Delivering the Future, today

Renate Powell, Carbon Trust

There is mounting significant evidence indicating that most buildings commissioned today provide poor working conditions, are unnecessarily expensive and complex to run and fail to account for the projected effects of climate change in their design. This is the case in both the public and private sectors, as is widely observed by the Carbon Trust as well. We are still not learning the lessons for the design of new buildings, making it even more difficult for refurbished buildings that have further limitations on options, even though the underlying principles are the same.

The Audit Scotland report, "Improving the School Estate" from 2007, investigated how effective the new and refurbished schools are and how well the Scottish Government and the councils were managing the improvements. Although it identified a general level of satisfaction with the design quality, it noted that when assessed against best practice the schools could be better designed. In particular, two areas were identified where improvements could be made:

- Environmental conditions such as the balance between day lighting, ventilation and temperature are often unsatisfactory and;
- Environmental sustainability can be inadequate. It became apparent that these features were only considered where their inclusion did not significantly increase the overall capital costs.

Furthermore, extensive evidence indicates these failures re-occur across all building types. Such problems are not restricted to Scotland. A National Audit Office report on the UK Government estate noted that of the projects that they examined, 80% failed the required sustainability standards.

Case Study 1 - Seaview Primary School

Figure 1. Angus Council's Seaview Primary School won the Carbon Trust Scotland's Low Carbon Building Award for a New Building in 2010.

They used an in-house team to manage the development process consisting of architects, interior designers, mechanical and electrical engineers, quantity surveyors as well as staff from the Council's energy and maintenance teams.

Natural ventilation by automated high level windows is controlled by the BEMS based on inside and outside temperatures and CO_2 levels. Where mechanical ventilation is required, heat recovery is used to temper the incoming air.

The school optimises its use of daylight using clerestory windows and skylights combined with artificial lighting controls based on occupancy detection and daylight dimming.

Seaview Primary School had no overall cost premium over a comparable building with higher emissions. The energy consumption is 49.8% lower than a typical new build primary school resulting in a cost saving of 67.7%. The lower energy consumption at the school will provide cost savings year-on year through the life of the building.

Productive environment

One of the issues identified in the Audit Scotland report was the unsatisfactory environmental performance of the new build and refurbished school buildings. This problem can have a significant detrimental effect on the productivity of the individuals in a building. Looking at it from the other side, the function of a building is to provide a more productive environment than standing out in the cold, wind and rain. So what do you need from a building to make it most productive for its occupants.

Issues with temperature, daylight, ventilation and acoustics may result in productivity losses. Dealing with them once the building is in operation is often expensive and results in decreased energy efficiency. For example, solving an acoustics problem by fitting acoustic panels to the ceiling or walls could mask the thermal mass of the building. Where the design of a building addresses such matters from inception, then such problems do not arise; however avoiding all of the potential issues may be costly.

Thermal comfort

The temperature that individuals find acceptable will vary according to a number of factors:

- The outside temperature; on warm days individuals are likely to accept a higher internal temperature than on cold days
- The company clothing policy
- How active they are
- What temperature they are used to at home and in the car.

A number of temperature-related problems can occur:

- Trapped warm air at ceiling level; the ceiling will radiate the heat back down causing occupants to sense a sizeable vertical temperature differential. People generally prefer a temperature difference of no more than 3°C from floor to ceiling. Hot air needs to be able to escape at high level.

Figure 1. Hot air trapped at the ceiling due to poor window design, only the middle and bottom panes can be opened preventing hot air from escaping

- Wholly or partially naturally ventilated buildings may be uncomfortable if ventilation air is not tempered.
- Large glazed areas can radiate cold and spill cold air. People's perception of temperature is based on a combination of the air temperature and the radiant heat from walls and windows. A large window can result in an area feeling colder despite a reasonable air temperature. Cold spill is caused by air coming into contact with the inside of a cold window and falling owing to convection, which then draws more warm air to the window, creating a draught.

Many buildings have a "Monday morning" problem caused by improperly controlled heating/cooling systems or the installation of an incorrectly sized heating plant, resulting in an unacceptable temperature for the building on a Monday morning.

One of the problems most frequently encountered is overheating, through excess solar gains, internal gains such as computers or poorly controlled heating. The latter is more an issue in spring and summer but can occur at any time of the year if a building is not correctly designed or controlled.

There are a number of studies investigating the relationship between temperature and performance. Generally it is acknowledged that performance drops by 2% for every 1˚C above 25˚C although this is dependent on the clothing being worn.

To design out overheating problems, it is most important for Clients to know how much the internal temperature will be above the external temperature, taking into account all internal heat gains as well. A good specification in Scotland would be not to exceed the external temperature at any time during the day.

Daylight

Achieving high levels of daylight results in a reduced requirement for artificial lighting and has been proven to result in improved performance of its occupants.

These improvements in performance are thought to result in:

- Improved visibility due to more consistent illumination levels, better distribution of light and better colour rendition
- Avoidance of seasonal affective disorder and suppression of melatonin production
- Improved mood, alertness and behaviour.

Badly designed daylight schemes can have a detrimental effect on performance. Typical problems include:

- Glare, causing occupants to look away
- Lack of brightness uniformity
- Inadequate integration with artificial lighting.

Wide-ranging research into the effects of day-lighting on productivity in schools, offices and shops has been carried out in California.

It found that in schools, students with the most day-lighting in their classrooms progressed 20% faster on maths tests and 26% faster on reading tests in one year than those with the least.

It also found that some office workers' performance deteriorated by up to 21% when they were subjected to glare.

Figure 1. Glare from tables that have a high gloss factor

To achieve the desired level of daylight it is essential to use a computer simulation of the day-lighting scheme. Standard tools only use "daylight factor", which ignores the affects of sunlight and brightness variation during the day.

Figure 2. Splayed window reveals, white mullions, astragals and light ceilings and walls reduce glare, making the most of the daylight

The low carbon impact is obviously that if there is good daylighting, then the artificial lighting can be switched off. For a Client it is therefore more important to know how much artificial light will be replaced by daylighting during the year.

Ventilation

Inadequate ventilation rates can result in a reduction of cognitive function, increased odours and raised levels of volatile organic compounds (VOCs).

Exeter University has conducted extensive research into the impact of ventilation on cognitive function. Research in a primary school showed a 5% loss of cognitive function when CO_2 levels had a mean of 2,900 ppm compared to normal levels of 1,000 ppm

High ventilation rates or drafts can also cause problems. Any airflow greater than 0.3 ms^{-1} can cause discomfort.

Natural ventilation is often the preferred low carbon means of ventilating a building however this can often result in lower ventilation rates than those desired. Natural ventilation schemes can be successful provided a detailed analysis of the proposed design takes place. Using natural ventilation for narrow buildings is more likely to be successful.

Many designs now use mechanical ventilation with heat recovery to decrease this risk. Where this is used, installing large ducts, short runs and clever control can be a lower energy option, but needs careful modelling to actual operating and non-operating hours.

Impact on low carbon design

For a productive workplace, the building elements and systems are likely to include good daylight levels, high insulation values and low summer solar gains as stated above. These can all contribute to a low carbon building if designed right.

Good daylight levels only reduce energy demand if the lights can be switched off when light levels are appropriate. High insulation levels mean lower heat demand in winter, but could also mean a significant cooling load in summer if not appropriately designed.

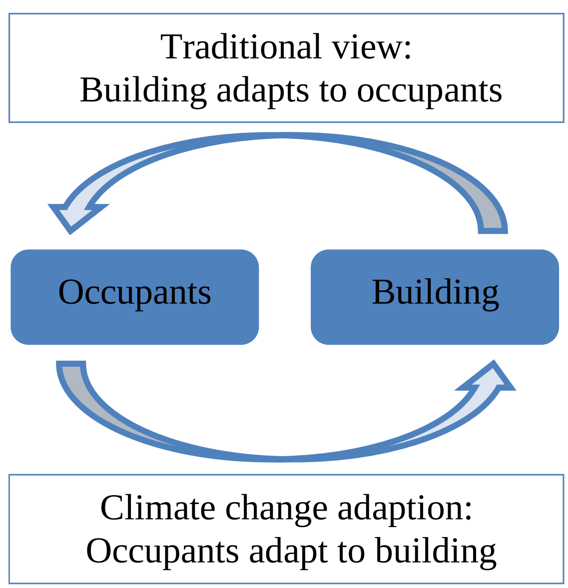
Figure 5. Excessive light levels in a corridor. Half the lights would still exceed minimum standards.

Ventilation rates determine a significant part of the heating requirements in winter, so increased levels that are continuous will result in higher heat losses. To make it low carbon, the ventilation should be controlled using, for example, CO_2 level control. High daylight levels will often lead to more sunlight that will cause blinds to be lowered, thereby increasing artificial lighting loads. Daylight from north and easterly directions, and coming from high clerestorey lights is a better all round solution.

Figure 6. The high clerestorey lights provide the majority of daylight. The low windows face north so there is no glare, and good uniformity of light. The clerestorey lights also open to let hot air escape when needed

Challenging the users

With the need to minimise carbon emissions and reduce energy costs some organisations are choosing to change employee's expectations of what an acceptable working environment is.



The specification gap

Avoiding the design flaws that undermine employee productivity as outlined above demands a new approach to building design and specification. Typically, few targets are given to building designers. Organisations procuring buildings, whether new build or leasehold, tend to specify one or two headline targets and then rely on compliance with building regulations to deliver an acceptable level of energy performance.

As the table shows, the Building Standards provide a minimum standard for some of the necessary factors that influence energy performance. However there are still a considerable number of elements that are unregulated or at the discretion of the building users and operators.

For the building specifier it is important to be familiar with what Building Standards include and exclude, so that a comprehensive specification can be provided to the designers that will minimise energy in use and give Best Value, whilst providing a productive environment.

The minimum standards set by the Building Standards are set to increase over the next few years aiming to reduce carbon emissions. The new section 7 enables organisations to set higher measurable targets for the design of buildings to achieve silver or gold sustainability label, however this is still based on the design of the building and does not govern how the buildings can be operated in practice.

Further advice on the specification gap is in the Carbon Trust publication Closing the Gap - CTG047.

Regulated	Unregulated	Building Manager Controlled	User Controlled
Overall design carbon emissions	Thermal mass and facade optimisation	Time and temperature control	Number of users
U-value and air tightness levels	Natural ventilation requiring extract at high level	Building monitoring	Small power loads and switching off
Ventilation levels	Avoiding a chilling requirement	Location of projection screens to position away from glare	Switching off lighting when not needed
Elemental carbon emissions	Daylight levels to offset artificial lighting	Maintenance	Opening and closing appropriate windows
Minimum equipment efficiencies	Min. and max. heating and cooling temperatures	Location and switching of vending machines	Opening blinds fully when times of glare have passed
Controls for individual items	Excess artficial light levels	IT and servers	
Metering and log book	Seasonal boiler standing and distribution losses		

Figure 7. Some of the regulated and unregulated aspects of building energy use. The green boxes represent the items influenced by building regulations and the red boxes are within the specification of the client organisation

For example, the Building Standards specify an initial minimum level of luminaire lumens per circuit watt and the control systems that are acceptable in different scenarios. However, there are a number of other factors that need to be specified to ensure that the building minimises its operational lighting load:

- Minimum daylight levels and uniformity
- Blinds to be located where they do not obstruct the windows when open
- How much artificial light will be displaced by daylight
- Brightness levels of walls and ceilings
- The maximum acceptable level of lumens in a room from artificial light
- Acceptable level of degradation of a luminaire over its life
- Acceptable range of colour rendering and colour temperature.

Incorporating as many of these measures as possible should ensure that the lighting design is carried out in sufficient detail that it is suitable for purpose and low energy in operation.

Figure 1. About 15% of the window is obscured by the blinds when they are open. The blinds will also hinder the ventilation

Case study 2 - Whitecross School in Herefordshire

Whitecross School in Herefordshire is a good example of what can be achieved when low carbon is addressed in a systematic way early in the project life. It was built under a PFI arrangement by Stepnell, and uses around 110 kWh/m2 per annum of floor area, about half of what many new schools are using. However, it has an excellent internal environment in the classrooms with good levels of daylight, high thermal comfort, well controlled ventilation and comfortable summer temperatures. Since it opened there have been hot summer days where the majority of local schools have had to close due to excessive temperatures and Whitecross has remained open and pleasant to work in.

Figure 9. Whitecross School in Herefordshire

The only complaint is that it has a slightly utilitarian feel in some areas but this is outweighed by the benefits of the high-quality internal environment and its influence on the learning environment. The strategy was to pay for items that would improve the productivity of staff and pupils and for reduced operating costs.

Operational Targets

The introduction of operational design targets can assist design and construction teams to deliver a building that operates in an energy efficient manner.

An issue that is sometimes highlighted by design teams is lack of guidance on detailed environmental design requirements provided by clients. Design teams are normally provided with the user requirements for room layouts, furniture and physical adjacencies but environmental conditions or building service requirements tend to be minimal with no distinction of room types. To help designers ensure that a building is fit for purpose, further guidance is required describing the internal environment required for the building. This will normally take the form of an overarching technical brief and detailed room data sheets with supporting schedules.

On the other hand, operational targets should not be a straightjacket for designers. A blanket approach that does not allow flexibility or discussion between a prospective design team and the users has often led to a building that becomes unnecessarily expensive and more complex to operate.

Case Study 3 - New South Glasgow Hospital

Use of operational targets in this project has changed the way the project team discuss options. Both cost and the carbon impact are now considered when design changes are proposed.

Operational targets are measures of building and equipment performance that are easily defined without ambiguity, are measurable and should be enforceable. One of the challenges with targets is to ensure that responsibility for delivering the target is clearly defined. The overall operational target should be what the building will consume in energy once in operation. The only way to control this during the design process is to use a Dynamic Model in operational mode, rather than in design mode, as has been done for some NHS projects.

The greater the level of specification at the beginning of the project, the more likely that they are to end up with a building that provides a productive workplace and is cost effective to run. In order to achieve a higher level of specification, the procurement team needs to have a wide range of skills available to them. Frequently knowledge gaps exist within procurement teams in the following areas:

Aspect	Skills and Knowledge
Architectural	• Passive design • Thermal mass • Air tightness • Day-lighting and brightness to reduce artificial lighting • Design for low summertime overheat • Facade Modelling • Space planning and massing • Allowing for appropriate internal heat gains • Ceiling shapes that give good acoustics
M&E	• Interaction with architects to improve the fabric design • Interpretation of daylight modelling • Thermal & ventilation modelling • Seasonal operational efficiency of heating and cooling plant • How building services are controlled with their integral controller and BMS to minimise energy use • User appropriate BMS systems
Finance	• Whole life costing • Single action – multiple benefit

Where these skills are not present in the client team it can result in dependence on external advisers who are responsible for delivery of the building and who therefore may not have their interests fully aligned with the clients.

If a knowledge and skills gap analysis is carried out at the start of the process of procuring a building, any training needs or external advisers' requirements can be identified. Where external advisers are used to fill these knowledge gaps, it is beneficial to ensure that they are independent of the building delivery team.

Similar knowledge and skill gaps occur within design teams as is evidenced by the variations in quality of Scotland's newer building stock. A knowledge and skills gap analysis can be used during the selection process to ensure that the design team is competent to deliver the required building.

Cost Implications

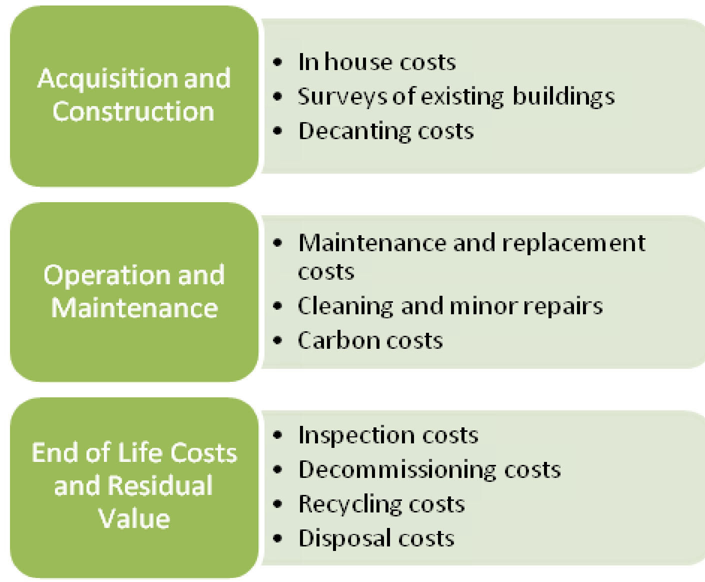
There is a range of estimates that have been published on the capital cost impact of achieving a low carbon building.
There is evidence from the schools building programme that significant operating cost savings have been achieved with minimal capital cost implications:

- The Angus Council Seaview Primary School project discussed in Section 2 achieved a 49.8% saving for no capital cost premium
- Whitecross school in Herefordshire has an energy consumption of 50% of typical new build secondary schools for a 0.7% cost increase
- Inverclyde Council has recently built four schools that encompassed many of the principals discussed in this document. They incurred a 4% increase in capital and expect to achieve a 30% reduction in operational energy usage.

Most of these projects have in common that decisions on the design and value engineering were made in favour of productivity and low carbon at the expense of other aspects.

Whole life costing

ISO 15686 Part 5 (12) describes a comprehensive method for calculating whole life costs for a building. The process involves evaluating all costs involved in:



Conclusion

There is considerable scope for improving the quality of the buildings that will be built over the next few years to ensure that they have a good internal environment and are affordable to operate. This will require changes to the procurement process, in house and external team member skills and construction techniques.

This article has highlighted a wide range of problems including:

- High operating costs
- Overheating
- Glare
- Acoustics issues
- Ventilation problems.

A number of exemplar buildings have also been identified where an excellent working environment and low operating costs have resulted from the use of an appropriately skilled team and a well-planned design.

The problems can be avoided by following a few simple steps. The Carbon Trust has created a suite of guidance documents and tools to assist this process. These include a project owner's guide; a project manager's guide; tools to help evaluate team members' and bidding parties' skills, knowledge and experience; templates for agendas and meeting report and documents to assist in the detailed specification required.

Figure 10. Acharacle school has natural ventilation with external shading screens when very bright, still giving good daylight in the room and allowing lights to be off

Figure 11. Potterow Informatics Building for Edinburgh University - a building that can attract high calibre postgraduate students in the international arena, without the heavy energy penalty