ENERGY MAPPING – Geoffrey Pope Building

Final v2.0

University of Exeter

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Quality Control

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Document Control

Report Version	Date	Summary of Changes	Name
Draft v1.0	20/11/19	Initial draft report	G Booy
Draft v2.0	08/12/19	Updated draft report	A Carter
Final v1.0	15/01/19	Report for Issue	A McKenzie
Final v2.0	18/02/20	Updated to include additional lab areas	G Booy

Contents

1. Executive Summary

An energy mapping study has been undertaken at the Geoffrey Pope building within the University of Exeter Streatham campus. The objective of the energy mapping study was to review the demand-side electrical, thermal and other energy streams with consideration of building operations to identify areas where energy consumption could be reduced, or trends of use altered, to provide energy savings for the University of Exeter. Additionally, consideration of current metering hardware and connectivity to support the delivery of operational and business performance KPIs.

This report represents an initial energy mapping exercise for the Geoffrey Pope building in as far as data and information provided. It is recommended by Schneider Electric that the following actions be considered for additional investigation to further develop the opportunities available for energy optimisation across this building operation.

No.	Recommendation
1	Conduct full thermal analysis of all GP integral systems once new heat meters available – this should include a CHP option for the central thermal plant and consideration of existing Living Systems building CHP units for more effective annual efficiencies
2	Conduct full main & LEV system performance analysis to Laboratory 101 including consideration of enhanced controls
3	Conduct full ventilation and cooling analysis of the basement Aquaria as the single largest energy user. This should include a full performance capability of existing chiller plant
4	Review opportunities for additional data acquisition as part of evolving metering upgrade and appropriate performance KPI's for all key systems
5	Consideration for additional LZC/R technologies to support current plans within the Carbon Management Plan 2020 in line with designs on items 1,2 & 3 above.

Methodology

In the calendar year of 2016 the university consumed over 53,383 MWh of energy at a cost of £3,938,336[1]. This is broken down into 27,465 MWh of electricity per annum and 24,727 MWh of natural gas. Environmentally, this resulted in the emission of 12,040 tonnes of Carbon Dioxide to atmosphere each year.

This study was carried out by Andrew Carter, Graham Booy and Andy McKenzie of Schneider Electric. The site discussions were held with Steve Newberry and Andy Seaman and subsequently other members of the site were involved. Generally, the Geoffrey Pope building operations are very efficient and those responsible should be commended.

The authors of the report would like to thank the participation of all team and Laboratory managers who assisted during the site study activities. Their knowledge of the site and equipment proved invaluable.

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[1] Carbon_Management_Plan_-_Projects_Final (002).xlsx

Tabular summary of site energies

12 months to Dec 16	Energy Consumption		Cost		CO₂ emissions
Utility	**kWh/year**	**%**	**£/year**	**%**	**Tonnes**
Electricity	27,464,976	52%	-	-	-
Natural Gas	24,727,228	46%	-	-	-
Oil	1,190,405	2%	-	-	-
Total Energy	**53,382,608**	**98%**	**3,938,336**	**0%**	**12,040**

Table 1a Site Energies

Risks and uncertainties

The energy savings advisory comments within this report for the various follow on recommendations are all estimates based on the limited information available for the assessment. The site survey took place during October 2019.

2. Background

The Geoffrey Pope buildings sits within the Streatham campus at the University of Exeter.

Figure 2a University of Exeter Location

The Geoffrey Pope building is shown as building 20 on the following Streatham campus map.

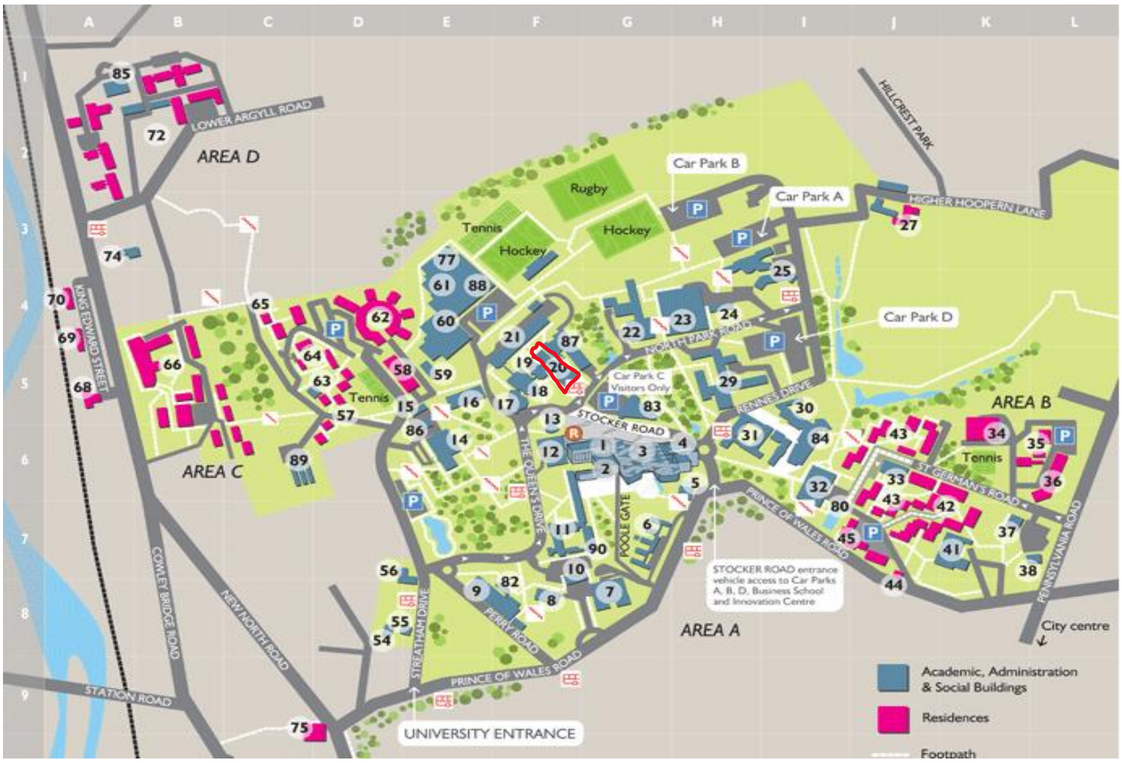

Figure 2b Streatham Campus Map

"The Geoffrey Pope building, the central hub of Biosciences in Exeter, is one of the tallest buildings on Streatham Campus and has magnificent views over the campus and the Exe Valley.

Following a £25m refurbishment, the building provides world-class research and teaching facilities with over 4,800m^2 of lab space and our state-of-the-art Millhayes teaching laboratory. The Geoffrey Pope building is also physically linked to the £52m Living Systems Institute and the recently established BioEconomy Centre".[2]

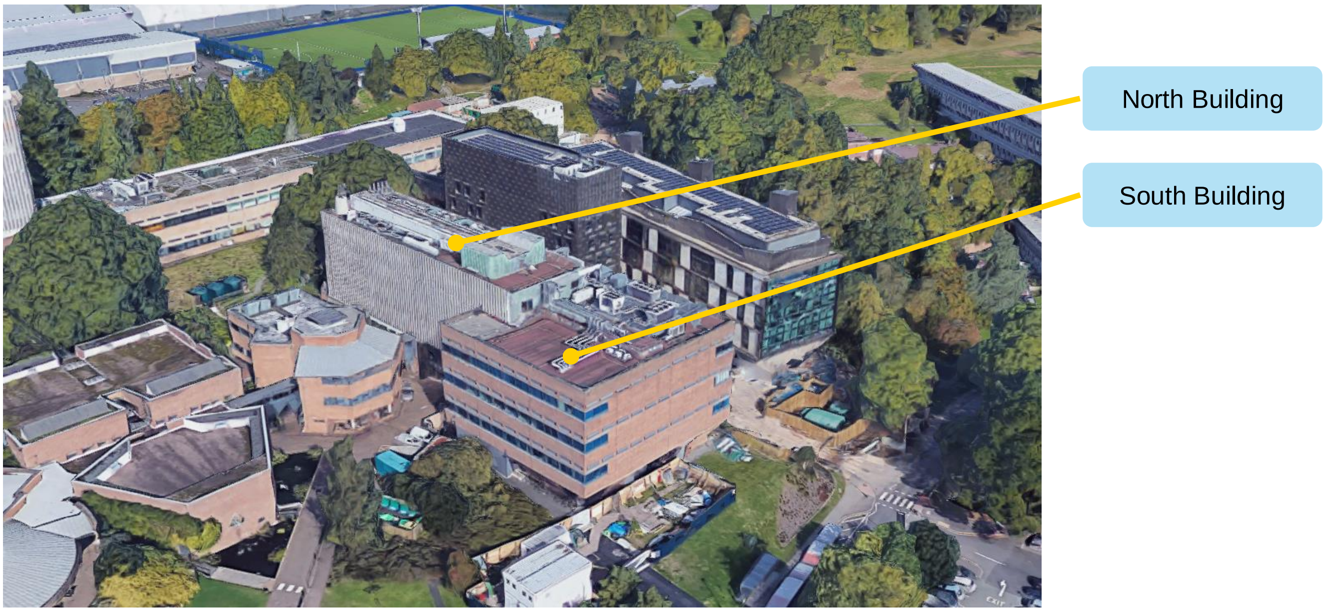

Figure 2c Geoffrey Pope Building

The report has been designed in such a way that someone of a non-technical background should be able to read and understand the recommendations, however in order to keep the report to an acceptable size, it is assumed that the reader has some working knowledge of the University of Exeter Geoffrey Pope building and the activities housed within.

The site survey activity took place during the following dates;

Visit	Date
Visit 1	8th to 10th October 2019
Visit 2	15th to 17th October 2019

Table 2b Site Survey Schedule

No direct recommendations in this report relate to building fabric. The costs incurred to make any structural changes to a building on the basis of the resultant energy savings are simply unrealistic. For example, improving the level of thermal insulation within roof panels would result in an energy saving, however, the cost to

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[2] Extract from "http://biosciences.exeter.ac.uk/exeter/facilities/"

undertake this work based only on energy savings would result in a payback of decades. The same would be true of any other alteration to the building fabric. Furthermore, it is recognised that several works pertaining to building fabric and insulation exist currently within the Carbon Management Plan.

Energy consumption savings related to structural changes should be considered, but only when the work needs carrying out for other reasons, e.g. replacement owing to failure. When building fabric is replaced the current best codes of practice and building regulations relating to energy efficiency and thermal insulation should be followed by the company undertaking the work.

3. Energy Flows

3.1. Site Energy Consumption and Cost

The University of Exeter consumed approximately 53,383 MWh of energy in the year January to December 2016 based on data supplied by the University. The total value of the supplied energy was £3.9M.

The comprises;

12 months to Dec 16	Energy Consumption		Cost		CO₂ emissions
Utility	**kWh/year**	**%**	**£/year**	**%**	**Tonnes**
Electricity	27,464,976	52%	-	-	-
Natural Gas	24,727,228	46%	-	-	-
Oil	1,190,405	2%	-	-	-
Total Energy	**53,382,608**	**98%**	**3,938,336**	**0%**	**12,040**

Table 3.1a Energy Summary

All energy values and associated calculations are in terms of delivered energy.

The average unit costs for electricity and natural gas for this period are 0.096 £/kWh and 0.0233 £/kWh respectively. Looking at prices for 12-months from this period; if prices were to rise by an average of 5%; assuming the same consumption, costs will rise by approximately £40,444.

The following charts detail the energy usage and energy cost graphically.

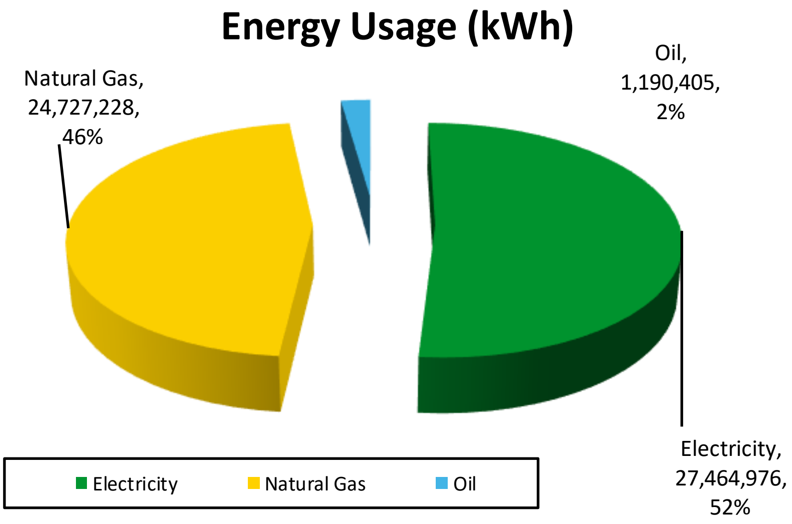


Chart 3.1a University Energy Split

The scope of the study has been limited to the Geoffrey Pope Building within the Streatham Campus. Using energy consumption and cost data provided by the University of Exeter (base-year 2016) the top 10 consuming buildings are listed in the following table.

Rank	Building	Total Area	Electricity (kWh)	Gas (kWh)	Oil (kWh)	Carbon Emissions (tCO2)	Energy Cost (£)	Total Energy (kWh)	% of Total
1	Geoffrey Pope	7,602	3,881,239	2,449,516	89,612	1,487	£531,949	6,420,368	12.0
2	Holland Hall	10,910	1,266,666	1,459,817	-	599	£185,486	2,726,483	5.1
3	Forum & Library Building	15,181	2,042,828	432,918	-	612	£260,622	2,475,746	4.6
4	Laver Building	6,005	1,844,751	581,127	-	588	£239,165	2,425,878	4.5
5	Harrison Building	9,833	1,346,664	104,385	884,260	610	£209,264	2,335,309	4.4
6	Amory	10,858	754,457	1,276,040	-	432	£118,631	2,030,496	3.8
7	Hatherly Labs	3,477	885,224	967,281	-	409	£128,568	1,852,505	3.5
8	Physics Building	6,628	614,588	932,733	-	332	£94,498	1,547,322	2.9
9	St Lukes North Cloisters	5,309	249,767	947,229	-	240	£49,795	1,196,996	2.2
10	St Lukes South Cloisters	1,892	524,676	599,558	-	247	£76,729	1,124,234	2.1

Table 3.1b Top 10 Building Energy Consumers

As can be seen in the above table the Geoffrey Pope building was the greatest consumer of energy in 2016, consuming 12.0% of the total University of Exeter energy.

The following sections of the report focus solely on the Geoffrey Pope building using recent energy consumption and cost data.

3.2. Geoffrey Pope Electricity Consumption and Cost

The following table details the total electricity monthly consumption for the Geoffrey Pope building for the academic year of September 2018 to August 2019. It should be noted that the data shown has been obtained from the buildings main electricity sub-meter (AMR_E_T040) which unfortunately during all months except October 2019, June 2019 and August 2019 the University had virtual server issues resulting in sporadic loss of consumption data. Therefore, the true electricity consumption of the building during the interrupted months will be greater. See Appendix 1 for daily demand profile charts.

Month	Day Units (kWh)	Night Units (kWh)	Total Units (kWh)	MPAN Rate (£/kWh)	Estimated Energy Cost (£)
Sep-18	222,824	80,065	302,889	0.075727	22,937
Oct-18	241,298	88,855	330,153	0.091689	30,271
Nov-18	226,773	76,785	303,558	0.091689	27,833
Dec-18	221,453	77,208	298,661	0.091689	27,384
Jan-19	207,275	69,650	276,925	0.091689	25,391
Feb-19	186,049	59,895	245,944	0.091689	22,550
Mar-19	202,164	61,339	263,503	0.091689	24,160
Apr-19	178,164	66,037	244,201	0.091689	22,391
May-19	196,509	72,991	269,500	0.084139	22,675
Jun-19	198,495	74,438	272,933	0.084139	22,964
Jul-19	198,214	72,083	270,297	0.084139	22,743
Aug-19	202,099	71,650	273,749	0.084139	23,033
Total	**2,481,317**	**870,996**	**3,352,313**	**0.087800**	**294,333**

Table 3.2a – Historical Electricity Consumption and Cost

The costs shown are estimated based on the unit rate for the supply to MPAN 2200030347110 as detailed in the Sigma Teams cloud portal. During this time, the total electricity consumption of Geoffrey Pope building was 3,352 MWh at a total cost of £294,333.

Chart 3.2a shows graphically the monthly electricity consumption for the period September 2018 to August 2019 represented as average daily consumptions to normalise data.

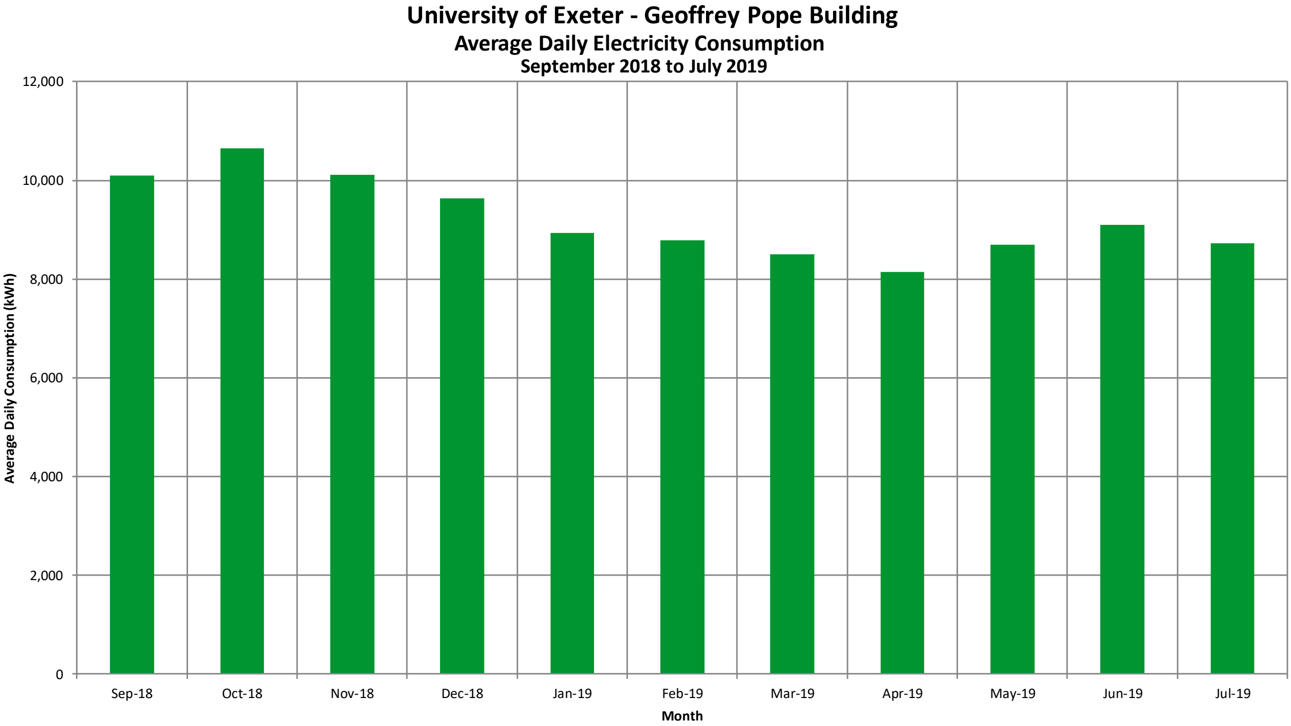


Chart 3.2a Monthly Electricity Consumption

The above chart shows the average daily electricity consumption, by month, for the building for the period September 2018 to August 2019. The chart profile shows that greatest electricity consumption occurred during October 2018, reducing gradually to the lowest consumption in April before increasing slightly during May and June 2019.

In addition to analysing the monthly electrical data the site half hourly interval electricity data has been examined to understand the demand profile further. Twelve months of data have been condensed down into a single week and have been presented graphically in the following chart.

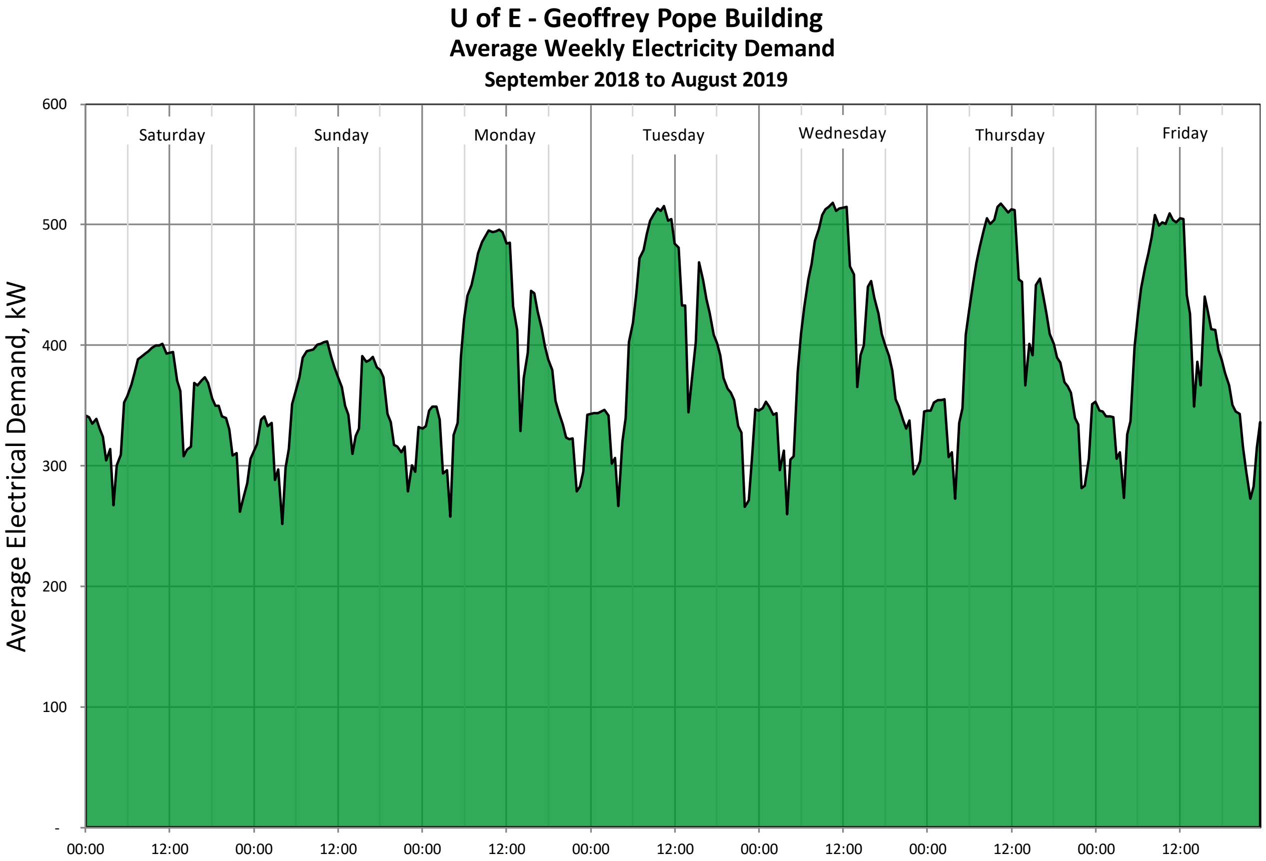


Chart 3.2b Average Weekly Electrical Demand Profile

The demand profile chart, although distorted by the AMR virtual server issues, clearly shows a typical demand profile for a location operating with a 9:00 to 17:00 Monday to Friday occupancy. The profile shows a high base-load demand, both during weekends and weekdays, of approximately 252 kW, increasing to peak demand in the region of 519 kW throughout the working week. The peak demand reduces at approximately 16:00 each day (Monday to Friday).

The peak demand during the above profile is 518 kW, occurring on Wednesdays and Thursdays between 10:00 and 10:30. For the average weekly demand profile shown above, the base-load represents 89% of the total site electrical consumption.

The following chart details the daily electrical consumption (kWh) for the period September 2018 to August 2019.

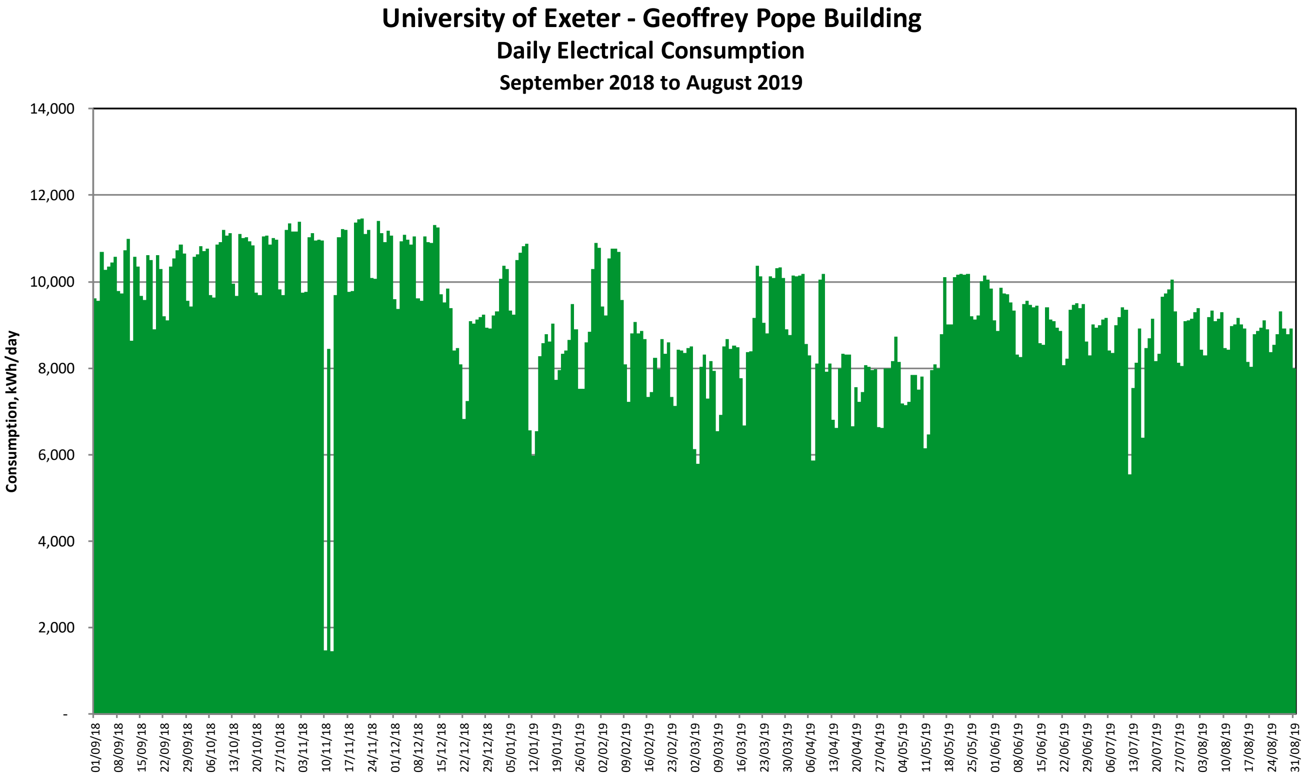


Chart 3.2c Daily Electrical Demand Profile

In the above chart it is clear to see the weekend periods with reduced consumption. The following table provides a summary of the electrical demand profile.

	Baseload (kW)	Peak Weekend (kW)	Peak Weekday (kW)	Weekday Baseload (kW)	Peak Time
Geoffrey Pope	126	202	259	129	Wed & Thurs 10:00 – 10:30

Table 3.2b Electrical Demand Profile Summary

3.3. Geoffrey Pope Natural Gas Consumption and Cost

The following table details the average monthly gas consumption and estimated cost for the Geoffrey Pope buildings between the period September 2018 and August 2019. In the absence of a mains sub-metered AMG data the sub-metering for the heating boilers (G121) has been used to demonstrate the buildings consumption profile, being the greatest consumer. Again, the data has been obtained from the Teams portal and costs are based on the unit rate for gas meter MPR 74231700.

Month	Total Units (AMR G121) (kWh)	MPR Ave Rate (p/kWh)	Estimated Invoice Total (£)
Sep-18	165,125	2.7470	4,536
Oct-18	369,085	2.3300	8,600
Nov-18	464,911	2.2610	10,512
Dec-18	458,159	2.3180	10,620
Jan-19	568,786	2.2680	12,900
Feb-19	420,352	2.3240	9,769
Mar-19	390,459	2.2930	8,953
Apr-19	332,485	2.3440	7,793
May-19	276,344	2.5090	6,933
Jun-19	113,768	2.4190	2,752
Jul-19	97,905	2.5630	2,509
Aug-19	94,362	3.8250	3,609
Total	**3,751,740**	**2.3852**	**89,487**

Table 3.3a – Historical Natural Gas Consumption and Cost

The costs shown are the estimated costs (exclusive taxes) paid by the University of Exeter for the supply of natural gas for the period September 2018 to August 2019. During this time, the total natural gas consumption was 3,752 MWh at a total cost of £89,487.

The following chart shows graphically the average daily natural gas consumption, averaged for each month, for the period September 2018 to August 2019. Also shown is the monthly heating degree day profile for the region.

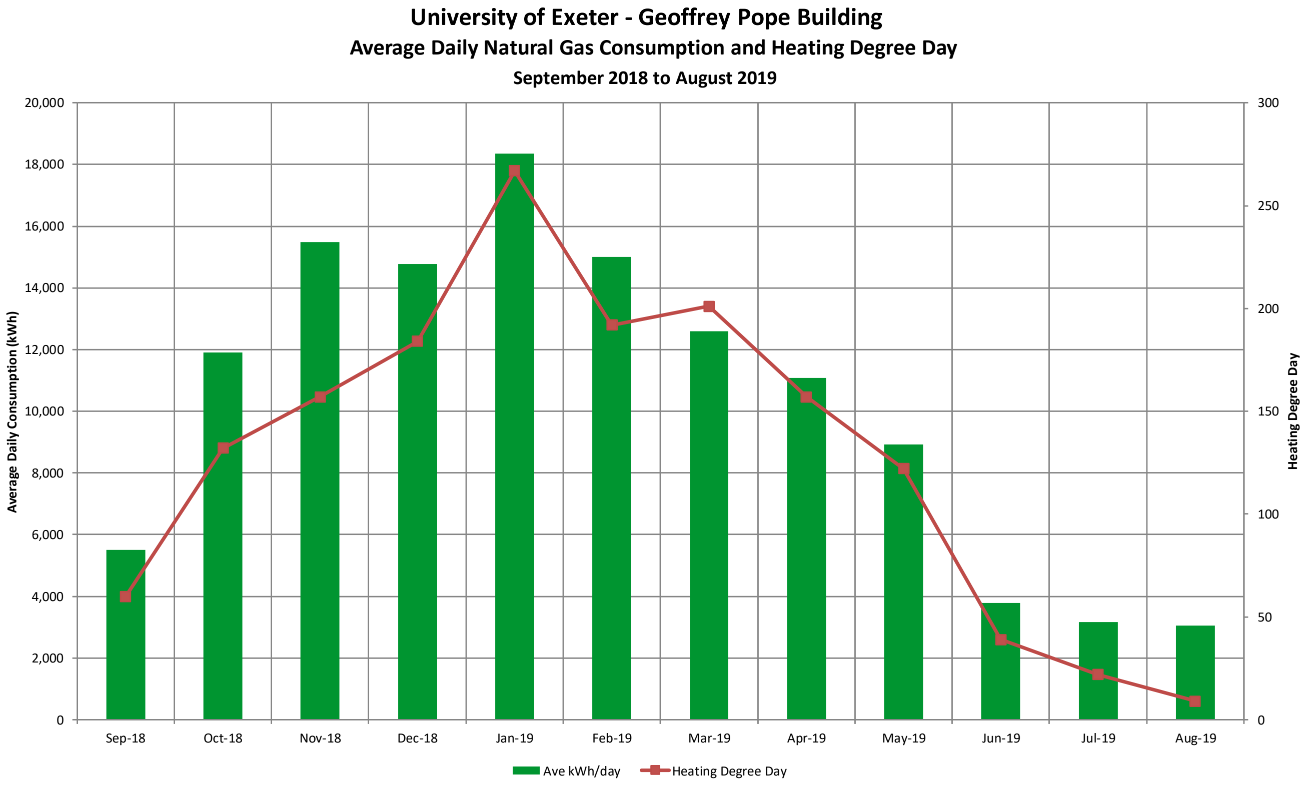


Chart 3.3a 12 Months Daily Natural Gas Consumption Profile

The above chart shows that the natural gas consumption of the Geoffrey Pope building has a strong relationship with monthly heating degree day data. There is however a large base-load consumption throughout the year, as shown in July and August 2019. It is assumed that this consumption, when there was no requirement for comfort heating, is associated with the buildings domestic hot water provision. The base-load during August 2019 was 3,044 kWh/day which equates to, when extrapolated for the year, 1,111,033 kWh/year. This represents 29.6% of the total annual natural gas consumption. It should be noted that the site has a series of 'summer boilers' which are operated during low heating demands. The gas supply however to these boilers is unmetered before the heating boiler AMR meter (G121).

In order to understand the main relationship between natural gas consumption and installed heating systems, regression analysis is used whereby natural gas is plotted against other known variables, in this case heating degree days. The plot gives an indication of the relationship between monthly natural gas consumption and another variable, heating degree days in this instance. An R^2 coefficient of above 0.95 is indicative of a strong relationship between the two variables.

Heading Degree Day Regression Analysis

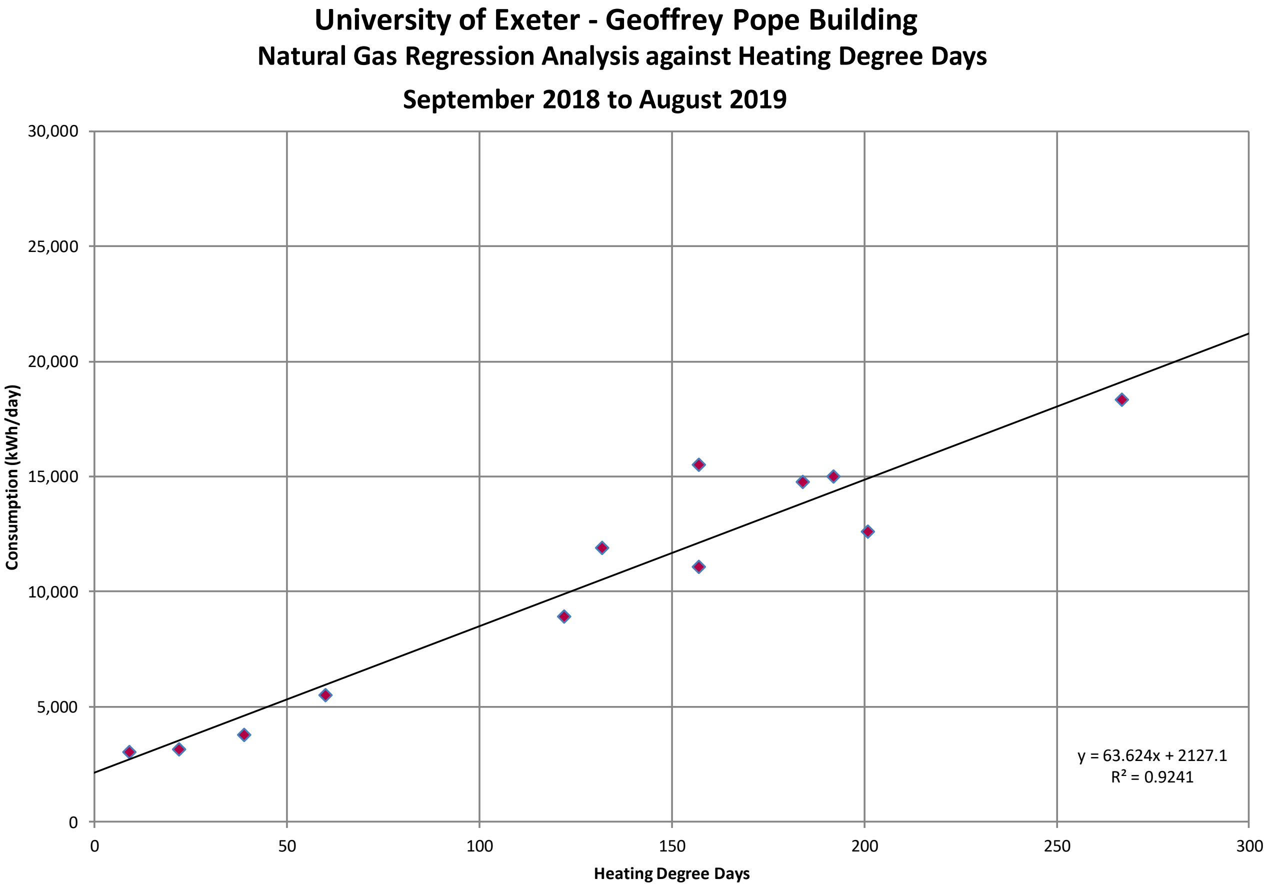


Chart 3.3b – Natural Gas Regression Analysis – Heating Degree Days

The chart shows that natural gas consumption within the Geoffrey Hope building has a strong relationship with heating degree days. The R^2 coefficient during the period shown was 0.9241. Based upon the above correlation, the average daily natural gas consumption when there was no heating demand at site (zero-degree days) was 2,127.1 kWh. Extrapolated for the whole year this consumption is estimated at 776,392 kWh which equates to 21% of the total building heating consumption as measured by meter G121.

4. Building Energy Mapping

This section of the report provides the analysis of the energy mapping completed within the Geoffrey Pope building during October 2019.

4.1. Data Collection - Electricity

To map the electrical energy flow of the building the sites fixed sub-metering within the LV room has been used. Within the LV room there are 40x outgoing circuit isolators with 38 having fixed sub-metering provided by panel mounted ND Multicube multi-parameter meters. A handful of these meters are connected to the University's 'Team Energy Management' Software whereby interval data is available. Also, there is metering provided on the main LV supply which is connected to the Teams system (ref E291). The following table details the LV outgoing circuits, metering quantity and Teams connectivity.

MCB Ref	Meter Ref	Sub-metered?	Teams Ref	Description	Primary	Secondary	Secondary	Secondary	Secondary	Secondary	Secondary
1	BT SM6	Yes									
2	Lab 301	Yes		South Block 3rd Floor - Lab 301	DB						
3	Master Fire Alarm Panel	Yes		North Block Gnd Floor Fire Alarm	Fire Alarm						
4	STP1 Sub-Mains Panelboard	Yes	E299	South Block Roof Plant Areas	STP 1A - Panelboard	STP 1B - Fume Cupboards	STP 1C - Fume Cupboards				
5	STP3 Sub-Mains Panelboard	Yes	E300	South Block Roof Plant Areas	New DB						
6	1T SM2 Sub-Mains Panelboard	Yes		South Block 1st Floor	1T SM2 - Panelboard	DB101 - Lab 101 DB	DB102 - Lab 101 DB				
7	1TSM1 Sub-Mains Panelboard	Yes		South Block 1st Floor	IT SM1 - Panelboard	1TL1 - Lighting	1TP1 - Power				
8	BH LAB COMP MCB Dist Board	Yes		North Block Boiler House Plant Room - Upper	BH Lab Comp - DB	MCCP					
9	GR SM1 Sub-Mains Panelboard	Yes		North Block Gnd Floor	GR SM1 - Panelboard	BTSM6 DB - Toilets					
10	GR G01 MCB Dist Board	Yes		North Block 3rd Floor - IT Comms	GR G01 - DB						
11	Chiller 1	Yes	E297	Chiller	Chiller 1						
12	1R SM1 Sub-Mains Panelboard	Yes		North Block 1st Floor	1R SM1 - Panelboard						
13	2T SM3 Sub-Mains Panelboard	Yes		South Block 2nd Floor	2T SM3 - Panelboard	2TL3 - Lighting	2TP3 - Power	BMS Panel			
14	3T SM2 Sub-Mains Panelboard	Yes		South Block 3rd Floor (Lighting and Power)	3T SM2 - Panelboard	3TL2 - Lighting	3TP2 - Power	3TSM3 - Lab 301			
15	BS14 Water Heater Control Panel	Yes			BS14 Water - Panel						
16	MCCB Panel Lab 101	Yes		South Block 1st Floor	MCCB - Lab 101						
17	MR1 Sub-Mains Panelboard	Yes		North Block Lift Plant Room	MR1 - Panelboard						
18	2T SM1 Sub-Mains Panelboard	Yes		South Block 2nd Floor	2T SM1 - Panelboard						
19	2T SM2 Sub-Mains Panelboard	Yes		South Block 2nd Floor	2T SM2 - Panelboard	2TL2 - Lighting	2TP2 - Power				
20	BT SM5 Sub-Mains Panelboard	Yes		South Block Basement - LV1 Switch Room	BT SM5 - Panelboard	BT SW5 - Panelboard					
21	RT SM1 Sub-Mains Panelboard	Yes		South Block Roof Plant Room	RT SM1 - Panelboard	STP2 - Panelboard	BMS Panel	Scrubber DB			
22	3T SM1 Sub-Mains Panelboard	Yes		South Block 3rd Floor	3T SM1 - Panelboard	3TL1 - Lighting	3TP1 - Power	BMS Panel			
23	DB A1 NEW DB IN POTTING ROOM	Yes		South Block Basement	DB A1 New DB - Room						
24	Chiller 3	Yes	E295	Chiller	Chiller 3						
25	Chller 2	Yes	E296	Chiller	Chiller 2						
26	BH CP Sub-Mains Panelboard	Yes		North Block Boiler House 1st Floor	BH CP - Panelboard						
27	Spare	No			Spare						
28	Essential Services Switchboard	Yes		North Block Boiler House 1st Floor	Essential Serv DB	DB Lights & Power	Boosted Water Pumps	BMS Panel	BSL3 Panel Board	MCCP 1 - Roof	MCCP 2 - Roof
29	Generator Intake	Yes		External Generator Connection	Intake						
30	Feeder to Aquarium SB2	Yes	E339	South Block Basement	Feeder - SB2						
31	2R SM1 Sub-Mains Panelboard	Yes		North Block 2nd Floor	2R SM1 - Panelboard	2RP1 - Power	2RL1 - Lighting				
32	2R SM2 Sub-Mains Panelboard	Yes		North Block 2nd Floor	2R SM2 - Panelboard	2RP2 - Power	2RL2 - Lighting				
33	BT EX1 MCB DIST BOARD	Yes		External & Carpark Lighting	BT EX1 - DB						
34	MR SM1 Sub-Mains Panelboard	Yes		North Block Mezz	MR SM1 - Panelboard						
35	MR SM2 Sub-Mains Panelboard	Yes		North Block Mezz	MR SM2 - Panelboard						
36	RR SM3 Sub-Mains Panelboard	Yes		North Block 5th Floor - Roof Plant	RR SM3 - Panelboard						
37	4R SM1 Sub-Mains Panelboard	Yes		North Block 4th Floor	4R SM1 - Panelboard						
38	4R SM2 Sub-Mains Panelboard	Yes		North Block 4th Floor	4R SM2 - Panelboard						
39	3R SM1 Sub-Mains Panelboard	Yes		North Block 3rd Floor	3R SM1 - Panelboard	3RP1 - Power	3RL3 - Lighting				
40	3R SM2 Sub-Mains Panelboard	Yes		North Block 3rd Floor	3R SM2 - Panelboard	3RP2 - Power	3RL2 - Lighting				

Table 4.1a Geoffrey Pope LV Metering

During the site survey activities, the LV metering was recorded manually on a daily basis. This has enabled electricity energy mapping analysis to be completed to provide a 'snap-shot' for the building.

4.2. Energy Mapping - Electricity

The following table details the meter reads of the LV meters taken on 9th October and 16th October 2019.

MCB	Circuit Description	Meter Read		Consumption	% of Total
		09/10/2019	16/10/2019		
		09:23	09:26	kWh	
1	BT SM6	18,729	18,816	**87**	0.1%
2	Lab 301	2,032,953	2,033,702	**749**	1.2%
3	Master Fire Alarm Panel	6,292	6,304	**13**	0.0%
4	STP1 Sub-Mains Panel board	738,313	739,916	**1,603**	2.5%
5	STP3 Sub-Mains Panel board	891,786	892,592	**807**	1.3%
6	1T SM2 Sub-Mains Panel board	432,693	433,800	**1,107**	1.7%
7	1TSM1 Sub-Mains Panel board	340,057	340,960	**903**	1.4%
8	BH LAB COMP MCB Dist. Board	30,358	32,471	**2,113**	3.3%
9	GR SM1 Sub-Mains Panel board	612,805	613,131	**327**	0.5%
10	GR G01 MCB Dist. Board	458,882	459,611	**730**	1.1%
11	Chiller 1	1,666,331	1,670,064	**3,733**	5.9%
12	1R SM1 Sub-Mains Panel board	1,280,897	1,283,643	**2,746**	4.3%
13	2T SM3 Sub-Mains Panel board	1,102,787	1,105,213	**2,425**	3.8%
14	3T SM2 Sub-Mains Panel board	1,208,429	1,208,898	**469**	0.7%
15	BS14 Water Heater Control Panel	2,477	2,487	**10**	0.0%
16	MCCB Panel Lab 101	275,788	276,376	**588**	0.9%
17	MR1 Sub-Mains Panel board	85,013	85,208	**195**	0.3%
18	2T SM1 Sub-Mains Panel board	1,054,872	1,056,855	**1,983**	3.1%
19	2T SM2 Sub-Mains Panel board	779,906	781,747	**1,842**	2.9%
20	BT SM5 Sub-Mains Panel board	312,067	312,564	**497**	0.8%
21	RT SM1 Sub-Mains Panel board	1,263,015	1,265,681	**2,666**	4.2%
22	3T SM1 Sub-Mains Panel board	996,640	997,656	**1,016**	1.6%
23	DB A1 New DB in Potting Room	403,031	403,450	**419**	0.7%
24	Chiller 3	135,251	135,374	**123**	0.2%
25	Chiller 2	142,242	142,326	**84**	0.1%
26	BH CP Sub-Mains Panel board	3,470,449	3,470,935	**486**	0.8%
27	Spare				
28	Essential Services Switchboard	2,322,934	2,326,954	**4,020**	6.3%
29	Generator Intake				
30	Feeder to Aquarium SB2	4,344,012	4,359,736	**15,724**	24.7%
31	2R SM1 Sub-Mains Panel board	847,377	849,272	**1,895**	3.0%
32	2R SM2 Sub-Mains Panel board	844,661	846,559	**1,899**	3.0%
33	BT EX1 MCB DIST BOARD	162,534	163,206	**672**	1.1%
34	MR SM1 Sub-Mains Panel board	1,477,170	1,479,377	**2,207**	3.5%
35	MR SM2 Sub-Mains Panel board	688,396	690,088	**1,692**	2.7%
36	RR SM3 Sub-Mains Panel board	1,600,533	1,604,009	**3,476**	5.4%
37	4R SM1 Sub-Mains Panel board	316,517	317,384	**867**	1.4%
38	4R SM2 Sub-Mains Panel board	673,308	674,677	**1,369**	2.1%
39	3R SM1 Sub-Mains Panel board	225,602	226,064	**461**	0.7%
40	3R SM2 Sub-Mains Panel board	103,782	103,956	**174**	0.3%
41	Mains	**4,253,198**	**4,315,374**	**62,176**	

Table 4.2a LV Metering Reads

During the monitored period the LV mains supply had a consumption of 62,176 kWh. The above data is used to map the energy consumption by building (North and South) along with central building services (plant room etc). This is shown in the following table.

	North	South	Building	Total
kWh	20,008	33,345	8,823	62,176
% of total	32%	54%	14%	

Table 4.2a Electricity Split by Building Area

The above table shows the largest proportion on electricity is consumed within the South building, which is to be expected given the equipment and building use, most notably the aquatic labs and associated plant equipment. The building includes common services such as the fire alarm, lifts, external lighting, main plant room, LV electrical room and the IT Comms.

The following figure demonstrates the building level energy flow in the form of a Sankey diagram for the period Wednesday 9th October to Wednesday 16th October 2019.

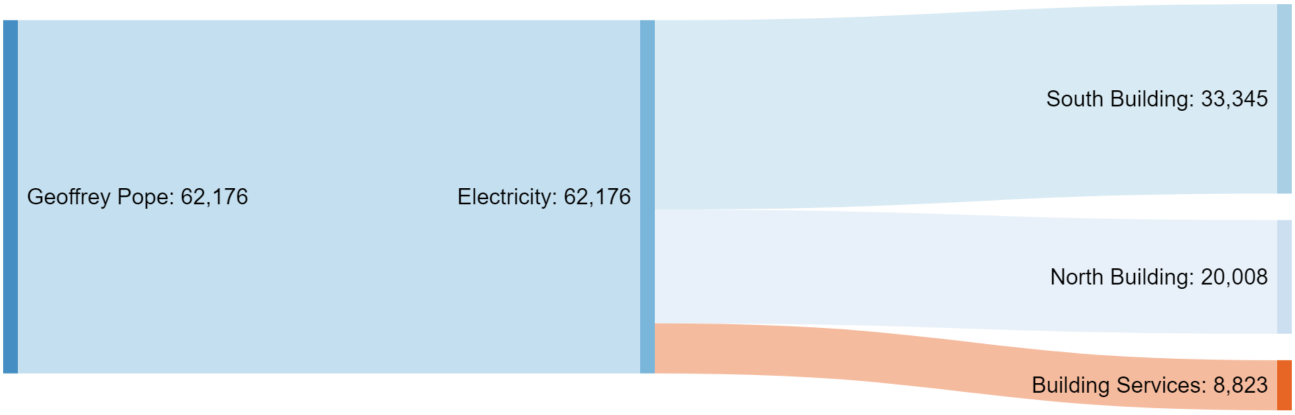


Figure 4.2a Energy Flow Sankey Diagram – Building Level (kWh)

The above energy flow diagram was created using data within a 'typical academic week' and could therefore be assumed as a typical week across the academic calendar.

Studying the LV metering data further electricity mapping is created by floor level. The following table details the energy consumption by physical floor within the Geoffrey Pope building between the period discussed.

North Building	kWh	% of building
Ground	327	1.6%
1st floor	2,746	13.7%
2nd floor	6,219	31.1%
3rd floor	469	2.3%
Mezzanine	4,535	22.7%
4th floor	2,236	11.2%
Plant	3,476	17.4%
Total	**20,008**	

South Building	kWh	% of building
Basement	16,143	80.7%
1st floor	2,598	13.0%
2nd floor	3,824	19.1%
3rd floor	1,765	8.8%
Plant	9,015	45.1%
Total	**33,345**	

Building Services	kWh	% of total
N Plant room	6,619	75.0%
Ext lighting	672	7.6%
IT Comms	730	8.3%
LV Room	497	5.6%
Lift Room	195	2.2%
Other	110	1.2%
Total	**8,823**	

Table 4.2b Electricity Split by Building Area and Floor

The following Sankey diagram shows the electricity flows within the Geoffrey Pope building between the period Wednesday 9th October to Wednesday 16th October 2019.

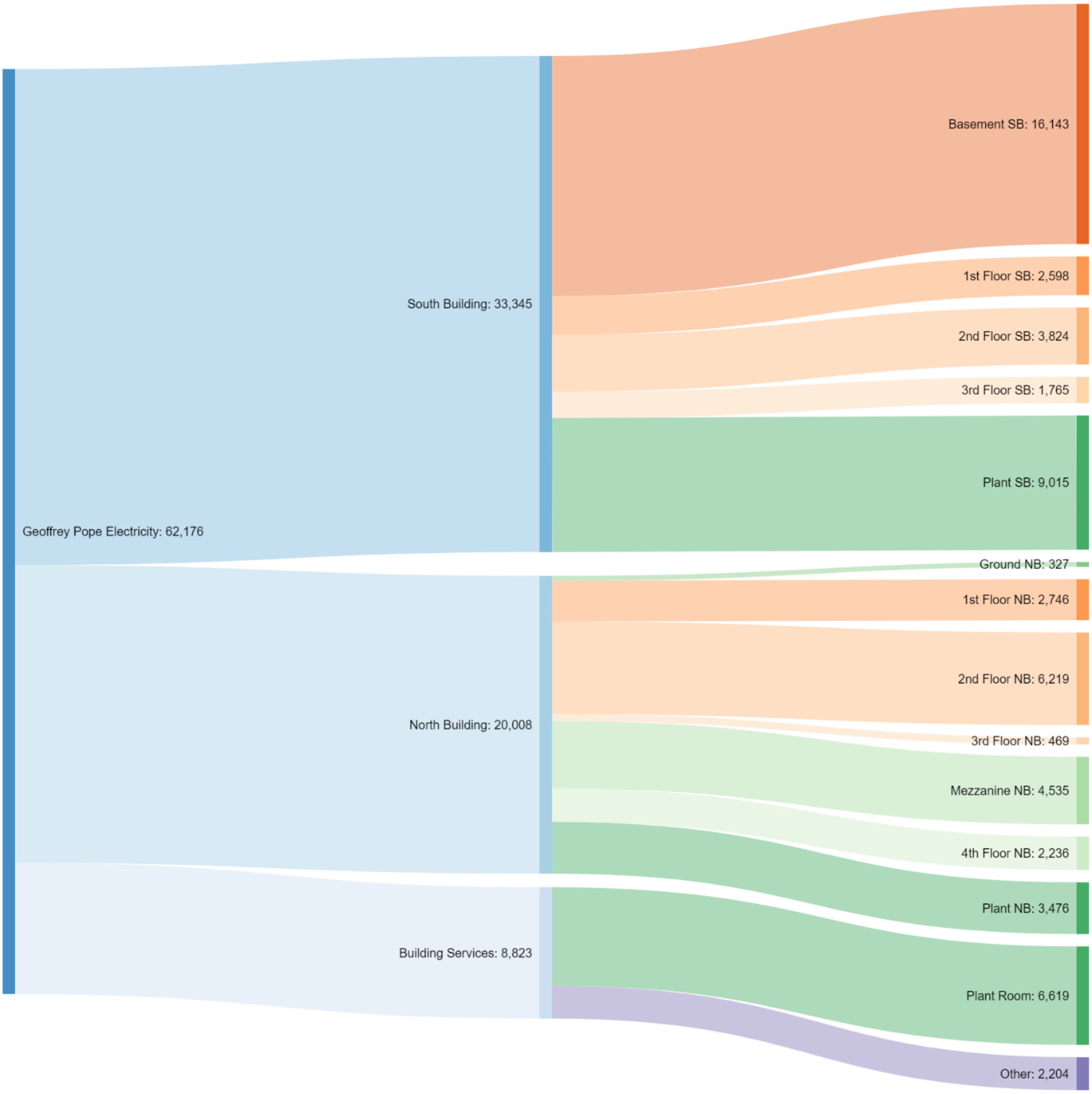


Figure 4.2b Energy Flow Sankey Diagram – Building Floor Level Electricity

4.3. Energy Benchmarks - Electricity

Data supplied by the University of Exeter shows the total gross internal area (GIA) of the Geoffrey Pope building is 6,871.52 m^2. The following table shows the GIA split by area within the building.

Area	m^2	% of building
Total	6,871.52	
South	3,513.95	51.1%
North	2,795.00	40.7%
Building Services	580.48	8.4%

Figure 4.3a Geoffrey Pope Gross Internal Area

The electricity energy intensity of the Geoffrey Pope building, and sub-areas can be calculated using the electricity consumption. The data presented in chart 3.2c previously suggests that electricity consumption is consistent in all weeks of the calendar year despite the academic year being approximately 32 weeks. Therefore, the estimated annual electricity consumption of the building can be assumed, as shown in the following table.

Area	Electricity Consumption (kWh)	
	sample week	Per annum
Total	62,176	3,233,131
South	33,345	1,733,956
North	20,008	1,040,390
Building Services	8,823	458,786

Table 4.3b Geoffrey Pope Estimated Annual Electricity Consumption

The estimated annual electricity consumption based upon the sample week, assuming it's a reflection of all 52 weeks of the year, is 3,233,131 kWh. The actual electricity consumption for the period September 2018 to August 2019 was 3,352,313 kWh, as shown in table 3.2a of this report. The estimations and assumptions made calculate to 96.5% of the actual consumption and therefore can be used to reflect the energy intensity of the building and sub-areas.

Analysis of the GIA and the estimated electricity consumption enables the energy performance (electricity) to be calculated and compared with recognised benchmarks. The Chartered Institute of Building Services Engineers (CIBSE) provides energy efficiency guidance within its 'Guide F Energy Efficiency in Buildings'. Comparisons between the Geoffrey Pope building energy intensity and the Guide F benchmarks provides a viewpoint of the university's performance. The following table details the energy performance benchmarks for Education (further and higher) building type. Highlighted are the benchmarks considered for the Geoffrey Pope building.

Education (further and higher)	Energy Consumption benchmarks for existing buildings / (kWhm^2) per year			
	Good Practice		Typical Practice	
	Fossil Fuels	Electricity	Fossil Fuels	Electricity
Catering, bar/restaurant	182	137	257	149
Catering, fast food	438	200	618	218
Lecture room, arts	100	67	120	76
Lecture room, science	110	113	132	129
Library, air-conditioned	173	292	245	404
Library, naturally ventilated	115	46	161	64
Residential, halls of residence	240	85	290	100
Residential, self-catering/flats	200	45	240	54
Science laboratory	110	155	132	175

Table 4.3c Geoffrey Pope Estimated Annual Electricity Consumption

The following table details the estimated electricity of the Geoffrey Pope building and sub-areas. It should be noted that the building services electricity consumption has been apportioned between the North and South buildings to calculate the individual electricity intensities shown.

Area	Electricity Consumption (kWh)			GIA	Elec Intensity (kWh/m2)
	Sample week	Apportioned	Annum	m^2	
Total	62,176		3,233,131	6,872	471
South	33,345	4,914	1,989,489	3,514	566
North	20,008	3,909	1,243,642	2,795	445
Building Services	8,823				

Table 4.3d Geoffrey Pope Estimated Electricity Intensity

Comparing the estimated electricity intensities shown in table 4.3d and the CIBSE Guide F benchmarks shown in table 4.3c it is clear to see that the Geoffrey Pope building, and sub-buildings, are far greater than the benchmarks.

4.4. Thermal Energy Load Analysis

A high-level review of existing plant pertaining to thermal energy streams was conducted principally within the main North plant room and direct services to the Geoffrey Pope building.

The plant room area has recently completed an upgrade and extension to services including the utilisation of an external Thermal Store which is still undergoing final commissioning.

The equipment and services are as typical in many areas of the site i.e. of a high quality and well maintained standard and therefore observations are limited to the generation and distribution factors pertaining to the consideration of thermal energy utilisation.

The provision of drawing 17659-M-001 (*Revision T1 – tender support drawing, "Proposed Main Schematic")* attached within Appendix 2 supported physical investigations of the area and ascertained the following information.

Information on actual thermal energy flows is not readily accessible even though there are some heat meters fitted on some secondary circuits so a mix of available data and calculated (from gas meter readings) and observations has been undertaken at this stage to support further development and forthcoming advice. Furthermore, information from installed data systems and solicited from the 'Team Energy Management' software files have in many cases significant gaps in data acquisition.

To commence understanding the thermal profile the following extracts show Team software data outputs for the period of Saturday 01 September 2018 to Saturday 31 August 2019.

4.4.1. GP Building – HO64 Laboratories 101 & 301

Month	Consumption *kWh*	Max Demand *kW*	Min Demand *kW*	Ave Demand *kW*
Sep-18	1,970.0	170.0	0.0	12.3
Oct-18	15,100.0	90.0	30.0	48.1
Nov-18	17,825.0	100.0	30.0	47.7
Dec-18	17,935.0	90.0	30.0	48.4
Jan-19	20,450.0	60.0	30.0	49.4
Feb-19	14,935.0	70.0	30.0	45.7
Mar-19	13,095.0	50.0	30.0	38.1
Apr-19	8,870.0	60.0	0.0	31.3
May-19	5,195.0	180.0	0.0	31.9
Jun-19	0.0	0.0	0.0	0.0
Jul-19	0.0	0.0	0.0	0.0
Aug-19	0.0	0.0	0.0	0.0
Total	**115,375.0**			

Table 4.4.1a Teams Thermal Data – H064 Laboratories (101/301) Annual

A MD of 180kW occurred on 09/05/2019 @ 07.00 hours.

Day	Average Daily *kWh*	Min Daily *kWh*	Max Daily *kWh*	Min *kW*	Max *kW*	Ave *kW*
Sat	528	0.0	1,870.0	0	70	10.2
Sun	578	0.0	1,650.0	0	60	11.4
Mon	670	0.0	1,990.0	0	60	12.9
Tue	653	0.0	2,110.0	0	60	12.6
Wed	646	0.0	2,180.0	0	170	12.8
Thu	696	0.0	2,190.0	0	180	13.8
Fri	656	0.0	2,030.0	0	100	12.7

Table 4.4.1b Teams Thermal Data – H064 Laboratories (101/301) Summary for period

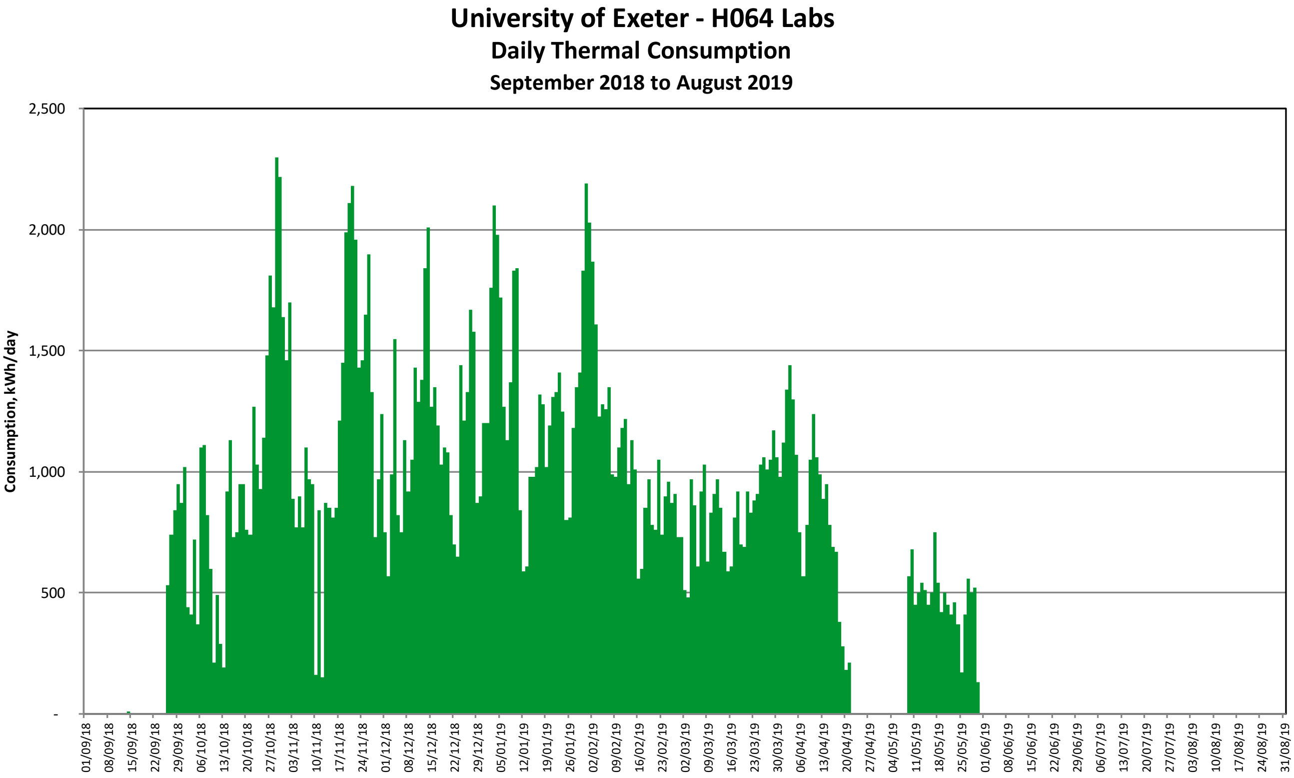


Chart 4.4.1a Teams Thermal Data – H064 Laboratories (101/301)

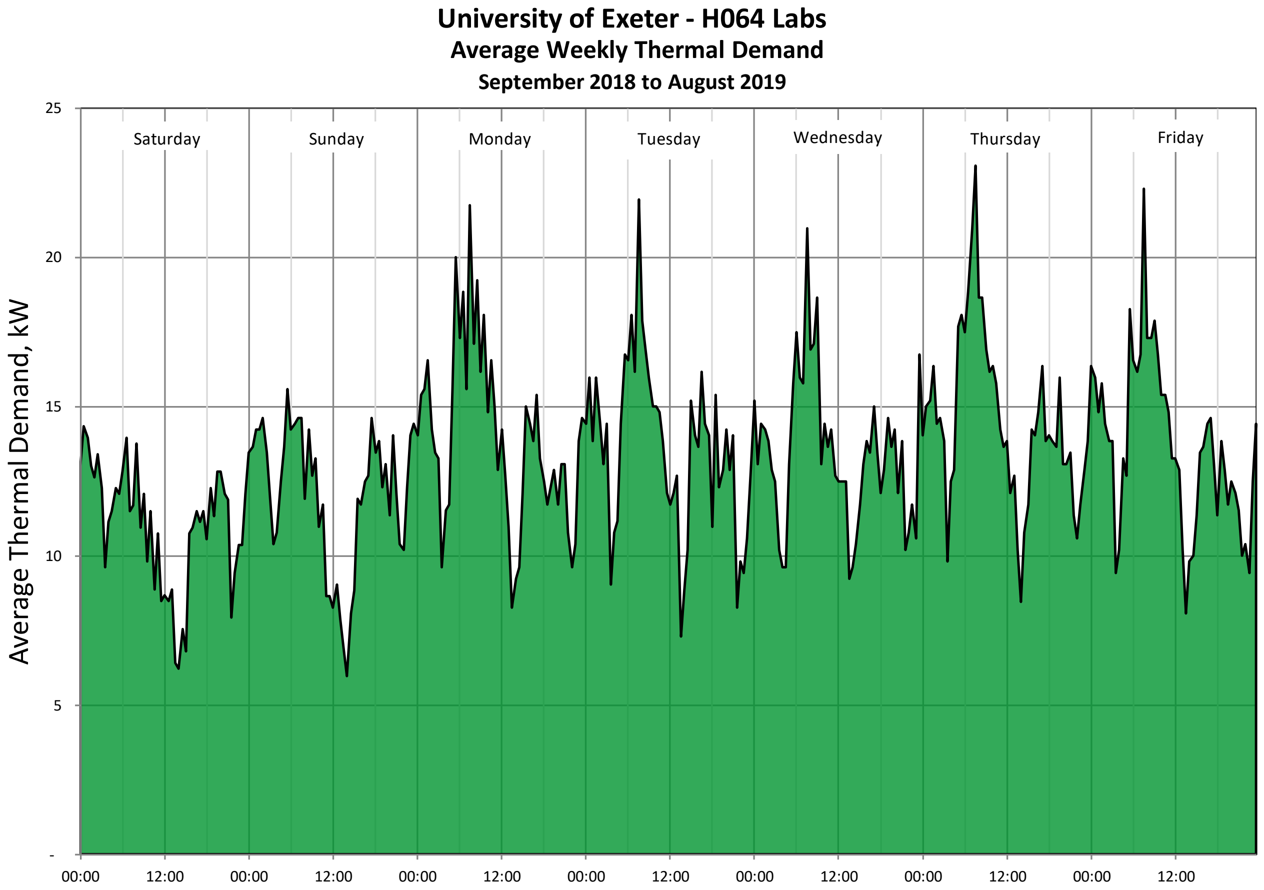


Chart 4.4.1b Teams Thermal Data – H064 Laboratories (101/301)

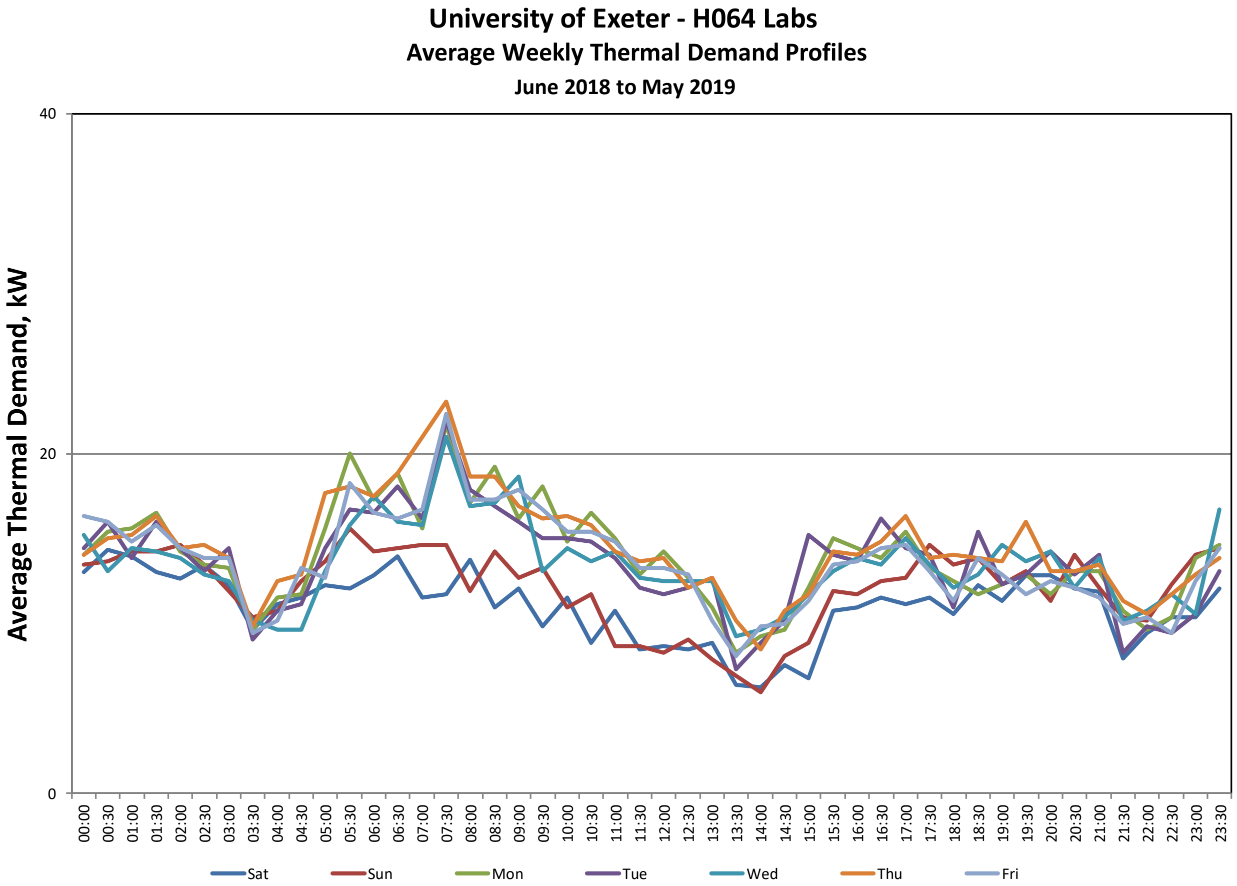
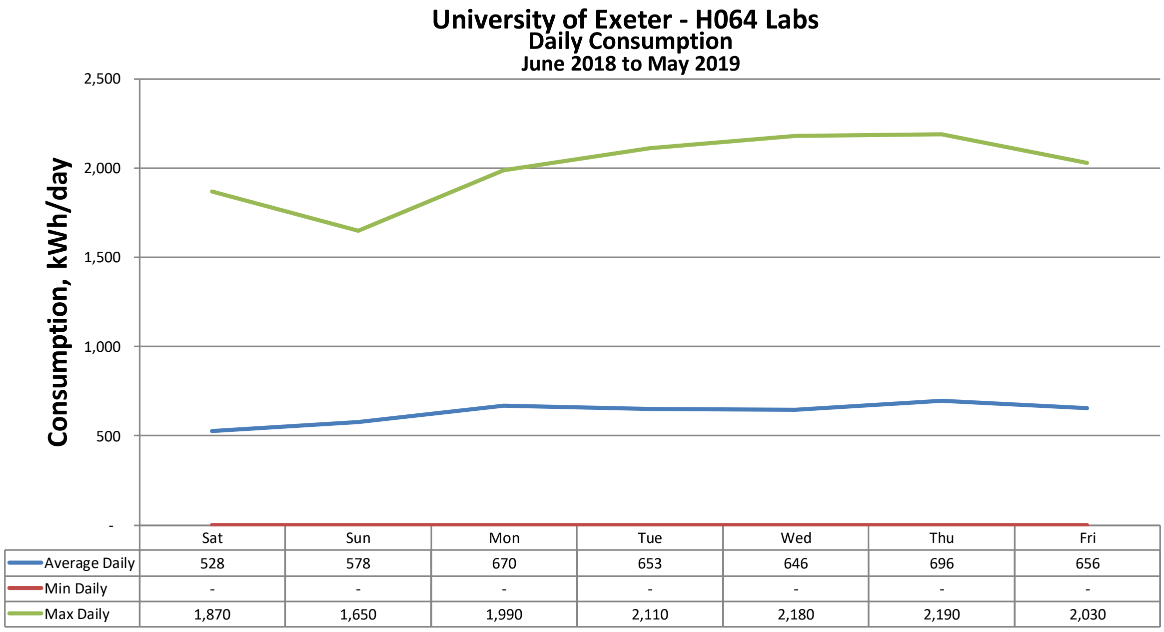


Chart 4.4.1c Teams Thermal Data – H064 Laboratories (101/301)



	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Average Daily	528	578	670	653	646	696	656
Min Daily	-	-	-	-	-	-	-
Max Daily	1,870	1,650	1,990	2,110	2,180	2,190	2,030

Chart 4.4.1d Teams Thermal Data – H064 Laboratories (101/301)

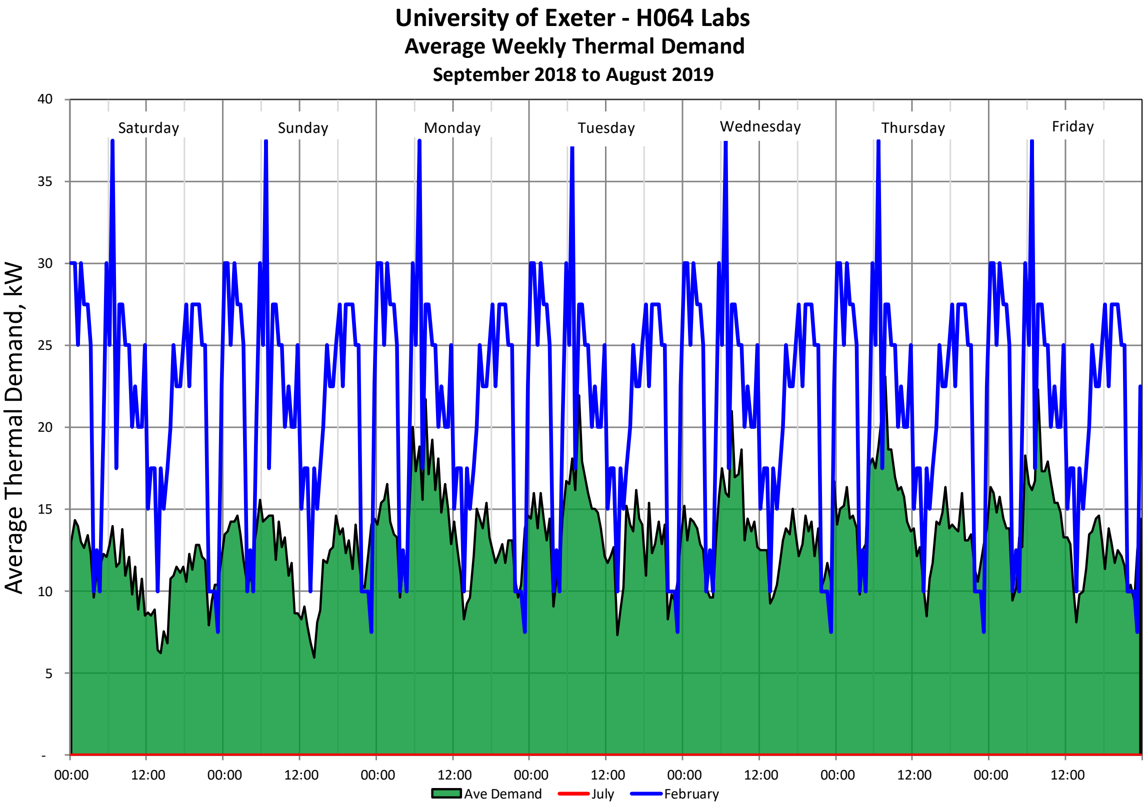


Chart 4.4.1e Teams Thermal Data – H064 Laboratories (101/301)

The profiles for Saturday & Sundays are somewhat like the weekday profiles and seem at odds with the operating hours stated by the site team contacts – this is an area for additional investigation in line with comments on the HVAC services for the building in subsequent sections.

4.4.2. GP Building – Domestic Hot Water (DHW)

Month	Consumption *kWh*	Max Demand *kW*	Min Demand *kW*	Ave Demand *kW*
Sep-18	5,988.6	76.0	17.9	57.9
Oct-18	2,492.9	66.0	0.0	21.1
Nov-18	173.8	3.4	0.0	1.6
Dec-18	62.0	2.2	0.0	0.6
Jan-19	56.5	2.2	0.0	0.9
Feb-19	59.8	2.2	0.0	1.2
Mar-19	56.5	2.2	0.0	1.0
Apr-19	47.5	1.1	0.0	0.9
May-19	40.8	1.1	0.0	0.8
Jun-19	67.1	2.2	0.0	0.8
Jul-19	40.2	1.1	0.0	0.8
Aug-19	44.2	1.1	0.0	0.8
Total	**9,129.9**			

Table 4.4.2a Teams Thermal Data – DHW

A MD of 76kW occurred on 10/09/2019 @ 02.30 hours. The significant drop off in consumption post October suggests an equipment status change e.g. boilers coming off-line. Table 4.4.2b illustrates Min/Max and Average values for a week profiling and the daily profiles in chart 4.4.2a similarly illustrates the change in consumption.

Day	Average Daily *kWh*	Min Daily *kWh*	Max Daily *kWh*	Min *kW*	Max *kW*	Ave *kW*
Sat	38	0.0	382.3	0	64.84	0.8
Sun	36	0.0	315.2	0	70.43	0.8
Mon	59	0.0	509.8	0	76.02	1.3
Tue	61	0.0	504.2	0	55.90	1.3
Wed	55	0.0	497.5	0	55.90	1.2
Thu	57	0.0	477.3	0	57.01	1.2
Fri	46	0.0	468.4	0	58.13	1.0

Table 4.4.2b Teams Thermal Data – DHW

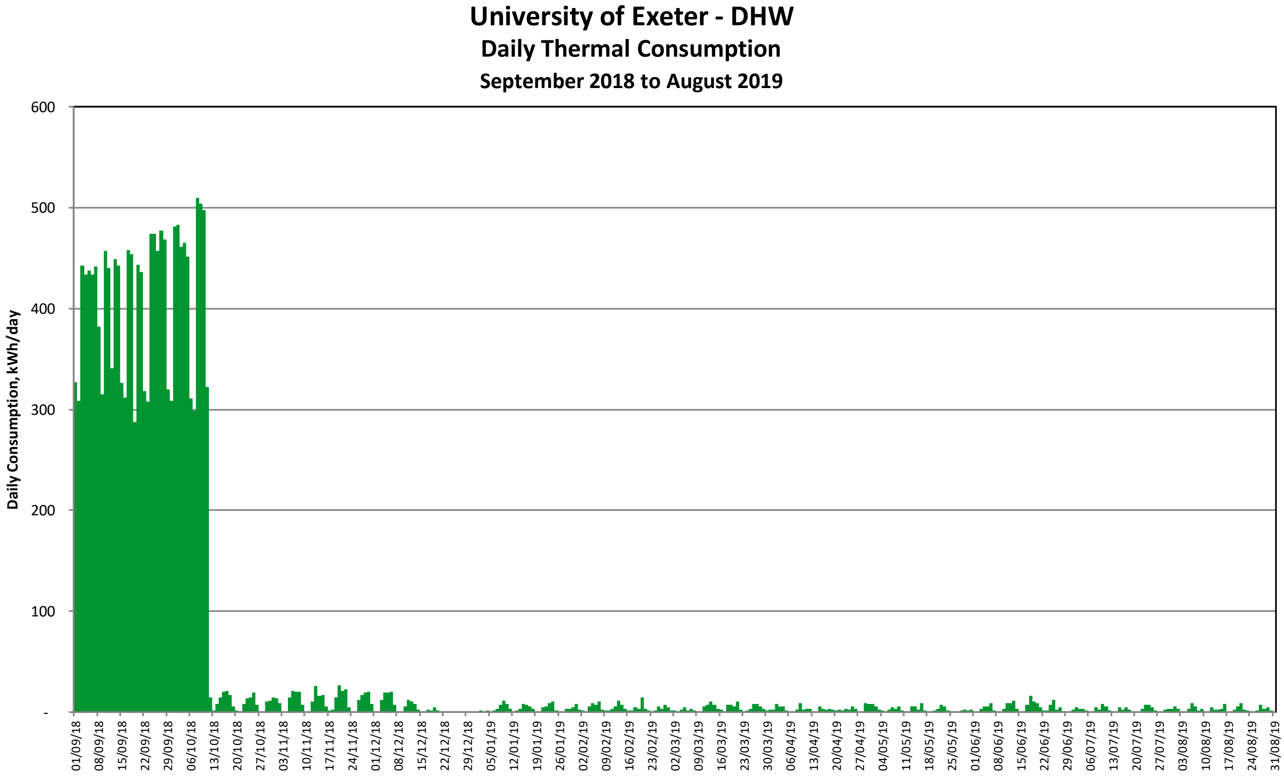


Chart 4.4.2a Teams Thermal Data – DHW

5. Interval Data Analysis - Electricity

5.1. Teams EMS Datalogging

As discussed in the previous section of this report (Section 4.1) the Geoffrey Pope building has 40x outgoing LV supplies from the LV MCC. Of these 6x have their metering connected to the Teams energy monitoring system and provides consumption data based on 30-minute interval periods. These meters are shown in the below table. It should be noted that meters E299 and E300 could not be found within the Teams EMS.

MCB Ref	Meter Ref	Teams Ref	Description	Primary	Secondary	Secondary
4	STP1 Sub-Mains Panel board	E299	South Block Roof Plant Areas	STP 1A – Panel board	STP 1B - Fume Cupboards	STP 1C - Fume Cupboards
5	STP3 Sub-Mains Panel board	E300	South Block Roof Plant Areas	New DB		
11	Chiller 1	E297	Chiller	Chiller 1		
24	Chiller 3	E295	Chiller	Chiller 3		
25	Chiller 2	E296	Chiller	Chiller 2		
30	Feeder to Aquarium SB2	E339	South Block Basement	Feeder - SB2		
41	Main LV Supply	E291				

Table 5.1a Teams Electricity Meters

Extracting the data from the Teams EMS it is possible to visualise where some of the buildings electricity has been consumed. The following chart shows the electrical demand profile for the period Wednesday 9th October to Tuesday 16th October 2019. The profile shows the total building profile as measured by meter E291 (blue line) along with the Teams measured meters. The consumption associated with ‘other’ is the sum of the unmetered consumption (grey area).

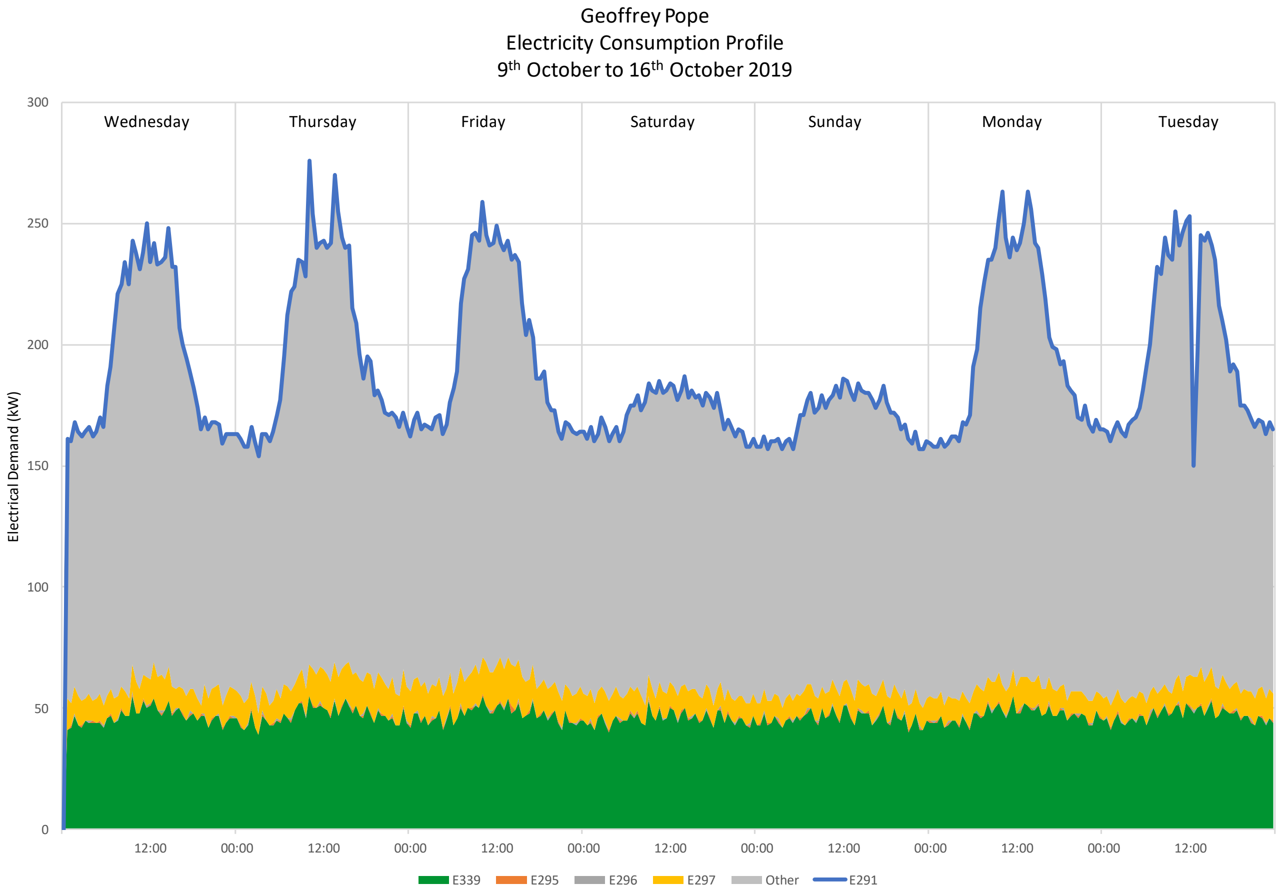


Chart 5.1a Electricity Demand Profile – Teams Metering

Chart Observations

- The demand profile covers the period Wednesday 9th October to Tuesday 16th October 2019
- There are 4x sub-meters shown as captured by the Teams EMS
- During the week shown in the above chart 30.7% of the electricity consumption within the Geoffrey Pope building was captured within the Teams EMS
- The largest metered supply was E339 to the Feeder to Aquarium SB2
- The profile for E339 shows a consistent profile with slight increases during the working week
- The maximum demand was 55 kW and the average for the week shown was 46.72 kW
- The base-load demand (lowest) was 39 kW
- The demand profile for Teams meter E339 (Feeder to Aquarium SB2) shows a high and consistent profile throughout the week, equating to 24.5% of the total building consumption
- Teams meter E297 (Chiller 1) shows a constant demand profile, even during autumn, which equated to 5.8% of the total consumption

5.2. Schneider Electric Datalogging

To understand the electricity profile of other consumers captured within the 'other' demand profile a series or portable dataloggers was installed by Schneider Electric between Wednesday 9th October to Tuesday 16th October 2019. The following table details the electrical circuits data-logged.

MCB Ref	Meter Ref	Description	Datalogger Type
1	BT SM6		
2	Lab 301	South Block 3rd Floor - Lab 301	
3	Master Fire Alarm Panel	North Block Gnd. Floor Fire Alarm	
4	STP1 Sub-Mains Panel board	South Block Roof Plant Areas	
5	STP3 Sub-Mains Panel board	South Block Roof Plant Areas	
6	1T SM2 Sub-Mains Panel board	South Block 1st Floor	Schneider Electric
7	1TSM1 Sub-Mains Panel board	South Block 1st Floor	
8	BH LAB COMP MCB Dist. Board	North Block Boiler House Plant Room - Upper	
9	GR SM1 Sub-Mains Panel board	North Block Gnd. Floor	
10	GR G01 MCB Dist. Board	North Block 3rd Floor - IT Comms	
11	Chiller 1	Chiller	Teams EMS
12	1R SM1 Sub-Mains Panel board	North Block 1st Floor	
13	2T SM3 Sub-Mains Panel board	South Block 2nd Floor	Schneider Electric
14	3T SM2 Sub-Mains Panel board	South Block 3rd Floor (Lighting and Power)	
15	BS14 Water Heater Control Panel		
16	MCCB Panel Lab 101	South Block 1st Floor	Schneider Electric
17	MR1 Sub-Mains Panel board	North Block Lift Plant Room	
18	2T SM1 Sub-Mains Panel board	South Block 2nd Floor	Schneider Electric
19	2T SM2 Sub-Mains Panel board	South Block 2nd Floor	Schneider Electric
20	BT SM5 Sub-Mains Panel board	South Block Basement - LV1 Switch Room	
21	RT SM1 Sub-Mains Panel board	South Block Roof Plant Room	Schneider Electric
22	3T SM1 Sub-Mains Panel board	South Block 3rd Floor	
23	DB A1 NEW DB IN POTTING ROOM	South Block Basement	
24	Chiller 3	Chiller	Teams EMS
25	Chiller 2	Chiller	Teams EMS
26	BH CP Sub-Mains Panel board	North Block Boiler House 1st Floor	
27	Spare		
28	Essential Services Switchboard	North Block Boiler House 1st Floor	Schneider Electric
29	Generator Intake	External Generator Connection	
30	Feeder to Aquarium SB2	South Block Basement	Teams EMS
31	2R SM1 Sub-Mains Panel board	North Block 2nd Floor	Schneider Electric
32	2R SM2 Sub-Mains Panel board	North Block 2nd Floor	Schneider Electric
33	BT EX1 MCB DIST BOARD	External & Carpark Lighting	
34	MR SM1 Sub-Mains Panel board	North Block Mezz	
35	MR SM2 Sub-Mains Panel board	North Block Mezz	Schneider Electric
36	RR SM3 Sub-Mains Panel board	North Block 5th Floor - Roof Plant	Schneider Electric
37	4R SM1 Sub-Mains Panel board	North Block 4th Floor	Schneider Electric
38	4R SM2 Sub-Mains Panel board	North Block 4th Floor	Schneider Electric
39	3R SM1 Sub-Mains Panel board	North Block 3rd Floor	Schneider Electric
40	3R SM2 Sub-Mains Panel board	North Block 3rd Floor	

Table 5.2a Interval Data-logging

The following charts detail the demand profiles from the obtained data along with those already presented for the Team EMS data.

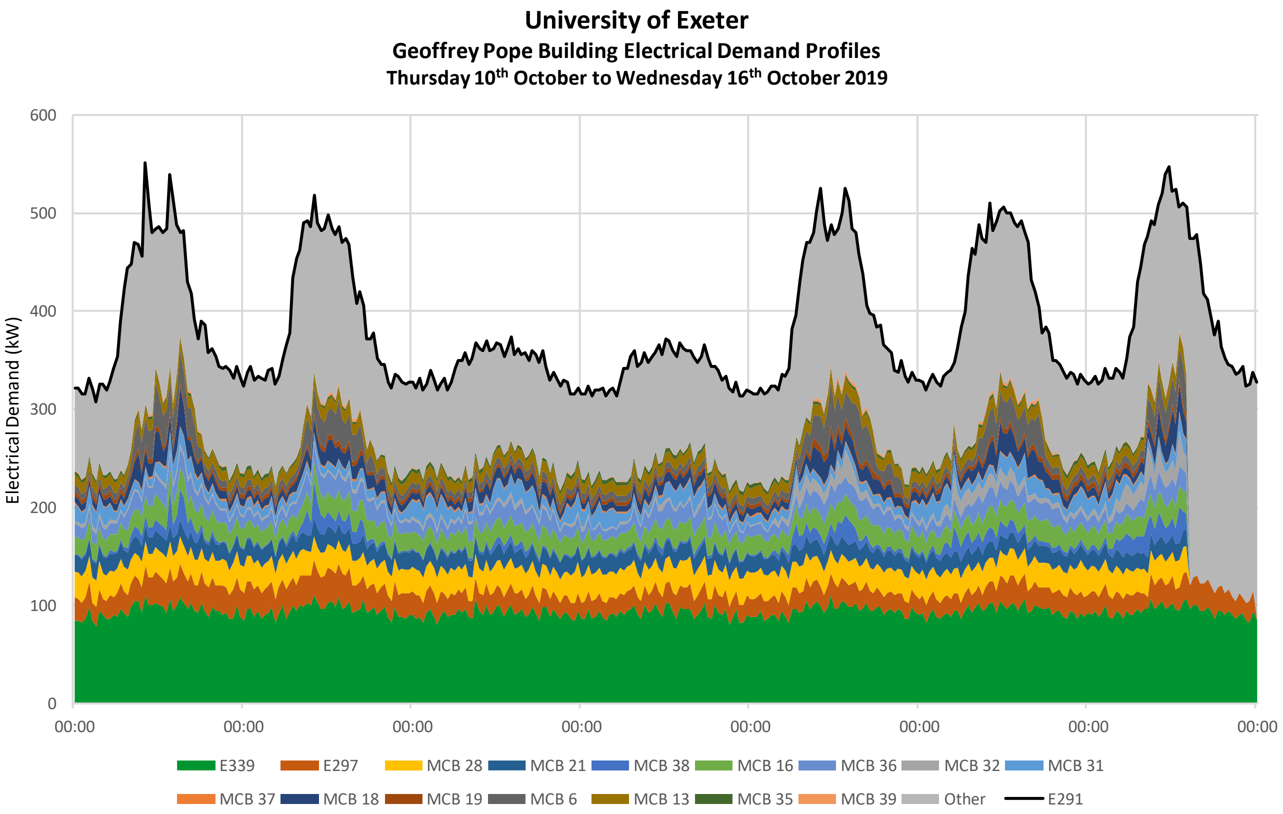


Chart 5.2a Electricity Demand Profile – Teams Metering and Schneider Electric Data-logging

Chart Observations

- The demand profile covers the period Thursday 10th October to Wednesday 16th October 2019
- There are 2x sub-meters shown as captured by the Teams EMS (E339 Aquarium and E297 Chiller 1)
- There are an additional 14x sub-meters shown as captured by Schneider Electric data-loggers
- MCB16 and MCB 28 have the highest demand profile of the Schneider Electric data-logged supplies

During the week shown in the above chart over 68% of the electricity consumption within the Geoffrey Pope was captured by either the Teams EMS meters or the Schneider Electric portable data-loggers.

The following chart details the individual demand profiles of the supplies monitored.

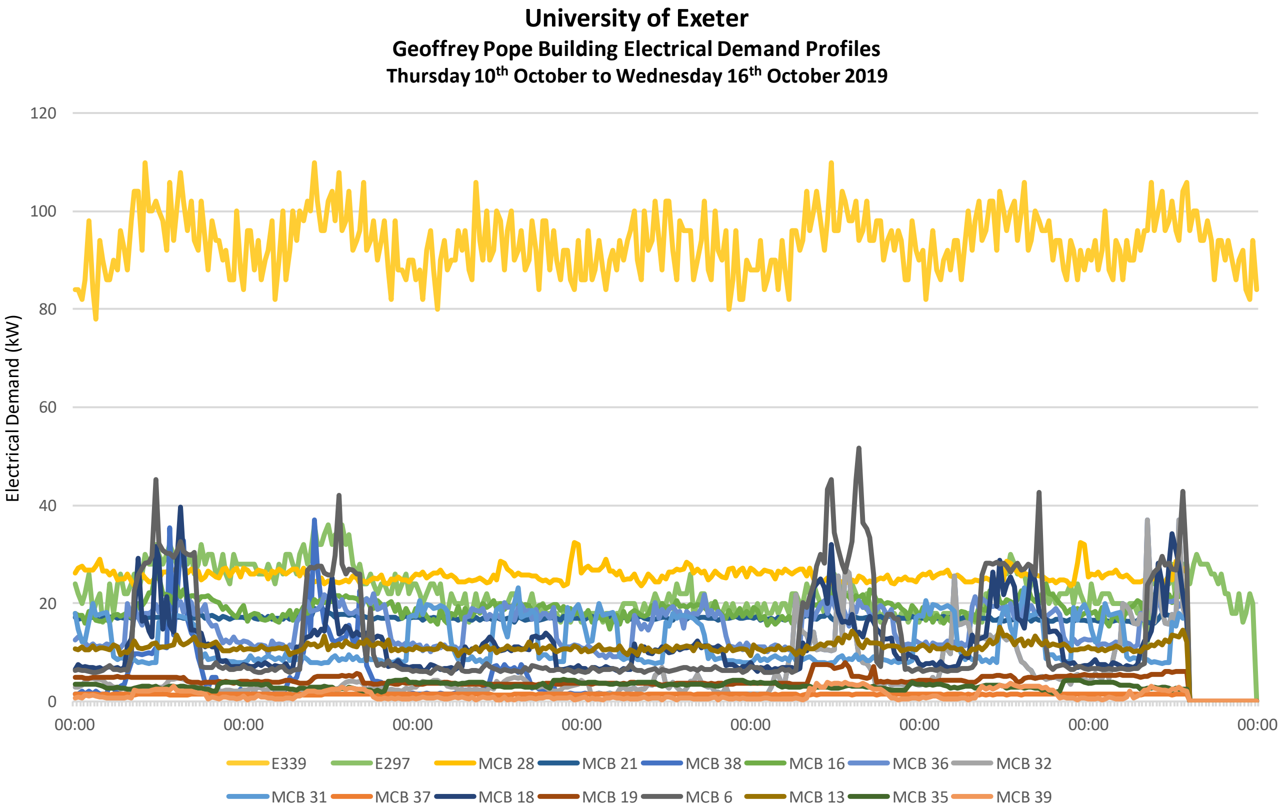


Chart 5.2b Electricity Demand Profile – Teams Metering

Chart Observations

- The supply with the greatest electrical demand was E339 – Feeder to Aquarium SB2 with an average demand over the period of 95.5 kW (min 78.0 kW and max 110.0 kW)
- The supply from MCB 28 (North Building Plant Room) had a maximum demand of 32.3 kW and average of 23.5 kW during data-logging – 3rd highest average
- The profiles also show that most electrical supplies have a constant demand throughout the weekend period

The following charts shows the individual demand profiles whereby it is possible to view the electrical supplies that have wither a constant demand throughout the weekend periods or high base-load demands during this period.

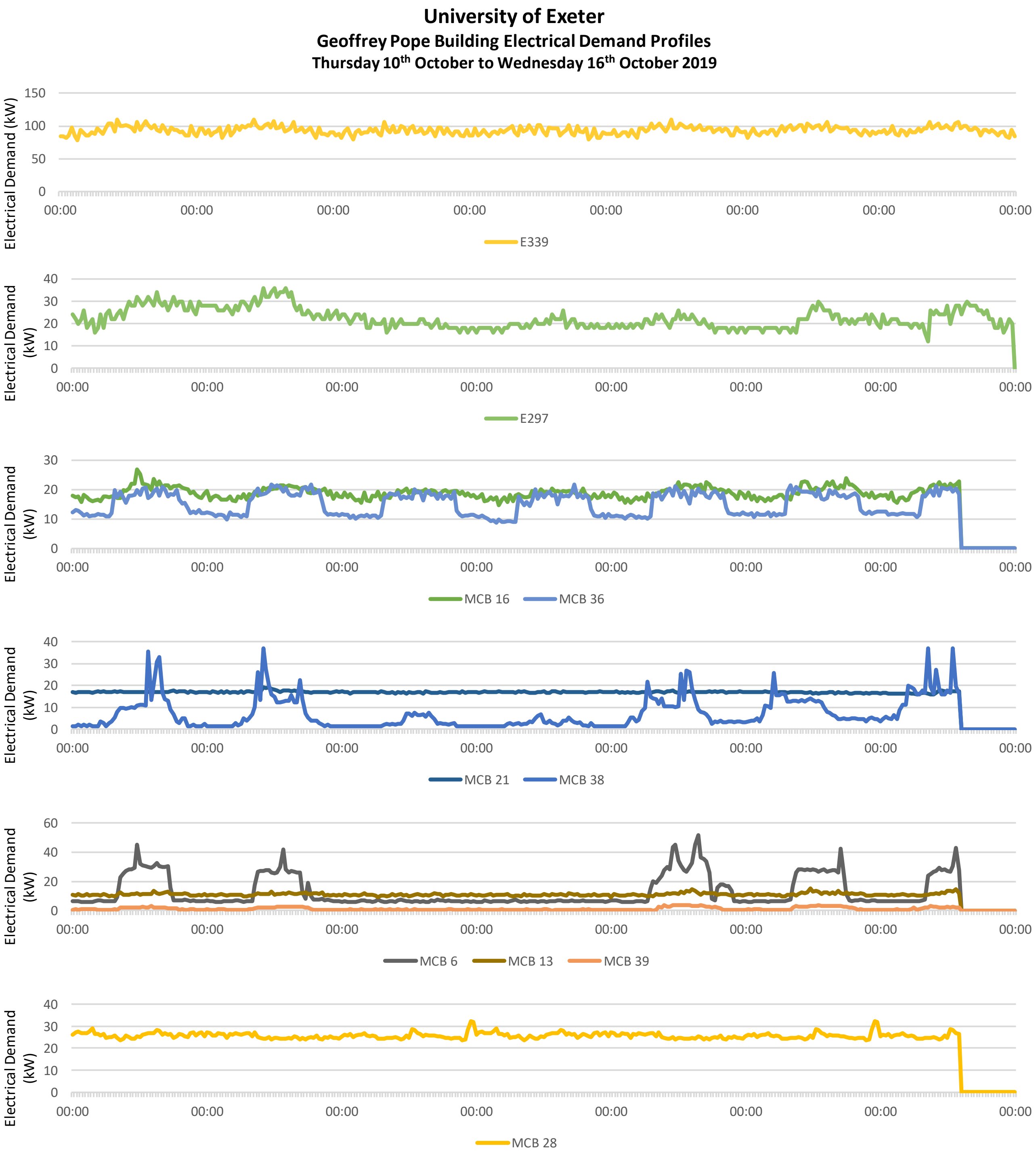


Chart 5.2c Electricity Demand Profiles

Chart Observations

- Profiles showing constant demand throughout the monitored period are;
  - E339 – Feeder to Aquarium SB2
  - E297 – Chiller 1
  - MCB 36 – North Block Roof Plant Room
  - MCB 21 – South Block Roof Plant Room

  - MCB 13 – South Block 2nd Floor
  - MCB 28 – North Block Boiler House
- The profile for MCB28 shows a constant demand until the end of the data-logging period. It is believed the main consuming item of plant within the North Block Plant Room is as externally located air compressor.

6. Area Specific Energy Analysis

The following section provides analysis of areas observed during the on-site survey activity.

6.1. South Building 1st Floor – Lab 101

6.1.1. General Description of Area

The Millhayes Teaching Lab 101 consists of a large open planned teaching lab. With a total floor area of 544 m^2 the lab occupies 60% of the total south building first floor area (35% of Geoffrey Pope first floor). The lab area was surveyed with the assistance of the lab manager.

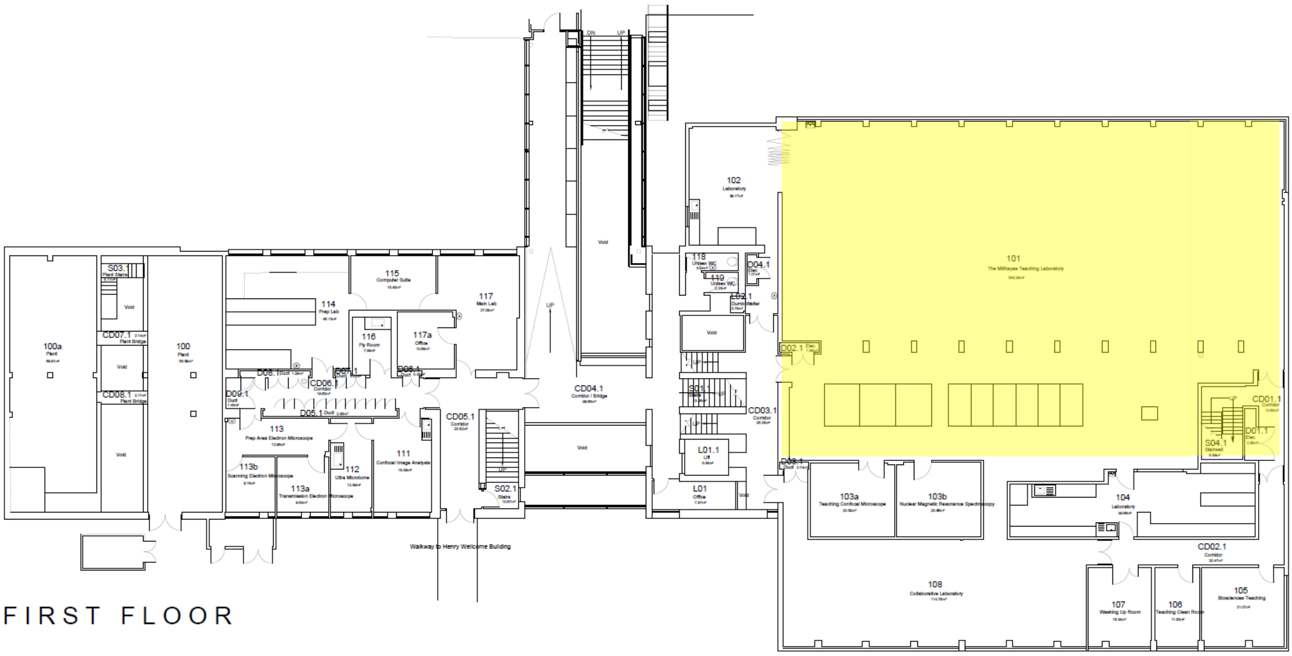


Figure 6.1.1a First Floor Building Layout

Figure 6.1.1b Lab 101

Figure 6.1.1c Lab 101 Fume Cupboards

6.1.2. Area Energy Demand Profile

As discussed in section 5.2 of this report a series of portable dataloggers were installed within key electrical supplies within the Geoffrey Pope building. The LV electrical supply to Lab 101 is provided by circuit 6 referenced as 1T SM2 Sub-Mains Power board (South Block 1st Floor) which in turn supplies DB101-Lab 101 DB and also DB102-Lab 101DB. The following chart details the electrical demand of the supply from the LV room.

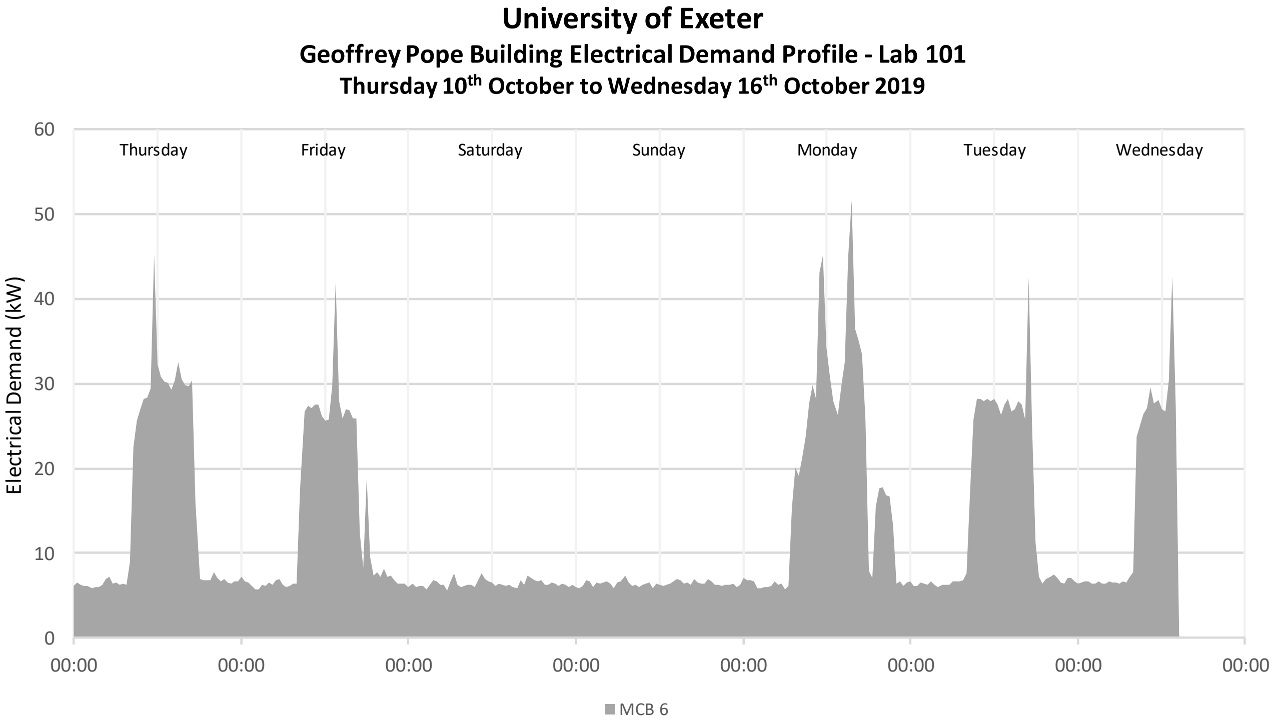


Chart 6.1.2a Electrical Demand Profile MCB 6 – Lab 101

Chart Observations

- The demand profile covers the period Thursday 10th October to Wednesday 16th October 2019
- The chart profile shows increased demand between Mondays to Fridays, typically from 07:00 to 17:30
- There is a constant base-load of approximately 5.7 kW throughout the period

The following table details the min attributes of the demand profile.

Day	Start	End	Peak Period	Peak (kW)	Base-load (kW)
Thursday	08:00	17:00	11:00 to 11:30	45.23	5.92
Friday	08:00	17:00	13:00 to 13:30	41.98	5.76
Saturday	-	-	-	7.60	5.65
Sunday	-	-	-	7.36	5.80
Monday	07:00	17:30	15:00 to 15:30	51.60	5.77
Tuesday	08:00	18:00	16:30 to 17:00	42.52	6.05
Wednesday	08:00	-	15:30 to 16:00	42.75	6.35

Table 6.1.2a Lab 101 Electrical Demand Analysis

Using the electricity sub-metering data presented in table 4.2a whereby the weekly electricity consumption was measured at 1,107 kWh, the estimated annual electricity consumption of the Lab 101 is 57,579.2 kWh (assuming 52 weeks at the same demand profile).

6.1.3. Lab 101 Energy Benchmark

As detailed in section 5.3 of this report the use of CIBSE Guide F Benchmarks can be used as a yardstick to determine energy performances.

Education (further and higher)	Energy Consumption benchmarks for existing buildings / (kWhm^{-2}) per year			
	Good Practice		Typical Practice	
	Fossil Fuels	Electricity	Fossil Fuels	Electricity
Lecture room, science	110	113	132	129
Science laboratory	110	155	132	175

Table 6.1.3a CIBSE Guide F Benchmark

The stated floor area of The Millhayes Teaching Lab (Lab 101) is 544 m^2. Using the estimated annual electricity consumption for the lab of 57,579 kWh the energy efficiency of the lab can be determined. It should be noted that the electricity consumption stated <u>does not</u> include energy associated with the HVAC system, which is assumed to be supplied from other sources.

The following table details the estimated energy intensity of Lab 101.

MCB	Circuit Description	Meter Read		Consumption	Annual Consumption	GIA	Energy Intensity
		09/10/2019	16/10/2019				
		09:23	09:26	kWh	kWh	m^2	kWh/m^2
6	1T SM2	432,693	433,800	1,107	57,569	543.93	105.84

Table 6.1.3b Lab 101 Energy Intensity

Comparing the estimated energy intensity of Lab 101 (electricity only) against the CIBSE Guide F benchmark the University of Exeter is within the good practice benchmark. This figure may be increased if the HVAC energy was included.

6.1.4. Area Observations

The lab mostly consists of lab benches within the middle section which are used for teaching between 60-200 students at a time. To assist with the teaching activities a series of Audio Visual (AV) equipment is supplied down the length of the lab. There are 19x fume cupboards provided along the centre of the floor area, as shown figure 6.1.1c.

The air within the lab is conditioned through the use of 6x Air Handling Units (AHUs) mounted within the ceiling void. The AHUs are controlled from the centralised Building Management System (BMS) which the lab manage, and users, do not have access to. The fan drives of the AHUs have variable speed drive (VSDs) controls were observed to be operating at 12.2 Hz (24.4% speed) at the time of the survey (16th October 2019). Unfortunately, the University were unable to provide technical details on the AHU installation such as fan drive rating (kW).

It was communicated that the lab is used by chemistry students for up to 6 hours per day (Monday to Friday), sometimes a minimum of 3 hours per day. Lighting is provided by a series of recessed ceiling mounted fluorescent fittings comprising twin T5 2-foot tubes. In total there are approximately 138 fittings within the teaching lab. The lighting is controlled manually and typically turned on at 08:30 and off at 17:30. Throughout this period the lighting is operational regardless of occupancy.

Figure 6.1.4a Lab 101 AHU Control Panel

Figure 6.1.4b Lab 101 Fridges and Freezers

A series of mains powered 220VAC single phase fridges and freezers are provided (approximately 13x) for the storage of products related to the department.

Probably the main energy consumer within the lab are a series of fume cupboards. As mentioned there are 19x provided within the teaching lab and adjoining preparation room. All cupboards have VSD controlled local exhaust ventilation (LEV) operating based upon the sash door position (high flow when door fully open, low when closed). It was communicated that all the fume cupboard are operational whilst only approximately 6 being essential requiring 24/7 operation. It was however observed that many are used for storage of materials that do not emit any fumes or solvents requiring LEV controls.

It was also communicated that due to the design of the Heating Ventilation and Air Conditioning (HVAC) system within the lab the fume cupboards can be used to increase ventilation air change rates (ACR) during the summer months whereby the fume cupboard sash doors are intentionally opened.

Figure 6.1.4c Lab 101 Example Fume Cupboard Storage

Figure 6.1.4d Lab 101 Fume Cupboard VSD Controls

Signage is provided to encourage users to close the fume cupboards when not required, see below figure.

Figure 6.1.4e Lab 101 Fume Cupboard Signage

During the survey the fume cupboard operation was tested (sash door opened). When the sash doors are opened the VSD fan speeds ramps up to 100% and then reduces to approximately 43% when closed to its lowest position. When closed there is a constant reduced draw of air through the fume cupboard and within the LEV system.

6.1.5. Area Main Mechanical & Local Extract Ventilation (LEV)

The utilisation of fume cupboards within a laboratory of this type clearly has specific design and control parameters which form not only part of the design but is typically inherent within standard operating procedures (SOP’s). Whilst our initial observations have been noted it is suggested that as part of a deep dive into the ventilation provision (including heating & cooling services) should be undertaken in order to ascertain more detailed design and performance criteria that pertains to energy intensity within the strict control parameters appropriate to this facility.

There are clear guidelines on main mechanical ventilation, local extract ventilation (LEV) e.g. fume cupboards which are undoubtedly adhered to within a facility of this standard but not readily evidenced from current observations.

The areas have little or any natural ventilation flows so by definition are a 'controlled zone' under mechanical supply and extract systems. Main areas of interest should be focused now on how the original design and any subsequent amendments performs in operation e.g. flow rates, air change rates, temperature and relative humidity (RH) levels and how from a demand perspective this is managed for varying internal and external conditions.

Where there are potentially high air supply requirements due to the amount of LEV in place mechanical ventilation is typically maintained at a continuous flow with options for set-back to a minimum flows and wider temp/RH tolerance ranges during hours when the laboratory is unoccupied is possible, and even desirable, provided it is carefully managed and can be over-ridden when laboratory work is undertaken out of normal hours.

If make-up air is provided, a net inflow of air into the room should be maintained to give a negative room pressure relative to surrounding non-scientific areas. Operation of equipment over evenings and weekends or other controlled condition requirements may necessitate continuous operation of ventilation and cooling.

There is no official guidance on ventilation rates for research laboratories. The only strict limit is for Home Office licensed rooms where a minimum number of 'full fresh' air change rate (ACR) of 15x an hour may be specified depending on the species. The Home Office requirement for 15 ACR per hour is a very strict one which is difficult to justify for normal laboratories unless dictated by other factors such as the number and size of fume cupboard(s) relative to the room size.

Minimum ACR levels are typically 6x per hour dropping to 4x per hour for out of hours depending on laboratory conditions.

ACRs are only one criterion, room occupancy controls/management, layouts, mixed uses with differing risks and flexible working tasks offer significant challenges to design also.

The key task will be to ensure that the ventilation system is as optimized as possible under all or the majority of operational variances – this will include a full review of the cooling and heating provisions specific to the laboratory areas so that a comprehensive appraisal supports a specification for design and/or operational changes appropriate to maximising the energy intensity for the desired conditions

6.2. South Building 2nd Floor – Lab 201 and 211

6.2.1. General Description of Area

Within the Geoffrey Pope South building the main area users are Labs 201 and 211, as shown in the following figure. The labs have floor areas of 207.1 m^2 (lab 201) and 219.72 m2 (lab 211) resulting in a total area of 426.82 m^2 which is 49% of the south building; 30% of the Geoffrey Pope 2nd floor.

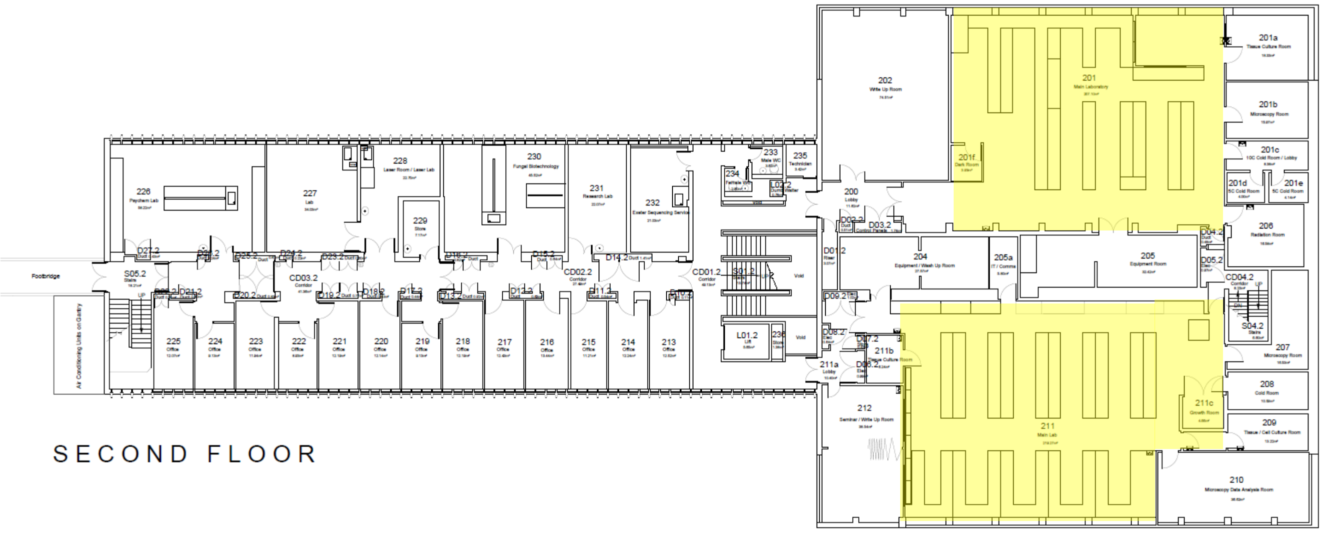


Figure 6.2.1a Second Floor Building Layout

6.2.2. Area Energy Demand Profile

As discussed in section 5.2 of this report a series of portable dataloggers were installed within key electrical supplies within the Geoffrey Pope building. The LV electrical supply to the South Building 2nd floor is provided by circuits 13, 18 and 19. The following chart details the electrical demand profiles for the supplies from the LV room.

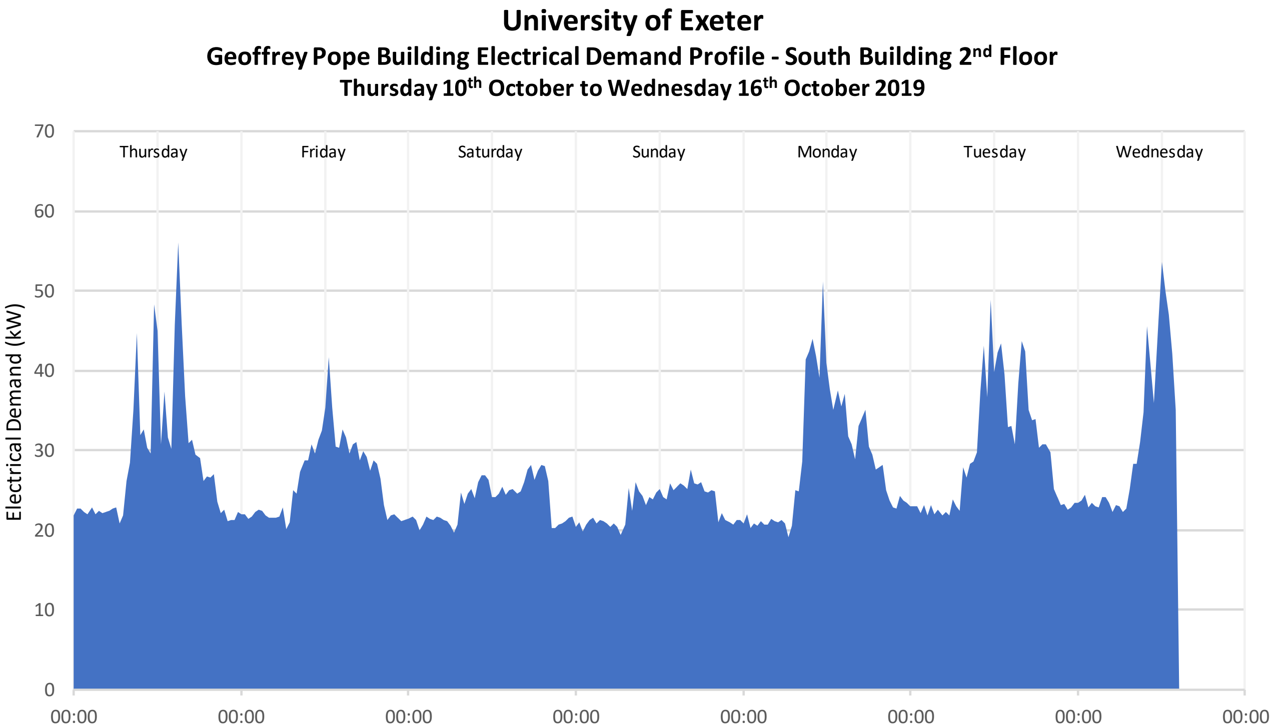


Chart 6.2.2a Electrical Demand Profile – South Building 2nd Floor (MCB 13,18,19)

- The demand profile covers the period from 00:00 on Thursday 10th October to 14:00 on Wednesday 16th October 2019
- The chart profile shows increased demand between Mondays to Fridays, typically from 07:00 to 16:30
- There is a constant base-load of approximately 19.12 kW throughout the period
- The average demand over the monitored period was 27.04 kW
- The peak demand over the monitored period was 56.15 kW

The following table details the min attributes of the demand profile.

Day	Start	End	Peak Period	Peak (kW)	Base-load (kW)
Thursday	07:00	20:00	14:30 to 15:00	56.15	20.77
Friday	07:00	20:00	12:00 to 12:30	41.72	20.04
Saturday	07:00	20:00	18:30 to 19:00	28.20	19.62
Sunday	07:00	20:00	16:00 to 16:30	27.60	19.43
Monday	07:00	20:00	11:00 to 11:30	51.20	19.12
Tuesday	07:00	20:00	11:00 to 11:30	48.95	21.81
Wednesday	07:00	-	11:30 to 12:00	53.59	22.19

Table 6.2.2a South Building 2nd Floor Electrical Demand Analysis

The regular start and end time of the increased electrical demand from the baseload, as shown at 07:00 and 18:00 respectively, suggests electrical equipment operating based on a regular time schedule. It is therefore assumed that equipment controlled by the BMS, such as the HVAC installation, is the main contributor of the increased electrical demand. It is also shown in the chart that this equipment is also operated during weekend periods when there is zero occupancy of the floor area.

The increased electrical demand during the core hours Monday to Friday will be influenced by manually controlled equipment such as lighting systems, small power devices (computers, printers, kitchen equipment etc). Chart 6.2.2a is shown again below with these main features annotated.

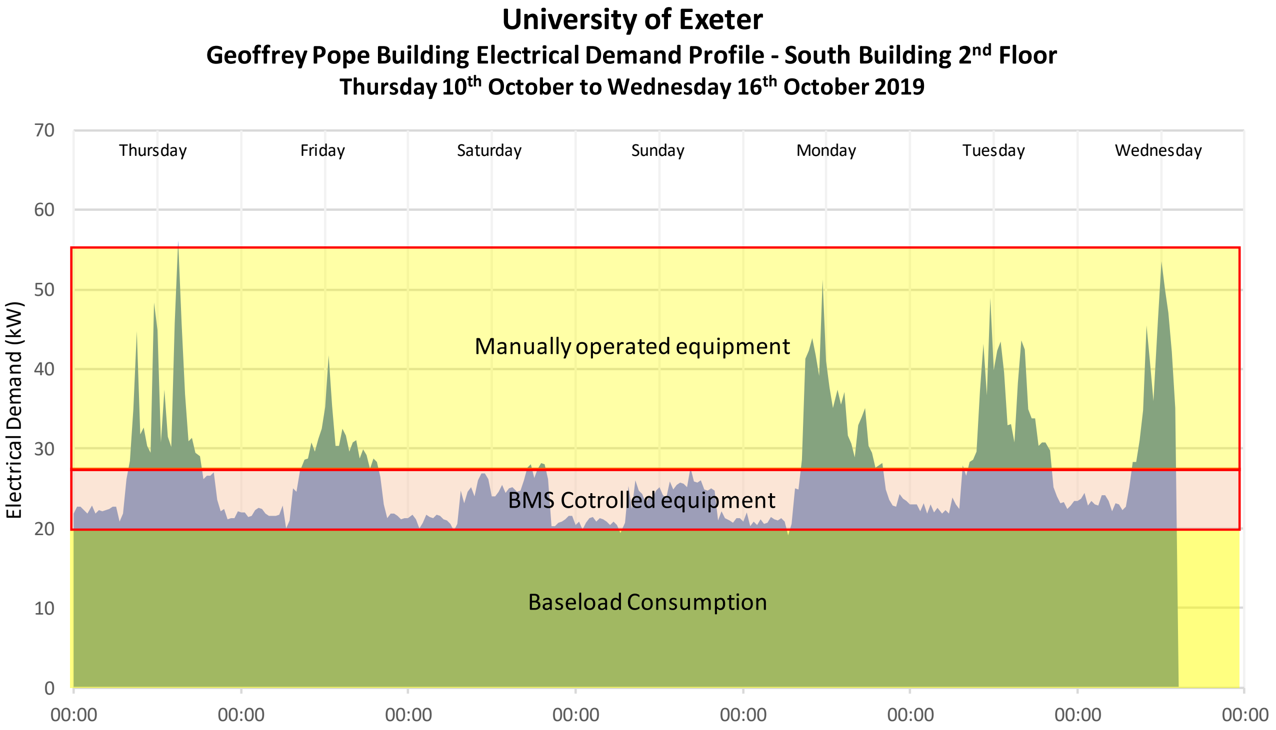


Chart 6.2.2b Electrical Demand Profile – South Building 2nd Floor (MCB 13,18,19) Annotated

Using the electricity sub-metering data presented in table 4.2b whereby the weekly electricity consumption of the South Building 2nd floor was measured at 3,824 kWh, the estimated annual electricity consumption of the floor is 198,848 kWh (assuming 52 weeks at the same demand profile).

6.2.3. Energy Benchmark

As detailed in section 5.3 of this report the use of CIBSE Guide F Benchmarks can be used as a yardstick to determine energy performances.

Education (further and higher)	Energy Consumption benchmarks for existing buildings / (kWhm^{-2}) per year			
	Good Practice		Typical Practice	
	Fossil Fuels	Electricity	Fossil Fuels	Electricity
Lecture room, science	110	113	132	129
Science laboratory	110	155	132	175

Table 6.2.3a CIBSE Guide F Benchmark

The stated floor area of south building 2nd floor is 869.96 m^2. Using the estimated annual electricity consumption for the lab of 198,848 kWh the energy efficiency of the floor and lab areas can be determined. It should be noted that the electricity consumption stated does not_include energy associated with the HVAC system, which is assumed to be supplied from other sources.

The following table details the estimated energy intensity of floor area.

MCB	Circuit Description	Meter Read		Consumption	Annual Consumption	GIA	Energy Intensity
		09/10/2019	16/10/2019				
		09:26	09:26	kWh	kWh	m^2	kWh/m^2
13	2T SM3 Sub-Mains Panelboard	1,102,787.4	1,105,213	2,425	126,105		
18	2T SM1 Sub-Mains Panelboard	1,054,872.4	1,056,855.0	1,983	103,095		
19	2T SM2 Sub-Mains Panelboard	779,905.9	781,747.4	1,842	95,758		
Total				**6,249**	**324,958**	**869.96**	**373.53**

Table 6.2.3b South Building 2nd Floor Energy Intensity

Comparing the estimated energy intensity of the South Building 2nd floor (electricity only) against the CIBSE Guide F benchmark, the University of Exeter is greatly above the benchmark, over double the recommended .

6.2.4. Area Observations

The labs on the 2nd floor of the South Building and used be research students rather than teaching as in Lab 101 previously discussed. The areas surveyed were all to a high standard and all responsible should be praised.

Lab 201 has a floor area of 207.1 m^2 and is mostly open planned with a series of benches running across the area. It was communicated that the area was refurbished circa 10 years ago and occupancy is mostly between 08:00 to 18:00 Monday to Friday. Lab 211 has a floor area of 219.27 m^2 with most of the floor area being used for benches along its length. Additional rooms are provided for write up areas, analysis rooms, equipment rooms and specific areas for cold rooms, tissue culture rooms amongst others.

Lighting within the lab area is provided by fluorescent fittings recessed within the suspended ceiling. All lighting controls are manual and therefore were observed to be operating continuously regardless of the area occupancy. Within Lab 211 there are approximately 58x individual fluorescent fittings, each comprising 3x T8 2ft tubes rated at 18 watts each (3.1 kW total excluding switchgear losses).

Heating Ventilation and Air Conditioning (HVAC) is provided by two Air Handling Units (AHUs) in each lab area mounted within the ceiling void and is controlled by the Building Management System (BMS) and therefore outside the operational control of the lab manager and users. The HVAC system is provided for comfort heating although air change rates (ACR) are also provided allowing fresh external air to provide ventilation.

A series of fume cupboards are provided within Lab 201 (5 in total) with all having VSD extraction control on their sash doors. To provide energy management fume cupboards should only be used for the storage of materials requiring localised ventilation. If used for the storage of other items, the ventilation system should be switched off and restored when required. Sash doors should be kept in the lower position at all times allowing the ventilation rate to reduce to its low speed setting. As such lab users should be educated in the correct use of fume cupboards.

The main observed electrical demanding equipment observed within Lab 201 was a series of stand-alone refrigerators and freezers used for the storage of samples and experiment specimens. There were approximately 20x full height freezers at -20 °C, 6x full height freezers at -80 °C and 5x fridges at 5 °C.

Figure 6.2.4a Lab 201 Freezers

Figure 6.2.4b Lab Freezers

The constant electrical demand associated with the installed freezers and fridges will be a high contributor of the electrical demand profile chart shown in chart 6.2.2a of 19.12 kW.

Whilst difficult to control and manage, education should be provided to the lab users on correct cold storage management and energy good practices such as;-

- Defrost at regular intervals
- Maintaining an air gap to the rear of freezers and fridges
- Remove items no longer required to reduce the mass of stored items
- Keeping doors closed when not required
- Maintain an inventory of stored items to shorten door opening times
- Reduce the use of high density storage boxes

6.3. North Building Mezzanine Floor

6.3.1. General Description of Area

The North Building Mezzanine floor is a mixed occupancy floor comprising of a large Molecular Biology / Research Laboratory along with smaller rooms associated with offices, plant growth and write up areas, as shown in the following figure.

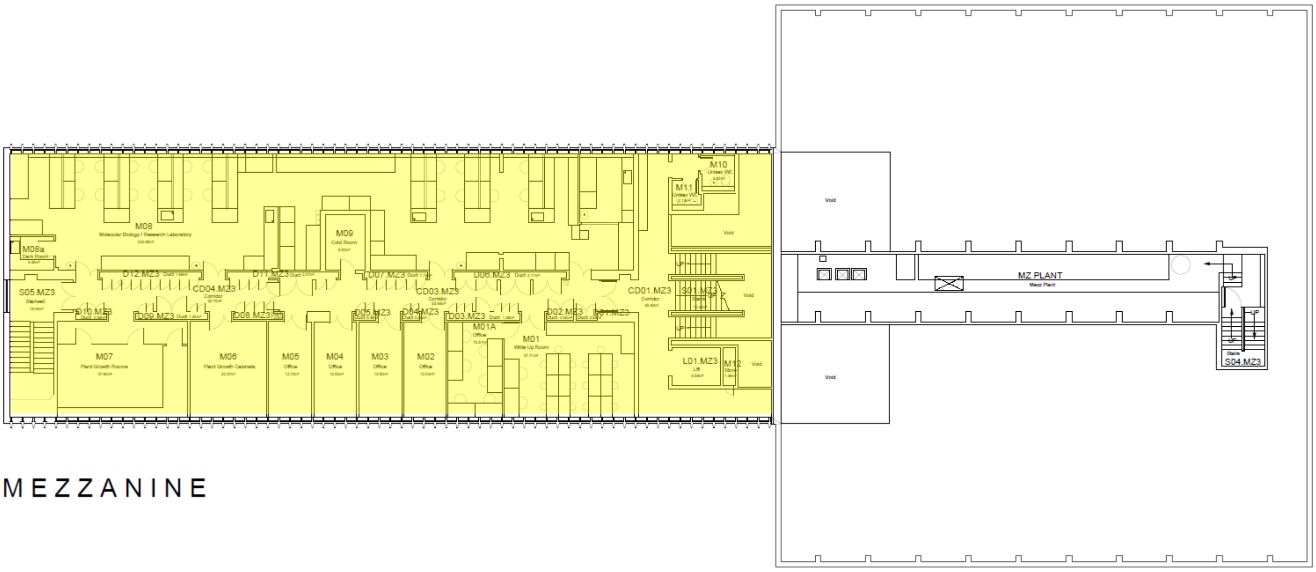


Figure 6.3.1a North Building Mezzanine Floor Layout

The mezzanine floor has a total floor area of approximately 515.4 m2 with 202.85 m2 of which being associated with the Molecular Biology / Research Laboratory. This equates to 39.4% of the Mezzanine floor total. As shown in the above figure the Molecular Biology / Research Laboratory occupies virtually half the mezzanine floor area and has a north-east orientation.

6.3.2. Area Electrical Consumption

During the initial stages of the building energy mapping exercise it was determined that the mezzanine floor had a low overall energy demand and therefore portable dataloggers were not deployed on the electrical supplies of the area. Nevertheless these electrical supplies have permanent electricity meters installed within the buildings LV room. The following table details the mezzanine floor electrical supplies and the associated manual meter reads.

MCB	Circuit Description	Meter Read		Consumption	Annual Consumption
		09/10/2019	16/10/2019		
		09:23	09:26	kWh	kWh
34	MR SM1 Sub-Mains Panelboard	1,477,169.9	1,479,377.2	2,207	114,780
35	MR SM2 Sub-Mains Panelboard	688,396.1	690,088.3	1,692	87,994
			Total	**3,900**	**202,774**

Table 6.3.2a North Building Mezzanine Floor Manual Meter Reads

As shown in the previous table there are two electrical supplies that provide the mezzanine floor of the North Building. For the period between 9th October and 16th October 2019 the electrical consumption of the MCB supplies 34 and 35 was 2,207 kWh and 1,692 kWh respectively. Therefore the total electrical consumption of these supplies was 3,900 kWh for the 7 day period monitored. Assuming the electrical consumption to be reflective of every week of the year, the annual electricity consumption of the mezzanine floor is estimated at 3,900 kWh. The total Geoffrey Pope building for the same period had a consumption of 63,778 kWh. The mezzanine floor therefore consumed 6.1% of the total Geoffrey Pope building.

6.3.3. Energy Benchmark

As detailed in section 5.3 of this report the use of CIBSE Guide F Benchmarks can be used as a yardstick to determine energy performances.

Education (further and higher)	Energy Consumption benchmarks for existing buildings / (kWhm^{-2}) per year			
	Good Practice		Typical Practice	
	Fossil Fuels	Electricity	Fossil Fuels	Electricity
Lecture room, science	110	113	132	129
Science laboratory	110	155	132	175

Table 6.3.3a CIBSE Guide F Benchmark

The stated the total floor area of the north building mezzanine floor is 515.4 m^2. Using the estimated annual electricity consumption of 202,774 (table 6.3.2a) kWh the energy efficiency of the floor and lab areas can be determined. It should be noted that the electricity consumption stated does not include energy associated with the HVAC system, which is assumed to be supplied from other sources.

The following table details the estimated energy intensity of floor area.

MCB	Circuit Description	Meter Read		Consumption	Annual Consumption	GIA	Energy Intensity
		09/10/2019	16/10/2019				
		09:26	09:26	kWh	kWh	m^2	kWh/m^2
34	2T SM3 Sub-Mains Panelboard	1,477,169.9	1,479,377	2,207	114,780		
35	2T SM1 Sub-Mains Panelboard	688,396.1	690,088	1,692	87,994		
			Total	**3,900**	**202,774**	**515.4**	**393.43**

Table 6.3.3b North Building Mezzanine Floor Energy Intensity

Comparing the estimated energy intensity of the North Building Mezzanine floor (electricity only) against the CIBSE Guide F benchmark, the University of Exeter is greatly above the benchmark, over double the recommended.

6.3.4. Area Observations

As with all floors within the North Building a central corridor runs the length of the floor to which the Molecular Biology / Research Laboratory resides on one side and offices / work areas to the other.

Figure 6.3.4a Mezzanine Floor Corridor

Figure 6.3.4b Mezzanine Floor BMS Panel

The suspended ceiling of the corridor accommodates two air handling units (AHUs), AHU 6 and AHU 8. The AHU systems are controlled locally by BMS panels located within service cupboards within the corridor (Figure 6.3.4b). Each BMS panel is fitted with a supply electrical meter. At the time of the study the BMS board associated with AHU 6 (MRD/1) was showing an electrical demand of 0.47 kW (470 W). The AHU 6 system comprises of two fan drives (6a and 6b) which are controlled by the BMS via variable speed drives. The fan drives, each rated at 0.75 kW, were observed to be operating at 37.5 Hz (75 % speed) providing electrical savings of over 48%.

Each of the office areas are provided with wall mounted radiators fitted with thermostatic radiator valves (TRVs). Observations indicate that TRVs are operated manually by the occupants providing the necessary comfort levels.

Lighting is provided by T8 fluorescent fittings recessed within the suspended ceiling. All lighting controls are manual operated with good discipline being observed when rooms are unoccupied.

6.4. North Building 4th Floor

6.4.1. General Description of Area

The fourth floor of the Geoffrey Pope North Building is a multi-use area comprising of various laboratories, academic offices, write-up rooms and a large common room. The largest room area is within the Microbiology Laboratory (room 410) which occupies 117.11 m^2. The total floor area is 549.84 m^2 based upon site layout drawings and equates to 8% of the Geoffrey Pope building.

The floor also accommodates the BSL lab (room 408) which provides research into pathogens and as such is a restricted access area. As a result this area was not surveyed by Schneider Electric.

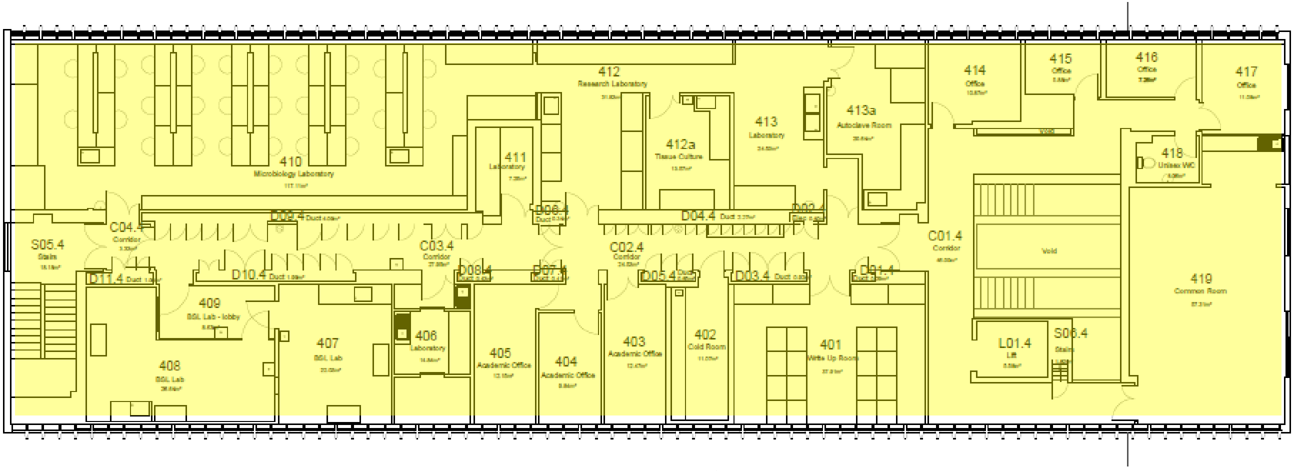


Figure 6.4.1a North Building 4th Floor Layout

6.4.2. Area Electrical Consumption

As per the Mezzanine Floor it was determined that the fourth floor had a low overall energy demand and therefore portable dataloggers were not deployed on the electrical supplies to the area. Nevertheless these electrical supplies have permanent electricity meters installed within the buildings LV room. The following table details the fourth floor electrical supplies and the associated manual meter reads.

MCB	Circuit Description	Meter Read		Consumption	Annual Consumption
		09/10/2019	16/10/2019		
		09:26	09:26	kWh	kWh
37	4R SM1 Sub-Mains Panelboard	316,517.1	317,384	867	45,079
38	4R SM2 Sub-Mains Panelboard	673,307.8	674,677	1,369	71,204
			Total	**2,236**	**116,282**

Table 6.4.2a North Building 4th Floor Manual Meter Reads

As shown in table 6.4.2a there are two electrical supplies that provide the fourth floor of the North Building. For the period between 9th October and 16th October 2019 the electrical consumption of the MCB supplies 37 and 38 was 867 kWh and 1,369 kWh respectively. Therefore the total electrical consumption of these supplies was 2,236 kWh for the 7 day period monitored. Assuming the electrical consumption to be reflective of every week of the year, the annual electricity consumption of the fourth floor is estimated at 2,236 kWh. The total Geoffrey Pope building for the same period had a consumption of 63,778 kWh. The mezzanine floor therefore consumed 3.5% of the total Geoffrey Pope building.

6.4.3. Energy Benchmark

As detailed in section 5.3 of this report the use of CIBSE Guide F Benchmarks can be used as a yardstick to determine energy performances.

Education (further and higher)	**Energy Consumption benchmarks for existing buildings / (kWhm^{-2}) per year**			
	Good Practice		**Typical Practice**	
	Fossil Fuels	**Electricity**	**Fossil Fuels**	**Electricity**
Lecture room, science	110	113	132	129
Science laboratory	110	155	132	175

Table 6.4.3a CIBSE Guide F Benchmark

The stated the total floor area of the north building fourth floor is 549.84 m^2. Using the estimated annual electricity consumption of 116,282 (table 6.4.2a) kWh the energy efficiency of the floor and lab areas can be determined. It should be noted that the electricity consumption stated does not include energy associated with the HVAC system, which is assumed to be supplied from other sources.

The following table details the estimated energy intensity of floor area.

MCB	**Circuit Description**	**Meter Read**		**Consumption**	**Annual Consumption**	**GIA**	**Energy Intensity**
		09/10/2019	**16/10/2019**				
		09:26	**09:26**	**kWh**	**kWh**	**m^2**	**kWh/m^2**
37	4R SM1 Sub-Mains Panelboard	316,517.1	317,384	867	45,079		
38	4R SM2 Sub-Mains Panelboard	673,307.8	674,677	1,369	71,204		
			Total	**2,236**	**116,282**	**549.84**	**211.48**

Table 6.4.3b North Building 4th Floor Energy Intensity

Comparing the estimated energy intensity of the North Building 4th floor (electricity only) against the CIBSE Guide F benchmark, the University of Exeter is slightly over the benchmark energy intensities.

6.4.4. Area Observations

Due to the restricted access of the North Building 4th floor there are no observations to comment upon.

6.5. Aquarium – South Building Basement

The basement of the South Building contains rooms and equipment solely for the Aquarium as detailed in the following floorplan. The total floor area of the basement is approximately 1,023 m2, which equates to 15% of the building.

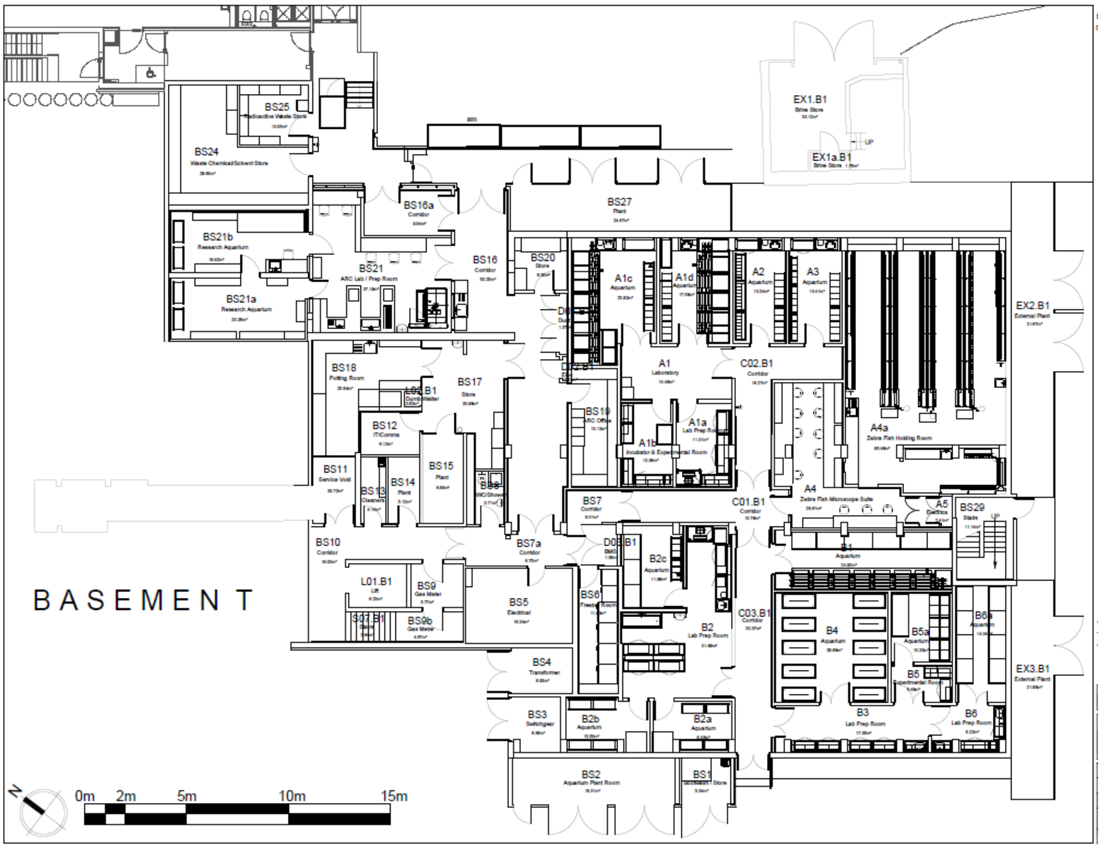


Figure 6.5a South Building Basement Floorplan.

Approximately 103 m^2 of the basement is assigned to building services i.e. IT/Comms room, cleaners cupboard, internal plant rooms and external plant rooms.

6.5.1. Historical Electrical Demand Analysis

As shown in section 5 of this report the electrical supply to the basement is the largest single consumer of the Geoffrey Pope building. The electrical demand profile chart obtained from the Teams EMS is shown below.

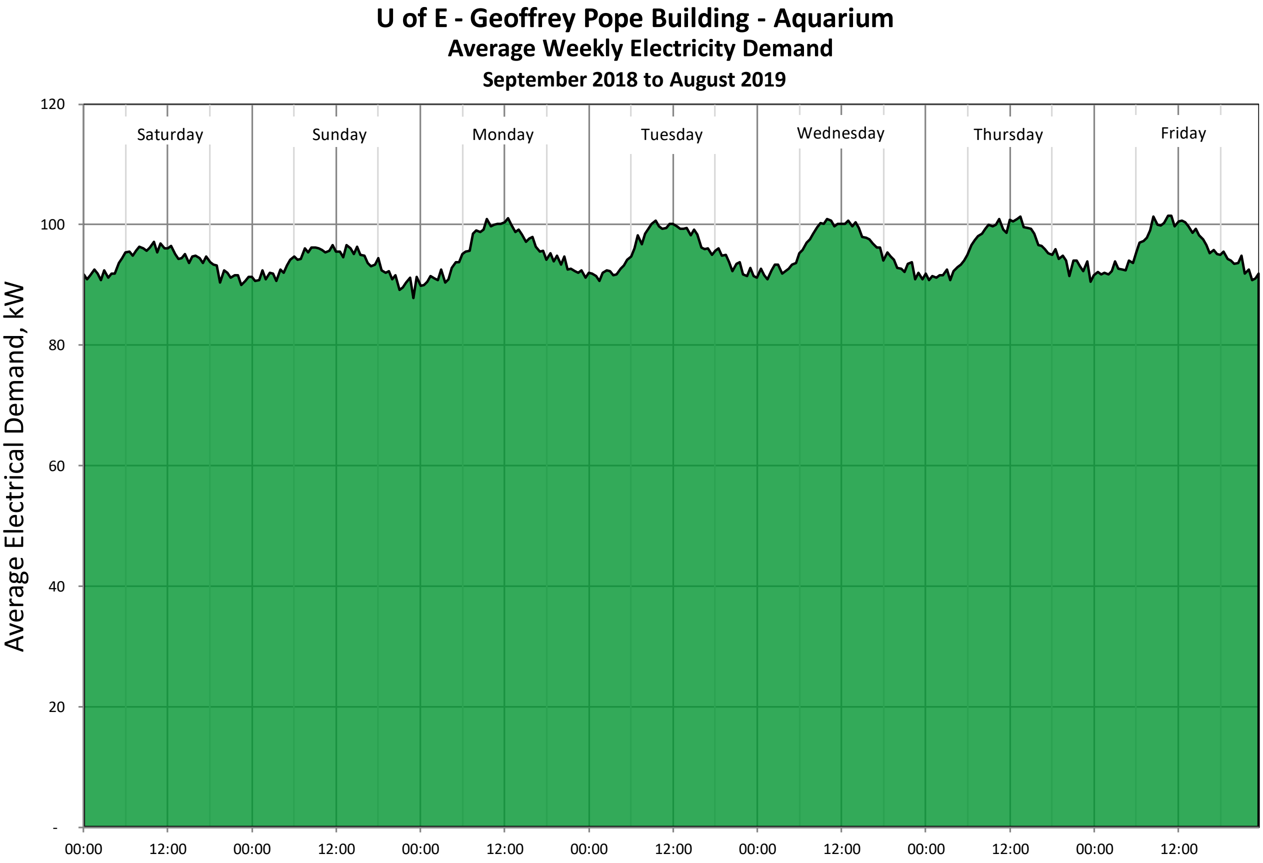


Chart 6.5.1a Average Weekly Electrical Demand Profile – MCB 30

The electrical demand profile above shows a very high and constant demand that has increased demand during the daytime throughout the week although more pronounced between Monday to Friday. The baseload of the average week shown is 88 kW with peak demand at 102 kW. The actual peak demand for the period covered was 116 kW. The following chart shows the daily electrical consumption of the electrical supply for the period 1st September 2018 to 31st August 2019.

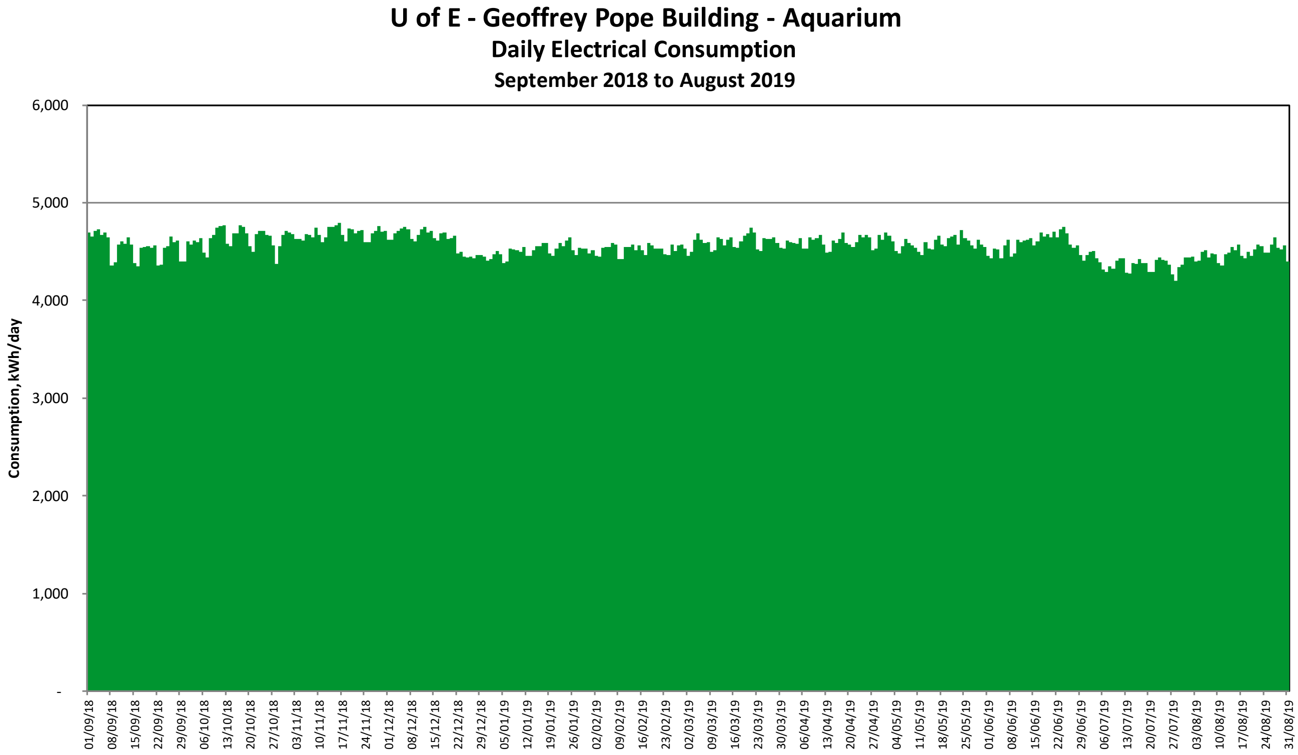


Chart 6.5.1b Daily Electrical Consumption – MCB 30

The above profile shows that the electrical demand of the Aquarium remains constant throughout the period covered with no significant reductions throughout the holiday periods.

During the survey activities the basement plant rooms were visited. In general most contained large vessels of treated water, for use within the ground floor aquariums, along with associated circulation pumps. Pumps were observed to be 1.3 kW peak.

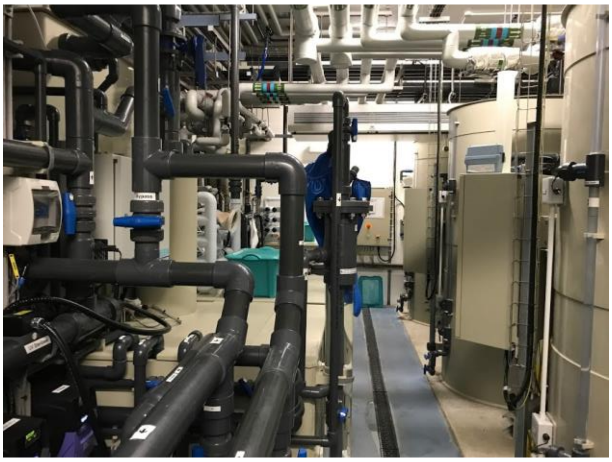


Figure 6.5.1a Basement Plant Room – Zone 1

Figure 6.5.1b Typical Water Circulation Pumps – Zone 1

6.5.2. Observations – Basement Plant Rooms

The following observations were made during the site survey activities within the basement area.

- Large areas of the basement area are set aside for the preparation, storage and treatment of used within the ground floor research aquariums,
- Two external plant rooms are provided (EX2.B1 and EX3.B1) with each accommodating Air Handling Units with supply and extract fan drives being VSD controlled,
- Large ABS water storage tanks are provided within the plant rooms,
- All water storage tanks were observed to be open lid with no secondary insulation properties provided,
- The air space within the water preparation plant rooms was kept very low through the use of fan coil units with CWS being provided from the roof top chillers,
- It was communicated that the air space is kept low to assist in maintaining water temperatures but also to reduce condensation from the tank surfaces

The following chart details the historical daily electricity consumption (data provided from Teams EMS) of the three rooftop chillers which are used for the aquarium areas.

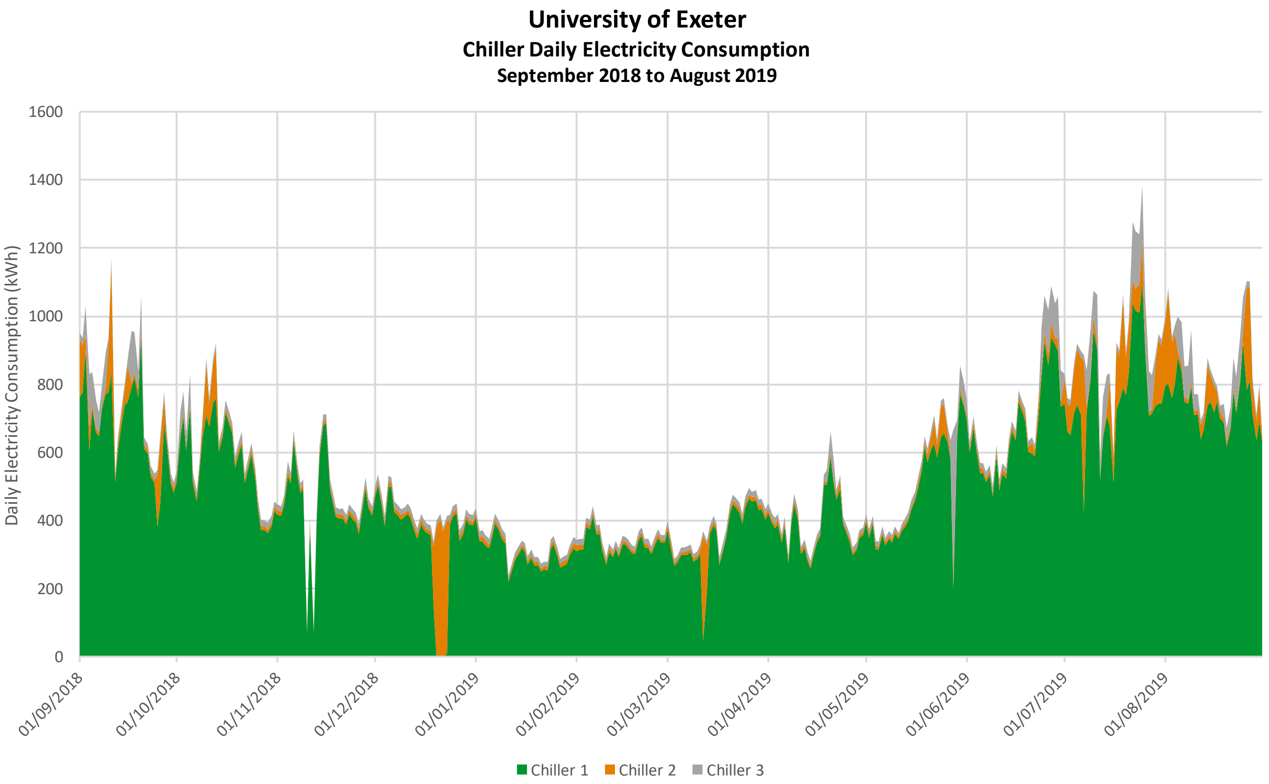


Chart 6.5.2a Chiller Historical Daily Electricity Consumption

The profile in the above chart shows that Chiller 1 is operated as the lead chiller with Chiller 2 and Chiller 3 as the lag. The profile confirms a high daily electricity consumption all year round although there is a season profile with highest consumption during the summer months and lowest in the winter.

The aquarium and associated plant rooms has a significantly high electrical demand which is contributing to the Geoffrey Pope buildings high energy consumption when compared with other buildings within the Streatham campus. It is therefore suggested by Schneider Electric that the aquarium plant rooms be investigated further to map out the main energy flows, identify the main energy demanding items of plant and the establish suggested improvements in their overall control and operation.

7. Building Observations

The following sub-sections details energy saving observations made during the site survey activities.

7.1. Reception Entrance Doors

The main entrance reception to the Geoffrey Pope building consists of a double set of automatic sliding doors approximately 3 meters apart. The doors create an entrance lobby that extends approximately 5m high.

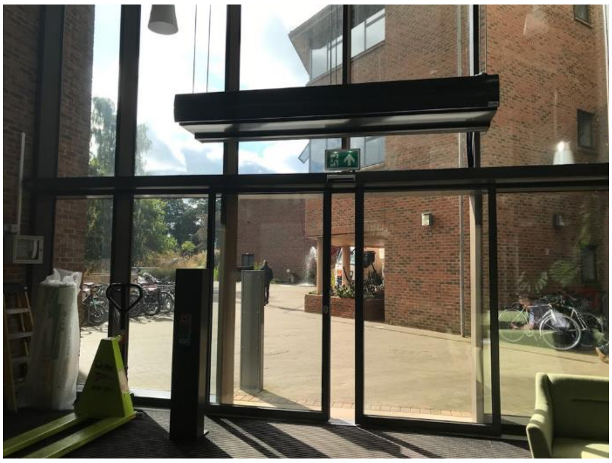


Figure 7.1a Reception External Automatic Doors

Figure 7.1b Reception External Doors Air Curtain

Figure 7.1c Reception Internal Automatic Doors and Heaters

Figure 7.1d Reception Entrance Lobby

The entrance lobby was observed to have a very high footfall, mostly being used for students attending the building. To minimise heat losses of the building both sets of doors operate automatically with the external doors operating on proximity and the internal doors on security card swipe. Additionally, the external doors have a Biddle air curtain installed above which at the time of the survey activities was turned off. The internal doors have a set of vertical warm air heaters mounted on either side of the door opening. Again, at the time of the survey activities the heaters were switched off due to the perceived high operating noise to those who work within the reception area.

Whilst the reception area and stairwell are not a heated environment there was significant thermal losses to the building through the ingress of cold external air during every movement of the reception doors. Additionally, within the entrance lobby there is a section of the stairwell that is open to the entrance lobby environment, as shown in figure 7.1d.

7.2. Thermal Insulation - Internal

In recent months the north building plant room has benefitted from a refurbishment project of the LTHW distribution pipework thermal insulation. New insulation was being fitted to all pipework within the plant room, as shown in the following figure. The installation is to an excellent standard and should assist in reducing thermal losses within the plant room.

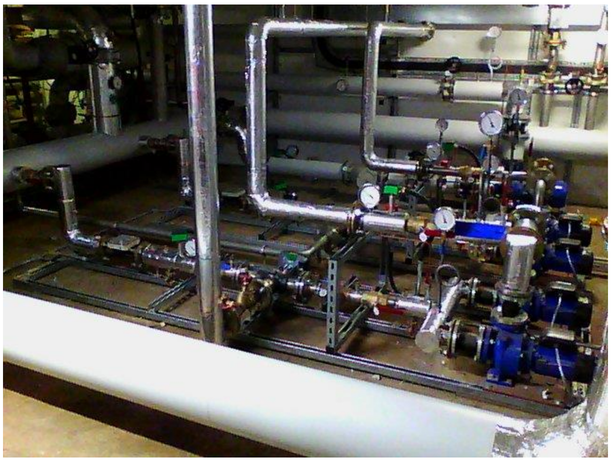


Figure 7.2a North Building Plant Room Thermal Insulation

There were however areas observed where thermal insulation improvements within plant room distribution tunnel might not be included within the replacement project. One such area is the tunnel between the north to south buildings. As detailed within the following thermal imaging photos, significant thermal losses are visible either from damaged or missing thermal insulation. If not already replaced, or planned, these areas should be considered for improvements.

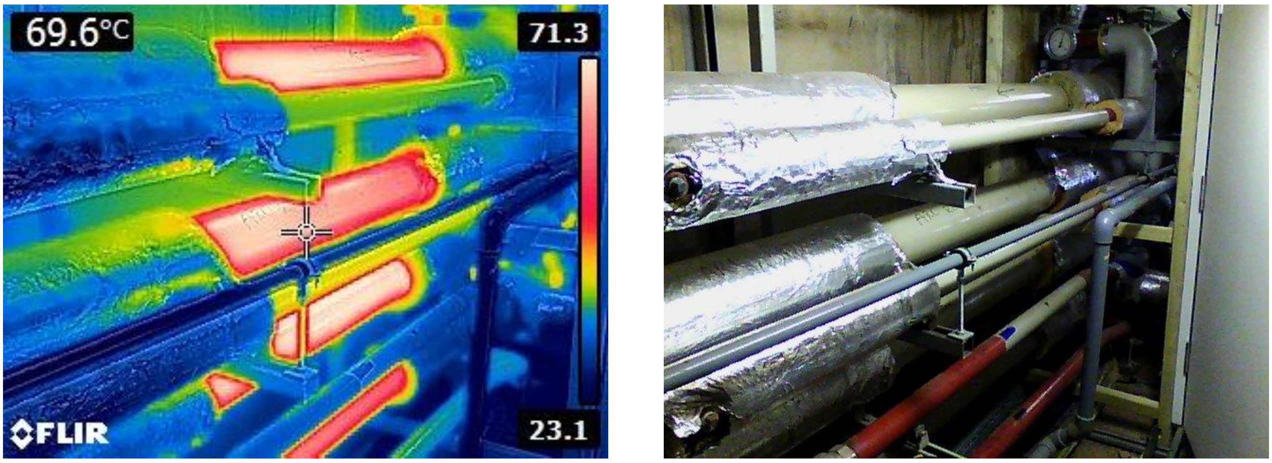


Figure 7.2b Thermal Heat Losses – Tunnel

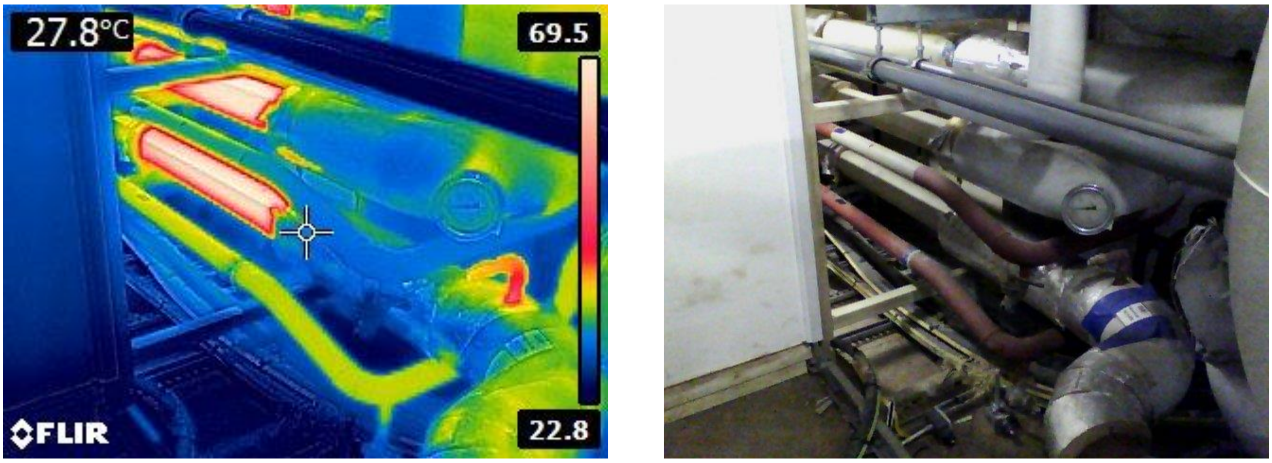


Figure 7.2c Thermal Heat Losses – Tunnel

Additionally, further improvements can be made within the south building basement where LTHW distribution pipework has no thermal insulation producing significant thermal losses, as demonstrated in the following figure.

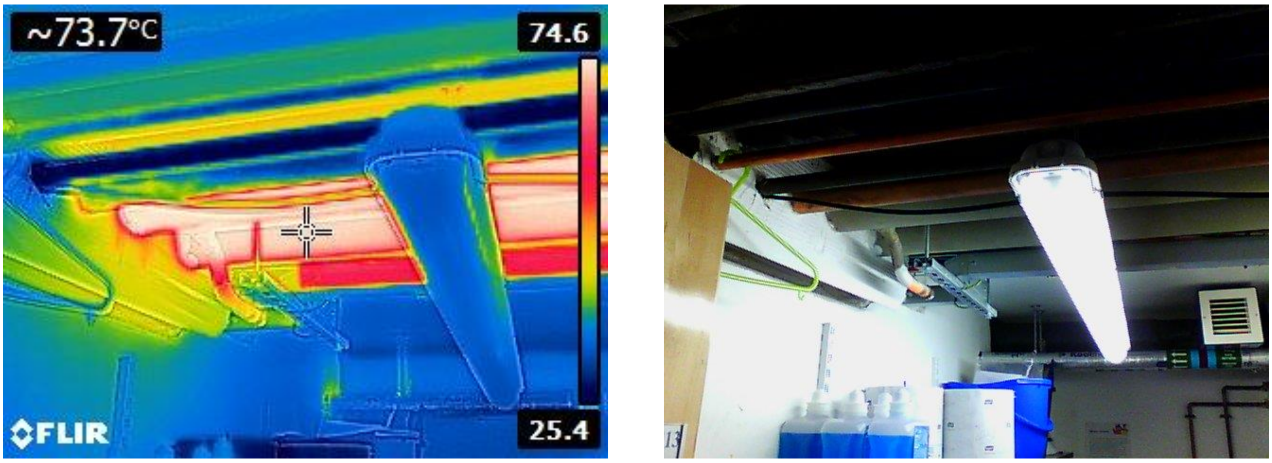


Figure 7.2d Thermal Heat Losses – South Building

7.3. Thermal Insulation - External

There are some areas external to the Geoffrey Pope building that would benefit from improved thermal insulation. Below photographs show examples of those observed during the site survey activities. It is believed there would be further areas captured should a full investigation be made.

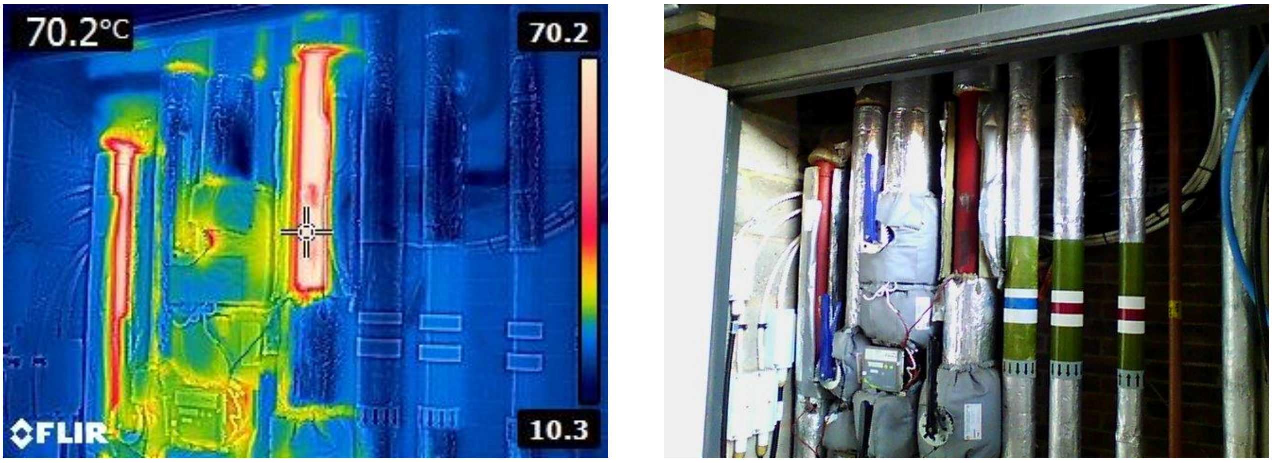


Figure 7.3a – Thermal Heat Losses – External Riser

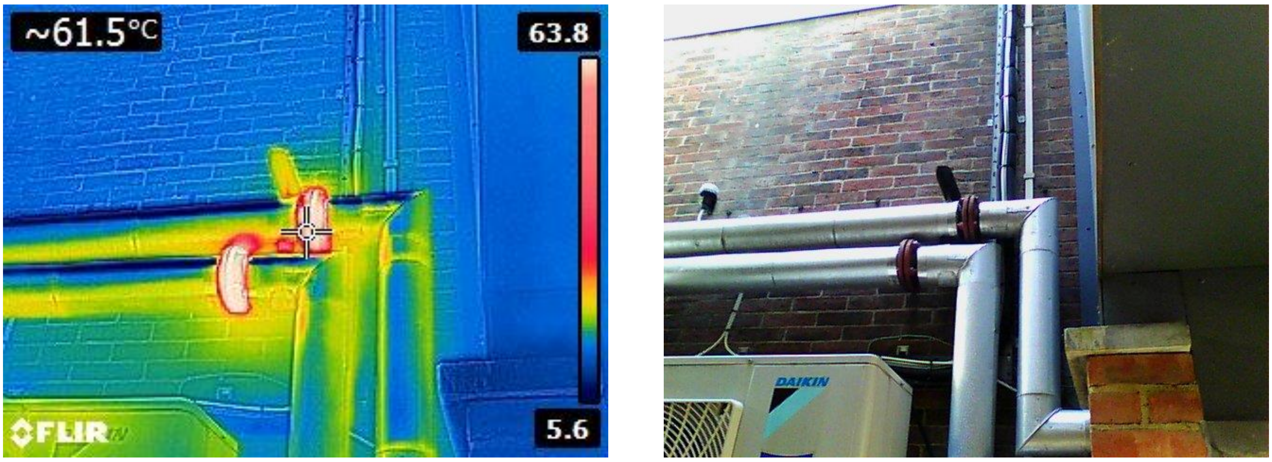


Figure 7.3b – Thermal Heat Losses – Pipework Flanges

7.4. Living Systems CHP

As part of the initial site survey the Living Systems building ground floor plant room was visited. The area was viewed to observe the high standard installation which includes 2x combined heat and power (CHP) units supplying both electricity and heat to the Living Systems building. The Tedom R-Micro T50 SP CHP units have an electrical output of 50 kW$_e$ and provide a stated (UofE) heat output of 150 kW$_{th}$ (101.5 kW based on OEM specifications). At the time of the survey CHP No 1 was operational with an electrical output of 48.0 kW. A plate heat exchanger is provided for the transfer of heat from the CHP system to the Living Systems building. It should be noted that the plate heat exchanger has very good thermal installation, along with the rest of the heating pipework.

The following table details the main attributes of the installed CHP units according to the Tedom specification sheet. As shown, for every 146.0 kW of natural gas supplied to the CHP unit the total output is 151.5 kW (50.0 kW electrical, 101.5 kW heat).

Make	Tedom
Model	Micro 50
Electrical Output (kW)	50.0
Max Heat Output (kW)	101.5
Total Efficiency (kW)	103.8
Power input in Fuel (kW)	146.0

Table 7.4a Living Systems CHP Specifications

The P&ID for the Living Systems building shows a thermal output of 91.0 kW rather than that of the OEM specifications and that stated by the UofE. The true thermal output of the system should therefore be determined.

Figure 7.4a Tedom CHP Units

Figure 7.4b CHP LTHW Plate Heat Exchangers

It was communicated during the site survey activities that the CHP units are operated as duty/standby and therefore only 1x unit is ever operational. Also, the units are switched off during the summer months when the Living Systems building heat demand is too low. Given the financial investment of the system and constant heat demand of the Geoffrey Pope building the CHP operation should be investigated to determine the viability of operating the CHP system with both units operational and supplying heat to the Geoffrey Pope building.

Whilst the Coefficient of Performance for the CHP unit on an electrical output only is low (0.34), natural gas cost is approximately a third that of electricity plus there is a constant heat demand within Geoffrey Pope. It should also be considered operating the CHP units during the summer months, again supplying Geoffrey Pope, reducing the natural gas demand of the summer boilers.

It is understood that the LTHW pipework connections between the Living Systems building and Geoffrey Pope have already been installed.

7.5. Building Asset list

To effectively manage and support energy management it is vital that the University understands all equipment within its buildings particularly the energy intensive Geoffrey Pope building. As part of the energy mapping project Schneider Electric sent a Request For Information (RFI) for an asset list for the Geoffrey Pope building, which was gratefully received (Energy Audit GP.xlsx). Whilst the list was useful in determining the quantity of equipment installed, such as Air Handling Units, unfortunately the list did not provide great detail on the energy demand associated with the assets. Of the 517 pieces of equipment detailed within the asset list only 50x items had a known energy demand.

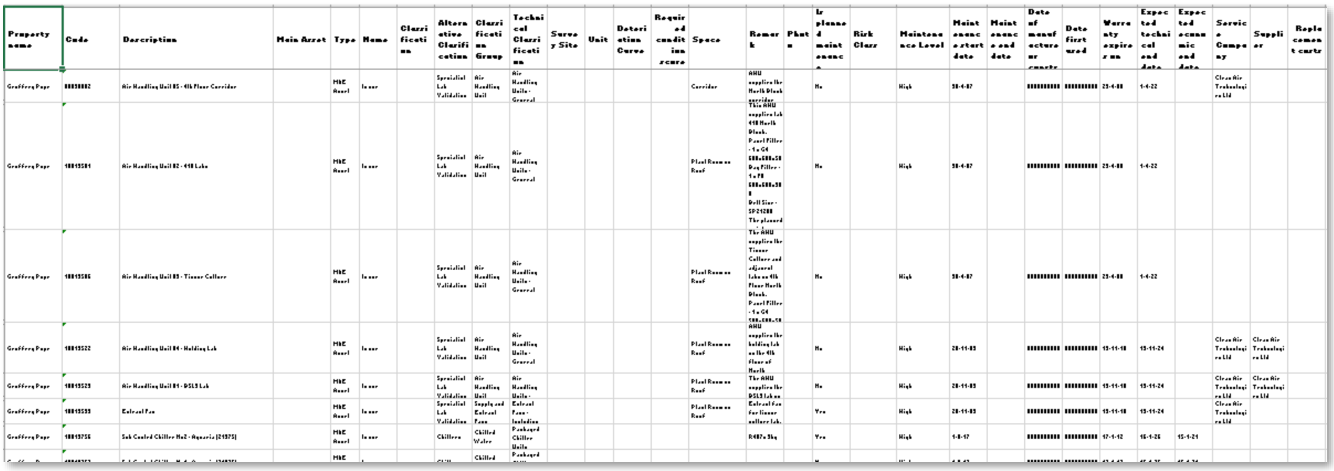


Figure 7.5a Extract of Geoffrey Pope Asset List

It is therefore recommended that the University updates the building asset list to include all relevant OEM energy demand data. The list can then become an effective tool in the overall management of the campus building.

8. Power Quality Study

As an addendum of the energy intensity studies it was agreed to undertake a power quality study of the main incomer (Substation 40 main LV Panel). This is typically done to validate that the incoming power supply is effective and as efficient as possible for the building's requirements, in effect a root cause appraisal at point of entry for the power provision.

8.1. Power Quality Study Findings

This report has been compiled to analyse power quality data recorded at Substation 40 main LV panel at the University of Exeter, Geoffrey Pope Building between 15/10/2019 and 23/10/2019.

The monitoring point is shown on Figure 4.1a.

All power quality data was recorded using a *Chauvin Arnoux Qualistar C.A 8334B (serial number 156609HJH).*

Judging from trend plots of the data recorded, it appears that some or all of the inputs to the power quality monitor may have been disconnected before recording was stopped, as most parameters recorded 'drop off' at the final data point recorded on 23/10/2019 at 13:20:00. Note that the power quality monitor was disconnected by University staff without the knowledge of Schneider Electric. As such, where applicable, to increase the clarity of the trend plots, the final data point recorded is not shown on trend plots. This report is based on the assumption that the fault level at each of the monitoring points is 10MVA.

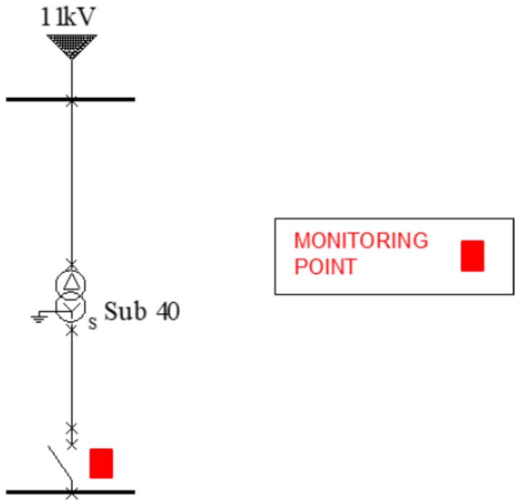


Figure 8.1a Monitoring Point for Power Quality Survey

8.2. Data monitored

8.2.1. Line Voltages (all data points recorded)

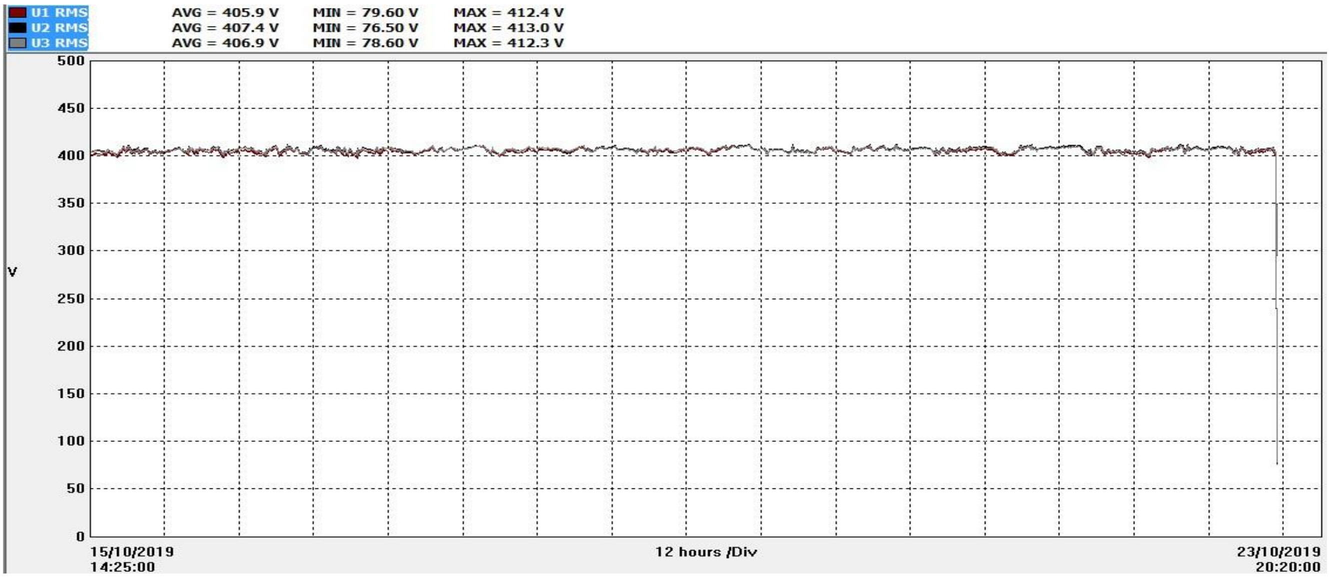


Figure 8.2.1a Line Voltages

As mentioned previously, it appears that some or all of the inputs to the power quality monitor may have been disconnected before recording was stopped, as most parameters recorded 'drop off' at the last data point recorded (see above). As such, where applicable, to increase the clarity of the trend plots, the last data point recorded is not shown on the subsequent trend plots (starting with Section 8.2.2).

8.2.2. Line Voltages (final data point omitted)

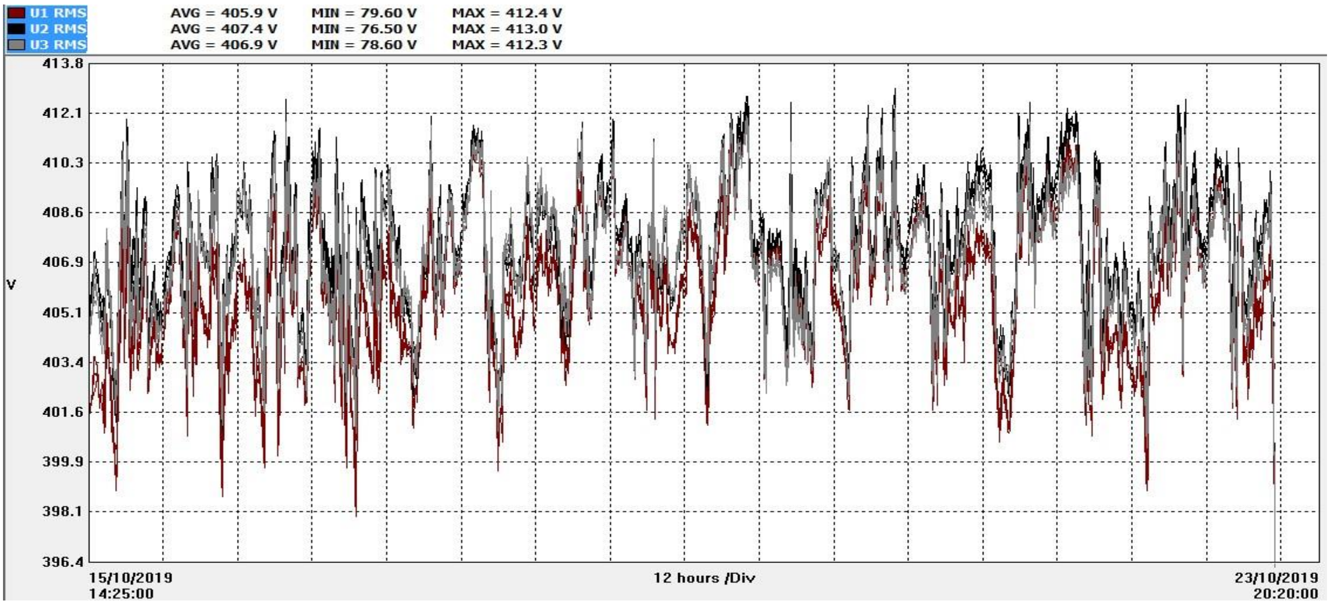
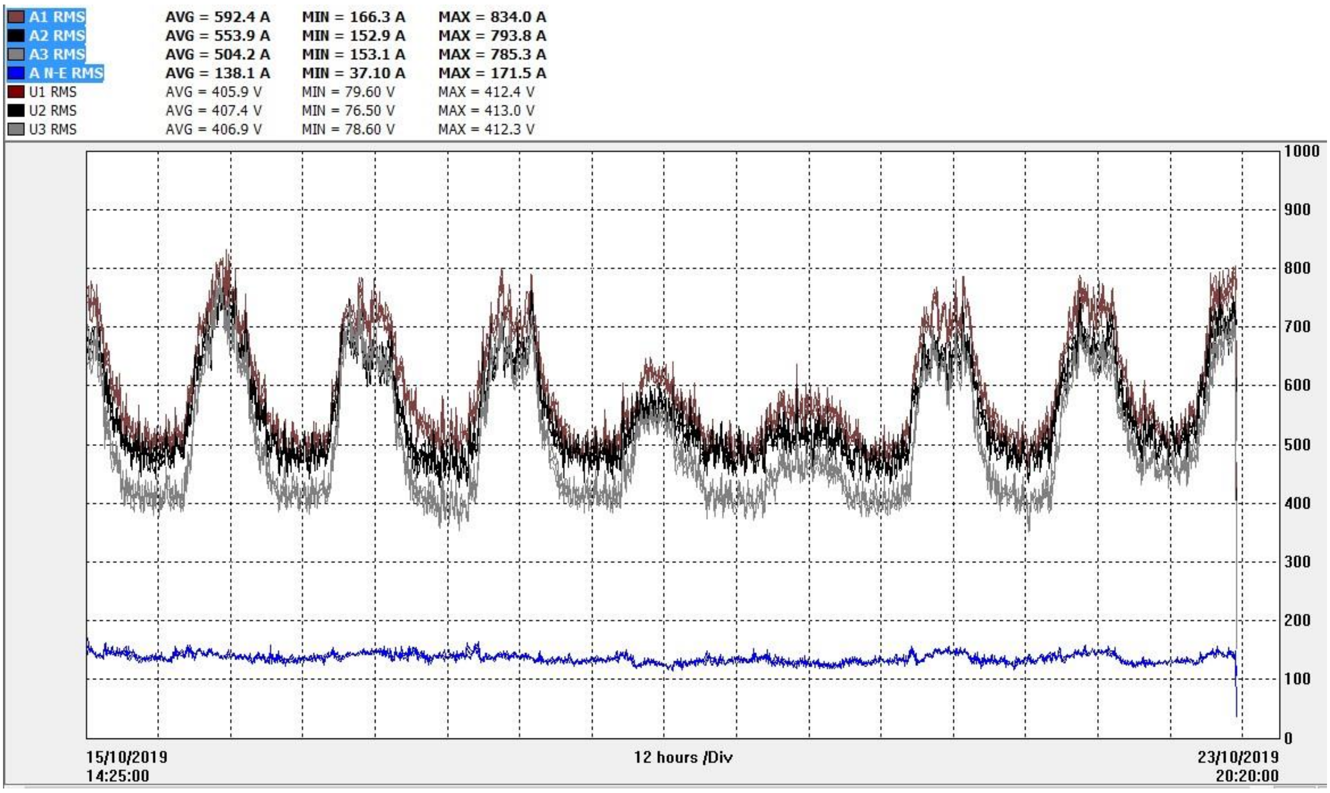


Figure 8.2.2a Line Voltages

A single line diagram provided shows Transformer 40 voltage ratio to be ‘11,000/400V’. Although the transformer’s tap position is not known, it is suspected from the above trend plot that the transformer no-load secondary voltage rating is in the region of 415V-417V. If so, the line voltage values recorded are in line with what would be expected for a transformer with this voltage ratio. As such, there are no recommended actions resulting from the above data.

8.2.3. Phase Currents



🟥 A1 RMS	AVG = 592.4 A	MIN = 166.3 A	MAX = 834.0 A
⬛ A2 RMS	AVG = 553.9 A	MIN = 152.9 A	MAX = 793.8 A
▨ A3 RMS	AVG = 504.2 A	MIN = 153.1 A	MAX = 785.3 A
🟦 A N-E RMS	AVG = 138.1 A	MIN = 37.10 A	MAX = 171.5 A
🟥 U1 RMS	AVG = 405.9 V	MIN = 79.60 V	MAX = 412.4 V
⬛ U2 RMS	AVG = 407.4 V	MIN = 76.50 V	MAX = 413.0 V
▨ U3 RMS	AVG = 406.9 V	MIN = 78.60 V	MAX = 412.3 V

Figure 8.2.3a Phase Currents

A single line diagram provided shows Transformer 40 power rating to be ‘150kVA’. Based on the 2,500A current rating of the associated LV incomer, it is assumed that the actual power rating of Transformer 40 is 1500kVA. Assuming a secondary voltage of 417V would yield a rated secondary current of 2077A. The values recorded are within 2,077A and as such, there are no recommended actions resulting from the above data.

8.2.4. Active Power

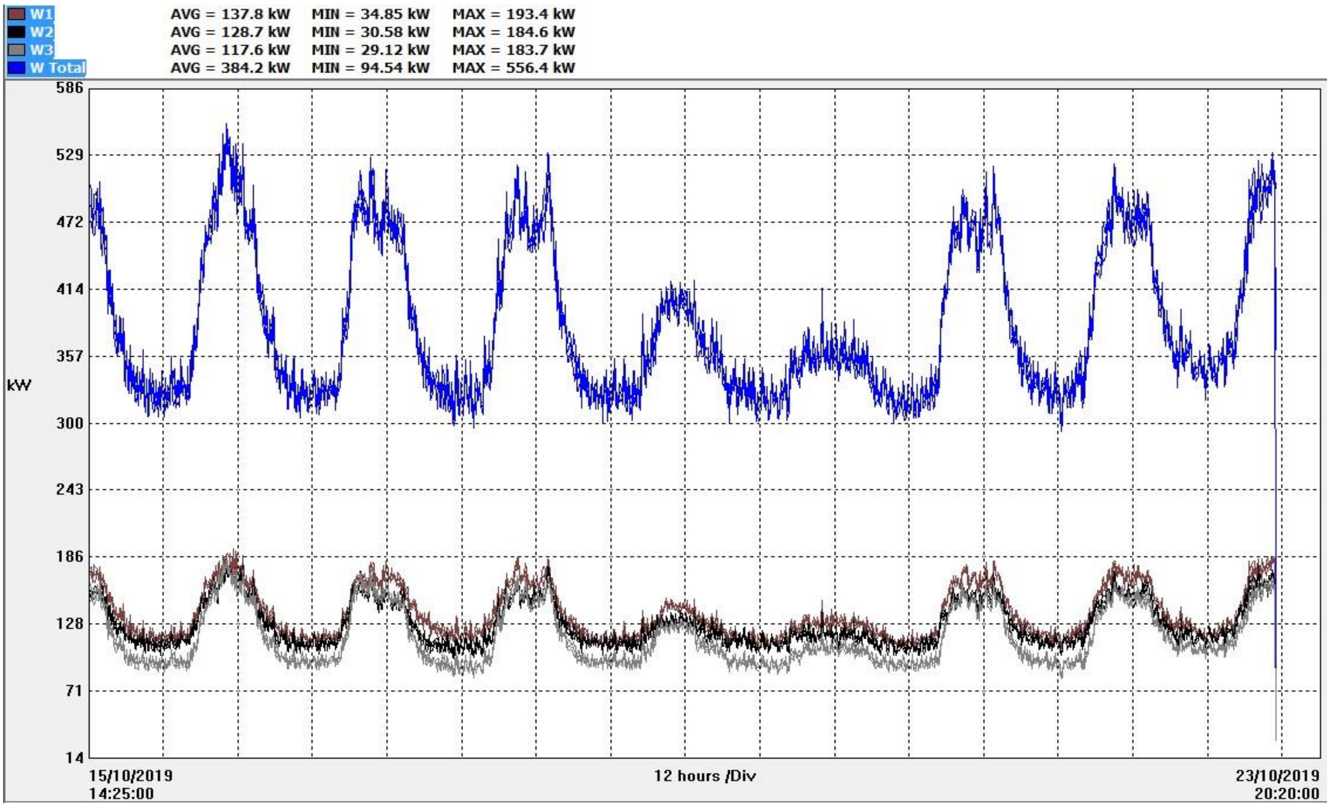


Figure 8.2.4a Active Power

Maximum 3ph total kW recorded: 556.4kW which occurred on 16/10/2019 at 12:25:00.

8.2.5. Total Three Phase Apparent Power

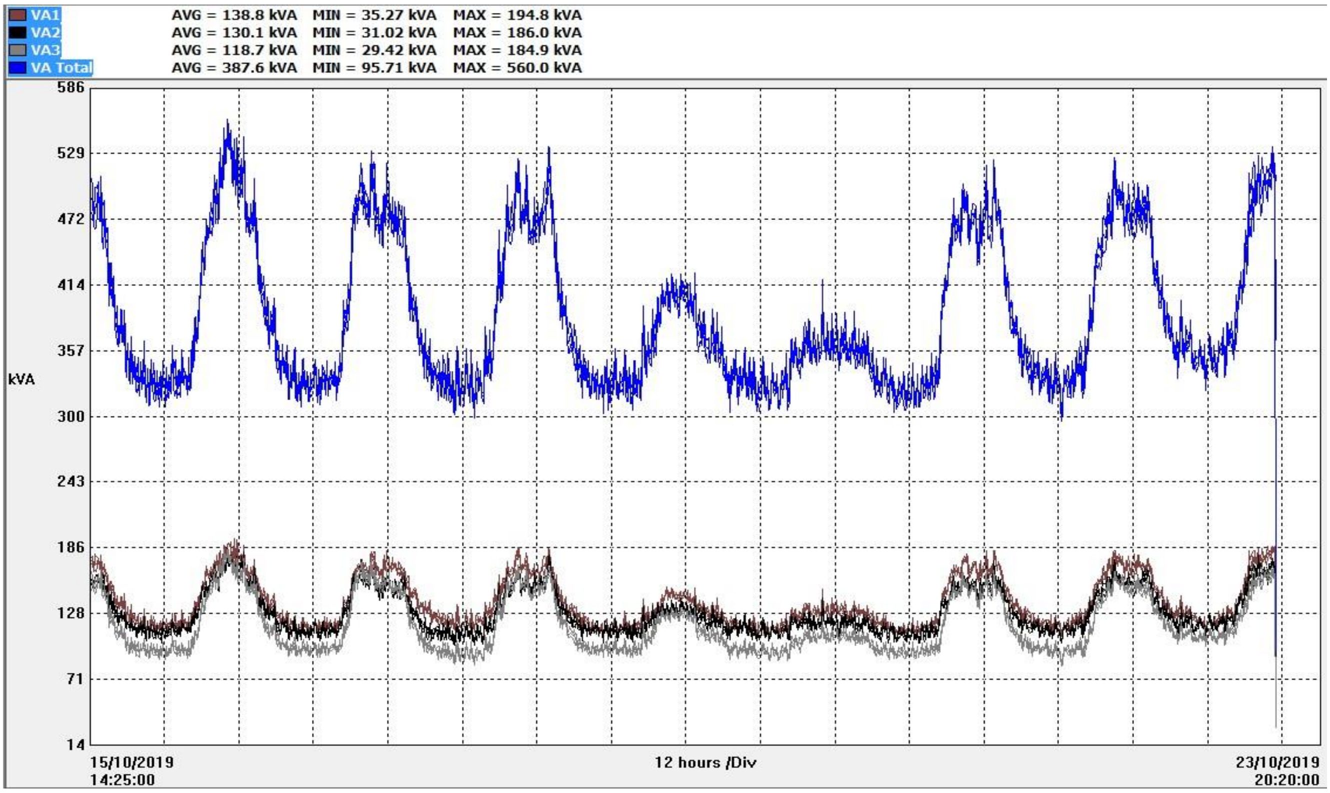


Figure 8.2.5a Three Phase Apparent Power

Maximum 3ph total kVA recorded: 560.0kVA which occurred on 16/10/2019 at 12:25:00. The values recorded are within the assumed 1,500kVA apparent power rating of the transformer. As such, there are no recommended actions resulting from the above data.

8.2.6. Power Factor (average of three phases)

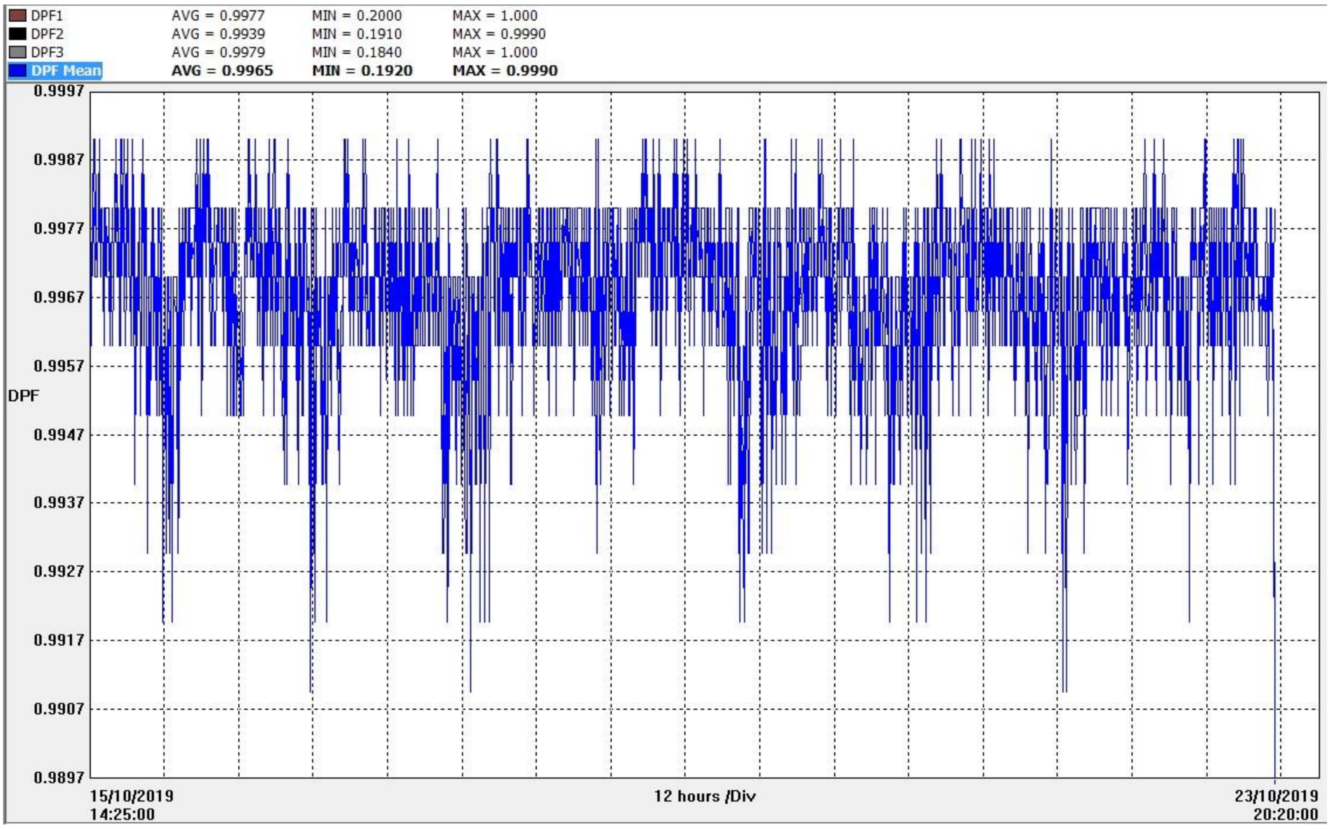


Figure 8.2.6a Power Factor

The displacement power factor average was 0.9965 during the monitoring period.

8.2.7. Total Harmonic Distortion (line voltages and current)

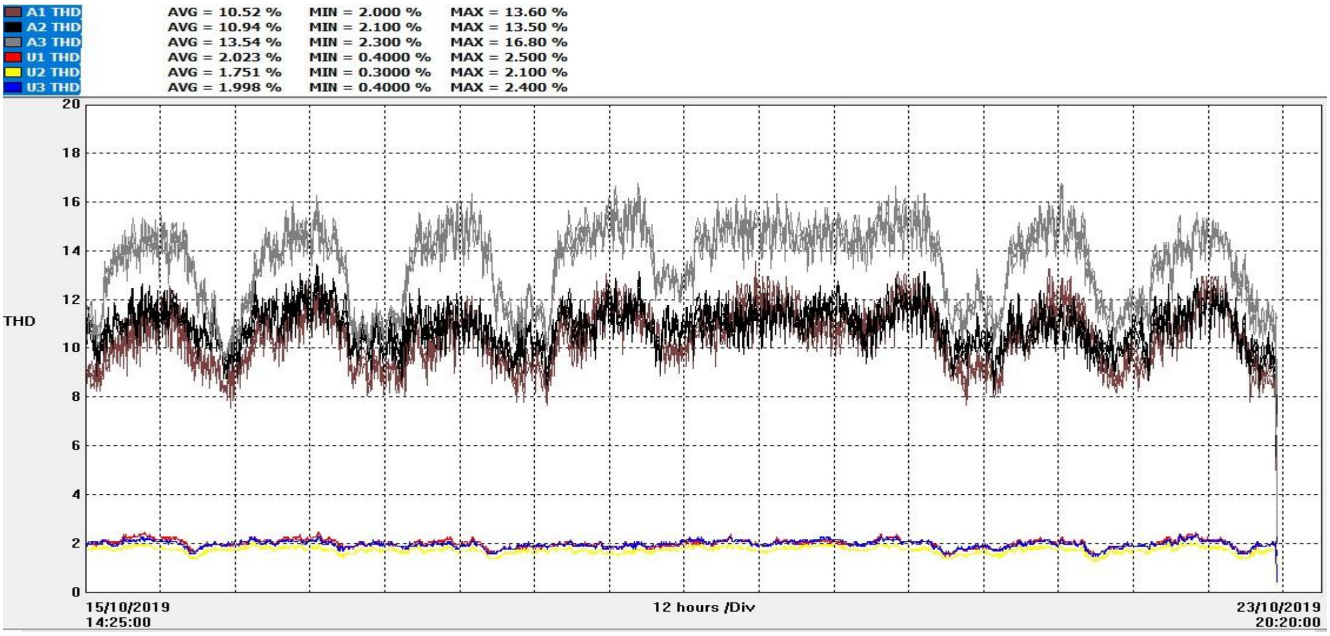


Figure 8.2.7a Total Harmonic Distortion

The maximum line voltage THD_V value recorded was 2.5% on U_1 which occurred on 15/10/2019 at 23:50:00, 17/10/2019 between 03:35:00, and 03:45:00 (inc.) and 23/10/2019 at 00:15:00. The maximum THD_I value recorded was 16.8% on L3 which occurred on 22/10/2019 at 02:45:00.

The maximum THD_V values recorded were all below the 400V Table 8.3c THD_V 5% limit in G5/4-1, therefore there are no recommended actions resulting from these values recorded. There are also no recommended actions resulting from the THD_I values recorded.

8.2.8. 5th Line Voltage Harmonics (% of fundamental)

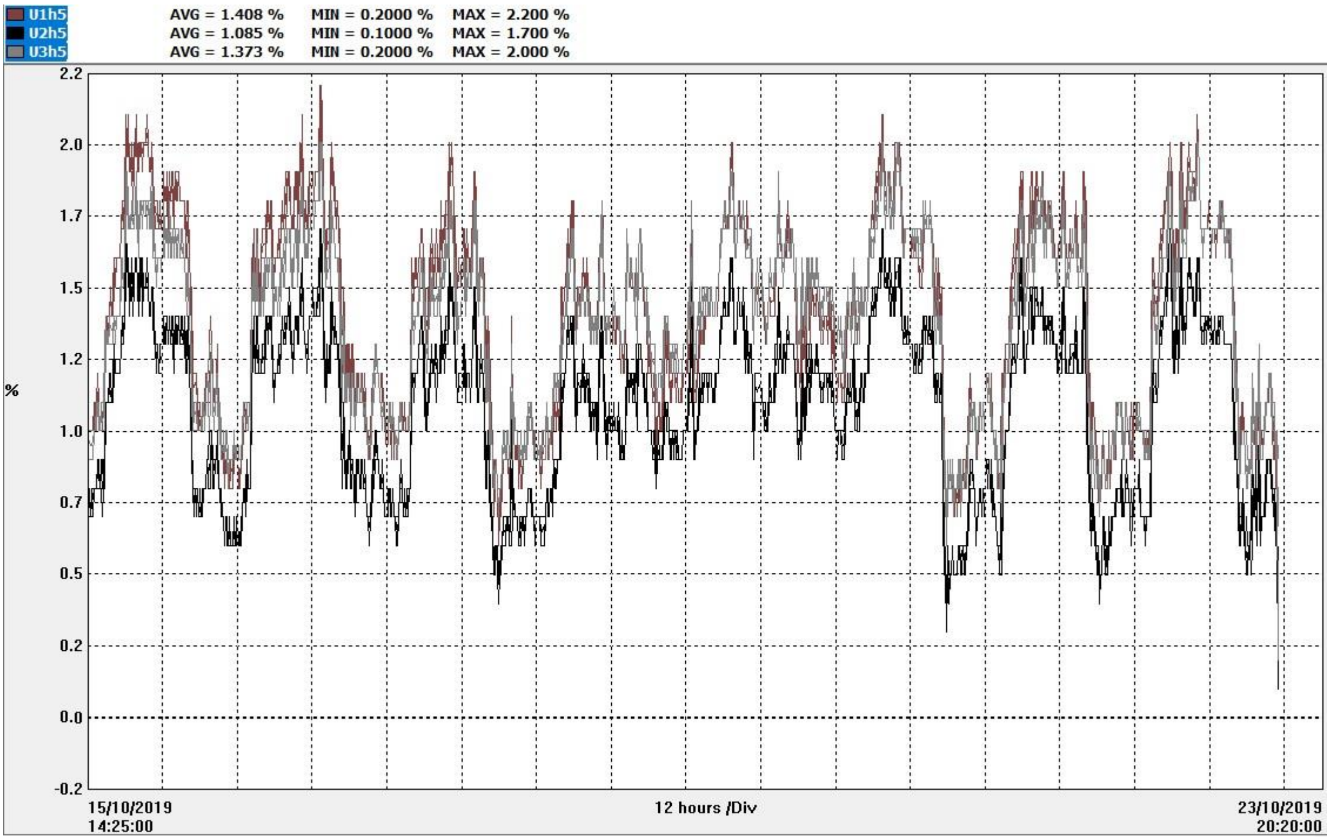


Figure 8.2.8a 5th Line Harmonics

The 5th harmonic voltage values recorded were all below the 400V Table 4.2.11c 5th harmonic limit of 4.0% in G5/4-1, with the maximum value of 2.2% recorded on U_1 on 17/10/2019 between 03:35:00 and 03:40:00 (inc), therefore there are no recommended actions resulting from these values recorded.

8.2.9. Harmonic Spectrum Currents (% of fundamental)

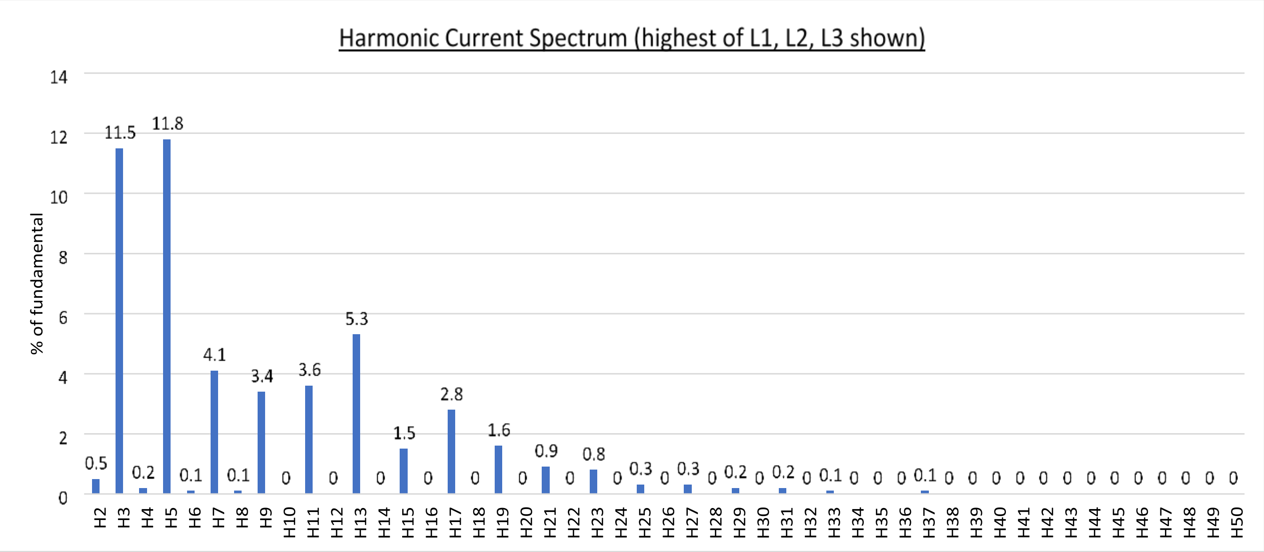


Figure 8.2.9a 5th Line Harmonics

Predominant current harmonics are the 3rd and 5th .

8.2.10. Harmonic Spectrum: Line Voltages (% of fundamental)

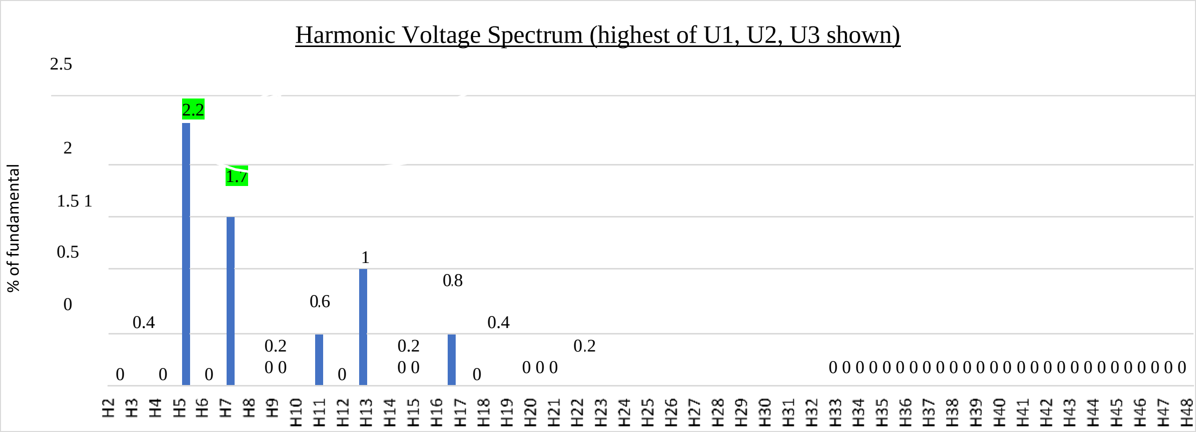
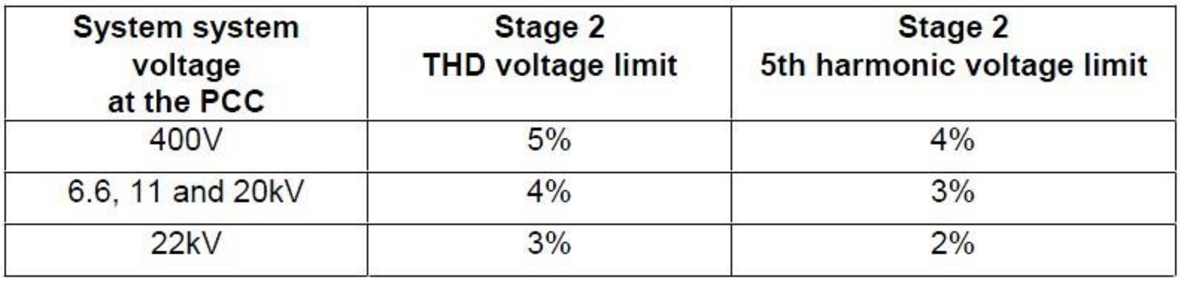


Figure 8.2.10a 5th Line Harmonics

Predominant voltage harmonics are the 5th and 7th. The maximum 5th harmonic voltage recorded was 2.2% on U_1, which is below the 400V Stage 2 4.0% limit.

8.3. Analysis Data Recorded



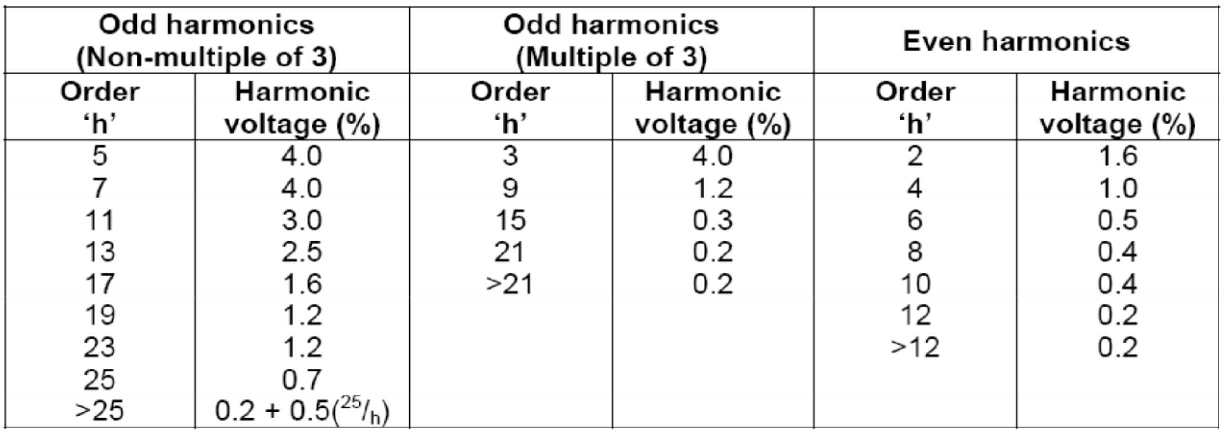
System system voltage at the PCC	Stage 2 THD voltage limit	Stage 2 5th harmonic voltage limit
400V	5%	4%
6.6, 11 and 20kV	4%	3%
22kV	3%	2%

Table 8.3a G5/4-1 Extract

The maximum line voltage THD_V value recorded was 2.5%, which is below the 400V Stage 2 THD_V 5.0% limit. Also, the maximum 5th harmonic line voltage recorded was 2.2%, which is below the 400V Stage 2 4% limit. Therefore, for G5/4-1 compliance, there is no requirement to analyse current harmonics recorded.

ENA Regulation G5/4-1 applies only at the point of common coupling (PCC) with other users. This test was carried out on the customer's site to establish local levels of distortion and to use the data to make an informed judgement as to whether G5/4-1 compliance is achieved for the existing site.

Given the above, it is our judgement that the network associated with Transformer T40 would be deemed to be compliant with G5/4-1.



Odd harmonics (Non-multiple of 3)		Odd harmonics (Multiple of 3)		Even harmonics	
Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)	Order 'h'	Harmonic voltage (%)
5	4.0	3	4.0	2	1.6
7	4.0	9	1.2	4	1.0
11	3.0	15	0.3	6	0.5
13	2.5	21	0.2	8	0.4
17	1.6	>21	0.2	10	0.4
19	1.2			12	0.2
23	1.2			>12	0.2
25	0.7				
>25	$0.2 + 0.5(^{25}/_{h})$				

Table 8.3b - G5/4-1 Extract – Planning Levels for Harmonic Voltages in 400V Systems

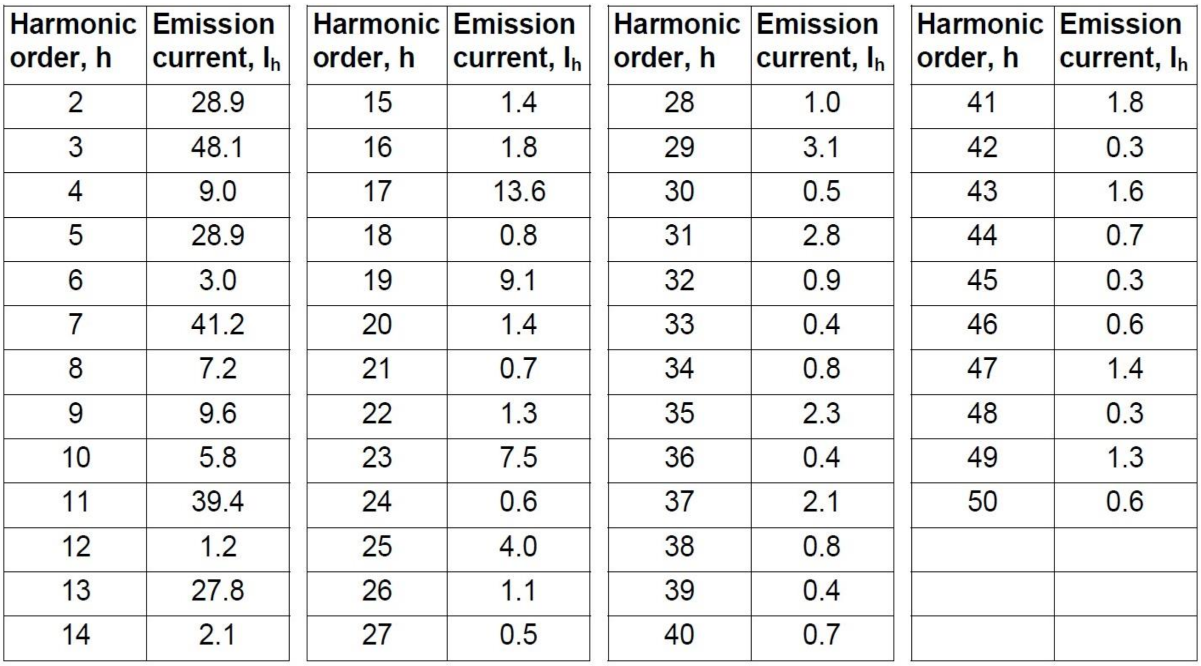
The Total Harmonic Distortion (THD) level is 5%.

Harmonic	Voltage (%)	G5/4 Limit (%)	Result
2	0	1.60	Pass
3	0.4	4.00	Pass
4	0	1.00	Pass
5	2.2	4.00	Pass
6	0	0.50	Pass
7	1.7	4.00	Pass
8	0	0.40	Pass
9	0.2	1.20	Pass
10	0	0.40	Pass
11	0.6	3.00	Pass
12	0	0.20	Pass
13	1	2.50	Pass
14	0	0.20	Pass
15	0.2	0.30	Pass
16	0	0.20	Pass
17	0.8	1.60	Pass
18	0	0.20	Pass
19	0.4	1.20	Pass
20	0	0.20	Pass
21	0	0.20	Pass
22	0	0.20	Pass
23	0.2	1.20	Pass
24	0	0.20	Pass
25	0	0.70	Pass

Table 8.3c LV Harmonic Voltages (%)

As can be seen in table 8.3c, all individual voltage harmonics fall within those stated in G5/4-1 Table 8.3b so no further recommendations result from the recorded values shown in table 8.3c.

All harmonic orders above the 25th were considered negligible and hence not considered for analysis.



Harmonic order, h	Emission current, I_h
2	28.9
3	48.1
4	9.0
5	28.9
6	3.0
7	41.2
8	7.2
9	9.6
10	5.8
11	39.4
12	1.2
13	27.8
14	2.1
15	1.4
16	1.8
17	13.6
18	0.8
19	9.1
20	1.4
21	0.7
22	1.3
23	7.5
24	0.6
25	4.0
26	1.1
27	0.5
28	1.0
29	3.1
30	0.5
31	2.8
32	0.9
33	0.4
34	0.8
35	2.3
36	0.4
37	2.1
38	0.8
39	0.4
40	0.7
41	1.8
42	0.3
43	1.6
44	0.7
45	0.3
46	0.6
47	1.4
48	0.3
49	1.3
50	0.6

Table 8.3d Stage 1 Maximum Permissible Harmonic Emissions in Amperes RMS for Aggregate Loads and Equipment Rated >16A per phase

Harmonic	Current (A)	G5/4 Limit (A)	Result
2	2.83	28.9	Pass
3	53.96	48.1	Fail
4	1.32	9	Pass
5	54.27	28.9	Fail
6	0.68	3	Pass
7	26.34	41.2	Pass
8	0.64	7.2	Pass
9	16.01	9.6	Fail
10	0.00	5.8	Pass
11	23.21	39.4	Pass
12	0.00	1.2	Pass
13	25.26	27.8	Pass
14	0.00	2.1	Pass
15	9.07	1.4	Fail
16	0.00	1.8	Pass
17	13.21	13.6	Pass
18	0.00	0.8	Pass
19	7.33	9.1	Pass
20	0.00	1.4	Pass
21	3.61	0.7	Fail
22	0.00	1.3	Pass
23	4.21	7.5	Pass
24	0.00	0.6	Pass
25	1.73	4	Pass
26	0.00	1.1	Pass
27	1.33	0.5	Fail
28	0.00	1	Pass
29	1.10	3.1	Pass
30	0.00	0.5	Pass
31	1.04	2.8	Pass
32	0.00	0.9	Pass
33	0.46	0.4	Fail
34	0.00	0.8	Pass
35	0.00	2.3	Pass
36	0.00	0.4	Pass
37	0.41	2.1	Pass
38	0.00	0.8	Pass
39	0.00	0.4	Pass
40	0.00	0.7	Pass
41	0.00	1.8	Pass
42	0.00	0.3	Pass
43	0.00	1.6	Pass
44	0.00	0.7	Pass
45	0.00	0.3	Pass
46	0.00	0.6	Pass
47	0.00	1.4	Pass
48	0.00	0.3	Pass
49	0.00	1.3	Pass
50	0.00	0.6	Pass

Table 8.3e LV Harmonic Currents (RMS)

8.4. Summary – Substation 40 Main LV

Given the previously-mentioned transformer rating assumptions, the voltage and current data recorded was in line with what would be expected for a transformer of this type, which is being used within its capacity.

The maximum line voltage THD_V value recorded was 2.5%, which is below the 400V Stage 2 5% limit. Also, the maximum 5th harmonic line voltage recorded was 2.2%, which is below the 400V Stage 2 4% limit. Therefore, for G5/4-1 compliance, it is our judgement that the network associated with Transformer T40 would be deemed be compliant with G5/4-1.

Although compliant with G5/4-1 absolute voltage limits, some of the individual harmonic currents recorded, namely the 3rd, 5th, 9th and 15th were outside the indicative limits shown in Table 4.3b.

To improve the overall reliability of supply, we would consider it good practice to consider active filtration being added to comply with the individual Table 4.3e current limits. Some of the effects of harmonic currents in networks are shown below:

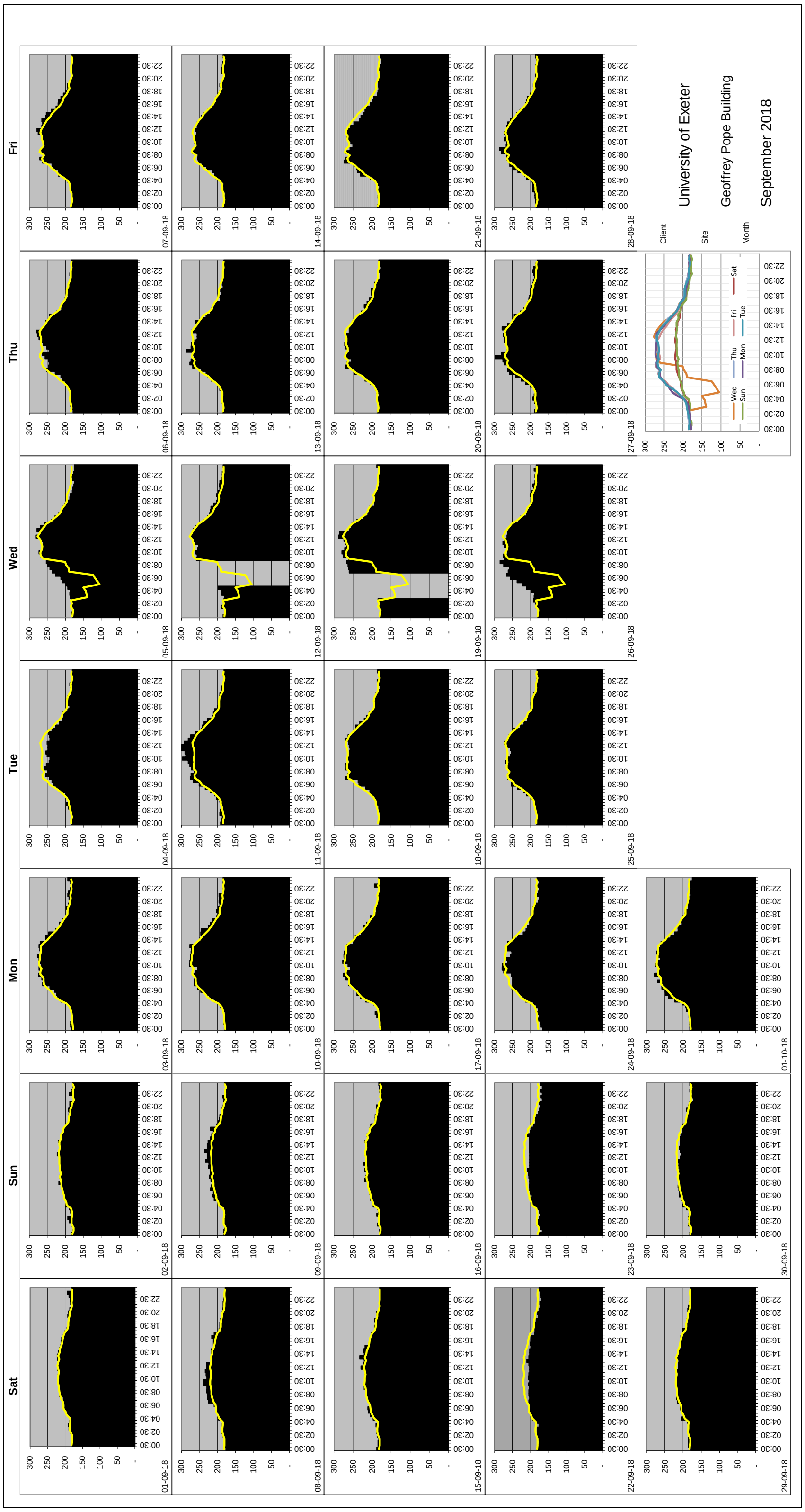
- Overheating of conductors and insulation degradation;
- Increased transformer losses (need to over-size);
- Nuisance tripping of circuit breakers;
- Significant voltage distortion on networks with generators;
- Overheating and possible resonance with capacitors;
- Re-injection of harmonic currents into the utility network.

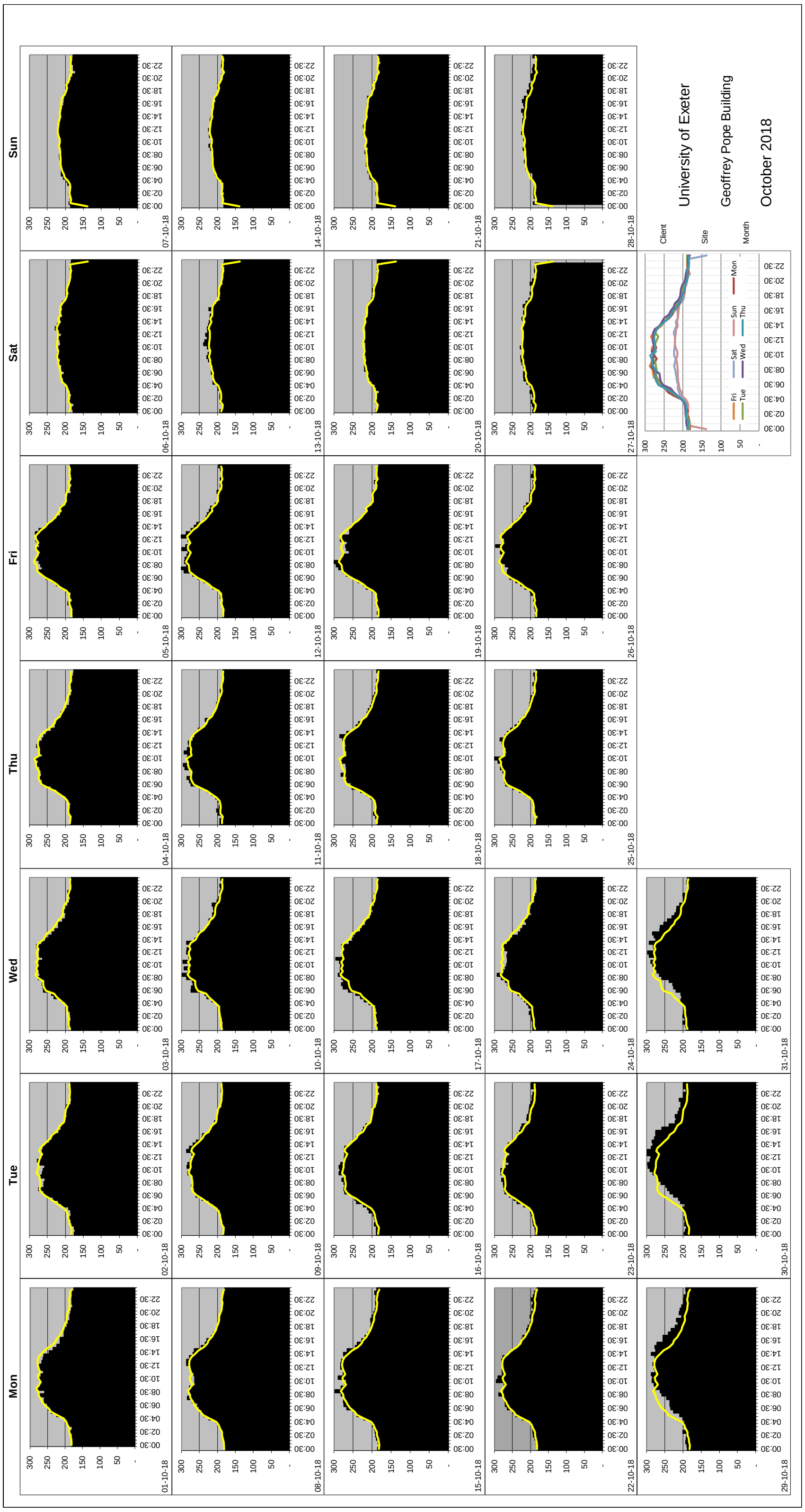
9. Abbreviations

The following abbreviations have been used in this report document;

ACR	Air Change Rate
AHU	Air Handling Unit
CHP	Combined Heat and Power
CoP	Coefficient of Performance
CO_2	Carbon Dioxide
CWS	Chilled Water System
DHW	Domestic Hot Water
HDD	Heating Degree Day
HHD	Half Hourly Data
kW	Kilo Watt (1,000 Watts)
kWh	Kilo Watt hour (1,000 Watt-hour)
LTHW	Low Temperature Hot Water
m/s	Meters per second
MPHW	Medium Pressure Hot Water
MW	Mega Watt (1,000,000 Watts)

10. Appendix 1 – Daily Demand Profiles





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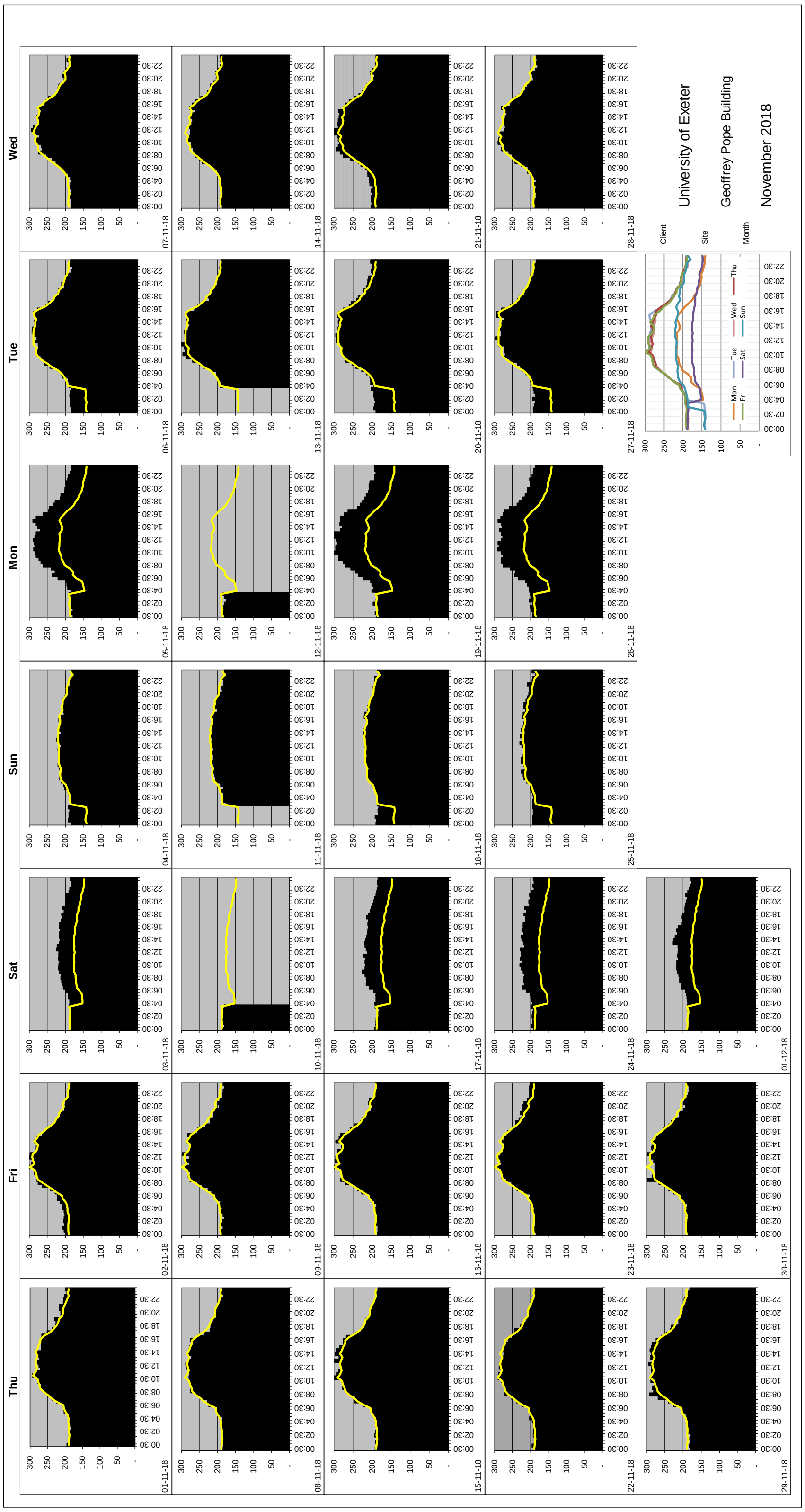
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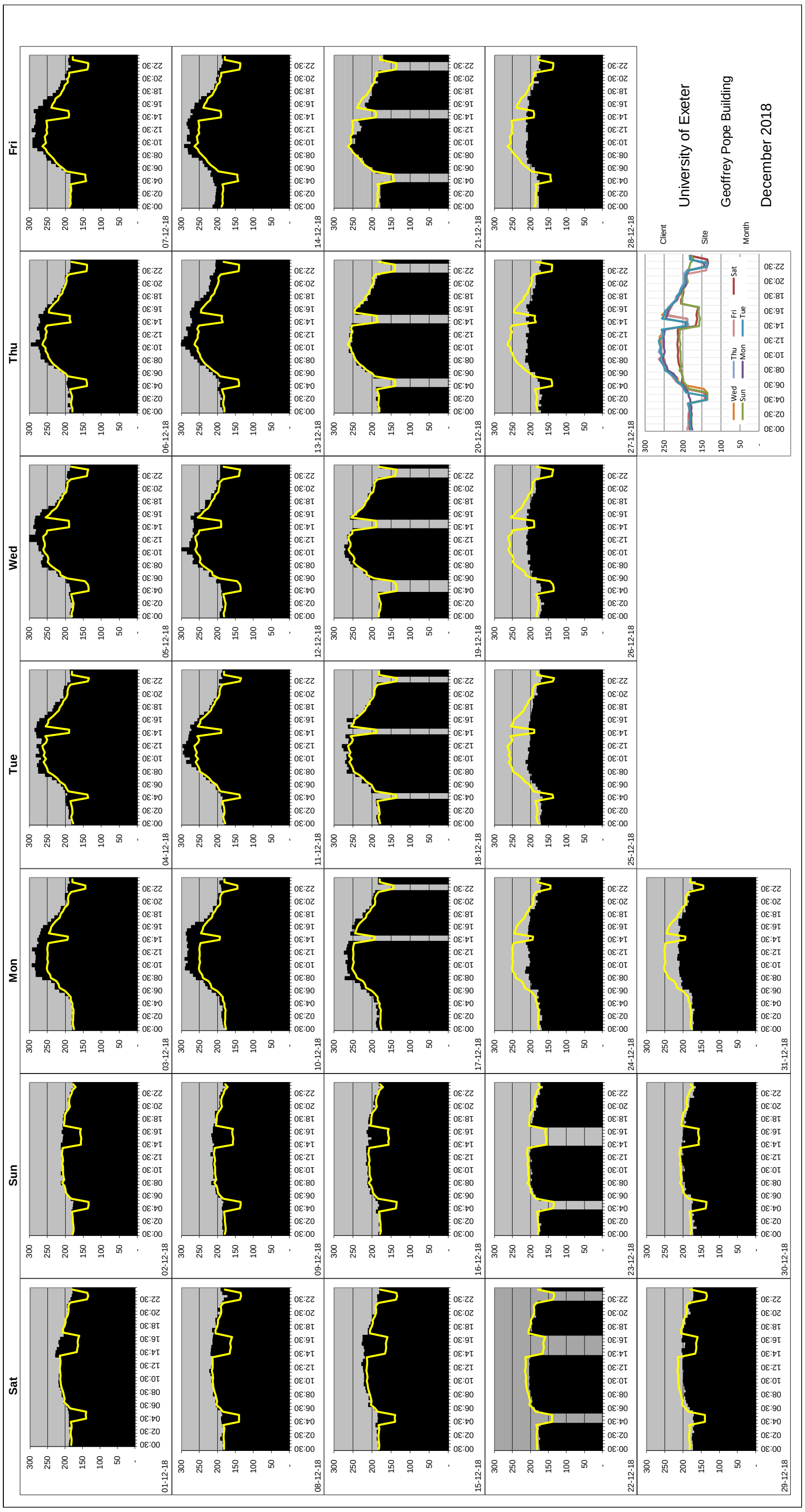

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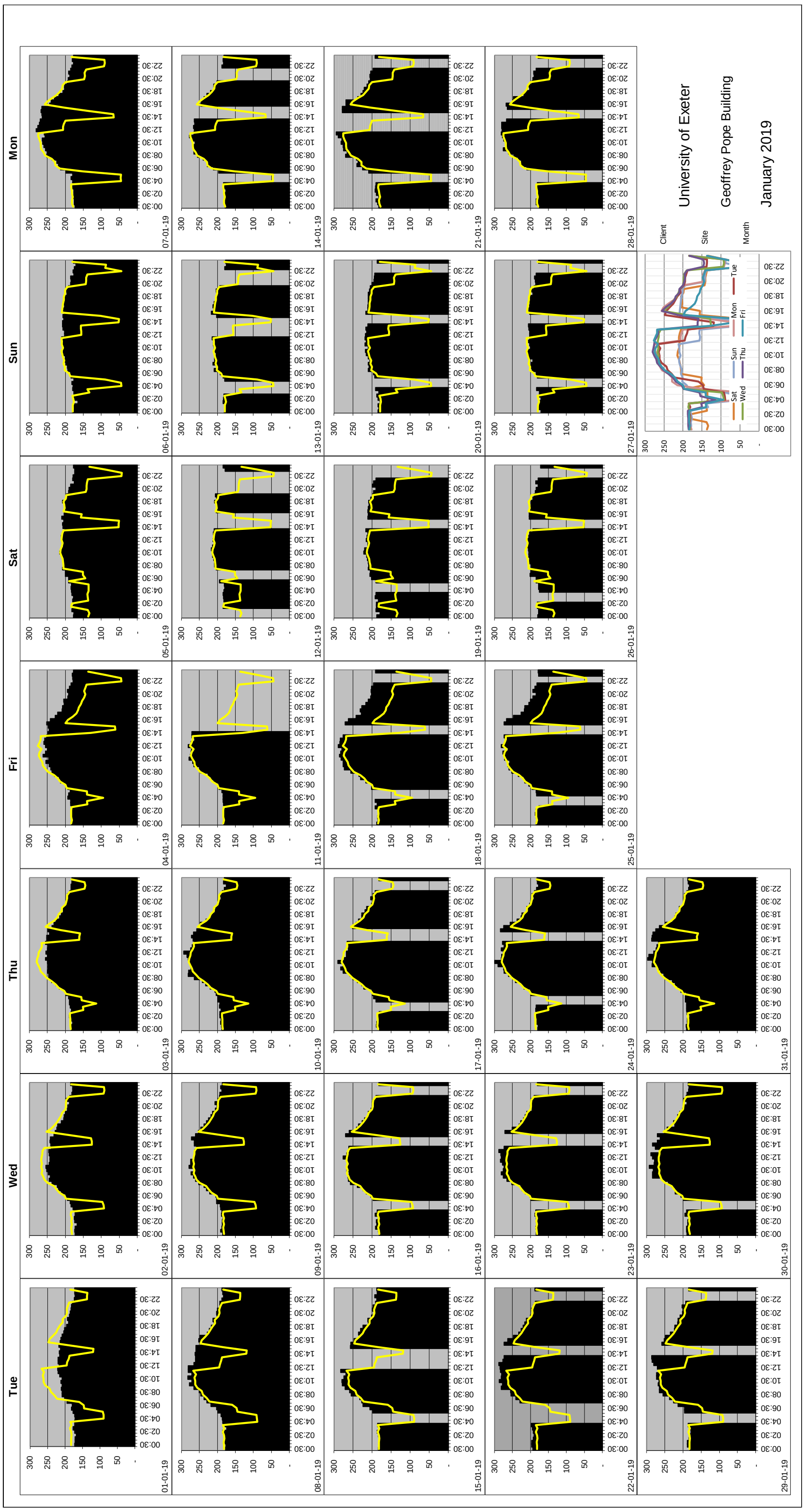
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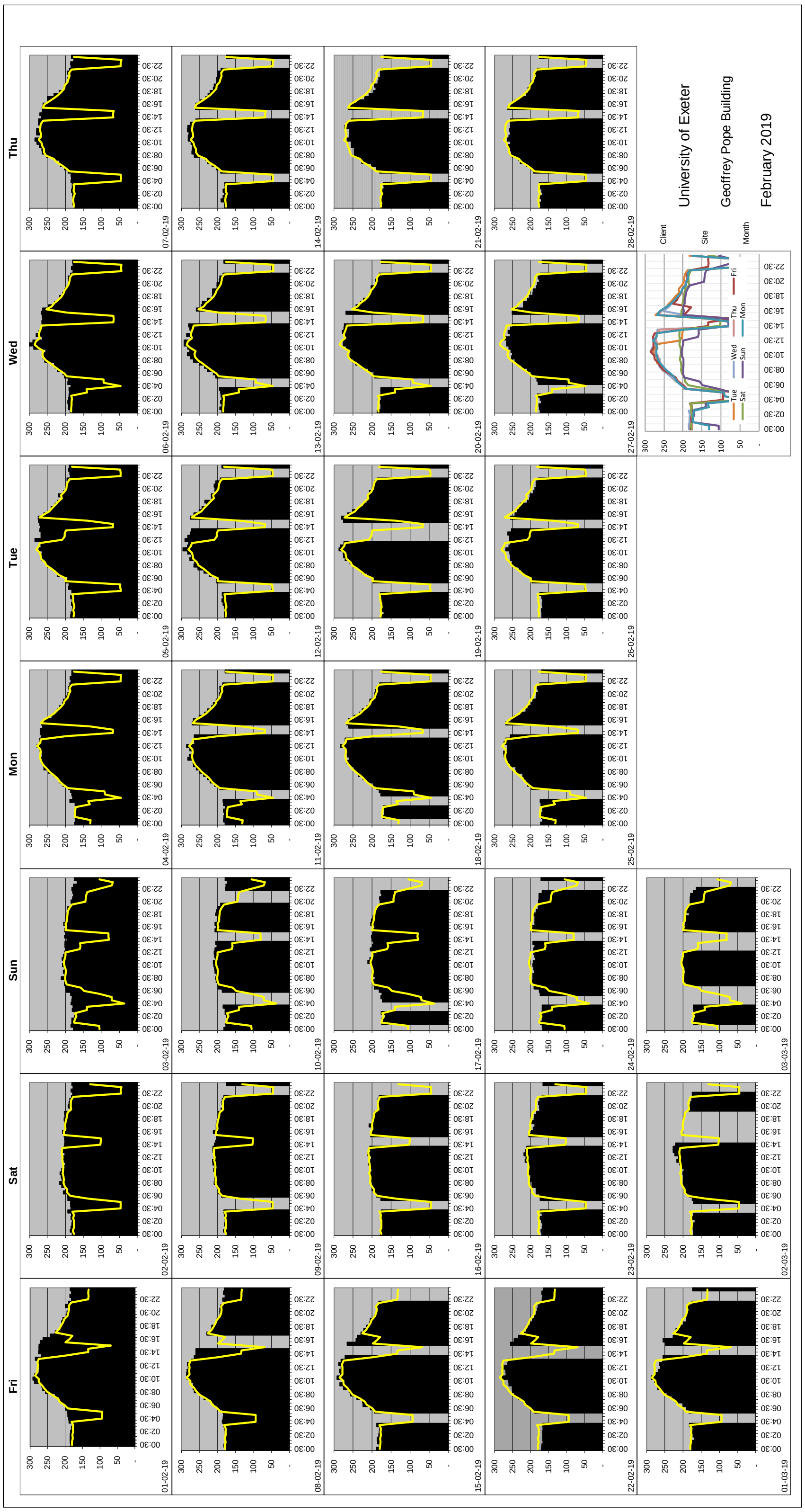
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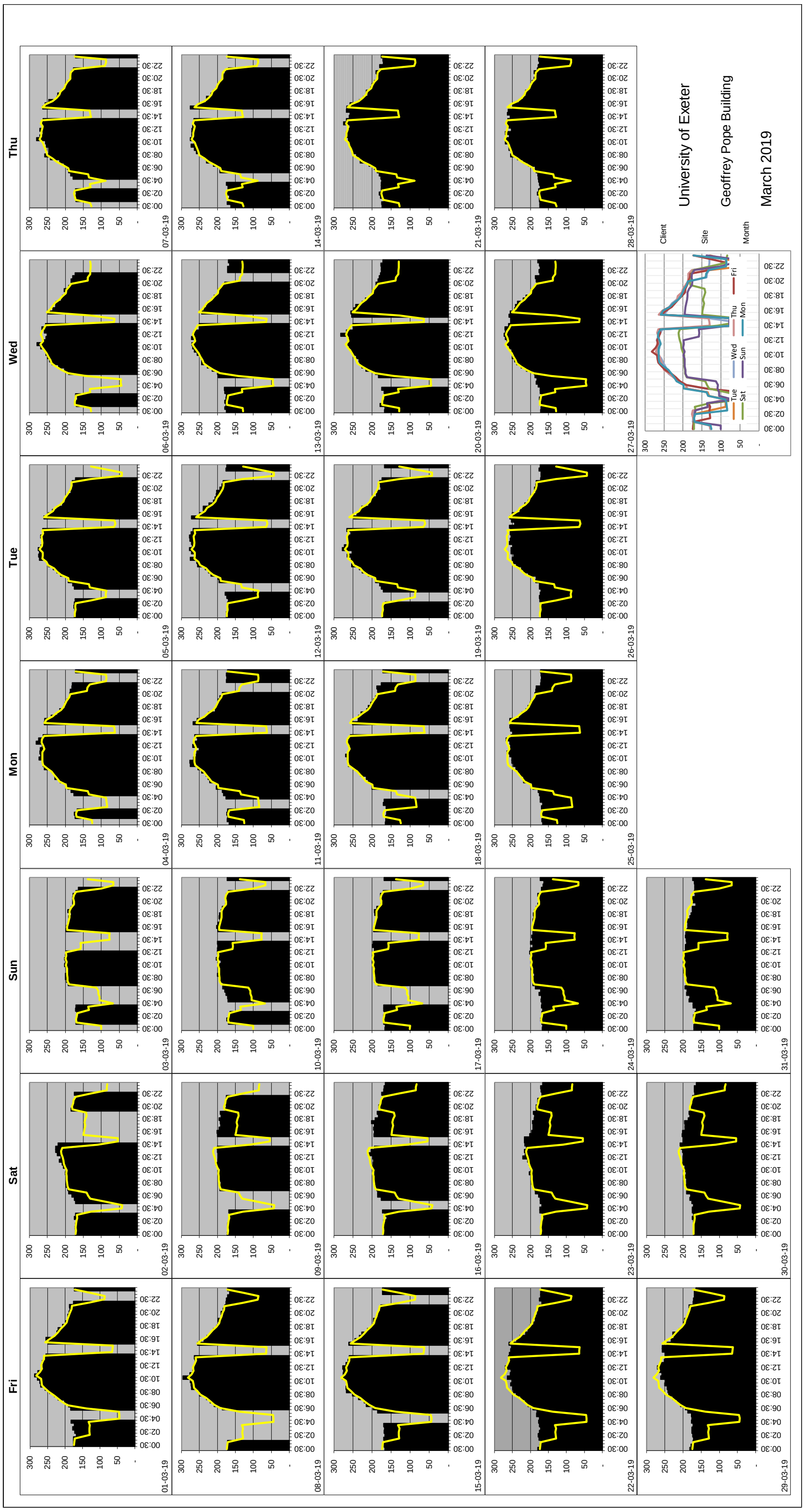
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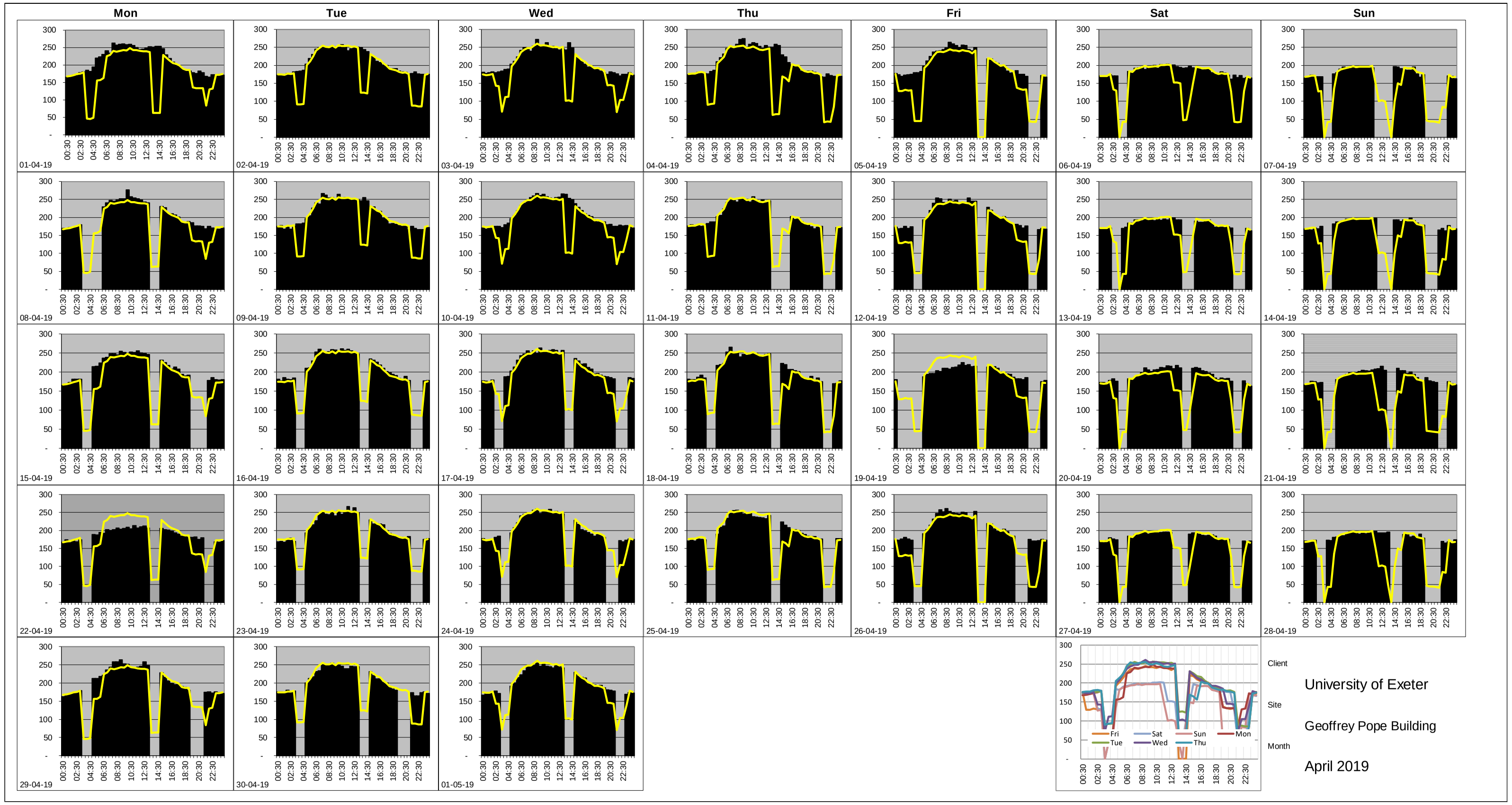
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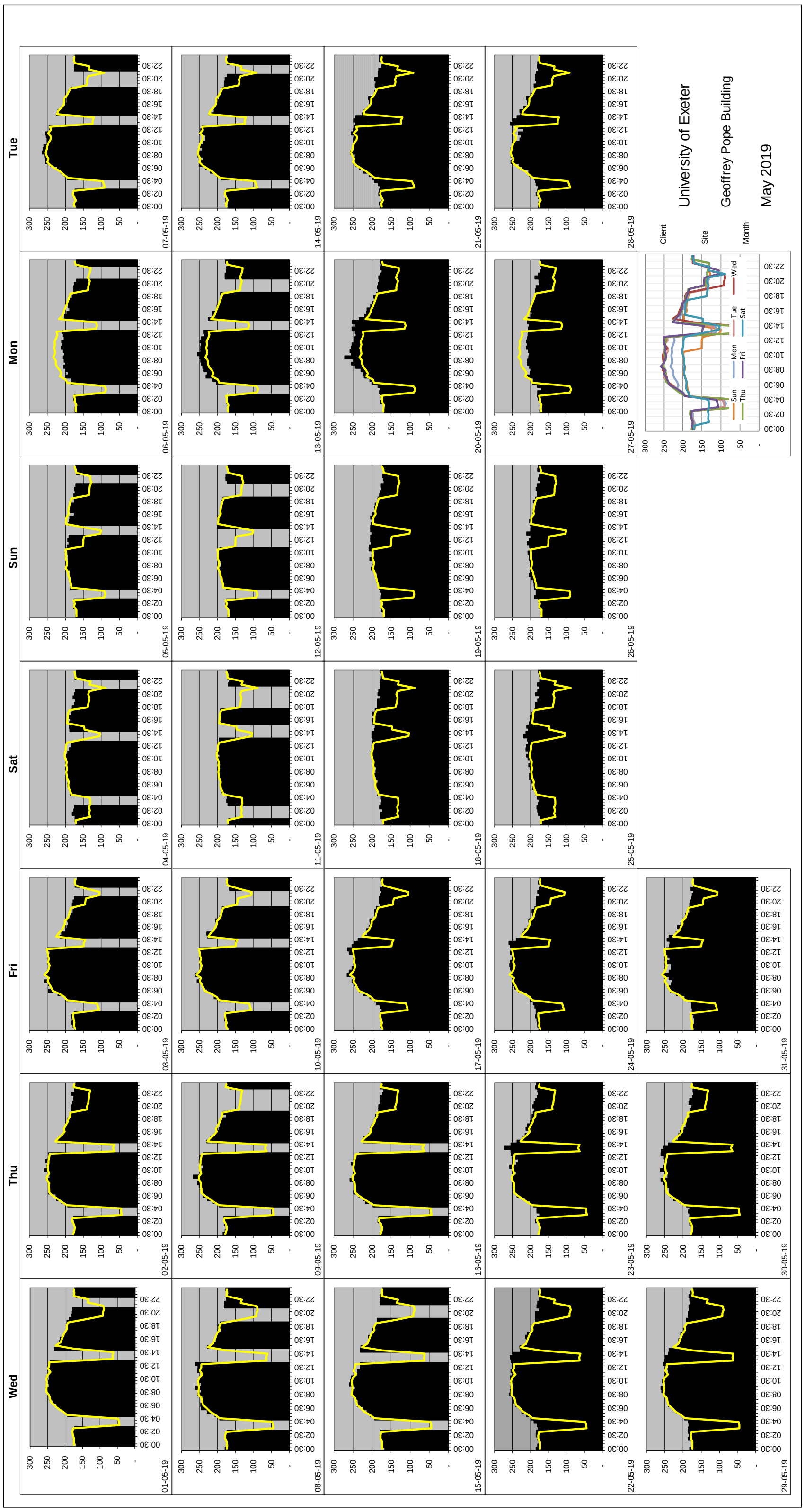
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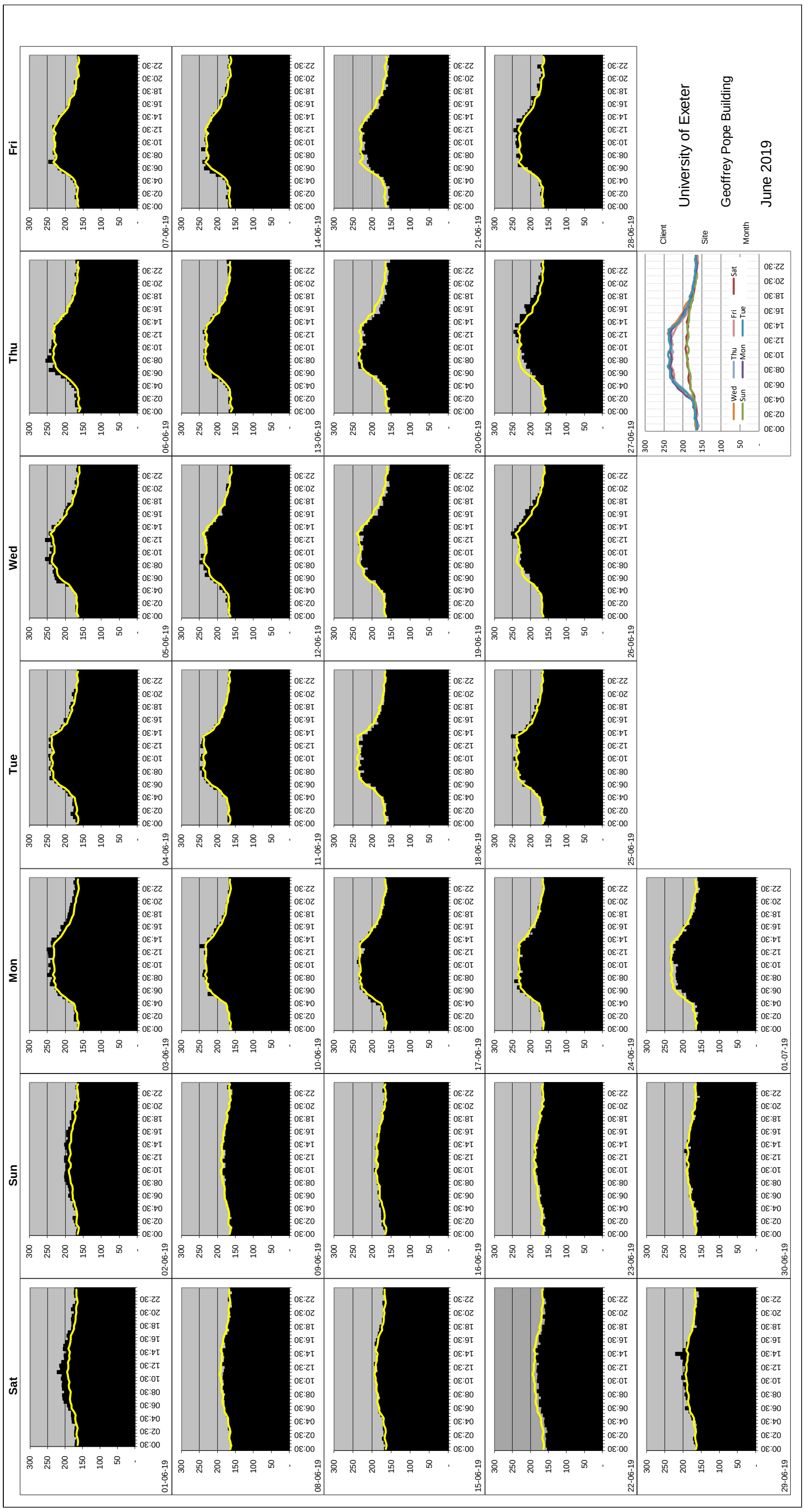
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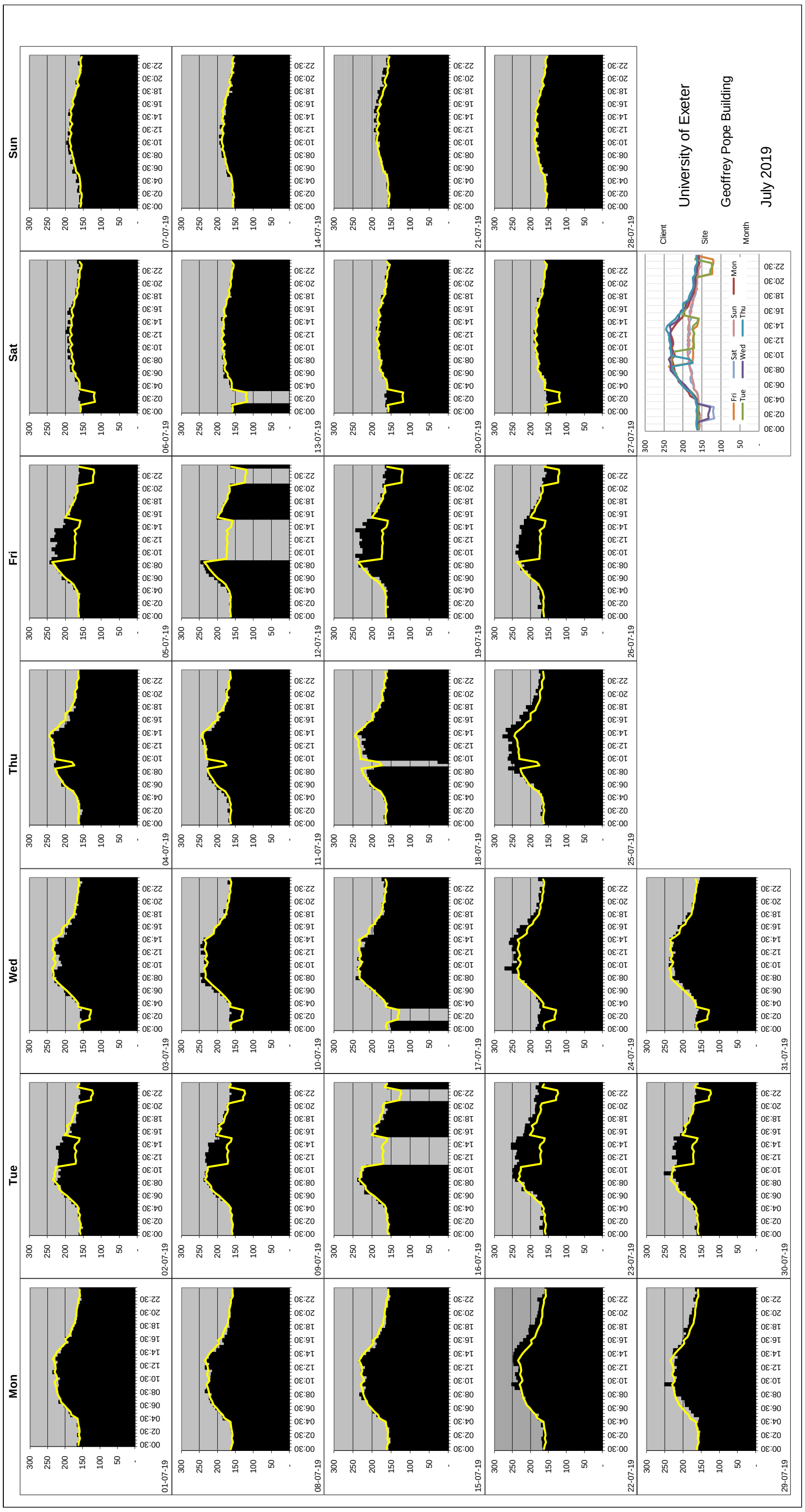
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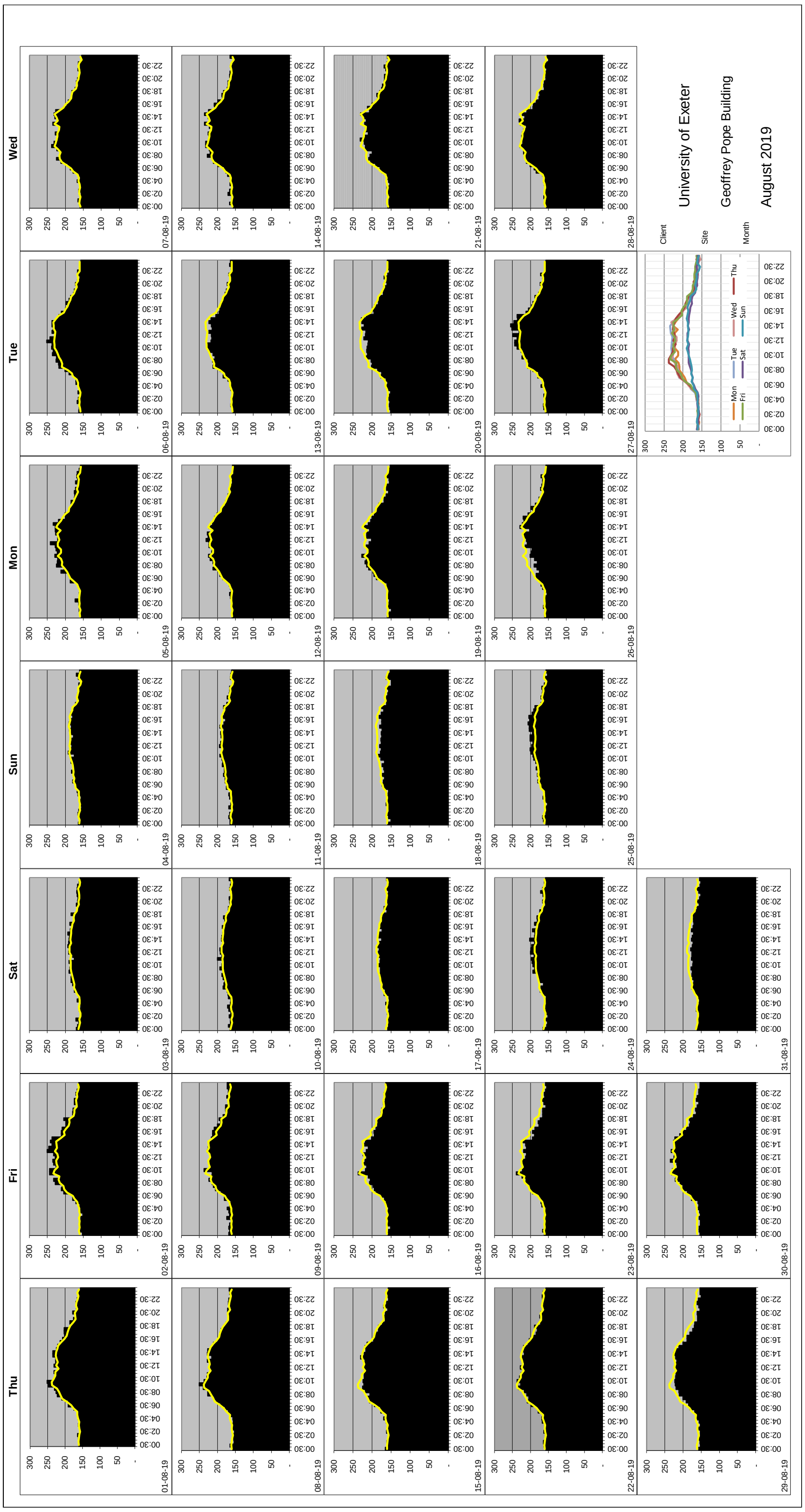
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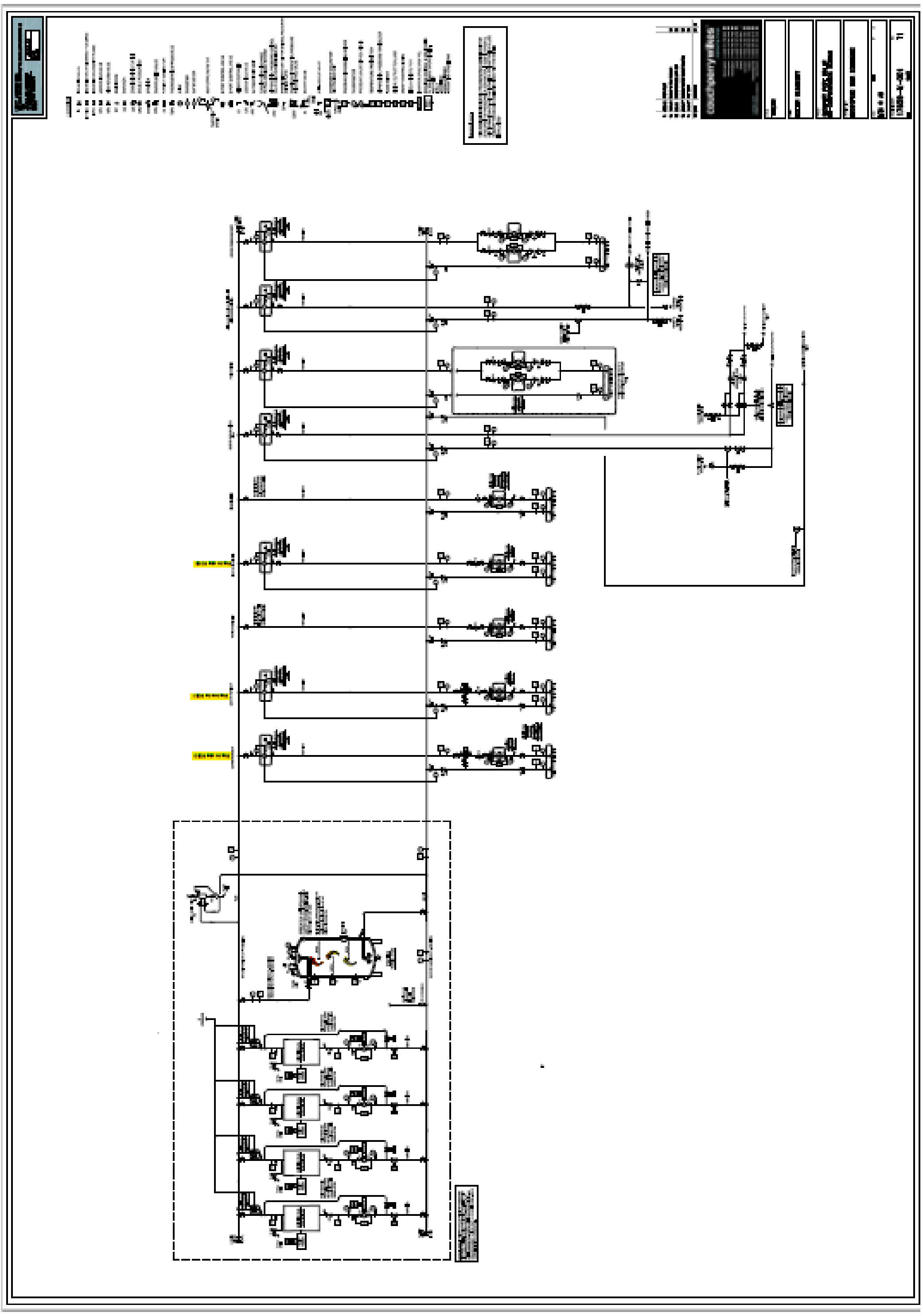
Month
August 2019

11. Appendix 2.0 – Thermal Plant Room Schematic

Schematic added for reference only – drawing size causes loss of clarity so an attached copy is issued as attachment to the report.



12. Contacts

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Email Address:	Andrew.mckenzie@se.com