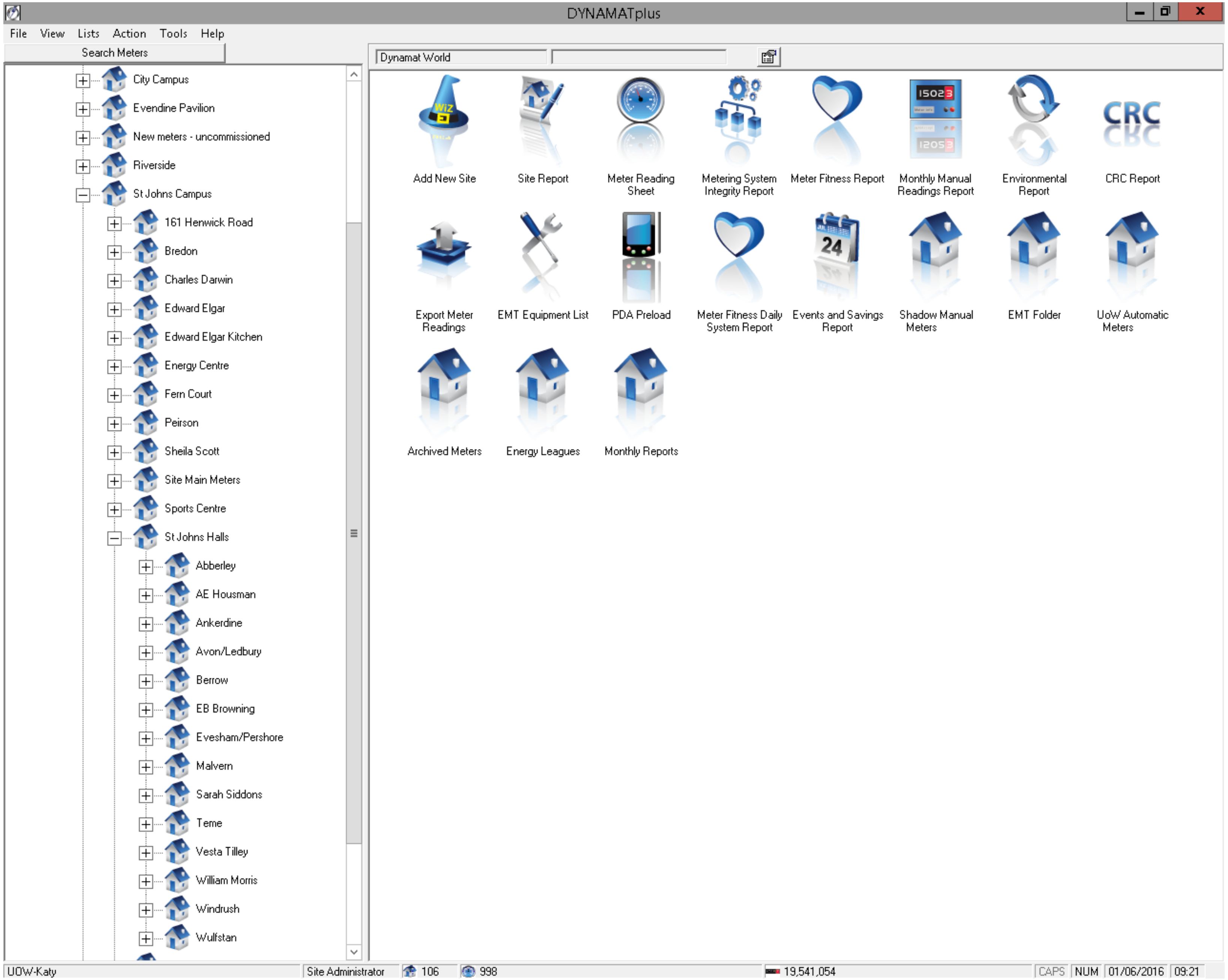
This work placement has allowed me to work for the first time in a field relating to my studies. At the beginning, I encountered several difficulties owing to the language barrier. I found it difficult to adapt to a new environment with a foreign language. I needed a number of weeks to gain a better understanding of my work. However, to do a work placement abroad is a great opportunity for students. This brings lots of benefits. I'm satisfied with my work and found that the University was a good place to work. Thanks to the work completed, the organisation will be able to have a better understanding of their buildings' consumption. Thanks to my internship, I realized that the sustainability sector is of great interest to me and that's why I want to continue working in this sector. I would like to study renewable energy.

IX. <u>Appendices</u>

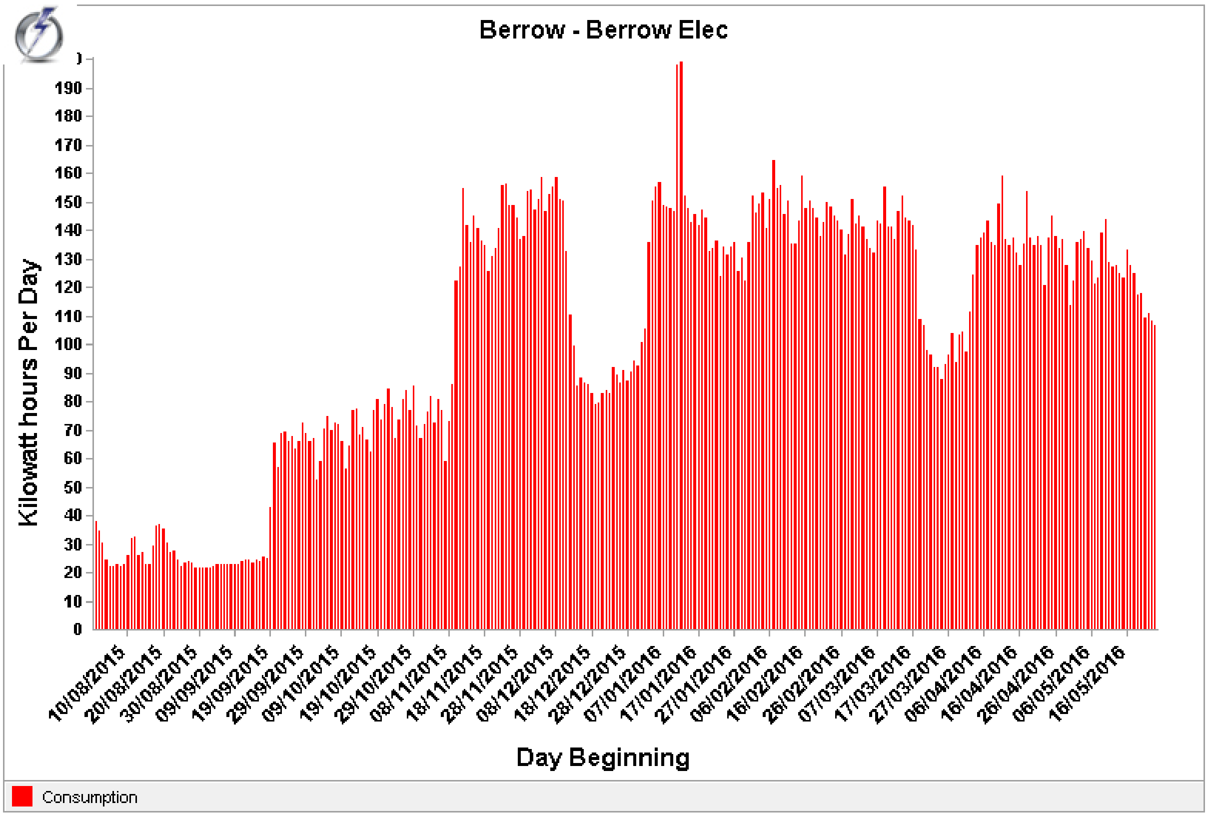
Appendix 1: Map of St John's Campus

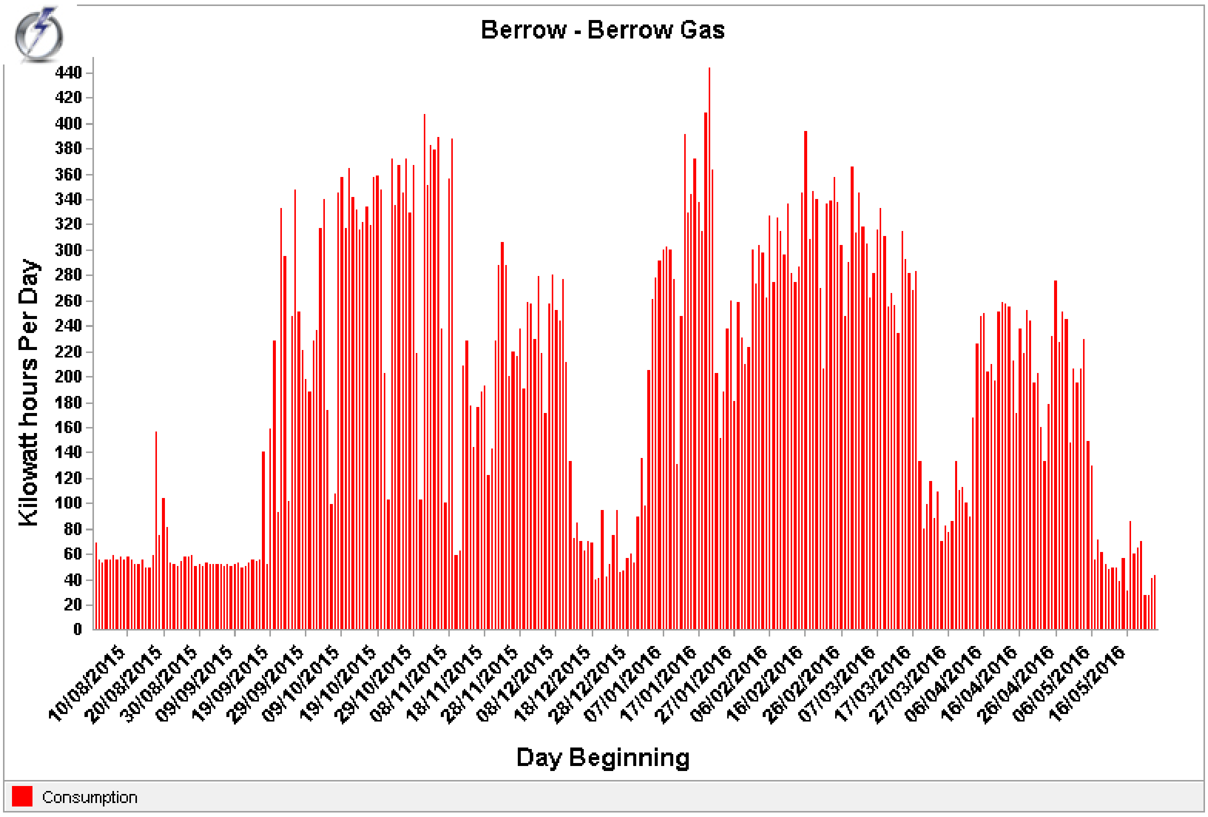
Appendix 2:

Software DYNAMAT



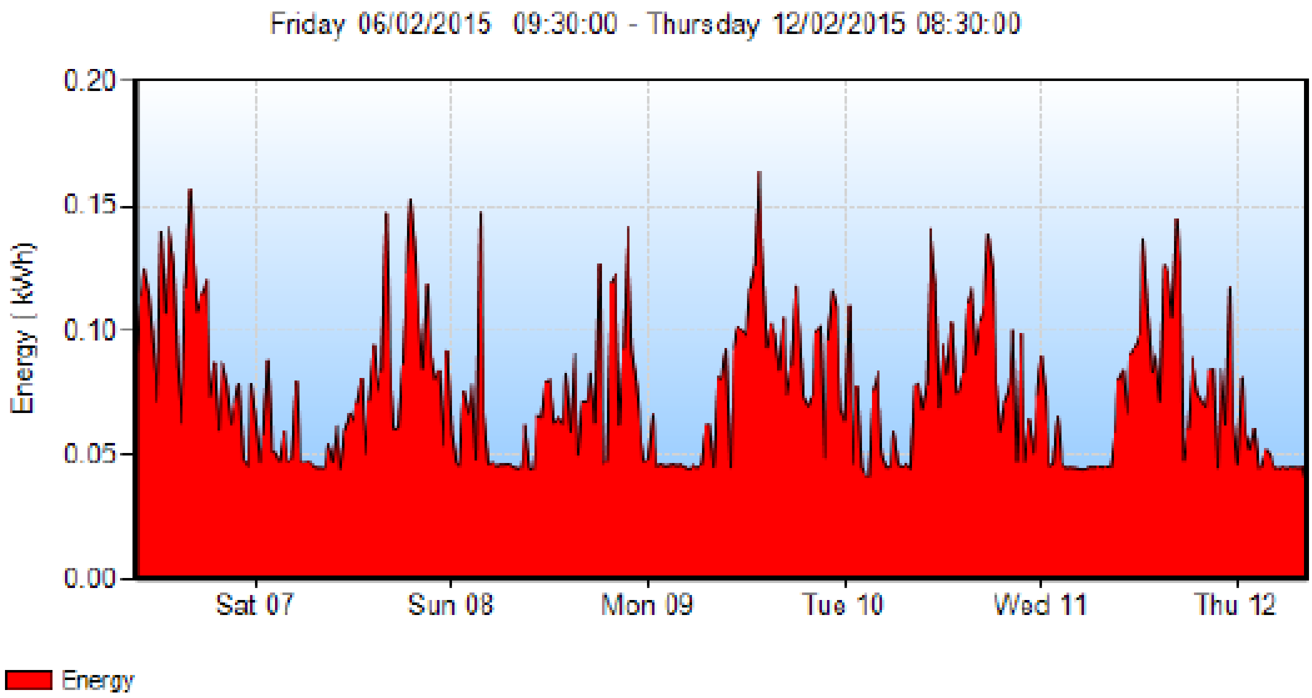
Appendix 3: Graphs produced by Dynamat



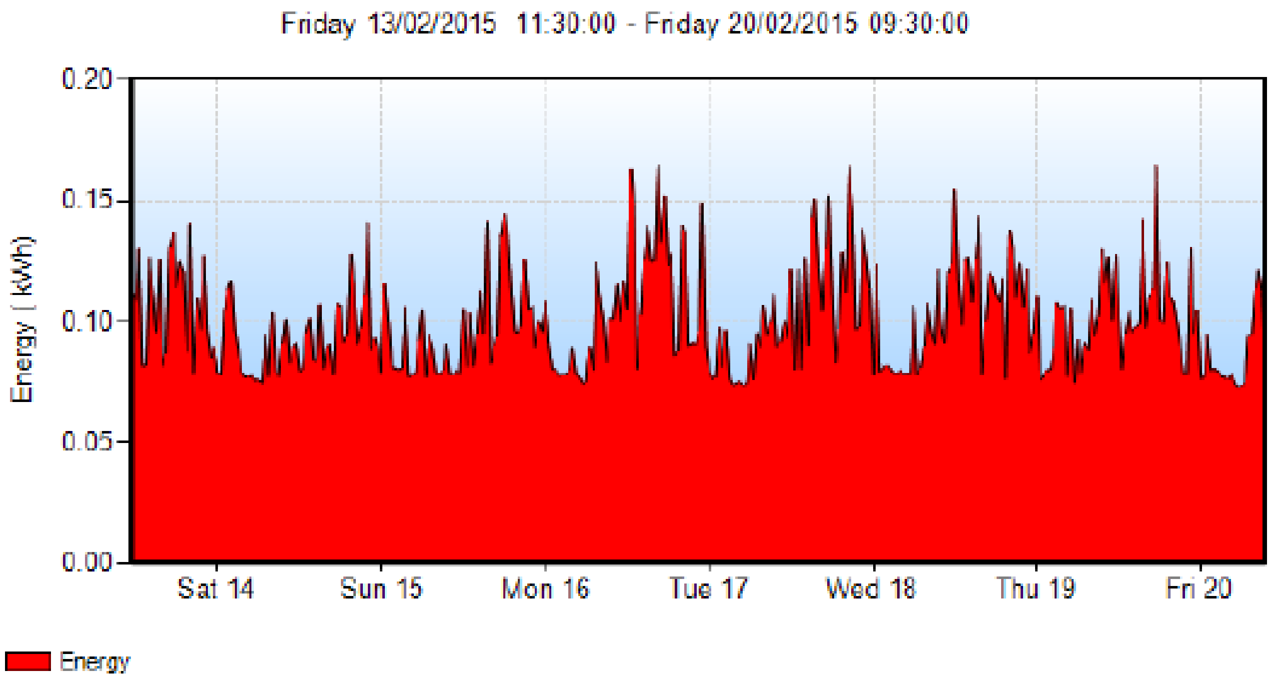


Appendix 4: Report concerning the lifts consumption

Lifts consumption in AEH



Lifts consumption in EBB



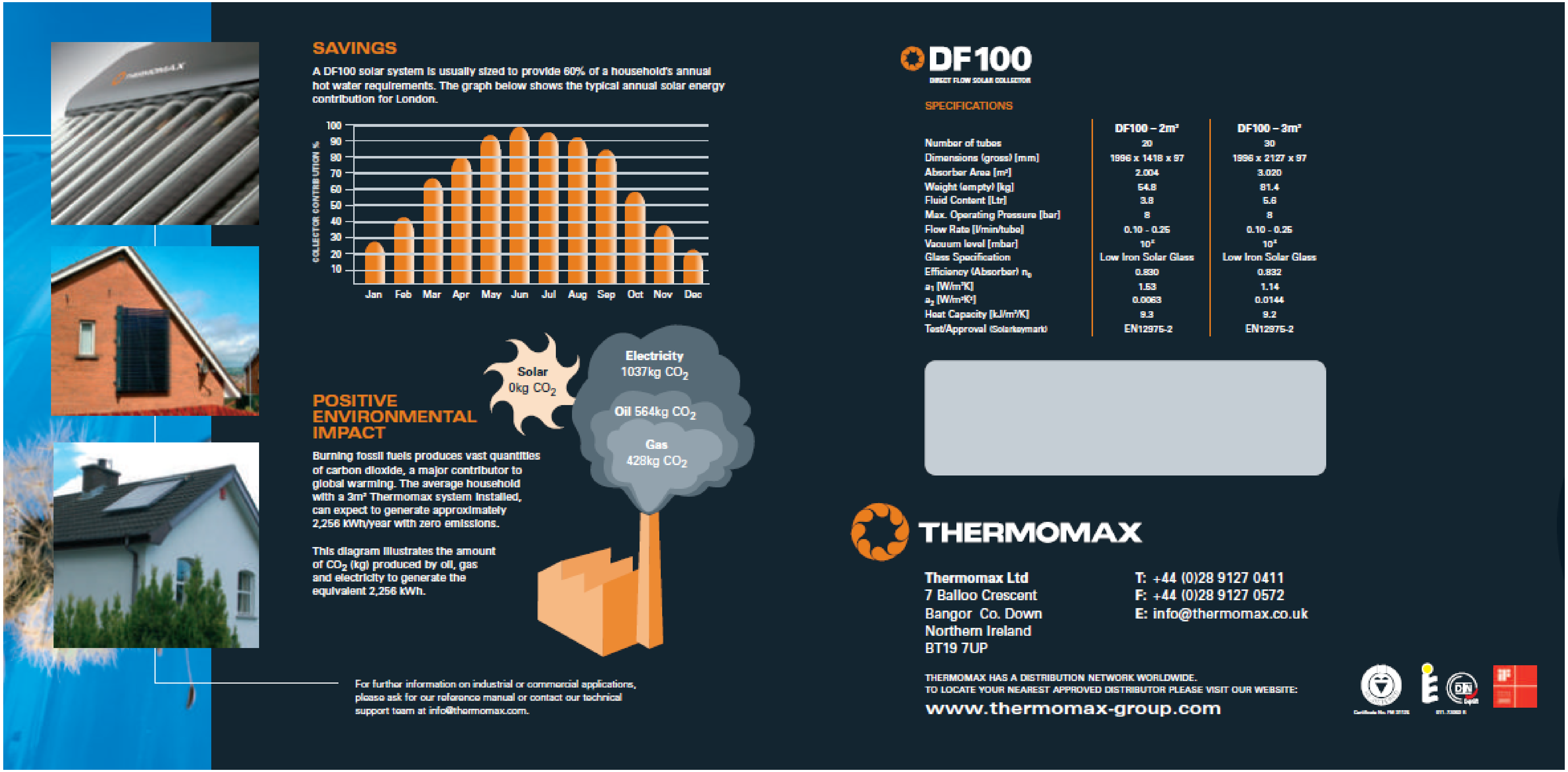
Appendix 5: Details concerning the consumption of accommodation buildings for two years

This table was completed mainly thanks to Dynamat
Data in green mean that there are missing data.

	Buildings	Electricity (kWh/year)	Gas (kWh/year)	Total energy consumption (kWh/year)	Water (m^3/year)	Electricity cost (£/year)	Gas cost (£/year)	Water cost (£/year)	Total cost (£)	Carbon emission Electricity (kg of CO2/year)	Carbon emission Gas (kg of CO2/year)	GIA (m^2)	Energy intensity Elec (kWh/m^2/year)	Energy intensity Gas (kWh/m^2/year)	NPI gas (kWh/m^2/year)	Bed spaces	Cost per bed space (£/per capita/year)
2013-2014	Abberley	13,551.70	34,991.00	48,542.70	1,602.39	1,212.78	668.68	1,415.71	3,297.17	6,263.46	6,454.09	521.80	25.97	67.06	74.79	36	91.59
	AE Housman	117,556.00	144,269.50	261,825.50	1,812.03	9,173.19	2,756.99	1,600.93	13,531.11	54,333.21	26,610.51	2588.00	45.42	55.75	62.17	91	148.69
	Ankerdine	21,849.70	100,972.00	122,821.70	671.85	1,933.16	1,929.57	593.58	4,456.32	10,098.71	18,624.29	772.40	28.29	130.73	145.80	36	123.79
	Avon and Leburry			0.00	5,797.90	0.00	0.00	5,122.44	5,122.44	0.00	0.00	3949.10	0.00	0.00	0.00	194	26.40
	Berrow	27,176.10	98,444.00	125,620.10	1,211.99	2,438.19	1,881.26	1,070.79	5,390.24	12,560.52	18,158.00	772.40	35.18	127.45	142.15	36	149.73
	Elizabeth Barret Browning	121,569.00	129,037.00	250,606.00	391.25	10,879.51	2,465.90	345.67	13,691.08	56,187.98	23,800.87	2588.00	46.97	49.86	55.61	91	150.45
	Evesham & Pershore	44,878.70		44,878.70		4,016.31	0.00	0.00	4,016.31	20,742.49	0.00	1,544.80	29.05	0.00	0.00	60	66.94
	Malvern	22,181.30	80,612.00	102,793.30	630.79	1,985.06	1,540.50	557.30	4,082.86	10,251.98	14,868.88	772.40	28.72	104.37	116.40	36	113.41
	Sarah Siddons	10,256.80	92,118.00	102,374.80	886.82	917.91	1,760.37	783.51	3,461.79	4,740.59	16,991.17	772.40	13.28	119.26	133.02	36	96.16
	Teme	29,272.50	20,885.40	50,157.90	403.99	2,619.67	399.12	356.93	3,375.71	13,529.46	3,852.31	521.80	56.10	40.03	44.64	24	140.65
	Vesta Tilley	44,330.00	81,800.00	126,130.00	728.74	3,967.20	1,563.20	643.84	6,174.24	20,488.88	15,088.01	958.80	46.23	85.31	95.15	40	154.36
	William Morris	22,115.50	87,582.00	109,697.50	927.79	1,979.17	1,673.69	819.70	4,472.57	10,221.56	16,154.50	958.80	23.07	91.35	101.88	40	111.81
	Windrush	17,394.00	37,356.00	54,750.00	375.51	1,556.63	713.87	331.76	2,602.27	8,039.33	6,890.31	601.20	28.93	62.14	69.30	24	108.43
	Wulfstan	21,780.30	68,705.00	90,485.30	538.73	1,949.17	1,312.95	475.97	3,738.09	10,066.64	12,672.64	772.40	28.20	88.95	99.21	36	103.84
2014-2015	Abberley	13,392.40	39,029.00	52,421.40	1,561.49	1,198.52	745.84	1,379.58	3,323.94	6,189.83	7,198.90	521.80	25.67	74.80	79.77	36	92.33
	AE Housman	107,813.00	155,249.00	263,062.00	1,927.25	8,412.92	2,966.81	1,702.73	13,082.45	49,830.09	28,635.68	2588.00	41.66	59.99	63.98	91	143.76
	Ankerdine	21,280.50	85,006.00	106,286.50	650.93	1,882.80	1,624.46	575.10	4,082.36	9,835.63	15,679.36	772.40	27.55	110.05	117.37	36	113.40
	Avon and Leburry			0.00	4,938.00	0.00	0.00	4,362.72	4,362.72	0.00	0.00	3949.10	0.00	0.00	0.00	194	22.49
	Berrow Hall	24,497.50	95,042.00	119,539.50	1,029.34	2,197.87	1,816.25	909.42	4,923.54	11,322.50	17,530.50	772.40	31.72	123.05	131.23	36	136.77
	Elizabeth Barret Browning	113,351.00	122,812.00	236,163.00	1,985.55	10,144.06	2,346.94	1,754.23	14,245.24	52,389.70	22,652.67	2588.00	43.80	47.45	50.61	91	156.54
	Evesham & Pershore	40,997.90		40,997.90		3,669.00	0.00	0.00	3,669.00	18,948.82	0.00	1,544.80	26.54	0.00	0.00	60	61.15
	Malvern	21,495.20	67,756.00	89,251.20	524.20	1,923.66	1,294.82	463.13	3,681.61	9,934.87	12,497.59	772.40	27.83	87.72	93.56	36	102.27
	Sarah Siddons	8,804.40	75,838.00	84,642.40	595.33	787.93	1,449.26	525.97	2,763.17	4,069.31	13,988.32	772.40	11.40	98.18	104.72	36	76.75
	Teme	16,190.20	1,622.84	17,813.04	587.81	1,448.90	31.01	519.33	1,999.24	7,482.95	299.33	521.80	31.03	3.11	3.32	24	83.30
	Vesta Tilley	44,673.00	61,349.00	106,022.00	966.87	3,997.90	1,172.38	854.23	6,024.51	20,647.41	11,315.82	958.80	46.59	63.99	68.24	40	150.61
	William Morris	20,410.60	92,453.00	112,863.60	752.22	1,826.60	1,766.78	664.59	4,257.96	9,433.58	17,052.96	958.80	21.29	96.43	102.84	40	106.45
	Windrush	18,442.80	37,869.00	56,311.80	410.80	1,650.49	723.68	362.94	2,737.11	8,524.08	6,984.94	601.20	30.68	62.99	67.18	24	114.05
	Wulfstan	25,618.30	69,701.00	95,319.30	671.56	2,292.65	1,331.99	593.32	4,217.96	11,840.52	12,856.35	772.40	33.17	90.24	96.24	36	117.17

Appendix 6:

Solar installation on AEH and EBB



SAVINGS

A DF100 solar system is usually sized to provide 60% of a household's annual hot water requirements. The graph below shows the typical annual solar energy contribution for London.

POSITIVE ENVIRONMENTAL IMPACT

Burning fossil fuels produces vast quantities of carbon dioxide, a major contributor to global warming. The average household with a 3m² Thermomax system installed, can expect to generate approximately 2,256 kWh/year with zero emissions.

This diagram illustrates the amount of CO_2 (kg) produced by oil, gas and electricity to generate the equivalent 2,256 kWh.

For further information on industrial or commercial applications, please ask for our reference manual or contact our technical support team at info@thermomax.com.

DF100

DIRECT FLOW SOLAR COLLECTOR

SPECIFICATIONS

	DF100 – 2m²	DF100 – 3m²
Number of tubes	20	30
Dimensions (gross) [mm]	1996 x 1418 x 97	1996 x 2127 x 97
Absorber Area [m²]	2.004	3.020
Weight (empty) [kg]	54.8	81.4
Fluid Content [Ltr]	3.8	5.6
Max. Operating Pressure [bar]	8	8
Flow Rate [l/min/tube]	0.10 - 0.25	0.10 - 0.25
Vacuum level [mbar]	10^{4}	10^{4}
Glass Specification	Low Iron Solar Glass	Low Iron Solar Glass
Efficiency (Absorber) n_0	0.830	0.832
a_1 [W/m²K]	1.53	1.14
a_2 [W/m²K²]	0.0063	0.0144
Heat Capacity [kJ/m²/K]	9.3	9.2
Test/Approval (Solarkeymark)	EN12975-2	EN12975-2

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X. Glossary of technical terms

- **Building Management Systems** (BMS) are computer-based systems that help to manage, control and monitor building technical services (HVAC, lighting etc.) and the energy consumption of devices used by the building. They provide the information and the tools that building managers need both to understand the energy usage of their buildings and to control and improve their buildings' energy performance.
  (Definition from www.trendcontrols.com)
  La « Gestion Technique du Bâtiment » (GTB) est un système informatisé qui aide à gérer, contrôler et surveiller des points tels que l'éclairage ou encore la ventilation. Ce système permet également de visionner l'énergie que le bâtiment utilise en fournissant des informations et des outils dont le responsable a besoin pour comprendre l'usage d'énergie. Grâce à cela, il est possible de contrôler et d'améliorer la performance énergétique des bâtiments.

- **DYNAMAT** is data analysis software that turns raw energy consumption data from meter reading systems into meaningful management information where carbon emissions and different consumptions can be monitored and savings can be realised.
  (Definition from http://energymeteringtechnology.com/products/dynamat/)
  DYNAMAT est un logiciel d'analyse de données qui fournit des informations concernant la consommation d'énergie. Ces données sont fournies grâce à la lecture de différents compteurs, ce qui permet de collecter des informations concernant les émissions de carbone ainsi que la consommation des bâtiments. Il est alors possible de contrôler cela et donc d'optimiser des bâtiments.

- **Condensing boilers** use heat from exhaust gases that would normally be released into the atmosphere through the flue.
  (Definition from https://www.worcester-bosch.co.uk/archive/boilers/what-is-a-condensing-boiler)
  Les chaudières à condensation utilisent la vapeur d'eau qui devrait normalement s'échapper dans l'atmosphère par une conduite.

- A **Display Energy Certificate** (DEC) is an operational energy rating that identifies the actual energy use of a building and compares this against the energy use for a benchmark building of the same type. The operational rating is a numerical indicator of the actual annual carbon dioxide emissions from the building.
  (Definition from www.nesltd.co.uk/sites/default/files/DEC%20Explained%20Final)
  Le diagnostic de performance énergétique (DPE) renseigne sur la performance énergétique d'un logement ou d'un bâtiment, en évaluant sa consommation d'énergie et son impact en terme d'émission de gaz à effet de serre. Il s'inscrit dans le cadre de la politique énergétique définie au niveau européen afin de réduire la consommation d'énergie des bâtiments et de limiter les émissions de gaz à effet de serre.

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