Chapter 5

Buildings for Low Energy Air Conditioning

Dr Tadj Oreszczyn

INTRODUCTION

Over half of global warming is thought to be attributable to the burning of fossil fuels and slightly less than half of this is due to conditioning the environment within buildings. Since the UK government is committed to reducing carbon dioxide emissions by 20% between the years1990 and 2010, the pressure to improve the energy efficiency of our building stock is likely to increase in the coming years.

Field studies have identified that, on average, fuel costs for air conditioned buildings are twice that of naturally ventilated buildings and result in twice the CO_2 emissions[1]. Air conditioning is therefore often thought of as an environmental evil by environmentalists with calls to ban it. Air conditioning protagonists argue that air conditioning provides for a better environment within buildings and only accounts for 6% of CO_2 emissions in commercial and public buildings (i.e. 1% of total UK CO_2 emissions).

This chapter explores some of the issues that can impact on the design of energy efficient air-conditioned buildings. The arguments presented in this chapter are based on research carried out at the Bartlett, University College London (UCL) and on the authors' experience of running the Department of Trade and Industry funded Energy Design Advice Scheme (EDAS) office based at UCL. EDAS provides free advice to any building professional involved in the design and/or commissioning of a new building or refurbishment of an existing building. The office based at the Bartlett has been involved in providing advice on over 700 projects with predicted cumulative energy savings for the scheme as a whole of £15 million per annum.

WHY AIR CONDITION?

Air conditioning can provide cleaner air, reduce externally generated noise and control humidity and temperature. In theory, the increased energy use of air conditioning can produce better environmental control, which in turn may improve the health, comfort and productivity of occupants, see Chapter 1. The problem appears to be that in many cases air conditioning has not resulted in an improved, environment, but has resulted in increased energy consumption. An example of this is the conditioning of museums and galleries.

Some museum objects require a stable humidity to prevent object deterioration. Theoretically if visitor comfort is also to be achieved, this stable humidity can not be achieved by heating alone but also requires dehumidification and humidification. In addition, many museums are located in polluted inner city areas where the objects need to be protected from the potentially corrosive external environment. The introduction of full air conditioning in such buildings provides the potential for improved humidity and pollutant control.

However, the monitoring of relative humidity in different museums suggests that the variation in humidity can be as large in air conditioned galleries as in naturally ventilated galleries. Figure 5.1 shows the range of monitored relative humidities in six different galleries over a year. Two of the galleries were naturally ventilated (N/V), one was naturally ventilated with humidification (N/VH), one had a hybrid system, mechanical ventilation controlled by carbon dioxide sensors plus humidification and dehumidification within the gallery space (H), and two had fully ducted central air-conditioning (A/C). There is relatively little difference in the annual variation in RH and none of the galleries was achieving a ± 5% variation RH although this was the design intent in galleries 4, 5 and 6. Perhaps more important than the seasonal variation in RH, to which objects may acclimatise, are short-term variations. Interestingly, the smallest variation that occurred in any week was in the naturally ventilated gallery. Achieving good humidity control is difficult in museums for the following reasons:

- The level of control required is not typical of other buildings
- The spaces requiring conditioning are often large in volume
- The internal gains can vary dramatically.
- Budgets for the operation and maintenance of museums are very limited.

Also, gaseous and particulate pollutant measurements in both naturally ventilated and air conditioned museums show that only some of the potentially harmful pollutants are significantly reduced in air-conditioned museums[3]. Therefore, in practice, air conditioning may not provide a significantly better environment for the display of objects. Yet the energy consumption of air-conditioned galleries is twice that of naturally ventilated galleries[4]. Figure 5.2 shows the large increase in energy use associated with different bands of humidity control.

Although energy costs in real terms are at their lowest level for over 20 years and for many organisations energy costs are an insignificant element of a company's operational cost. However, many organisations are unaware of the expenditure required to properly commission, operate and maintain an air conditioning system. Without this investment air conditioning will not produce the controlled environment expected of it. Clients need to be made aware that, over the predicted lifetime of services; the capital outlay may account for only one-third of the total cost, the other two-thirds being accounted for by maintenance and operating costs. Although it is often stated that services may account for 40% of the total capital cost of a new building, they may total 90% of the lifetime cost of a building. EDAS projects have consistently found that clients unfamiliar with air conditioning are not aware of the true costs of its operation and maintenance. Neither do they realise that their design team can provide them with these costs.

COST EFFECTIVENESS

During the design of energy efficient building there are many opportunities to invest in energy efficiency. Often these investments are simply dismissed as too expensive. Occasionally, however, pay back calculations are carried out to determine if the investment is cost effective. What determines whether a particular investment is cost effective or not will vary from client to client. For example, an environmental organisation may accept a payback time of 20 years during the design of their headquarters, whereas a commercial company commissioning a DIY superstore may only consider payback times of less than 6 months. However designers should also be aware of the non-energy saving benefits of some energy efficient technologies, as it is often these additional benefits that sell a particular energy technology to a client. For example, the installation of double-glazing is one of the most popular energy saving technologies in the domestic market. Yet it has one of the longest paybacks times ranging from 10 to 30 years. The reason for its popularity is that double-glazing has many benefits beyond simple energy efficiency. These include the following:

- The lack of surface condensation and hence improved visibility and reduced maintenance.
- A perception of improved security.
- Improved thermal comfort close to the glazing due to higher internal surface temperatures.
- Improved noise reduction.

The energy measures most often adopted during EDAS advice have been those which have benefits additional to simple energy efficiency. For example:

- High frequency lights have been shown to reduce the incidence of headaches and eyestrain.
- Automatic control of electric lighting when daylighting is adequate can reduce overheating and hence improve occupant comfort.
- External insulation can eliminate cold bridges and protect the fabric.

Very often such measures will be adopted even though a simple energy payback calculation may identify them as not being cost effective. Therefore, designers should be fully aware of these additional advantages of energy efficient technologies to increase the likelihood of them being accepted.

There is a tendency among designers to be followers of fashion when adopting energy efficiency, and in particular adopting a centre piece or energy efficient statement, normally a visible feature. For example, large areas of south facing glazing, solar chimneys and photovoltaic cells (PV's) are popular "green" statements. Monitoring building energy use has shown that, buildings which focus their energy attention on one particular issue, are often not energy efficient in practice. Energy flows within air-conditioned buildings are complex and many faceted, see figure 5.3. All the different forms of energy use in a building must be considered if the overall performance of the building is going to be energy efficient. The introduction of a nationally agreed non-domestic energy-labelling scheme would assist this process and allow clients to take more informed decisions.

Not only do the various energy efficient technologies have to compete for limited funds against inefficient technologies, but also against themselves and renewable energy technologies. Although, design teams often argue that PV's may be competitive against fossil fuel in the long term as fossil fuel prices rise, they should also be aware that renewables have to compete against other energy efficiency measures and it may be far more cost effective to invest in fabric improvements, energy efficient fans or lights than say PV's. Table 5.1 and Figure 5.4 shows typical payback periods and the cost effectiveness of different measures per tonne of carbon saved for different fabric energy improvements, service improvements and renewable technologies in the domestic an commercial stock. Sometimes however, the primary aim is to make a visual statement, i.e. an advert for the company, in which case the design team should be aware that this is the primary reason for implementing that particular technology.

INTEGRATED DESIGN

Somehow, once the decision that air conditioning is going to be installed in a building has been taken, professional roles seem much simpler. The principles of integrated design, which all designers are aware of, too often seem to be forgotten. Without integrated design the architect can simply design the fabric focusing on the aesthetic and structural properties. The services engineer can then fix the environmental control in the building! We all know that it should not be like that. Yet this still occurs in many projects, after all it can suit all parties. Architects can get the building to look just how they want to, while the services engineer does not have to get involved in complex debates with the rest of the design team. The services engineer can simply design a system for a building where all the fabric variables have already been fixed, making the whole process less time consuming. There really is no motivation for the engineer to reduce the capacity of the installed plant when their fees are related to the cost of the plant. The net result can be an air conditioned building which uses far more energy than it need, at the same time as making the system more complex to operate and maintain. If the occupants cannot afford to maintain or operate such systems adequately, the benefits in improved environmental control are lost. In extreme cases the lack of integration in the design team between the design of the fabric and services can result in the fabric failing. For example, a recently designed award-wining museum has never achieved the level of environmental control required, uses excessive energy and has water condensing on walls and windows. Meanwhile the occupants think that better environmental control would have been achieved in a medieval building with earth floors.

The advantages of an air conditioned building which incorporates the principles of integrated design go beyond simple energy saving. For example, when the plant fails

– invariably on the hottest day or over the Christmas period, the consequences are minimised in a building where both the fabric and services act to control the environment.

FORM

The importance that form has on deciding whether a building is air-conditioned or not is very important and reasonably well understood, see figure 5.5. The impact that form and fabric can have on the annual energy consumption of air-conditioned buildings is less clear. For example, preliminary work undertaken at the Bartlett by Dr Alan Young as part of the EPSRC funded project "Natural Ventilation" indicates that a change in aspect ratio for an air conditioned building from 1:1 to 6:1 increases primary energy consumption by only 1 to 1.5 %.

ROBUST SOLOUTIONS

Energy monitoring within buildings designed to be energy efficient often shows that the building uses far more energy than expected. The reasons for this discrepancy are many, including the following:

- Energy efficient features left out during the latter stages of construction e.g. a BEM system left out due to cost cutting even though the initial design strategy was dependent on a BEMs system being installed.
- Inadequate commissioning.
- Complex design.
- Occupant use different from original design assumptions.
- Inadequate resources and expenditure on operation and maintenance.

Energy efficient designs must be robust enough to cope with the range of conditions that the building will experience over its lifetime. In particular systems designed today should be able to cope with the impacts of climate change and changes in occupant use.

Climate Change

Although the evidence for global warming is still controversial, the majority of world climate experts now agree that global warming will occur and there is growing evidence that it is already happening. Figure 5.6 shows that during the last 20 years the average monthly degree day to base 15.5°C has decreased by some 11% [8.] Total cooling degree-hours to base 18°C have more than doubled on average for most UK locations over the last 35 years [9]. Designers should at least examine the impact that such warming may have on the comfort of occupants and the energy consumption over the lifetime of the building

Occupant Use

During the design of a building many assumptions are made about how the occupants will interact/use the building. Given such assumptions it is possible to model how a building will perform. However, many designs are very dependent on occupants using a particular space in a certain way, or controlling various elements of the building and its services in a particular way. If the real occupant's behaviour differs from the original assumptions, then the building can often perform differently from the original design intentions. Three examples of this are as follows:

1. **Atria and glazed walkways**: These are very often designed to be energy efficient features allowing daylight and enhanced ventilation to penetrate a building.

During the design the assumption is that the spaces are treated as buffer spaces and so are not actively conditioned i.e. treated as uninhabited zones. The reality is often very different. Because such spaces are very often attractive, the tenants want to make use of them all year round in a similar way to other spaces within the building, e.g. as meeting areas, restaurants, classrooms etc and as such they require extensive conditioning. So what was initially planned as an energy saving feature turns out to be an energy-guzzling feature. Further, had the original design assumed the space was to be fully conditioned it would have probably been designed differently. Similar results have been found in the domestic sector where 90% of conservatories are in fact heated[6].

2. **The use of Venetian blinds**. Heavily glazed facades can allow daylight to reduce the need for electric lighting. However they can also result in high solar gains. Blinds can assist in allowing adequate daylight while reducing solar gains and glare. The assumption often made during the design is that during overcast periods the blinds are pulled up, or at least the slats are in the open position, and that during sunny periods when cooling or shading is required, they are pulled down and their slats are in the closed position. The reality is that on average some 40% of the glazed façade is occluded with blinds and that there is relatively little adjustment due to variation in solar gain[7].
3. **Controls**. Buildings which require sophisticated controls, also require sophisticated controllers and in turn these require knowledgeable operators. If the occupants of the building are unlikely to have adequate knowledge, or cannot afford to buy in the necessary expertise, systems should be kept simple.

However, the above areas all require further research, in particular there is a need to test the sensitivity of different design strategies to different assumptions about occupant use in order to assess the robustness of the various options. As a result of such work it is expected that several strategies currently thought of as energy efficient will be found to be inefficient.

CONCLUSIONS

The design of energy efficient buildings is far more complex than was originally thought in the 70's and 80's. In particular, theoretical energy savings do not always materialise; similarly installing more plant does not always result in improved occupant comfort and environmental control.

Energy efficient design has now moved beyond the simple theoretical analysis of predicted savings to the adoption of proven techniques, based on the results of monitoring buildings over the last 20 years. In particular, the importance to detail throughout the design process, and the role of good commissioning, operation and maintenance have been identified.

Where appropriate, air conditioning should be incorporated in the design and not treated as an unnecessary evil. Clients should however be warned of the operating and maintenance costs and designers should be realistic as to the environmental benefits that will materialise.

The design team needs to strive for an integrated design minimising the degree of active control of the environment and maximising the passive control features even if air conditioning is to be installed. The overall system design should be robust to future climate change and changes in occupant use. Also, the energy strategy for a building should rely on more than token visual statements or single elements of energy efficiency and should cover all aspects of energy use within a building. The introduction of a national energy labelling system for non-domestic buildings could play a significant role in making sure this is the case.

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FIGURES

Figure 5.1 Range of relative humidity measured over a period of one year inside six galleries and outside. [2]

Figure 5.2 Effect of relative humidity control on plant energy consumption. [5]

Figure 5.3 Typical energy flows in an air-conditioned office.

Figure 5.4 Net annual saving per tonne of carbon saved for different measures applied to the UK commercial building stock assuming an 8% discount rate and electricity generated from coal-fired plant. [11]

Figure 5.5 Average energy performance of different building forms. [10]

Figure 5.6 Monthly degree-day data to a base temperature of 15.5°C for the Thames Valley Region plus linear trend line[8]

TABLES

Table 5.1 Typical savings and payback times for domestic retrofit measures

MEASURE **Tradesman installed - 1992 costs**	**SAVINGS** **/£**	**PAYBACK** **/years**
Hot Water Tank Jacket (DIY)	10 to 25	0.5 to 3
Central Heating Programmer/Thermostat	15 to 40	2 to 6
Low Energy Lighting (per lamp) DIY	2 to 5	2 to 5
Loft Insulation to 150 mm	50 to 80	3 to 5**
Cavity Wall Insulation	65 to 140	4 to 8
Draught-proofing	10 to 20	6 to 20**
Condensing Boiler Installation (full cost - gas CH)	120 to 200	6 to 12
(marginal cost when replacing boiler)	*50 to 80*	*3 to 5*
Solar Hot Water Heating System	**20 to 100**	**12 to 40**
External Wall Insulation	60 to 140	20 to 35
Low-emissivity Double Glazing	40 to 100	60 to 110
Photovoltaic Roof Tiles	**50 to 200**	**80 to 130**[+]

[+] Based on Swiss IEA data and multi-family dwelling; single family homes would be worse
** DIY would halve payback