An Architect's Environmental Responsibility in Non-Domestic Architecture: Integration of Natural Day-lighting and Ventilation

By Jamie Evans

Abstract

Environmental values within architecture are become more important as climatic changes and dwindling resources come to the forefront of the public domain. Buildings are responsible for approximately 47% of carbon emissions from EU countries placing a high portion of responsibility on architects and design teams. This discourse aims to investigate the global environmental changes and reducing resources, offering passive building strategies as a means of lowering architecture's impact on the environment. The analysis on a series of case studies also demonstrates systems that have worked across the sector. The main outcome is presented in the form of advisory guidelines on how to design a building to maximise environmental efficiency in regards to natural ventilation and daylighting.

Acknowledgements

I would like to thank Dr Ahmad Taki for all of the help he has given me during meetings and in previous lectures which have been very helpful. I would also like to thank all the other members of staff and fellow peers who have assisted me this year. It has all been very much appreciated.

Jamie Evans

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1. Introduction

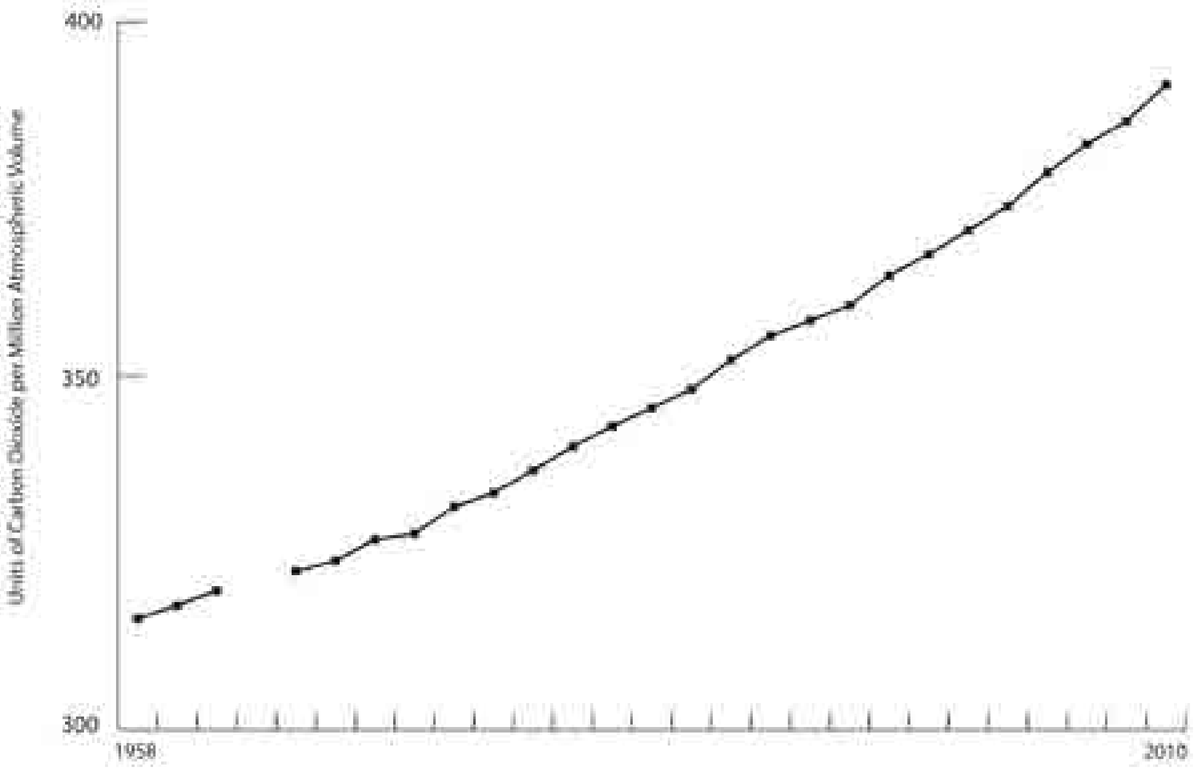
1.1 Background

The environment has become a growing concern for the global community over the last couple of decades. Climate change is now generally accepted to be a reality with around 90% of climate scientists agreeing that the increase in global temperatures is a result of human activity (Smith, 2005). Global warming is the main contributor to climate change, caused by the increased release of carbon into the environment, three-quarters of which is produced by the burning of fossil fuels and production of cement. The remaining quarter is a result of agriculture and deforestation. Buildings are responsible for around 47% of carbon dioxide released by countries in the European Union (Smith, 2005) with the UN Intergovernmental Panel on Climate Change (IPCC) targeting the building sector to have the greatest potential for improving energy efficiency (All Party Urban Development Group, 2008). The approximate two million non-domestic buildings in the UK are currently responsible for 17% of the national carbon emissions compared to the twenty six million residencies in the UK which produce 27% (All Party Urban Development Group, 2008).

Considering the information stated above this discourse will investigate the implications of non-domestic architecture on the environment. Residential buildings may be responsible for a larger percentage of carbon emission but that is due to the quantity of the buildings but non-domestic structures relatively produce more atmospheric carbon. As mentioned above there is greatest potential for improvement in this sector through various means.

Active on site generation systems producing energy through renewable sources is one way of reducing a building's carbon emissions. Solar panels and collectors can be positioned on the structure to generate electricity and hot water respectively. However photovoltaic panels are expensive and relatively inefficient, the market average presently is around fifteen percent (Solar-Facts.com, 2005). Despite this, efficiency is continuously improving, Sharp created a panel with 35.8% efficiency in 2009 (Phys.org, 2009), and prices constantly dropping. Wind energy can also be used on site with the incorporation of turbines; however these can appear tasteless and require being at a high level. Heat pumps offer renewable hot water as well as cooling by extracting heat from the surrounding environment and using that to create warm or cold air or water. Other active renewable systems such as hydro-electrical and biomass are dependent on

Figure 01. Graph illustrating the continuous rise in atmospheric carbon as found by ESRL



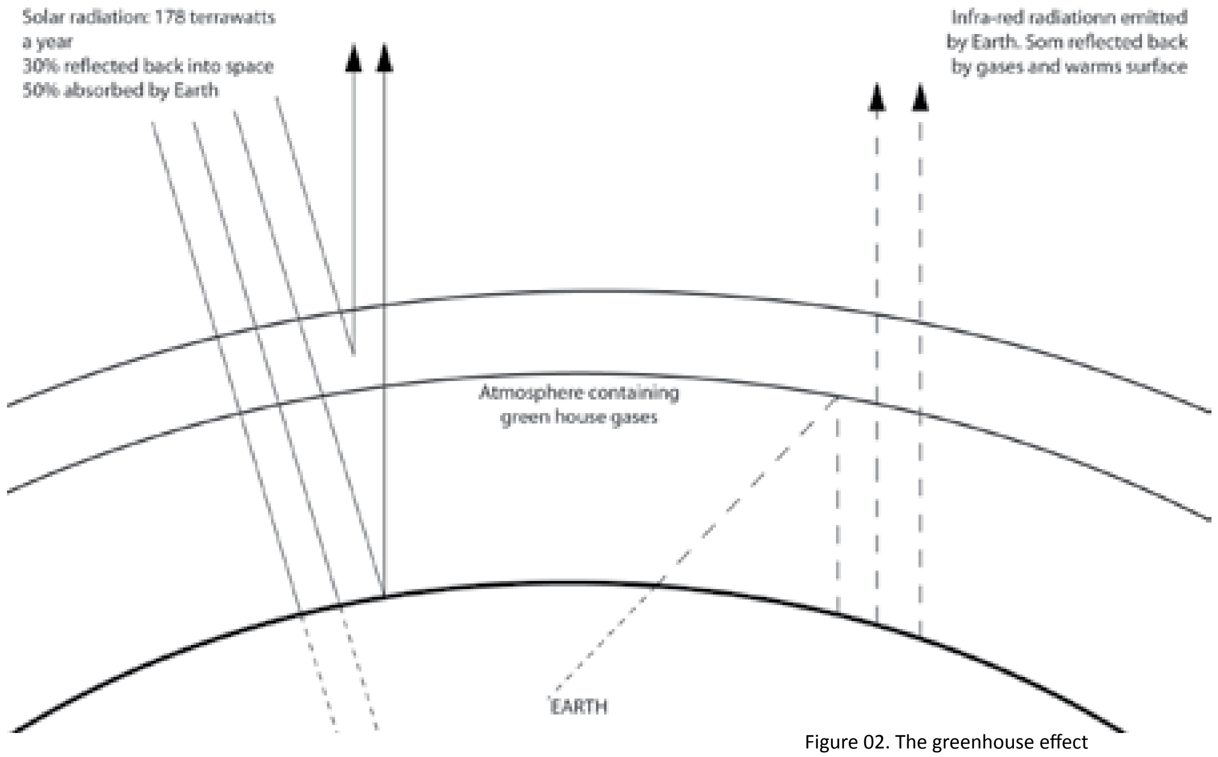


Figure 02. The greenhouse effect

site context, proximity to water and space, and can only be incorporated when parameters are met. They all have high starting costs with long payback periods and require maintenance. Though efficiency is constantly improving and may prove to be an effective option in the future.

1.2 Need for Change

As previously mentioned, it is agreed among the vast majority of scientists that humans are responsible for the increasing temperature of the planet and consequent effects, the root cause of this being the ever rising production of green house gases three quarters of which is created by the burning of fossil fuels and production of cement (Droege, 2010)[1]. Concentrations of these gases are now a third above historically sustainable levels and are continuing to grow as seen in figure 01 Current levels of atmospheric carbon have been recorded at 391.8 ppm (parts per million) according to Earth System Research Laboratory of The National Oceanic and Atmospheric Administration (ESRL, 2012).

Humans release an additional 6 billion tonnes of carbon dioxide into the atmosphere each year which is creating an imbalance. The carbon cycle is a naturally occurring process which controls the levels of carbon found in the environment. Atmospheric carbon is absorbed by plants during photosynthesis which is then gradually released into the ground through decomposition when the plant dies. This carbon can also be transferred into animals when eaten as part of the plant however the carbon still returns to the soil when the animal dies and defecates. Carbon can also be stored in what's referred to as a sink, oceans and rocks lock away 36 billion and 75 million billion tonnes respectively. Under natural conditions this cycle maintains equilibrium with an equal amount of carbon being released, through volcanic eruptions and weathering, and absorbed in photosynthesis. However with the burning of fossil fuels, carbon that was previously locked away is being reintroduced into the system. The imbalance has resulted in the heightened levels of carbon dioxide in the environment.

These gases collaborate in a transparent canopy in the higher levels of the atmosphere and cause an effect called global warming as depicted in figure 02. A total of 178 terawatts of solar radiation reaches the outer atmosphere of the planet each year. Of this, roughly a third is reflected back out into space with the rest being absorbed by the land and oceans on the surface. Under natural circumstances the level of radiation emitted by the earth would be the same

1. Carbon dioxide, methane, water vapour, nitrous oxide and triphospheric ozone are considered to be the main contributors to the greenhouse effect (Smith, 2005)

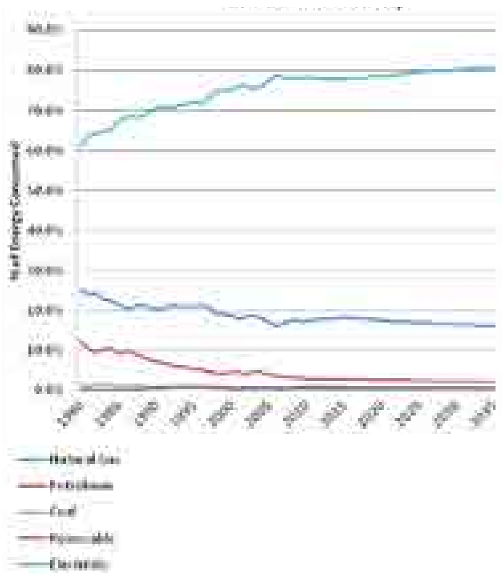


Figure 03. Energy consumed and predicted to consume US by fuel type. (U.S. Department of Energy, 2008)

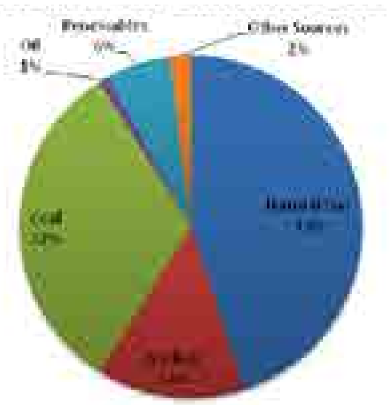


Figure 04. Energy sources used for electricity generation in UK 2009. (Black, 2009)

that reaches the surface, however due to the build up of greenhouse gases the long-wave radiation is reflected back onto the surface again, resulting in increased global surface temperature. Since the industrial revolution the levels of carbon dioxide in the Earth's atmosphere has risen by 26% (Smith, 2005), this has been attributed to the increased use of fossil fuels, mainly coal, for industrial mass production which began during the period (: 1790s to 1860s).

The environmental impact of climate change is not the only limiting factor of energy consumption today. The overwhelming majority of energy used by non-domestic buildings is generated directly from fossil fuels or indirectly through electricity from fuel burning power stations. Figures 03 and 04 illustrate the breakdown of energy sources. As mentioned above fossil fuels are made from carbon reserves that have been locked in the ground over millions of years which will inevitably run out.

The total oil within a reservoir is regarded as the oil in place; however it is not possible to extract all the oil due to technological restrictions, only the producible oil levels is used to calculate the oil reserves. It is also not financially prosperous for oil companies to continue extracting oil from some reservoirs as it becomes increasingly costly to drill further down, resulting in partially empty reservoirs. Though with advances in technology along with increasing demand and reducing supplies these abandoned reservoirs are beginning to be reopened.

In an interview with The Guardian's George Monbiot on the World Energy Report 2008, Fatih Birol, the chief economist for the International Energy Agency, claimed that oil supplies will peak around 2020 (Birol, 2008). Despite this plateauing in the next decade Birol is not worried about the diminishing resources claiming that unconventional oils will sustain the global demand during the transition to a renewable energy-based society. A viscous form of petroleum can be found in tar sands in several countries, most notably in the Athabasca Oil Sands, Alberta, Canada. However, obtaining oil from this source is incredibly inefficient and produces two to four times the amount of greenhouse gases as extracting conventional oil as well as having adverse effect on the llocal environment, such as polluting local water sources.

As for gas, previous records show a peak in production to be around 2035 (U.S. Energy Information Administration, 2011). However, separate reports claim that invention of new extraction technologies could allow access to gas supplies for another 250 years (Harrabin, 2011). The IEA claim that unconventional gas deposits in rock, which are extracted through small explosions fracturing rock, could open up 920 trillion cubic metres of previously unreachable gas. Though the supplies are dependent on the technological advances and individual scenarios, additional doubt is cast over its utilisation. Activists are claiming that the gas should remain in the ground to avoid further greenhouse gas emissions as well as localised water contamination (In some cases, gas displaces the water in domestic residences and flows from taps and hoses in regions surrounding the drilling area).

Fossil fuels not only have environmental impacts but also economical ones. The economy is incredibly dependent upon transportation which is almost completely run on petroleum. Changes in the supply of oil therefore have ripples across the markets as businesses lose confidence in sectors and money is withdrawn. Oil also has a huge role within politics, with prices ever increasing, government transport plans are deduced from predictions from bodies, such as the International Energy Administration. There is potential for economies to crash should petroleum prices rocket. With the scarcity of oil beginning to tell, oil rich countries are withholding information about the size of their oil reserves for political purposes and financial investment from other countries.

1.3 Statement of Problem

The issues discussed above and which are further explored below are beyond the construction industry's control. They are reliant upon political changes. However, figure 05 illustrates that 43% of carbon dioxide emissions are created by building, this is where architects and engineers can make an impact.

The discourse will focus on passive systems applied to non-domestic buildings rather than the active systems previously discussed due to their high running costs and present inefficiency. During the 20th century passive design was primarily discarded in order to maximise financial gains. Emphasis was placed upon maximising profit from investment by using quick construction techniques with the burden of energy demands passed onto clients and tenants. . illustrates the energy use of non-domestic buildings. It is clear the largest demand is for lighting, ventilation and cooling which can all be significantly lowered by the integration of passive design strategies such as natural ventilation, natural lighting and thermal mass.

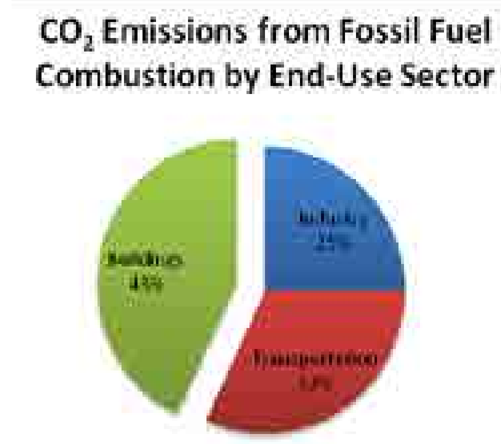


Figure 05. Carbon dioxide emissions from fossil fuel combustion (Talking Green, 2008)

1.4 Objectives & Methodology

- Inform clients of the importance of a building's environmental performance through research and presented data of current environmental factors and predicted future outcomes.

- Explore the advantages of individual passive strategies and define the context within which each are a viable solution. Analysis of effective scenarios coupled with diagrams and general rules of thumb along with examples of use within precedents will demonstrate the circumstances in which they are viable.

- Illustrate the progress shown and strategies utilised within the modern era as environmental values have become more and more important within society. A series of case studies will be analysed to identify passive systems used and developing trends within the sector. Even though this discourse argues for a larger consideration for a structures environmental impact, it is still and always an architect's obligation to shape space and design beautiful buildings, the aesthetics of a building should not have to be sacrificed.

"*All architecture is shelter, all great architecture is the design of space*" - Philip Johnson *(American Institute of Architects, 2011)*

- Finally a series of advice guidelines will be formed from investigation and case studies of good environmental practice to assist designers in the conception of environmentally sustainable projects.

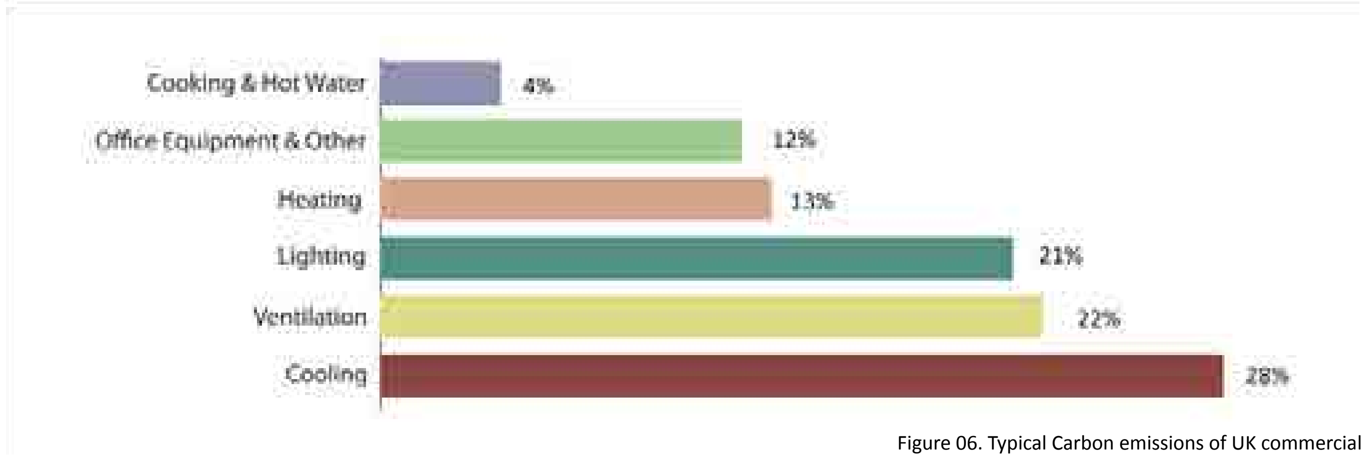


Figure 06. Typical Carbon emissions of UK commercial building (Droege, 2010)

2. Literature Review

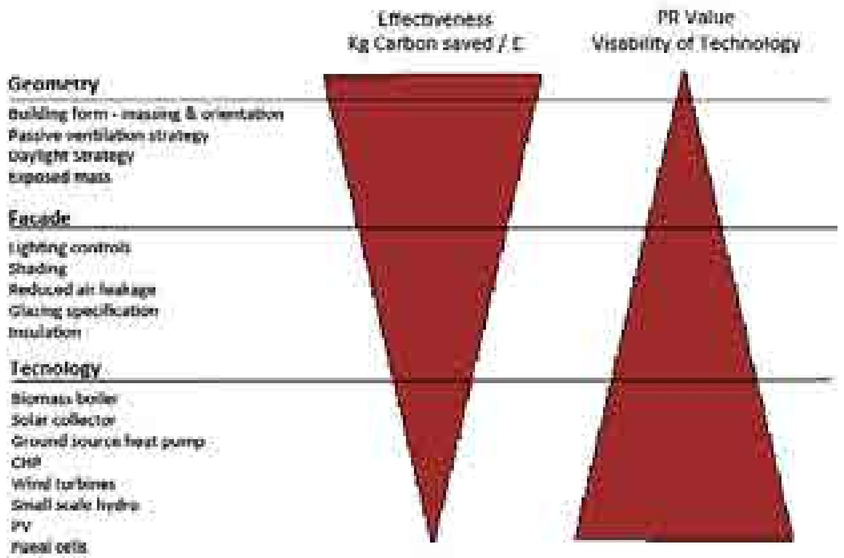
There are several good sources of information surrounding the topic of efficient energy use targeting buildings. Most of this has been aimed at domestic residences however there are still various texts that tackle the topic of this discourse, in particular, natural lighting and ventilation within non-domestic architecture. The majority of sources apply to specific building uses within the non-domestic sector, the most applicable of which are expanded upon below.

2.1 How to make Non-Domestic Buildings Green – RIBA Conference

On 21st May 2009 a one day conference was hosted by the Royal Institute of British Architects, supported by the Low Carbon Trust and SECBE (South East Centre for the Built Environment). The event was organised in an attempt to create a domain for concepts and research to be shared within the industry. Architects, building contractors, surveyors, engineers and other professionals as well as members of the government and local planning authorities were invited to the conference to raise awareness of the industry's impact and responsibility to the environment. Speakers included notable professors from leading universities, such as Shaun Fitzgerald from the University of Cambridge, and practicing architects, such as Robin Nicholson from Edward Cullinan Architects who was the keynote speaker.

There were several presentations discussing a whole range of issues surrounding the construction industry with a few applying directly to the topic of this discourse. For example David Oliver, of Energy Advisory Associates, presented a concise narrative of the changes in architectural language and changes for efficiency. An important idea put forward was on the optimum shape of a building. He stated that the most energy efficient shape for a structure in nearly all climates is to be long and narrow. This has been known for years as recognised in the extensive works of the Hungarian architect Victor Olgyay, and of Dr Nick Baker, of the University of Cambridge, The LT Method 2.0 , The technique of splitting a building into zones depending on the environmental strategy applicable to them depending on their orientation and position (Baker & Steemers, 1994). Oliver goes onto state that by orientating the building on an east west axis, having the long facades facing north and south, "*a building can potentially reduce its energy consumption by 40-50%*" (Oliver, 2009). Due to advances in construction technologies the building envelope of modern buildings loses considerably less heat than new structures even ten years ago. Therefore, in

Figure 07. Comparison between the effectiveness and visibility of different environmental strategies (Percy, 2009)



this formation the building is able to optimise solar gains by locating its glazing on the long facades, increasing natural light penetration into the building and warming the interior (Oliver, 2009).

An interesting lecture was also presented by Jerry Percy, head of sustainability for the management and construction consultants Gleeds. Figure 07 shows an image he presented illustrating the visual impact and efficiency impact of a series of strategies that can be used to improve the environmental performance of a building. He argued that the most effective systems, such as building form, passive ventilation, daylighting and exposed mass, were the most effective means of reducing the carbon emissions but had the lowest visibility and PR value. Technologies such as fuel cells, photovoltaic panels and wind turbines, had a high PR value but, due to lack of efficiency and the embodied energy in their construction, save the least amount of carbon dioxide. This creates an interesting relationship between the visual communication and the environmental performance of a building. Within a consumer driven economy, where profit and loss are one of the main indicators of a buildings success, the visual value of a building. This is backed up by an article in the Architect's Journal by Benjamin Lesser entitled 'How high-quality sustainable design creates value'. In the text Lesser explains that the cheaper running costs of a property increase the buildings value (Lesser, 2011). In addition to this the visible environmental characteristics increase the value of a building further due to the added PR value which Percy mentions in his presentation. Within the commercial sector image is vital to business' success and by communicating an environmental ethos a company is able to attract more customers. This has lead to a neglect of natural systems in favour of 'eco-bling'. Though initially this can only reduce the performance of a building, due to the investments from this newly formed trend the efficiency of renewable energy resources is constantly improving.

2.2 Heating, Ventilating and Air-Conditioning System Energy Demand Coupling with Building Loads for Office Buildings – Ivan Korolija (Korolija, 2011)

In his PhD theses Korolija explores the energy efficiency implications of integrating passive and active ventilation strategies to form a single hybrid HVAC system (Heating, ventilation and air conditioning). The paper recognises the necessities for non-domestic architecture to have a low environmental impact but also highlights other driving factors behind producing efficient buildings.

Non-domestic buildings can be simply split into two categories; public and private sectors. Public sector buildings include hospital and government/council properties, whereas private sector buildings have a much broader range including offices, shops, factories and hotels, to name a few. All these buildings generally have larger energy costs than domestic residences and depend on financial gains to maintain them. In a consumer driven economy, profit is the most important factor when assessing a building, like it is when assessing the performance of a business: "*a building with an ineffective HVAC system or high running cost is also unlikely to be leased or sold easily*" (Korolija, 2011). This suggests that businesses have several reasons for making new and/or existing buildings more efficient: to reduce running costs; adhere to government legislation on energy performance and emissions; and create a better public image.

The theses focuses primarily upon mechanical HVAC systems however it is made clear that hybrid systems are among the most efficient strategies that can be applied to a building. Given the size and functions of non-domestic buildings it is rare for a comfortable interior environment to be maintained throughout the year. However, by utilising environmental factors it is possible to ventilate and light using passive techniques for part of the year, thus reducing running costs.

2.3 Design Strategy for Low-Energy Ventilation and Cooling of Hospitals – Alan Short & Sura Al-Maiyah (Short & Al-Maiyah, 2009)

The report by Short and Al-Maiyah is directly targeted at passive ventilation within hospitals; however the principles discussed can be transferred across the whole of the sector. In the document the authors investigate the possibilities of proposed integration of passive ventilation systems within a hospital.

The report begins by highlighting the need for a reduction in carbon emissions from the NHS by referring to the recently launched carbon reduction strategy, a reaction to comparative energy figures between the UK and various international targets. The comparison suggested that “customary environmental design strategies for new hospitals will not deliver the performance required” (Short and Al-Maiyah, 2009), indicating that passive strategies are required.

Within the text, Short and Al-Maiyah categorise five ventilation systems and assesses each one’s ability to provide the required cooling, heating and air flow required. The aim was to deduce the simplest strategy that met the required performance. The first category is simple natural ventilation (SNV), the flow of air in and out of the space locally controlled by windows. Air does not necessarily need to go out through the same window however; other windows can be incorporated for cross ventilation or chimneys for stack ventilation. The second category is advanced natural ventilation (ANV) with passive cooling. Air is supplied to the space by stacks from the ground allowing pre-cooled or pre-warmed air to enter the space depending on the time of year. This system offers more control than the previous with the integration of a building management system (BMS) to control dampers on inlets and outlets to maximise efficiency. This results in an automated system with controls that require training to manage and maintain. This may also compromise the ‘well-being’ of the inhabitants as the quality of the air and space do not consistently correlate, a considerable factor for space that are used for long periods of time, and specifically to the report topic, hospitals. The third category is hybrid ventilation. A combination of natural and mechanical ventilation[2] are utilised to provide constant air flow and a maintained temperature. Similar to ANV, dampers are used to control air supply at the inlets and air flows out through stacks. The difference lies in the use of fans during peak loads to increase the cooling potential. PDC units encourage cool air to flow down into the spaces over cold water pipes from above to further cool the space if required. The performance of the strategy depends upon the efficiency of the fans to cope with peak loads and maintain a consistent environment. The fourth category is full mechanical ventilation for when the previously mentioned systems cannot deliver the required conditions to the space. Air flow is driven by variable fans giving fully automated control to a BMS unit; however the system does not provide mechanical cooling. The final category is full air-conditioning and filtration. This strategy provides a fully controlled environment where temperature, humidity and air flow remain constant. This strategy is sometimes required for spaces that are not viable for natural ventilation or where conditions need to be strictly regulated or isolated, for example surgery theatres and isolation wards in hospitals to prevent cross contamination. It is clear that a space’s use should dictate the means of ventilation and that the strategies are dependent upon the orientation, space use and climate to name a few factors.

2.4 Climate Change

Firstly, we must understand the reasons for such a change within an already well established industry. Climate change will affect a range of areas, most notably the environment, but also the economy and global ways of life.

2.4.1 The Evidence

The problems discussed above require proof to support the theory of the greenhouse effect. To prove the theory, scientists have looked back at historic climatic data to attempt to demonstrate the correlation between atmospheric carbon and global temperature. In 1999 the journal *Nature* published findings taken from ice core sample in the Antarctic. Ice cores show a remarkably accurate representation of environmental conditions over thousands of years. Melt layers are used to calculate the time span with individual layers providing information on each year. The warmth of each summer is indicated by the extent of which the ice has melted and refroze. In addition to this by analysing

2. Including passive downdraught cooling (PDC)

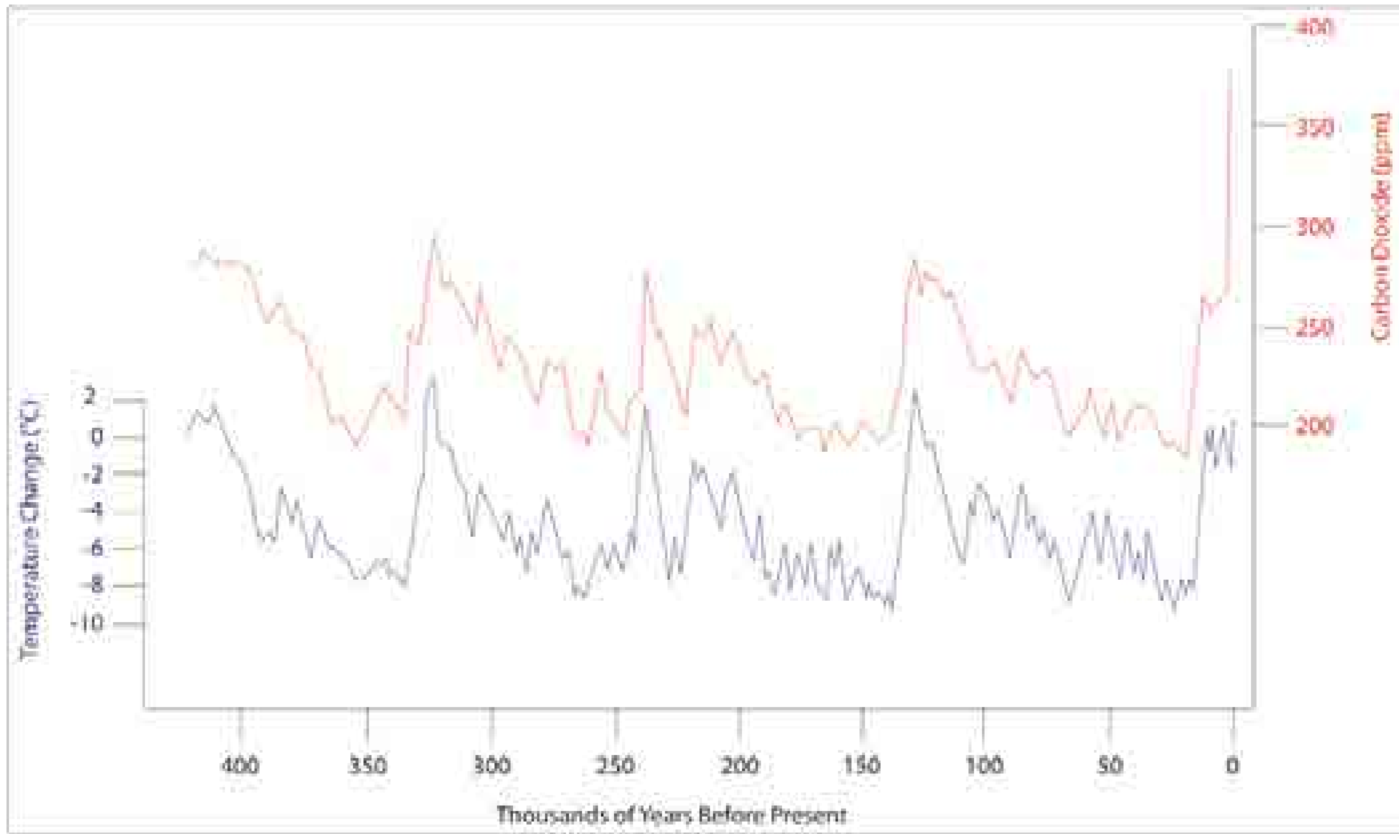


Figure 08. Historic correlation between carbon dioxide levels and global temperature (Petit, et al., 1999)

the melt layer’s compounds scientists are able to get a more accurate reading of temperature change by the presence of the heavy oxygen isotope oxygen-18 (^{18}O)[3]. In order to calculate the concentrations of carbon dioxide in the atmosphere, the trapped air is analysed to calculate the levels of atmospheric carbon. The findings published in *Nature* (Petit, et al., 1999) showed a strong and distinct correlation between the levels of CO_2 in the atmosphere and global surface temperature, as seen in figure 08. What is distinctly worrying, is the recent levels of carbon dioxide found in the ice core sample, the concentrations are far higher than any past historic levels. Proxy evidence which is obtained by the analysis of tree rings, a cross section of the trunk of the tree, reveals rings of growth with each ring being a year. By measuring the width of each ring you are able to determine how favourable the environmental conditions were going as far back as 6000 years. Particularly in northern latitudes trees are analysed to provide records of historic climates as climatic temperatures are the decisive factor to their growth[4]. According to the Climate Research Unit at the University of East Anglia (KR, et al., 2002) the proxy findings have an undeniable affinity to the ice core data.

To fully appreciate the context of climate change, consideration must be paid to historical fluctuations in the environment. Up until roughly 8000 years ago, the northern hemisphere was frequently thrust into arctic conditions due to disruption in the Gulf Stream (figure 09). The deep under currents are driven by the dense, cold and saline water in the arctic falling to the bottom of the ocean and moving towards the equator, by displacement, to be warmed up again. Water from the equatorial regions therefore moves north warming the area. It is thought that the melting of icebergs and glaciers in the north introduces fresh water into the ocean reducing the density and salinity. This effectively slowed or even stopped the ‘conveyor belt’ lowering western European temperatures by 10-15°C. Once the fresh water dispersed the current restarted and temperatures began to rise again. This happened about once every 3000 years but stopped 8000 years ago. The cause of the halt to the periodical freezing is still unknown but it created a more stable environment from which agriculture could be developed providing suitable conditions for civilisations to begin. However scientists are becoming concerned by the amount of glacial melting around Greenland and fear that the stream may once again slow or even stop completely.

Figure 09. Diagram of Gulf Stream (The American Liberal And Progressive Idea Blog, 2009)

3. Specifically the isotope ^{18}O is an indicator of precipitation temperature

4. Trees from northern latitudes are only used as there are now trees in the Antarctic

Palaeonclimatic and paleontological data must also be consulted as to the impact of environmental changes attributed to increased levels of carbon dioxide. There have been 5 mass extinctions, from what we know, the most recent and widely known being 65 million year ago when, it is believed, a giant meteorite hit the earth propelling millions of tonnes of debris into the atmosphere casting the surface into darkness for years. This caused ecosystems to breakdown as plants could no longer photosynthesise resulting in the extinction of 75-80% of life on earth (Benton, 2003), most notably the dinosaurs. However it is the third mass extinction that wiped out 94% of life on earth (Benton, 2003), has attracted the attention of climate scientists. Though there is much dispute about the cause of it, the generally accepted model at present is volcanic activity[5]. Rather than a typical cone-shaped volcano exploding, fissures opened up in what is now Siberia and Russia, which are believed to have spread for over a million square kilometres. The carbon dioxide and other greenhouse gases that this released, along with one or more 'methane burps'[6] created an intense greenhouse effect. This caused plant life to increase exponentially stripping the land and the seas of oxygen, the life on earth suffocated. Only 6% of life survived the event (Benton, 2003). What has caught climate scientists eye though is that all this was due to 6°C increase in global temperature, which, according to an IPCC estimate, is what the plant could reach by the end of century if carbon dioxide emissions are not reduced by 60% by 2050 (Smith, 2005).

2.4.2 Current Indicators

The immediate impact of climate change is not particularly easy to spot, however a trend begins to emerge when one looks at the widespread anomalous incidents that have occurred recently. It is only when one collates all data on these so called 'random acts of nature' that you see an overall shift in the earth's climate. Rising sea levels, droughts and extreme weather conditions are becoming more frequent.

One of the most evident places to witness these changes is in the small Eskimo village of Shishmaref, Alaska. Here, buildings are becoming unstable, sometimes collapsing, and the village is slowly becoming engulfed by the sea, a BBC report in 2004 described it as being "literally being swallowed by the sea" (Willis, 2004). The instability in the infrastructure is a result of permafrost[7] around the building's foundations melting, destabilising the ground on which they sit. In addition to this, rapidly rising sea levels are moving tides perilously close to the town. Temperatures in Alaska have risen 4.4°C over the last 30 years, a startling ten times faster than the global average (Smith, 2005), resulting in the melting of vast amounts of sea ice and increasing the ocean's progression inland at an alarming rate, 3 metres a year (Willis, 2004). This is caused by the melting of snow across the tundra. Being bright, the snow reflects most of the solar radiation the region receives, however as the snow melts, more land is exposed which absorbs the heat, warming the surface and surrounding area. As well as this the open tundra releases large amounts of carbon dioxide which further speeds up warming, a classic positive feedback scenario (figure 10).

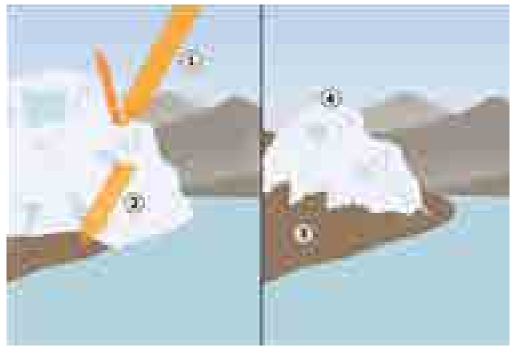


Figure 10. An example of a positive feedback effect.
1. Solar gains reflected by snow/ic
2. Exposed land absorbs radiation
3. More land exposed as snow/ice melts
4. Higher temperatures and reduced altitude reduces the amount of snow/ice reformed
(BBC News, 2012)

Another indicator of climate change is an episode of severe heat, or heat wave. Over the last decade however there have been two summers which have now been referred to as 'mega-heat waves'. In the summer of 2003 Western Europe was struck by a heat wave that was not only notable for its peak temperatures[8], but for its duration. High temperatures across many European countries, including UK, France, Spain, Italy and Germany, were blamed for over 35,000 heat related deaths from June to the end of August. The Earth Policy Institute (EPI) warned that these conditions were set to hit more frequently warning "*even more extreme weather events lie ahead*" (Bhattacharya, 2003). These claims were proved true when just seven years latter Russia was also struck by a severe heat wave. Though not as long, 2 million square kilometres of western Russia were hit by high temperatures, cities recorded temperatures close to 40°C, more than 10°C warmer than the regions norm. The high temperatures not only caused heat related deaths but was the cause of wide spread wildfires[9] which is believed to have killed nearly 5000 people (McElroy, 2010). In total it is believed to have caused 70,000 deaths across Russia and central Europe (Parry, 2011). Even though the root cause of these tragedies cannot be directly attributed to global warming and the greenhouse effect, the proximity of their occurrence has worried climate scientists as specialists from Zurich have reported that the kind of sustained temperature experienced in 2003 and 2010 could normally be expected every 450 years, but due to the changing climate, towards the latter part of the century it is predicted that they could occur as closely as every two years (Smith, 2005). Minor heat waves are still also a climate problem with 29 people dying over night due to high temperatures in Brisbane, Australia, alone in February 2004, a year after England recorded its highest February temperature of 17.6°C (Met Office, 2011)

5. The other model claim that helium and argon samples found in China are made up in a way that is not of this planet and therefore argue that the extinction was due to a meteor impact, similar but larger to the one at the end of the Cretaceous that killed off the dinosaurs, though supporting evidence is questionable

6. When a large pocket of methane trapped in ice explodes due to increased temperatures causing the ice to melt

7. Underlying soil that has been frozen for over two years (often for thousands). The water in the soil is below 0°C and stabilises the above ground

8. The UK recored its first ever temperature above 100° fahrenheit (37.78°C) (Bhattacharya, 2003)

One of the greatest effects of climate change to effect UK and the rest of Europe is flooding caused by rising sea levels and erratic weather conditions, such as heavy precipitation. There are many reports of flooding around the world and it is important for us to realise that now, thanks to technological advances and international media reports, people see more and more natural disasters. What may appear to be an increasing number may just be an increasing number of events being reported on. Monsoon flooding, in countries such as India, is a long standing naturally occurring process which has in fact been taken advantage of to re-fertilise farmland. However it is the growing trend of disasters which should be noted. One example was in Pakistan when heavy monsoon rains washed away crops and livestock as well as villages and towns in the provinces of Sindh and Balochistan. Over 400 people died with an estimated total of 8.2 million more affected by the floods (Bhatti, 2011). In the early months of 2000 Mozambique was hit by devastating floods killing 700 and leaving half a million homeless and was then struck again by similarly disastrous floods the following year which destroyed 27,000 hectares of farmland, killed 40 peoples and left another 77,000 homeless in an already impoverished country (Mason, 200). It's not only developing countries hit by flooding, in 2011 Brisbane, Australia, was struck by its worst floods for 37 years when rivers broke their banks creating an "*inland instant tsunami*" (Rourke, 2011). The floods completely swamped 14,972 buildings and partially flooding another 18,025 as the Brisbane River reached a peak of 4.46 metres (Calligeros, 2011).

Flooding is not just refined to just the southern hemisphere as devastating floods hit Europe in 2002. Areas of Central European countries, such as Czech Republic, Austria and Hungary, which are all landlocked, as well as Germany, were engulfed by water as rivers burst their banks after a week of heavy rain overflowed the waterways. Billions of Euros worth of damage was caused, most notably in Prague which experienced its worst floods for 200 years (Smith, 2005). As for the UK, a recent report[10] issued by the Department for Environment, Food and Rural Affairs (DEFRA) has targeted flooding to be the worst threat to UK from climate change (DEFRA, 2012). In 2007 large parts of Lincolnshire, Yorkshire, Nottinghamshire and Shropshire were left under water as the area received a sixth of its annual rainfall in just 12 hours (BBC News, 2007). In August 2011 southern England was hit by monsoon like precipitation when a fortnights worth of rain fell in half an hour in Bournemouth. Other examples of flooding in the UK can be found, for example Tewkesbury, Gloucestershire, was turned into an island as river burst their banks and flooded the area (figure 11), but it is important to view these within historic context. A series of cycles effect global weather and result in extreme conditions on a regular basis. One case is El Niño/La Niña-Southern Oscillation, a climate pattern that occurs roughly every five years across the Pacific Ocean, when variations in air pressure and surface temperature cause extreme weather conditions often resulting in floods or

Figure 11. Tewkesbury after flood in 2007 (Glancey, 2007)

9 Wildfires are another example of positive feedback as carbon dioxide is released into the atmosphere, adding to the greenhouse effect

10. UK Climate Change Risk Assessment (CCRA): Report assessing the impact of over 700 potential results of climate change and scaling them on their potential consequences

Figure 12. Predicted inundation of water after one metre rise in Miami, Florida, USA (Stratus Consulting Inc., 2009)

Figure 13. Predicted inundation of water after one metre rise in Hampton, New Hampshire, USA (Stratus Consulting Inc., 2009)

Figure 14. Areas of the UK lying below the 10m contour (Smith, 2005)

drought around the world (Herring, 2011). However none of the cases should be ignored but viewed as a whole to further understand their relationship and possible link to climate change.

2.4.3 The Future

Once data is collected on the current impact and historical trends climate scientist are able create digital models of the future and make predictions about the resulting climate. Most predictions are based on a 'business as usual' (BaU) scenario which considers that developing industrial countries will continue indefinitely. It also takes into account technological improvements and increased industrial efficiency. The impact of climate change spreads across many sectors affecting everyone in all industries, be it economical or health related.

The most anticipated result of global warming is rising sea levels. As mentioned earlier, this is the greatest threat to the UK posed by climate change. If recent patterns continue as predicted, sea levels are expected to rise by at least one metre by the end of the century (White, 2011), with other estimations being higher[11]. Even when you analyse the smallest predicted rise, figures 12 and 13 illustrate the estimated impact to Miami, Florida, and Hampton, New Hampshire, in the USA. As for the UK, Figure 14. highlights the land lying below the 5 and 10 metre contour levels which are most at risk of flooding. 10,000 hectares of mud flats and salt marshes rest in the highlighted areas but more importantly 50% of England's grade one agriculture land is threatened by storm surges. As the sea rises, storm surges will reach further inland damaging crops, the resulting salination will render the land infertile (Smith, 2005). In the UK it is predicted that 1.7 to 3.6 million people will be at risk of flood damage to homes and businesses, plus the knock on effects of increasing insurance premiums, physical health problems as well as mental health issues (Jowit, 2012). At present annual damages due to flooding totals at about £1.3 billion with the figure predicted to increase to between £2.1 to £12 billion by 2080 (DEFRA, 2012), a figure that is not surprising when considering the area of the UK that will be at risk of flooding (.).

However, flooding is a much greater problem for other countries which are a lot closer to sea level. One example is Singapore and its reclaimed territories. Millions of people live below one metre above sea level and are at risk after just a 20cm rise in sea level (Smith, 2005). In the UK the Thames barrier is already seen as being inadequate with the probability of London flooding halving from one in 2000 to one in 1000 chance since its completion in 1983, it is feared that it will be unable to cope by 2030 (BBC News, 2007).

11. Six metres by 2030 (Smith, 2005)

3. Theoretic Principles

3.1 Solar Design

Solar passive design is the implementation of lighting strategies which do not require intermediary operations or mechanical assistance. When considering that the sun drives all organic systems on the planet, it is not ridiculous to suggest that architecture can take advantage of the natural energy. By trapping solar energy either in spaces within buildings or in the building's material a huge percentage of a building, as previously mentioned, 22% of a non-domestic building's greenhouse gas emissions are produced for lighting.

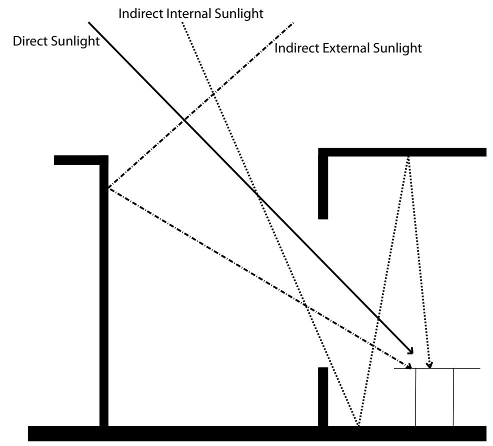
In conception of passive solar deign, the site's access to solar radiation needs to be measured to be evaluated the pre determined environment of the structure. The sun's altitude and azimuth, site orientation, slope, existing obstructions on site and overshadowing from objects outside of the site need to be analysed to calculate the levels of solar radiations the proposal will receive. There are instances, for example in an enclosed urban plot, where a site receives limited solar radiation which do not suit passive measures, however it is good practice to optimise whatever levels of daylighting a building receives (Smith, 2005).

Figure 15. Areas at risk of flood in England and Wales in 2080 (Smith, 2005)

3.1.1 Daylighting

To optimise the lighting efficiency of a building, it should take advantage of the solar radiation that falls onto the earth, 1000-1200 kWh/m²/yr in the UK (European Commission: Joint Reserch Centre - Institue for Energy and Transport, 2012)). Utilising this natural resource can reduce the 22% of energy a building uses to light its interior. Daylight is composed of three different components; direct sunlight, indirect internal sunlight and indirect external sunlight, as shown in figure 16. The total illuminance of a space is the combined total of these components, and is usually expressed as a percentage in the form of a daylight factor. However an average daylight factor, needs to be calculated to determine wether a space can be daylit. The equation below can be used to establish this at early design stages:

Figure 16. The three components of daylight (Taki, n.d)



$$\text{Average Daylight Factor} = \frac{W\,T\,\theta}{A\,(1-R^2)}$$

When:
W = Window area in m^2
A = area of all surfaces of the room in m^2
T = glass transmittance (multiplied by 0.9 to allow for dirt)
ϴ= visible sky angle in degrees
R= average reflectance of room surfaces (0.5 or 0.3 for light and dark surfaces respectfully)
(Taki, n.d.)

This equation can be used in conjunction with the table in figure 17 to calculate the levels of illuminance a space requires for its designated activity. Daylight factors are taken from the task height, for example desk height for an office.

Use	Average Daylight Factor	Minimum Daylight factor	Surface
Office	5	2	Desk
Classroom	5	2	Desk
Entrance Hall	2	0.6	Working Plane
Library	5	1.5	Table
Drawing Office	5	2.5	Board
Sports Hall	5	3.5	Working Plane

Figure 17. Table of recomended average daylight factors (Taki, n.d.)

Even if the average daylight factor of a space is met, the room could still be too deep for daylighting to be used. In the case of deep planned rooms the daylight factor reduces the further away from the window you go. A uniform level of light is required within daylit spaces to ensure the entire space has a daylight factor adequate for the designated activity. The equation below calculates the limited room depth:

$$\frac{L}{w} + \frac{L}{h} \leq \frac{2}{(1-R)}$$

Where:
L = depth of room
w = width of room
h = height of window head from floor
R = average reflectance in back half of room (usually 0.5 for typical office)
(Taki, n.d.)

To increase the illuminance at the back of a room you can ensure the surfaces are a light colour, make the room depth not much greater than its width and increase window head height to increase solar penetration.

A general rule of thumb can also be used to quickly estimate the effective daylighting depth when interior finishes are not yet known. It approximates that daylight penetration will reach 2.5 times the window head height above the floor (2 times with external shading).

Passive solar gains can be divided into three general categories: direct, indirect, and isolated.

3.1.2 Direct Solar Gains

Solar radiation is allowed to enter the space directly in an attempt to control both illumination and temperature. For this the majority of the buildings glazing needs to be on the sun facing façade, ±30° of south for buildings in the UK. The glazing should be at least double gazed or, preferably, low emissivity glazing to reduce the heat gains from direct light. The main risk when utilising this strategy is the possibility of overheating. Thermal gains through high levels of glazing can create an uncomfortably hot environment, particularly in west facing spaces as the sun is lower and therefore penetrates deeper into the room[12]. It is recommended that some sort of external shuttering or louvers are used to reduce the risk of increasing temperatures (Thomas & Garnham, 2007).

The surface onto which the direct light is cast is an important feature within the strategy. It is recommended that the floors or walls should have a high thermal mass. In doing this the heat gains incurred from direct solar penetration will be absorbed by the material and then released later on. In doing this a more consistent temperature is created throughout the space, reducing thermal fluctuations and maintaining a comfortable environment. It is also suggested that the main occupied rooms are located on the south side to take advantage of the passively warmed space, reducing the need for mechanical heating (New Mexico Solar Energy Association, 2004)

- South facing glazing
- Double glazed or low emissivity glazing
- High thermal mass on surfaces receiving direct light
- Main occupied rooms on south side
- External shuttering to reduce overheating and heat loss at night/during winter

12. This is not as bigger problem in east facing rooms as thermal gains tend to warm spaces that are cool in the morning.

- Light shelves to improve distribution of light
- Glazing should be around 25-35% of internal space floor area in UK (Smith, 2005)

3.1.3 Indirect Solar Gains

Indirect solar gains refers to the transfer of heat through an intermediate absorbing material to the required space. In this scenario the thermal mass is placed between the space and the sun and thus transfers the thermal energy 'indirectly'. The intermediate element can then be tailored to delay the heat from reaching the room till later on n the day when it is most required. Often a wall placed behind glazing (Trombe Wall) is used to create this thermal lag (U.S. Department of Energy, 2011).

Figure 18. Trombe wall

In the case of the trombe wall Figure 18., direct light falls on the thermal mass behind the window which absorbs the heat. The energy is the stored in the wall till later on in the day when it is slowly released into the space behind. The air in the gap between the window and wall will be warm and is allowed to circulate in the room. In the summer months this is reversed and the wall is used to cool the air to maintain a comfortable environment. In areas with inconsistent levels of solar radiation, such as the UK, the movement of air between the window and the wall is likely to be more beneficial to the occupants (Smith, 2005).

This strategy however, has the drawback of reducing views in and out of the space. Due to the restrictive nature of passive indirect strategies, an ugly façade is often created as the intermediate surface is usually dark in colour contrasting with the building form and appearance.

- High thermal mass material positioned between sun and space
- Thermal lag reduces the rate of heat exchange into the room delaying it till the evening when it is most required
- Wall should be approximately 15-20% of floor area of internal space (Smith, 2005)
- Glazing on outside of wall used to increase solar gains and insulate air behind trombe wall
- Heated air between glazing and wall circulated through space to provide warmth
- External shutters or blinds should be incorporated to avoid overheating in summer

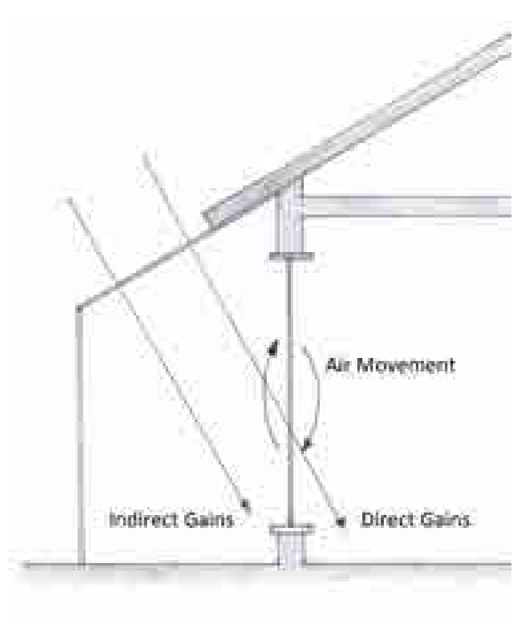


Figure 19. Sunspace

3.1.4 Isolated Solar Gains

The use of sunspaces, in residential buildings, has become very popular both being designed into new builds or as additional spaces on existing structures. However this strategy is also used within non-domestic buildings. Both the Manchester Civil Justice Centre and Innovate Green Office, which are discussed later on in the text, utilise this approach with large glazed atriums which not only work in a similar way to conservatories but provide deeper solar penetration into the building.

Figure 19 shows how a simple sunspace works. A glazed space is, preferably, located on the south façade of the structure in a position where it will receive optimum levels of solar radiation. The sunspace provides both direct and indirect solar gains to the attached space. Light can directly enter the building through the apertures between the building and sunspace to provide warmth and lighting. Indirect solar gains are also created as the air within the sunspace is heated by the penetrating soar radiation which is then circulated into the rest of the structure (U.S. Department of Energy, 2011). The sunspace however, has the potential to either overheat in summer or have high thermal loss in the winter so it is recommended that a means of cutting off air movement between the space and the rest of the building is inbuilt to avoid any energy loss. Overall, sunspaces are considered a net contributor to global warming due to poor design and management. Occupants do not use the spaces to their maximum effect and/or the design team have not briefed the client on how to manage the building. This has resulted in the sunspace being heated when cold instead of being cut off. The mechanical heating is quickly lost through the glazing and can require more energy to heat than the strategy saves (Smith, 2005).

- Provides both direct and indirect solar gains
- Located where the space will experience high solar radiation
- Heat store that warms air to be circulated through building
- Should be insulated and have external shuttering to avoid high thermal losses and overheating in summer
- Should be able to cut off the space from rest of building to avoid inefficient heat loss

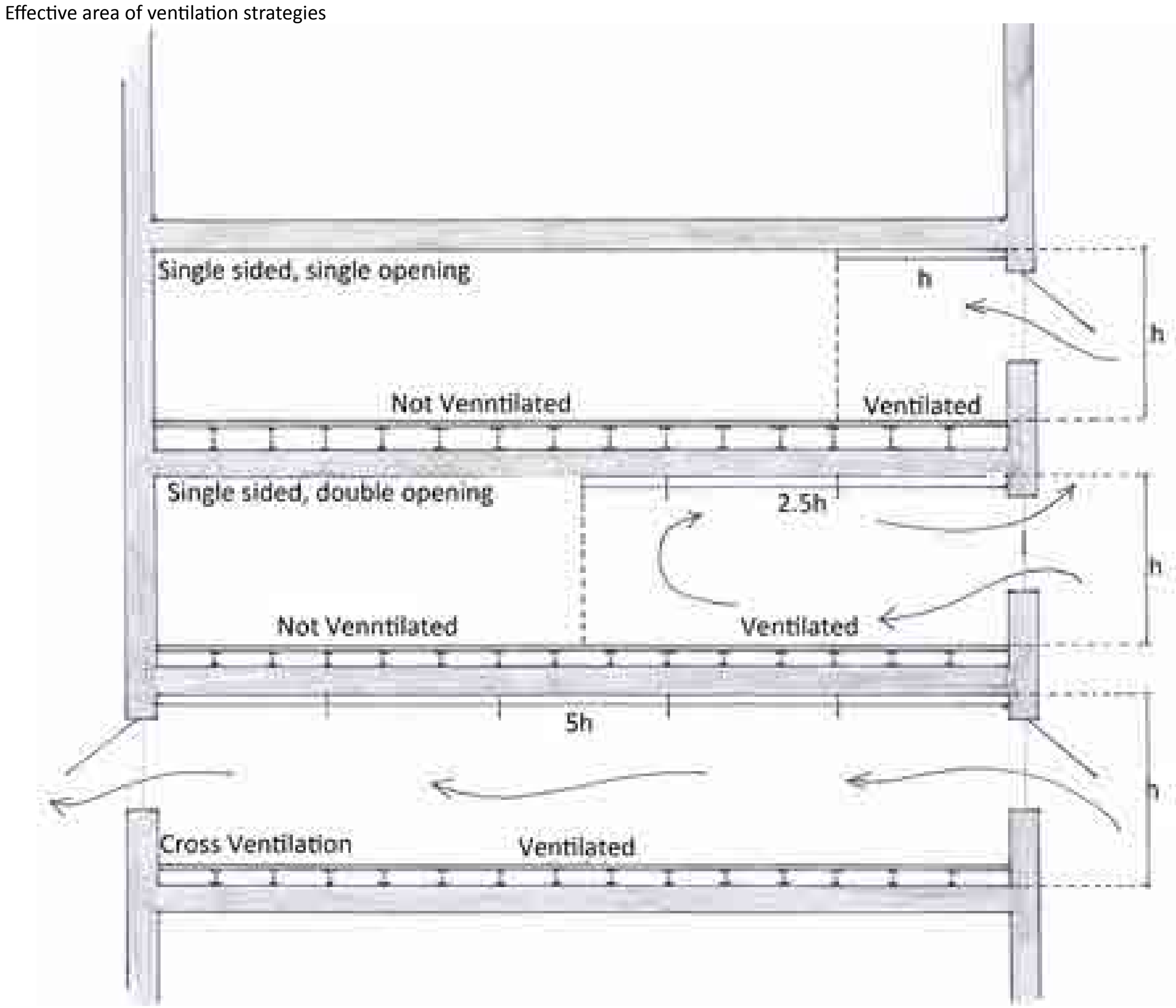
3.2 Natural Ventilation

The term natural ventilation encompasses a variety of passive strategies which circulate air through a building unassisted by mechanical means. These strategies are usually driven by external wind, thermal buoyancy or a combination of the two.

3.2.1 Wind Driven Ventilation

Wind driven ventilation is simply the movement of air through windows and other apertures of a building. They are more often than not locally controlled by the users of the space to adjust internal conditions. The type of opening greatly impacts on the distance into the room the strategy is effective for. Figure 20 illustrates the effective depth of single sided, single opening; single sided, double opening and cross ventilation. The general rules of thumb apply to all apertures around a building in the UK and provide designers with a preliminary understanding at early stages of design. The actual performance of the ventilation will depend of a series of factors including the location of heat generating equipment such as printers and computers, the height and positioning of partitions (no partition shoul be higher than 1200mm to avoid blocking cross ventilation (Sustainability Victoria, 2007)) and its orientation to the location's prevailing wind (south-west in the UK). The variable within the equations are the width (W) and height (H) of the room. Issues are raised however with location when using this strategy. As mentioned the efficiency of the aperture will depend on the orientation and external environment with regards to wind direction as well as noise pollution and air quality. It is not good practice to have high levels of openings facing a busy or polluted area, for example a busy road (Baker, 2012).

Figure 20. Effective area of ventilation strategies



3.2.2 Thermal Buoyancy Ventilation

Often referred to as stack ventilation, thermal buoyancy ventilation uses the temperature and resulting difference in pressure to move air through a building. This type of ventilation is usually typified in two building formations: atrium and chimney stack.

Figure 21 shows the movement of air through an atrium. Cool external air enters the building through apertures in the building fabric towards the atrium. As the air passes through the spaces it is warmed by the occupants and the activities carried out within as well as by equipment such as computers. As the air reaches the atrium the now warmed air rises as it has a lower pressure. The air in the atrium is warm and has a lower pressure than that outside so as a result escapes from high level openings. The escaping air then creates lower pressure within the building drawing more air into the building to continue the cycle by displacement. The air at the top of the rooms and atrium will therefore be warmer than the occupied zones at the bottom, referred to as stratification. This however can result I unwanted heat gains at higher floors of the building. A chimney stack, shown in Figure 22., works in much the same way but is usually only used to ventilate a single space. This is because air could instead flow from room to room instead of up the chimney (Baker, 2012)

Typically this effect is weak compared to wind driven ventilation. In order to improve the efficiency of the stack large openings are required at the top of the stack and at the opening of a chimney. Also the height of the stack can be increased to improve the efficiency. To calculate the section area of a chimney you need to know the inlet area, volume flow rate required and the air speed in the chimney. It is also recommended to reduce the resistance and obstruction of air along the air path.

It is possible to increase the efficiency of stack ventilation by using solar gains to warm air. By further warming the air with the heat gains from solar radiation the flow rate will increase creating a more effective system. In figure 23, the solar chimney has a glass face pointing south to take advantage of this effect (BRE, 2010).

3.2.3 Night Ventilation

When designing a building incorporating passive systems exposed thermal mass is vital in order to maintain a comfortable internal environment. As previously mentioned materials with high mass, such as concrete and stone, absorb heat and slowly release it over an extended period of time. It is possible to increase the efficiency of this absorption by cooling the building at night by allowing cool air into the building when unoccupied. The mass consequently releases the energy it has stored allowing it to absorb more heat gains during the day. This strategy requires a management system to open apertures at specific times of the day or when a predefined external or internal temperature is reached. Mechanical assistance is also sometimes used in the form of fans to increase the air flow throughout the building and allows smaller air ducts to be used[13] (Baker, 2012).

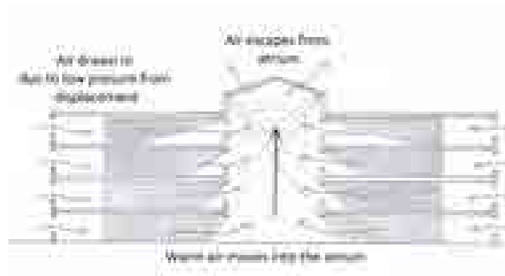


Figure 21. Air movement and daylighting of atrium

Figure 22. Chimney stack ventilation

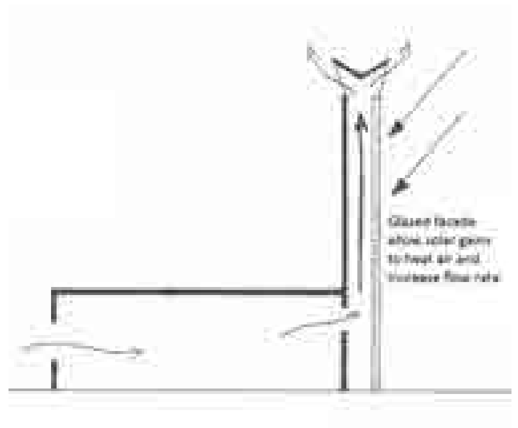


Figure 23. Solar chimney heats air in stack to increase flow rate

13. Small air ducts increase the resistance to air flow slowing down air circulation. Though large ducts are preferable often there is not enough space

4. Case Studies

4.1 Queens Building, De Montfort University – Short and Associates, Leicester (1993)

4.1.1 Function

Located in a central urban environment, Short and Associates were presented with the task of updating the tired campus of De Montfort University. In an attempt to catalyse the regeneration of the area, a new 10,000m^2 building for the School of Engineering and Manufacture was constructed on a tight 'L' shaped site surrounded by non-university buildings and private residences. The design brief was to provide laboratories, lecture theatres, classrooms, studios and offices to not only the 1500 students in the school but to the whole university as the lecture theatres are open to other departments (Short and Associates, n.d.).

The building can be split into three distinguishable sections, as shown in figure 24 At the east end of the building the electrical laboratories are housed within two, four storey fingers that stretch around a central entrance courtyard. Once through the courtyard the central piece of the building has a long, narrow concourse down its spine. On the south side classrooms sit at ground level with a double height electrical and mechanical lab above. Staffrooms and offices occupy the mezzanine levels beyond. Opposite, on the other side of the concourse, two 70-seat lecture theatres and 150-seat auditoria take up the ground, first and second floor. The third floor is used for drawing studios. The central communication route through the building is bridged by flying walkways with the space reaching the height of the building. The west end of the site houses the mechanical laboratories. The double height machine hall is used for printed circuit board production and metrology studies. Given the nature of the activities carried out fume cupboards are installed with mechanical ventilation units, however these do not provide cooling.

This was an opportunity to create a centrepiece for the university showing its commitment future development but a strict budget criteria set by Polytechnic and Colleges Funding Council meant the programme would be particularly complicated. However, Short and Associates were determined to use natural daylighting and ventilation through the core of the building resulting in a remarkable achievement (Short and Associates, n.d.).

4.1.2 Passive Systems

Starting from the east end of the building the electrical laboratories that line the entrance courtyard were design to be cross ventilated (figure 25). With a width of approximately 6 metres, cross ventilation is manually controlled through high performance openings on the north and south façade allowing sufficient movement of air through the space to dissipate high internal heat gains from the electrical equipment. The shallow plan also provides high levels of evenly distributed illumination within. The facades, however, are sloped to block solar gains and glare to create a comfortable working environment. Low angled light from the east in the mornings is also blocked by a series of bridges that span the courtyard (Thomas, 2006).

The main issue faced by the design team was the internal heat gains from students within the auditoria and the equipment in the electrical and mechanical labs. The central section of the building is a deep plan formation meaning that cross ventilation and daylighting from windows on the façade would not suffice. In response the central concourse that runs down the spine of the building is full height, acting as a light well and thermal buffer between the adjoining spaces (Lawson, 1997).

The auditoria posed a particular problem and was initially believed to require mechanical ventilation. However, digital modelling suggested that it would be possible to naturally ventilate using chimneys resulting in a predicted peak temperature of 27.6°C. A benchmark figure for internal temperature was set at 27°C, this is only predicted to be exceeded for 9 days of the year, all of which

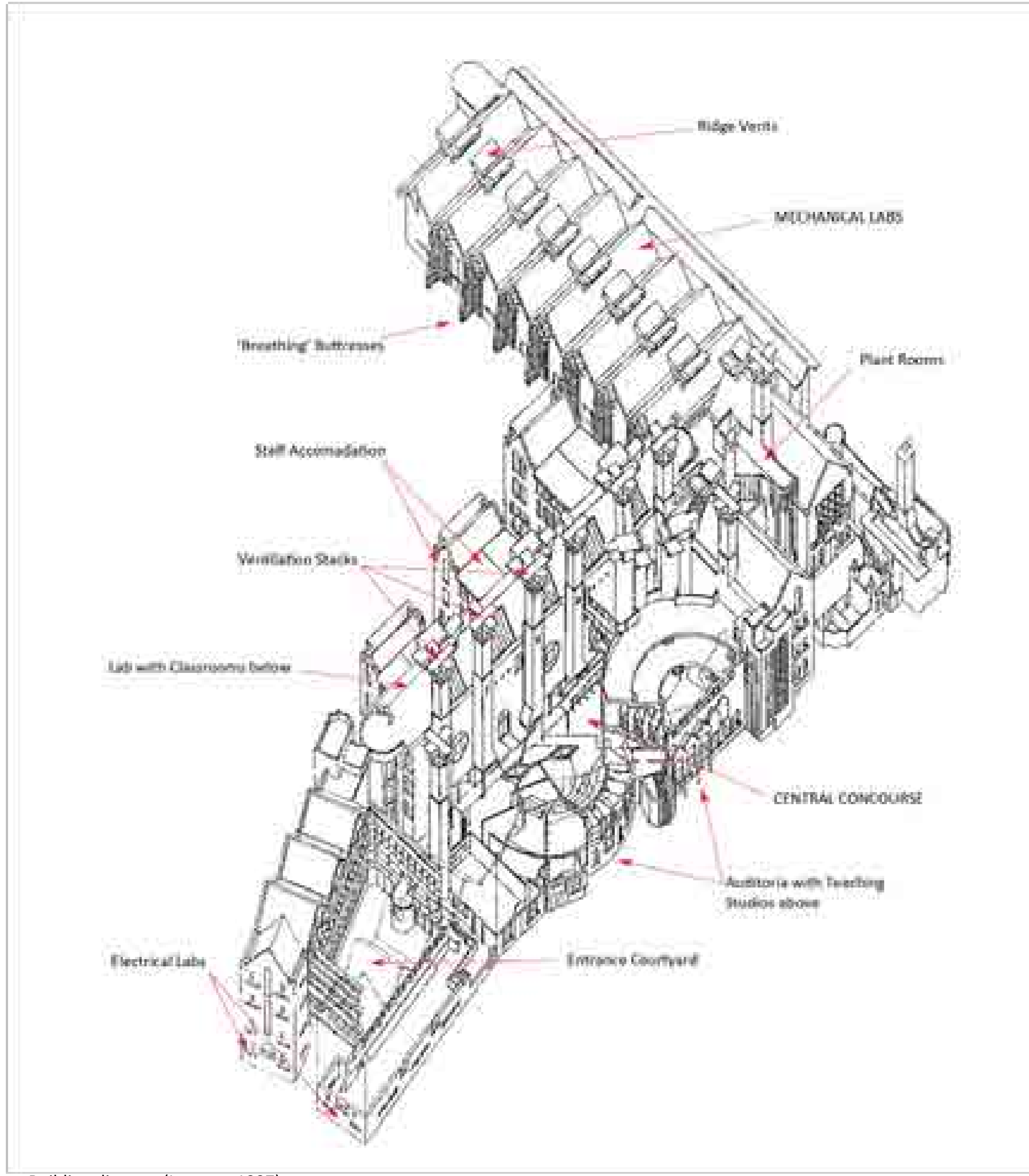


Figure 24. Queens Building diagram (Lawson, 1997)

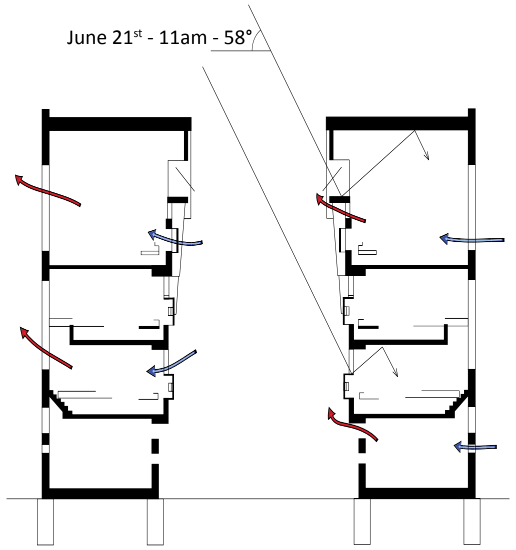


Figure 25. Section through electrical labs showing solar and ventilation strategy

will be out of term when the building is sparsely used. Additional saline tests[14] revealed that natural ventilation would be adequate, concluding that each space should have its own dedicated chimneys rather than shared to prevent air moving between rooms rather than up the chimneys (Dejan Mumovic, 2009).

Figure 27 illustrates the finalised ventilation strategy of the central section of the building. Chimneys expel warmed air from classrooms, concourse and auditoria. The only mechanical back up provided is from a single punkah fan located is one chimney per space to stimulate air movement on particularly still summer days. The auditoria are ventilated at floor level through grills below the seats. Louvered openings allow air to pass under the students and is warmed by finned heating tubes which are controlled by the building management system. This then heats the occupants rather than the space, a far more efficient strategy. During the summer, the air is heated by the users to maintain the temperature difference and continuous air movement (Lawson, 1997).

The machine hall at the west end of the building is ventilated through breathing buttresses[15] on the east façade and through a plenum between floors on the west facade, as shown in figure 26 The high ceilings and a series of roof lights adequately ventilate and provide daylight to the space reducing the energy demands of artificial lighting and extractor fans. Given the building's use, fume cupboards are incorporated with mechanical ventilation, as mentioned above, to dispel potential toxic fumes from filling the hall, a necessary precaution that could not have been avoided by the design team (Thomas, 2006).

14. A clear Perspex model of the auditoria was created and submerged in water. A dyed saline solution was then inserted to predict the movement of air through the space.
15. Hollow buttresses that allow air movement into the building

Physical models of each space were produced which considered their position, orientation and use in order to maximise efficiency. This informed window size and position as well as the need for shading such as the angled façades of the electrical labs. The conflict between quantity of glazing and solar gains was resolved with the preference of a series of small apertures over large glazing units. This results in a more even distribution of light throughout the interior and reduced solar gains from direct penetration. External shading, in the form of overhangs and recessed apertures, along with internal blinds give the user control of lighting conditions. Though these measures have been taken to improve daylighting, artificial lighting is inevitably required. This is provided from fluorescent energy saving bulbs which are arranged in strips so that the lights closest to the window can be turned off when lighting is still required deeper into the room, saving energy. The spaces are generally illuminated to 300 lux, a relatively low figure to provide general light, with an abundance of plug sockets to power task lighting where it is required (Lawson, 1997).

As previously mentioned, the structure uses a building management system (BMS) to monitor the internal and external environment. Sensors placed within the building and outside the envelope monitor carbon dioxide levels in the internal air, temperature, rain, wind, air movement within stacks, sound and light. The system uses the data collected to maintain a comfortable internal environment by opening louvers, activating fans as back up and turning on lights when illumination drops below 300 lux. The system also controls night time cooling to optimise the thermal mass of the structure. After a pre determined time the louvers open allowing cold air to circulate around the building cooling the

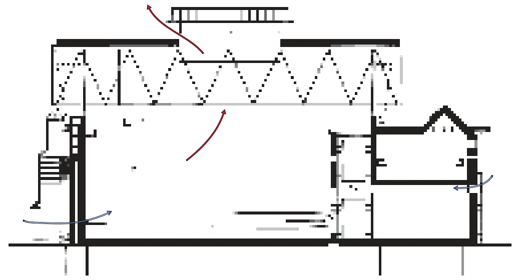


Figure 26. Section through machine halls demonstrating ventilation strategy through 'breathing' buttresses (Lawson, 1997)

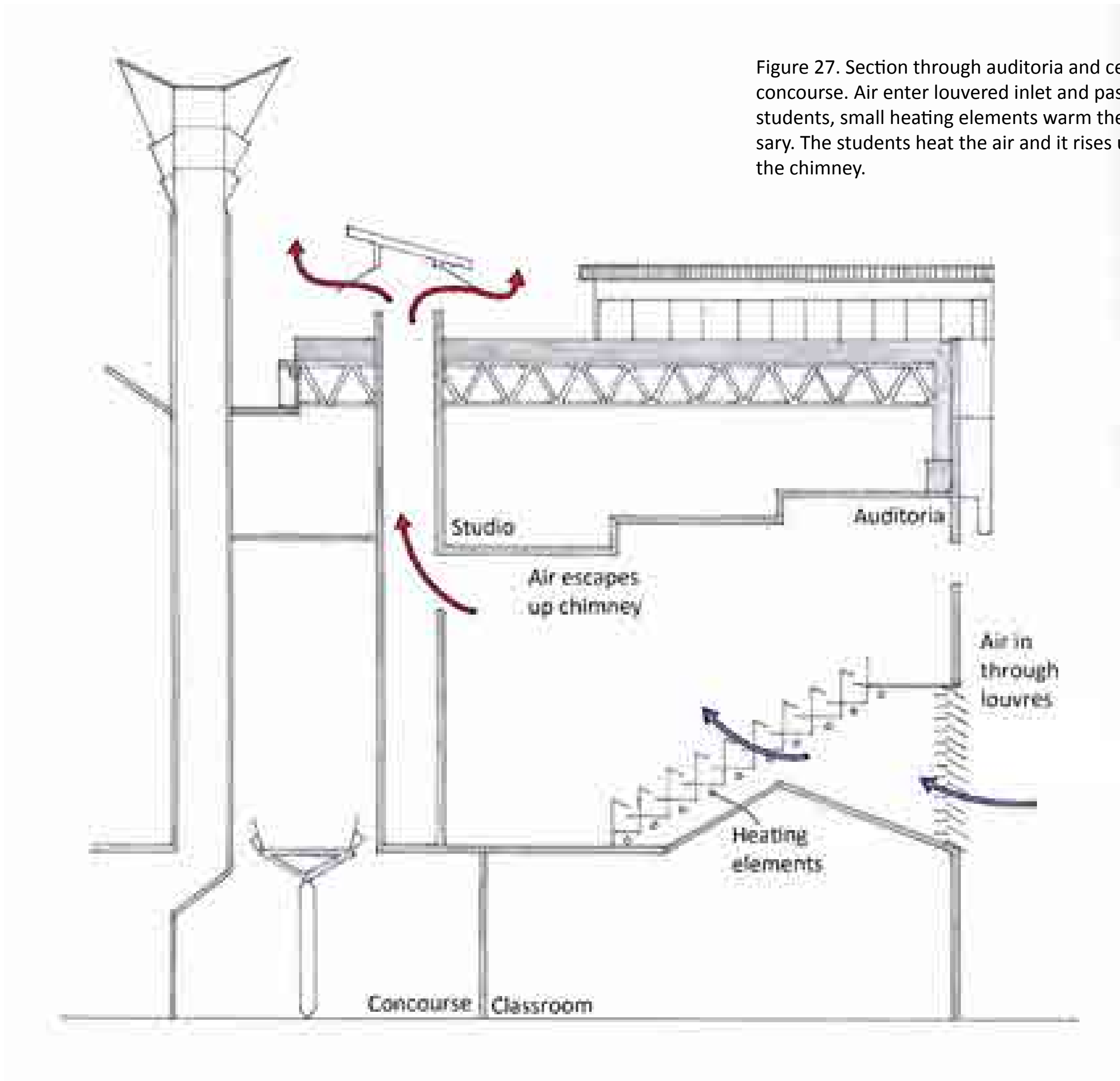


Figure 27. Section through auditoria and central concourse. Air enter louvered inlet and passes under students, small heating elements warm the air is necessary. The students heat the air and it rises up and out of the chimney.

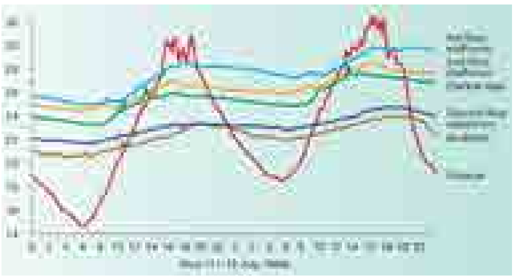


Figure 28. Room temperatures recorded on summer day (Lawson, 1997)

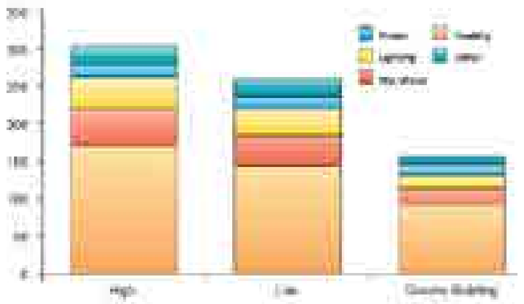


Figure 29. Graph showing the energy demand for each building requirement compared to DOE 'yardsticks' (Lawson, 1997)

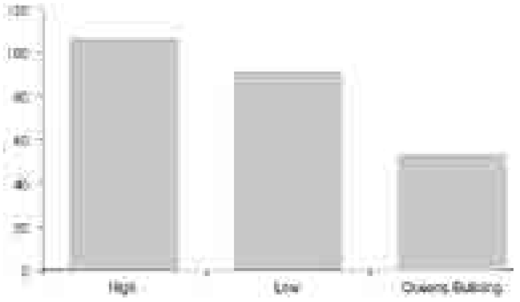


Figure 30. Graph comparing the carbon dioxide emissions of the Queens Building compared to the DOE's 'yardsticks' (Lawson, 1997)

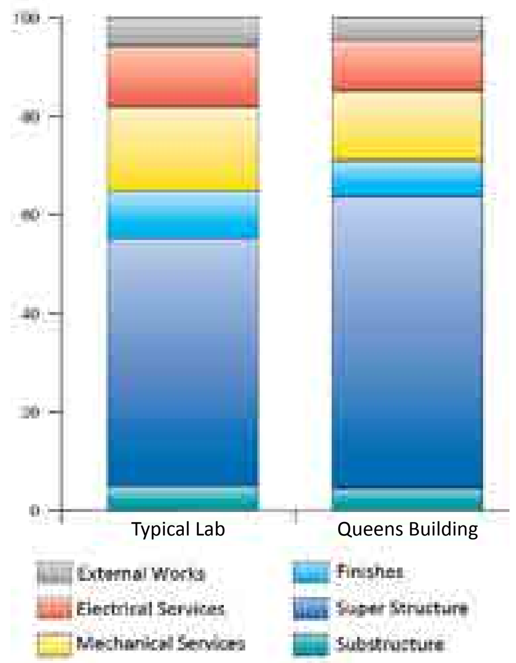


Figure 31. Comparative chart showing the construction cost distriubtion compared to typical (Lawson, 1997)

materials that have absorbed heat during the day. Once the temperature drops below 17°C the louvers are then shut again to sustain a comfortable environment. The system is constantly changing following user feedback with lighting levels based on an experimental strategy. The controls can also be locally overridden to maximise spatial comfort (Thomas, 2006).

4.1.3 Performance

The integration of passive strategies with BMS has resulted in a controlled internal temperature within thermal comfort. Figure 28 shows the summertime temperature profile a year into the build's use. It shows that all the spaces maintained a comfortable environment with exception to the third floor staffroom. This is due to the absence of a roof light opening mechanism and a fault with the internal heating system which has since been rectified. Though the temperatures for the second floor staffroom and central labs do peak over the benchmark 27°C, this is only for 22 and 7 hours respectively for the whole year, and these times are during the summer holidays when the building is generally not used (Thomas, 2006).

The energy consumption of the building is far below the Department of Environment's (DOE's) target levels, as shown in figure 29. In the building's first year of use the Queens Building's consumption of gas was 114kWh/m^2 and for electricity 43kWh/m^2. This has resulted is the building's CO2 emissions equating to 53kg/m^2, half of the DOE's target figures for the time (figure 30). The use of passive systems over mechanical ventilation and extensive artificial lighting, have lead to this low electricity requirement. However the most impressive feat is that of the low energy requirement. This is due to the high massing and insulation of the structure as well as the use of a condensing boiler and efficient combined heat and power unit (Lawson, 1997).

As for costs, the building was built in traditional materials and techniques and proved to be more expensive than new contemporary buildings at the time, £855/m^2. Though closer than normal integration between the design team was required for the success of the passive systems. The price breakdown (figure 31) shows that approximately 9% of the total cost was saved by the removal of mechanical systems. Though this saving was used in the superstructure costs due to the high quantity of insulation and mass as well as the chimneys. Due to the nature of passive design, the maintenance costs are dramatically lower than that of a standard mechanically ventilated building (Thomas, 2006).

4.1.4 Aesthetics

Built of traditional Leicester red brick, the Queens Building has a dramatic appearance which splits opinion. Within the architectural community it is held in high regard not only for its environmental accomplishments but also for its appearance and communication. The striking chimney stacks rise high above the neighbouring building giving an industrial aesthetic communicating the engineering uses of the space within. To those that understand, the exterior form is blatant in its use of passive systems. Large louvers which carry air to the auditoria are visible from the main road leading through campus, the previously mentioned chimneys are plain to see and the ambiguous window arrangement demonstrates the architects natural ventilation and daylighting strategy.

Charles Jencks refers to the building in his book 'Architecture of the Jumping Universe' saying

"I do not believe any historical labels do justice to the synthetic thinking behind the building which borrows as much from the contemporary pavilion planning of Frank *Gehry as the tradition of thin industrial structures."* (Jencks, 1995)

In this he is referring to the series of links between the building, its use and the city as well as its sculptural qualities. During the Industrial Revolution, Leicester grew as a manufacturing town with companies being attracted by its canal links to London and Birmingham. The chimneys and the red brick construction are both reminiscent of this. However from an exterior point of view the building can be seen to be ugly as members of the public, from outside the construction industry do not understand the communication of passive systems. Despite this the building is still considered one of the most impressive buildings in the area having won the RIBA award in 1995 and The Independent's Green Building of the year award 1995 (Short and Associates, n.d.).

Figure 32. External view of north facade showing louvered inlets that ventilate the auditoria.

Figure 33. Internal view of central concourse

Figure 34. External view (King, 2009)

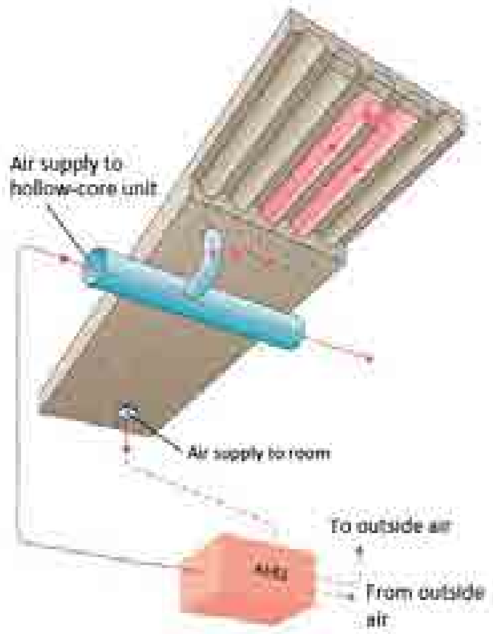


Figure 35. ThermoDeck floor slab diagram (Hartman, 2008)

4.2 Innovate Green Office – Rio Architects, Leeds (2007)

4.2.1 Function

Located in the Thorp Business Park Leeds, Innovated Green Office is the second office complex that Rio Architects have undertaken for Innovate Property. The 4,300 square meter building is split into two parallel blocks, one two storeys and the other three storeys high, linked by a glass atrium or enclosed 'street', as it is referred to by the design team. The architects challenged themselves to create a commercially viable green office but, however, had to compromise between the sustainable aspirations of the design team and what was financially possible. The resulting office provides flexible space which is sustainably serviced (Hartman, 2008)

4.2.2 Passive Systems

The building is orientated along a north to south axis with the main facades facing east and west. This contrasts to general sustainable design where the main glazed façade usually faces south, a bold choice as the site is not confined to a narrow plot like in the case of The Queens Building. The reasoning behind this decision was that brise soleil that would need to be fixed to a south glazed façade would block out too much light on a cloudy day resulting in an increased dependency upon artificial lighting. Working closely with service engineers King Shaw Associates, the 13.5 metre deep office blocks linked by a 5.5 metre wide atrium was calculated to optimise solar penetration to provide a daylight factor of 4.5% (Building Service Journal, 2007).

The building was initially intended to be naturally ventilated however digital modelling revealed that this would not be feasible in the layout due to high thermal gains from computers and other electrical equipment. Local ventilation is provided through windows and from the atrium but mainly air is provided through ThermoDeck floor slabs (Figure 35). These are specially engineered hollow floor slabs through which air is moved via an air handling unit (AHU). A series of loops through the slab maximise the concrete surface area for optimum heat transfer, pre cooling or warming the air before it enters the internal office space depending on the external temperature. High thermal mass is used throughout the building as heat from solar gains is absorbed into the concrete structure and released into the air with the ThermoDeck floor or at night as night cooling is implemented like in the Queens Building. In addition to this the building is super insulated with 250mm expanded polystyrene blocks lining the 125mm thick concrete walls. As a result, the U-value of the external walls is 0.1 5 W/m²K which significantly surpasses the 0.35 W/m²K required by building regulations (Building Service Journal, 2007). With the high U-values of the thermal envelope the proportion of total energy demand for heating has dropped from 44% to just 12% (Hartman, 2008).

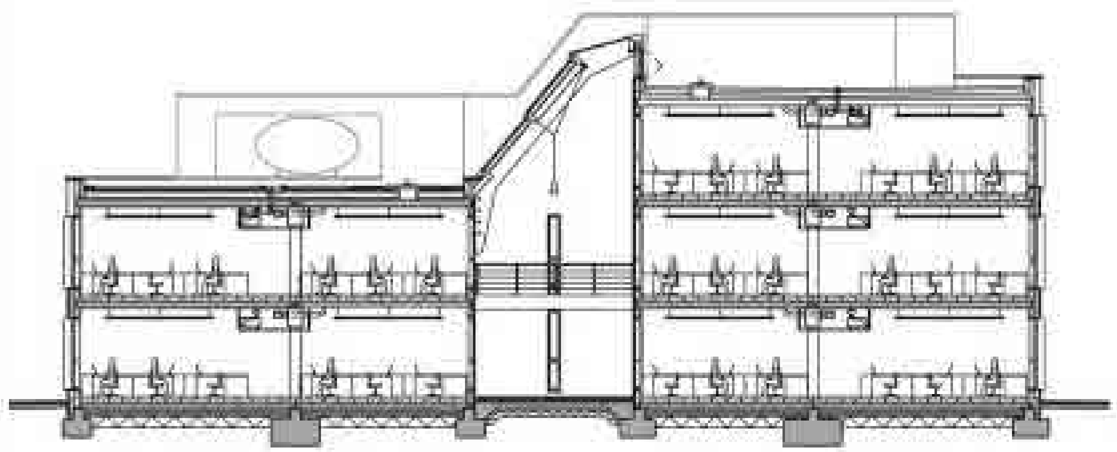


Figure 39. Section through central concourse (Hartman, 2008)

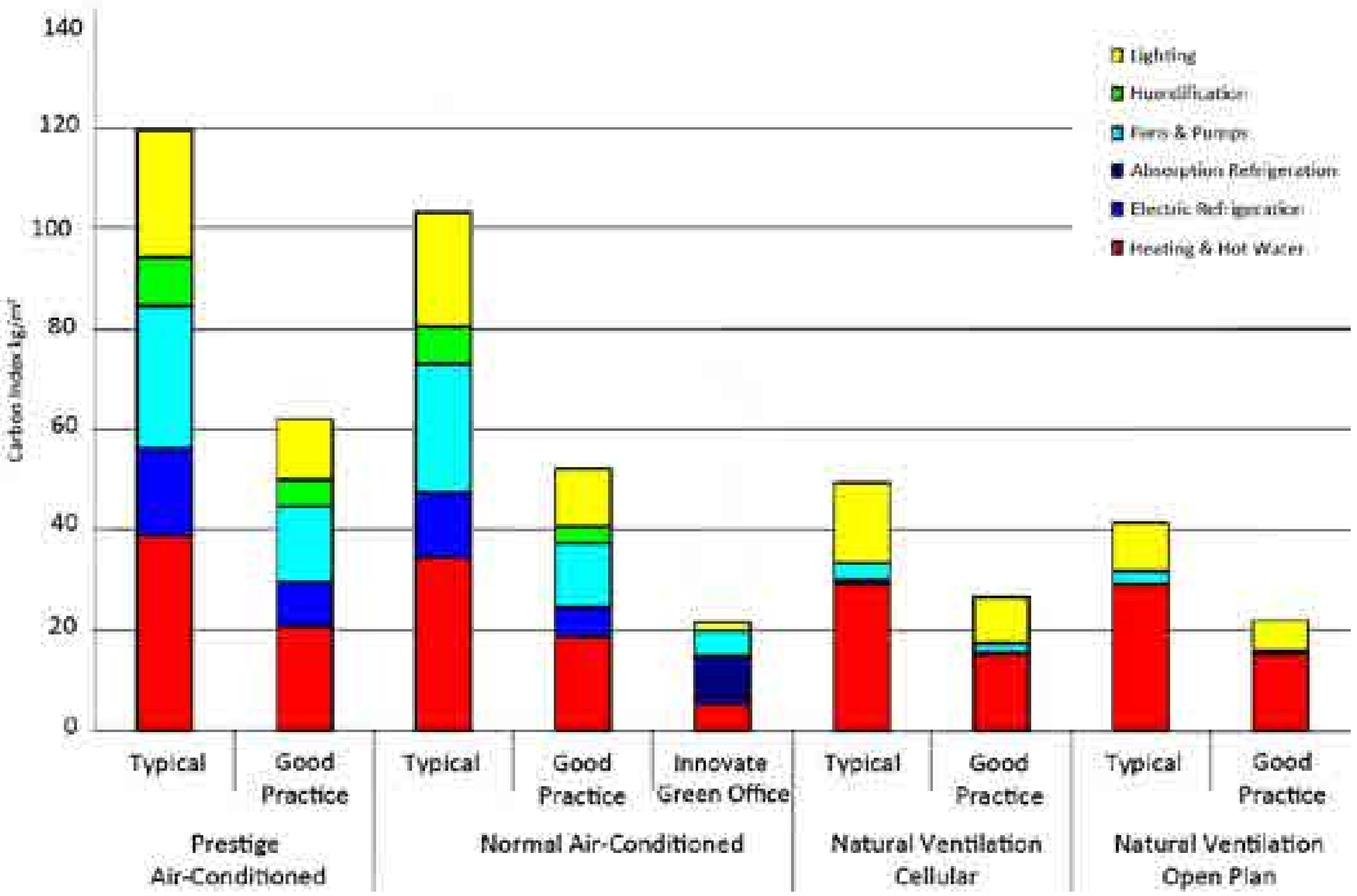


Figure 37. Carbon Index compared to other office type's emissions (King, 2009)

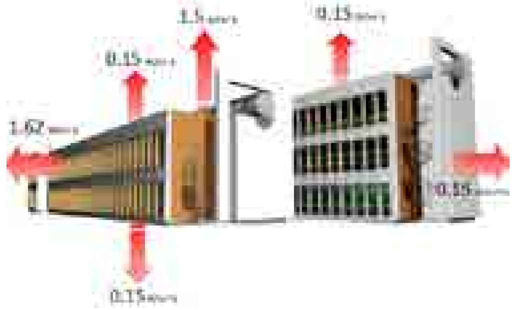


Figure 38. U-Values of the building (King, 2009)

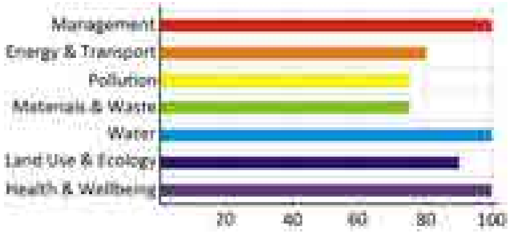


Figure 39. BREEAM Assessment results (King, 2009)

4.2.3 Performance

As a result of the systems mentioned above the building releases 80% less greenhouse gases than a conventional office. Only 22kg $C0_2$/m² is released annually saving 350 tonnes of carbon dioxide each year. This is considerably lower than a typical air conditioned office and is comparable to the emissions released by the best performing naturally ventilated offices (figure 37). These savings are made due to the building's thorough heating and lighting plans reducing the mechanical requirements to sustain a comfortable environment. The high insulation reduces the internal heat gains from escaping the envelope to reduce heating demands (figure 38). Solar gains also heat the interior but the high thermal mass prevents overheating. As for daylighting, the high daylight factor means that artificial lighting is only required for 20% of the year (MPA, 2007).

To put the building's environmental performance into context, the previous office building, Innovate Office (Sherwood Park, Nottingham) which Rio Architects also designed for Innovate Property matched the 2002 typical energy cost of an office building with 13p/m². However, Innovate Green office has an energy cost of 6 p/m² compared to the 2007 typical energy cost of 20 p/m². Such a big reduction in running cost is incredibly beneficial to the client as a larger proportion of the rental returns, roughly £12-£15/ft², will be profit (King, 2009).

In terms of financial performance the building was 25% more expensive than an equivalent steel structure. This is due to the high quantities of insulation and the specified ThermoDeck floor slabs. However due to the energy savings, calculated to be around 12p/m²/year in 2007, it was predicted that the building would pay this back in 14 years. Furthermore, with increasing energy prices this figure is likely to drop to 7 years (Hartman, 2008).

The Innovate Green Office was awarded the BREEAM rating of Excellent with the highest ever total of 87.55%. This is not only due to the strategies mentioned above but also thanks to the rainwater system, the combined heat and power system used to power the building and the reduced embodies energy in construction (local/recycled materials) figure 39. (King, 2009).

4.2.4 Aesthetics

The building façade is primarily a white sto-render finish with timber cladding lining portions of the exterior, for example, surrounding the spiral fire escape. This plain finish is punctured by a large quantity of windows along the lengthy east and west façades. Overall 40% of the building skin is glazed, these high levels of glazing is not uncommon in commercial office buildings. High levels of glazing and transparency is both literal and symbolic with a commercial workplace. Literal as organisations look to be more innovative and encompass cross-disciplinary integration; and symbolic as companies look to gain the public's trust and to become accountable. It is also shows their desire to be more visible and understood. The increased levels of glazing make the building a more hospitable environment with view out into the surrounding. The immediate area has been landscaped to include natural features such as tree and bodies of water to make the location more relaxing to stressed employees (Wymer, 2010).

It is not possible however to see that the building is sustainable from the outside, on the contrary, it looks like a typical industrial park office unit with the services located on the roof hidden by a cylindrical cover. Unlike the Queens Building which is open and blatant in its attempt to show off its sustainability, Innovate Green Office hides its environmental credentials. Here we are starting to see an environmental attitude incorporated into current building design, using passive measures within the established vernacular rather than creating a questionable facade, in the case of the Queens Building, style.

Figure 40. Exterior view of concourse (King, 2009)

Figure 40. Figure 43. Interior view of concourse (King, 2009)

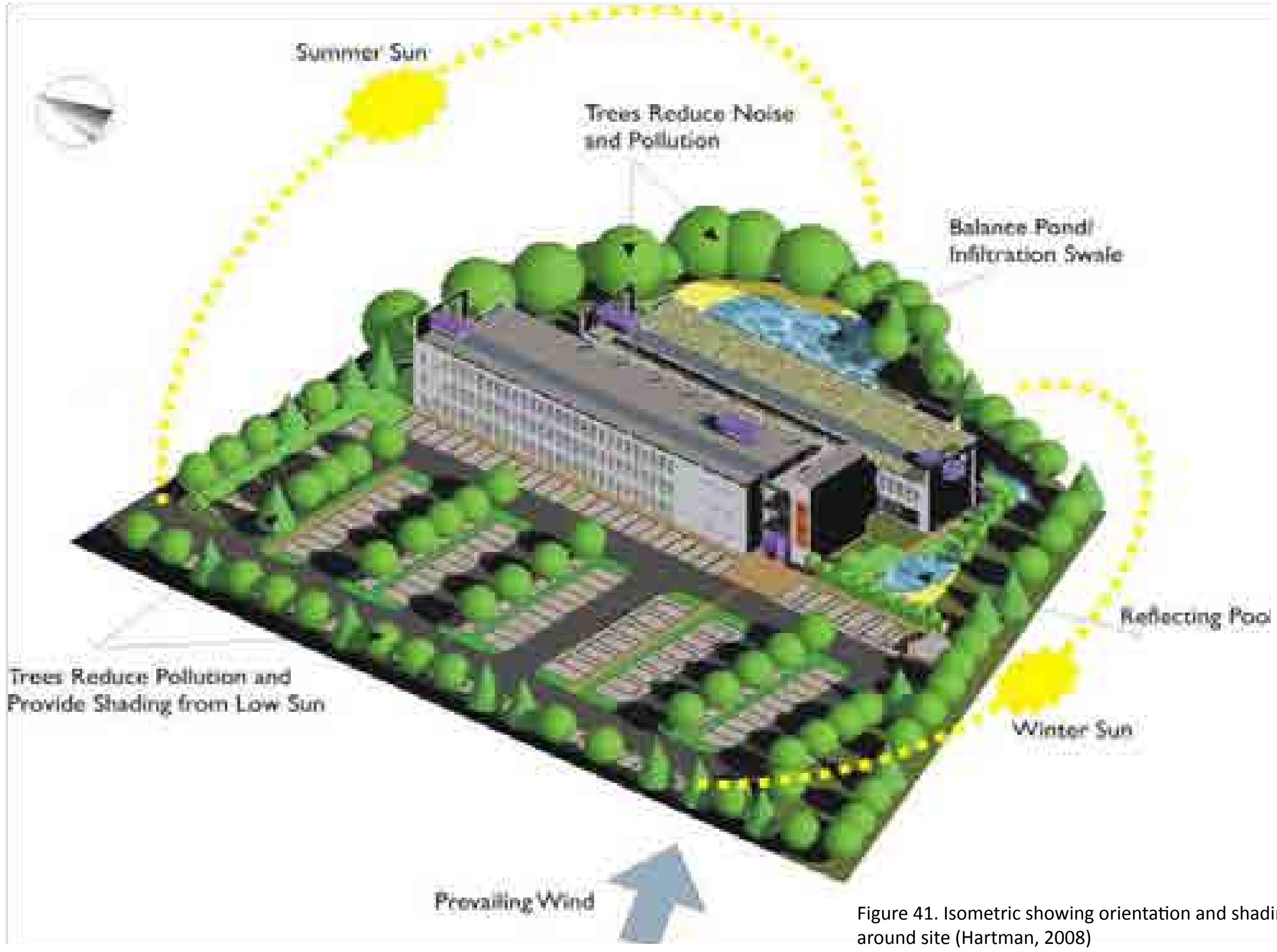


Figure 41. Isometric showing orientation and shading around site (Hartman, 2008)

4.3 Manchester Civil Justice Centre – Denton Corker Marshall, Manchester (2008)

4.3.1 Function

Sitting in the chiefly characterless financial and legal district of Manchester, Spinning fields, the Manchester Civil Justice Centre (MCJC) was designed by Denton Corker Marshall in 2008. The 15 storey complex is the largest judicial building to have been built since the Royal Courts of Justice in 1882 and contains 47 courtrooms and 75 consultation spaces. The building is characterised by cantilevered levels that extend out of the development's 34,000 square metre footprint. The building's courtrooms are housed within the protruding spaces, dealing mainly with family and commercial cases.

The structure is symbolic of the openness and accessibility of the justice system, an image the clients wished to project to the public. An open building was sought after rather than a reclusive design which suggested that it was only inhabited by criminals and lawyers. By housing the courts at the ends of the building the spaces are no longer concealed and communicate the requested public transparency (Slavid, 2008).

4.3.2 Passive Systems

Since its conception in a limited design competition against Pringle Richards Sharatt and Richard Rogers Partnership, sustainability has been at the heart of the design. All areas of the building are at least partly naturally ventilated with stacked ventilation combined with under floor plenums being utilised throughout the structure as passive systems require little technology and low levels of maintenance.

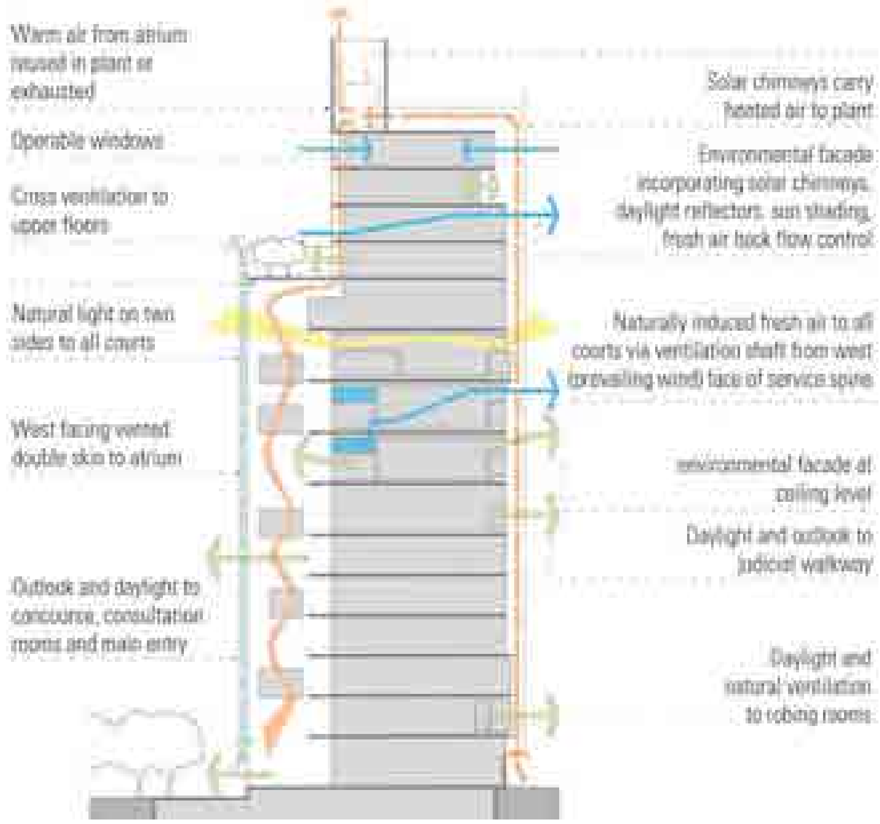


Figure 42. Diagrammatic section showing building passive strategies (Architect's Journal, 2007)

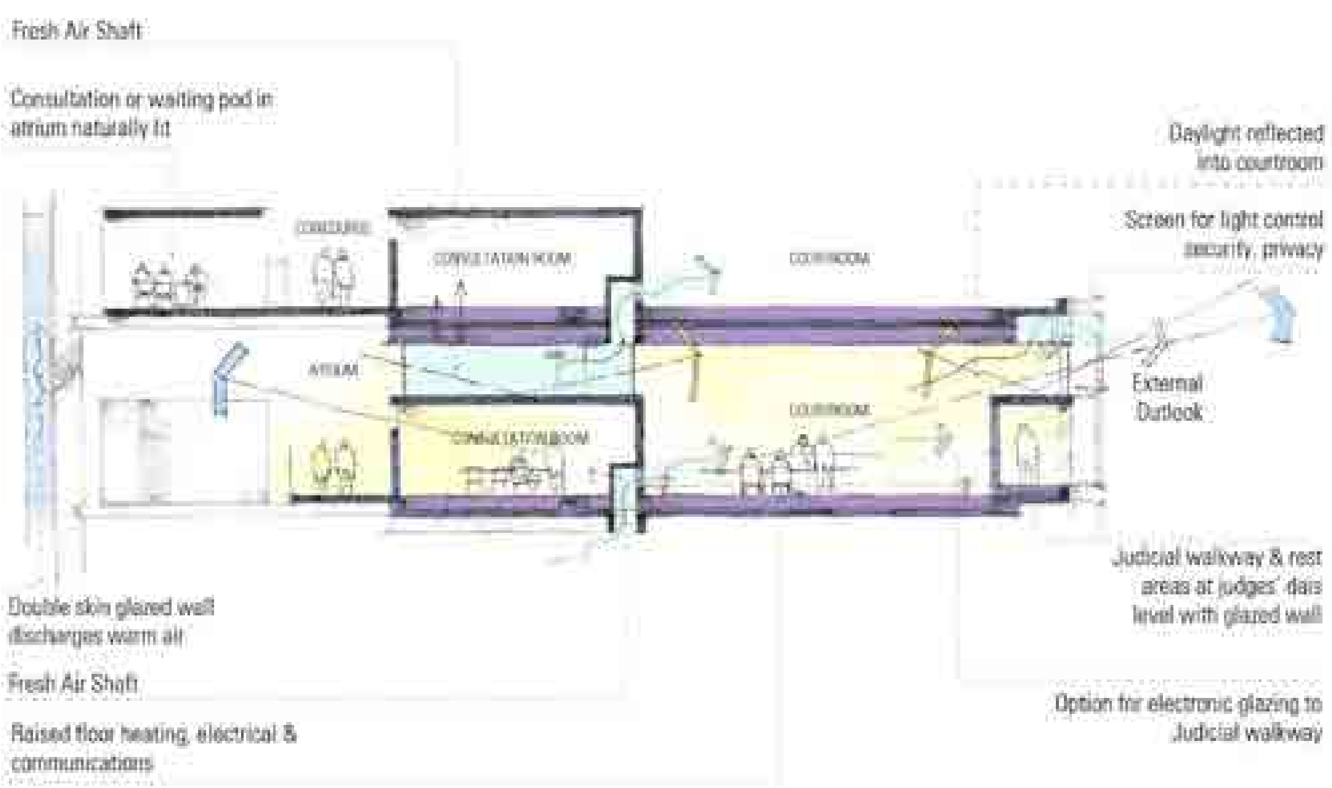


Figure 43. Single floor section showing integration of lighting and ventilation strategies (Duran & Fajardo, 2010)

Figure 44. Environmental screen on east façade to protect the interior from over heating (Architect's Journal, 2007)

into the building. With a café on the ground floor, natural ventilation carries warm air up through the building envelope. Sculptural, aluminium clad beams, support consultation areas which protrude into the atrium at high levels, the diffuse light that reflects from these not only provides deeper light penetration into the building but also improves the quality of light with the pastel glow that is created. The atrium incorporates a double skin glass façade which aids cooling in the summer and heating in the winter. During the warm months the cavity mitigates solar gains and vents the warm air out of the building envelope helping to keep the interior warm, whereas during the cooler months the air within the cavity which is heated by solar gains can be vented through the structure offsetting heat requirements.

Passive lighting and ventilation strategies can be clearly seen in Figures 42 and 43. The dynamic composition not only creates a distinctive profile but also forms a playful yet effective organisation of void and solid. This formation not only enables the whole envelope to be naturally ventilated but, along with the structure's shape and orientation, allows for deeper light penetration. An 'environmental veil' is incorporated into the east façade to reduce direct light penetration and solar gains that would lead to overheating in summer. Under floor plenums have been integrated throughout the building to further increase the effect of natural ventilation within the structure. Wind scoops targeting the prevailing wind from the south west, as well as a solar chimney, located within the spine of the structure, circulate fresh air throughout the building (Duran & Fajardo, 2010).

As previously mentioned, natural daylight is utilised where possible with diffuse light penetrating to the central spine. As a result, the courtrooms are naturally lit from two sides reducing the need for artificial lights during the day. This is provided through a combination of clerestory windows and reflected light from the west façade.

The architects clearly communicate the most important areas of the building, the courtrooms, by cantilevering them outside the building footprint and through the environmental strategy. For 63% of the year the courts are naturally ventilated with additional ventilation provided by mechanical means when required. The design is so effective that from May to October they are fully ventilated by the passive systems.

4.3.3 Aesthetics

The dramatic composition of the MCJC provides a much needed quality to the soulless district of Spinning fields, Manchester's legal and financial quarter. The surrounding buildings are dull commercial developments that lack character and offer no value to the city. The striking profile of the MCJC transforms the environment however, imposing itself on the area with its staggered arrangement and astute colouring.

As previously mentioned, the clients wished to create an open façade which communicated accessibility of the judicial system to the public. Denton Corker Marshall have taken the brief and expanded upon it creating links with the heritage of the city. Richard Williams' book 'The Anxious City' examines the morality of the built environment using Manchester as an example. The city was born out of the industrial revolution and within its urban layout it is clear to see Victorian values and social structure, the working class districts were hidden away with the middle class suburbs being connected to the central business district by wide roads lined with illustrious shops. As industry left the city a new model of authoritarianism emerged, but it was not until the 1970's when the Arndale centre was built. Williams perceives this to be the "*built representation of the modern moral city*" (Williams, 2004), an environment in which all social classes could safely enjoy retail and leisure facilities during the day which closes at night. However, during the 1990's and 200's this heritage was lost as consumerism took control of the city and began to control the architecture. It was not until the IRA bombings in 1996 and the commonwealth games in 2002 that the city experienced a major shift from commercial lead regeneration to traditional heritage regeneration. Glass and steel structures are now the trend, reminiscent of the industrial revolution which made the city. In the same year as the completion of the MCJC, the Beetham Tower was also finished. Though both sharing a similar vernacular the analytical meaning behind each varies, the Beetham Tower resembles the commercial lead architecture that controlled the city in the 90's and 00's, whereas, in response, the MCJC relates to the complex urban formation of the city from the industrial revolution and has created a spectacle of justice (Blueprint, 2011).

The building has not only incorporated a strong environmental strategy, achieving a BREEAM rating of 'Excellent', but has combined that with contextual meaning and aesthetic parity. As a result the building has won many awards including the RIBA English Partnerships Sustainability Award (Vadon, 2008).

Figure 45. Exploded diagram of conceptual elements (Architect's Journal, 2007)

Figure 46. Interior view of atrium (Architect's Journal, 2007)

Figure 47. Ground floor plan (Architect's Journal, 2007)

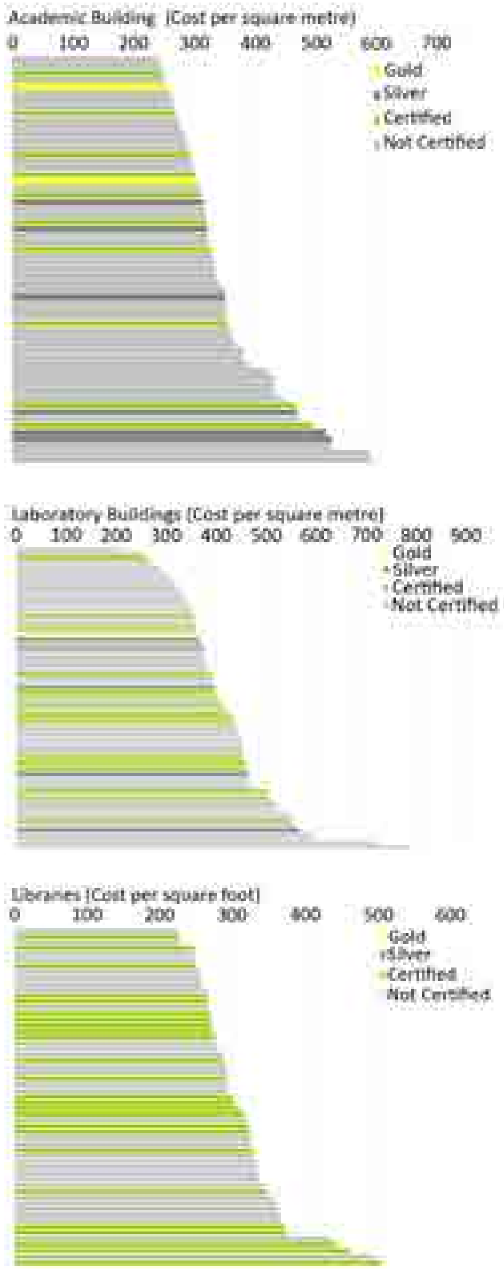


Figure 48. Comparative tables from different sectors of non-domestic architecture comparing the construction cost per square foot between LEED certified and non certified buildings (Morris, 2007)

	Queens	Innovate	MCJC
Year	1993	2007	2008
Floor Area	10,000m^2	4,300m^2	34,000m^2
Cost	£9,300,000	£6,000,000	£11,200,000
CO_2	53 kg/m^2/yr	22 kg/m^2/yr	54 kg/m^2/yr
Use	University: Lecture Laboratory	Office	Court

Figure 49. Comparative table of case studies discussed above

5. Analysis

When comparing the three buildings there are some clear and interesting similarities forming from which designers can learn and apply to new proposals. The selected buildings have a mixture of location from tight urban plot to an open business park site. However, despite the site differences all the case studies have a similar narrow form. Both the MCJC and Queens building clearly use this form to increase soar penetration and increase the daylight factor. It can also be found in the Innovate Green office when you consider the two working blocks are long and narrow with a glass concourse separating them. The increased daylight factor reduces the building's reliance on artificial lighting during the day greatly reducing the typical energy requirement for lighting of 21%.

Another clear similarity is the high levels of insulation and massing in the buildings. The high thermal mass in the form of masonry for the Queens Building, concrete on steel frame for Innovate Green Office and a concrete core in the MCJC, maintain a comfortable internal environment by absorbing internal heat gains from equipment and occupants as well as solar gains. The high level of insulation ensures very little heat that is generated escapes the building envelope to reduce heating requirements, another large energy user at 13%.

The most intriguing similarity though, is the lack of on site renewables. None of the precedents studied use any on site renewable power generation. When people think of an environmental building they imagine solar panels and wind turbines, however in reality this is not the case. In the vast majority of successful 'green' buildings, no 'eco-bing' is used. Instead they focus on the importance of reducing energy demand through considered design and the incorporation of passive measures. Presently the technology is neither efficient nor cheap enough to justify using it in most buildings. With photovoltaic panels for instance, rule of thumb states that one square metre of PV panels generates 100 kilowatt hours per year in the UK. Typically, a PV system costs on average £500 per square metre for a market average of 15% efficiency. That means that for £500 you are presently able to power a 60 watt light bulb's average yearly usage[16]. The use of on-site renewables should be considered against economic viability and with current technology it just isn't feasible.

Costing is arguably the largest factor within construction, particularly in the current economic climate. One argument that's held by green adverse people is claims that it is not cost effective to incorporate these environmental strategies into buildings (Morris, 2007). However, research carried out by Peter Morris, of construction consultants Davis Langdon, suggests that this is not that case and that it is in fact individual variables that cause price increases. He states that a large percentage of 'green' buildings, with LEED certification[17], fall within typical construction costs as non LEED certificated buildings. He compared a series of non-domestic building types and illustrated the variance in cost in the graphs in figure 48. (Morris, 2007). As for the case studies, only Innovate Green Office's cost was above that of a typical air conditioned building, and as mentioned above the energy and running costs saved suggested that the building would pay back the difference in seven to fourteen years depending on energy prices.

It is the means in which the buildings were designed that made the three case studies so successful; all major consultants were involved with the conception of the proposals from an early design stage. By doing this, the environmental strategies were imbedded within the design concept and were thoroughly developed throughout the building to optimise their efficiency, and at the core of all of them was natural ventilation and passive solar strategies. It was through this means that the buildings were able to stay technologically and environmentally strong combined with good architectural design. Aesthetically the proposals are all successful and have been able to avoid becoming engineered structures but instead beautiful buildings in their own right. MCJC in particular has not only been accredited for its environmental characteristics but also for its design and concept.

16. 99.6kWh/yr

17. Leadership in Energy and Environmental Design, the US equivalent to BREEAM certification in the UK

6. Conclusion

From the above text it is clear to see that the environment and fuel supplies are becoming a greater concern over time. Buildings are responsible for 47% of the carbon emissions produced by the whole of the European Union. Architects and engineers are therefore, at least partly responsible for nearly half carbon being released into the atmosphere. Though this also means design teams can make a big impact with their actions now and in the future by improving the environmental performance of new and existing buildings.

The case studies analysed above demonstrate the possibilities of integrating passive systems within a proposal. The buildings were purposely selected to show a range of locations and uses within the non-domestic sector over a period of time from when environmental concerns were only just becoming recognised, in the case of the Queens Building (built 1993), to when sustainability has become one of the largest concerns facing architecture, Manchester Civil Justice Centre (2008).

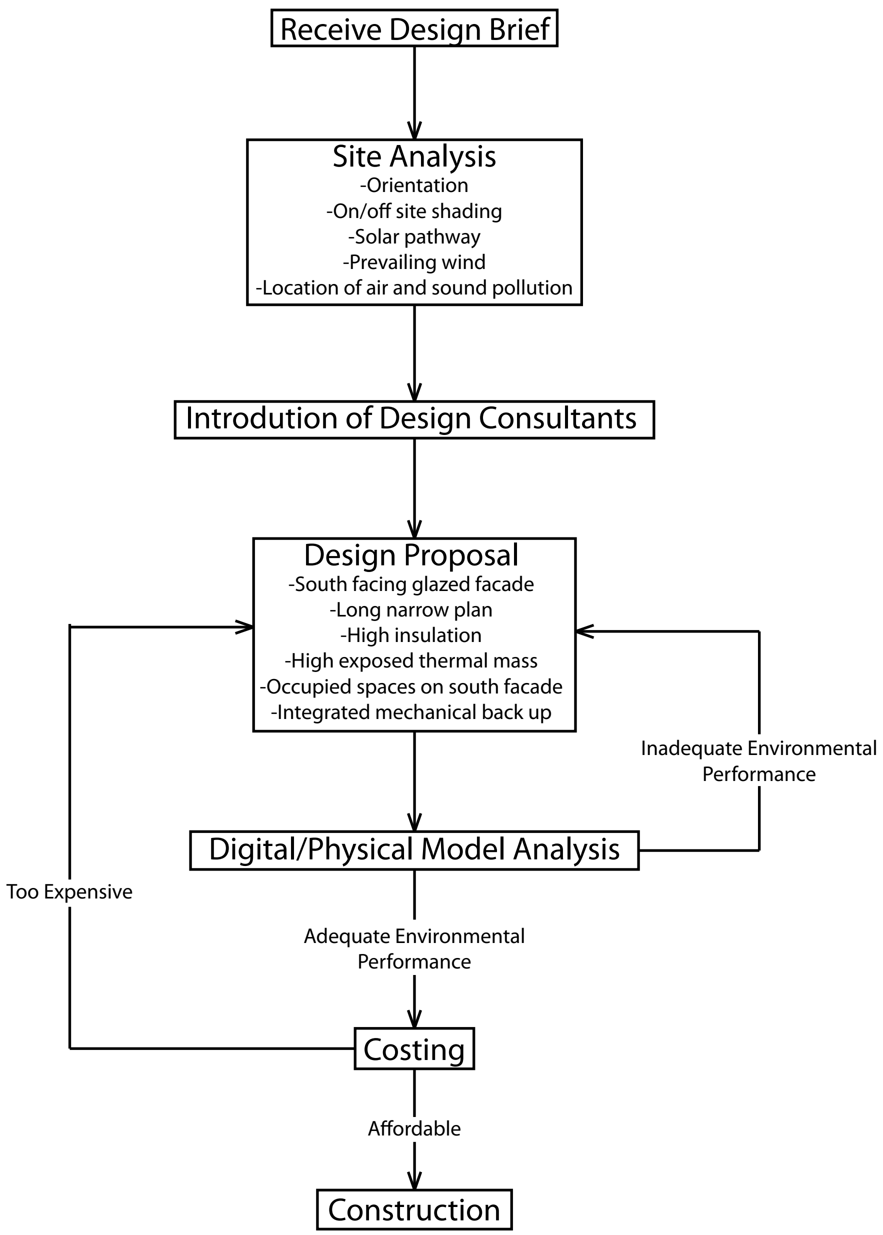
It is the architect's responsibility to add further value to the structure ad to create a beautiful, thought provoking and practical building which fit within its physical and social context. Frank Lloyd Wright famously wrote, in his book 'The Living City':

"All fine architectural values are human values, else not valuable" (Wright, 1958)

As concern grows the environment and a building's environmental performance are becoming more valuable to people, this is mentioned above in reference to the article in the Architect's Journal entitled 'How high-quality sustainable design creates value', the higher rent rates Innovate Green Office can charge is also demonstrative of this. There are now not only environmental pressures on the performance of the building but also public pressures within society. It is therefore recommended that the following guides are followed when approaching design:

- Involve all members of design team at early stages of conception
- Thorough site analysis to evaluate the best strategy for proposed building
- Building form should be long and thin with main glazed façade facing south to increase light penetration and take advantage of solar gains
- Building should be highly insulated
- High quantities of exposed thermal mass with night cooling
- Always consider the financial viability of on-site renewable resources, focus mainly on reducing the building's energy demands rather than covering up bad design with 'eco-bling'
- Place main occupied spaces along south side of building
- It is unrealistic to expect a building to be only maintained by passive systems, mechanical assistance should be incorporated to be used for short periods of the year where passive systems are not viable and for specific day, for example using small fans to drive ventilation on hot still days
- When possible install building management system to optimise passive strategies
- Apply flowchart to work process to design development (figure 50)

Figure 50. Step my step flowchart advising designers on how to develop an environmental proposal



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