The Carbon Advisory Service Ltd
5 Westhill Court
Millfield Lane
London
N6 6JJ
United Kingdom
Office +44(0)20 8347 0800
Fax +44(0)20 8347 0801
www.carbonadvisoryservice.com

Low Carbon Energy Strategy for Shell HQ, Aberdeen

by The Carbon Advisory Service Ltd, June 2010

Revision history

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2				
3				
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Contents

1 Summary

The Carbon Advisory Service (CAS) was commissioned by Shell Real Estate to undertake an energy review of their headquarters building at Tullos, Aberdeen, AB12 3FY.

The site comprises four buildings linked together with footbridges and known as Phases One, Three, Four and Five (phase two was never built or was subsumed into other phases). Additionally there is the Central Services Building and a laboratory which are outside the scope of this assignment.

The site was developed between the late 1970s and early 1980s, with a variety of heating, cooling and air-conditioning solutions, ranging from mechanical ventilation to large centralised air-conditioning plant.

Current record documentation is scarce and difficult to find, therefore this report is based mainly on a non-intrusive survey and anecdotal information.

As an overview, the plant and engineering systems are generally tired and in need of replacement, which provides an opportunity to use the plant replacement budget to improve the energy efficiency of the site.

Often within a given system comprising a number of different components, each component will require replacement at different times. The default action is to replace components like-for-like so that over time, the entire system is replaced with new versions of the original equipment, resulting in a new version of an old concept repeated in perpetuity.

The proposed strategy is to develop a longer-term energy-efficient vision for each building, so that when individual components are replaced, they are suitable for the longer-term vision as well as being able to work with the older components. In this way, over time the building will evolve, or morph, into a 21st Century low-carbon building without significant extra cost or disruption.

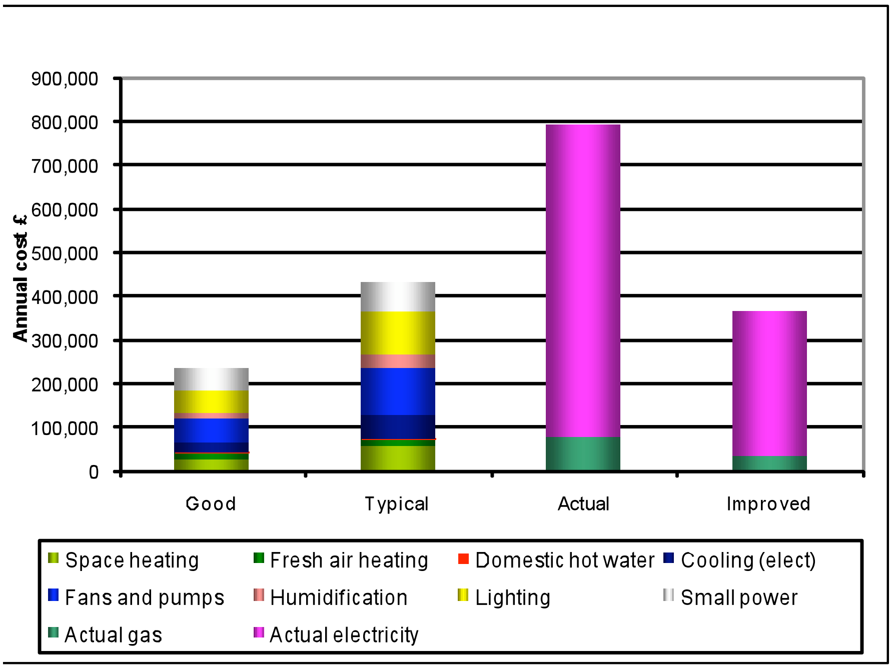
The headline issues are:

1. The site is costing about double that which would normally be expected (a waste of around £400K per year).
2. Cooling could be “free” for about 92 percent of the year using evaporative cooling or fresh air mixing.
3. The BMS has a large number of irregularities.
4. The Phase Three building is using a dilapidated air-conditioning system reliant upon an almost obsolete refrigerant that is leaking excessive amounts of greenhouse gases directly into the atmosphere and will need to be replaced by 2015, at the latest, if it does not fail suddenly before that.

5. The Phase Five air-conditioning system is unlikely to deliver adequate fresh air and very likely to be operating inefficiently with wasteful re-heat following unnecessary cooling and high fan power.
6. Exhaust air heat reclaim has generally not been installed where it could be gainfully deployed.
7. Boiler plant is not as efficient as it could be.
8. Improvements could be made to lighting control.
9. Plant starts at 04:50, including fresh air plant, without any optimised start and stop routine.
10. Record information is out-of-date.
11. Conflict is likely in Phase Five between perimeter heating and mechanical cooling.
12. There is an electrical base load of almost 1,000 kW, which is about three-quarters of the average load during the day. This is very high.

The recommendations of this report produce estimated annual savings of 4580 MWh electricity, 2012 MWh gas, representing c. 3000 tonnes of CO_2 and around £368K of energy costs. The additional capital expenditure is estimated at £365K suggesting ostensibly a repayment period of one year; however in practice the expenditure and savings will occur over a longer period because the recommendations make use of the natural plant replacement budget.

Occupation density	10 m^2/person (assumed)		Floor area	24,590	m^2
Fresh air vent rate	10 l/s/person		Elect mean rate (incl. CCL)	7.26	p/kWh
Supply temp	20 °C		Elect day rate (incl. CCL)	7.34	p/kWh
Operating hours	12 hours/day	5 dys/wk	Elect night rate (incl. CCL)	5.04	p/kWh
			Gas unit rate (incl. CCL)	1.59	p/kWh



0% Naturally ventilated cellular
0% Naturally ventilated Open-plan
100% Standard air con.
0% Presige air con.

Graph 7.1, Existing and Improved relative to Good and Typical Practice Benchmarks (ECG 19)

2 Introduction

The Carbon Advisory Service Ltd (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. 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 taken to be:

- 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.

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 CAS would be happy to assist if required under additional appointments.

This report is written to be accessible to both the technical and non-technical reader. Where possible technical terms are avoided in favour of plain English, even if this means some loss of technical exactitude in favour of clarity.

The report is structured in layers of detail with the technical sections limited to the appendices and Section 6 – Referenced Technologies. The executive reader can avoid these sections without missing the main strategic advice.

3 General description of the site

The site is the Shell, Tullos, Aberdeen, AB12 3FY
1.4 miles from Aberdeen railway station, off the A956 (Wellington Road). At the Nigg roundabout. Take the Hareness Road, then Altens Farm Road.

Figure 3.1.1 – Location map

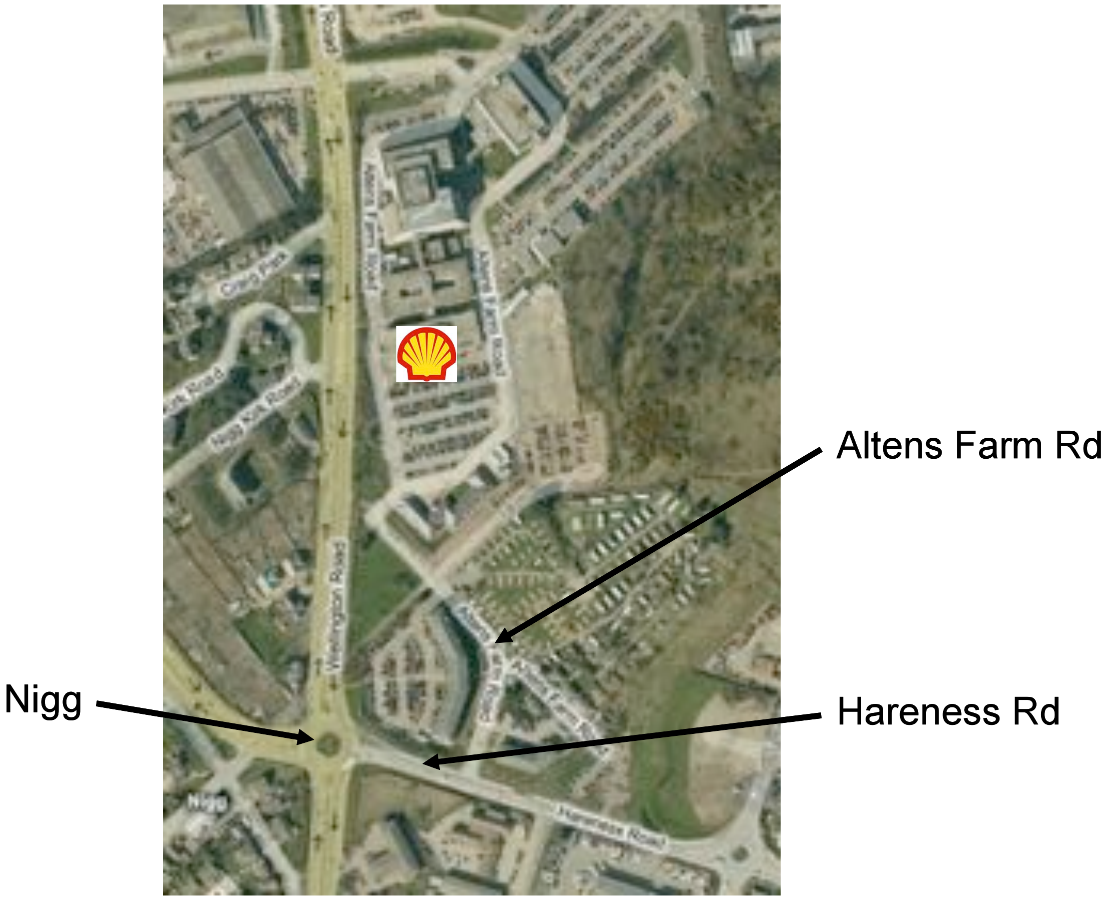


Figure 3.1.2 – Aerial View of Site

The site comprises four buildings linked together with footbridges and known as Phases One, Three, Four and Five (phase two was never built or was subsumed into other phases). Additionally there is the Central Services Building and a laboratory which fall outside the scope of this assignment.

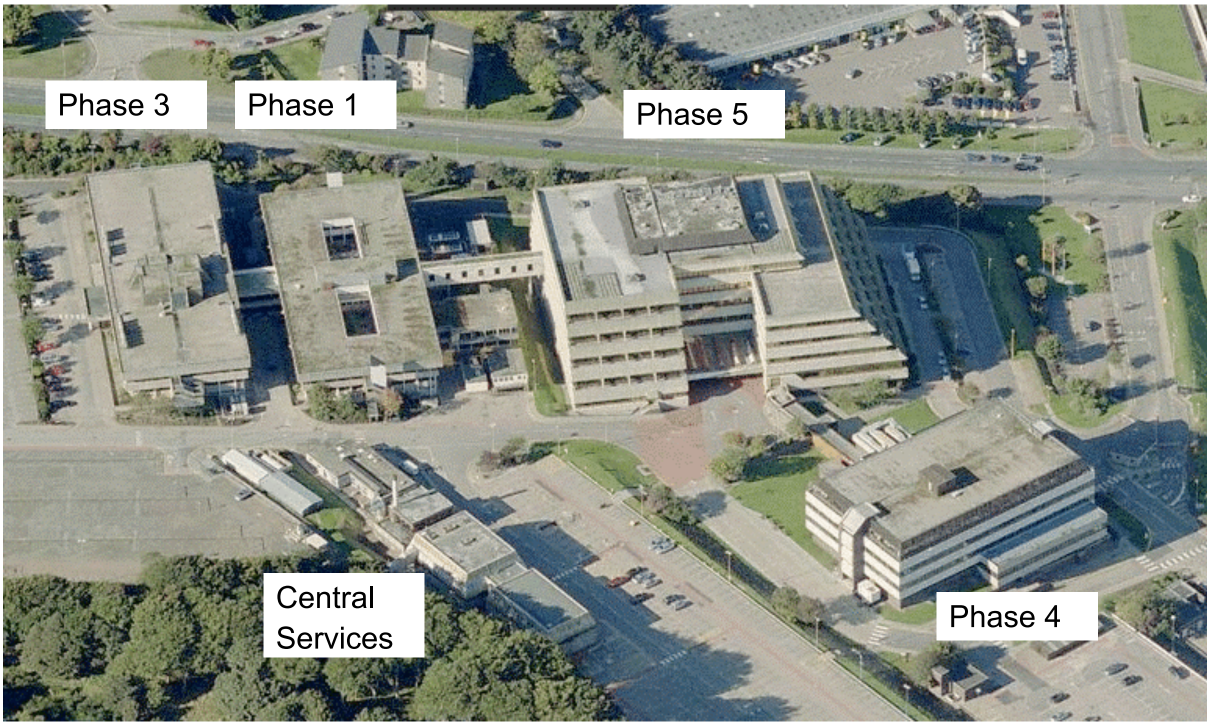


Figure 3.1.3 - Phases One, Three, Four and Five, plus Central Services.

Phase One was completed around 1977 and comprises 2624 m² over floors basement, ground and first wrapped around two atria. It is heated and mechanically ventilated, but has no cooling and reportedly over-heats in summer. Apparently it is due for refurbishment using chilled beams.

Figure 3.1.4 – Phase One

Phase Three comprises 3390 m² over floors basement, ground and first. It is very similar in appearance to Phase One, but with no atria.

Figure 3.1.5 – Phase Three

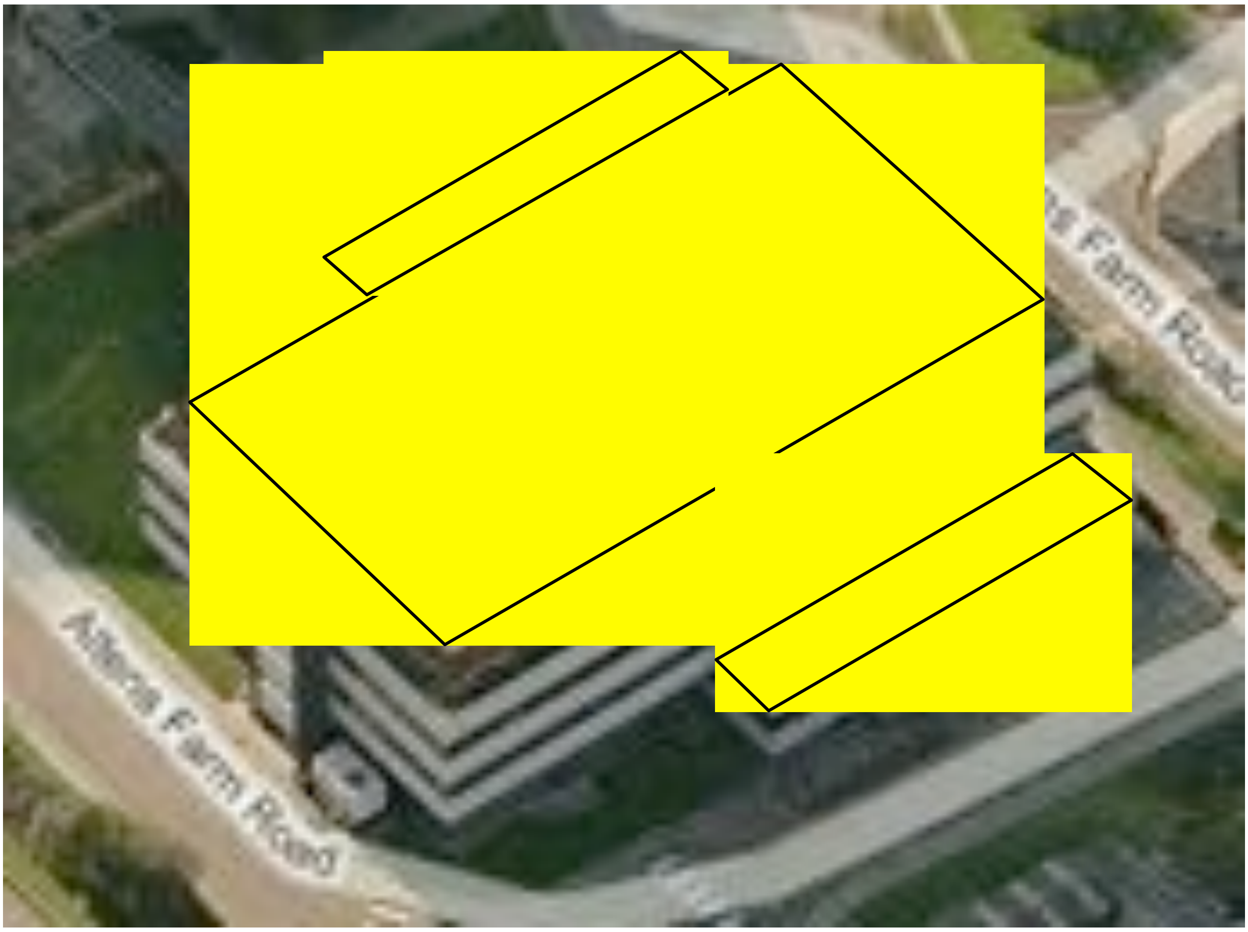


Figure 3.1.6 – Phase Four

Phase four comprises 5806 m² over floors basement, ground and first to third.

Figure 3.1.7 - Phase Five

Phase Five comprises 11,584 m² over floors basement, ground and first to fourth.

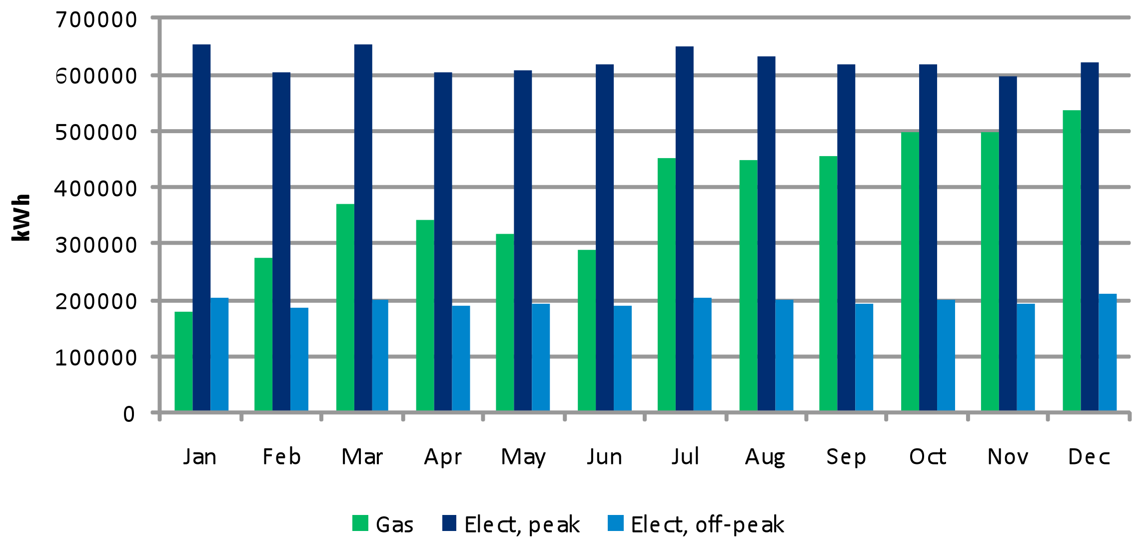
4 Benchmark analysis

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 offices is *Energy Consumption Guide 19 – Energy Use in Offices (ECG 019)*.

Graph 4.1.1 below shows the monthly electricity and gas consumption for the entire site, including the laboratory and Central Services Block which were not surveyed. Unfortunately there is no more detailed breakdown, but at only 1013 m² and 173 m² respectively, the laboratory and Central Services are very unlikely to significantly influence the results amongst a total surveyed area of 23,400 m².



Graph 4.1.1 – Monthly electricity and gas consumption 2009 for Phases 1, 3, 4 & 5, the Lab and CSB

Electricity consumption hardly varies at all across the year. Based upon the near-constant off-peak demand, an electrical base load of 930 kW can be deduced relative to a peak-rate (daytime) mean of 1204 kW. This means that the base load is about three-quarters of the mean daytime usage (very high).

The off-peak period lasts only seven hours per day and accounts for about one-quarter of total electricity consumption. All of this suggests very little variation due to time of day or time of year.

The results are now compared relative to the ECG benchmark data, shown in graph 4.1.2 below.

Occupation density	10 m²/person (assumed)		Floor area	24,590 m²
Fresh air vent rate	10 l/s/person		Elect mean rate (incl. CCL)	7.26 p/kWh
Supply temp	20 °C		Elect day rate (incl. CCL)	7.34 p/kWh
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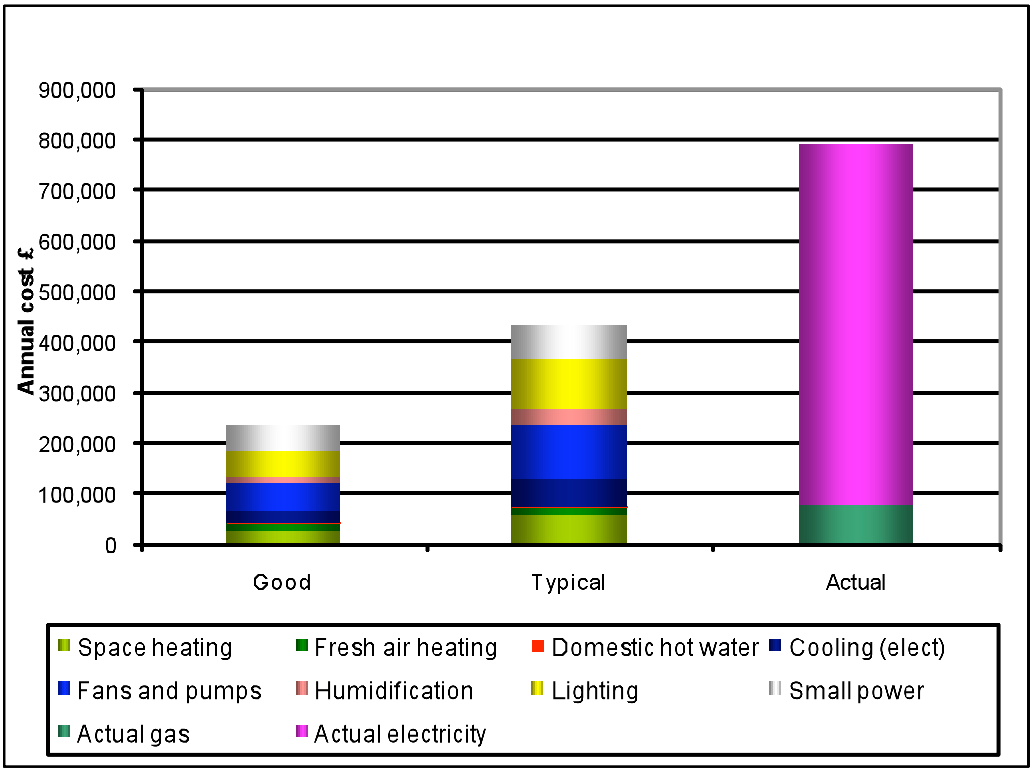

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Graph 4.1.2 – Actual electricity and gas consumption (year 2009) relative to national benchmark data (ECG 019) – corrected for the laboratory and the Central Services Building

Gas consumption is approximately as expected but electricity consumption is about double that of typically performing office accommodation of the same size and type.

Total site annual gas consumption: 4,657,798 kWh over 24,590 m² (189 W/m²).
Total site annual electricity consumption: 9,842,268 kWh over 24,590 m² (400 W/m²).
Surveyed area: 23,400 m² (95 percent of total).

5 Commentary

5.1 General

The detailed survey is provided in appendices A and B, some of which is unavoidably technical. This section is more of a discussion about what was found and is deliberately less technical. Technical readers, or those wishing to verify comments made in this section, are advised to also read the appendices; other readers may find no need to do so.

Rather than repeat technology descriptions over again where they are relevant to more than one phase, descriptions are provided in Section 6 – Technologies Referenced. Referenced technologies are written in italics.

5.2 General improvements

In general the following recommendations apply. Descriptions of technologies can be found in Section 6 – Technologies Referenced:

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 reliance upon 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, unless the building was being re-clad or re-glazed owing to age and condition.

b. Ensure that any loft spaces are insulated to at least 0.20 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 pipework and add insulated jackets to valves, strainers and the ends of calorifiers.

g. *Exhaust air heat recovery* – see Section 6 – Technologies Referenced.

h. *Evaporative cooling* – see Section 6 – Technologies Referenced.

i. Provide electricity sub-meters with half-hourly data logs and an energy management plan/strategy to identify waste, especially the high base load. Refer to Appendix C.

5.3 Cooling, heating and ventilation

5.3.1 Phase One

General

Phase One is mechanically ventilated and reportedly over-heats in summer. At the time of the survey it was being re-clad and insulated.

The re-cladding and insulating of the building is a very good measure for a building of this age. When re-cladding the envelope it should meet the current standards of the Building Regulations for the Conservation of Fuel and Power (Part J in Scotland). However, as an unintended consequence, this might exacerbate the summer over-heating problem and trigger a move towards mechanical cooling. Once mechanical cooling is installed, there is a tendency for its use to creep from summertime peaks, to more moderate weather not previously considered uncomfortable. Apparently, chilled beams are currently being considered.

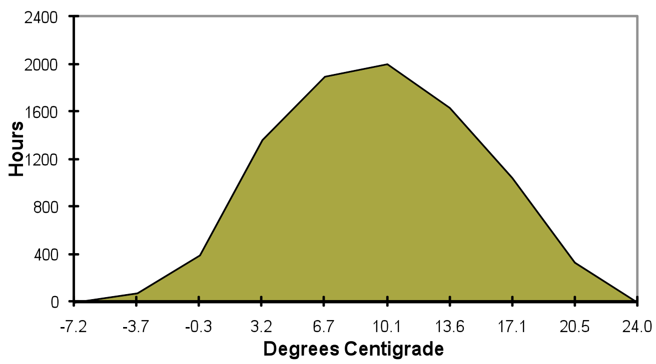
Cooling

This sub-section considers ways of avoiding excessive summertime temperatures without relying completely on mechanical cooling solutions.

Mechanical cooling systems can be thought of as machines that *manufacture* cool air. In comfort applications, this air can be as cool as 12 °C for extreme office applications such as trading floors, but 14 °C is more common for standard office applications and 17 °C would usually suffice (see tech bubble).

Tech Bubble
15 air changes per hour with a room temperature of 24 °C and supply temperature of 17 °C delivers over 90 W/m²

A review of the weather file for Aberdeen reveals that the outside air temperature exceeds 17 °C for less than four percent of the year. Therefore any air-conditioning system should be designed and controlled to operate for no more than four percent of the year: otherwise it will be *manufacturing* cool air that's warmer than the air outside the windows and inside the atria. This would make no sense at all, although this in fact is what usually happens.



Graph 5.3.1, Frequency of Dry-Bulb Temperature Occurrence, Aberdeen

If the report was prepared prior to the re-cladding, then a wider range of options would have been considered around the various ways of letting air into the building in a controlled fashion to provide "free" cooling. If other phases are to be re-clad, these alternatives should be considered. However for Phase One, discussion will be limited to the options currently available.

As an alternative to using cool air directly, use can be made of the ambient wet-bulb temperature. Wet-bulb temperature is the temperature measured on a standard mercury-in-glass thermometer when water is allowed to evaporate off the bulb. This evaporation has the effect of lowering the measured temperature. The dryer the outside air, the more readily the water will evaporate, and the lower the recorded temperature will be. Wet-bulb temperature is, in effect, a measure of how readily heat can be lost through evaporation (think of it like perspiration).

With carefully selected evaporative equipment, evaporation can be used to generate cool supply air whenever the ambient wet-bulb is below 12.5 °C. An evaporative cooling solution would therefore provide an environment just as good as conventional air-conditioning for about 92 percent of the year, but with virtually no energy consumption.

Quite a large area of the flat roof would be required for the evaporative coolers and a structural engineer will need to assess the roof loading.

For more complete technical details, refer to Section 6 - Technologies Referenced.

Heating and ventilation

Although installed quite recently, the existing boilers are not very efficient by modern standards. They have a Gross Seasonal Efficiency of just 82.4 percent, whereas a good modern condensing boiler can get into the low 90 percents and it is quite possible to achieve around 97 percent with the right boiler and a carefully crafted design (see Section 6 – Technologies Referenced)

The boilerhouse is apparently temporary providing an opportunity to improve on this when the permanent replacement is designed. A Gross Seasonal Efficiency of at least 95 percent should be targeted, giving a saving of 15 percent.

Mechanical ventilation is used without heat reclaim in a building that is ideally suited to natural ventilation from its two atria. The advantage of natural ventilation is avoidance of fan power, and the main advantage of mechanical ventilation is the potential for heat reclaim, but this building has the worst combination of both.

There are several common ways of transferring heat between warm exhaust air and cool fresh air. For more complete technical details, refer to Section 6 – Technologies Referenced

5.3.2 Phase Three

Heating and cooling

This building is fitted with an aged heat pump (three pipe) VRF (Variable Refrigerant Flow) system which is leaking large quantities of refrigerant R-22 into the atmosphere. R-22 is a greenhouse gas 1,700 times more potent than CO_2, therefore the reported 100 kg leaked last year is equivalent to 170 tonnes CO_2. 170 tonnes of CO_2 is the same as the emissions produced when 312,500 kWh of electricity is consumed, which is sufficient to power about 70 family homes for one year. Moreover, it is currently illegal to purchase virgin R-22 and recycled R-22 will be illegal by 2015, if not sooner.

The condenser units have suffered severe corrosion due to their proximity to the coast, and in any event, the installation is now 15 years old, which puts it at the very end of the normal economic life for this type of system. In fact, this system most likely reached that stage a number of years ago.

With plant of this age and condition, there is a risk of sudden irreparable failure requiring significant plant replacement. If the plant is allowed to fail, there will be little time to consider alternative strategies for its replacement, under which circumstances it is usual for the latest version of the older equipment to be installed on a like-for-like basis – this would be a significant lost opportunity to improve the energy performance of the building.

If there are plans to re-clad the building, as in Phase One, then it might be worth spending a little more to insulate the envelope to the point that winter heat gains off-set heat losses for say, 90 percent of the heating season. CAS can provide thermal modelling to establish what the thermal performance of the envelope would need to be. At this point, heating becomes a minor load and cooling is the bigger consideration.

Irrespective of whether or not the building is to be re-clad, mechanical cooling should be avoidable for most office applications in Aberdeen. Evaporative cooling, the details of which are provided in Section 6 – Technologies Referenced, is capable of providing a very low energy solution.

Ventilation

No device has been installed to reclaim heat from the warm exhaust air. There are a number of ways to do this, the most common of which are described in Section 6 – Technologies Referenced.

5.3.3 Phase Four

Heating and cooling heat-pump units transfer energy to and from an “energy loop” which is maintained between 15 and 30 °C using conventional boilers and air-cooled chillers. This type of system allows heat to be transferred around the building from places where there is too much (units in cooling mode), to places where there is insufficient (units in heating mode), with only the building-wide nett imbalance being made-good from conventional energy sources. This has many of the benefits of VRF but without the disadvantage of extended refrigerant circuits.

Although it was not possible to determine from the survey, this system is probably manufactured by Versatemp who had cornered this market at about the time the system was installed.

The most significant missed opportunity here is using conventional chillers to maintain the energy loop at a maximum of 30 °C. There is no time in the year when this could not be achieved with evaporative cooling. In fact, there is no time in the year when it could not be maintained below about 22 °C, at which temperature the individual heat pumps would have very little work to do (see Section 6 – Referenced Technologies). Where there is a nett cooling load, evaporative coolers could be used to drive the temperature of the energy loop down towards 15 °C and the air-cooled chiller could be disconnected.

The second missed opportunity is using conventional boilers to heat the loop to 15 °C. A good condensing boiler would maintain 15 °C in the loop with a gross efficiency of almost 100 percent, rather than the c.80 percent being achieved currently (see Section 6 - Reference technologies)

5.3.4 Phase Five

The existing system is a Carrier Moduline Variable Air Volume (VAV) system. Although often marketed as energy-efficient due to their ability to reduce fan power and achieve "free" cooling by blending the optimum proportion of fresh and recirculated air, the truth in practice is that these systems can be extremely inefficient with very high fan power and wasteful re-heating following unnecessary over-cooling. This is described in detail in Appendix A and Section 6 – Referenced technologies). Carrier Moduline is a 50 year-old technology (patent granted 1961), and a very basic form of VAV.

Details on the VAV system could not be established during the site survey, and since the survey, only the following additional information could be found:

- The Air handling units have a design off temp of 13 °C and a boost temp of 17 °C when outside air falls below 6 °C.

All-air systems served from central plantrooms invariably have high fan loads. Even though the installed power of the fan is usually small relative to the chiller and boiler (in terms of kW), the fans run continuously (albeit at variable speed) and are therefore often the largest single energy consumer of the system (in terms of kWh).

Reducing the peak air flow rate reduces the ability of the system to achieve the required supply temperature from blending alone, which is unfortunate; however it also brings a disproportionately large reduction in fan power. For instance; if the flow rate reduces by just 10 percent, the fan power will reduce by almost 30 percent.

The temperature re-scheduling strategy off the air-handling unit is very basic and likely to produce wasteful over-cooling followed by wasteful room re-heating. Air leaves the air-handling unit at 13 °C unless the outside air falls below 6 °C. For about 25 percent of the year, a supply temperature of 13 °C would require mechanical cooling. If this air is too cool for the conditioned space, even after the Moduline units have throttled the supply air to minimum, then the room will either over-cool (wasteful and uncomfortable), or otherwise the in-duct and perimeter heaters will operate (wasteful over-cooling followed by wasteful re-heating).

The existing arrangement is unlikely to ensure adequate fresh air to all parts of the conditioned space without significantly over-providing fresh air to the whole building with the associated energy implications.

The strategy for this system therefore needs to reduce fan power without increasing heat and cooling loads. In this regard, the following strategy is recommended:

- Establish the air flow rates, either by locating the relevant record information, or by taking new measurements. This information could not be found on the site survey or from subsequent searches.

- Reduce the peak air flow rate as much as possible to reduce fan power.
- The minimum fresh air should be set by CO_2 sensors to ensure a maximum CO_2 concentration of 1000 ppm (see section 6, Technologies Referenced)
- Provide evaporative cooling, as described in detail in Section 6 – Technologies Referenced.
- Provide heat reclaim between supply and exhaust air streams, as described in detail in Section 6 – Technologies Referenced.
- Monitor the system to check for simultaneous heating and cooling throughout the summer. If a serious problem exists, the temperature re-scheduling programme should be enhanced. This will all depend upon the idiosyncrasies of the building and occupation patterns.

The combination of evaporative cooling and heat reclaim will more than compensate for the system's reduced ability to achieve the supply temperature set-point through blending fresh air recirculated air.

If and when the system is due for a total replacement, then it is recommended that the VAV system be completely replaced with a fresh air-only system and local terminal units operating on elevated chilled water temperatures, such as chilled beams or dry fan-coils (see Section 6 – Technologies Referenced).

6 Technologies Referenced

This section describes the technologies referenced throughout this report.

6.1 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 1.80 $W/m^2.K$ and a good roof would be 0.20 $W/m^2.K$.

6.2 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.

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.

6.3 High frequency control gear

Fluorescent tubes require control gear to start the lamp, stabilise the current and improve the power factor. Older fittings, prior to the early 1990s, 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, for instance plantrooms, because high frequency control gear will avoid "strobing" which can make a spinning wheel or machine appear stationary.

6.4 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 extinguished 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 and other spaces where personnel may be shielded from the sensor by plant or equipment and in potentially hazardous 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.

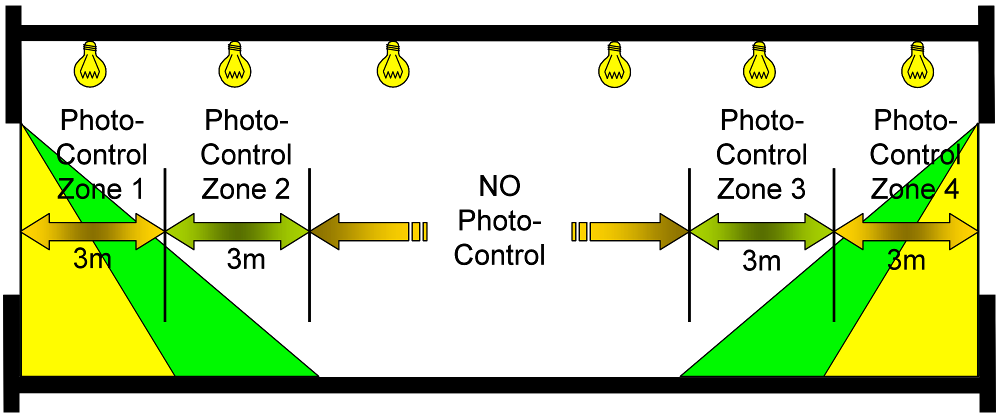


Figure 6.4.1 – Photocell Lighting Control Zoning

6.5 Exhaust air heat recovery

Exhaust air leaving heated accommodation can be used to pre-heat the incoming fresh air to around 13 °C using nothing more than a modest increase in fan power. There are a number of ways of achieving this, but the most passive is a cross-flow heat recuperator, also known as a plate heat exchanger.

A recuperator consists of slim air passageways divided by a thermally-conductive material (sometimes paper), through which cold outside and warm return air are alternately passed. The warm exhaust air transfers heat to the cold incoming air.

The colder the outside air, the more efficient the recuperator, and it is common for the incoming air to leave the recuperator warmer than the exhaust air – this condition occurs when condensation is formed on the recuperator, in which case latent energy is also transferred[1].

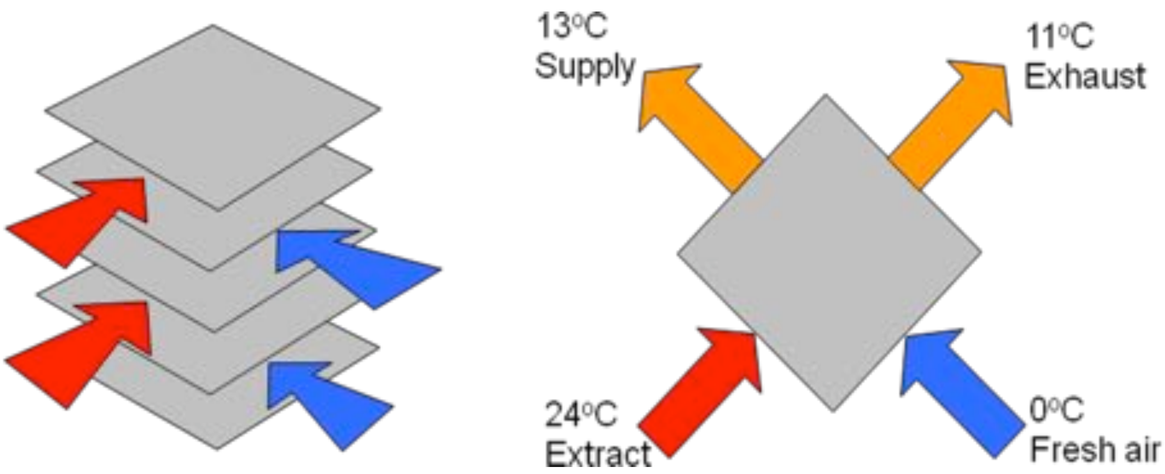


Figure 6.5.1 – Cross-flow recuperator

Other methods are thermal wheels and run-around coils which require less space.

6.6 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 plant 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.

6.7 Local plant overrides

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. Over time plant can be left running at night and weekends even though there is no occupancy.

6.8 Ultra-efficient boilers

The ubiquitous boiler operating temperatures of heating systems is 82 °C flow and 71 °C return, this being 180 to 160 °F, which was chosen years ago because it provided a good differential for gravity circulation. In other words, the industry still routinely specifies conditions that have not been relevant since the advent of the circulating pump.

[1] Latent energy is energy associated with a change of phase from vapour to liquid or vice versa. Sensible energy is energy associated with a change of temperature.

The choice of operating temperature is very important to energy efficiency and to the system's economics. The efficiency of a condensing boiler is very much related to the temperature of the return water and should always be below 60 °C, if not below 50 °C.

The temperature that is critical for the sizing of heat emitters is closely related to the median water temperature (half way between the flow and return[2]).

Increasing the temperature difference between flow and return allows the return water temperature to drop two degrees for every one degree dropped by the medium water temperature. Since it is the medium water temperature that influences the size of heat emitters, this approach combines high efficiency with moderately sized heat emitters, as the following examples will show:

Example one, normal practice

82 °C flow and 71 °C return. Median is 76.5 °C.

Example two, drop flow temperature at constant differential

72 °C flow and 61 °C return. Median is 66.5 °C.

Example three, Constant flow temperature at wider differential

82 °C flow and 61 °C return. Median is 71.5 °C.

Examples two and three have the same return water temperatures, so the same boiler efficiencies. However example three has a higher median water temperature, therefore smaller heat emitters. It also has about half the water flow rate, which means half the pumping power and smaller pipes.

Most modern boilers can comfortably tolerate a temperature differential of 20 °C, but a few have no limit at all, in which case the maximum differential is dictated by the need to maintain turbulent flow through heat exchangers.

A hybrid is to have a variable speed pump that operates with a smaller temperature differential on very cold days, switching to a wider differential on mild days. The controls and hydraulics of this need to be carefully considered, but this gives the best of both options.

Suitable boilers are Hoval's UltraGas and Viessmann's Vitocrossal.

6.9 Direct Expansion (DX) or Split Unit

In its most basic form, Direct Expansion is a proprietary refrigeration system "split" into two parts: a room cooling unit (fan-coil unit) and an outdoor heat rejection unit.

Where one outdoor unit supports more than one indoor unit, this is called a multi-split.

These units can be used as *heat pumps*, sometimes called "reverse cycle".

[2] For purists, the relevant temperature is the logarithmic mean water temperature but this closely approximates to the median.

Indoor unit

Outdoor unit

6.10 Variable Refrigerant Flow (VRF)

Sometimes called Variable Refrigerant Volume (VRV) but this is a trade name of Daikin.

In their simplest form they are just like large multi-splits, but their real advantage comes with the versions that can provide simultaneous heating and cooling across a number of room units. These were called three-pipe systems, because they used three refrigerant pipes rather than two, but at least one manufacturer has managed to achieve this effect with two pipes. In the absence of a better term, the term “three-pipe” survives for now.

With a DX heat pump system, even if a multi-split version, all room units will be in either cooling or heating mode. With so called three-pipe VRF, each fan-coil decides autonomously whether to heat or cool. This means that a room unit in cooling mode will transfer heat into the refrigerant circuit for use by another room unit in heating mode. Only the nett imbalance will be transferred to the outdoor unit – either to reject the surplus heat or to inject some additional heat from outside (see *heat pumps*).

6.11 Heat Pumps

Refrigeration units work by transferring heat from one place to another. With a domestic fridge, heat is transferred from the cabinet to the black coil at the back of the unit (the condenser). The ratio between electricity used to heat transferred is called the Coefficient of Performance (CoP).

It is very common for the CoP to be well above unity. For instance, a typical air-cooled chiller used in an air-conditioning process, will transfer about three units of heat for each unit of electricity consumed. It might seem as though the chiller is 300 percent efficient because the cooling effect is three times greater than the power that has been expended, however the energy has only been moved from one place to another: nothing has been created nor destroyed and the first law of thermodynamics remains intact.

If the purpose is to provide cooling, then refrigeration units are usually called chillers and the transferred heat is rejected to atmosphere. If however the primary purpose is to transfer heat from a fortuitous energy source, then refrigeration units are called *heat pumps*. Frequently units are used to provide both heating and cooling, in which case they are sometimes called “reverse cycle chiller-heat pumps”.

The heat rejected by a chiller or heat pump is the cooling effect plus the compressor power (as the energy all ends up as heat). Therefore the performance of a heat pump is measured by CoPH which equals CoP + 1.

Outside air is a source of heat, even when it's cold outside. For instance 0 °C is still 273 °C above absolute zero – that's a lot of heat.

Air-source heat pumps can therefore be used to transfer heat from the cold outside air to inside a building at a ratio greater than unity. The warmer the fortuitous heat source, the higher the heat output ratio (CoPH) and the less energy that will be used.

The disadvantage with using outside air as the heat source is that when the outside air is at its coolest, and therefore the heating load at its greatest, the source of heat is at its lowest. It is often better to use the ground or a body or water as the fortuitous heat source to improve the heat transfer ratio.

6.12 Carrier Moduline Variable Air Volume (VAV) with Perimeter Heating

This is a proprietary system manufactured by Carrier Air-conditioning of the USA. It was introduced to the market in the 1960s and is a basic pressure-dependent system. The main system components are:

- variable speed supply and extract fans
- heating and cooling coils
- mixing box for blending fresh and exhaust air together (using dampers)
- Carrier Moduline VAV terminals
- room heaters

The configuration of plant found at Tullos is shown in figure 1 in a cartoon format

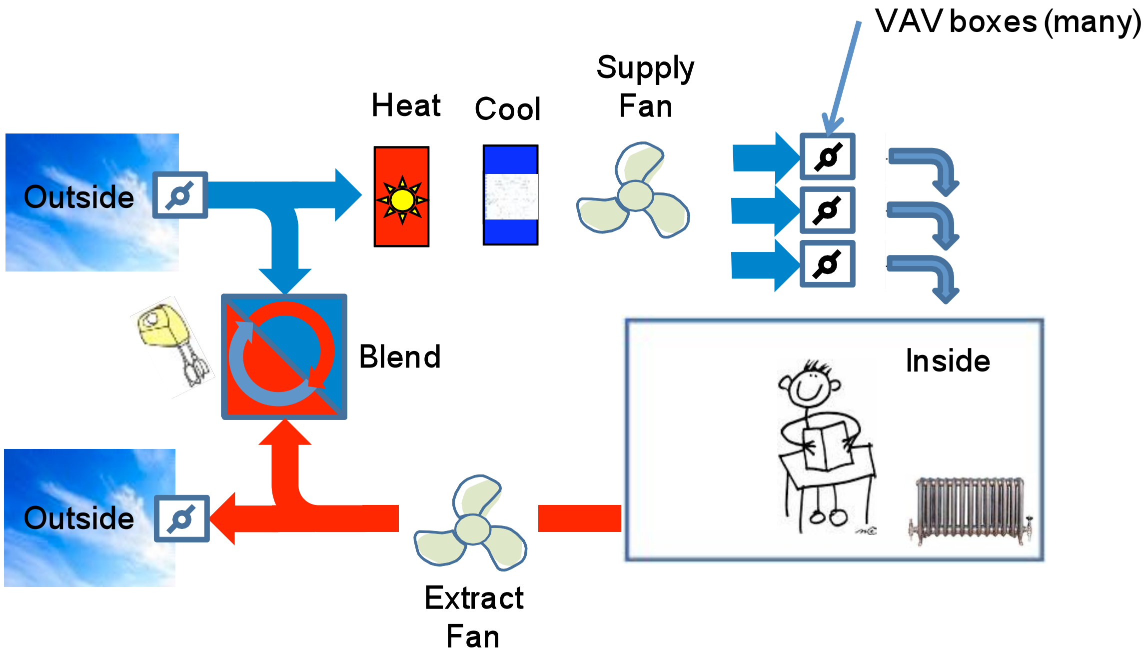


Figure 6.12. 1 - Moduline VAV with Perimeter Heating in the Arrangement Used at Tullos

Most air conditioning systems supply air for two purposes: as a medium to carry heat (or "coolth"), and to provide fresh (outside) air for human health and comfort. Usually the fresh air requirement is much lower than that required for heating and cooling, so the fresh air is supplemented with recirculated air. The reason not to use 100 percent fresh air is that fresh air usually requires a lot more heating and cooling than does recycled room air.

The Moduline units modulate their bellows in order to match the air flow to the cooling load, but there is a minimum below which they cannot go without compromising the fresh air provision and good air distribution. If a given space is too cold when the associated Moduline units are at their minimum, then the space will either over-cool or some form of re-heaters will be forced to operate. In this building there are in-duct re-heaters and perimeter heaters for this purpose.

Unless cooling is being performed for the purpose of de-humidification, it is obviously very wasteful for cooling to be provided at a central air-handling unit, only for some of it to be re-heated again in the rooms. For this reason, a temperature re-scheduling programme should be in place at the air-handlers.

There are a number of ways of re-scheduling the set-point for the air leaving the air-handlers, some more complex than others, but the general aim is to keep any re-heaters and room heaters off without compromising cooling to the warmest spaces. Without an effective strategy in place, high heating loads can occur throughout the summer in addition to wasteful cooling.

VAV systems are often considered to be energy-efficient because they reduce fan power to match the load, but a consequence of keeping the room/re-heaters off and the Moduline units within their control range (say 40 to 100%), is that air flow rates must be maximised thereby minimising any fan power savings. Further, being a centralised air system, the installed fan power for a VAV system is vastly higher than for other systems, such as fan-coils or chilled beams, so that any savings that are made, are made relative to a very high starting point.

A second energy-efficiency merit often claimed for VAV is their ability to use the most efficient blend of fresh and recirculated air, in order to get as close as possible to the required supply air condition before resorting to heating and cooling. Often they will be able to achieve the right supply condition with no heating or cooling whatsoever. The method by which this is done is called *enthalpy optimisation.*

Enthalpy optimisation finds the blend of fresh and recirculated air that is closest to the required supply condition, without reducing fresh air below the minimum required for the purposes of health, comfort and statutory code (currently 10 litres per second per person).

Using *enthalpy optimisation*, it will often be the case that fresh air is throttled to its minimum. The air leaving the air-handlers will be a mixture of recirculated and minimal fresh air, and distributed via the Moduline units on the basis of the cooling load: those spaces with the lowest demand for cooling receive the least air, and therefore the least fresh air.

It must follow that if the total fresh air supplied to a floor or building is the minimum required for the total number of occupants, and some occupants receive less fresh air than others, then some occupants will receive less fresh air their statutory minimum whilst others receive more. The only way to overcome this is to set the minimum fresh air in the inverse proportion to the turndown ratio. So if the maximum turndown is to 40 percent, then the minimum fresh air at the air-handler must be increased by 250 percent from 10 to 25 litres per second per person.

Setting the minimum fresh air to 25 litres per second per person will reverse any benefit from the *enthalpy optimisation*. VAV systems invariably trade efficiency with air quality, being either efficient at blending fresh air but poor at distributing it, or delivering a surplus of fresh air with the associated energy penalty.

The system shown in figure 6.12.1, which is the arrangement found at Tullos, is unlikely to even guarantee that the minimum fresh air provision is supplied to the floor, let alone that it be properly distributed.

The best configuration uses three fans: one to provide fresh air, one supplying fresh and recirculated air blended together, and one to extract stale air from the conditioned space. With this configuration, there is complete control over the fresh air provision through its dedicated fan, and the variable flow affects only the recirculated amount.

With the arrangement shown in figure 6.12.1, the fresh air proportion varies with the damper settings on the mixing box "blender" and with the speed of the fans. So if, for example, at full volume the fresh air should be 25 percent of the total supply air volume; at 50 percent fan speed, the fresh air should be 50 percent of the total volume. To achieve this with the current system would require a complex control strategy with a great deal of on-site calibration and conditioning.

During commissioning, a relationship would have to be established between damper position and fresh air flow rate. The control regime would then have to continuously calculate the minimum fresh air damper position corresponding to the actual fan speed. Although this level of detail was not available from the survey, this level of complexity is uncommon.

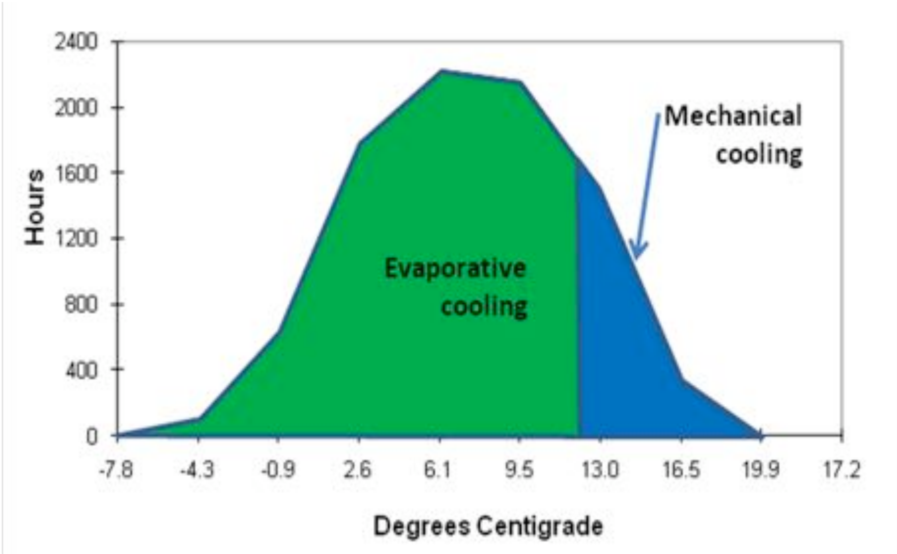
It is more likely that the fresh air dampers simply have a minimum setting, say 25 percent, which only ensures that a given percentage of all air is fresh, irrespective of how much (or little) air is being supplied. This problem at least can be resolved with the retro-fit of CO_2 sensors in the return air duct to prevent the enthalpy optimiser reducing the fresh air to the extent that the whole building's CO_2 concentrations exceed 1000 ppm. This would not, however, prevent poor spatial distribution of fresh air.

6.13 Evaporative Cooling

Use can be made of the ambient wet-bulb temperature to provide "free" cooling to internal spaces.

Wet-bulb temperature is the temperature measured on a standard mercury-in-glass thermometer when water is allowed to evaporate off the bulb. This evaporation has the effect of lowering the measured temperature. The dryer the outside air, the more readily the water will evaporate, and the lower the recorded temperature will be. Wet-bulb temperature is, in effect, a measure of how readily heat can be lost through evaporation (think of it like perspiration).

With carefully selected evaporative equipment, evaporation can be used to generate cool supply air at 17.0 °C whenever the ambient wet-bulb is below 13 °C, but say 12.5 °C to be conservative. According to the weather file, the ambient wet-bulb is above 12.5 °C for less than eight percent of the year.



Graph 6.13.1 - Wet-bulb temperature distribution curve, Aberdeen.

An evaporative cooling solution would therefore provide an environment just as good as conventional air-conditioning for about 92 percent of the year, but with virtually no energy consumption. In effect, the building is losing its surplus heat through perspiration where the evaporative coolers are the building's "sweat glands".

To achieve a supply air temperature of 17 °C with a wet-bulb temperature of 12.5 °C requires generously sized evaporative equipment, occupying a lot of external plant space, typically located on the roof. Fortunately, all buildings have plenty of empty flat roof that could be used for this purpose. Although evaporative coolers are not especially heavy, a structural survey will be required.

Figure 6.13.1 - Evaporative cooler – the building's sweat glands

The ubiquitous standard for chilled water systems is a flow temperature of 6 °C and a return temperature of 12 °C. The low flow temperature is chosen for the purpose of de-humidification which is seldom required in Aberdeen.

For a number of reasons, the lower the chilled water temperature, the higher the energy consumption. It is fairly intuitive that generating chilled water at 6 °C would require more energy than generating chilled water at say 15 °C, but this is only part of the issue.

At 6 °C more moisture will be stripped from the supply air than is necessary for human comfort, and it takes as much energy to condense a litre of water out of a sample of air as it does to boil a litre in a kettle. It is common for this unnecessary dehumidification to represent over 20 percent of the chiller load. Elevating the chilled water can reduce this waste to nil.

The higher the chilled water temperature, the more hours per year the chilled water can be generated through evaporation. In the case of Aberdeen, a chilled water temperature of 6 °C can be generated evaporatively for about one-third of the year, compared to nine-tenths for chilled water at 15 °C.

The infrequent requirement for dehumidification should not therefore be allowed to determine the operating conditions of the chilled water system, where doing so forces the system to operate inefficiently for the greater portion of the year. It is better to use a unitary *Direct Expansion* system for dehumidification and design the chilled water system for sensible[3] cooling only.

Elevated chilled water temperatures can be used with fan-coils, in which case they run dry; chilled beams; and chilled ceilings. De-humidification, when required, is provided by de-humidifying the fresh air with a unitary *Direct Expansion* chiller.

For the circa eight percent of the year when chillers are required, the evaporative coolers are used to help the chillers reject their heat. The evaporative coolers are now allowing the chillers to reject their surplus heat through perspiration, which gives the chillers an easier task thereby reducing their energy consumption.

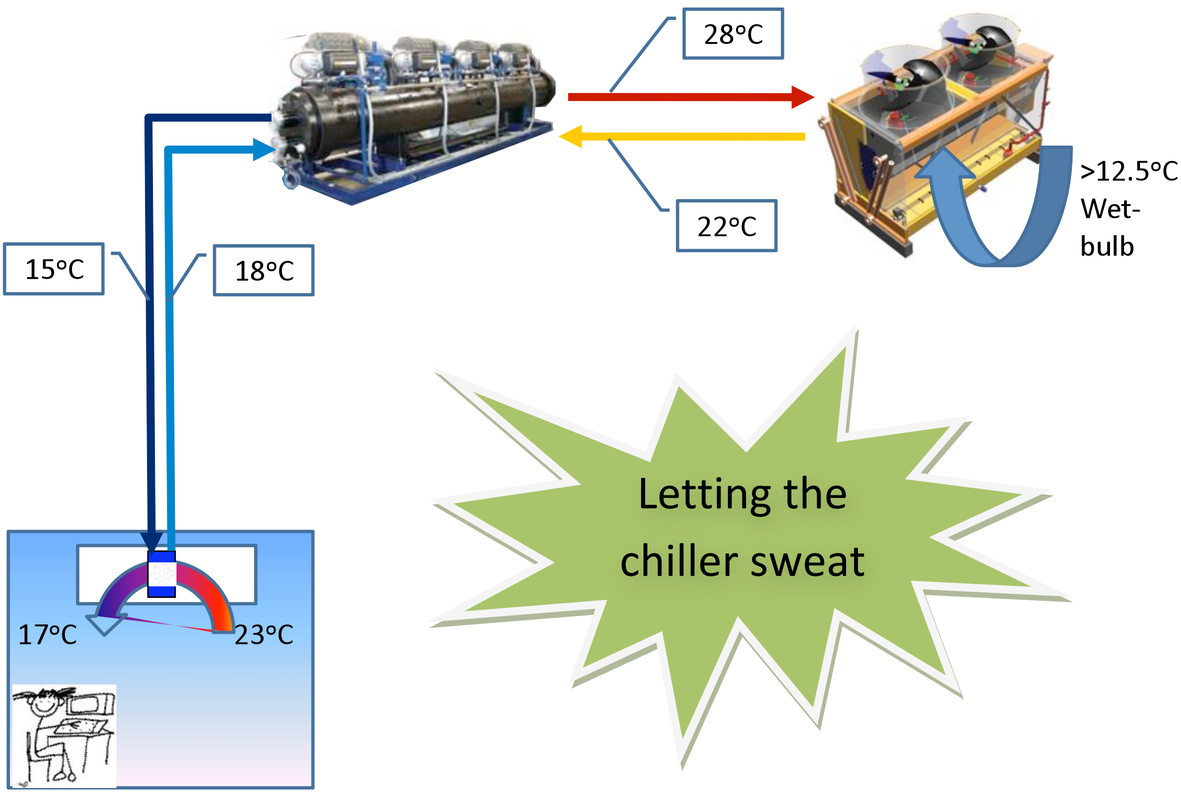


Figure 6.13.2 - Cooling on a very hot day

[3] Sensible cooling involves a drop in temperature, latent cooling involves the condensation of water vapour.

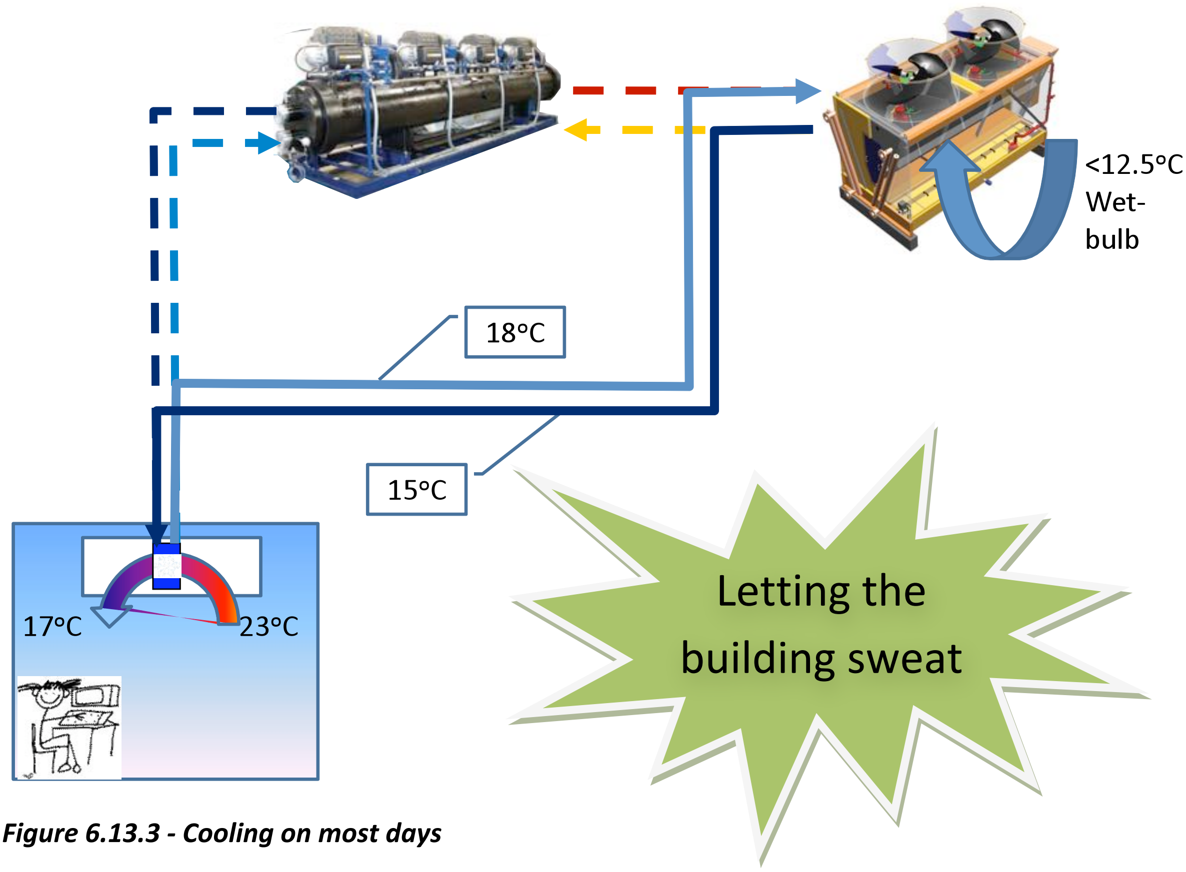


Figure 6.13.3 - Cooling on most days

Although water is a valuable resource in its own right, it is much less valuable in the UK than the electricity it saves. In fact this is true in most places around the world, even where water has to be desalinated using electricity. So long as there is access to a body of water, electricity and potable water are usually interchangeable (via Reverse Osmosis and other technologies).

One cubic metre of water can provide 680 kWh of cooling. Using a conventional air-cooled chiller, this would require 227 kWh electricity, the carbon footprint of which would be circa 123 kg CO_2, and cost around £23 (depending upon the tariff).

In the UK water has embodied carbon of circa 1.0 kg CO_2 per m^3 and costs under £2 (including disposal which ought not apply, but most likely will). Therefore the savings are more than 10-fold in terms of cost and more than 100-fold in terms of CO_2.

6.14 Temperature Optimisation

A control regime that varies the proportion of fresh and recirculated air in order to get as close as possible to the required supply air temperature before resorting to the use of heaters or cooler. For example, if the outside air is at 0 °C, the room air at 24 °C, and the supply air needs to be at 12 °C, then the *Temperature Optimiser* will supply 50 percent fresh air and 50 percent recirculated air, as below:

0.5 x 0 plus 0.5 x 24 = 12 °C.

The hardware comprises just three air dampers: one in the fresh air duct, one in the exhaust duct and one in a duct linking the fresh air and exhaust ducts together. There is usually a minimum fresh air provision.

6.15 Enthalpy Optimisation

As for *Temperature Optimisation* but for enthalpy.

Enthalpy is a measure of the energy in a sample of air by reason of its temperature and moisture content. Enthalpy therefore combines two important terms into one (much like wet-bulb temperature).

An *Enthalpy Optimiser* varies the proportion of fresh and recirculated air in order to get as close as possible to the required supply air enthalpy. There is usually a minimum fresh air provision.

7 Conclusions and recommendations

All costs and benefits are estimates and require further validation before committing to order or design.

High priority

Medium priority

Low priority

Ref	Recommendation	Annual Benefit		Indicative capex
a	Site-wide improvements: Metering, targeting and monitoring, Energy Management Plan, staff engagement, BMS overhaul, time-scheduling, optimum start and stop, local plant overrides, base-load reduction (note1).	2,600 MWh elect 1,414 tonnes CO_2 £190K		£100K (note2)
b	Building fabric/envelope improvements, replacement of pipe insulation	1,000 MWh gas 181 tonnes CO_2 £16K		£100K (note 3)
c	Photocell lighting control to each building, with appropriate zoning, as defined within the report.	630 MWh elect 343 tonnes CO_2 £46K		Do as floors are refurbished £50K
d	Phase one air-conditioning, as described	100 MWh elect 54 tonnes CO_2 £7.3K		£20K (note 4)
e	Phase one ultra-efficient boilers, as described	70 MWh gas 13 tonnes CO_2 £1.1K		neutral
f	Phase one fresh air heat reclaim, as described	314 MWh gas 57 tonnes CO_2 £5K		£10K
g	Phase three, VRF removal to save release of harmful refrigerant.	170 tonnes CO_2		System needs to be replaced
h	Phase three air-conditioning, as described	120 MWh elect 65 tonnes CO_2 £8.8K		£25K (note 5)
i	Phase three ultra-efficient boilers, as described	48 MWh gas 8 tonnes CO_2 £0.8K		neutral
Sub-totals		3450 MWh elect 1432 MWh gas 2305 tonnes CO_2 £275K		

Ref	Recommendation	Annual Benefit		Indicative capex
j	Phase three fresh air heat reclaim, as described	380 MWh gas 68 tonnes CO_2 £7.5K		£10K
k	Phase four energy loop. Replace chiller with evaporative cooler, as described.	130 MWh elect 70 tonnes CO_2 £9.5K		£50K
l	Phase four ultra-efficient boilers, as described	200 MWh gas 36 tonnes CO_2 £3.2K		neutral
m	Phase five improvements to air-conditioning, as described.	1,000 MWh elec 544 tonnes CO_2 £73K		
Grand total		4,580 MWh elec 2012 MWh gas 3,023 tonnes CO_2 £368K		£365K

Note 1

Recommendation a), site-wide improvements have been grouped together because it is impossible to quantify the extent of saving to attribute to each measure. It is known however that there is a very high base load as a result of a combination of poor control, behaviour and out-of-hours plant operation. This package of measures combined should conservatively achieve the savings indicated.

Note 2

Energy meters £70,000; Energy Management Plan plus staff engagement £10,000; BMS overhaul £nil – routine maintenance requirement. Time scheduling and local overrides £20,000. Base load reduction £nil – behavioural or included elsewhere. Total cost £100,000

Note 3

The cost allowance here is for upgrades beyond the minimum required by Building Regulations in the event that thermal elements or fittings (cladding,roofs, windows, etc.,) require replacement for other reasons. It is unlikely to be cost-effective to replace otherwise satisfactory sections of the building fabric only for the improved thermal performance.

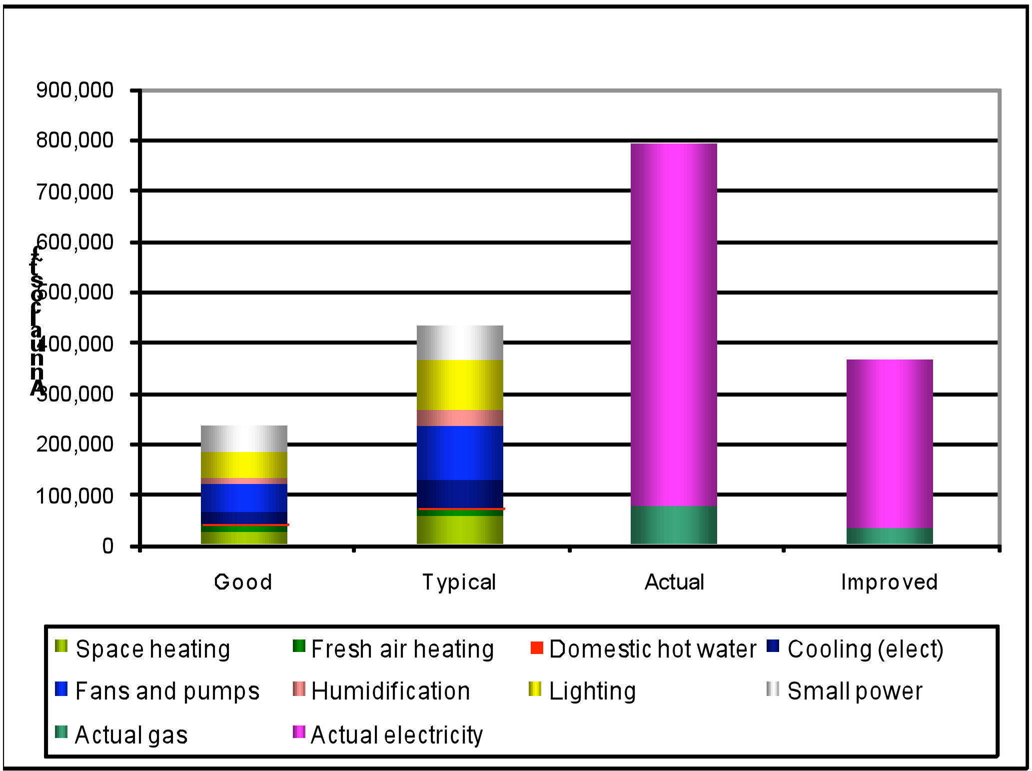
Note 4

This is the additional cost relative to the planned replacement.

Note 5

This is the additional cost relative to a typical replacement

Occupation density	10 m^2/person (assumed)		Floor area	24,590 m^2
Fresh air vent rate	10 l/s/person		Elect mean rate (incl. CCL)	7.26 p/kWh
Supply temp	20 °C		Elect day rate (incl. CCL)	7.34 p/kWh
Operating hours	12 hours/day	5 dys/wk	Elect night rate (incl. CCL)	5.04 p/kWh
			Gas unit rate (incl. CCL)	1.59 p/kWh



0% Naturally ventilated cellular
0% Naturally ventilated Open-plan
100% Standard air con.
0% Presige air con.

Graph 7.1, Existing and Improved relative to Good and Typical Practice Benchmarks (ECG 19)

8 Appendix A – Building Survey

8.1 Generally

Shell's Aberdeen headquarters were surveyed on 29th January 2010. The site comprises four buildings linked together with footbridges and known as Phases One, Three, Four and Five (phase two was never built or was subsumed into other phases). Additionally there is a Central Services Building and laboratory which fall outside the scope of this survey.

It is understood that Phase One was completed around 1977 and Phase Five was completed around 1983. The buildings are very much of their era, generally incorporating a continuous band of bronze tinted double-glazing circa 1.5m high.

Figure 8.1 – Phase Four, but a similar style to other office accommodation at the site

Phase	Floor	Net Useable Area m²
One	Basement	338
	Ground	1234
	First	1052
	Total	*2624*
Three	Basement	530
	Ground	1421
	First	1439
	Total	*3390*
Phase 4	Basement	318
	Ground	1692
	First	1313
	Second	1329
	Third	1155
	Total	*5806*
Phase 5	Basement	1826
	Ground	2823
	First	2213
	Second	1965
	Third	1692
	Forth	1065
	Total	11584
CSB Block	Total	173
Lab Block	Total	1013
Grand Total		**24590**

Table 8.1, Floor Area Schedule

8.2 Heating, cooling and ventilation

Phase One

This building was refurbished around 10 years ago. At the time of the survey, the building was in the process of being re-clad and insulated. Windows are double-glazed.

The ground and first floors are heated by means of a perimeter LTHW radiator system. There is no mechanical cooling and the building reportedly over-heats in summer.

Fresh air is supplied to the ground floor from two air-handlers located in plantrooms at the east and west escape stairs, and the first floor is served by three air-handlers located in a rooftop plantroom. Each air-handler comprises LTHW heating coils, but no heat recovery, cooling coils or humidifiers.

The LTHW heat source serving the radiator and air-handling unit circuits is a packaged plantroom located in the services courtyard between Phases One and Five, adjacent to the Phase Five chiller compound.

The heating system is weather-compensated.

The boiler specification is:

Manufacturer : MHS Boilers Ltd.

Model A : Regency 4/255

Gross seasonal efficiency: 82.4%

Year of Manufacture : unknown

Output : 255 kW

Quantity : four

Medium : LTHW

Fuel : Natural gas

Three run and standby pumps, Grundfos UPE 50-120F, as follows:

East wing ground and first, 1.1 l/s against 80 kPa

Basement, 1.1 l/s against 80 kPa with 1 kW motor

West wing ground and first, 3.0 l/s against 80 kPa

One run and standby Grundfos LDP 80-125/117, as follows:

Constant temperature circuit, 10.5 l/s against 120 kPa with 2.2 kW motor

One run and standby Grundfos UPS 65-60/4, as follows:

Boiler primary circuit, no duty details, 1.1 kW motor

Domestic hot water is gas-fired hot water heating.

Phase Three

The ground and first floors are heated and cooled by a Daikin heat pump (three-pipe) VRF system, comprising indoor ducted fan-coils and 12 external roof-mounted condensers (23.6 Amp per phase, three-phase) with a total connected load of 195 kVA (circa 250 kW).

The refrigerant gas is R-22, a hydrochloroflurocarbon (HCFC) and a greenhouse gas 1700-times more potent than CO_2. It is therefore being phased out under EU legislation.

From 1 Jan 2010 it will be illegal to use virgin R-22 when servicing and maintaining air conditioning equipment. Until the 31 December 2014 temporary use of recycled R-22 is allowed but availability could become limited and therefore increase costs. From 1 January 2015 sales or use of recycled R-22 will be prohibited making these units completely redundant as they will not be fully serviceable.

Apparently they leaked approximately 100 kg of R-22 last year. Not only will it not be possible to replace this after 2015, but this is equivalent to 170 tonnes CO_2, or 313,000 kWh of grid-supplied electricity – sufficient to power around 70 standard homes. Moreover, units running at less than full charge are less efficient.

In any event, the installation is now 15 years old and therefore very much towards the end of its economic life (usually 12 to 15 years). Despite corrosion-inhibiting coatings, the external units have suffered accelerated corrosion due to their costal location.

With plant of this age and condition, there is a risk of sudden irreparable failure requiring significant plant replacement. If the plant is allowed to fail, then there will be little time to consider alternative strategies for its replacement, under which circumstances it is likely the latest version of the older equipment is installed on a like-for-like basis – this could be a significant lost opportunity.

Fresh air is provided to the building by two air-handlers located in a rooftop plantroom and one air-handler located in the basement plantroom. Each air-handler comprises LTHW heating coils, but no heat recovery, cooling coils or humidifiers.

The heat source is the Centralised Packaged Boiler Room.

Phase Four

There are two fresh air and exhaust air-handlers serving the north and south general office spaces separately, each compromising a run-around coil and LTHW heating coil. No cooling or humidification is provided to the fresh air. A third air-handler serves the conference suite.

There are 120 packaged heat-pump units connected to a two-pipe water circuit circulating around the building (similar to a Vesatemp system). The water circuit uses conventional boilers and chillers, via plate heat exchangers, to maintain a flow temperature in the range of around 15 and 30 °C. The heat-pump units use the water circuit as a low temperature heat-sink when in cooling mode, and a low-grade heat source when in heating mode. In this way, heat is transferred around the building from those fan-coils in cooling mode (rejecting heat), to those fan-coils in heating mode (requiring heat). Only the nett imbalance of the whole building needs to be made good from central plant.

The system would have worked more efficiently if there was an evaporative cooling bypass.

This system offers many of the benefits of VRF but without the extended runs of refrigerant gas and associated global warming and maintenance implications (especially with the F-gas regulations now in force).

The boiler specification is:

Manufacturer	: Beeston Heating
Model	: Beverley
Year of Manufacture	: 2000
Input	: 403 kW (gross)
Output	: 324 kW
Quantity	: three
Medium	: LTHW
Fuel	: Natural gas

Phase Five

There are 14 air-handlers on Phase Five; most of them are used to condition the office space, but there are a number of ancillary units, as follows:

AHU 06 : Kitchen

AHU 07 : Restaurant

AHU 10 : Reception

AHU 11 : Centre

AHU 12 : Link to Phase Four

AHU 13 : Link to Phase One

AHU 14 : not known

The offices are air-conditioned by a Carrier Moduline Variable Air Volume (VAV) system with pre-heating and cooling performed at the central air-handlers with in-duct re-heaters and perimeter heating controlled with thermostatic radiator valves. Unusually, the air-handling unit heating coils are prior to the cooling coil, which means that they cannot be used for re-heat following dehumidification. Because the minimum supply air temperature leaving the air-handling units is 13 °C, this limits the amount of dehumidification the cooling coils can provide. This is not necessarily a problem.

A detailed description of the VAV systems installed in this building is provided in Section 6 – Referenced Technologies, but in summary, it is unlikely that they can be relied upon to provide adequate fresh air to all of the cellular spaces, as well as being difficult to control efficiently.

Refer to Appendix B for air-handling unit graphics and a commentary on the controls.

Phase Five is also fitted with perimeter radiator heating controlled using Thermostatic Radiator Valves and no means of preventing conflict between the perimeter heating and the VAV cooling. This was not so much of a problem when the perimeter heating was powered with heat reclaimed off the chillers, but now that they are served off gas-fired boilers, this could be a double waste of energy.

LTHW and chilled water are each supplied from centralised packaged boiler room and air-cooled chiller compound, respectively.

Run and standby 11 kW pumps.

Chiller compound

Manufacturer	: Carrier
Model	: 30GX-267-A0206-PEE
Serial number	: 12S308180
Year of Manufacture	: 2003
Output	: three
Quantity	: two
Medium	: Chilled water
Power	: 169 A per phase x two circuits (check)

The Phase Four and Phase Five chilled water systems can be linked together.

8.3 Centralised Package Boiler Room

The central boilers serve the laboratory and Phases Three and Five

Manufacturer	: Allen Ygnis
Model	: AYT/650/65
Year of Manufacture	: 1983
Output (each)	: 6,500,000 BTU/hr
	(1,900 kW)
Quantity	: three
Medium	: MTHW
Fuel	: Natural gas

Figure 8.2, Centralised Packaged Boilerroom

8.4 Lighting

8.4.1 Phase One

Phase I was refurbished around 10 years ago with 36 W T5 fluorescent lamps and occupancy-sensitive lighting control.

8.4.2 Phase Three

Passive infra-red occupancy sensing

8.4.3 Phase Four

T5, 14W per lamp, three lamps per fitting. Photocell control but mostly bypassed.

8.4.4 Phase Five

Fourth floor – mixture of T8 and T5 linear fluorescent lamps and occupancy-sensed passive infra-red lighting control. There is no photocell control, although this might have been provided originally and subsequently overridden.

9 Appendix B - Building management system (BMS) review

9.1 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.

9.2 Phase One

Figure 9.2.1 – Phase One, Front Page

This screen-dump is included only to help identify the block – there are no comments to make.

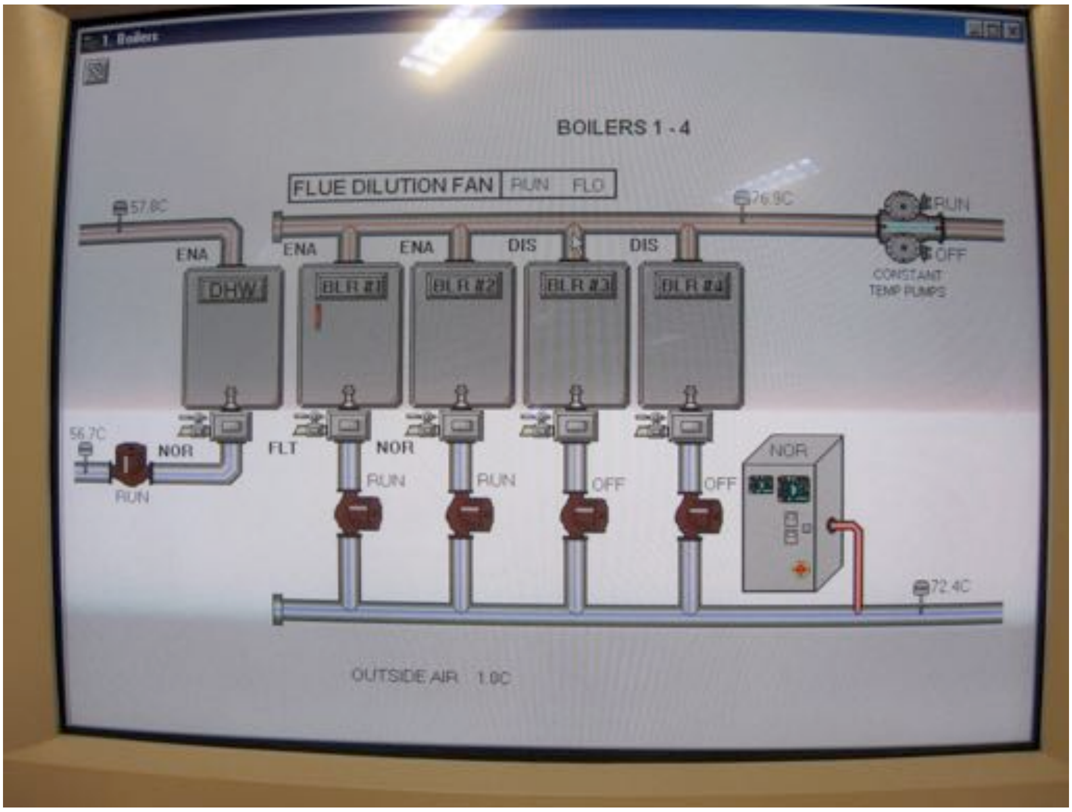


Figure 9.2.2 – Phase One, Boilers

a. The temperature differential between flow and return was only 4.5 °C, which is low for such a cold day (around 0 °C). Similarly, only half the boilers were enabled. This suggests that the building would have a year-round cooling demand.

9.3 Phase Three

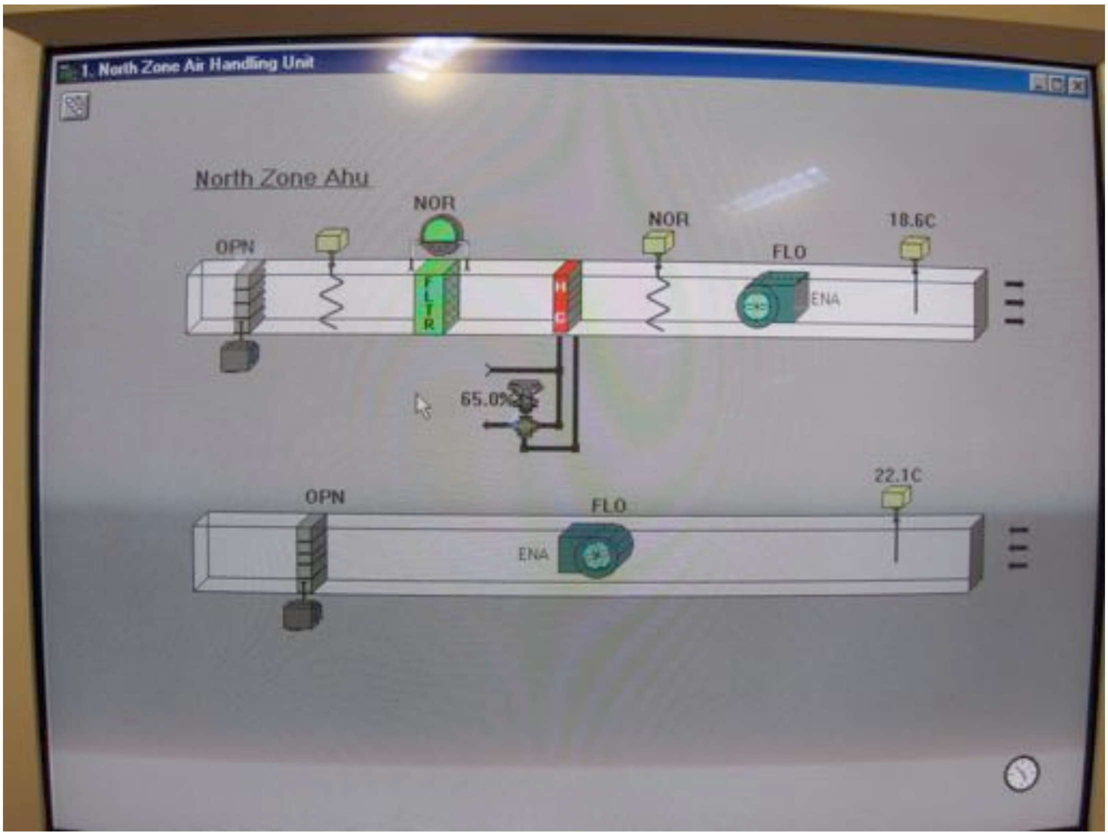


Figure 9.3.1 - Phase Three, North Zone AHU

a. There are no errors evident from the graphic, but most of this heating could have been achieved using heat recovery off the exhaust air duct if heat reclaim had been in place.

b. Plant on-time is before 05:00 which is very early for plant generally, but especially for fresh air plant. Fresh air does not need to be on during the pre-heat period.

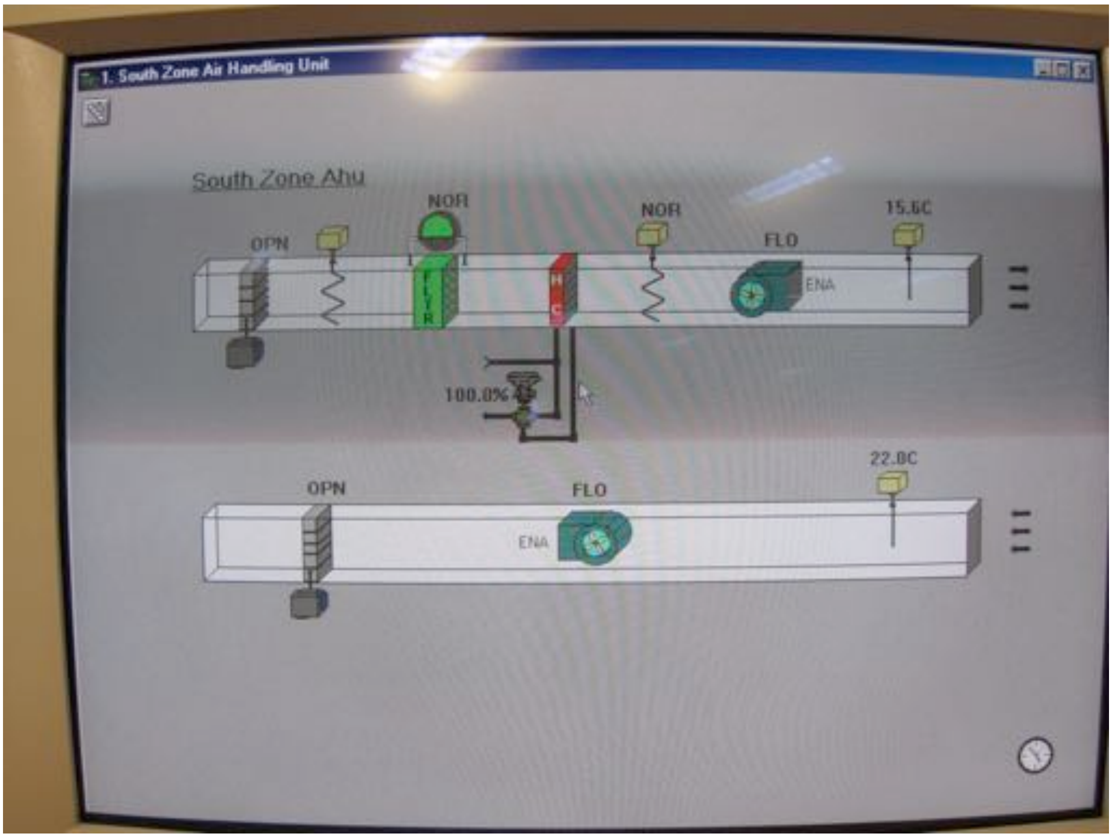


Figure 9.3.2 – Phase Three, South Zone AHU

a. The north zone AHU (figure 9.3.1 above) uses 65 percent heat output to reach a supply temperate of 18.6 °C, whereas this unit uses 100 percent output to reach 15.6 °C. In the likely event that both units were sized on the same criteria, a correlation would be expected between supply temperature and heat output. This large disparity suggests an error. Possible causes include: inaccurate BMS feedback, south zone has too much air or too little LTHW.

b. As with the north zone, this fresh air plant is on before 05:00, which is very early.

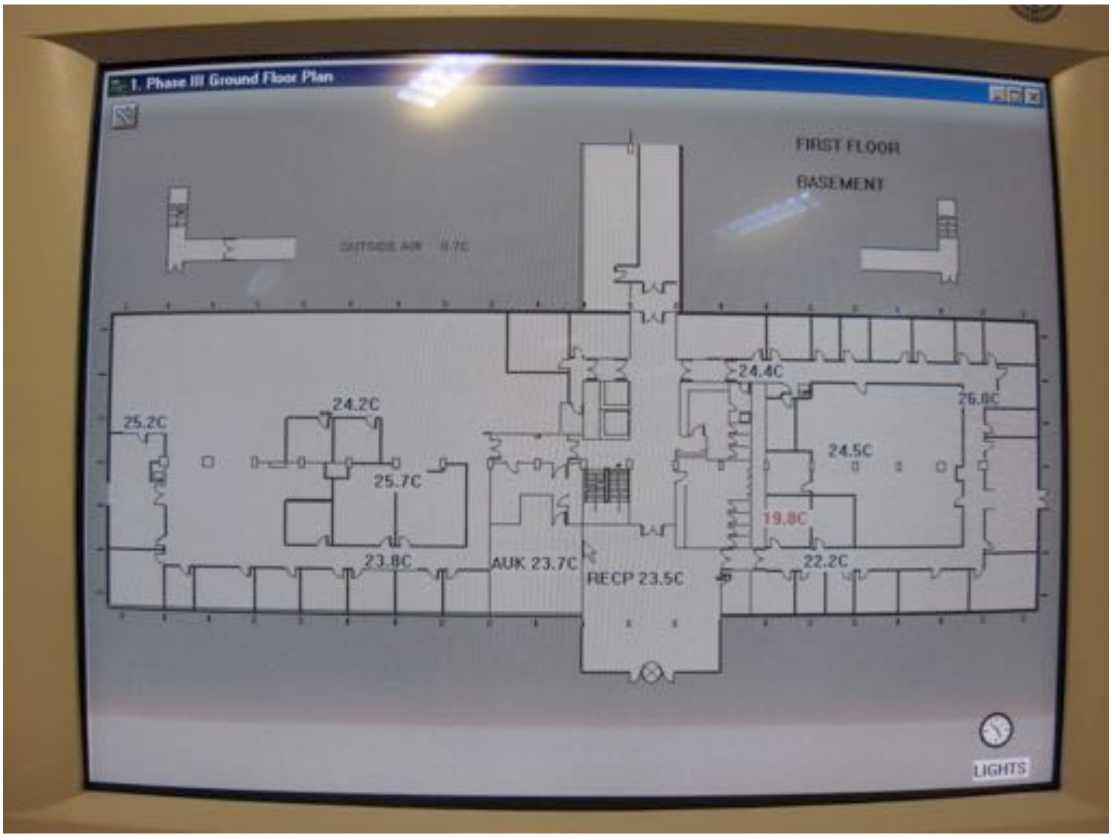


Figure 9.3.3 – Phase Three, Ground Floor Plan

a. Again, plant on before 05:00 (typical for all floors).

b. The temperature set-points are very high; some spaces are almost 26 °C, which is much higher than most people would require as minimum. In fact, it is higher than most people would prefer as a maximum. It is likely that there is a malfunction with the heating system and that the set-points are not being achieved.

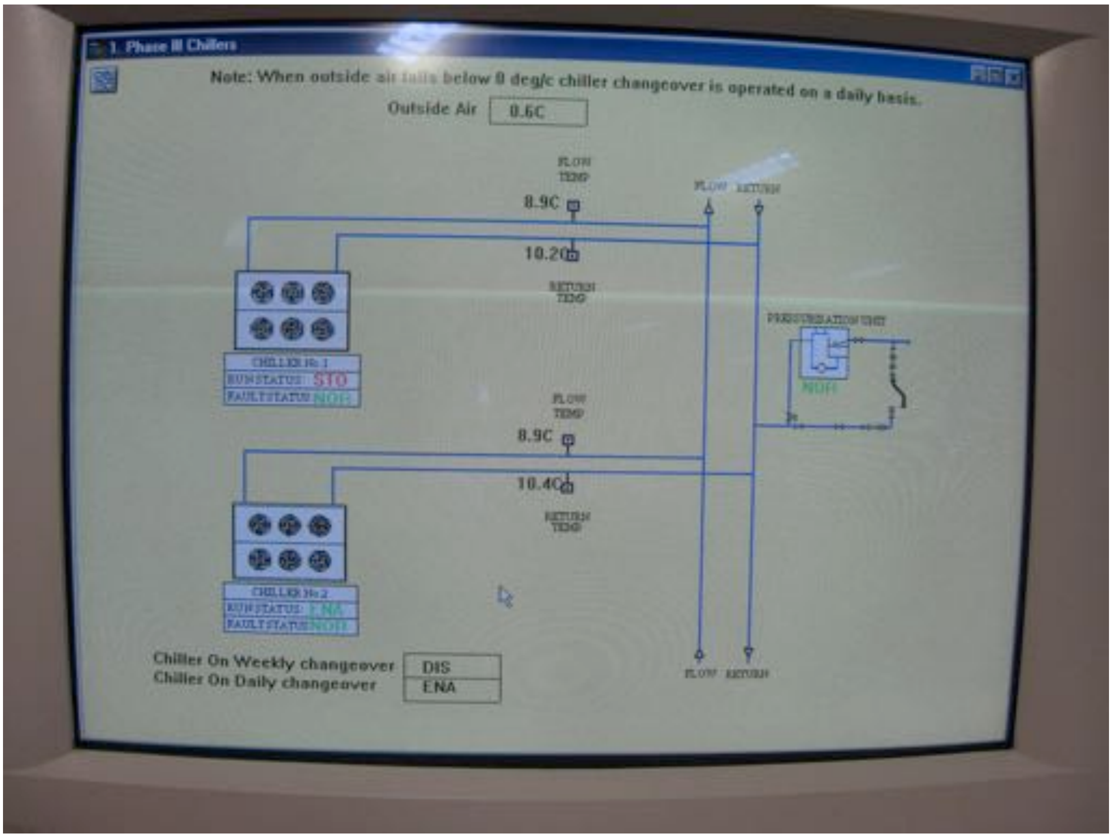


Figure 9.3.4 – Phase Three, Chillers

a. A small temperature differential across the chillers indicating a low cooling load, as would be expected on such a cold day.

9.4 Phase Four

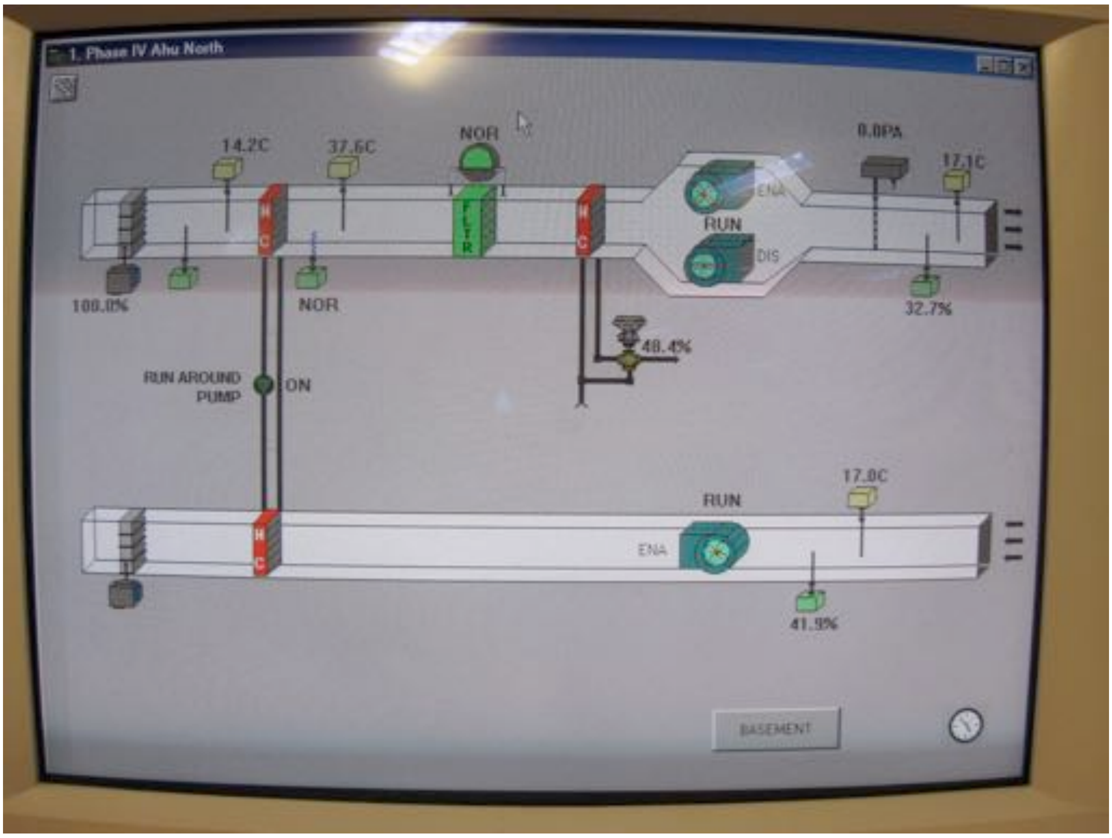


Figure 9.4.1 – Phase Four, Air-handling Unit, North

a. The inlet temperature is 14.2 °C, which is much higher than the outside air temperature. Either the inlet is situated adjacent to a heat source, in which case this source should be identified to ensure that it is not in any way contaminated, or otherwise the temperature sensor must be faulty.

b. The heat reclaim run-around coil heats the inlet air to 37.6 °C with a heat source of only 17.0 °C (the exhaust air) – this is impossible.

c. The LTHW is at almost 50 percent output which, if the temperature sensors are to be believed, <u>cools</u> the air by almost 20 °C to 17.1 °C. Clearly cooling cannot occur over a heater battery.

d. Air enters the air-handler at 14.2 °C and leaves at 17.1 °C. Overall, the heater battery and run-around coil combined heat the air by just 2.9 °C, which begs the question: is the run-around coil working properly and if so, does it justify the additional pump and fan power?

e. Again, time scheduled on prior to 05:00. Why?

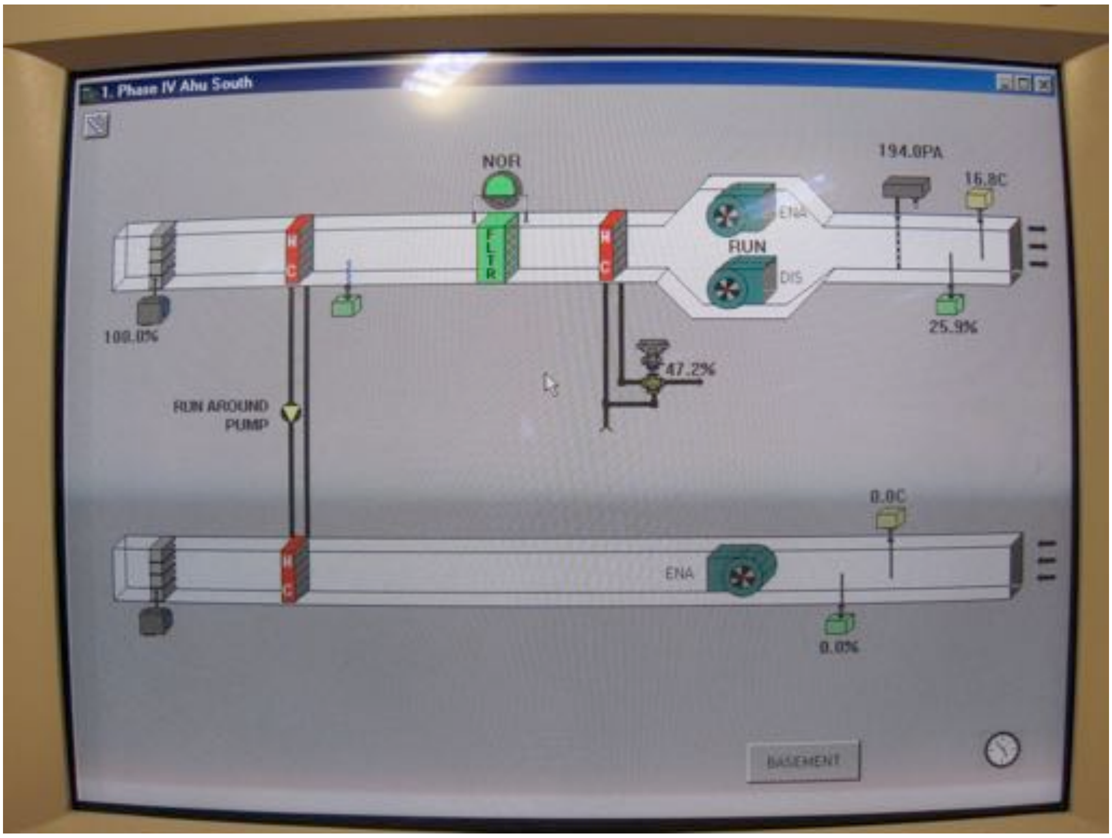


Figure 9.4.2 – Phase Four Air-handling Unit, South

a. The extract fan apparently has no flow.

b. The extract air is apparently 0 °C.

c. Again, time-scheduled on before 05:00 – why?

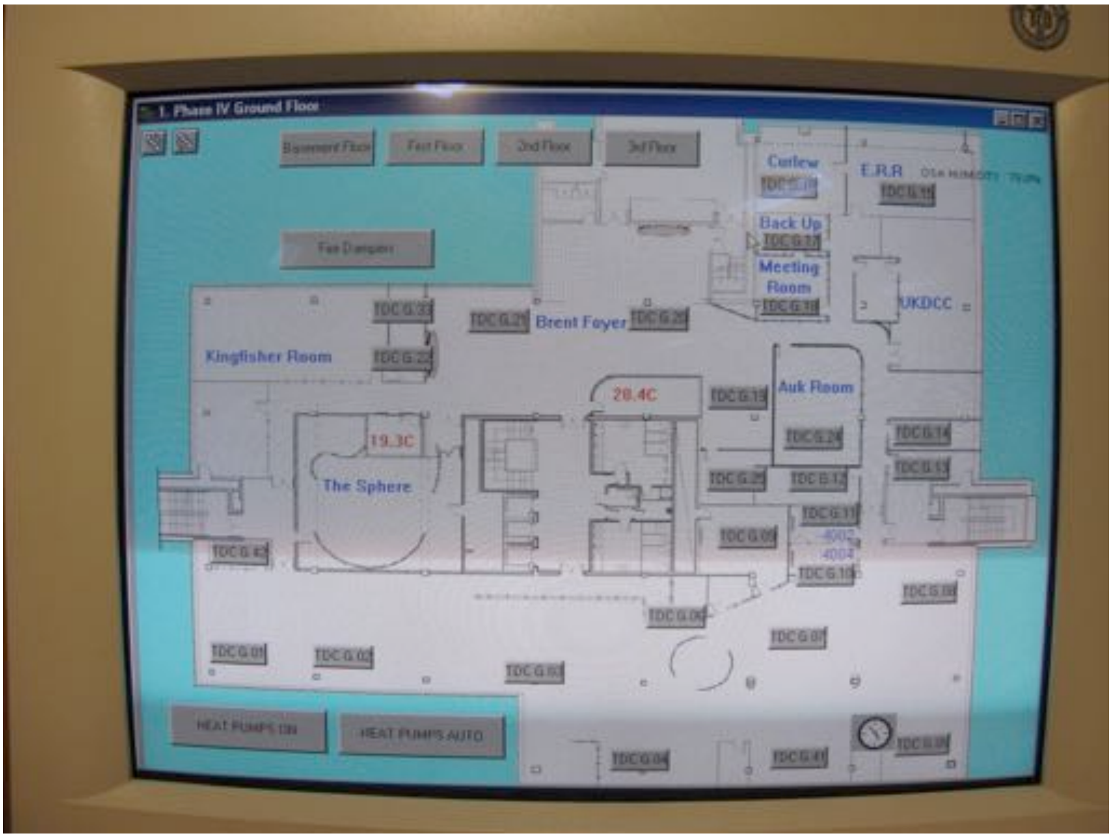


Figure 9.4.3 – Phase Four, Ground Floor

a. Time scheduled on before 05:00 (typical for all floors). Why so early?

9.5 Phase Five

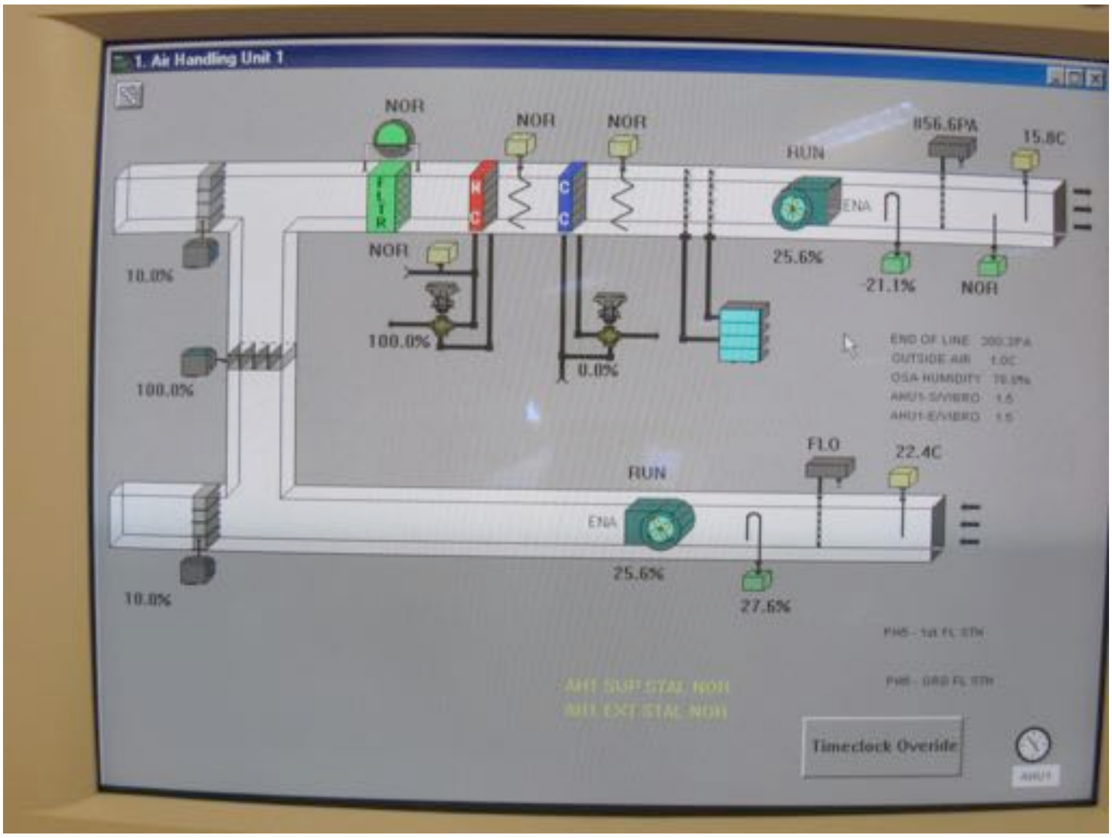


Figure 9.5.1- Phase Five, Air-handling Unit One, Ground and First Floors, South

Comments

a. The fresh air and exhaust dampers are equal, which is as expected, but the recirculation damper should be 100 percent minus the fresh air (or exhaust) percentage – i.e. in this case, 90 percent. Not 100 percent as shown.

b. If the system has been properly balanced, the resistance for full fresh air and exhaust should exactly equal the resistance for full recirculation. The relationship between damper position and air flow depends upon the profile of the damper blades (so 10 percent damper open doesn't necessarily mean 10 percent air flow), but unless this air-handling unit has a very high restriction between the exhaust and fresh air decks, the screen-dump is showing near-full recirculation air.

   Not only is the fresh air damper at a very low percentage, but the fan speed is at 25.6%. Unless operating on the dictates of CO_2 sensors, this proportion of fresh air is likely to be below recommended levels for health and hygiene, however there were insufficient details on site to confirm this. This needs be checked in detail.

If operating in near-full recirculation mode, as the dampers suggest, then the mixed air temperature should be close to the extract air temperature, in this case 22.4 °C. However, even after 100 percent output from the heating coil, the supply air temperature is only 15.8 °C, suggesting 30 percent fresh air.

30 percent fresh air looks fine, but the question remains: why are the fresh air and exhaust dampers so highly throttled for 30 percent?

Possible causes are: a restriction in the recirculation path or misinformation on the BMS.

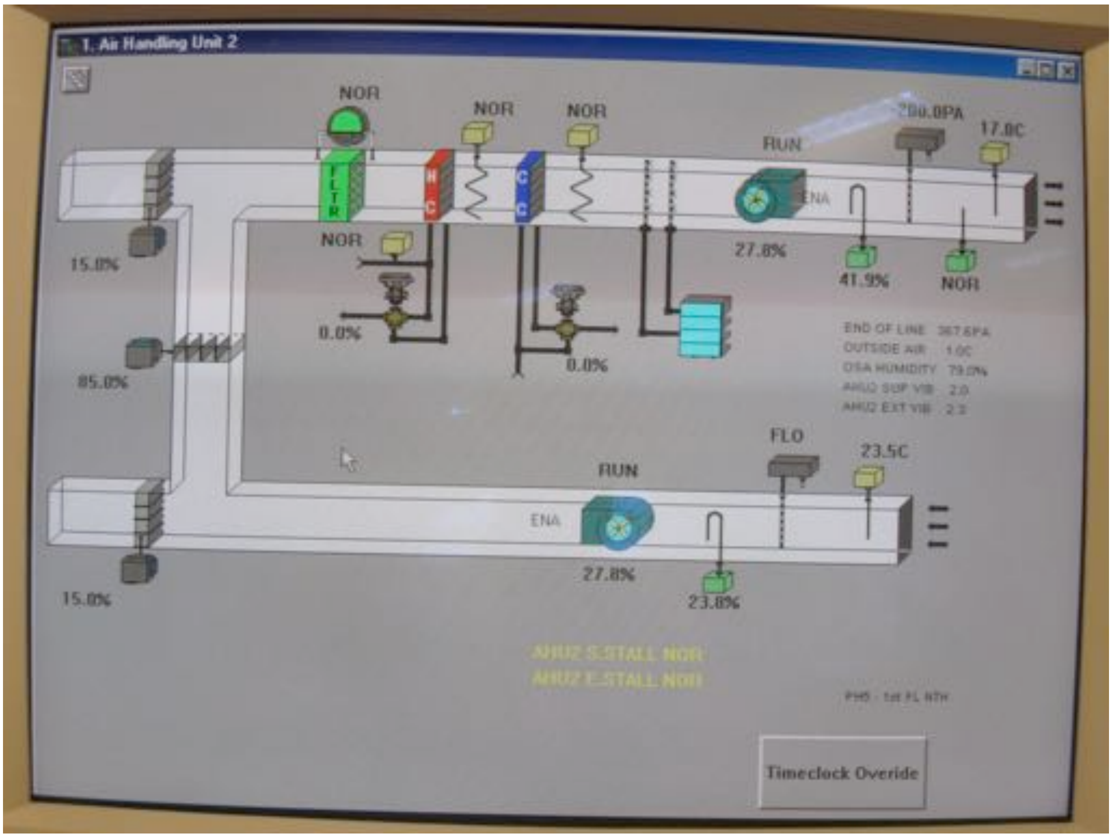


Figure 9.5.2 - Phase Five, Air-handling Unit Two, First Floor, North

Comments

a. This air-handler <u>does</u> have a correlation between the fresh /exhaust air dampers and the recirculation damper (15% + 85% = 100%). This virtually confirms that there is a problem with air-handling unit one.

b. If the temperature sensors are to be believed, the fresh air provision is 30 percent of the total – identical to what the temperature sensors suggest for air-handler one.

c. Although this air-handler is providing a very similar function under very similar circumstances to air-handler one with return air 1.1 °C warmer, supply air 1.2 °C warmer, and with a similar proportion of fresh air; this unit's heater battery is fully shut, but the heater battery in air-handler one is at full output. This disparity between very similar systems should be investigated.

d. Comparing this unit with air-handler one suggests that all of the heat output from air-handler one, at the time of the survey, was a complete waste of energy.

e. The static pressure in the supply air duct is minus 200 Pa – this cannot be correct, as the pressure must be positive at this point (unless the fan has failed, in which case it would be zero).

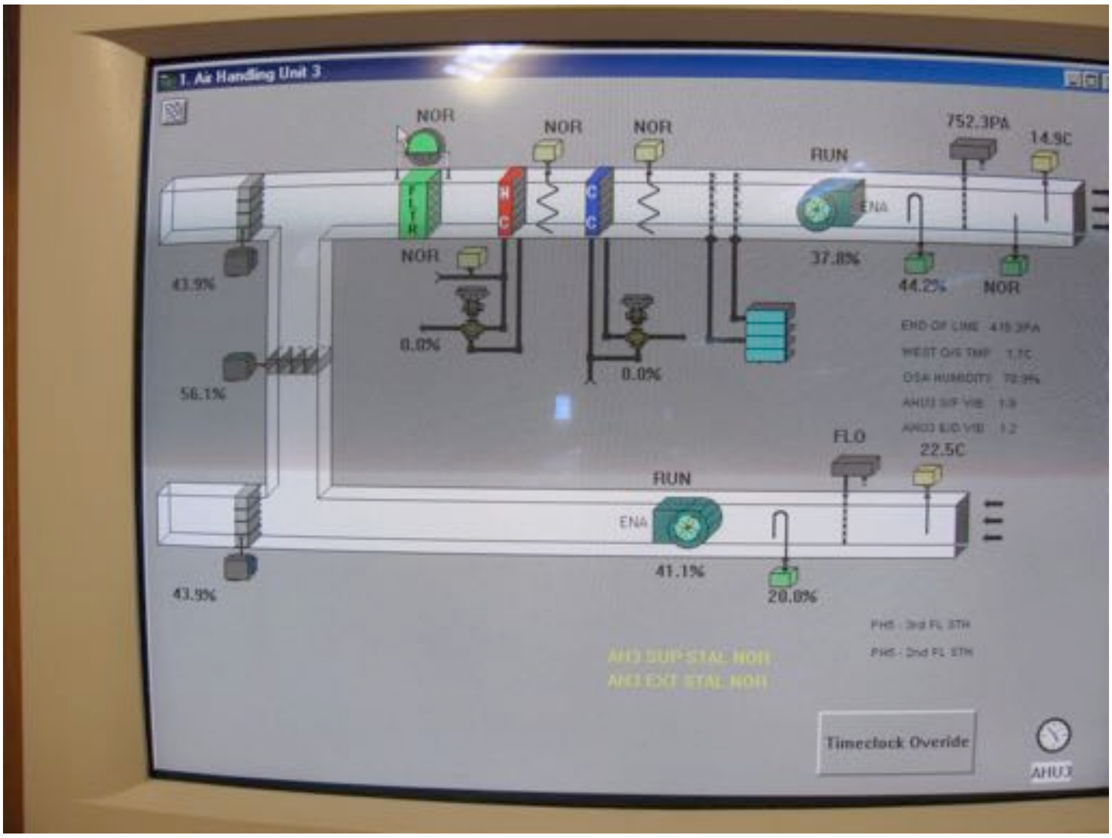


Figure 9.5.3- Phase Five, Air-handler Three, Third and Second Floors, South

Comments

a. There are no errors identifiable from the graphic. The *enthalpy optimiser* has managed to avoid all heating and cooling at the air-handler.

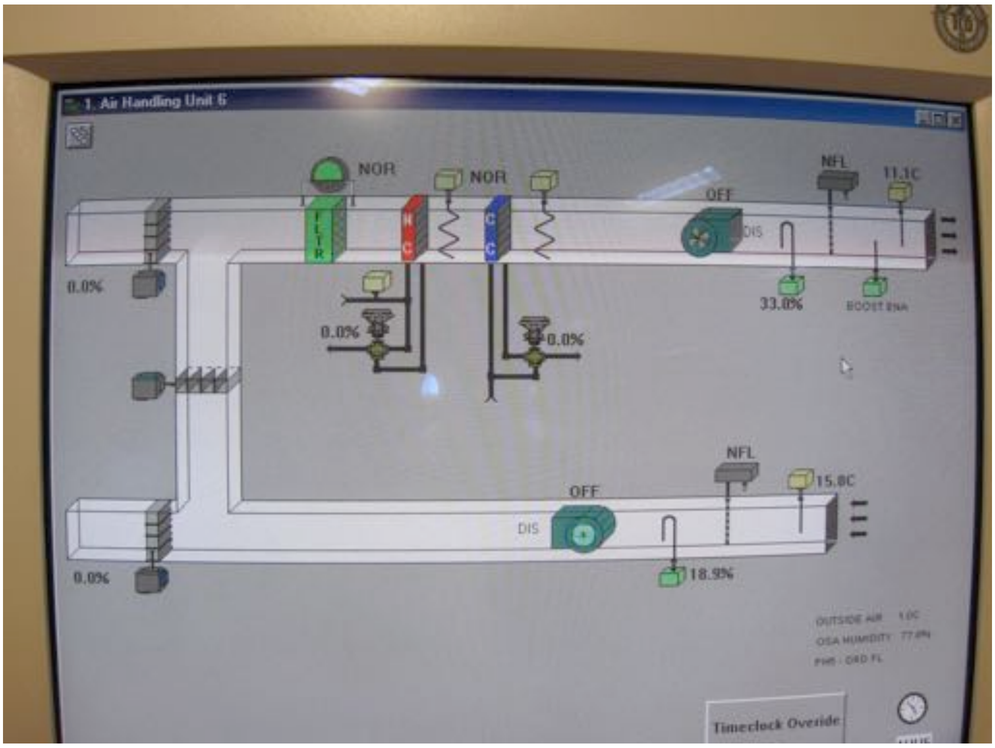


Figure 9.5.4- Phase Five, Air-handling Unit Six, Ground Floor, Kitchen

a. This unit was off.

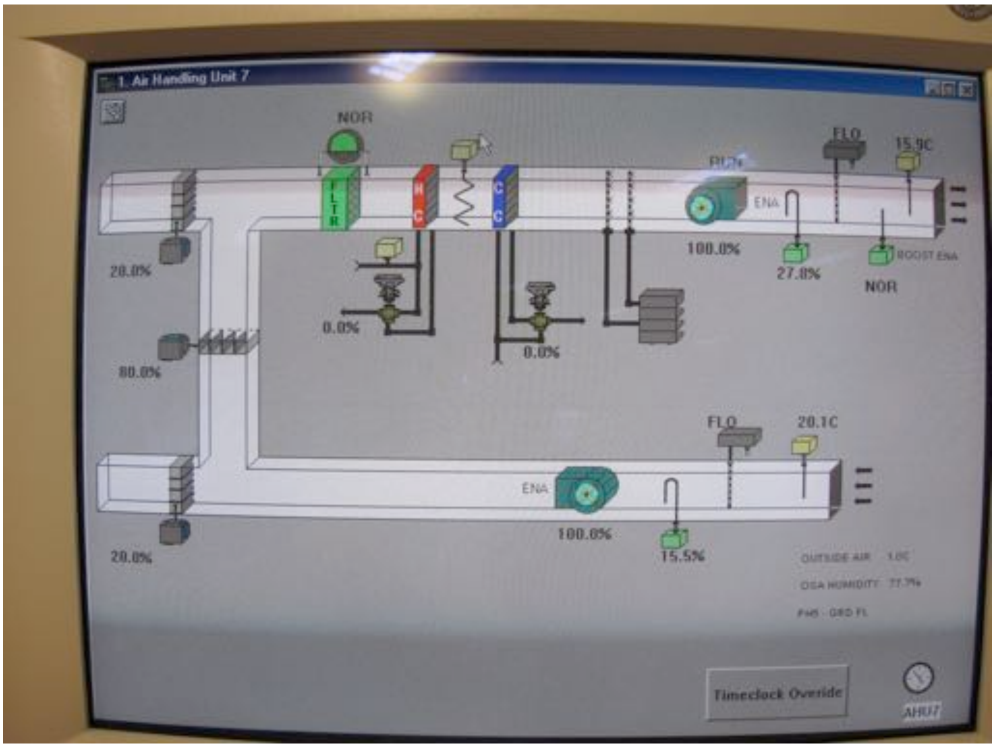


Figure 9.5.5 – Phase Five, Air-handling Unit Seven, Restaurant

a. There are no errors apparent from the graphic.

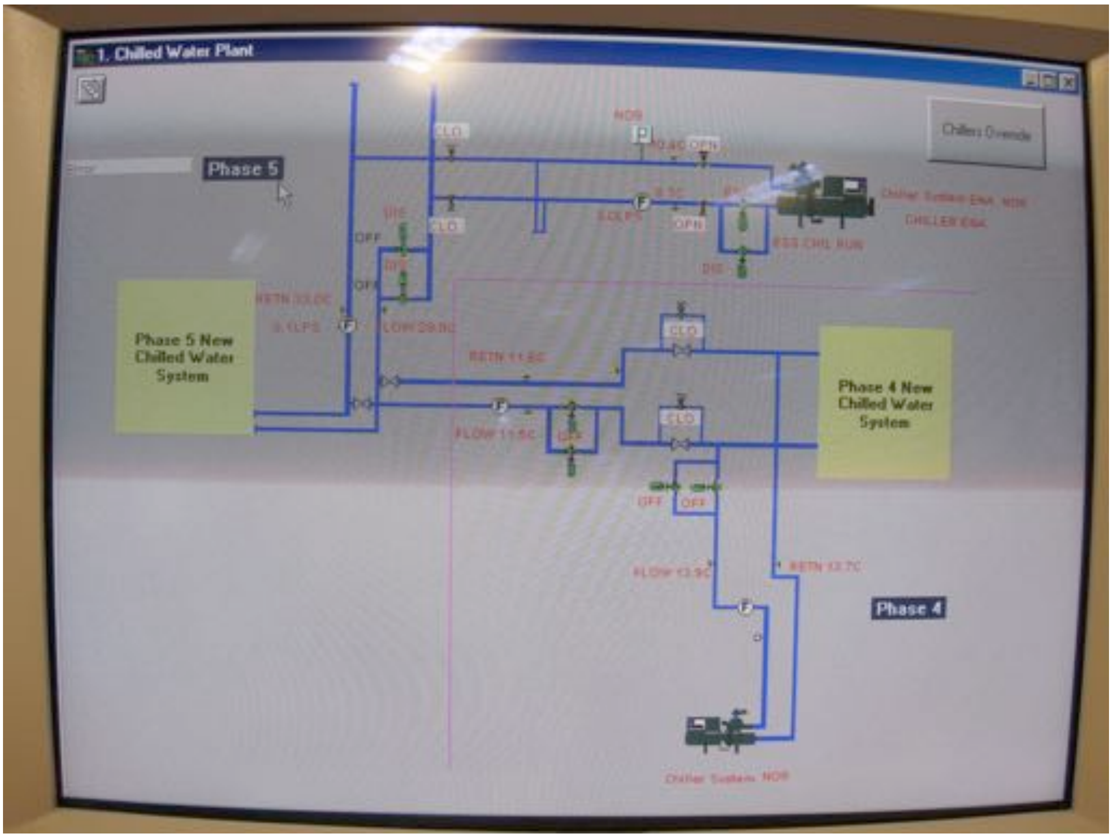


Figure 9.5.6 – Phase Four and Five, Chilled Water

a. Only the essential-circuit chilled water system, used for data rooms and the like, was enabled to run, which given that it was a very cold day, is reasonable, but shows that the general office accommodation does not have a year-round demand for cooling, as many office buildings do.

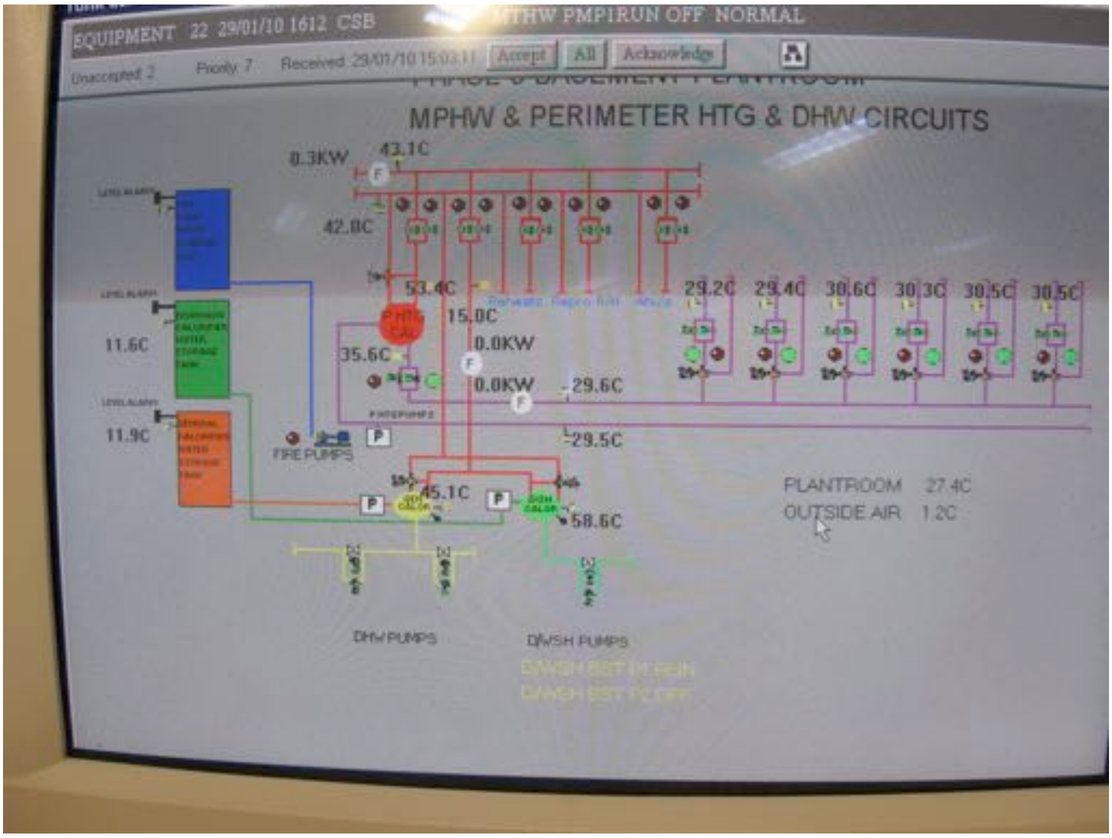


Figure 9.5.7- MPHW and Perimeter Heating

a. Given that this was a very cold day with no general space cooling in operation, it is interesting to note that there was virtually no heating either (0.3 kW). It would be an extreme coincidence if the survey occurred at a time when heat loss and heat gains were in near-perfect equilibrium.

Note: the MPHW was undergoing maintenance which might at least partially explain this. However the building didn't seem at all cold.

Figure 9.5.8 – Phase Five, Basement

a. Plant on-time is before 05:00 (typical for all floors)

b. Some temperature set-points are very low and are adjacent to others that are much warmer within open-plan offices (typical generally). For instance a VAV box with a set-point of 15.1 °C is adjacent to another at 21 °C. One box is even indicating a set-point of 0 °C.

   Open-plan spaces need to be controlled to a single, homogenous temperature. They cannot provide micro-climates. Boxes should be slaved together.

10 Appendix C, Metering, Targeting and Monitoring

Since 2002 edition of Part L of the Building Regulations, all new installations require sub-metering and a monitoring strategy.

Metering

The 2006 edition requires:

- At least 90 percent of the annual energy consumption of each fuel to be assigned to be assigned to the applicable service, such as lighting, cooling, heating and so on.
- The performance of any low- or zero-carbon system to be monitored
- Buildings with a useful floor area over 1000m2 to have automatic data logging

The precise details are given in CIBSE TM 39: 2006 which states the capacity of equipment requiring individual metering, as summarised below:

Boiler and CHP	50 kW input
Chillers	20 kW input
Electric humidifiers	10 kW input
Fans and pumps	10 kW input
Distribution boards (note 1)	50 kW input
Separately tenanted areas	>500 m^2
Heating or cooling supplied to separately tenanted spaces	>2500 m^2
Process loads	all

In order to properly allocate 90 percent of loads to their end-uses, it is necessary separately measure lighting and small power.

Targets and Monitoring

The designer is responsible for providing the energy targets for each meter, ideally for each month of the year. This information is included in the building's logbook which has also been a mandatory requirement since 2002.

Occupants are encouraged to collect the data for each building on a weekly or monthly basis, compare them to the estimates and to past performance, and to act upon unexplained increases.

Beyond the Legislation

We generally recommend sub-metering, targeting and monitoring in existing buildings, even where this was not a legal requirement when they were built, but this forms part of a wider Energy Management Plan where we would help building users to:

- Develop an energy strategy
    - Understand their aspiration (to be best in class, carbon-neutral, a percentage reduction and so on)
    - Understand how they compare against their aspiration (gap analysis)
    - Energy audits
    - Brief for maintenance contractors
- Appoint and train a building energy manager
    - Usually an existing member of staff with other roles
    - NOT be responsible for day-to-day building operations
    - Direct report to senior person
    - Clear roles, responsibilities and authority
    - Checks monthly meter reads against predicted & takes action
    - Interface between senior management and staff on energy issues
- List of meters with anticipated monthly usage
    - National benchmark data, but can be misleading for some building types
    - Computer modelling and expert assessment
    - Don't use historic data – might be too high
- Read the meters monthly
- Address high usage
    - Anything using more than expected
    - Any large user should be targeted
- Encourage behavioural change
    - Manage expectations
    - Teach staff about their building

- Explain energy implications of behaviour and what can be expected from the building
- Initiate new staff members
- Communicate with staff – tea room posters, etc.