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Low Carbon Energy Strategy for Shell Technology Centre, Thornton

by The Carbon Advisory Service, May 2009

Revision history

Issue No.	Status	Date	Author	Reason for issue
1	Work-in-progress	24th February 2009	Darren Ball	Client comment
2	Work-in-Progress	10th March 2009	Darren Ball	Added benchmark analysis
3	Work-in-progress	20th March 2009	Darren Ball	Revised high-lighted colours to differentiate questions from incomplete work
4	Work-in-progress	21st April 2009	Darren Ball	Air-handling modelling added
5	Final	25th May 2009	Darren Ball	Completed

Contents

1 Summary

The Carbon Advisory Service (CAS) was commissioned by Shell Real Estate to undertake an energy review of their fuel Technology Centre in Thornton. Research sites are amongst the most difficult to compare against national benchmarks because activities and processes vary widely depending upon the nature of the research. Nevertheless, it is useful to note that the Thornton site uses about two-thirds more electricity and about three times more heat than a “typical” complex research establishment. One of the most important recommendations of this report is to install many more energy check-meters to gain a better understanding of where the energy is being used, at what times and why.

Approximately 80 percent of electricity is used by twenty percent of buildings (if the laboratory buildings 301, 303, 304 and 305 are taken as one), of which the engine test bay building, building 55, is by far the largest.

The energy consumption of the site cannot be explained by the building services systems in operation and therefore must be mainly due to one or a combination of: processes, distribution heat losses or malfunctioning controls.

Because of the energy relationship with the adjacent Stanlow oil refinery, the benefits of the recommendations made in this report are not consistent across energy, carbon and running cost. For instance, because most of the heat is carbon-emission-free low pressure steam, reducing heating consumption in most cases makes no reduction in carbon emissions. And although switching from Stanlow’s site-generated electricity reduces carbon emissions by more than any other single recommendation, the effect would be to <u>increase</u> operating costs (depending upon tariff negotiations).

The results of all the modelling and analysis have led to the following recommendations:

Decommission the medium pressure steam heating and replace with low pressure, saving circa 2,274 tonnes CO_2 and £9,000 per year; recover heat from the exhaust air in laboratory and engine test facilities, saving circa £96,000 per year (but no CO_2 reduction if zero carbon LP steam is used as the source, as elsewhere); improve the lighting and associated controls, saving circa 600 tonnes CO_2 and £40,000 per year; insulate roofs, saving circa £7,000 per year; install optimum start and stop heating routines, saving circa £12,000 per year; repair faulty and missing steam pipework thermal insulation, saving circa £5,000 per year; switch to the national grid for electricity, saving circa 6,200 tonnes CO_2 per year but costing an estimated extra £229,000 per year; overhaul the BMS, saving an estimated 500 tonnes CO_2 and £60,000 per year; install a comprehensive energy monitoring and check-metering system – this makes no direct savings but is likely to help identify the largest potential savings.

Based on the information received, the site currently has an annual electricity consumption of 14,202 MWh with associated CO_2 emissions of 12,540 tonnes and a cost of £752,706. Added to this is 26,704 MWh of mostly carbon-neutral waste steam costing approximately £425,000 with annual CO_2 emissions (from the MP steam) of an estimated 2,274 tonnes. The total for the site is therefore **£1,177,706** and **14,814 tonnes CO_2**.

The expectations for the site, using benchmarks, are around 8,703 MWh electricity (circa £609,000 and 3,655 tonnes CO_2) and 9,210 MWh thermal (£276,000 and 2,440 tonnes CO_2) making a total of **£885,000** and **6,095 tonnes CO_2. The CO_2 emissions are therefore well over double and the costs about one-third higher (£293,000) than expected.**

The implementation of the recommendations will reduce CO_2 emissions by an estimated 9,574 tonnes (to **5,240 tonnes**) but annual energy costs are likely to remain unchanged at around £1,147,706 because the energy cost savings of approximately £229,000 per year are likely to be offset by the higher price of grid electricity. If the switch to grid is justified on the basis of the site's electrical resilience, as has been suggested, then the full **saving of £229,000** can be claimed for energy efficient measures.

The estimated capital expenditure is **£3,845,000** but most of this is not additional cost, but rather expenditure that would otherwise be spent in routine piecemeal replacements over the next five years. Most of this cost is for replacing aged luminaires with low energy modern fittings. Many of the luminaires on site are very old and they will start failing, if they are not doing so already.

The problem with piecemeal replacement is that items are gradually replaced like-for-like, so that over time the whole installation is replaced with a newer clone of the original. Implementing a bulk replacement strategy, or just replacing units to meet a medium- or long-term strategy, allows the building to evolve into a modern replacement for little extra cost.

The table overleaf has been reproduced from Section 10 – Conclusions and Recommendations.

Ref	Recommendation	Benefit	Indicative capex
A	Decommission the medium pressure steam heating and replace with low pressure.	Save c.2,274t.CO_2 and £9,000/year (£22 per tonne)	£50,000
B	Recover heat from exhaust air in laboratory and engine test buildings.	Save c.£96,000 / yr (simple repayment within c. 4 yrs)	£500,000
C	Replace all older light fittings (T8s and T12s) with high efficacy modern fittings incorporating high frequency control gear, photocell control, occupancy sensing and time-schedule switching.	Save c.£40,000 and c.600 t.CO_2 / yr (simple repayment: see note 1)	£2,000,000
D	Apply thermal insulation to all roof spaces to achieve a maximum thermal transmittance (U) value of 0.25 W/m2.K	Save c.£7,000 / yr (simple repayment within c. 15 yrs)	£100,000
E	Install optimum start and stop routines for heating plant.	Save c.£12,000 / yr (simple repayment within c. 4 yrs)	£50,000
F	Undertake a detailed survey of pipework thermal insulation and repair where necessary.	Save c.£5,000 / yr (simple repayment within c. 5 yrs)	£25,000
G	Switch to the national grid for electricity.	Save c.6,200 t.CO_2/yr EXTRA c. £229,000/yr	£nil
H	Undertake a full audit of the BMS and rectify all errors and replace or calibrate all sensors.	Unpredictable – could be extremely high or negligible Estimate 500 t.CO_2 and £60,000/yr	£20,000
I	Install a comprehensive energy sub-metering system, especially in the nine buildings that represent 80 percent of the site's electricity consumption, and establish targets for each sub-meter.	Allows problems and opportunities to be identified – could lead to very high savings.	£100,000
TOTAL		SAVES c.9,574 t.CO_2 /yr and £229,000 (note 2)	£3,845,000

Note 1: The c.£2,000,000 replacement cost and c,£40,000 annual saving from the lighting cannot be used as the basis to calculate a repayment period because these older fittings are approaching the end of their obsolescence period and would otherwise be replaced piecemeal over the next few years. What is being recommended here is to bring the expenditure forward in order to benefit sooner from the energy cost and carbon savings.

Note 2: The energy cost savings are approximately eliminated by the likely higher tariff for grid electricity. However Shell were already considering this for reasons of electrical resilience.

2 Introduction

The Carbon Advisory Service (CAS) was appointed by Shell Real Estate to appraise the site's energy consumption with a view towards reducing carbon emissions and energy costs through cost-effective recommendations. The CAS is cognisant of the fact that all recommendations must be practical and achievable in the context of this being a busy, business-critical operation.

The success criteria for this report are as follows:

- Clear recommendations that can deliver cost-effective carbon and/or energy reductions
- Recommendations that can be incorporated without significant disruption to business
- An auditable path
- Recommendations that do not compromise other important considerations such as health and safety, resilience, longevity and maintenance
- Indicative capital cost estimates sufficient to direct priorities
- Estimated carbon and energy reductions
- Estimated repayment periods

In order to produce a report meeting these criteria, dynamic simulation models have been used to predict the carbon and energy savings arising from the options under consideration. These predictions are only important insofar as they allow the right recommendations to be offered and the right decisions to be taken, and this in turn has influenced the extent of modelling that has been undertaken. The actual energy and carbon savings are subject to variation year-on-year dependent upon weather, behaviour and site activity.

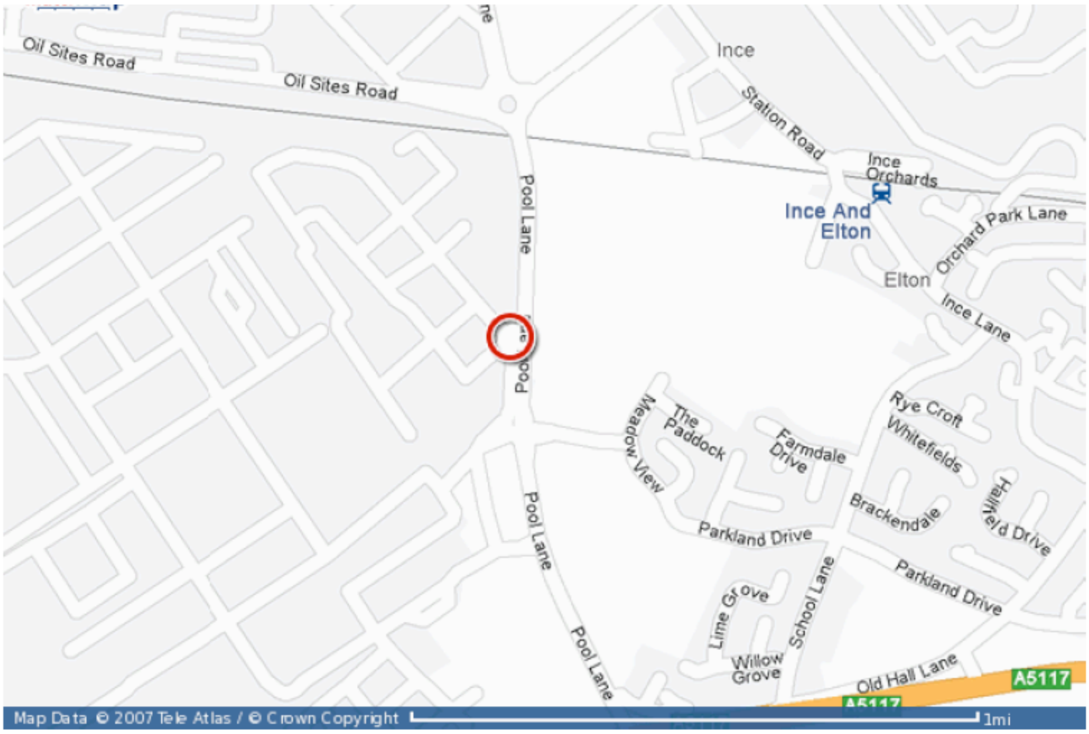
The recommendations in this report do not, and at this stage cannot, constitute completed designs and specifications: this level of detail is for subsequent stages of development and the CAS would be happy to assist if required under additional appointments.

This report is written to be accessible to both the technical and lay person. Where possible technical terms are avoided in favour of plain English, but where this is not possible, supplementary descriptions are given alongside in blue boxes.

The surveyor, Darren Ball, is grateful to David Bowers and Martin Lea for their assistance, both during the two site surveys and in answering emailed questions.

3 General description of the site

The site is the Shell Technology Centre, Thornton, Pool Lane, Ince, Cheshire, CH2 4NU.



If arriving by train, the nearest stations are Ince Orchards or Thornton, but trains to these stations are very infrequent. Trains are much more frequent at nearby Helsby.

Figure 3.1.1 – Aerial View of Site

The site was founded in the 1930s as Shell's centre for aeronautic fuel research, especially for defence purposes. The site comprises 43 buildings with a total nett internal floor area of 32,587m^2 over 65 acres.

Buildings date from a variety of periods, with the earliest being the Ince Building (B50) built around 1930, and the latest being the four fuel laboratories 301, 303, 304 and 305 built around 1996. Buildings also serve a wide range of functions from staff welfare to offices, laboratories and storage.

Most buildings are not air-conditioned and cooling is generally provided only for laboratories and processes. Lighting is generally T8 fluorescent tubes although there are some T5s, T12s and compact fluorescents.

The site is located above a large aquifer and a substantial borehole supplies the whole site's non-potable water demands.

The site is immediately adjacent to Shell's Stanlow oil refinery from where it derives all of its electricity as well as heat off the generators' steam turbines, mostly in the form of low pressure (2.5 Bar) steam but some medium pressure (17 Bar) steam is also used. There is no natural gas to the site and the only gaseous fuel used is LPG for cooking and processes.

Discussions are currently underway about decoupling from Stanlow's electricity supply whilst retaining the steam supply.

Apparently it is uneconomic to return the low pressure steam back to the boiler as condensate so it is simply discharged back to the aquifer. It is also apparently true that all of the low pressure steam has already been put to good use on the Stanlow site before arriving at the Technology Centre. On the basis of these two statements, it is argued that the low pressure steam is carbon-free, although the technology centre is charged for its use.

4 Benchmark analysis

4.1 General

The government publish benchmark data for all sorts of different building types under their 'Action Energy' programme. These provide reasonable guidance on expected annual energy use. By comparing historic energy use against the benchmark it is possible to see if the site is a good, poor or average performer.

The most applicable benchmark data for laboratories is *Energy Consumption Guide 83 – Energy Use in Government Laboratories (ECG 083)*, which divides laboratories into 'simple' and 'complex', of which ready-benchmarks are provided only for 'simple'.

For 'complex' laboratories, ECG083 recommends three possible approaches: approach one – use benchmarks for 'simple' laboratories plus sub-metered loads for specific processes; approach two – use historic data; approach three - either use the historic data from approach two but deduct any no-cost savings that could be achieved (top-down), or use the 'simple' benchmark data and add an allowance for specific processes (bottom-up).

With the information currently available, only approach two (historic) is possible, but this approach cannot indicate whether the historic consumption is high or low and is therefore meaningless for the purposes of this report. Approach three needs to be followed, but this is covered in subsequent sections of this report.

Notwithstanding the above, ECG083 does state that complex laboratories will typically fall between 500 and 1,000 kWh per square metre per year, as below:

> **3.1 BENCHMARKS FOR COMPLEX LABORATORIES**
>
> The complex and unique characteristics of Type 2 laboratories means that it is impractical to formulate meaningful generic benchmark figures against which their performance can be measured. Their total energy consumption will typically lie between 500-1,000 kWh/m^2 per year, but little can be drawn from this fact due to the diverse range of equipment and activities that give rise to these higher consumptions. Alternative 'site specific' approaches are required to benchmark these complex laboratories. Three options are described below, the most appropriate for each site will depend on local circumstances.

Another authoritative source, The Chartered Institution of Building Services Engineers' (CIBSE), Guide F – *Energy Efficiency in Buildings*, Table 20.20, suggests 669 kWh/m^2 per year for space heating, 538 kWh/m^2 per year for other building related uses and 346 kWh/m^2 per year for process loads, making a total of 1,553 kWh/m^2.

Guide F does not differentiate between fuel and electricity, but a reasonable assumption is that heating is fuel and the remainder is electricity. Therefore, for the purpose of this section and to get an indication of performance, the benchmarks for laboratories shall be 669 kWh/m^2 per year for fuel and 884 kWh/m^2 per year for electricity. However these comparisons cannot, in themselves, be taken as proof of a well or poorly performing site.

4.2 Electrical

As far as possible, benchmarks have been related to the electricity sub-meters so that individual buildings can be compared as well as the site as a whole. Table 4.2.1 below was supplied by Shell in the form of an Excel spreadsheet file: *STCT space june 08.exl.*

Building	Floor area, m^2					
	Circulation	Laboratory	Offices	store	other	total
306			8	57	192	256
305	1109	809	427	32	62	2438
304	819	1120	852	67	68	2926
303	957	1009	990	8		2965
301	754	760	1303	73	70	2959
250	7	11	81		11	110
242					76	76
160	162	46	81	374	49	713
110	17		90	10	16	134
106				112	0	112
105	76		7	61	412	557
104	293		796	701		1790
103					43	43
102	898	343	216	207	71	1734
101			586	43		629
99	262		81		579	921
98					71	71
97	286	296	12	83	492	1168
95	0	1,215	550			1765
90	156		236			392
71	0				43	43
68	0				195	195
67	0				190	190
66	0				879	879
62	912		1120	297		2329
58	47		30	48	451	577
56	424			272	587	1283
55	466		70		702	1238
49	1332	23	2319	155	415	4244
40	344		22	103	1262	1731
38	823		2271		253	3347
35					117	117
30				126		126
29					31	31
27		3	487	49	473	1012
24	259		203	497	485	1445
20					71	71
19	51		48			99
14	11				156	167
10	28				164	192
9	70		81	64	1037	1252
1&2	47			539	286	872
TOTAL	**10,609**	**5,634**	**12,968**	**3,976**	**10,008**	**43,196**

Nett internal **32,587** m^2
Gross minus circulation

Table 4.2.1 – Floor Areas by Building and Usage (source: Shell Real Estate)

Metered annual electricity usage was provided by Shell in the form of an Excel spreadsheet file: *Elect Consump End DEC 08.exl.*

The two spreadsheets have been merged together in table 4.2.2 below to give annual electricity usage relative to floor area, sorted in descending order and grouped in terms of: top 80 percent, top 90 percent and lower 10 percent.

Annual Meter Reads (1)				Building	Floor area, m^2 (2)						
Building	Main activity	MWh	kWh/m²		Circ	Labs	Offices	store	other	total	
55	Eng. Test bays	2621	2117	55	466		70		702	1238	Top 80 Percent
303	Lab (fuels)	1892	638	303	957	1009	990	8		2965	
301	Lab (fuels)	1553	525	301	754	760	1303	73	70	2959	
305	Lab (fuels)	1341	550	305	1109	809	427	32	62	2438	
304	Lab (fuels)	1386	474	304	819	1120	852	67	68	2926	
97	Labs	1064	911	97	286	296	12	83	492	1168	
99, 105	Rolling road	535	362	99 + 105	338	0	88	61	991	1478	
40	Restaurant	493	285	40	344		22	103	1262	1731	
56	Eng. Test bays	487	380	56	424			272	587	1283	
49	Office	469	111	49	1332	23	2,319	155	415	4244	Top 90 Percent
27		335	331	27		3	487	49	473	1012	
160	Office & storage	311	437	160	162	46	81	374	49	713	
101 & 104	Archives	272	113	101+ 104	293	0	1,382	744	0	2419	
95	serves 97	0	0	95	0	0	0			0	Last 10 percent
90 & 102	Fuels lab & offices	235	111	90 + 102	1054	343	451	207	71	2125	
62	Offices	211	90	62	912		1120	297		2329	
24	Offices & w/shops	195	135	24	259		203	497	485	1445	
9	Garage & car wash	88	71	9	70		81	64	1037	1252	
38		75	22	38	823		2271		253	3347	
19	Office	62	624	19	51		48			99	
10	Garage annex	44	229	10	28				164	192	
306	Garage	12	46	306			8	57	192	256	
14	Garage annex	0.1	1	14	11				156	167	
1 & 2	W/shop & Gym	0.0	0	1&2	47			539	286	872	
TOTAL		13,681		TOTAL	10,072	4,409	12,146	3,680	7,112	37,418	

Table 4.2.2 - Floor Areas and Annual Electricity Usage, Ranked in Descending Order

Ref. 1. Elect Consump End DEC 08.exl

Ref. 2. STCT space june 08.exl.

Ref. 3. Loads for B95 have been added to B97, and loads for 300 have been apportioned to 301, 303, 304 and 305.

Ref. 4. B91 and B100 are not included because they are plantrooms serving other buildings.

Ref. 5. B56 is nearly empty but still one of the most significant loads.

Ref. 6. B27 meter has apparently been proved inaccurate from calculations and deductions from other meters.

Ref. 7. B19 has a suspect meter. The floor area is low but it also serves the forecourt blending area.

Ref. 8. B8 is empty but to be fully refurbished as an open plan office.

Ref. 9. B306 is empty.

Ref. 10. B1 is an infrequently used joinery workshop.

Building 300 is the energy centre serving laboratories 301, 303, 304 and 305. Its electricity usage has therefore been divided by the buildings it serves in proportion to their respective floor areas, as below:

APPORTIONING ENERGY CENTRE 300 OVER 301, 303, 304 & 305

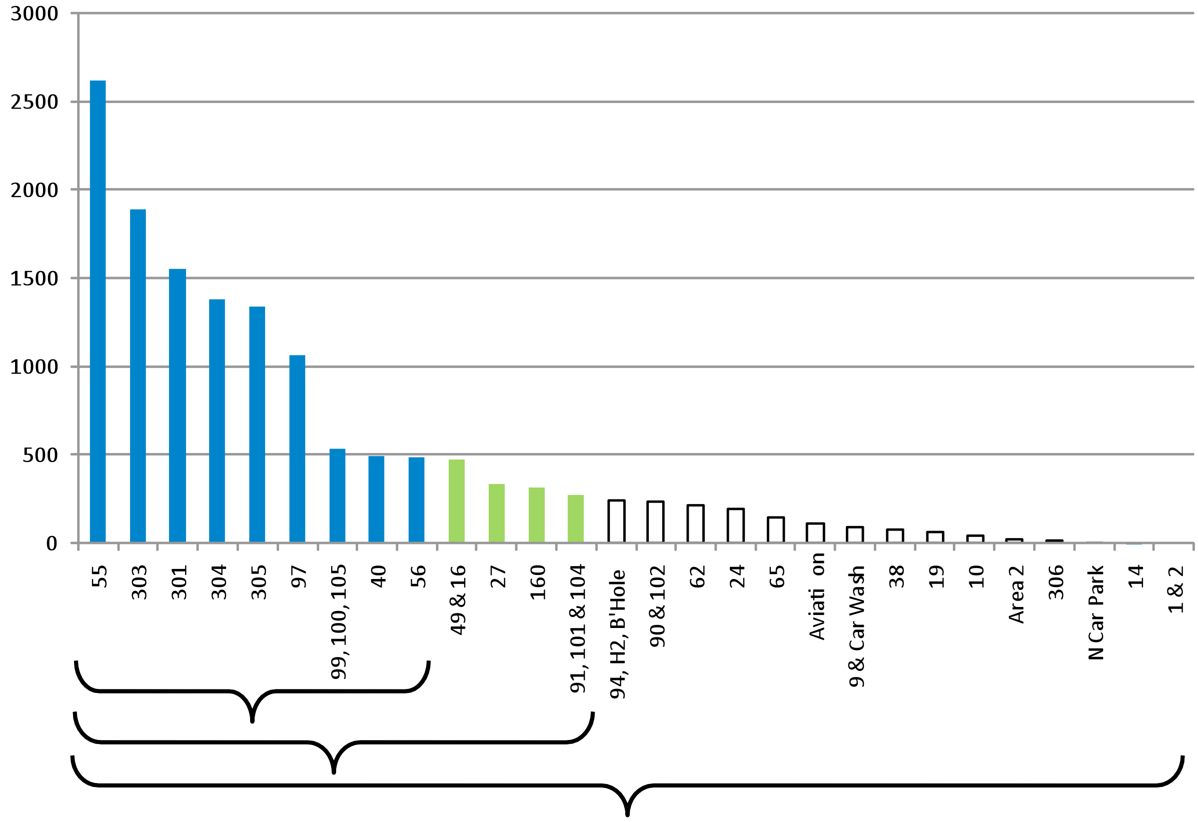
300 seves 301, 303, 304 and 305

300 = 1604 MWh

Total area, 301, 303, 304 & 305 = 11288 m^2

Bldg Ref	Apportionment			Bldg MWh	Total MWh
	m^2	fract.	MWh		
301	2959	26%	420	1133	1553
303	2965	26%	421	1471	1892
304	2926	26%	416	970	1386
305	2438	22%	346	994	1341
Total	**11288**	**100%**	**1604**		

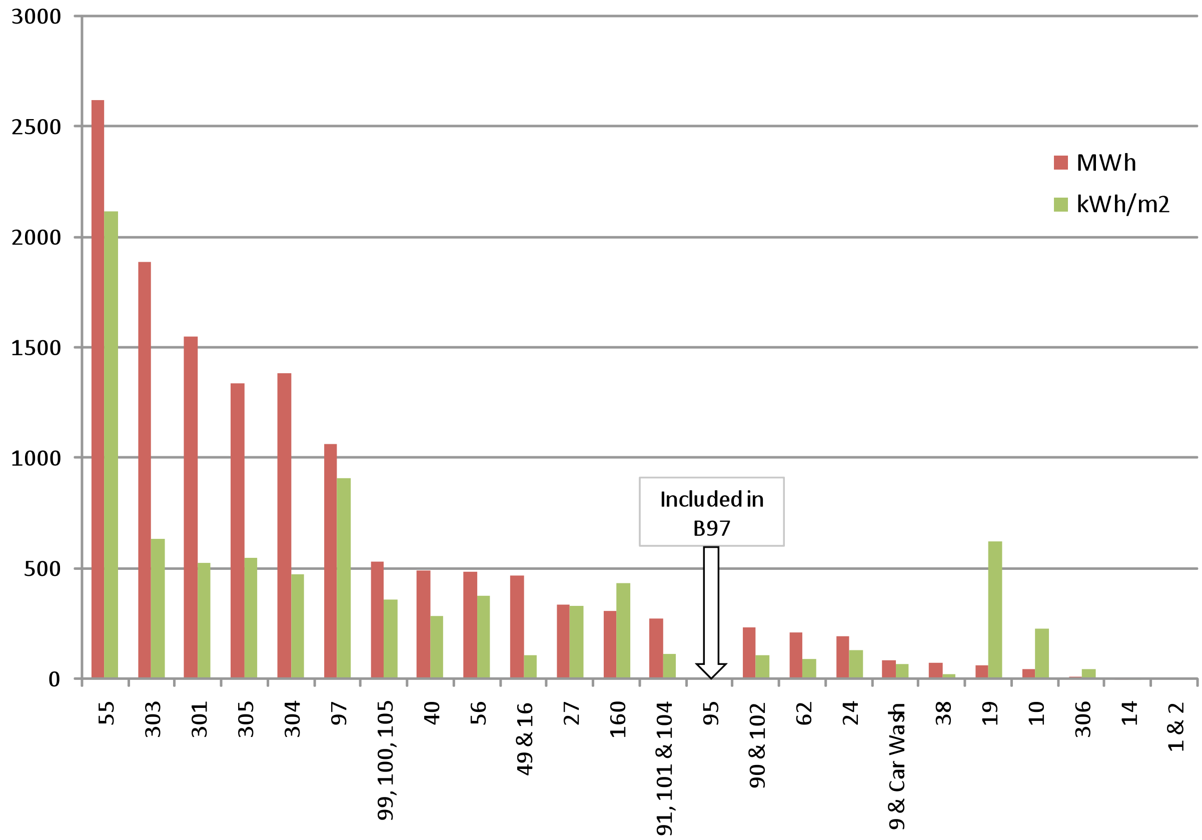
Table 4.2.2 is presented graphically in graph 4.2.1 below:



Graph 4.2.1 – MWh per Year, by Building Reference, Ranked in Descending Order of Total Usage, All Buildings

As a rule-of-thumb, 20 percent effort generates 80 percent of savings. Graph 4.2.1 above shows that 80 percent of emissions arise from nine loads out of 30. However buildings 301, 303, 304 and 305 are identical other than floor area, so really they can be considered as one. This means that 80 percent of consumption arises from six loads out of 30, or 20 percent – just as the rule-of-thumb suggests.

Most effort shall therefore be directed at the top 80 percent of loads. The next 10 percent are interesting because they include some different building types, such as offices, and therefore will be assessed to the extent that information is readily available. The lower decile, comprising half the load sources, will not be specifically targeted but some will benefit from the general recommendations given in Section 6 – Buildings Energy Strategy, and from recommendations arising from the analysis of the top 80 to 90 percent.



Graph 4.2.2 – MWh and KWh/m^2 per Year, by Buildings Ranked in Descending Order of Total Usage, All Buildings

Graph 4.2.2 above is similar to graph 4.2.1 but also shows annual energy use per square metre. In general, those buildings with the highest overall energy use also have the highest specific energy use; the most notable exception being building 19, but this is only a very small office and control room and its overall use is too low to have any significant affect on the site as a whole. Its specific energy use is so high because it also serves a forecourt, the floor area of which is not included in the table.

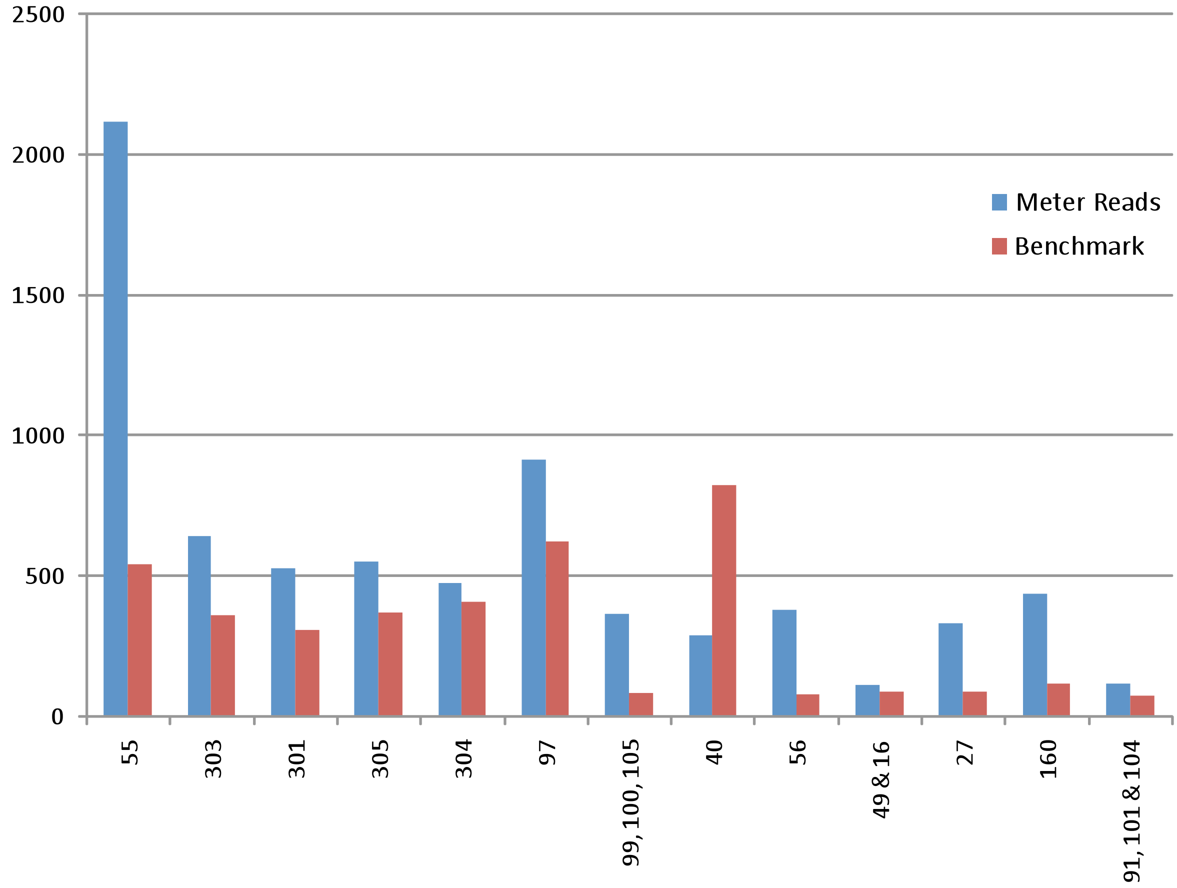
	kWh/m² per year		
	Oil/Gas/Coal	**Electricity**	**Total**
Offices, natural vent, cellular			
Typical	151	54	205
Good Practice	79	33	112
Offices, natural vent, open plan			
Typical	151	85	236
Good Practice	79	54	133
Offices, air conditioned			
Typical	178	226	404
Good Practice	79	128	225
Workshops			
Typical	244	80	324
Good Practice	175	29	204
Motor transport facilities			
Typical	353	33	386
Good Practice	317	20	337
Stores/warehouses, occupied			
Typical	229	47	276
Good Practice	187	34	221
Stores/warehouses, unoccupied			
Typical	76	7	83
Good Practice	54	3	57

Table 4.2.3 - Benchmarks for Non-Laboratory Buildings on Laboratory Site (ECG083's table 5.1)

Annual Meter Reads			Floor Areas, m^2							Benchmark, kWh/m^2 per Annum						B/mark
Bldg	**kWh/m^2**	**MWh/yr**	**Bldg**	**Circ**	**Labs**	**Offices**	**Store**	**Other**	**Total**	**Circ**	**Labs**	**Offices**	**Store**	**Other**	**Mean**	**MWh/yr**
55	2,117	2,621	55	466	0	70	0	702	1,238	85	884	85	47	884	538	666
303	638	1,892	303	957	1,009	990	8	0	2,965	85	884	85	47	884	357	1,058
301	525	1,553	301	754	760	1,303	73	70	2,959	85	884	85	47	884	308	911
305	550	1,341	305	1,109	809	427	32	62	2,438	85	884	85	47	884	370	901
304	474	1,386	304	819	1,120	852	67	68	2,926	85	884	85	47	884	408	1,195
97	911	1,064	97	286	296	12	83	492	1,168	85	884	85	47	884	621	725
99, 100, 105	362	535	99 + 105	338	0	88	61	991	1,478	85	884	85	47	85	83	123
40	285	493	40	344	0	22	103	1,262	1,731	Benchmark applies to gross floor area					820	1,419
56	380	487	56	424	0	0	272	587	1,283	85	884	85	47	85	77	99
49 & 16	111	469	49	1,332	23	2,319	155	415	4,244	85	884	85	47	85	88	373
27	331	335	27		3	487	49	473	1,012	85	884	85	47	85	86	87
160	437	311	160	162	46	81	374	49	713	85	884	85	47	85	117	83
91, 101 & 104	113	272	101+ 104	293	0	1,382	744	0	2,419	85	884	85	47	85	73	177
Total		12,760														7,819
At 100%		14,202													Pro rated	8,703

Table 4.2.4 – Meter Readings against Benchmark Data

Benchmarks are generally taken from ECG083, table 4.2.3 above. Laboratory benchmarks were taken from CIBSE Guide F table 20.20, as previously detailed. The benchmark for the restaurant was taken from CIBSE Guide F, table 20.1 - fast food restaurants. Table 4.2.4 is reproduced graphically in graph 4.2.3 below.



Graph 4.2.3 – Meter Reads against Benchmarks, by Buildings Ranked in Descending Order of Total Usage, Excluding Lower Decile.

Only in building 40 (restaurant) is the metered energy less than the benchmark, but this is a comparatively minor load. Most of the major loads exceed their benchmarks by significant margins, especially building 55 – engine test bay.

As previously explained, there are no reliable benchmarks for complex laboratories, and certainly none for engine test bays. Graph 4.2.3 cannot be interpreted as showing that the laboratories and engine test bay are inefficient as there might be very good reasons for their high energy use, but it is showing that the laboratories are using much more energy than most complex laboratories and that the electricity consumption for the engine test bay is vast.

Overall the site has an annual electricity consumption of 14,202 MWh and a pro-rated benchmark total of 8,703 MWh, suggesting that the site is using almost two-thirds more electricity than a typically performing campus of this type. It is necessary to understand why these loads are so large and whether they can be justified by the site's activities.

4.3 Thermal

Less detailed analysis is possible for the thermal energy usage because there is only one meter for the whole site. Benchmark data has been applied to the floor areas supplied by Shell, as indicated in table 4.3.1 below. Benchmarks were generally taken from ECG083, table 4.2.3. Laboratory benchmarks were taken from CIBSE Guide F table 20.20, as previously detailed. The benchmark for the restaurant was taken from CIBSE Guide F, table 20.1 - fast food restaurants.

Bldg No.	Main Activity	Floor area, m^2						Benchmark, kWh/m^2 per Annum						Annual MWh
		Circ	Labs	Offices	Store	Other	Total	Circ	Labs	Offices	Store	Other	Mean	
306				8	57	192	256	151	669	151	76	151	134	34
305	Labs (fuels)	1,109	809	427	32	62	2,438	151	669	151	76	151	322	785
304	Labs (fuels)	819	1,120	852	67	68	2,926	151	669	151	76	151	348	1,017
303	Labs (fuels)	957	1,009	990	8		2,965	151	669	151	76	151	327	970
301	Labs (fuels)	754	760	1,303	73	70	2,959	151	669	151	76	151	282	835
250		7	11	81		11	110	151	669	151	76	151	202	22
242						76	76	151	669	151	76	151	151	11
160	Office & store	162	46	81	374	49	713	151	669	151	229	151	226	161
110		17		90	10	16	134	151	669	151	76	151	145	19
106					112	0	112	151	669	151	76	151	76	8
105	Rolling road	76		7	61	412	557	151	669	151	76	151	143	80
104	Archives	293		796	701		1,790	151	669	151	76	151	122	218
103						43	43	151	669	151	76	151	151	6
102		898	343	216	207	71	1,734	151	669	151	76	151	245	424
101	Archives			586	43		629	151	669	151	76	151	146	92
99	Rolling road	262		81		579	921	151	669	151	76	151	151	139
98						71	71	151	669	151	76	151	151	11
97	Labs	286	296	12	83	492	1,168	151	669	151	76	151	277	323
90		156		236			392	151	669	151	76	151	151	59
71		0				43	43	151	669	151	76	151	151	7
68		0				195	195	151	669	151	76	151	151	29
67		0				190	190	151	669	151	76	151	151	29
66		0				879	879	151	669	151	76	151	151	133
62		912		1,120	297		2,329	151	669	151	76	151	141	329
58		47		30	48	451	577	151	669	151	76	151	145	84
56		424			272	587	1,283	151	669	151	76	151	135	173
55	Eng. test bays	466		70		702	1,238	151	669	151	76	151	151	187
49	Office	1,332	23	2,319	155	415	4,244	151	669	151	76	151	151	641
40	Restaurant	344		22	103	1,262	1,731	Benchmark is based on gross floor area					670	1,160
38		823		2,271		253	3,347	151	669	151	76	151	151	505
35						117	117	151	669	151	76	151	151	18
30					126		126	151	669	151	76	151	76	10
29						31	31	151	669	151	76	151	151	5
27			3	487	49	473	1,012	151	669	151	76	151	149	151
24	Office & w/shop	259		203	497	485	1,445	151	669	151	76	151	125	181
20						71	71	151	669	151	76	151	151	11
19	Office	51		48			99	151	669	151	76	151	151	15
14		11				156	167	151	669	151	76	151	151	25
10		28				164	192	151	669	151	76	151	151	29
9	Car Wash	70		81	64	1,037	1,252	151	669	151	76	151	147	184
1&2		47			539	286	872	151	669	151	76	151	105	91
TOTAL		10,609	4,419	12,418	3,976	10,008	41,431							9,210

Table 4.3.1 – Use of Benchmarks to Estimate Annual Thermal Demands

According to table 4.3.1, the annual demand for heat would typically be 9,210 MWh. According to Shell's Energy Management Plan, the annual demand for steam is 26,704 MWh. On this basis, the site is using almost three times more heat than typically expected.

As with the electrical benchmarks, there are no reliable benchmarks for complex laboratories and therefore table 4.3.1 cannot be used as evidence of inefficiency, but it does show that the site uses much more heat than would be typically expected from a campus of this type. As part of this assessment, it is necessary to establish whether or not this high usage is adequately explained by the on-site activities or if there are savings to be made.

5 Site-wide energy strategy

5.1 Existing

The existing site takes all of its electricity from the adjacent Stanlow oil refinery. The electricity is produced by electrical generators which are powered from steam turbines, and the steam to drive the turbines is generated by oil-fired steam boilers. The water supply for the steam is drawn from the aquifer via a borehole.

Steam leaves the turbine at 17 Bar and used to provide heat for buildings and processes, after which the steam leaves at 2.5 Bar. This lower pressure steam is then passed on for further space heating purposes before being discharged into the aquifer from where it came.

Most of the Technology Centre's heat demand is supplied by low pressure steam from Stanlow, however buildings 301, 303, 304 and 305 are supplied with medium pressure steam.

The low pressure steam will have already provided two useful functions before arriving at the Technology Centre and could therefore be regarded as carbon-free. It is not however cost-free and Stanlow levy a charge of between £5.00 and £18.00 per tonne. At the time of writing the charge is £10.63 per tonne, equating to approximately 1.56 p/kWh.

The MP steam has a calculated carbon factor of $0.279\ kgCO_2/kWh_{heat}$ (refer to sub-section 5.2.3) and a current charge of £11.39 per tonne, equating to approximately 1.67 p/kWh.

Originally Stanlow provided the Technology Centre with power autonomy from the national grid, however Stanlow's electricity needs have grown over time, so that now when there's a grid failure Stanlow shed their non-essential circuits, one of which is the Technology Centre.

There is no benefit for the Technology Centre being generator-backed if they're isolated from the generator each time there's a grid failure. In fact this is the worst of both worlds because the Technology Centre loses power if either the grid or the Stanlow plant fails. For this reason the Technology Centre is currently considering a permanent grid connection and its own standby generators for essential circuits.

5.2 Options

The existing strategy offers three significant opportunities for improvement; a) stop using medium pressure steam in buildings 301, 303, 304 and 305, b) use low pressure steam to provide cooling through absorption or desiccant cooling, c) opt for a permanent grid connection because the national grid has lower carbon-emission than the on-site, oil-fired, steam-driven generators.

These options are considered below.

5.2.1 Stop using medium pressure steam in 301, 303, 304 & 305

If the low pressure (LP) steam is a waste by-product with no carbon footprint, why use medium pressure (MP) steam for low grade applications? According to information received from Shell, MP steam was introduced in the 1990s because historically the LP steam was of poor quality (not fully vaporised) and this in turn had a deleterious effect on valves. Its poor quality also precluded its use in humidification systems, although since the 1990s the quality of the LP steam has improved and the need for humidification has been removed from the only buildings served with MP steam (301, 303, 304 and 305).

From a technical and cost viewpoint the MP steam makes good sense: all of the problems with poor quality avoided for a unit rate just seven percent higher. But from a carbon view point, the LP steam is very attractive.

The MP steam is converted into Medium Temperature Hot Water (MTHW) for use in the air-handling units. However air-handling units do not inherently require MTHW, in fact quite cool Low Temperature Hot Water (LTHW) can easily be made to work. Rather than use MP steam, or poor quality deleterious LP steam to generate MTHW, it would be much more energy-efficient to fully condense the LP steam and use the hot condensate to generate LTHW via a heat exchanger for heating purposes. Since the humidifiers are no longer operational, the need for MP steam is removed.

Usually air-handling units use LTHW operating at 82^{o}C flow and 71^{o}C return (180 and 160^{o}F) respectively. These temperatures were chosen many years ago before circulators were commonly used in heating systems and designers still use them today, even though it is very easy to select deeper counter-flow heating coils operating at 60^{o}C flow and 40^{o}C return – temperatures at which condensing boilers and heat pumps operate efficiently.

Steam at 2.5 Bar is 127^{o}C and easily capable of generating LTHW hot enough to heat fresh air to say 35^{o}C (all that would be required). A modification might be required to the air-handling units for which there is plenty of room. This is discussed in more detail in section 6.

5.2.2 Use medium pressure steam to generate cooling

Paradoxically, heat can be used to generate cooling. The most common way of doing this is through an absorption chiller. The energy compound has four chillers, two Carrier units and two McQuay. The McQuay units are no longer operating and so could be replaced with absorption units. The existing McQuay units could be retained for standby or for meeting occasional summer peaks.

Chillers often appear to be more than 100 percent efficient, this is because they transfer heat from one place to another and they transfer more energy than they consume. The ratio between energy used and cooling effect is termed Coefficient of Performance (CoP). Conventional electrically powered chillers generally have a CoP between 2.5 and 6.0

Absorption chillers could also be used to replace existing building-integrated chillers, especially as peak heating and cooling demands are unlikely to be coincident.

Absorption chillers work best with a heat source in excess of 90°C, so for building-integrated absorption chillers there will need to be a separate MTHW circuit within some buildings. If operating at or around 120°C, double-effect absorption chillers with Coefficients of Performance (CoPs) in excess of 1.0 are possible. Whilst this is much lower than the CoP for a conventional chiller, this is not an issue if the energy input is carbon-free (although energy costs might be higher. See Section 10, Conclusions and Recommendations, for detailed assessment).

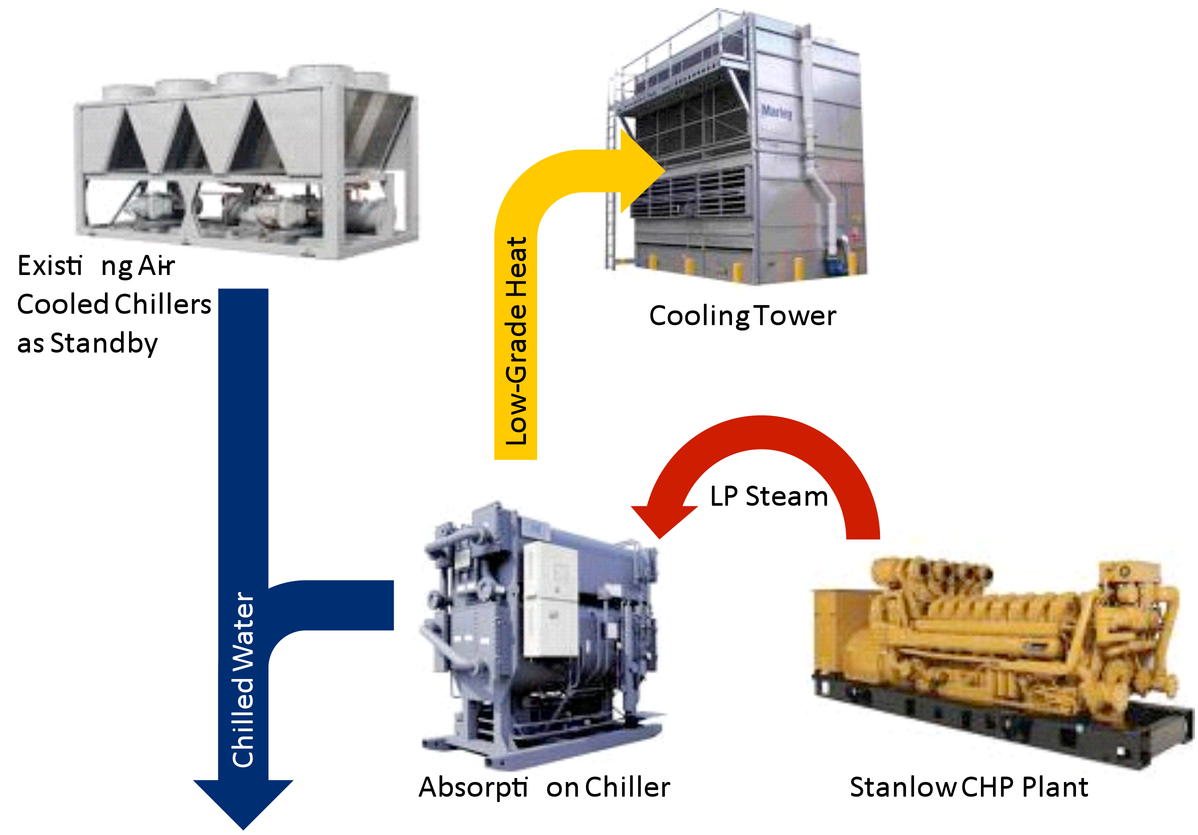


Figure 5.2.1 – Absorption Cooling Off Low Pressure Steam from Stanlow

Desiccant dehumidification and cooling is also possible. This involves drying the supply air with a desiccant wheel and rejecting about half of the attendant temperature rise through a thermal wheel to the cooler exhaust air stream so that the air is now very dry and at about the initial temperature. Water is then sprayed into the air stream which simultaneously cools and humidifies the air to the correct condition.

Because this is a completely reversible process (isotropic), its theoretical maximum efficiency is 100 percent (CoP =1), but in practice it's likely to be about 70 percent (CoP = 0.7). Again, this is very inefficient relative to a conventional chiller but this is no problem if the heat input is carbon-free (other than the potential cost penalty).

Evaporating water has a cooling effect (sweating) and absorbing water has the opposite heating effect – this is a reversible process (isotropic). Using a desiccant material we can over-dry the fresh air but this makes it very warm. When it is this warm we can easily reject much of the surplus heat to the cooler atmosphere. The air is now much the same temperature as it was when we started but it is now much drier. Finally water is sprayed back into the air-stream until the moisture content and temperature are just right

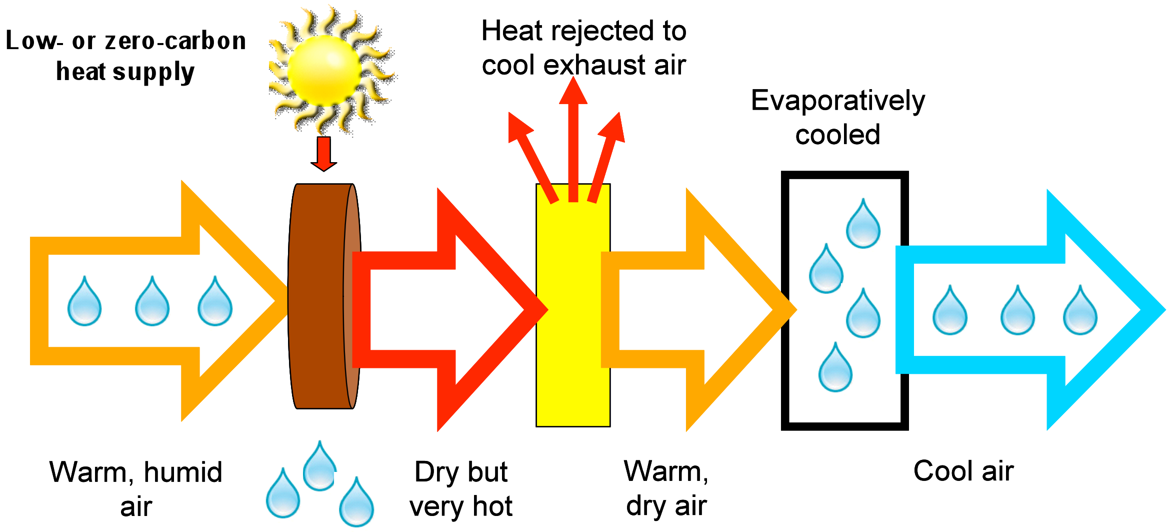


Figure 5.2.2 – Principle of Desiccant Dehumidification and Evaporative Cooling

As an alternative to a desiccant wheel, liquid desiccant can be used, such as lithium chloride or lithium bromide (salt solution). This works with exactly the same principle, but because the desiccant is circulating in pipes, there are no additional restrictions on the cross-section of the air-handling plant. A further advantage is that the heat released when moisture is absorbed is transferred directly into the heat rejection circuit and the air never gets any warmer (just drier). The heat rejection circuit is usually a cooling tower but it could be a coil in the exhaust air duct – much the same as with a desiccant wheel solution.

On a site such as the Technology Centre which already has chilled water systems in place, the easiest, cheapest and most flexible solution is absorption chillers.

5.2.3 Have permanent grid connection

Although details from Stanlow are limited, the on-site oil-fired plant is likely to combust circa 3.3 kWh of oil to generate 1.0 kWh electricity (oil-to-electricity efficiency assumed to be 30 percent).

Oil has a carbon emission factor of 0.265 $kgCO_2$ /kWh (source, Building Regulations, Part L, 2006). Therefore the carbon factor of on-site electricity generation is:

$$3.3\ kWh_{oil} \times 0.265 = 0.883\ kg\ CO_2/kWh.$$

The national grid generates electricity using a combination of sources but the overall factor is 0.42 $kgCO_2$/kWh (source, DEFRA). Therefore simply switching to the national grid reduces emissions by 52 percent.

To set against this, the on-site generation has the advantage of being able to reclaim most of the waste heat in the form of HP steam, and therefore might be overall more carbon-efficient than the grid when heating and process loads are also considered, as below:

Typically 20 percent of waste heat is unrecoverable, so 3.3 kWh oil generates 1 kWh is electricity, 0.66 kWh unrecoverable heat and 1.33 kWh of useful high-grade heat.

The carbon emissions factor of the waste heat is calculated thus:

$$(0.883\ kg\ CO_2/kWh_{elect} - 0.420\ kg\ CO_2/kWh_{elect})/1.66\ kWh_{heat} = 0.279\ kgCO_2/kWh_{heat}$$

Oil burned in a conventional boiler at 85 percent efficiency has a carbon emission factor of 0.265/0.85 = 0.311 $kgCO_2$/kWh, which is 12 percent higher than the carbon emissions factor for the waste heat – ***but only if Stanlow use ALL of the waste heat ALL of the time. Where there is no use for the waste heat, Stanlow are producing electricity about twice as "dirty" as the grid with no compensating benefits.***

Currently there IS an excess of waste heat, so reducing on-site generation to the point where all of the waste heat can be put to good use will provide the 52 percent saving calculated above.

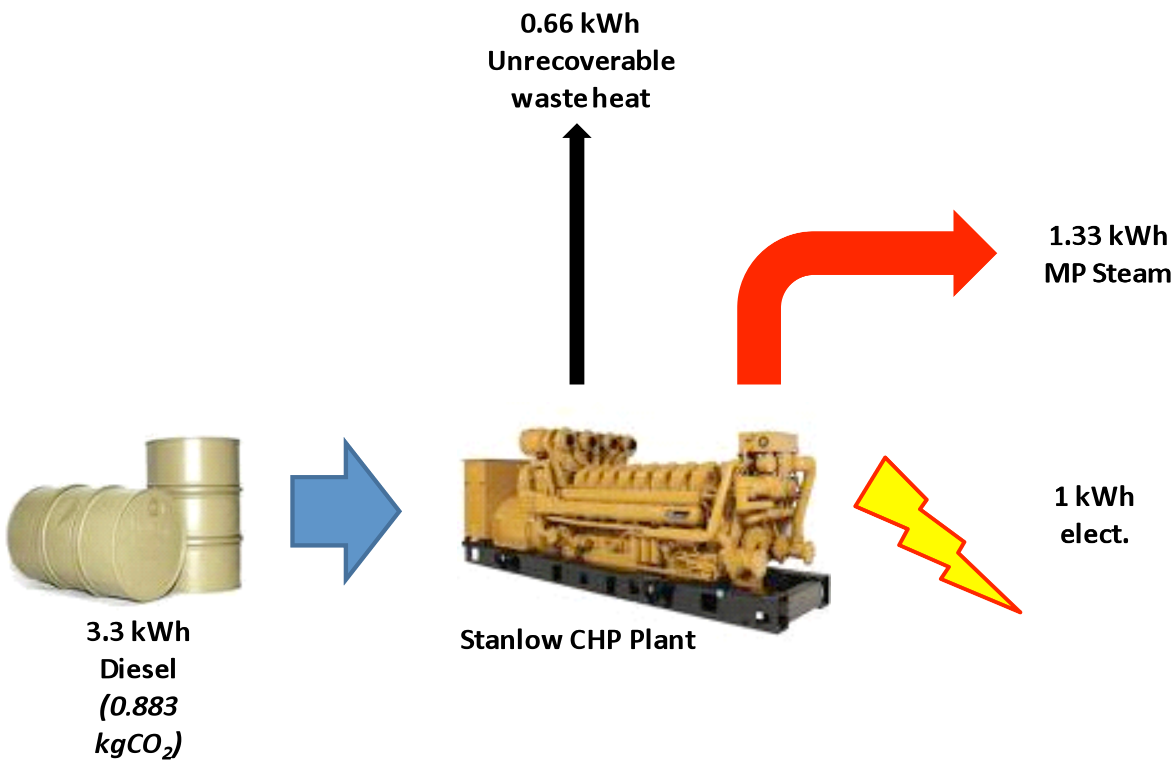


Figure 5.2.3 – Steam and Electricity from Stanlow

5.2.4 Photovoltaics

One way to reduce energy consumption is to install photovoltaics on the large roof area. It is estimated that around 8,500m2 of roof could be usefully used for this purpose.

8,500m2 of photovoltaics would generate about 1,275 MWh electricity per year, saving about £67,000 and circa 1,129 tonnes CO2. However it is likely to cost around £4,250,000 (about £3,764 per tonne CO_2). As with some other options explored in this report, it is considered but not recommended.

6 Buildings' energy strategy

6.1 Existing

The existing buildings date from a variety of periods, with the earliest being the Ince Building (B50) built around 1930 and the latest being the fuel laboratories 301, 303, 304 and 305 built around 1996. Buildings also serve a wide range of functions from staff welfare to offices, laboratories and storage.

Most buildings are naturally ventilated, but laboratories and some test facilities have air-conditioning and mechanical cooling. The heat source is generally the low pressure steam and can be considered carbon-neutral, but three laboratory buildings, 301, 303, 304 and 305, use medium pressure steam which is not.

Lighting is generally T8 fluorescent tubes, although there are some compact fluorescent lamps, some more efficient T5 fluorescent tubes and some older, less efficient, T12 fluorescent tubes. Light switching is manual with no automatic time-scheduled switching and no occupancy- or daylight-sensing control.

6.2 Options

6.2.1 General improvements

In general the following recommendations apply. Descriptions of technologies can be found in sub-section 6.2.3 – Technology Descriptions:

a. When refurbishing buildings, consider replacing old single glazing with high performance, low-emissivity double glazing with a U-value no worse than 2.0 $W/m^2.K$. Avoid argon filled units as the gas escapes over time. This option has not been included as a general recommendation to roll out across the whole site because the costs and disruption would be very high relative to the benefit.

b. Ensure that any loft spaces are insulated to at least 0.25 $W/m^2.K$ where practicable to do so.

c. Bring all lighting and controls to modern standards, including T5 fluorescent tubes, high frequency control gear, occupancy- and daylight sensing-control, and automatic time schedule switching where it is safe to do so.

d. Provide optimum start and stop heating control.

e. Provide local one hour time schedule overrides for out-of-hours plant operation. Staff can elect to operate plant outside of normal working hours, but only for one hour at a time.

f. Replace missing thermal insulation from heating and steam pipework and add insulated jackets to valves, strainers and the ends of calorifiers.

g. Replace conventional chillers with thermally-driven absorption machines.

h. Replace any medium steam heating application with low pressure.

6.2.2 Building-specific improvements

a. Laboratories 301, 303, 304 and 305
   - Transfer from medium to low pressure steam

     This option requires no modifications to the air-handling plant if the existing heating coils can operate on LTHW. This is because LP steam is easily hot enough to generate water below 90^{o}C. The only change required will be to feed the steam-to-water heat exchanger from LP stream rather than MP steam.

     If the coils require MTHW, then the LP steam might struggle, in which case it will be necessary to supplement the existing heating coils. Supplementary heating coils can be located on the fresh air inlet, as shown below under the exhaust air heat reclaim option, or in the supply air ductwork, or possibly within the air-handling unit itself. If the exhaust air heat reclaim option is adopted, then this alone could provide the necessary supplementary heating.

   - Exhaust air heat reclaim

     A heat exchanger in each of the three exhaust air stacks and one heat exchanger on the inlet to each of the fresh air air-handlers, with interconnecting pipework, a pump and three-port control valves, allows heat to be reclaimed from the exhaust air and transferred to the fresh air.

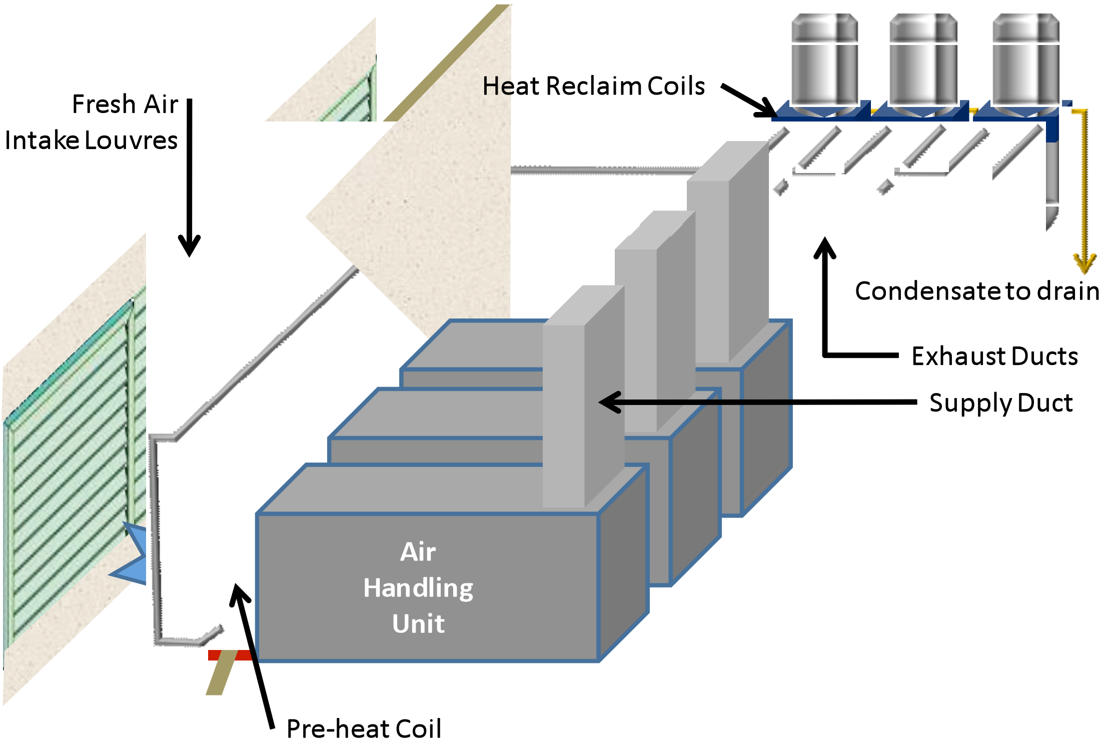


Figure 6.2.1 – Laboratory Exhaust Air Heat Reclaim

It will be possible to select coils that transfer both sensible and latent heat from the exhaust air. Typically, exhaust air at say 24°C and 50 percent relative humidity would be able to heat an equal amount of fresh air by about 9°C. Since the extract mass flow is about 20 percent higher than the fresh air provision, the fresh air can be heated by around 11°C. This is a very significant energy saving.

b. Building 55, Engine Test Bays

- Free Evaporative Cooling

Building 55 is by far the largest energy consumer on site. There are 16 test bays where engines are tested against variable levels of torque to simulate different driving conditions. Engines range from small family car engines to large HGV engines, and may be tested to simulate anything from urban driving to full throttle, for many hours or even days. Critical to the repeatability, and therefore the validity of the test, is tight control of room temperature which is usually held at about 22°C, but sometimes as high as 28°C. Relative humidity is not controlled.

The high energy consumption is not due to the fuel being used in the engines because fuel figures are not included in the energy figures received from Shell and is beyond the scope of this report. However energy that is included in the figures received from Shell and that does fall within the scope of this report is the electricity used by the chillers to keep the test bays within their temperature tolerance.

The engine testing is very varied, so there is no standard day in building 55. Therefore the writer asked the section leader, Mr. Greg Brown, for his best approximation of a representative scenario to model. Greg's suggested modelling scenario was five test bays running continuously with half the engines delivering 90kW each and half delivering 60kW each.

Each cell has its own full fresh air air-handler comprising: frost coil, cooling coil, re-heater and fan. The air-handlers are cooled by two water-cooled chillers which reject heat to three cooling towers.

The shaft resistance is created by devices called dynamometers and these reject their heat to three additional cooling towers. One of the dynamometers creates the resistance by producing a variable electromagnetic field which has the key advantage of acting like an alternator and generates electricity to feed back into the site-wide power grid. The disadvantages are cost and space for the control equipment.

Cooling the engine test bays to 22^{o}C should rarely require the use of chillers in a climate such as Thornton's. For most of the year it should be sufficient to simply supply air directly from outside, assisted at times with some direct evaporative cooling.

From the design schematics, the chilled water flow rate is 2.5kg/s and the air flow rate is 3.1m^3/s. From these two figures it is possible to approximate, with reasonable accuracy, that the design minimum supply temperature is 16^{o}C (because that's about as cool as it would be possible to achieve on a warm summer day with the available chilled water).

The test scenario is a typical family car engine and much less demanding than a peak design condition (say a HGV engine), therefore a supply temperature of 18^{o}C is assumed for the purpose of illustration – which is very similar to the supply conditions witnessed on the day of the survey.

In order to achieve a supply temperature of 18^{o}C with an adiabatic humidifier, the maximum ambient wet-bulb would be just under 17^{o}C. According to the annual-hourly weather file for the site (Chester), 18^{o}C dry-bulb is exceeded for approximately 8 percent of the year, whereas 17^{o}C wet-bulb is exceeded for less than 2 percent of the year. It follows therefore that adiabatic cooling would reduce chiller loads by a factor of about four.

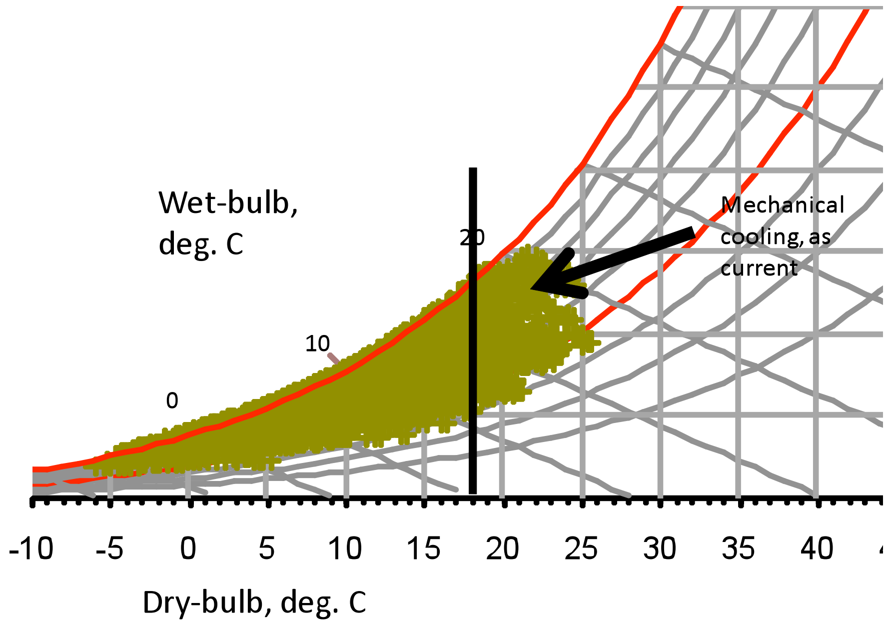


Figure6.2.2 – Mechanical Cooling Period, As Currently Designed (to the right of the thick line) - About 8 Percent of Year

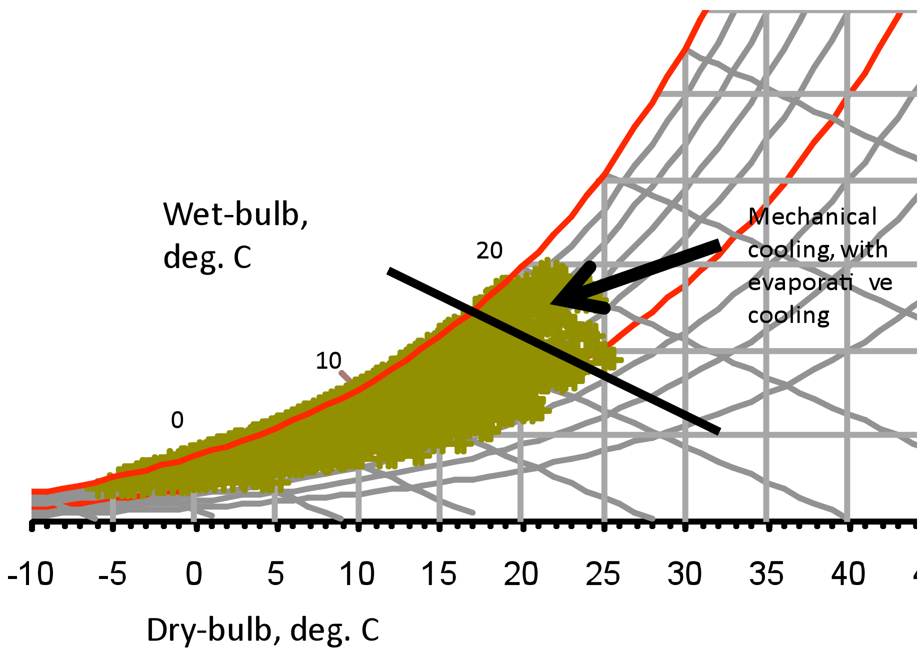


Figure 6.2.3 – Mechanical Cooling Period, with Direct Evaporative Cooling (to the right of the thick line) - About 2 Percent of Year

It is well understood that resilience is absolutely critical to the operation of this building, as a failure to the cooling system could ruin several days of work and disrupt the testing programme. Therefore the recommendations made here are not only to reduce energy consumption, but also to increase the system resilience and reliability.

Currently the system relies on the operation of two chillers, three cooling towers, chilled water pumps and condenser water pumps. Chillers in particular are complex pieces of equipment, incorporating many moving parts and working under very high pressures – in many ways, not dissimilar to the engines being tested. Even with good maintenance they are amongst the least reliable components in any cooling system.

The evaporative cooling solution is very simple with few moving parts; there is one unit per air-handler – so failure of one unit will effect only one test bay; and if a humidifier did fail, then the chilled water system would automatically take over the load.

It is understood that the chillers currently cycle on and off, possibly because they are over-sized. Frequent starting and stopping places great strain on a chiller and increases the probability of failure. A simple solution is to install a buffer vessel.

A buffer vessel is simply a water storage tank through which the cooling medium is passed. The increased thermal capacity of the system means that the chillers start less often, but when they do start, they stay on for longer.

Not only will this reduce chiller fatigue, but it also provides an immediate source of cooling in the event that an adiabatic humidifier fails or the outside wet-bulb temperature unexpectedly rises.

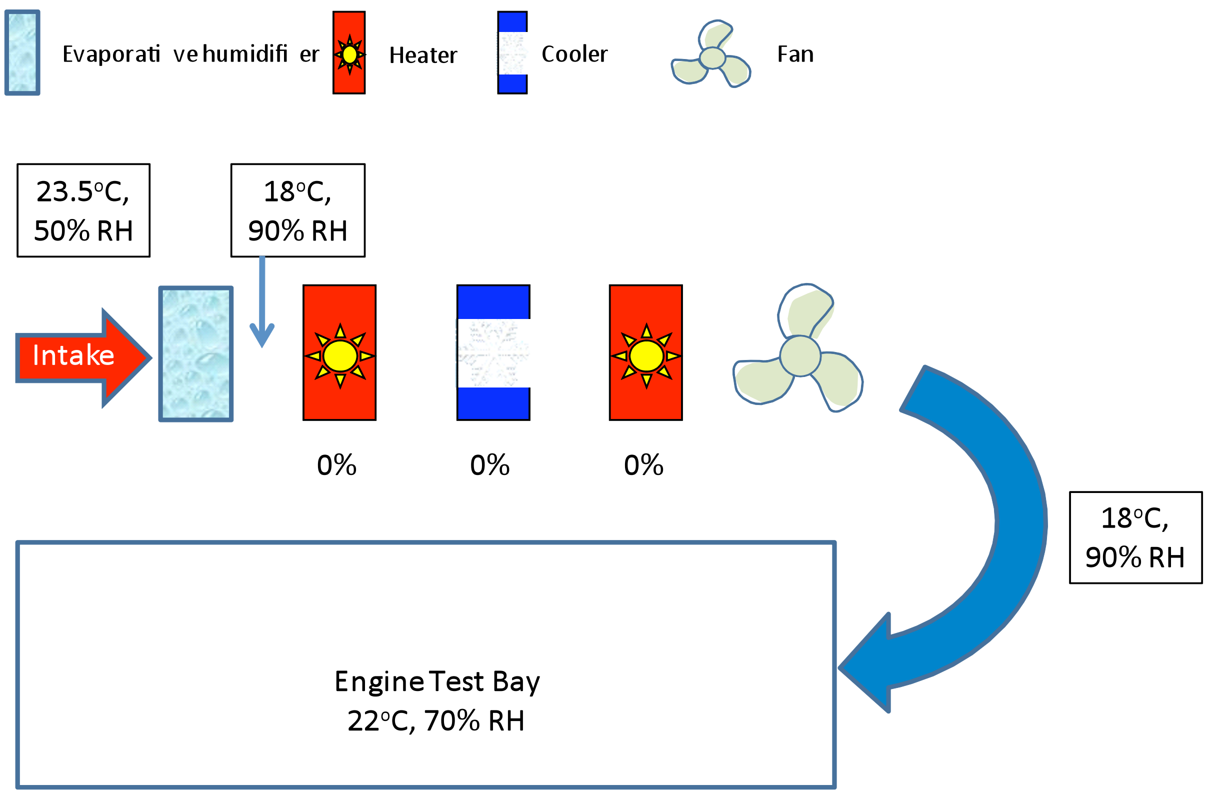


Figure 6.2.4 – Evaporative Fresh Air Cooling

Note: there is no energy benefit in evaporatively cooling the fresh air unless it is possible to achieve the required supply temperature entirely using this method. The evaporative cooling should not be used as a pre-cooler with supplementary conventional sub-cooling because the evaporative humidifier will increase the latent cooling load on the cooling coil and increase energy consumption.

These scenarios are modelled in Section 8.3, Dynamic Energy Modelling - Engine Test Bays, Building 55

- Ventilation heat recovery

  The strategy here is exactly the same as that used for the laboratory buildings, section 6.2.2.

c. Building 300, Energy centre
   - Replace defunct McQuay chillers with absorption machine
     Refer to Section 5, site-wide Energy Strategy

   - Replace missing thermal insulation

6.2.3 Technology descriptions

The technologies referenced in sub-section 6.2.1 – General improvements, are described here.

a. U-values of building materials

   The thermal insulation properties of building materials are usually expressed as Watts per square metre per degree temperature difference across the element, $W/m^2.K$

   A good window would be 2.00 $W/m^2.K$ and a good roof would be 0.25 $W/m^2.K$.

b. Choice of fluorescent tubes

   Lighting technology is improving all the time and old fluorescent tubes are not as efficient as new modern ones. As tubes have become more efficient, they have also reduced their diameter. Diameters are expressed as a code relating to the number of 8ths of an inch. An old T12 is 12/8ths of an inch whereas a modern efficient T5 is 5/8ths of an inch. Most of the tubes on site seemed to be old T8s (one inch).

   Less frequently lamp diameters are quoted in their metric equivalent, so a T8 (1 inch) would be T26 (26mm) in metric.

T5s (or metric T16s) have been around since the 1990s. They are more efficient than T8s and T12s which date from the 1930s.

Consideration should also be given to colour temperature and colour rendering. Colour temperature affects mood and ambiance. Most commercial spaces prefer a cool white light with a colour temperature of 4100K; this is to create a vibrant energised feel.

Lamps also vary significantly in their colour rendering qualities. Tungsten lamps, which are perfect but very energy-intensive, have a Colour Rendering Index (CRI) of 100. A poor fluorescent lamp, say a halophosphate tube, will have a CRI of only 50 but a good triphosphor lamp will manage 99 – virtually as good as tungsten but much more energy efficient.

c. High frequency control gear

Fluorescent tubes require control gear to start the lamp, stabilise the current and improve the power factor. Many of the fittings on site appear to be of an age, prior to the early 1990s, where they would have magnetic ballasts for this purpose. Modern fittings have electronic ballasts which are more efficient and eliminate flicker. It is especially important to consider flicker when using fluorescent tubes around rotating machinery because high frequency control gear will avoid “strobing” which can make a spinning wheel or machine appear stationary.

d. Automatic light switching

i. Time schedule switching

Lighting can be switched off automatically at the end of the normal working day; however there are some limits to this. It might not be prudent to turn the lights off at the stroke of 5:00pm because this might prompt people to leave who might otherwise have been happy working for a while longer.

Not all of the lights should be automatically switched off because in winter this would plunge the space into total darkness, with obvious health and safety implications. Sufficient lights should remain on to allow people to safely navigate the room, especially where there might be unusual hazards, such as in a laboratory or test facility. For those people who want to work on later, they should be able to switch the lights on again for an hour at a time, but only the lights in their immediate working area and not the entire floor.

There is no requirement for the lights to be automatically switched on in the morning – staff should do this manually when they arrive for work. Again, each light switch should control only a small area of lights.

Automatic light switching needs to be considered on a space-by-space basis with due regard to health and safety and operational requirements. For instance they would not be appropriate on any stairs, most plantrooms and some laboratories.

ii. Occupancy sensing

Passive Infra-Red (PIR) sensors can be used to extinguish lights when there is no occupancy. Sensors such as these earned a bad name when they first came onto the market back in the 1980s, but like most things, technology has significantly improved since then.

They will often be inappropriate in plantrooms, engine test bays and other spaces where personnel may be shielded from the sensor by plant or equipment and in potentially dangerous positions. As always, a health and safety assessment is essential.

iii. Daylight sensing

The best daylight controls dim the lights as the daylight penetration increases so that occupants notice no change to the illuminance. A cheaper solution is to switch the lights off when the internal illuminance exceeds the design minimum by a factor of three, and turns them back on again if the illuminance falls back to the design level.

It is important for lighting to be appropriately zoned for this; lights close to windows should be one control zone, those a little further away should be another and those more than six metres from a window receive no daylight and therefore require no photocell control.

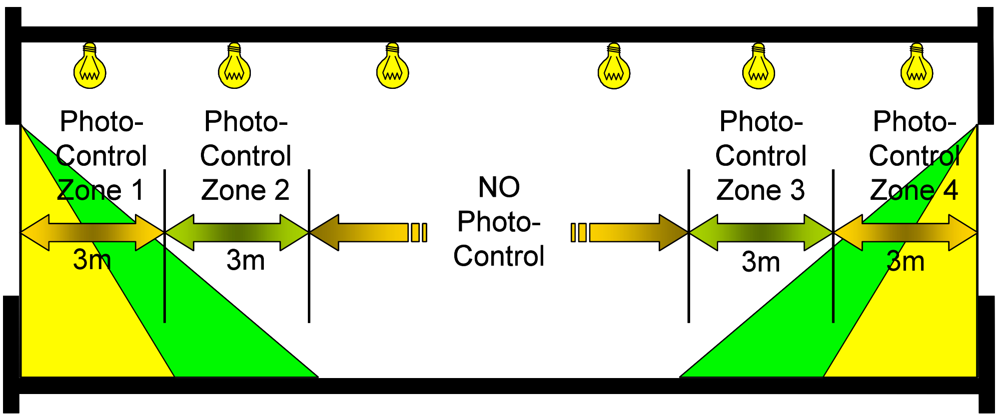


Figure 6.2.5 – Photocell Lighting Control Zoning

e. Optimum start and stop

Optimum start and stop is a self-learning algorithm that delays the start of heating plant to the latest possible moment and stops the heating at the earliest possible moment - all based upon the occupancy schedules, temperature set-points and the prevailing internal and external air temperature. Fresh air plant must operate independently of this routine because fresh air is not required during the pre-conditioning period but is required until the very end of the working day.

f. Local plant overrides

There is a facility where staff choosing to work out-of-hours can locally extend operational hours by one hour at a time. This is preferable to asking for the default schedules to be extended which are often never returned to their original settings. Overtime plant can be left running at night and weekends even though there is no occupancy.

g. Building-integrated absorption chillers

An absorption chiller is similar to a conventional chiller but where the power input is heat rather than electricity. Absorption chillers work best if the source of heat is above 90^{o}C, which is easily achieved off the low pressure steam through a separate heat exchanger.

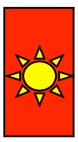
7 Building management system (BMS) review

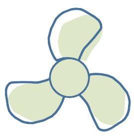
7.1 Introduction

The building management system was reviewed by taking snapshot reviews of the graphics pages. It is the nature of BMSs that it is always very difficult to test all possible scenarios. The best chance to do this is during the commissioning where false conditions can be applied to test the BMS's reaction, but this approach cannot usually be applied to an occupied building without causing disruption. For this reason this is not, and cannot be, an exhaustive review. BMSs require regular vigilance and a critical eye at all times throughout the year.

Problems were found with the BMS, but those recorded here are unlikely to be the only problems. The most important message of this section is the on-going process and approach that should be adopted by maintenance staff so that defects are identified and eradicated over time.

Legend for the following graphics


Heating (frost or re-heater)

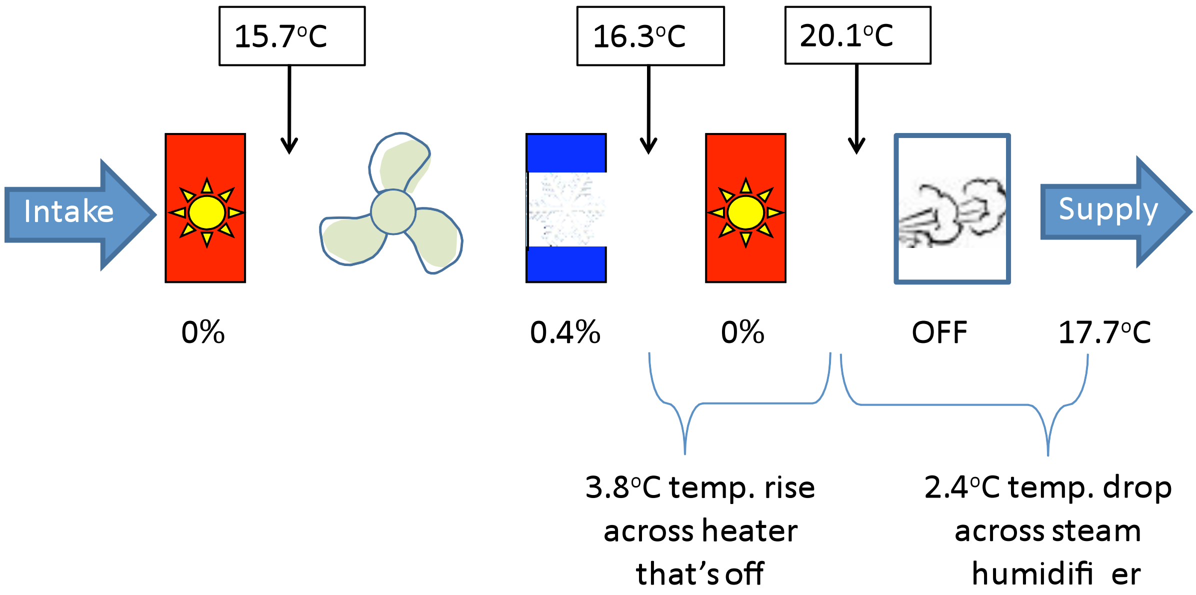

Fan


Cooling coil


Steam humidifier

7.2 Building 303

Air-Handling Unit 1



Frost coil set-point = 10°C
Minimum supply temp. = 18°C
External stati c pressure = 730Pa

Figure 7.2.1, B303, AHU 1

Comments

a. There is a temperature rise of 3.8°C across a heating coil that’s fully shut. This either means that the temperature sensors are inaccurate or that the heating valve is letting-by.

b. There is a temperature drop of 2.4°C across the steam humidifier. There should be no temperature change across a steam humidifier, and in this case, the humidifier is off. This can only mean that the temperature measurements are inaccurate.

Air-Handling Unit 2

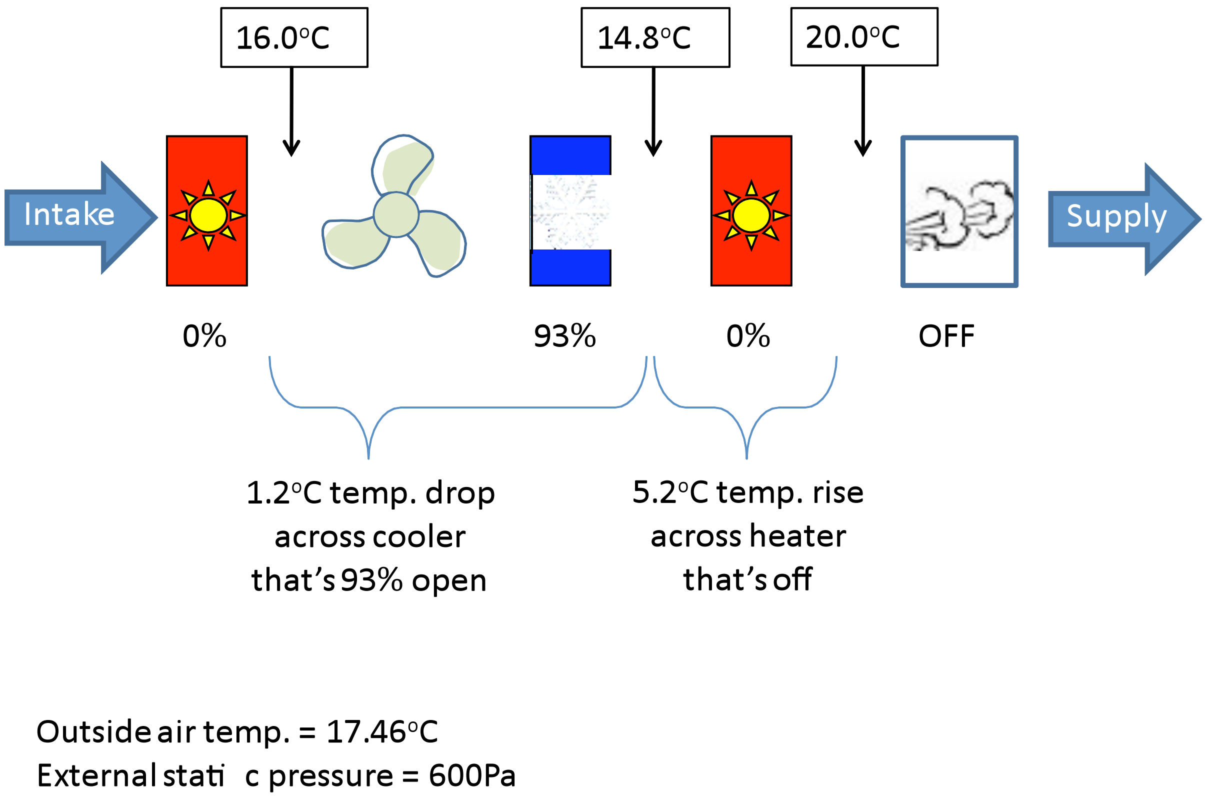


Figure 7.2.2, B303, AHU 2

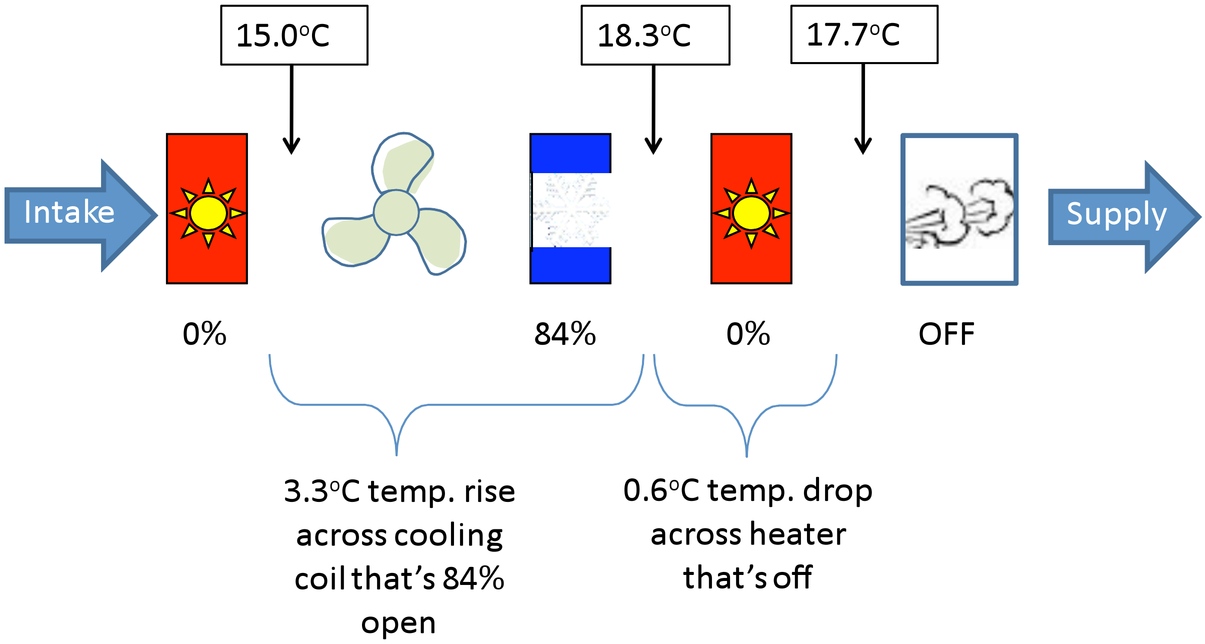
Comments

a. There is a temperature rise of 5.2°C across a heating coil that's fully shut. This either means that the temperature sensors are inaccurate or that the heating valve is letting-by.

b. There is a temperature drop of just 1.2°C across the cooling coil that's almost fully open. This is a negligible drop for a cooling coil that's working so hard. Unless the outside air is very humid, this coil should be fully shut because the outside air is cooler than the minimum supply set-point for the laboratories. There is something wrong with either the sensors or the control strategy.

c. The outside air temperature is 17.46°C and the temperature after the frost coil is only 16°C – why the drop? Again, sensor accuracy is likely to be at fault.

Air-Handling Unit 3



Frost coil set-point = 10°C
Minimum supply temp. = 18°C
External static pressure = 610Pa

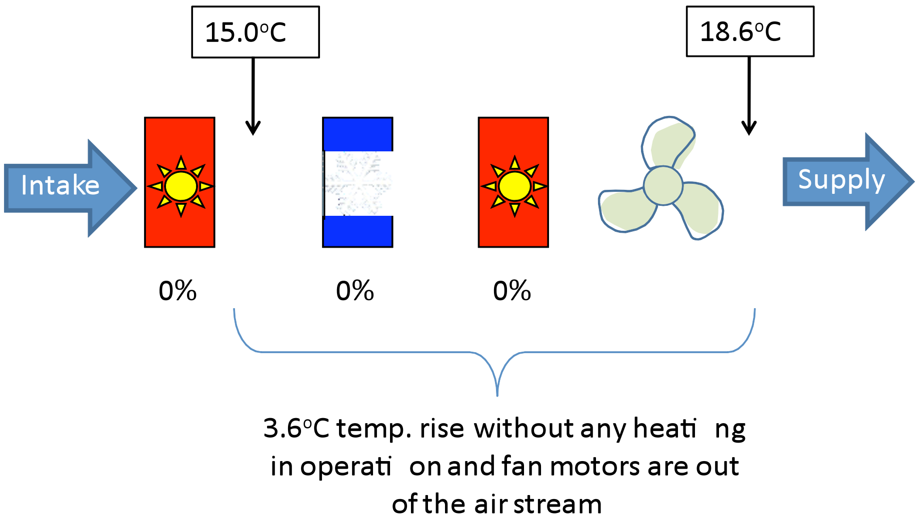
Figure 7.2.3, B303, AHU 3

Comments

a. There is a temperature rise of 3.3°C across the cooling coil that's 84 percent open – this cannot be right. Further, unless the outside air is very humid, the cooling coil should be fully shut because the outside air is cooler than the minimum supply temperature set-point. If the cooling coil is in dehumidification mode, the re-heater should be in use, which it isn't.

b. There is a temperature drop of 0.6°C across a heating coil that's fully shut. Whilst this difference is small and easily explained by reasonable accuracy tolerance, the temperature off the re-heater (17.7°C) is still much higher than that off the frost coil (15°C), despite there being a cooling coil in between at 84 percent output – this cannot be correct.

7.3 Building 55



Outside air temperature = 13.58°C

Figure 7.3.1 – B55, Test Cell 1, AHU

Comments

a. There is a temperature rise of 3.6°C across the air-handler despite there being no heating in operation. The heat gain cannot come from the fan motors because they are outside of the air stream. Either the sensors are inaccurate or the heating valves are letting-by.

b. The outside air temperature sensor is reading 13.58°C and the sensor downstream of the frost coil is reading 15°C – a temperature rise of 1.4°C across a frost coil that's fully shut. The outside temperature sensor is likely to be reading at least 2°C too low.

7.4 General

Sensors reading outside air temperature, including those downstream of closed frost coils, range from 13.58°C (B55, cell 1) to 17.46°C (B303, AHU2). This is a very large error.

There is evidence of faulty sensors and/or faulty control routines and/or valves letting-by. Faulty BMSs have unpredictable consequences on energy consumption. For instance if a heating coil is fighting a cooling coil, the energy waste can be huge and continue for years without being detected.

8 Dynamic energy modelling

8.1 Method

The purpose of the modelling here is to estimate the benefits of options sufficient to assist with decision-making. Rarely are models perfectly accurate and this is especially true of building energy predictions where even the real situations are subject to the variances of weather and human behaviour. Since the actual energy use of a building will vary year-on-year, there can be no single correct answer against which to judge the models' outputs. All that really matters is that the right decisions are taken.

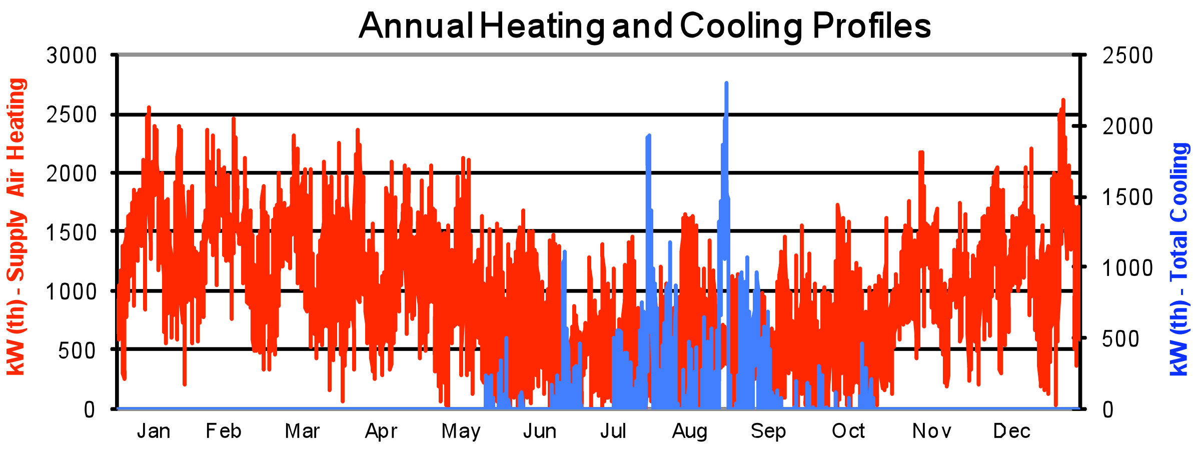
Three dynamic models have been produced: one for the fresh air plant to laboratories 301, 303, 304 and 305; one to test the benefit of evaporative cooling and heat reclaim to the engine test bays; and one for a representative office building using building B49 as an example of shape and construction elements. Each of these is described in turn.

8.2 Fresh air modelling, laboratories 301, 303, 304 and 305

No proprietary software adequately models air-handling plant, which is why we have developed our own software over the last 10 years for this specific purpose. This makes our results especially accurate for this sort of analysis.

The as-installed schematics were reviewed to establish the total supply air volume for all four buildings. Using the measured values (as opposed to design values), the total flow rate was found to be 92.6 m^3/s.

The air-handling plant was modelled using an annual-hourly weather file from a weather station in Chester, about 30 miles south of the site. The air-handling plant was modelled with the current configurations. For full input data, please refer to Appendix B, Modelling Data. The results are shown below.

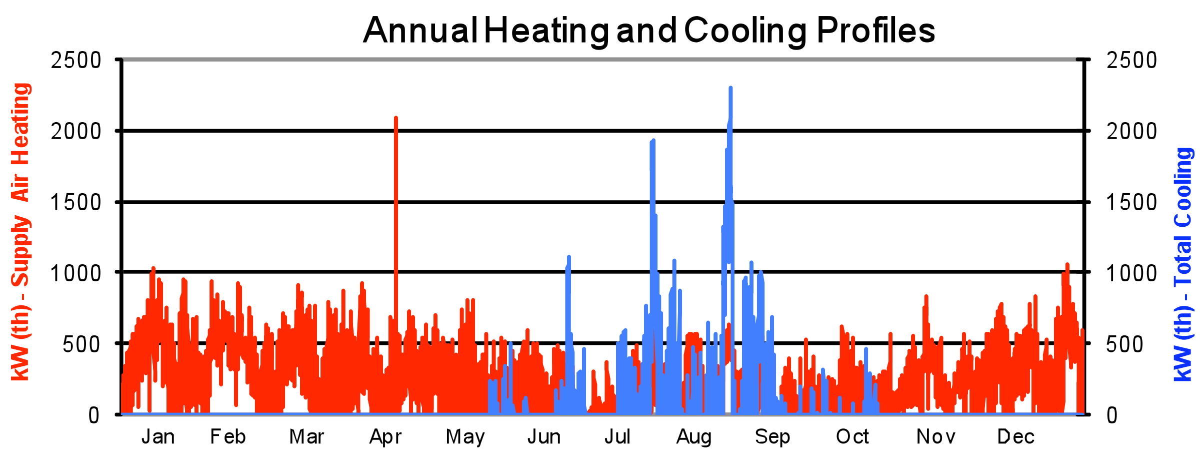


Graph 8.2.1 – Annual Supply Air Heating and Cooling Profiles for all Air-handlers, As Installed

Service	$t.CO_2$	MWh	kWh/m^2
Supply air cooling (elect)	59 (2%)	140 (1.3%)	12
Supply air heating	2,274 (68%)	8,151(76%)	722
Supply and extract fans	1,022 (30%)	2,434 (23%)	216
TOTALS	**3,355**	**10,725**	**950**
ANNUAL RUNNING COST			**£285,851**

Table 8.2.1 – Annual Usage, As Installed

The model was re-run, but this time with heat reclaim between the supply and exhaust ducts. The results follow.



Graph 8.2.2 – Annual Supply Air Heating and Cooling Profiles for all Air-handlers, with Heat Reclaim. *The graph is showing significantly less heating than shown in graph 8.2.1.*

Service	$t.CO_2$	MWh	kWh/m^2
Supply air cooling (elect)	60 (4%)	143 (1.3%)	13
Supply air heating	564 (34%)	2,023 (76%)	179
Supply and extract fans	1,022 (62%)	2,434 (23%)	216
TOTALS	**1,647**	**4,599**	**407**
ANNUAL RUNNING COST			**£183,446**

Table 8.2.2 – Annual Usage, with Exhaust Air Heat Reclaim

Four significant conclusions can be drawn from this analysis:

a) If the supply air heating was transferred from medium to low pressure steam, approximately 2,274 tonnes of carbon dioxide and £9,000 would be saved annually

CO_2 saving: all CO_2 arising from supply air heating, see table 7.2.1
Cost saving: 8,151,000 kWh x (1.67 - 1.56 p/kWh) / 100 = £8,966

b) If the supply air heating remained on medium pressure steam but heat reclaim was introduced, approximately 1,709 tonnes of carbon dioxide and £102,000 would be saved annually.

CO_2 saving: 2,274 – 564 = 1,710 t.CO_2
Cost saving: (8,151,000 – 2,023,000 kWh) x 1.67 p/kWh / 100 = £102,338

c) If the supply air heating was transferred from medium to low pressure steam, and the heat reclaim was introduced, approximately 2,274 tonnes of carbon dioxide and £105,000 would be saved annually.

CO_2 saving: all CO_2 arising from supply air heating, see table 7.2.1
Cost saving: 8,151,000 kWh x 1.67 p/kWh / 100 = £136,122
minus
2,023,000 kWh x 1.56 p/kWh / 100 = £31,559
equals £104,563

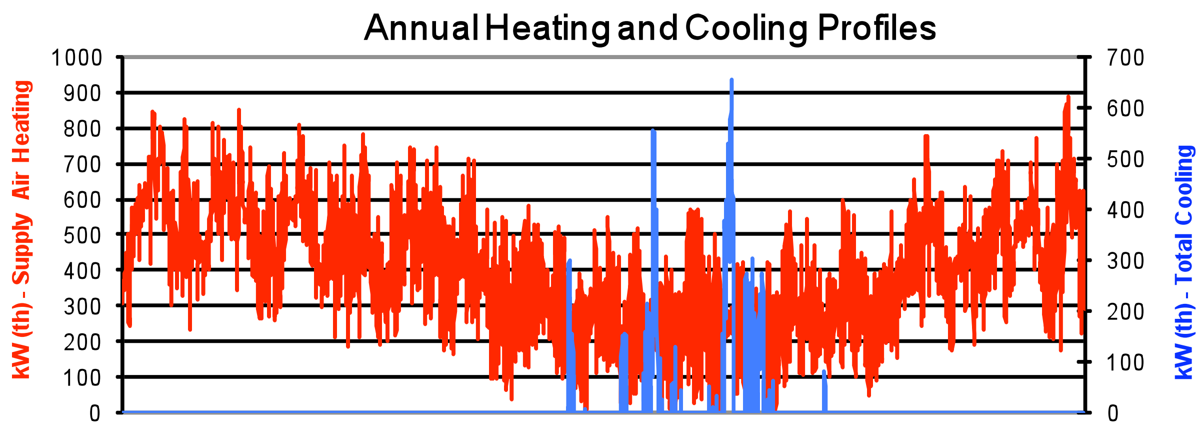
d) If the absorption chillers provided all of the cooling, approximately 59 tonnes of carbon dioxide and £800 would be saved annually. The reductions are modest because the outside air is usually sufficiently cool to not require mechanical cooling. Therefore this option will be recommended.

CO_2 saving: all CO_2 arising from supply air cooling, see table 7.2.1
Cost saving: 140,000 kWh x 5.30 p/kWh = £7,400
minus
3 x 140,000 kWh x 1.56 p/kWh = £6,552
equals £848

8.3 Engine test bays, building 55

8.3.1 Description

Using the same modelling tool used for the laboratory buildings, but this time applied to the air-handling units in B55 with Greg Brown's suggested scenario, we get the following results:

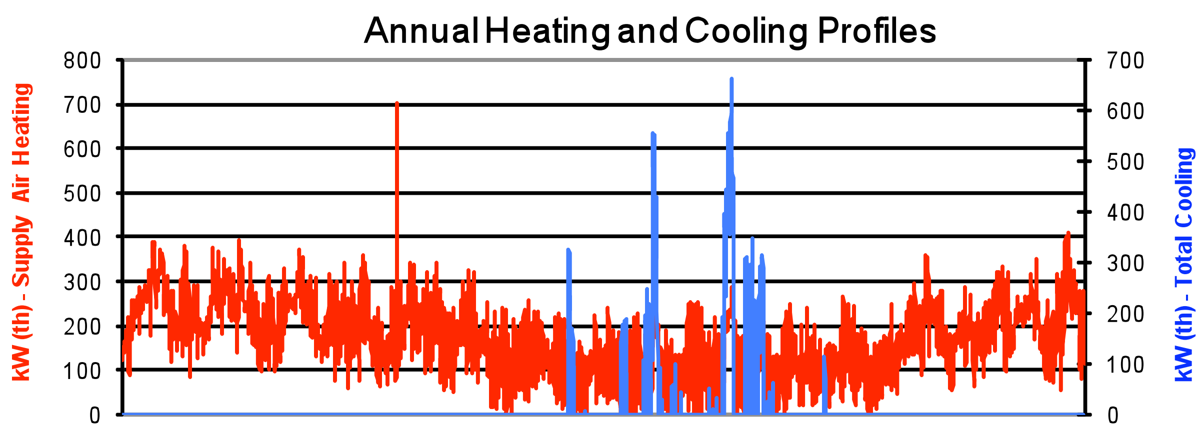


Graph 8.3.1 – Annual Supply Air Heating and Cooling Profiles for all Air-handlers, As Installed

Service	t.CO_2	MWh
Supply air cooling (elect)	16 (7%)	18 (0.5%)
Supply air heating	0 (0%)	3,432(93.2%)
Supply and extract fans	205 (93%)	232 (6.3%)
TOTALS	**221**	**3,682**
ANNUAL RUNNING COST		**£74,439**

Table 8.3.1 – Annual Usage, As Installed

The model was re-run, but this time with heat reclaim between the supply and exhaust ducts. The results follow.

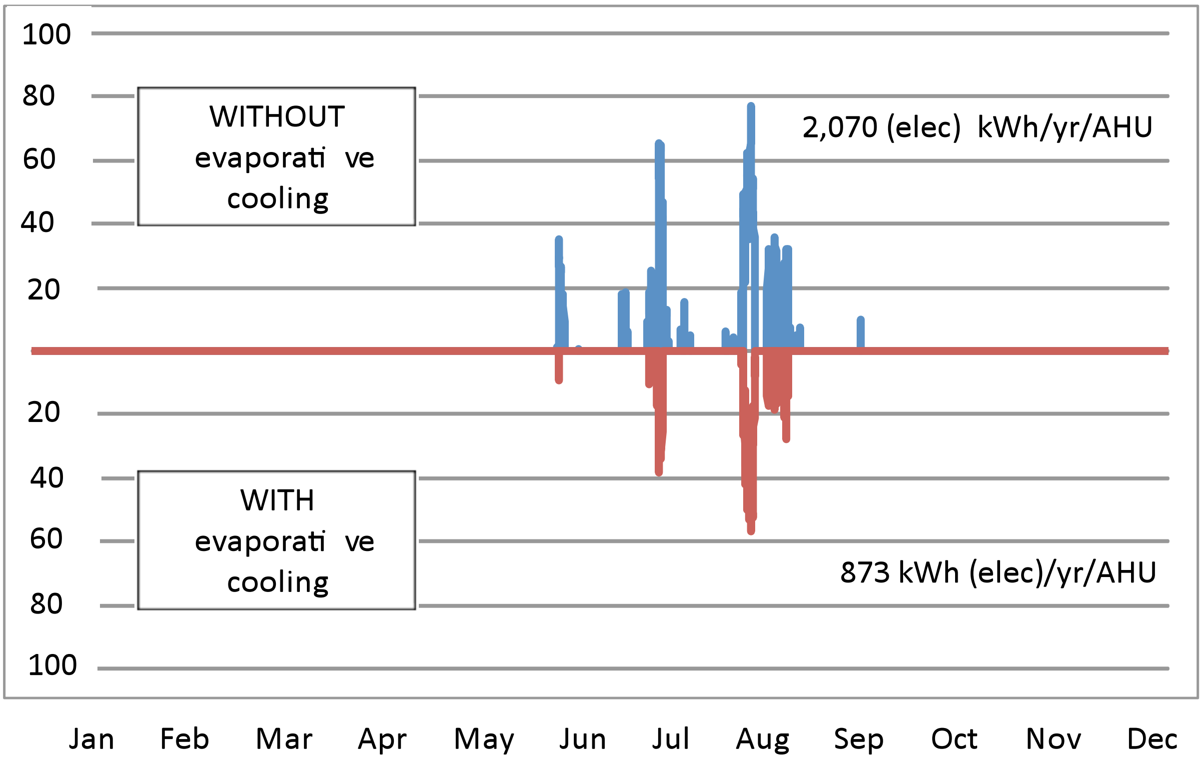


Graph 8.3.2 – Annual Supply Air Heating and Cooling Profiles for all Air-handlers, with Heat Reclaim. *The graph is showing significantly less heating than graph 8.3.1.*

Service	t.CO_2	MWh
Supply air cooling (elect)	18 (8%)	20 (1.2%)
Supply air heating	0 (0%)	1,474 (85.3%)
Supply and extract fans	205 (92%)	232 (13.5%)
TOTALS	**223**	**1,724**
ANNUAL RUNNING COST		**£41,822**

Table 8.3.2 – Annual Usage, with Heat Reclaim

The model was run a third time to test the benefits of evaporative cooling, with the results shown below. For comparison purposes, the cooling without evaporative cooling was shown above the axis and the cooling with evaporative cooling was shown going below the axis. This clearly shows on one graph the benefit of the system.



Graph 8.3.3 – Annual Supply Air Cooling Profiles for one Air-handler, with and without Evaporative Cooling

Service	t.CO_2	MWh
Supply air cooling (elect)	8 (4%)	9 (0.5%)
Supply air heating	0 (0%)	1,474 (86.0%)
Supply and extract fans	205 (96%)	232 (13.5%)
TOTALS	**213**	**1,715**
ANNUAL RUNNING COST		**£41,239**

Table 8.3.3 – Annual Usage, with Evaporative Cooling

Two significant conclusions can be drawn from this analysis:

a) Exhaust air heat recovery saves approximately £33,000 annually.
Cost saving: £74,439 - £41,822 = £32,617

b) Evaporative cooling saves a modest circa 10 tonnes of carbon dioxide and £600 annually. The benefit is small because the outside air is usually below the required supply temperature and therefore requires no cooling. For this reason this option will not be recommended.

CO_2 saving: 18 – 8 = 10 t.CO_2
Cost saving: £41,822 – £41,239 =£ 583

8.4 Typical office

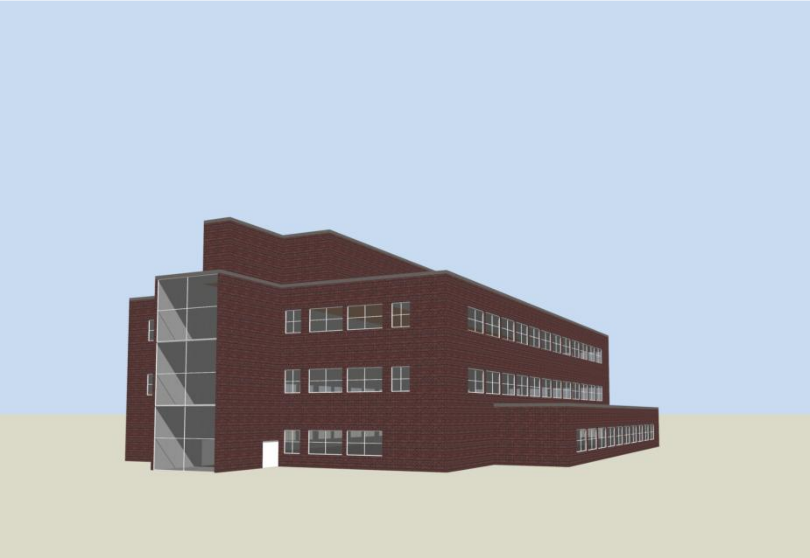
8.4.1 Description

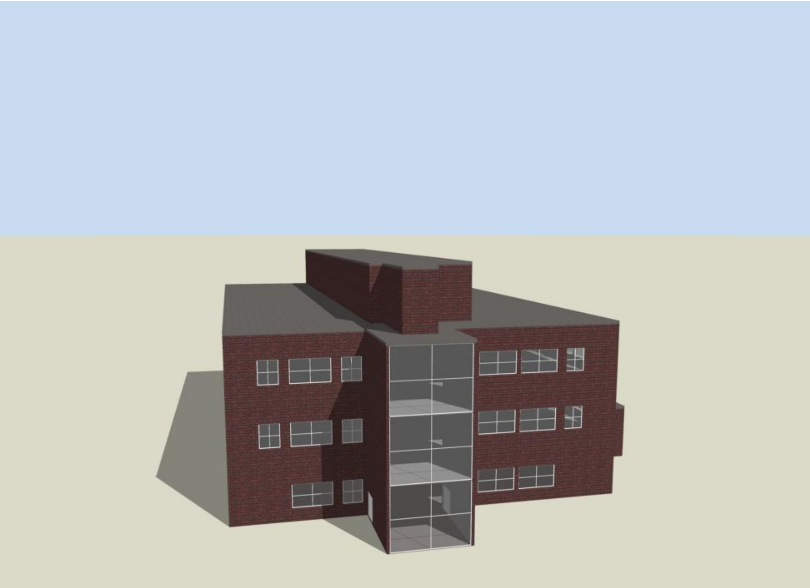
A representative office structure, B49, has been thermally modelled to test the benefit of some of the recommendations made in Section 6, Building Energy Strategy. Some recommendations cannot be modelled in this way, such as thermally insulating valves. For these it is sufficient to recognise that they are good things to do and provide additional benefits.

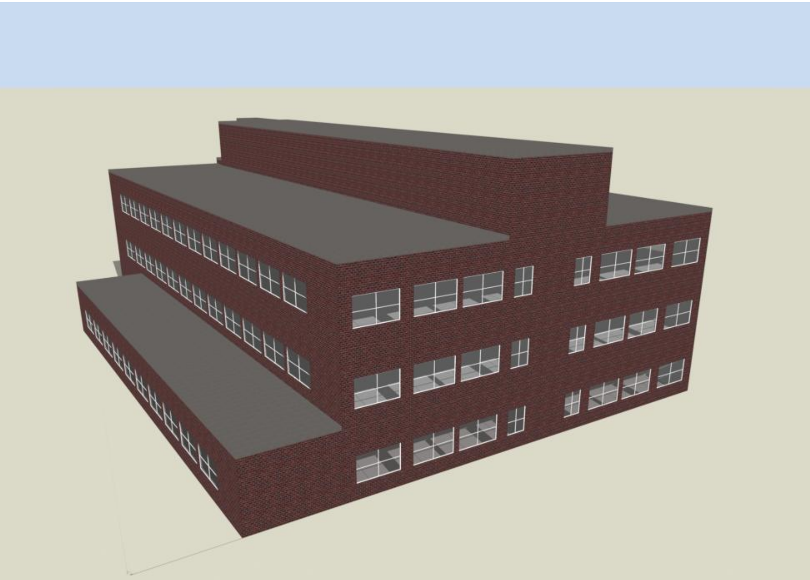
From a modelling perspective, it would have been just as acceptable to model a totally fictitious thermally representative building, but B49 was chosen for illustrative purposes because it is visually recognisable as an office building on campus. The purpose of this modelling exercise is to derive conclusions that can be generally applied across all office buildings and not to provide conclusions that specifically apply to B49. Therefore B49 has not been modelled with the actual engineering services because B49 is air-conditioned whereas most of the office accommodation is not.

Typical construction details from the early 1980s were assumed and windows are clear single glazing.

The images below were generated from the thermal modelling software.







The building was modelled using a weather file from Manchester airport and then improvements were progressively applied. The graphs below, 8.4.1 to 8.4.3, indicate the benefit of each option and how the building compares to national benchmarks taken from ***Energy Consumption Guide 19 for Offices (ECG019)***.

The bars on the chart are as follows:

- ✓ Best – Naturally ventilated office, ECG019 'Best Practice' but with the lighting benchmark taken from a standard air-conditioned building. This change was made because lighting on site more closely reflects this figure.

- ✓ Typical – Naturally ventilated office, ECG019 'Typical Practice' but with the lighting benchmark taken from a standard air-conditioned building. This change was made because lighting on site more closely reflects this figure.

- ✓ Current – typical for the building stock on site.

- ✓ Option 1 – Old T8 fluorescent tubes replaced with T5s, high frequency control gear and photocell light dimming to half of the floor plate.

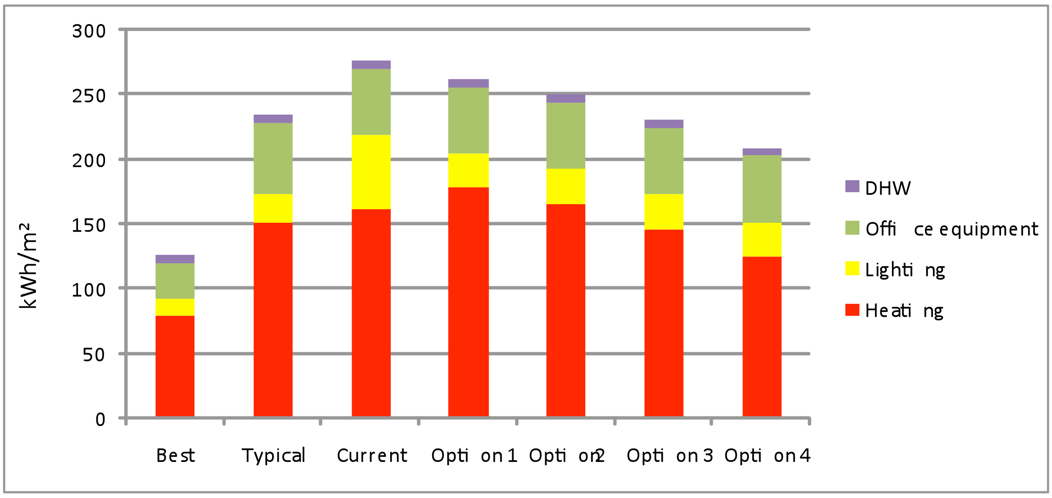
- ✓ Option 2 – as option 1 PLUS double glazing to current building code standards.

- ✓ Option 3 – as option 2 PLUS roof insulation to current building code standards

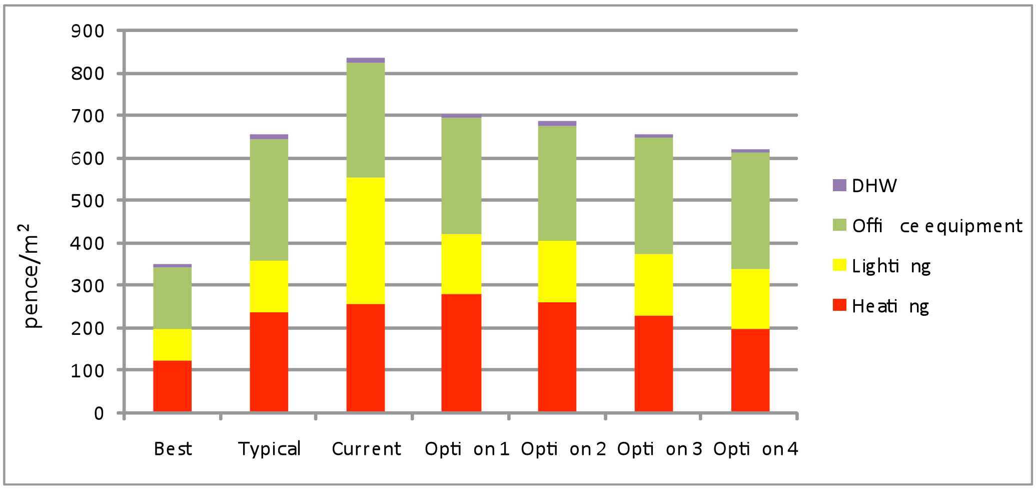
- ✓ Option 4 – as option 3 PLUS optimum start and stop.

The graphs present the results in terms of energy, cost and emissions. Heating and domestic hot water were considered carbon-free. The carbon emission factor for electricity assumes electricity taken from the Stanlow CHP plant at 0.883 $kgCO_2/kWh$. A tariff of 1.56 p/kWh was applied to the LP steam and a flat rate of 5.3 p/kWh was allowed for electricity.

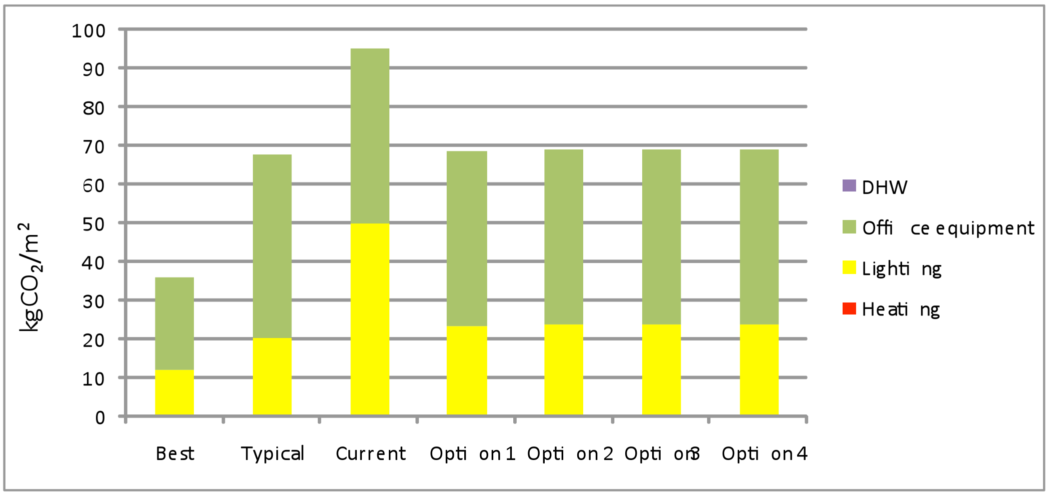
8.4.2 Results



Graph 8.4.1 – Annual Energy Use per Square Metre



Graph 8.4.2 – Annual Energy Cost per Square Metre



Graph 8.4.3 – Annual CO_2 Emissions per Square Metre

Tables 8.4.1 to 8.4.3 show the results tabulated.

Service	Best	Typical	Current	Option 1	Option 2	Option 3	Option 4
Heating	79	151	162	178	165	147	125
Lighting	14	23	56	27	27	27	27
Office equipment	27	54	51	51	51	51	51
DHW	6	6	6	6	6	6	6
TOTAL	**126**	**234**	**276**	**262**	**250**	**231**	**209**

Table 8.4.1 – Annual Energy Used per Metre Square (kWh/m^2)

Service	Best	Typical	Current	Option 1	Option 2	Option 3	Option 4
Heating	123	236	253	278	258	229	194
Lighting	74	122	299	141	145	144	144
Office equipment	143	286	271	271	271	271	271
DHW	10	10	10	10	10	10	10
TOTAL	**350**	**653**	**833**	**700**	**684**	**654**	**619**

Table 8.4.2 – Annual Energy Costs per Metre Square (pence/m^2)

Service	Best	Typical	Current	Option 1	Option 2	Option 3	Option 4
Heating	0	0	0	0	0	0	0
Lighting	12	20	50	24	24	24	24
Office equipment	24	48	45	45	45	45	45
DHW	0	0	0	0	0	0	0
TOTAL	**36**	**68**	**95**	**69**	**69**	**69**	**69**

Table 8.4.3 – Annual Emissions per Metre Square (kgCO$_2$/m^2)

8.4.3 Findings

- ✓ The building is currently costing an estimated 28 percent more to run than a typically performing building of its type.
- ✓ Applying each of the options will reduce energy consumption by an estimated 27 percent and will bring the energy costs below typical practice by circa five percent.
- ✓ The estimated total annual saving for a naturally ventilated building otherwise similar to building 49 is circa £10,000.
- ✓ The emissions savings are distorted by the use of a carbon-neutral source of heat, so that only savings in electricity usage impact on the results. The estimated current emissions are 40 percent higher than a typically performing building but this difference can be eliminated through the deployment of the recommended four options.

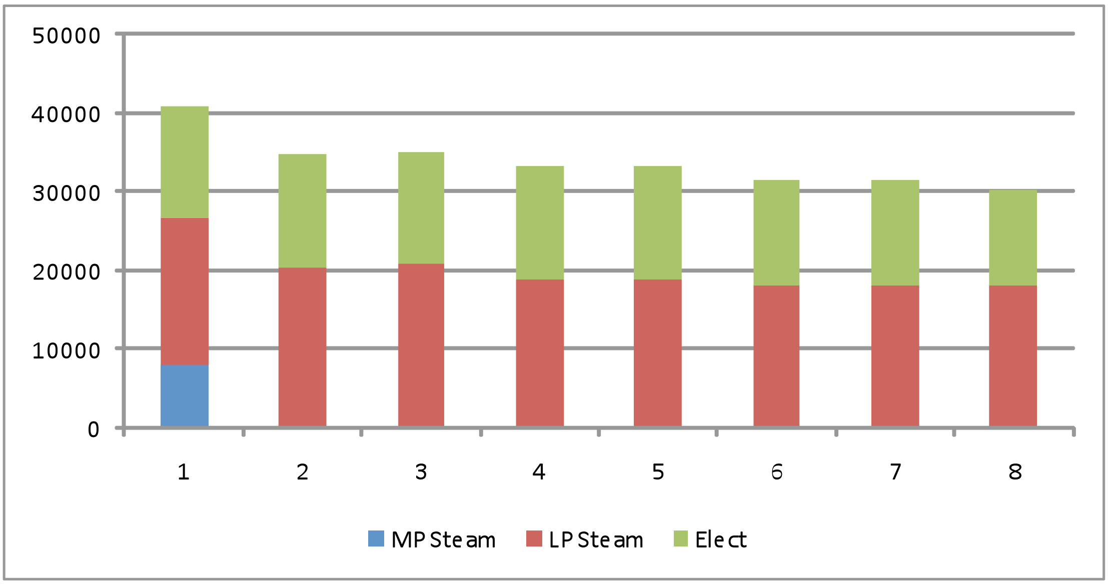
9 Site-wide results

The results of all three models are represented in graphs 9.1.1 to 9.1.3 and also represented in tables 9.1.1 to 9.1.3.

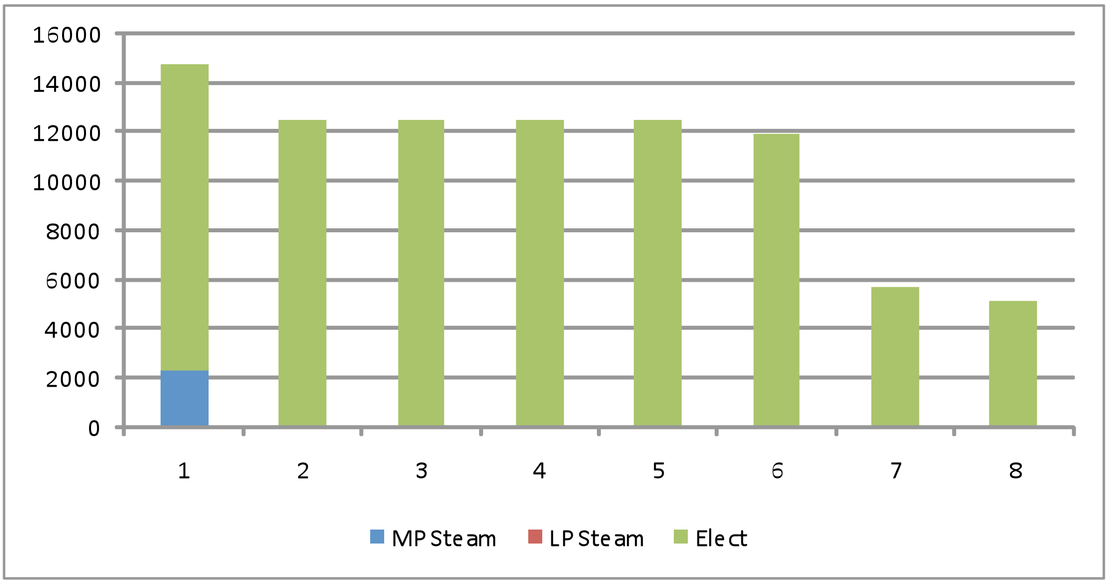
The modelled options are summarised thus:

Option	Description
1	Current
2	Labs 301, 303, 304 and 305. No MP Steam plus exhaust air heat reclaim
3	Labs 301, 303, 304 and 305. LP steam absorption chillers
4	B55 engine test bays. Exhaust air heat recovery
5	B55 engine test bays. Evaporative cooling
6	General building and fit-out improvements
7	Switching to national grid
8	Photovoltaics

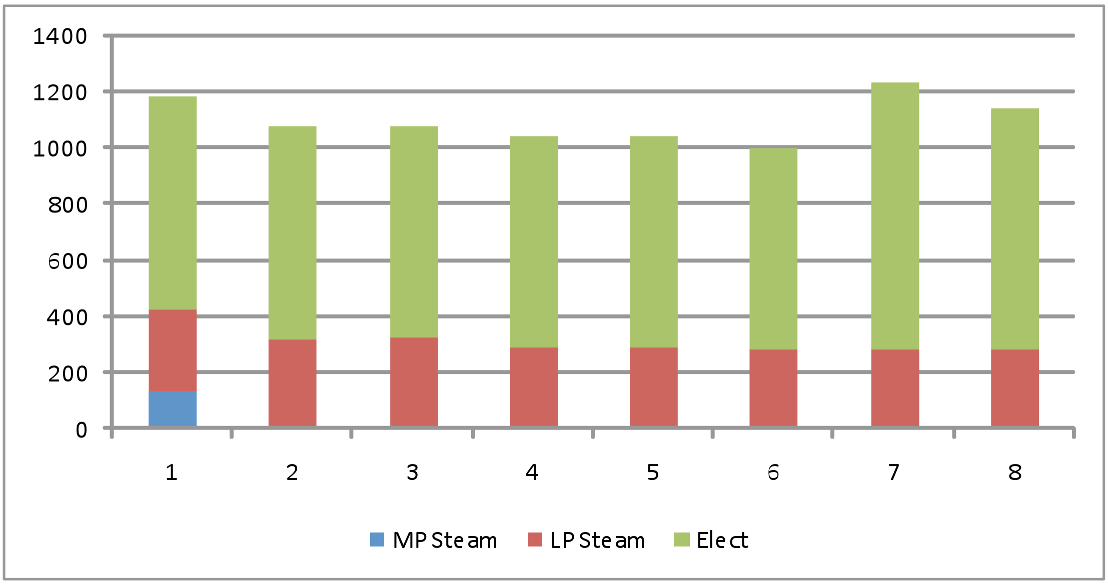
Not included in these graphs are reductions that cannot be modelled and have been estimated, such as repairing damaged pipework insulation and correcting faults with the BMS.



Graph 9.1.1 – Sequentially Applied Options 1 to 8, Annual Energy (kWh)



Graph 9.1.2 – Sequentially Applied Options 1 to 8, Annual Carbon Dioxide (tonnes)



Graph 9.1.2 – Sequentially Applied Options 1 to 8, Annual Costs (£ thousands)

The benefits of the various measures are not consistent across energy, carbon and running costs.

Energy: Options 2, 4 and 6 are the only significant reduction strategies (exhaust air heat reclaim and general building improvements)

Carbon dioxide: The significant savings come only from options 2 (laboratory heat reclaim and removal of MP steam) and 7 (grid electricity).

Annual running costs: Options 2, 4, 6 and 8 are significant (exhaust air heat reclaim and general building improvements and photovoltaics). Option 7, which gives the largest reduction in carbon dioxide emissions, is likely to increase costs.

10 Conclusions and recommendations

The Technology Centre is extremely atypical from an energy perspective and its energy consumption is extremely high, even for a research site. Because the site benefits from carbon-free waste heat from the adjacent Stanlow oil refinery, measures which save the most energy costs, such as heat reclaim, have no bearing on carbon emissions. Conversely, measures which save the most carbon, such as switching to the national grid for electricity, are likely to increase energy costs.

The site-wide energy consumption is not very sensitive to improvements in the building services and envelope design, suggesting that process loads, malfunctioning controls and losses from the site-wide low pressure steam network are the predominant factors.

Nevertheless, the solutions recommended here are likely to reduce carbon emissions by about 55 percent, significantly increase electrical resilience and make no overall increase in annual energy costs. The recommendations are:

Ref	Recommendation	Benefit	Indicative capex
A	Decommission the medium pressure steam heating and replace with low pressure.	Save c.2,274t.CO_2 and £9,000/year (£22 per tonne)	£50,000
B	Recover heat from exhaust air in laboratory and engine test buildings.	Save c.£96,000 / yr (simple repayment within c. 4 yrs)	£500,000
C	Replace all older light fittings (T8s and T12s) with high efficacy modern fittings incorporating high frequency control gear, photocell control, occupancy sensing and time-schedule switching.	Save c.£40,000 and c.600 t.CO_2 / yr (simple repayment: see note 1)	£2,000,000
D	Apply thermal insulation to all roof spaces to achieve a maximum thermal transmittance (U) value of 0.25 W/m2.K	Save c.£7,000 / yr (simple repayment within c. 15 yrs)	£100,000
E	Install optimum start and stop routines for heating plant.	Save c.£12,000 / yr (simple repayment within c. 4 yrs)	£50,000
F	Undertake a detailed survey of pipework thermal insulation and repair where necessary.	Save c.£5,000 / yr (simple repayment within c. 5 yrs)	£25,000
G	Switch to the national grid for electricity.	Save c.6,200 t.CO_2/yr EXTRA c. £229,000/yr	£nil
H	Undertake a full audit of the BMS and rectify all errors and replace or calibrate all sensors.	Unpredictable – could be extremely high or negligible Estimate 500 t.CO_2 and £60,000/yr	£20,000
I	Install a comprehensive energy sub-metering system, especially in the nine buildings that represent 80 percent of the site's electricity consumption, and establish targets for each sub-meter.	Allows problems and opportunities to be identified – could lead to very high savings.	£100,000
TOTAL		SAVES c.9,574 t.CO_2 /yr and £229,000 (note 2)	£3,845,000

Note 1: The c.£2,000,000 replacement cost and c,£40,000 annual saving from the lighting cannot be used as the basis to calculate a repayment period because these older fittings are approaching the end of their obsolescence period and would otherwise be replaced piecemeal over the next few years. What is being recommended here is to bring the expenditure forward in order to benefit sooner from the energy cost and carbon savings.

Note 2: The energy cost savings are approximately eliminated by the likely higher tariff for grid electricity. However Shell were already considering this for reasons of electrical resilience.

In order to gain insight into where the energy is being used, at what times and for what purposes, more detailed check-metering is required.

Any individual electrical load over 20 kW, such as chillers, large pumps and fans, lighting circuits, small power circuits, and test equipment, should be individually monitored. Each meter should be entered into a logbook and read at least monthly. Over time it will become very clear why the energy consumption is as high as it is, whether or not it is reasonable, and where to direct any further effort.

Each building should also be fitted with a heat meter fitted to the water side of any steam-to-water heat exchanger. Again these meters should be entered into a logbook and read at least monthly. The sum of all of these meters can also be compared against the site's steam meter to see what the distribution losses are.

Based on the information received, the site currently has an annual electricity consumption of 14,202 MWh with associated CO_2 emissions of 12,540 tonnes and a cost of £752,706. Added to this is 26,704 MWh of mostly carbon-neutral waste steam costing approximately £425,000 with annual CO_2 emissions (from the MP steam) of an estimated 2,274 tonnes. The total for the site is therefore **£1,177,706** and **14,814 tonnes CO_2**.

The expectations for the site, using benchmarks, is around 8,703 MWh electricity (circa £609,000 and 3,655 tonnes CO_2) and 9,210 MWh thermal (£276,000 and 2,440 tonnes CO_2) making a total of **£885,000** and **6,095 tonnes CO_2. The CO_2 emissions are therefore well over double and the costs about one-third (£293,000) higher than expected.**

The implementation of the recommendations will reduce CO_2 emissions by an estimated 9,574 tonnes (to **5,240 tonnes**) and annual energy costs by around £30,000 (to **£1,147,706**). The estimated capital expenditure is **£3,845,000** but most of this is not additional cost, but rather bringing forward expenditure that would otherwise be spent over the next five years in order to take early benefit from the available improvements.

11 Appendix A - Site survey 12th February 2009

11.1 Building 2 – Gymnasium

- DX cooling system
- Electric space heater
- Radiators
- T8 fluorescent lamps

11.2 Building 9 – Road test garage

- T8 fluorescent lamps
- Unit heaters
- Engine exhaust extract

11.3 Building 24 – [Offices and workshop]

- Some T12 fluorescent tubes and others that are much larger in diameter
- T8 fluorescent tubes to offices
- Manual light switching only, no occupancy- or daylight-sensing lighting control
- Radiator heating to office space
- No cooling
- Double glazing

11.4 Building 40 – Restaurant

- Single storey
- Significant areas of glazing, about 70 percent
- Double glazed
- Double-D compact fluorescent lamps
- Radiator heating, no cooling

11.5 Building 49 – Offices

- Three-storey office with fourth floor roof plantroom
- Half of one floor is a conference room with its own stand-alone DX cooling system
- Also contains a major IT equipment room that serves the whole site, also with autonomous DX cooling system.
- Office accommodation is mechanically ventilated with TRV-controlled perimeter radiators and no cooling (TRV means Thermostatic Radiator Valve).
- T5 fluorescent lamps, occupancy- and daylight-switching.
- Built late 70s/early 80s. Refurbished in 2008.
- Double glazed
- Appears to have a cross-flow heat reclaim recuperator

11.6 Building 55 – Engine test bay

- 16 test bays
- One full fresh air air-handling unit per test bay (16 units)

- Frost coil
- Cooling coil
- Heating coil
- Fan

- Four extract fans, no heat reclaim.
- Engines run against a load varied by dynamometers. Heat from the engine is rejected via the engine radiators to cooling towers, and heat off the dynamometers is rejected via water-cooled chillers.
- Dynamometer water-cooled chiller
    - Two units
    - Carrier Evergreen 19XR05004201 REV A
    - Model 02XR-277BGS52
    - R134a
    - Model SN 63232
    - 299 Amps per phase
    - Flow temperature at 11^{o}C
    - No “free-cooling” chiller bypass

- Six cooling towers, three engine radiator cooling and three for chiller heat rejection
- Low pressure steam to LTHW
- T8 fluorescent lamps with manual light switching only. No photocell- or occupancy-switching

11.7 Building 90 – Offices

- T8 lamps with local manual switching. No occupancy or daylight-sensing control
- Radiator heating, no cooling
- Single glazed with metal frames
- Looks early 1960s.

11.8 Building 97 – Labs with some offices

- Single storey
- T8 lamps with local manual switching. No occupancy or daylight-sensing control
- Radiator heating
- Fume cupboards but no general mechanical ventilation
- No cooling

11.9 Building 99 – Rolling road

- Electrically-powered rolling road
- Air-conditioning to simulate different climatic conditions

11.10 Building 101 – Offices

- Two storey
- T8 lamps with local manual switching. No occupancy or daylight-sensing control
- Heating but no cooling
- Looks early 1960s

- Sparsely occupied

11.11 Building 102 – Offices and laboratories

- Joined to building 90
- T8 lamps with local manual switching. No occupancy or daylight-sensing control
- Radiator heating, no cooling
- Single glazed with metal frames
- Looks early 1960s.
- Thermal insulation missing in plantroom, especially valves and some straight lengths

11.12 Building 104 – Archives and stores

Archives

- T5 lamps with local manual switching. No occupancy or daylight-sensing control.
- Specialised air-conditioning

Stores (similar to a warehouse)

- T8 lamps with local manual switching. No occupancy or daylight-sensing control.
- Unit heaters

11.13 Building 105 – Rolling Road

- Electrically-powered rolling road.
- Air-conditioning to simulate different climatic conditions.

11.14 Building 160 – Offices and warehouse

- Compact fluorescent lamps to reception, mainly T5 and T8 fluorescent lamps elsewhere but warehouse has T12 fluorescent lamps.
- Radiators with Thermostatic Radiator Valves (TRVs)
- Heated fresh air to warehouse

11.15 Building 300 - Energy centre

Serves buildings 301, 303, 304 and 305.

- Lots of thermal insulation missing around modified pipework. Valves and strainers not lagged at all.
- Very large air compressors for processes.
- Medium pressure steam to generate Medium Temperature Hot Water (MTHW).
- Two McQuay air-cooled chillers, out of service.
- Two Carrier air-cooled chiller
    - R134a
    - 350 kW absorbed power
    - Model 30GH260 0011EE
    - SN 12L417399
    - Manufactured 1994
    - Possibly suitable for evaporative cooling mesh

Figure A1.1 – chiller compound

Figure A1.2 – missing thermal insulation

11.16 Building 303 laboratory (304 and 305 are similar)

DIRTY CORRIDOR	LABORATORY MODULE	CLEAN CORRIDOR	OFFICE
Radiators	Air supply from clean corridor	Full fresh air air-con.	Radiators
Compact fluorescent lamps manually switched	Manual light switching per lab module	T8 fluorescent lamps, manually switched	T8 fluorescent lamps with local manual switching

- Built around 1996.
- Two-port control valves to heating and cooling coils, therefore variable speed pumps.
- Five fresh air air-handlers; one for each lab module, comprising very large builderswork inlet plenum, frost coil, supply fan with diffuser plate, cooling coil, re-heater, humidifier, and large supply air plenum.
- No heat reclaim off extract air
- Three very large centrifugal extract fans to vertical discharge stacks.

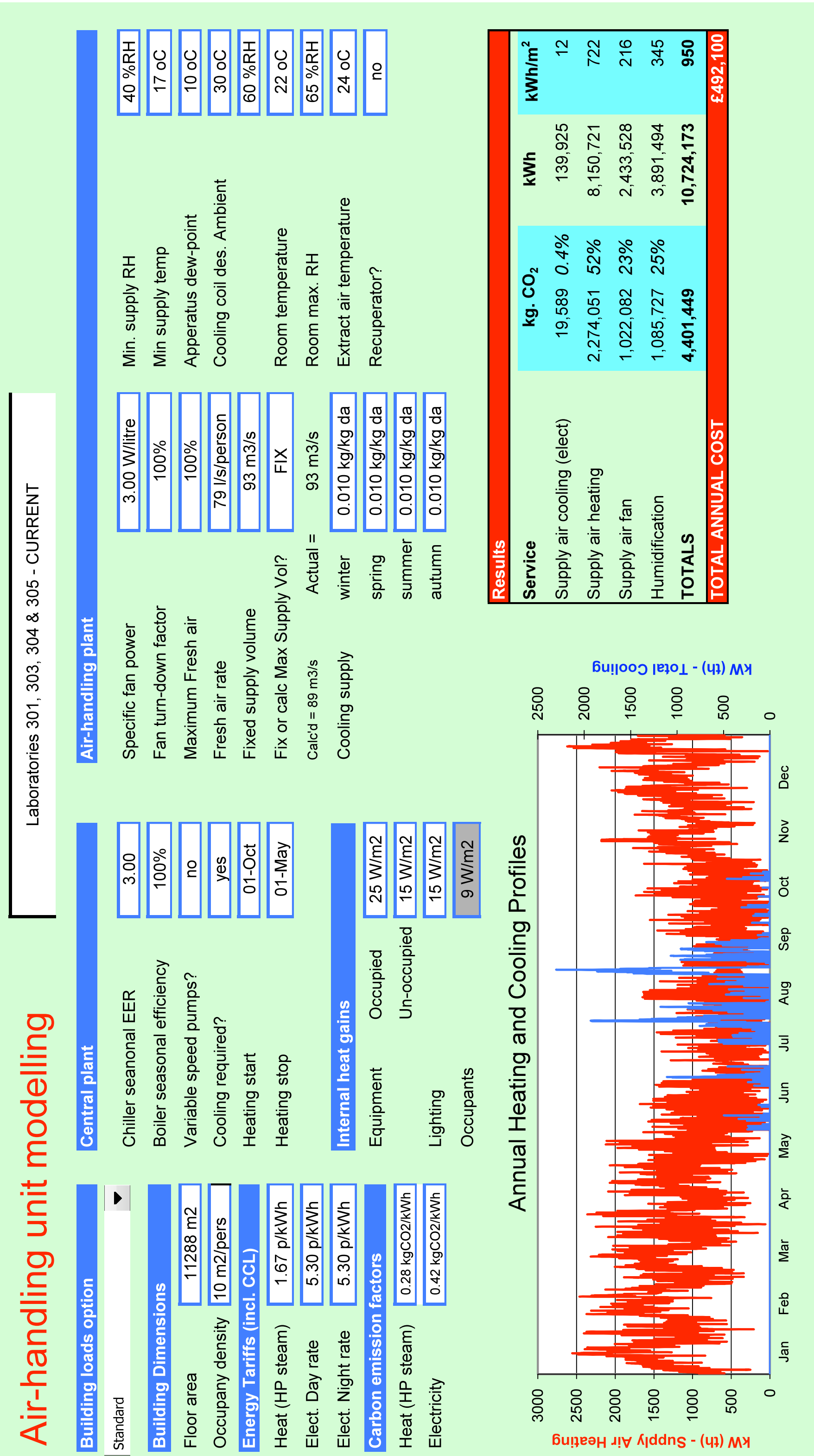
Figure A1.3 – a typical fresh air air-handler serving one laboratory module

Figure A1.4 – a number of laboratory fresh air air-handlers in a row

12 Appendix B - Modelling Data

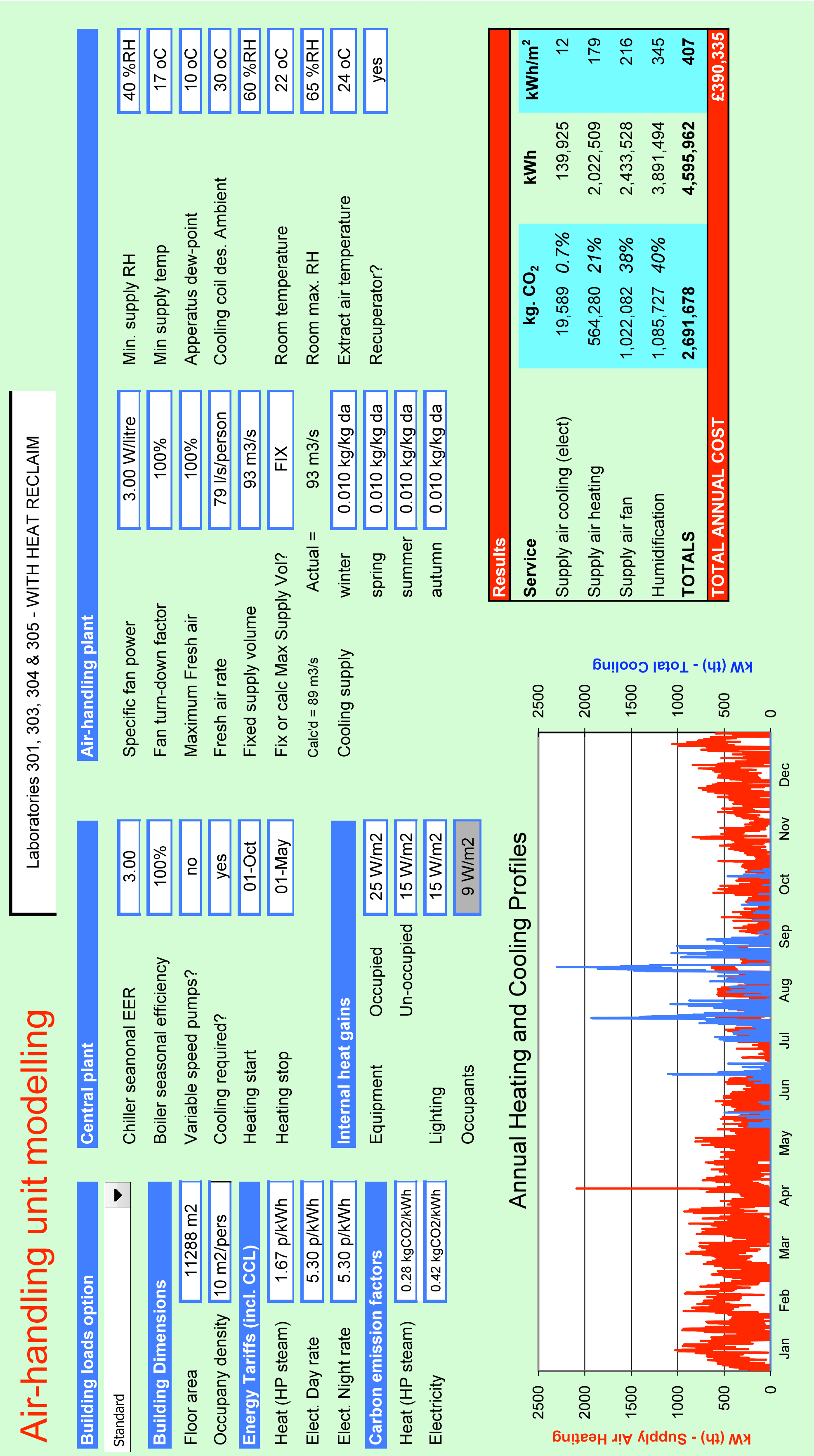
12.1 Laboratory Supply

Current



Service	kg. CO_2		kWh	kWh/m²
Supply air cooling (elect)	19,589	0.4%	139,925	12
Supply air heating	2,274,051	52%	8,150,721	722
Supply air fan	1,022,082	23%	2,433,528	216
Humidification	1,085,727	25%	3,891,494	345
TOTALS	**4,401,449**		**10,724,173**	**950**
TOTAL ANNUAL COST				**£492,100**

With heat reclaim



Air-handling unit modelling

Laboratories 301, 303, 304 & 305 - WITH HEAT RECLAIM

Building loads option	
Standard	
Building Dimensions	
Floor area	11288 m2
Occupancy density	10 m2/pers
Energy Tariffs (incl. CCL)	
Heat (HP steam)	1.67 p/kWh
Elect. Day rate	5.30 p/kWh
Elect. Night rate	5.30 p/kWh
Carbon emission factors	
Heat (HP steam)	0.28 kgCO2/kWh
Electricity	0.42 kgCO2/kWh

Central plant		
Chiller seanonal EER		3.00
Boiler seasonal efficiency		100%
Variable speed pumps?		no
Cooling required?		yes
Heating start		01-Oct
Heating stop		01-May
Internal heat gains		
Equipment	Occupied	25 W/m2
	Un-occupied	15 W/m2
Lighting		15 W/m2
Occupants		9 W/m2

Air-handling plant				
Specific fan power		3.00 W/litre	Min. supply RH	40 %RH
Fan turn-down factor		100%	Min supply temp	17 oC
Maximum Fresh air		100%	Apperatus dew-point	10 oC
Fresh air rate		79 l/s/person	Cooling coil des. Ambient	30 oC
Fixed supply volume		93 m3/s		60 %RH
Fix or calc Max Supply Vol?		FIX	Room temperature	22 oC
Calc'd = 89 m3/s	Actual =	93 m3/s	Room max. RH	65 %RH
Cooling supply	winter	0.010 kg/kg da	Extract air temperature	24 oC
	spring	0.010 kg/kg da	Recuperator?	yes
	summer	0.010 kg/kg da		
	autumn	0.010 kg/kg da		

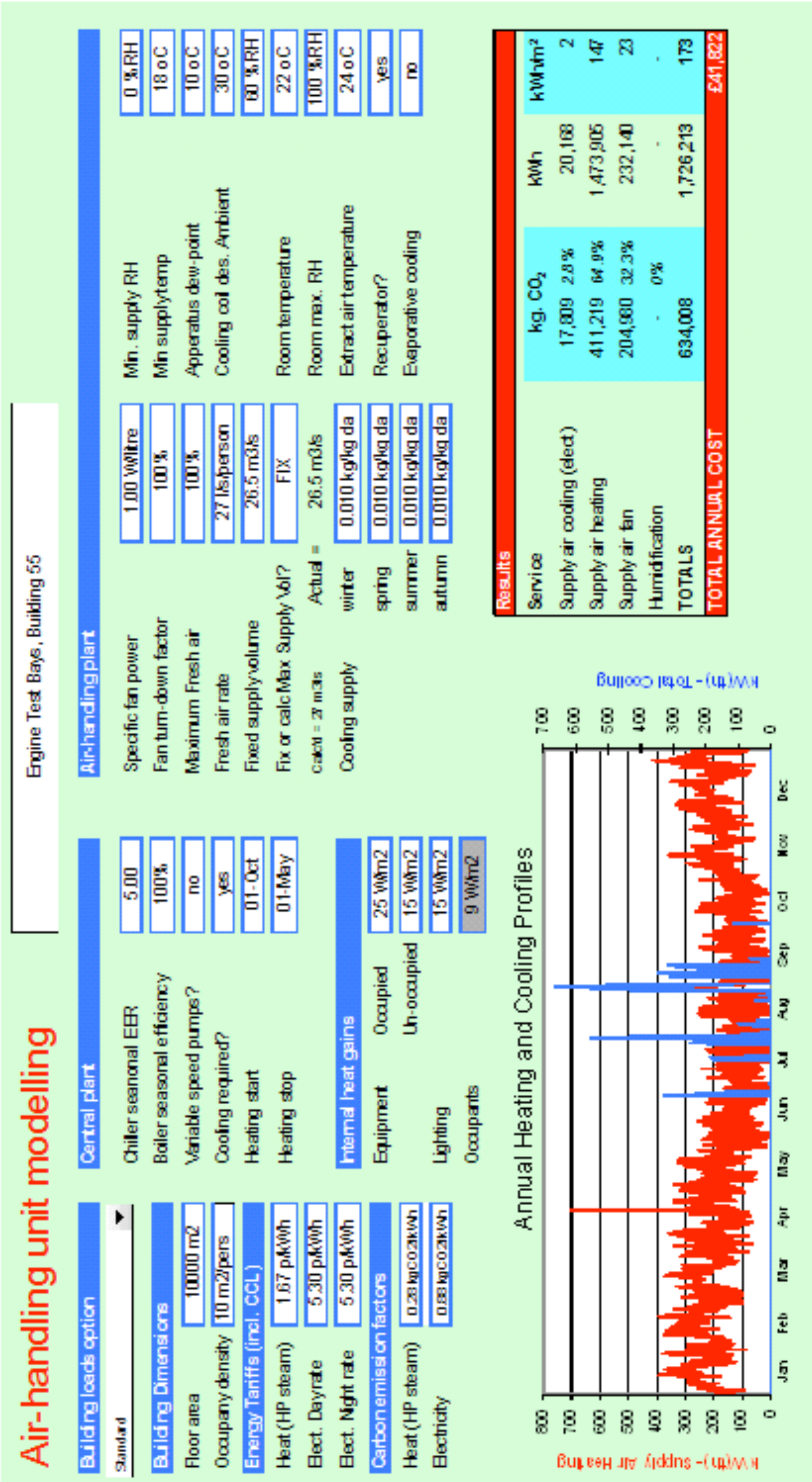
Annual Heating and Cooling Profiles

Results

Service	kg. CO_2		kWh	kWh/m^2
Supply air cooling (elect)	19,589	0.7%	139,925	12
Supply air heating	564,280	21%	2,022,509	179
Supply air fan	1,022,082	38%	2,433,528	216
Humidification	1,085,727	40%	3,891,494	345
TOTALS	**2,691,678**		**4,595,962**	**407**
TOTAL ANNUAL COST				**£390,335**

12.2 Engine test bay

Recuperator



Evaporative Cooling (for cooling only - ignore heating results on this model)