Gr16 HW02 - Vernacular and Climate sensitive Architecture

Samantha Mora [1], Arnab Chatterjee[2], and carlos1.hidalgo[1]

[1]Building Energy Modeling and Envelope Design
[2]Politecnico di Milano

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Abstract

Abstract content goes here

Chapter 1. Examples of local vernacular architecture

1.1 Climate 1: Tunis

Location: Tunisia, Northern-Africa Latitude: 36° 49' 8.29"N Longitude: 10° 09' 56.84Ë

Figure 1: Tunis geographic location respect to Africa and Tunisia (tun)

Weather Description

Tunis has a hot-summer Mediterranean climate characterized by a hot and dry season and mild winters with moderate rainfall. The local climate is also affected somewhat by the latitude of the city, the moderating influence of the Mediterranean Sea and the terrain of the hills.

Tunis annual temperature trend in general, presents temperatures that reach the lowest values at the period of December- January- February and the highest at July-August-September, both delimit the winter and summer months respectively and they show values interesting for design purposes. The monthly average range goes from 11.120C (January) to 27.460C (August), is possible to establish a previous idea about the mixed weather whose trend predict a lower heating period and hours than the cooling period and hours. As it can be seen in the Psychrometric chart a balanced number of temperature values, whose hours are below and above the proposed set points of 20 and 260C, gives the idea of similar heating and cooling periods, the comfort hours also may be incremented taking advantage on this.

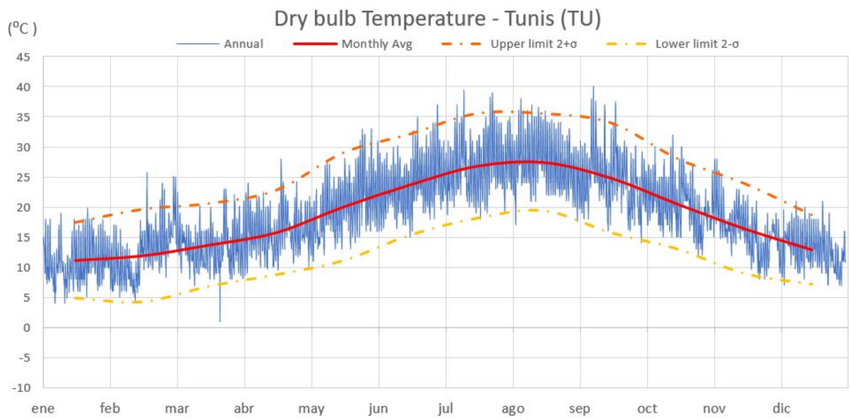

Figure 2: Tunis Dry bulb temperature: Annual and monthly average values

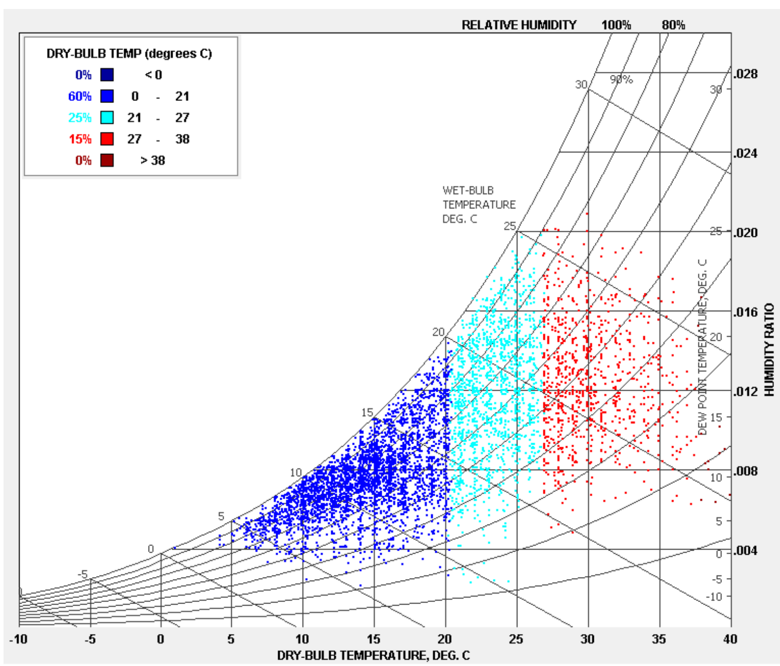

Figure 3: Tunis Dry bulb temperature annual distribution- Psychrometric chart(Climate consultant)

Vernacular architecture in Tunis

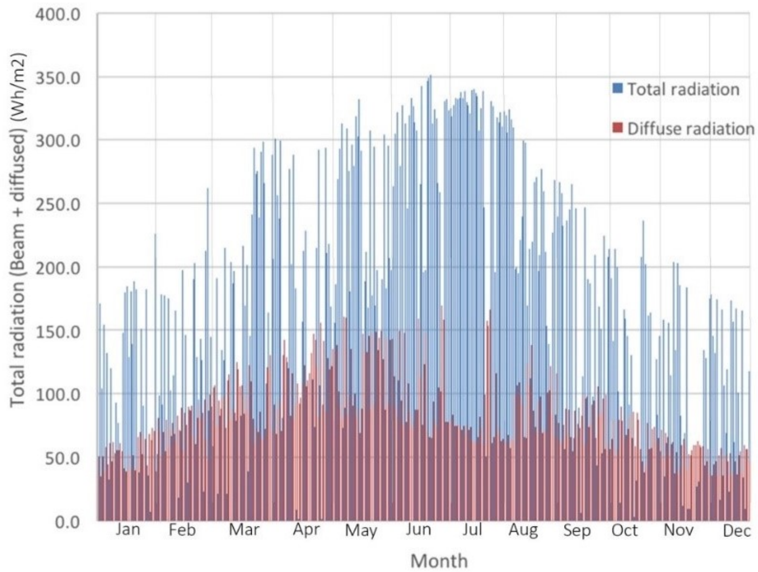

Figure 4: Average daily amount of the solar energy received by the horizontal surface for Tunis

Due to the several ancient cultures settled in Tunisia, which were spread all over the country, it is possible to find a diverse landscape. In the north due to the ancients' settlements, the different buildings which remain can be cataloged as:

- Roman architecture
- Islamic architecture
- Punic architecture

In some other parts of the country, due to the natural conditions, people needed to keep the food dry and cool since the climate was extreme for the housing and living conditions in that time. A good illustration about how was the living condition during the ancient times in the south part of Tunisia, can be seen in the cities of Tataouine and Ksar Hadada which preserve some examples of buildings where can be appreciated the use of vernacular materials.

[6]Example:	South of Tunisia, Tataouine
Ubication:	South of Tunisia, Tataouine
Use:	Residential
Period of construction	Ancient times
Materials:	brick, adobe

Figure 6: Ksar Hadada (arc, b)\ref{??}

Figure 7: Southern Tunisia(arc, b)

were carved into the soft rock to create atrium houses that had several excavated rooms with up to 4 to 10 meter high and vaulted ceilings opening out onto a single sunken courtyard. The original objective for going below the ground in this case was to protect the inhabitants from the extremes of daytime North African heat and nighttime cold, typical of this desert region. (hou, b)

Figure 8: Ksar Ouled Soltane, southern of Tunisia(arc, b)

Figure 9: Matmata, south of Tunisia(arc, b)

Constructive techniques and envelope materials

In fact, during the human history, the use of earth as a building and construction material has been common and well spread all 6 around the different civilizations. Compared to brick or cement walls, the earth walls are better thermal insulators. Besides, the embodied energy is too much lower as compared to the modern materials such concrete. On the other hand, the compressive strength is low as well as the environmental attack resistance. This is the reason why the use of straw in some of the cases showed above was necessary. Recent studies have shown their positive impact on the general performance of an adobe building, in which adding or making a reinforce using straw fibers, can improve considerably the structure performance.

In the following picture is possible to see how the final performance during the first 90 days has been improved by adding straw fibers. This test was carried out following the Indian standards (IS: 2720-3, 1980).

Concluding that adding fibers can improve the mechanical performance of an adobe structure by 50-225%.

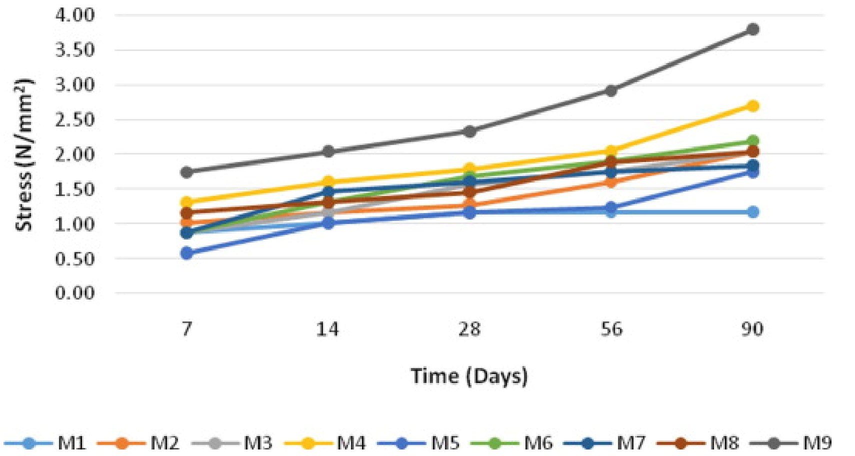

Figure 10: Maximum stress carrying capacity adding different fibers.(sci, a)

Regarding to the case of underground buildings, such as Matmata example, as it is well known that during the summer, the earth temperature is much lower than the ambient one, and during the winter the earth temperature is higher than the ambient temperature. This is the reason why during the ancient times, the solution for some civilizations was built underground cities. Some thermal studies that present the benefits in terms of internal conditions, like temperature and relative humidity, of subterranean dwellings over above ground houses have been done in Matmata, like the case of the Marhala hotel, a typical building of this city. The first inhabitants of this city discovered that the ideal depth for the dwelling is 10 meters.

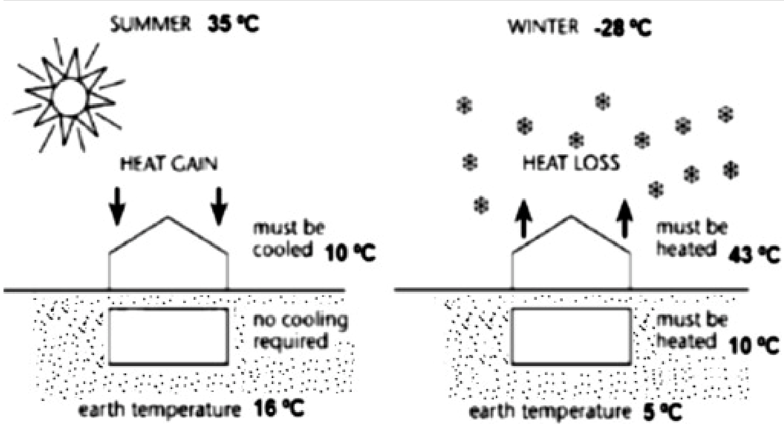

Figure 11: Earth and ambient temperature comparison (sci, b)

Akubue Anselm made a study in which he calculated the thermal flow pattern in buildings which have different contact area with the earth. The purpose was to investigate the different effects on the passive annual heat storage of the earth as is showed in the Fig.7. The result showed that with a higher contact area, better the indoor condition will be.

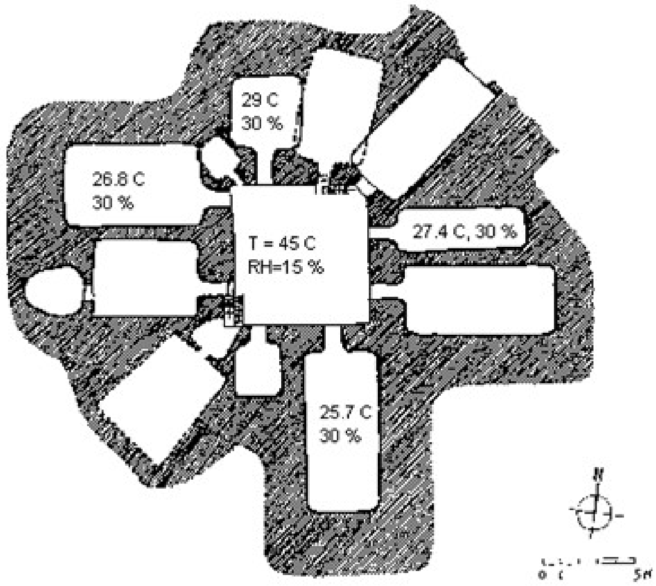

Figure 12: Summer thermal conditions in the underground Marhala hotel in Matmata, Tunisia (dow)

Dwelling Type	*Subterranean Dwelling*		*Above-grade Dwelling*	
Season	Winter	Summer	Winter	Summer
Outdoor Temp.	6.6 ºC (44 ºF)	41.1 ºC (106 ºF)	6.6 ºC (44 ºF)	41.1 ºC (106 ºF)
Outdoor RH	70 %	11 %	70 %	11 %
Indoor Temp.	15 ºC (59 ºF)	25.5 ºC (78 ºF)	10.5 ºC (51 ºF)	36.5 ºC (98 ºF)
Indoor RH	48 %	38 %	60 %	20 %

Figure 13: Comparision of the indoor environment for typical winter and summer days in a subterranean and an above ground house in Matmata (dow)

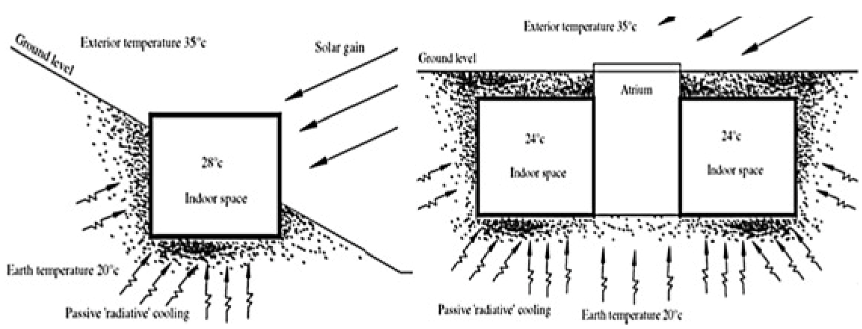

Figure 14: . Different configurations of an underground building changing the contact area with the earth (sci, b)11

In Montana, USA, Hait published for the first time the concept of passive annual heat storage. Within the investigation, was found that at an underground depth of 6 m, the average of the annual temperature remains constant approximately at 6^{o}C for both summer and winter, showing why during the ancient times, due to the lack of indoor climate control systems, in some hot-dry climates the underground cities construction was carried out.

In addition to the concept exposed above, there is a theory formulated by Dr. Nofziger in which is possible to predict annual variation of daily average soil temperature at different depths, and it is possible using the following sinusoidal function:

$$T\left(z,t\right) = T_a + A_0 e^{-z/d} \ \sin\left[\frac{2\pi(t-t_o)}{365} - \frac{z}{d} - \frac{\pi}{2}\right]$$

Figure 15: Sinusoidal function to estimate the temperature of the soil at different depths. (sci, b)

Where T(z, t) is the soil temperature at the depth z at time t. Ao is the annual amplitude of the surface soil temperature, To is the time lag chosen randomly depending on the case.

In the following graph is possible to detail the performance of various vernacular buildings in different parts of the world, and how the main material (adobe) can be high performance building material in different conditions:

Apart from the good thermal performance of the vernacular buildings, as it is evident, the embodied energy of this material is extremely low contributing as well decreasing the CO2 emissions.

Properties of the materials

The materials surrounding the occupants of a building are of prime importance for protection against heat and cold. Great care must be taken in the choice of the wall and roof materials and their thicknesses with respect to their physical properties, such as thermal conductivity, resistivity and transmission, and optical reflectivity. In hot arid climates, the coefficient of thermal transmittance should be about 1.1 kcal/hm^{2}C° (0.225 Btu/hft^{2}F°) for an outer wall to have an appropriate thermal resistance. (reg).

Regarding to the to the thermal properties of the materials used in the different construction, is possible to see a common pattern, which is the use of brick made by adobe and other natural biomass found nearby, which was used for both types of construction underground and on the surface. The thermal conductivity of the possible different bricks used in the constructions are shown in the following graph:

It is possible to see different thermal conductivities regarding to the adobe brick, and it is due to the use of different agricultural components such as rice and coconut husk which comparing to the mortar has a lower conductivity. The main reason is because the thermal conductivity mainly depends on the structure of the materials, being rice husk porous material resulting in a good thermal insulator, but decreasing the compressive strength comparing with the mortar.

On the other hand, the structure of the coconut husk is less porous than the rice, resulting in a increasing of both thermal conductivity and compressive strength. Based on this and depending mainly on the local climate and correct combination of the local materials, it was possible to have a high thermal performance buildings, keeping an indoor confort without using any active implementation such a indoor climate control system.

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Country	Context	Outdoor temperature (°C)	Indoor temperature (°C)
China	Vernacular houses	24.3–42	28–31
North -East India	Vernacular house in Tezpur, Imphal, Cherrapunjee regions	10–35 (Tezpur)	26–26.3
		10–35 (Imphal)	24.2–28.9
		5–25 (Cherrapunji)	22.2–24.2
Hyderabad, India	Naturally ventilated apartment houses	21–34	28–32
Tamil Nadu-India	Vernacular buildings in coastal regions of Nagapattinam	22–34	28–32
China	Vernacular dwellings	−10.4–34	8.3–27
Malaysia	Vernacular dwellings	24–36	26–29
Chongqing, (China)	Naturally ventilated lecture building	4.8–39.2	8.8–38.10

Figure 16: Different performance of vernacular buildings. (sci, c)

respect to their physical properties, such as thermal conductivity, resistivity and transmission, and optical reflectivity.

1.2 Climate 2: Birmingham

Location: United Kingdom-Europe Latitude: 52° 29' 22.1'' N Longitude: 1deg 53' 55" W

Weather Description

Birmingham has a temperate maritime climate. It is a snowy city relative to other large UK conurbations, due to its inland location and comparatively high elevation. Extreme weather is rare but the city has been known to experience tornadoes.

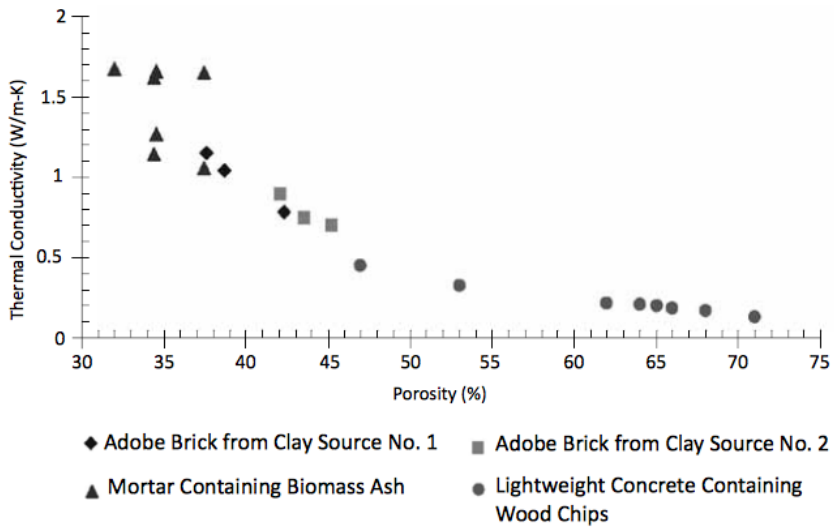

Figure 17: Thermal conductivity for the different bricks used.(nok)

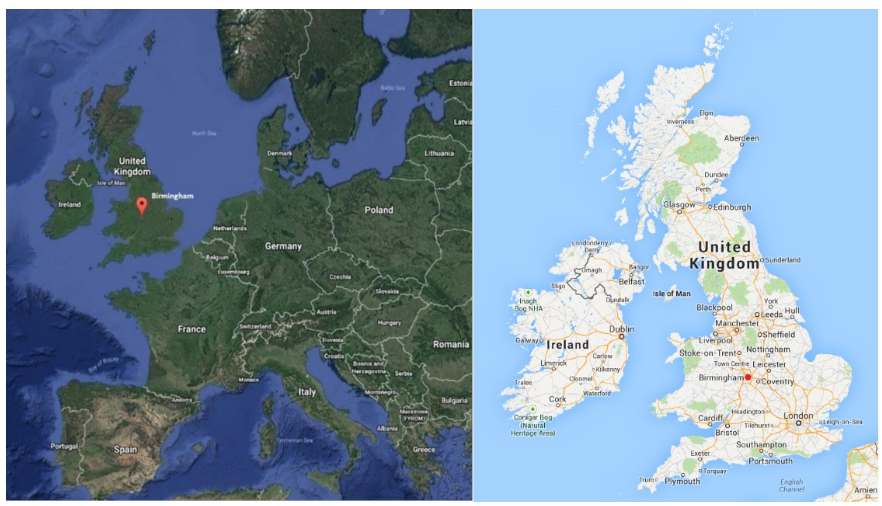

Figure 18: Birmingham geographic location, respect to Europe and United Kingdom (map)

Birmingham annual temperature trend in general, presents temperatures that reach the lowest values at the period of December-January - February and the highest at July-August, both delimit the winter and summer months respectively and they show values interesting for design purposes. Due to the monthly average range goes from 4.5 0C to 17.18 0C, is possible to establish a previous idea about the cold weather whose heating period hours will be a significant number, it becomes the first concern for design . As it can be seen in the Psychrometric chart , a high number of hours whose temperatures are below the proposed set point of 150C, gives the idea of a longer heating period than the cooling one which is very short (values higher than set point=260C) and may be even considered occasional even in the summer months.

Vernacular architecture in United Kingdom:

In Birmingham, as in other cities of United Kingdom, vernacular buildings such as houses and cottages, have been built in the main from locally available materials that reflect custom and tradition. They share common

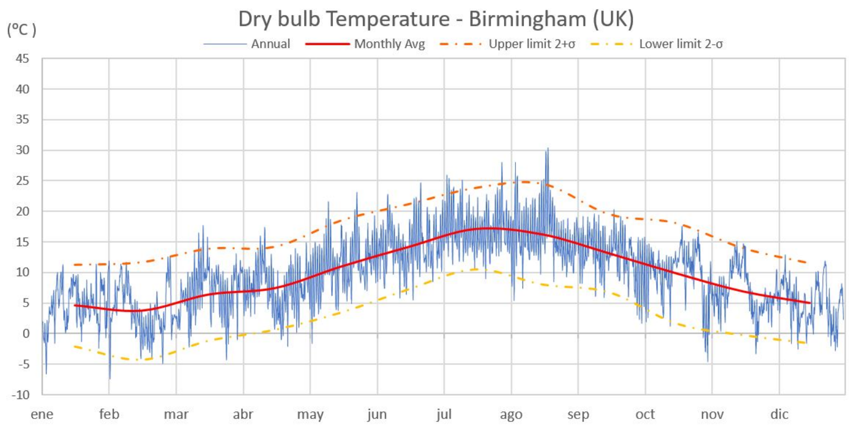

Figure 19: Birmingham Dry bulb temperature: Annual and monthly average values

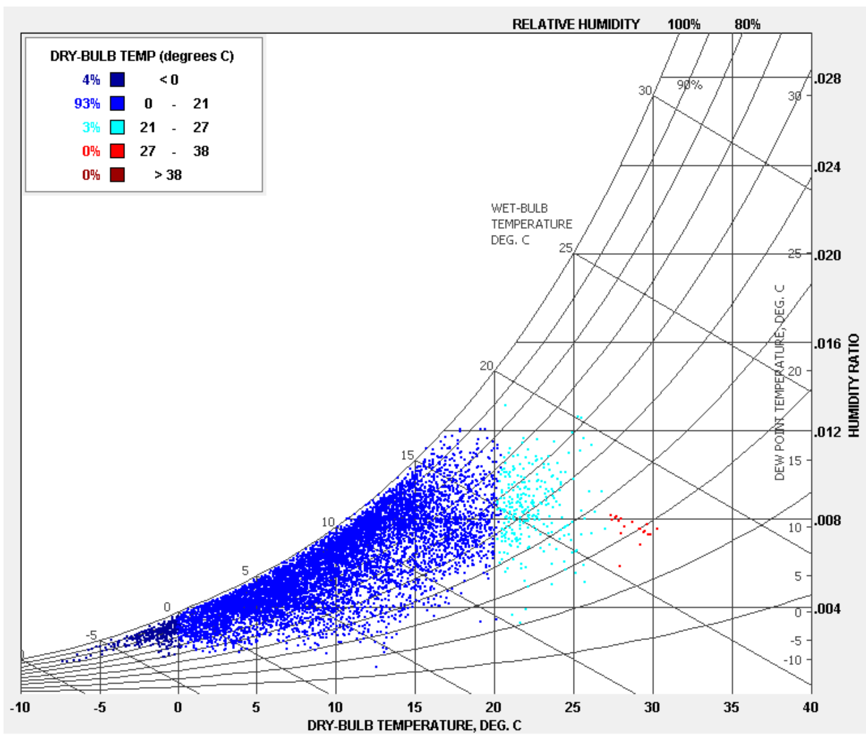

Figure 20: Birmingham Dry bulb temperature annual distribution - Psychrometric chart(Climate consultant)

features such as the use of timber frames for structural purposes and masonry made with mass walls (of stone, brick or mud) or with timber-framed walls incorporating non-structural infill, or with a combination of the two.

Nowadays, buildings which represent vernacular architecture are not so visible in Birmingham, due to the renovation of the construction field in the United Kingdom and the transition fron Medieval, Victorian and Contemporary ages. Although, there are few examples of the influence of the Arts and Modern architectonical

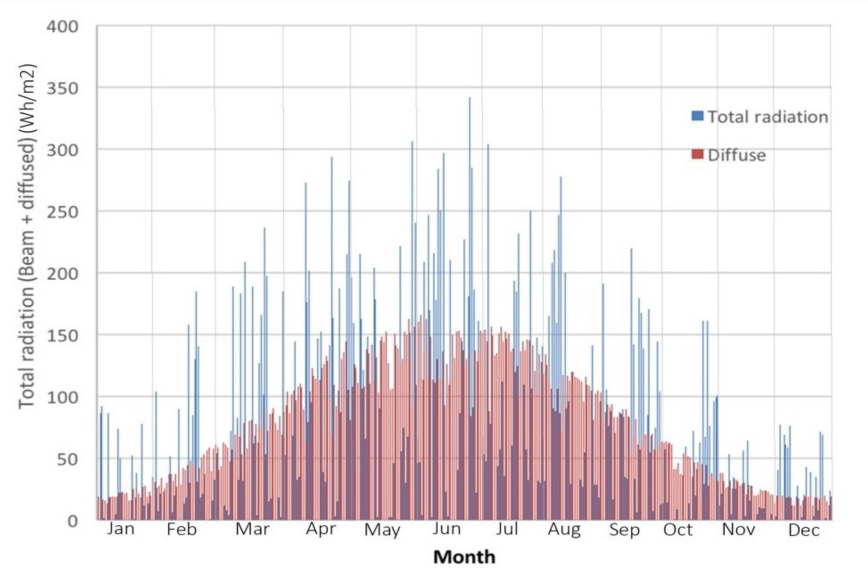

Figure 21: Average daily amount of the solar energy received by the horizontal surface for Birmingham

movement, where the local materials are widely employed and adapted to satisfy the climatic actions.

A good example to analyze and understand the vernacular architecture that remains nowadays in the United Kingdom, are the **traditional cottages**. They are small dwellings for some of the poorest and labours in the society in United Kingdom. They are made of one or two bays, single-storeyed, and a chimney for heating purposes.

Most surviving cottages from the 17th century or earlier are one-and-a-half storeys high and just one room deep. They are characterized by low ceilings, small windows, steep roof pitches and low eaves. Being narrow, usually less than 18-feet wide, and having small windows, they were frequently dark. Most historic cottages are one-room deep, simply because of the problem of span. Few builders of these traditional homes were able to put their hands on a beam that would span a room more than around 18 feet, with traditional roof pitches of 48-55° (ren)

Example	Style Cottage
Ubication	Uffington, Oxfordshire UK.
Use	Residential
Period of construction	Since 1700
Materials:	Chalk-block, limestone, timber

together, and it is possible to visualize the considerable size of the masonry walls, as it can be seen in the following figure:

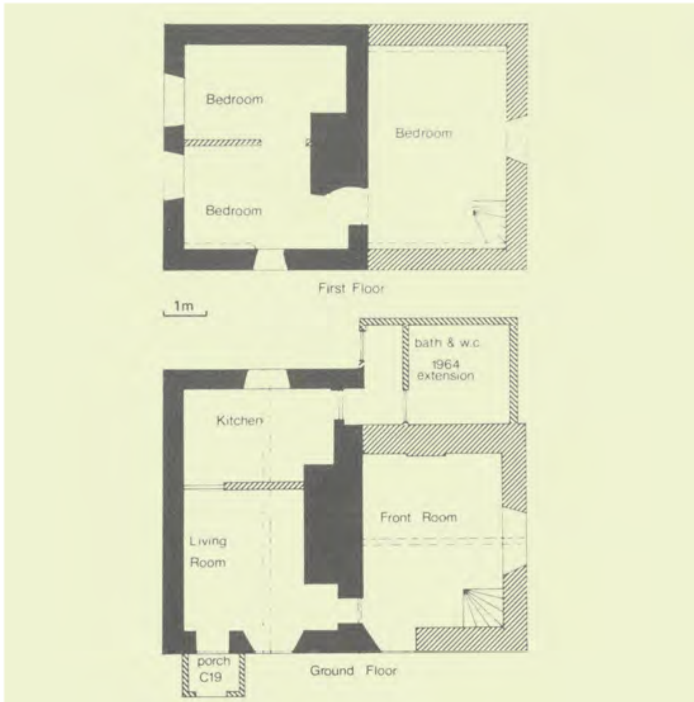

Figure 23: Plan distribution of traditional cottages (hou, a)

Constructive techniques and envelope materials

External Walls:

Vernacular buildings display a wide range of construction techniques and local materials, ranging from thick stone, chalk block , clay bricks or earth walls (COB, rammed earth), to timber-framed buildings with comparatively thin and lightweight wattle-and-daub infill panels and craftspeople work. Since medieval ages, these materials have been used as a strategy for winter heating due to the important values of thermal mass they can provide, which is high making the walls act as a thermal buffer zone inside the home, as it can be seen in the figure 24. Due to the mild cold winter is predominant in the United Kingdom, high mass walls were used to preserve heat and the number of windows is very restricted to avoid a high number of thermal loses. The thick walls provided excellent thermal mass which was easy to keep warm in winter and cool in summer, for example the bricks of a wall are nominally 240 mm by 115 mm by 113 mm (Goodhew and Griffiths, 2005) . The walls of a cob house are generally about 24 inches (61 cm) thick.

Properties of the materials

There are several studies that can provide an idea to assess the different thermal properties of these vernacular materials for tentative thermal models.

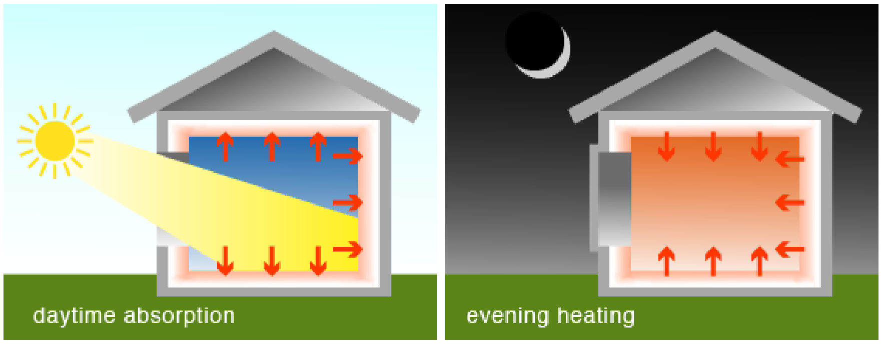

Figure 24: Winter heating process for weathers like Birmingham (uk)

Figure 25: Vernacular building mostly made of brick and timbered frames © John Sewell PDNP (bui)

Figure 26: COB dwellings in Devon, United Kingdom(mod)

For example, like the one performed by (Goodhew and Griffiths, 2005) mostly with unfired clay bricks, composed of clay–silt–sand mixed with straw and wood chippings with a ratio of the clay–silt–sand mixture to straw between 1:2 and 1:3 and COB (constituted by straw, water, and sub-soil which provides it the main resistance).

Also, (Li et al., 2014) evaluated the typical U-value for UK solid walls used for stock-level energy demand estimates and energy certification is 2.1 Wm-2 K-1. It was an analysis (based on 40 brick solid walls and 18 stone walls) using a lumped thermal mass and inverse parameter estimation technique gives a mean value of 1.3 ± 0.4 Wm-2 K-1 for both solid wall types.

The measured thermal properties of the materials

	Density, ρ (kg/m^3)	Thermal conductivity, λ (W m^{-1} K^{-1})	Specific heat capacity, $\lambda/\alpha\rho$ (J/kg K)	Volumetric heat capacity, λ/α ($\times 10^{-3}$ J m^{-3} K^{-1})	Diffusivity, α ($\times 10^7$ m^2 s^{-1})
Straw bale	60	0.067 (0.002)	600 (10)	36.8 (0.7)	18.2 (0.5)
Clay–straw mixture	440	0.18 (0.01)	900 (100)	400 (50)	4.6 (0.4)
Bricks, claytec	800	0.24 (0.02)	750 (30)	650 (20)	3.8 (0.3)

The values inside the parentheses are standard deviation.

The thermal properties of the additional materials used in the calculations and comparisons

	Density, ρ (kg/m^3)	Thermal conductivity, λ (W m^{-1} K^{-1})	Specific heat capacity, c (J/kg K^1)	Volumetric heat capacity, ρc ($\times 10^{-3}$ J m^{-3} K^{-1})	Diffusivity, $\lambda/\rho c$ ($\times 10^7$ m^2 s^{-1})
Paper (cellulosic insulation)	43	0.042	1380	59.34	7.08
Pads (straw + clay slip)	110	0.073	425	46.8	15.6
Wool	140	0.038	840	117.6	3.23
Plywood sheathing	700	0.15	1420	994	1.51
Plasterboard	950	0.16	840	798	2.01
Cob (Devon earth, mean)	1450	0.45	800	1153	3.93
Clay (USA)	1460	1.3	880	1285	10.12
Glass (soda-lime)	2500	1.05	840	2100	5.00

Figure 27: Thermal properties of materials for walls in vernacular buildings in UK(Goodhew and Griffiths, 2005)

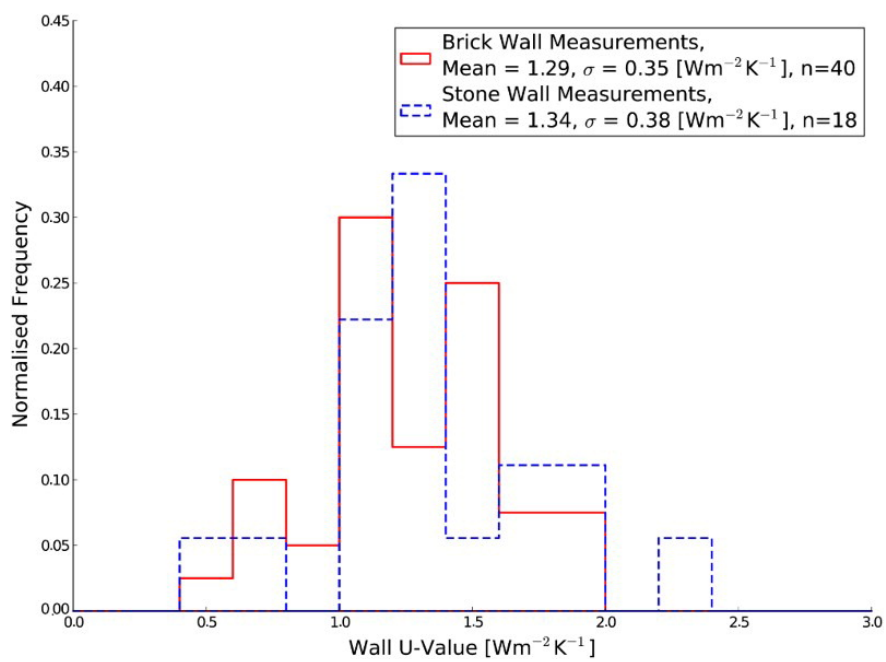

Figure 28: Distribution of U-values on solid brick and stone walls in the UK (Li et al., 2014)

Most historic buildings in this country have solid walls constructed in porous materials, with internal finishes such as lime plaster. This porosity has helped to keep many buildings in good condition because:

* On the outside, it encourages the absorption of rainwater, which is then able to run down, drain out and later to evaporate

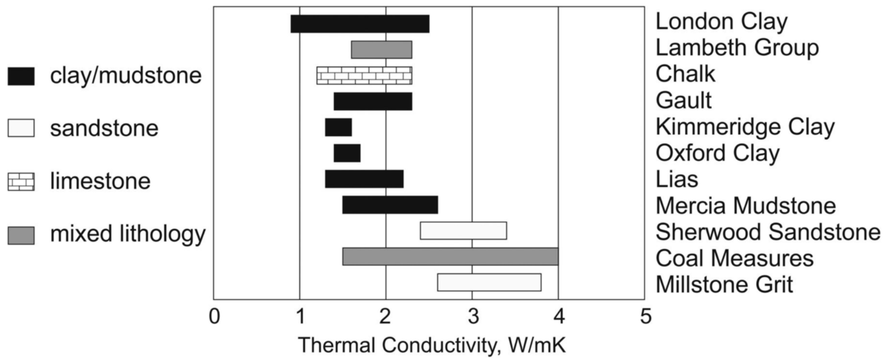

Figure 29: Thermal conductivity values of typical envelope materials for vernacular houses in the UK (Cassar and Standing, 2017)

* On the inside, it helps to stabilise moisture levels in rooms and often averts surface condensation, for example in crowded conditions or when cooking

* Moisture can also pass through the wall and evaporate both externally and internally as conditions allow, as can any dampness rising from the earth.

This approach differs greatly from most modern buildings, which rely externally on impervious or rainscreen systems and internally on construction which is completely protected from moisture – at least in theory – by cavities, damp-proof membranes, and vapour control layers.

Unfired clay brickwork, plus vapour-permeable render and paint, provides passive environmental control in buildings through buffering of the temperature in the building (through the provision of thermal mass), and through buffering relative humidity by absorbing moisture from the air at high humidity, and releasing it at low humidity. Buffering of temperature and humidity will normally reduce the energy required to operate buildings. As it is shown in the figure from below, the unfired brickwork can absorb significantly more moisture from the air than either concrete blockwork or fired brick masonry. (des)

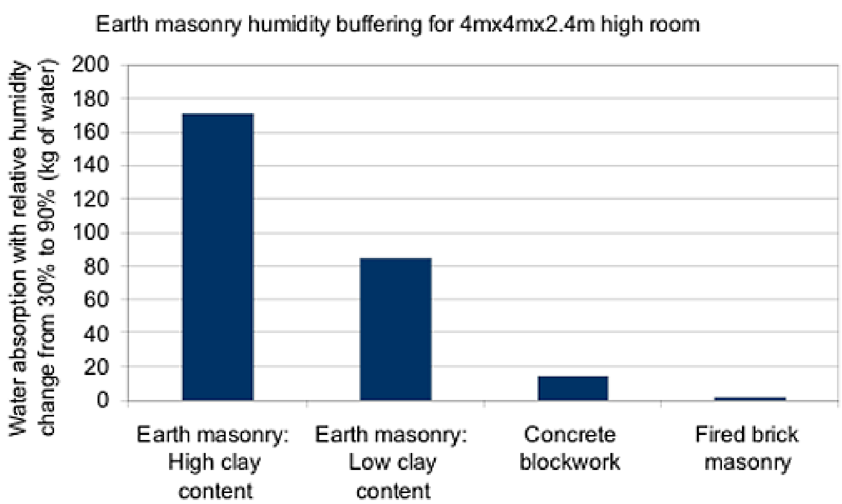

Figure 30: Amount of moisture that will be absorbed by the walls (bri)

Traditional buildings are characterized by the widespread use of ‘breathable’ materials which allow moisture within the building fabric to evaporate freely away. This applies particularly to solid masonry external walls (whether of brick or stone), but is also relevant to earth buildings, infill panels in timber-framed construction, solid ground floors, plastering and rendering, and internal and external decorative finishes.

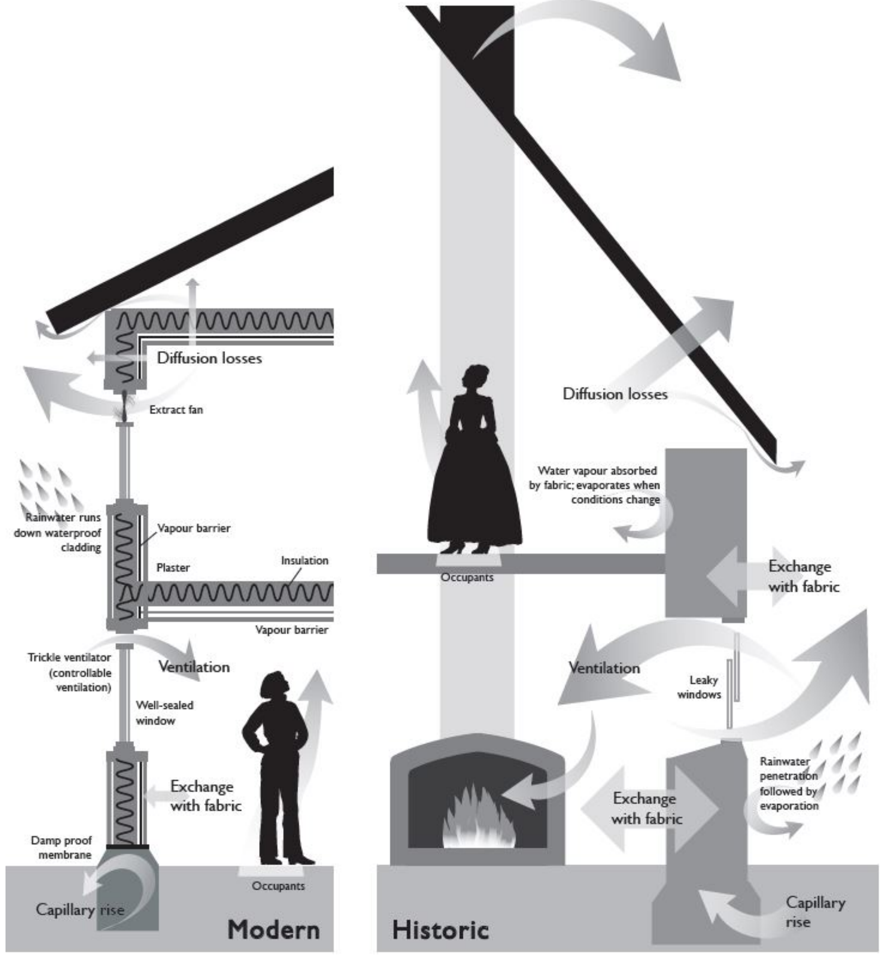

Figure 31: Typical differences in the movement of moisture between an historic building (right) and a modern building (digital image by Robyn Pender)(bui)

Roofs:

The roof of a historic building is often its most striking feature. Most have survived in a remarkably unchanged condition for many centuries. Most historic flat roofs are covered with lead, a few being clad in zinc or copper. Repairs and replacements using bitumastic materials and felts have been widely used. Flat roofs show a wide variety of designs, although most are akin to the ‘cold roof’ with a small roof-space (sometimes deliberately ventilated to the outside, but often not) above the ceiling. There is often a generous amount of ventilation in historic buildings from their roof-spaces. The internal moisture that may be generated, if it is in the way into the roof, can be quickly removed. The moisture-buffering effect of the large amounts of hygroscopic material in many historic buildings can also be helpful.

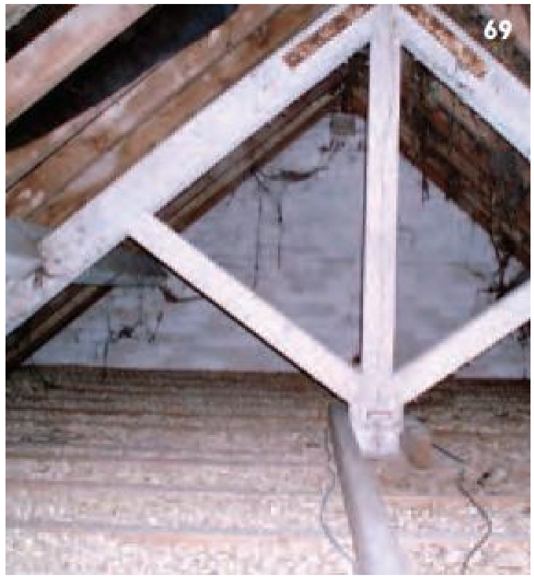

Figure 32: A typical ‘cold roof’ insulated with vermiculite between the ceiling joists © Oxley Conservation (bui)

Floors

The earliest floors were ‘earth’ floors formed usually of a locally available compacted material such as earth, clay, gravel or chalk material (about 50 - 100 mm thickness). The finished surface was then often covered with rushes and herbs to reduce the amount of dust.

For moisture issues, solid floors of traditional construction were normally bedded directly on the earth or on permeable fills or mortars with no damp proof membrane, and consequently have different physical characteristics to modern solid concrete floors. These floors are able to absorb and evaporate moisture from the whole surface area without detriment to the materials. Interfering with this quality can easily drive moisture into vulnerable adjacent construction. (eff)

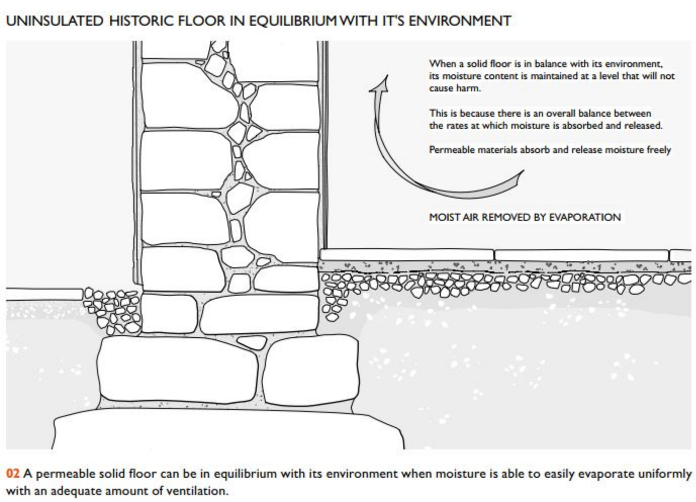

Figure 33: Uninsulated floors in vernacular buildings in the UK (eff)

Windows

England has a rich tradition of window designs and materials from different periods of history. Most historic windows are timber-framed. Iron frames had been used in medieval times, and by the 16th century metal-framed glass windows were beginning to appear in secular homes. By the middle of the 18th century metal sash windows were being cast and even copper was being set in wooden frames, usually of oak. Shutters are also used to minimise heat losses at night and to reduce the unwanted solar gains. Internal shutters can also be draught-proofed to improve thermal performance, in a similar manner to windows. Air infiltration through old windows is often excessive, so draught-proofing and weather stripping can be very effective in reducing not only heating bills but also reducing levels of noise and dust too. (bui)

Figure 34: Glass windows and timber frames plus external wooden shutters © Linda Hall (bui)

Existing examples of the different eras in the vernacular architecture in Birmingham

Example	The Old Crown
Ubication	Birmingham UK.
Use	Residential/Restaurant
Period of construction	Late 15th century
Materials:	brick, black and white timber frames timber and stone
Dimensions:	Wide= 21.7m Depth=6.10m groundfloor

It is one of the oldest buildings existing in Birmingham. At the beginning, the structure was poorly supplied with building stone and dominated by timber framing, with dark wooden structures in complex patterns infilled with lightly colored plaster. The wall framing includes the use of close studding and decorative braces within panels in herringbone and quadrant patterns.

On the first floor, it shows overhangs at the front. Below the central hall, there was a number of arched cellars. Clay bricks were used in the masonry, because they have the reputation as optimum building materials that

Figure 35: Old Crown Pub Facade (cro)

provide an effective barrier against weather actions. As it can be seen, this building is characterized for extended brick walls with a smaller glazing areas, due to the predominant mild cold weather, even though the amount of natural light is reduced. Clay bricks are able to absorb heat and release it over time, helping to preserve temperatures near to the comfort for winter and reducing dependence on artificial cooling.

Figure 36: Old Crown Pub Facade interior view of the constructive system(cro)

Example:	Victoria Law Courts
Ubication:	Birmingham UK. South side.
Use:	Public Offices
Period of construction:	1887-1894
Materials:	brick, timber and roughcast

Birmingham's dominant architectural style suffered changes at the end of the 19th century, buildings started to adopt traditional forms of local vernacular architecture following the Arts and Craft tendency. Red bricks and terracotta were useful as substitutes for natural stone, which Birmingham lacked, and they also were resistant to soot and smoke, prevalent in the city due to the heavy industrial presence. The Victoria Law Courts is a representative example of this tendency, whose masonry was predominantly made of brick, roughcast and half-timbering frames. The interior, including the Great Hall, is faced with sandy-yellow terracotta and intricate ornamentation. (bel)

The mild cold winters forced the use of massive brick walls and it was possible to adopt a larger number of windows to improve the amount of natural light received.

Figure 37: Victoria Law Courts red brick and terracotta Façade (bel)

Figure 38: Victoria Law Courts masonry and glazing parts (bel)

movement, he incorporated arty features such as stepped gables, small Venetian windows over canted bays, timber corner porches below dormers with very concave little leaded roofs for ventilation, as it can be seen in the following figures:

Example:	Winterbourne House
Ubication:	Edgbaston, Birmingham UK.
Use:	Commercial, Eagle Insurance Company

Period of construction:	1903
Materials:	Bricks, tiles, timber

Following the Arts and Crafts trend, craftspeople and local materials, such as bricks, timber and stone were employed to provide an enduring feel of quality. The house walls were made of brick and tile. Also, it has an intentionally wavy roof line. The design of the house was intended to make the best use of available light; notable features are its large windows, white painted paneling and large south-east facing rooms. The house contains restored rooms, drawing rooms, study, bedrooms and nursery and furniture dating from the late Victorian period to the 1920s.(tru)

Chapter 2. Energy Saving strategies proposal

2.1 Tunisia

In order to reduce building energy consumption and increase its energy performance, an integrated design approach is recommended to evaluate a wide range of energy efficiency measures or EEMs. This approach is especially required when designing high performance buildings targeting net-zero energy use and carbon neutral level. The interactive effects of various EEMs can be difficult to assess without the use of detailed simulation tools. Typically, building designers perform a series of parametric analysis to evaluate the impact and cost-effectiveness of individual energy efficiency measures. This type of parametric analysis often neglects the interactive effects between various measures on building energy use and thus may not select the most cost-effective building design features that provide the highest energy efficiency level at an optimal cost. More comprehensive set of parametric analyses that involves the simultaneous evaluation of several energy efficiency measures require significant computer efforts and are often not considered in the design phase of residential buildings. To overcome the deficiencies the parametric analysis approach, optimization-based design methodology has been proposed to identify and select design and operating measures in order to minimize energy costs for residential buildings.

In an analysis, the most common design and operating energy efficiency measures available in Tunisia for residential buildings were evaluated. Below are listed eleven EEMs considered for the optimization analysis. These measures and associated options include building envelope, lighting, appliances, temperature settings, and HVAC systems. A brief discussion of the options associated with each EEM is provided below:

· Orientation defined by the azimuth angle between the true south and the front of the house. Seven options for the orientation were considered varying from 0 °(baseline) to 270°.

· Exterior wall and roof insulation defined by the thickness of polystyrene insulation. Four options were considered with a no insulation (RSI $\frac{1}{4}$ 0) to 6-cm insulation (RSI-3.0).

· Window size defined by the window-to-wall ratio (WWR). Four options were evaluated ranging from small windows(WWR $\frac{1}{4}$ 10%) to large windows (WWR $\frac{1}{4}$ 40%).

· Glazing type characterized by the number of panes and the coating type applied to the glazing surfaces. Six glazing types were considered in the analysis.

· Lighting type defined by the lighting power density. Four lighting options were considered including (i) all fixtures are incandescent lamps (baseline with 7.3 W/m2), (ii) 1/3 of the fixtures are compact fluorescent lamps (CFLs) while the other remain incandescent lamps (i.e., 30% reduction in baseline lighting power density), (iii) 2/3 of the fixtures are CFLs while the other remain incandescent lamps (i.e., 50% reduction in baseline lighting power density), and (iv) all the fixtures are CFLs (i.e., 70% reduction in baseline lighting power density).

Figure 39: Birmingham Bournville villages, nowadays shops(wik, a)

Figure 40: Bourville village, nowadays rest house(wik, a)

· Air leakage level defined by the air infiltration rate. Four levels were considered: leaky (baseline with an infiltration rate of 0.7 L/s/m2), moderate leakage level with 25% reduction in baseline infiltration rate, good leakage level with 50% reduction in baseline infiltration rate, and tight level with 75% reduction in baseline infiltration rate.

· Cooling temperature setting defined by the maximum acceptable indoor temperature needed to maintain thermal comfort. Three temperature settings were evaluated 24 °C, 25 °C, and 26 °C.

· Refrigerator energy efficiency level defined by its class label. Four options were considered: baseline with an annual use consumption of 800 kWh/year, refrigerator of class 3 with 30% reduction in baseline annual energy consumption, refrigerator of class 2 with 45% reduction in baseline annual energy consumption, and refrigerator of class 1 with 65% reduction in baseline annual energy consumption.

Figure 41: Winterbourne House, brick details and external view (tru)

· Boiler type defined by its energy efficiency level. Four energy efficiency levels were considered: 80% (baseline with lowefficiency), 85% (standard efficiency), and 90% (high efficiency), and 95% (premium efficiency consisting of a condensing boiler).

· Cooling system type defined by its coefficient of performance or COP level. Four COP levels were considered: COP ¼ 2.6 (baseline with low-efficiency), COP ¼ 3.0 (standard efficiency), and COP ¼ 3.3 (high efficiency), and COP ¼ 3.5 (premium fficiency).

The results indicate the effectiveness of each design measure when implemented individually on both energy use and life cycle costing. As expected, a home built with energy efficient measures such as adding insulation, improving glazing type, and lowering lighting level, save up to 14.5% of total annual energy use when compared to than the baseline house. Based on a survey of energy end uses, it is found that refrigerators and lighting fixtures contribute respectively, 41% and 18% of the total electricity used in a typical home in Tunisia. It is therefore reasonable that the use of energy efficient refrigerators and lighting fixtures have the most impact in reducing source energy use by up to 14.5% and 13%, respectively. The use of double pane low-e glazing instead of single pane clear glazing for all windows saves 7.3% in total villa electricity consumption. For Tunis, small windows (with WWR ¼ 10%) can reduce energy use by 5.7% compared to larger windows (with WWR ¼ 40%) due to lower solar gains.

However, changing the orientation of the villa does not seem to have any significant impact on the energy use. Indeed, the total energy use of the villa changes by only 0.8% for all the orientations considered in the analysis. When adding all savings from the individual EEMs, maximum energy savings of 63.9% is reached. However, this sum of energy savings is not realistic and provides only indication of the potential maximum energy savings since this sum does not take into account the interactive effects between various EEMs.

In this section, the developed optimization simulation environment was used to investigate the interactions between incremental sets of EEMs listed above. First, a 2-EEM set was defined to include optimal values of WWR (i.e., 10%) and orientation (i.e., azimuth ¼ 90°). These measures, once defined, were difficult to change due to site and owner specifications. Then, additional EEMs using their optimal options are added incrementally based on their impact ranking.

In the analysis, a wide range of design and operating measures are considered including orientation,window location and size, glazing type, wall and roof insulation levels, lighting fixtures, appliances, and efficiencies

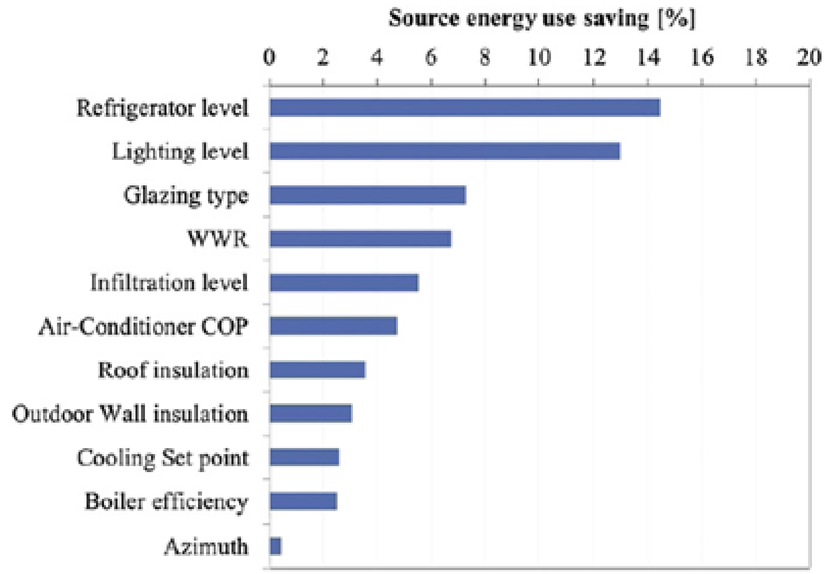

Figure 42: Maximum source energy use savings for each design measure applied to a villa located in Tunis

	Number of EEMs										Initial Implementation Cost [TND]	Annual Energy Cost [TND]	Life Cycle Cost [TND]	Energy Savings [%]
	2	3	4	5	6	7	8	9	10	11				
Reference building											18,935	13,346	32,281	0.0
Azimuth	O	O	O	O	O	O	O	O	O	O				
WWR	O	O	O	O	O	O	O	O	O	O	19,683	12,366	32,049	6.8
Refrigerator energy level		O	O	O	O	O	O	O	O	O	20,083	10,206	30,289	21.2
Lighting level			O	O	O	O	O	O	O	O	20,218	8238	28,456	34.4
Glazing type				O	O	O	O	O	O	O	20,218	8238	28,456	34.4
Infiltration level					O	O	O	O	O	O	20,350	8058	28,408	36.3
Air-Conditioner COP						O	O	O	O	O	20,264	8033	28,296	37.6
Roof insulation							O	O	O	O	21,128	7103	28,231	45.6
Exterior wall insulation								O	O	O	21,128	7103	28,231	45.6
Cooling Setpoint									O	O	19,072	8959	28,031	29.2
Boiler efficiency										O	19,072	8952	28,024	29.5

Figure 43: Summary of the optimization results associated with the incremental sets of design measures for a villa located in Tunis (O: selected design option)

of heating and cooling systems. It is found that source energy use savings up to 59% can be achieved cost-effectively using an optimal design compared to the current construction practices of homes in Tunisia. Moreover, it is found that the specific selection of optimal design features vary depending on the climatic and economic conditions. Typically, adding roof insulation, reducing air infiltration, installation energy efficient appliances, lighting fixtures, and heating and cooling equipment are common energy efficiency measures recommended for optimal homes designs for all climatic zones in Tunisia.

In Tunisia, the improvement of living standard induced higher comfort requirements translated into an increase in the use of heating and air-conditioning equipment. In addition, no attention is drawn to improve the thermal quality of the building envelope. Consequently, the energy consumption in residential and commercial buildings has significantly increased. This sector is expected to be the first energy consumer by 2020. One of the most effective ways to reduce heat transmission rate and energy consumption for space cooling and heating is the use of an appropriate thermal insulation in the building envelope. An optimum thickness of insulation is the value that provides the minimum total cost including the insulation cost and the energy consumption cost over the lifetime of the building.

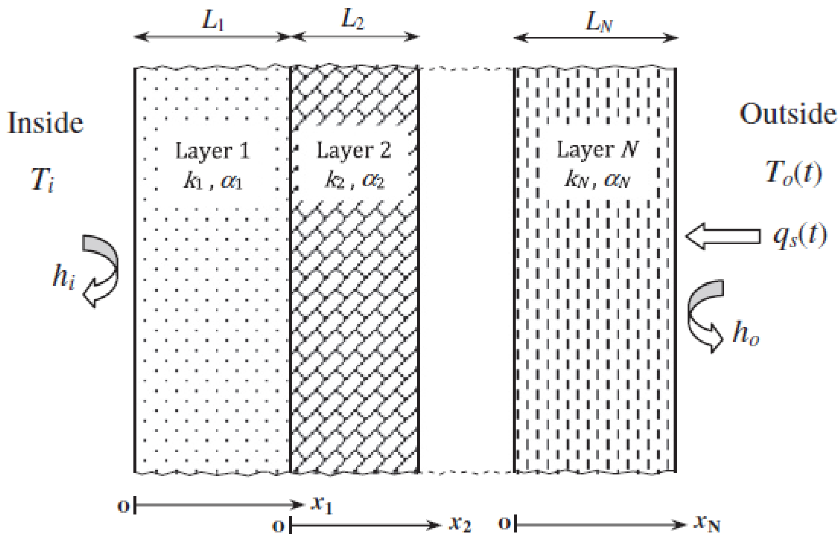

Figure 44: Model of N-layered composite wall

A heat transfer model based on the analytical CFFT technique was used in order to determine an exact solution of the transient heat transfer through a multilayer external wall submitted to steady periodic outdoor temperature and solar radiation specific to the climate of Tunis. This method allowed accurate prediction of inside surface conditions for two typical uninsulated walls made of brick and stone within the limitations of plausible physical input. Results presented for both cold and hot seasons showed a significant effect of wall orientation on thermal performance of the two walls. In this study, the CFFT technique was extended to calculate rigorously annual heating and cooling transmission loads through a typical building wall with an insulation layer in the middle. Yearly transmission loads versus insulation thickness showed significant changes with respect to wall orientation, notably between south and north-facing walls. The west and east orientations are the least favourite in the cooling season, whereas the north orientation is the least favourite in the heating season.

Calculated annual transmission loads were used as the main inputs in an economic model. Optimum insulation thickness and resulting energy saving and payback period based on both cooling and heating loads were determined in a life-cycle cost analysis over a building lifetime of 30 years. Different wall orientations were considered and comparison with the degree-days model was performed. Results showed that the south orientation is the most economical one with an optimum insulation thickness of 10.1 cm, 71.33% of energy saving and a payback period of 3.29 years. Wall orientation has a small effect on optimum insulation thickness, but a more significant effect on life-cycle energy savings whose highest value of 23.78 TND/m2 is reached for the east orientation.

A sensitivity analysis to economic parameters showed that higher values of optimum insulation thickness and energy saving are obtained when increasing the lifetime period, the inflation rate or the cost of energy. On the other hand, optimum insulation thickness and energy saving decrease with increasing the discount rate and the cost of insulation material. Effect of the base indoor temperature was also investigated in both cooling and heating cases. Results were compared to those of the degree-days method which provided the same variations as the present study but underestimated values of optimum insulation thickness.

The energy demand for refrigeration and air conditioning has continuously increased throughout the last decades, especially in developing countries like Tunisia. This increase is caused amongst other reasons, by increased thermal loads of buildings, occupant comfort demands, and architectural trends. This has been responsible for the escalation of electricity need especially for the high peak loads due to the use of electrically driven vapor compression machines. Moreover, the consumption of primary energy and the emission of greenhouse gases associated with electricity generation from fossil fuels have led to considerable environmental consequences and monitory costs. Conventional energy will not be enough to meet the continuously increasing need for energy in the future. On the other hand, the compression machines have impacts on the stratospheric ozone depletion due to the chlorofluorocarbons (CFCs) and the hydro fluorocarbon (HCFC) refrigerants.

In this case, renewable energy sources associated with environmentally friendly refrigerants will become important. An alternative solution for this problem is solar energy, which is available, plentiful in most areas, and represents also a good source of thermal energy. One wide-spread application of a solar-powered system is for absorption cooling that is largely thermally driven and requires little external work. Another major advantage of absorption cooling machines is that, they do not use CFC refrigerants and therefore do not contribute to depletion of the ozone layer. Taken together, these characteristics make the absorption air conditioning technology a very interesting option both from long-term financial and environmental viewpoints.

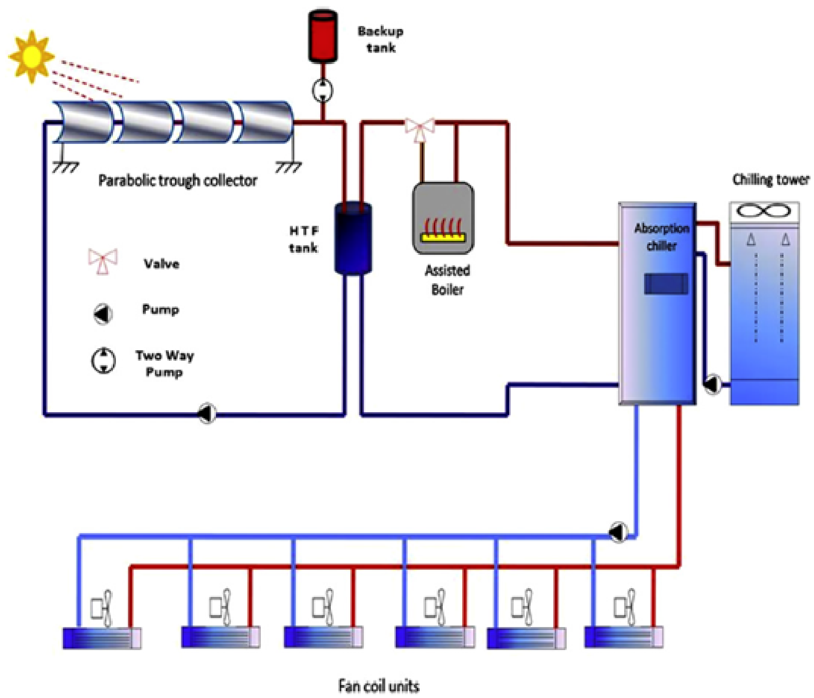

Figure 45: Scheme of the solar absorption cooling installation

One of the essential purposes of the solar cooling installations is to reduce the non-solar energy sources, such as electricity or fossil fuels burning resulting also in a reduction of CO2 emissions. According to a study done by the National Agency for Energy Management in Tunisia ANME, there are 680 g of CO2 emitted into the atmosphere for each kW h of electricity produced. Thus, the conversion factor to calculate the quantities of CO2 emitted is fc = 0.68 kg/kW h. The amount of CO2 emitted during the hot season (summer) using a compression air conditioning with an equivalent cooling power to the solar installation (13 kW) could be estimated.

Assuming a mean COP for the electric chillers of 2.5 and a mean operating duration of 6 h per day throughout the hot season in Tunis from mid May to mid October (150 days), the CO2 emissions are 3182 kg for the compression chiller of 13 kW cooling capacity. Using this solar cooling installation with an average solar fraction SF of 0.54 and an auxiliary gas burner releasing 0.2 kg/kW h and 1 kW electricity consumption, the CO2 emissions are 413 kg. This corresponds to 2769 kg of CO2 emission prevented from being released into the atmosphere. If the solar cooling installation uses the backup night storage, the mean solar fraction SF increases to 0.77 and the prevented CO2 emissions increase to 3000 kg. Given that the burning of 1 l of gasoil releases 2.6 kg of CO2, the equivalent saved energy is 1065 l of gasoil for the installation operation without the night storage and 1154 l when the backup night storage is used.

There are simulation results that show that absorption solar air-conditioning systems are suitable under Tunisian conditions. Despite their high first cost, these systems could help to minimize fossil fuel-based energy use, reduce electricity demand on the national grid especially at peak demand periods in summer and eliminate the use of CFCs. The simulation should be followed by an experimental work under real conditions so as to determine the system effective performances. The installation of a pilot solar cooling machine is under way at the Energetic Research and Technologic Centre (CRTE, Tunisia).

Several studies carried out during the last years, highlighted the high contribution of buildings in primary energy consumption all around the world and especially in developed countries where this contribution reaches 20–40% of the total energy use. Heating, ventilation and air conditioning systems (HVAC) are the most energy-consuming amongst the buildings services. For these reasons, the conception of energy-efficient buildings has become a priority and the integration of cooling and heating passive techniques is increasingly encouraged by international regulations.

Passive cooling relies on the use of techniques that enable controlling and dissipating the solar radiation and thermal gains during summer. Contrarily, heat passive features take advantage of sunlight and its heating effect thanks to their high capacity of absorbing solar radiation, storing and releasing heat inside the building. Hence, low-energy or 'zero-energy' buildings incorporate efficient passive features that guarantee indoor conditions within comfort range without consuming any primary energy.

Reducing energy consumption in buildings can be guaranteed, first by designing envelopes passively taking into account the climatic conditions in order to choose the best orientation, walls and windows compositions. Second, by improving the efficiency of the building equipments, especially cooling and heating systems and supplying them if possible by renewable resources rather than electrical or fossil energy. Based on few studies, few main conclusions can be drawn:

* The insulation of the walls and the cool roof guaranteed important savings of 46% in winter and 80% in summer compared to an ordinary building.

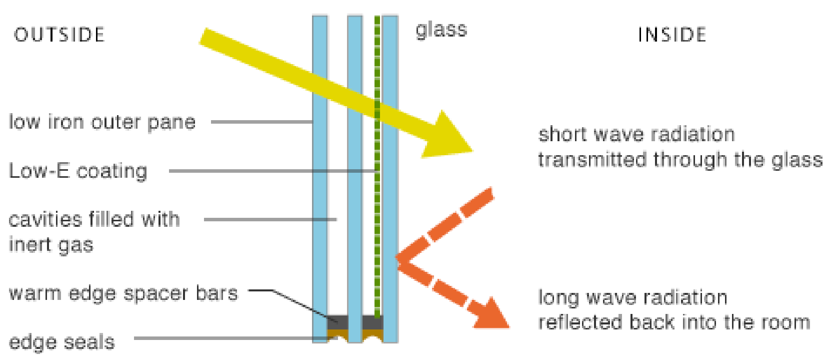

Figure 46: Low E coating glazings

* The analysis of the effect of glazings types (simple, double, triple, low-e, low-e,Ar) on the thermal perfor-

mance of the building has shown that the most efficient windows were the low-emissive Argon coatings that allowed an attenuation of 60% in heating requirements.

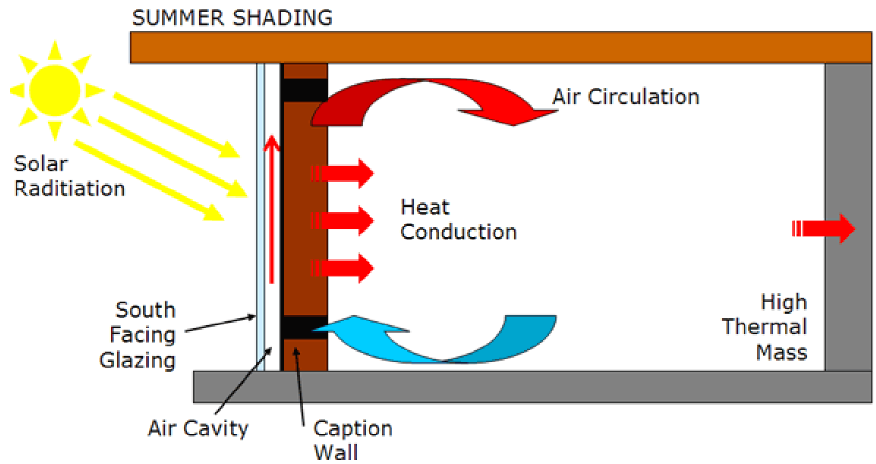

Figure 47: Mechanism of Trombe walls

* The trombe walls have contributed in decreasing the total heating requirements ([?]21%) and improving the comfort level inside the building in winter but still have an overheating effect in summer.

* A building predictive model that gathers all the selected characteristics and the new passive strategies was proposed. It features the integration of low-emissive Argon windows, internal shading devices and movable solar overhangs shading every storage wall and every window. The thermal performance simulation of the predictive model showed a relevant decrease in total energy demands (47.7% for cooling demands and 60.3% for heating demands).

* The peak cooling load was estimated to 8.68 kW, a cooling power that can be provided by the water–Bromide absorption chiller without any operating problem. The important decrease of the new envelope configuration cooling load leads to a reduction of the auxiliary heating power supplied to the absorption chiller which guarantees in its turn important savings in gas consumption expenses.

* Improvements solutions could be added to the solar cooling system. A cooling storage tank able to store the amount of excessive produced cooling power as chilled water could be integrated in the installation. The cooling storage could be exploited either to cool other nearby offices or to cool the building after 16 h. This leads to a reduction of the functioning duration of the absorption chiller and allows important savings of gas and electrical consumption.

3.2 Birmingham

In the last few decades, the UK has experienced periods of uncharacteristically hot summer weather leading to some buildings overheating, particularly in London and the south-east. This overheating is especially common in domestic properties, which rarely have mechanical cooling systems installed. Significant negative impacts of these periods of overheating upon the population's health and well being have been reported, and it is therefore very important that a sustainable and practical solution to this issue is found.

In the search for such a solution, phase change materials (PCMs) have been identified as an effective means of moderating internal air temperatures by making use of their significant thermal storage characteristics. Ling et al. reported on the successful application of PCMs within greenhouses in China which led to an improved thermal environment due to the ability of the PCM to store heat as the greenhouse warms up, and then release the stored heat at night as the greenhouse naturally cools down. The effectiveness of macro-encapsulating PCM and embedding them into construction materials was investigated by Shi et al. A naturally ventilated room benefiting from the installation of PCM was reported to experience a 4°C drop in peak air temperature and a 16% drop in relative humidity compared to the same room without PCM. A composite PCM wall system was studied by Diaconu et al. in an air conditioned building located in a continental climate, and annual energy savings of 12.8% and a 35.4% reduction in peak cooling load were reported.

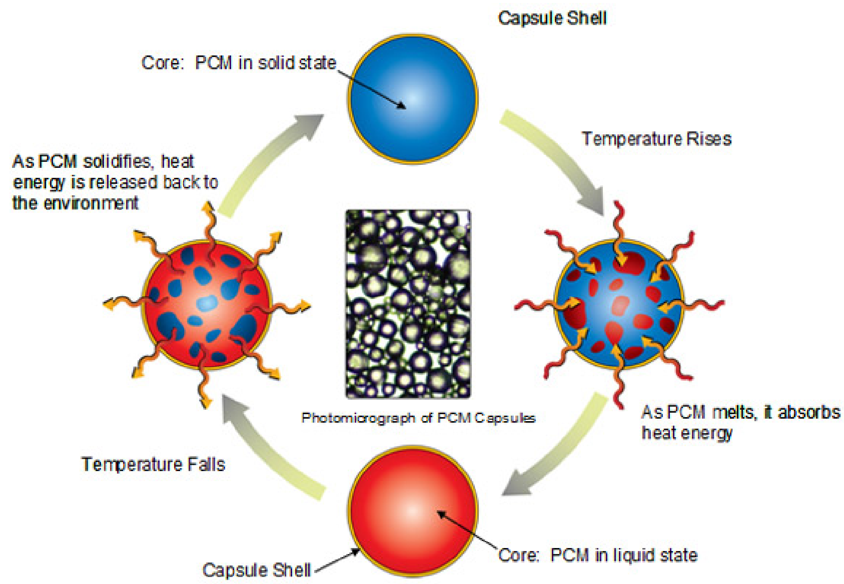

Figure 48: Mechanism of Phase Change Materials

The mean indoor air temperature for the entire study building, with and without PCM, using the 'current' weather data is illustrated in figure below for the month of August. CIBSE Guide A recommends an indoor comfort temperature of 25°C and it is evident that both datasets exceeded this value regularly. However, the effect of the PCM has been to reduce the magnitude of the peak daytime temperatures thus maintaining the indoor conditions closer to the recommended ideal value. The night time temperatures are also noticeably higher for most of the month when using PCM, subsequently the indoor air temperature is observed to fluctuate within a narrower range with the use of PCM.

Incorporating the PCM into the case study building would have a financial cost. Therefore, understanding where best to install the PCM (i.e. into which surfaces) for the optimal financial return is important. In order to assess this the PCM was sequentially modelled on the inward facing surfaces of the following construction components; external walls, partition (internal) walls, roof, floor and ceiling.

There are many different reasons to want to control the amount of sunlight that is admitted into a building. In warm, sunny climates excess solar gain may result in high cooling energy consumption; in cold and temperate climates winter sun entering south-facing windows can positively contribute to passive solar heating; and in nearly all climates controlling and diffusing natural illumination will improve day lighting.

Well-designed sun control and shading devices can dramatically reduce building peak heat gain and cooling requirements and improve the natural lighting quality of building interiors. Depending on the amount and location of fenestration, reductions in annual cooling energy consumption of 5% to 15% have been reported. Sun control and shading devices can also improve user visual comfort by controlling glare and

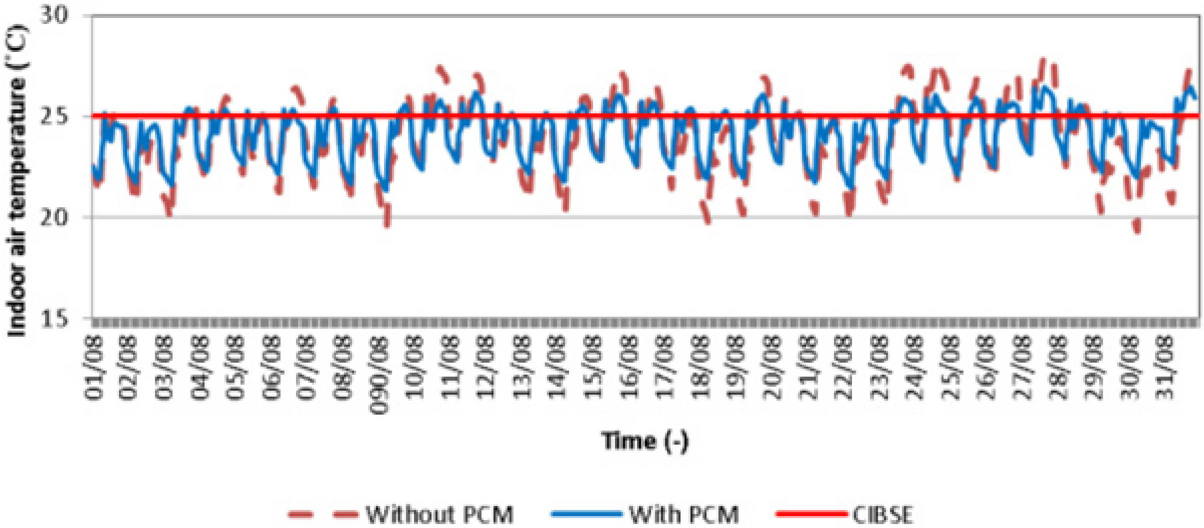

Figure 49: Predicted indoor air temperature for the case study model with and without PCM

reducing contrast ratios. This often leads to increased satisfaction and productivity. Shading devices offer the opportunity of differentiating one building facade from another. This can provide interest and human scale to an otherwise undistinguished design.

The use of sun control and shading devices is an important aspect of many energy-efficient building design strategies. In particular, buildings that employ passive solar heating or day lighting often depend on well-designed sun control and shading devices.

During cooling seasons, external window shading is an excellent way to prevent unwanted solar heat gain from entering a conditioned space. Shading can be provided by natural landscaping or by building elements such as awnings, overhangs, and trellises. Some shading devices can also function as reflectors, called light shelves, which bounce natural light for daylighting deep into building interiors.

The design of effective shading devices will depend on the solar orientation of a particular building facade. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer.

Exterior shading devices are particularly effective in conjunction with clear glass facades. However, high-performance glazings are now available that have very low shading coefficients (SC). When specified, these new glass products reduce the need for exterior shading devices. Thus, solar control and shading can be provided by a wide range of building components including:

- Landscape features such as mature trees or hedge rows;
- Exterior elements such as overhangs or vertical fins;
- Horizontal reflecting surfaces called light shelves;
- Low shading coefficient (SC) glass; and,
- Interior glare control devices such as Venetian blinds or adjustable louvers.

Fixed exterior shading devices such as overhangs are generally most practical for small commercial buildings. The optimal length of an overhang depends on the size of the window and the relative importance of heating and cooling in the building.

Figure 50: Aluminum architectural sun shade, horizontal sun control device, vertical fins

In the summer, peak sun angles occur at the solstice on June 21, but peak temperature and humidity are more likely to occur in August. Remember that an overhang sized to fully shade a south-facing window in August will also shade the window in April when some solar heat may be desirable.

Given the wide variety of buildings and the range of climates in which they can be found, the following design recommendations generally hold true:

1. Use fixed overhangs on south-facing glass to control direct beam solar radiation. Indirect (diffuse) radiation should be controlled by other measures, such as low-e glazing.

2. To the greatest extent possible, limit the amount of east and west glass since it is harder to shade than south glass. Consider the use of landscaping to shade east and west exposures.

3. Do not worry about shading north-facing glass in the continental United States latitudes since it receives very little direct solar gain. In the tropics, disregard this rule-of-thumb since the north side of a building will receive more direct solar gain. Also, in the tropics consider shading the roof even if there are no skylights since the roof is a major source of transmitted solar gain into the building.

4. Remember that shading effects daylighting; consider both simultaneously. For example, a light shelf bounces natural light deeply into a room through high windows while shading lower windows.

5. Do not expect interior shading devices such as Venetian blinds or vertical louvers to reduce cooling loads since the solar gain has already been admitted into the work space. However, these interior devices do offer glare control and can contribute to visual acuity and visual comfort in the work place.

6. Study sun angles. An understanding of sun angles is critical to various aspects of design including determining basic building orientation, selecting shading devices, and placing Building Integrated Photovoltaic (BIPV) panels or solar collectors.

7. Carefully consider the durability of shading devices. Over time, operable shading devices can require a considerable amount of maintenance and repair.

8. When relying on landscape elements for shading, be sure to consider the cost of landscape maintenance and upkeep on life-cycle cost.

9. Shading strategies that work well at one latitude, may be completely inappropriate for other sites at different latitudes. Be careful when applying shading ideas from one project to another.

The science of daylighting design is not just how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects. Beyond adding windows or skylights to a space, it involves carefully balancing heat gain and loss, glare control, and variations in daylight availability. For example, successful daylighting designs will carefully consider the use of shading devices to reduce glare and excess contrast in the workspace. Additionally, window size and spacing, glass selection, the reflectance of interior finishes, and the location of any interior partitions must all be evaluated.

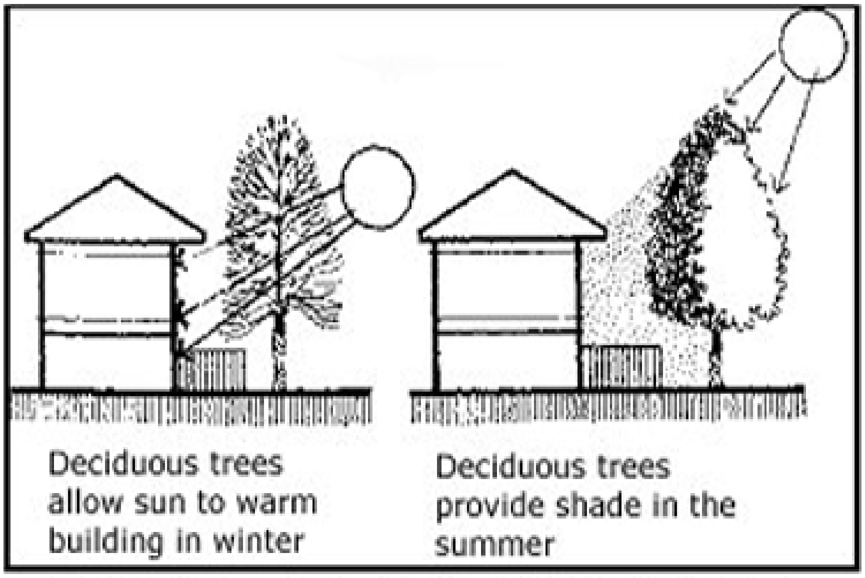

Figure 51: Examples of side landscape features that help to conserve energy

A daylighting system consists of systems, technologies, and architecture. While not all of these components are required for every daylighting system or design, one or more of the following are typically present:

- Daylight-optimized building footprint
- Climate-responsive window-to-wall area ratio
- High-performance glazing
- Daylighting-optimized fenestration design
- Skylights (passive or active)
- Tubular daylight devices
- Daylight redirection devices
- Solar shading devices
- Daylight-responsive electric lighting controls
- Daylight-optimized interior design (such as furniture design, space planning, and room surface finishes).

Since daylighting components are normally integrated with the original building design, it may not be possible to consider them for a retrofit project.

If possible, the building footprint should be optimized for daylighting. This is only possible for new construction projects and does not apply to retrofits. If the project allows, consider a building footprint that maximizes south and north exposures, and minimizes east and west exposures. A floor depth of no more than 60 ft., 0 in. from south to north has been shown to be viable for daylighting. A maximum facade facing due south is the optimal orientation. Deviation from due south should not exceed 15° in either direction for best solar access and ease of control.

A high-performance glazing system will generally admit more light and less heat than a typical window, allowing for daylighting without negatively impacting the building cooling load in the summer. This is typically achieved through spectrally-selective films. These glazings are typically configured as a double pane insulated glazing unit, with two 0.25 in. (6 mm) thick panes of glass that are separated by a 0.50 in. (12 mm) air gap. This construction gives the insulated glazing unit a relatively high insulation rating, or R-value, as compared to single pane glass. A low-emissivity coating is also often part of these high-performance glazing units, which further improves the R-value of the unit.

In addition to the considerations above regarding windows, a daylighting-optimized fenestration design will increase system performance. The window has two essential functions in a daylit building: (1) daylight delivery or admittance, and (2) provision of view to the occupants. The former dictates a glazing with a very high visible light transmittance (commonly abbreviated as VLT, or Tvis), the latter merely needs to be clear, and, in fact, should have a relatively low Tvis to prevent glare. As a general rule, the higher the window head height, the deeper into the space the daylight can penetrate. Therefore, good daylighting fenestration practice dictates that the window should ideally be composed of two discrete components: a daylight window and a view window. The daylight window should start at 7 ft., 6 in. above the finished floor at a minimum and have a high Tvis (50% to 75%); the view window should be placed lower and have a Tvis of less than 40% in most climates.

Many daylighting designs will employ skylights for toplighting, or admitting daylight from above. While skylights can be either passive or active, the majority of skylights are passive because they have a clear or diffusing medium (usually acrylic) that simply allows daylight to penetrate an opening in the roof. They are often comprised of a double layer of material, for increased insulation. Active skylights, by contrast, have a mirror system within the skylight that tracks the sun and are designed to increase the performance of the skylight by channeling the sunlight down into the skylight well. Some of these systems also attempt to reduce the daylight ingress in the summer months, balancing daylighting with cooling loads.

Tubular daylight devices are another type of toplighting device. These devices employ a highly reflective film on the interior of a tube to channel light from a lens at the roof, to a lens at the ceiling plane. Tubular daylight devices tend to be much smaller than a typical skylight, yet still deliver sufficient daylight for the purpose of dimming the electric lighting.

Daylight redirection devices take incoming direct beam sunlight and redirect it, generally onto the ceiling of a space. These devices serve two functions: glare control, where direct sun is redirected away from the eyes of occupants, and daylight penetration, where sunlight is distributed deeper into a space that would not be allowed otherwise. Daylight redirection devices generally take one of two forms: a large horizontal element, or louvered systems. Horizontal daylight redirection devices are often called lightshelves.

As mentioned previously, the windows must be carefully designed to control the solar gains and potential glare stemming from a daylighting design. To this end, solar shading devices are often employed-particularly on the view windows-to minimize the amount of direct sun that enters the space. These are typically called overhangs.

Daylight-responsive electric lighting controls are absolutely essential to any daylighting system. No daylighting design will save any energy unless the electric lights are dimmed or turned off when there is sufficient illumination from daylight. Indeed, if daylighting features such as windows and skylights are not paired with daylighting functionality such as daylight-responsive dimming controls, then the daylighting-enhanced building will more than likely use more energy, not less, than a comparable building without any daylighting features. Daylight-responsive lighting controls consist of continuous dimming- or stepped-ballasts in the light fixtures, and one or more photocells to sense the available light and dim or turn off the electric lighting in response.

An often overlooked element in a successful daylighting design is the interior design. A daylight-optimized interior design considers furniture design, placement, and room surface finishes with respect to daylight performance. For example, office cubicle partition heights will be limited, particularly those running parallel to the south facade, enclosed offices will be kept to a minimum, and walls and ceilings will be as highly reflective as possible, to help “bounce” and distribute the redirected daylight more fully. By positioning work surfaces at a distance from the south facade, solar control is easier with smaller solar shading devices than if a desk or office is placed directly against the south facade. This concept is illustrated in the following figure, and shows how a relatively small overhang provides full direct seasonal solar protection to the workspace. The area immediately adjacent to the south facade is circulation space.

Daylighting is an energy-efficient strategy that incorporates many technologies and design philosophies. It

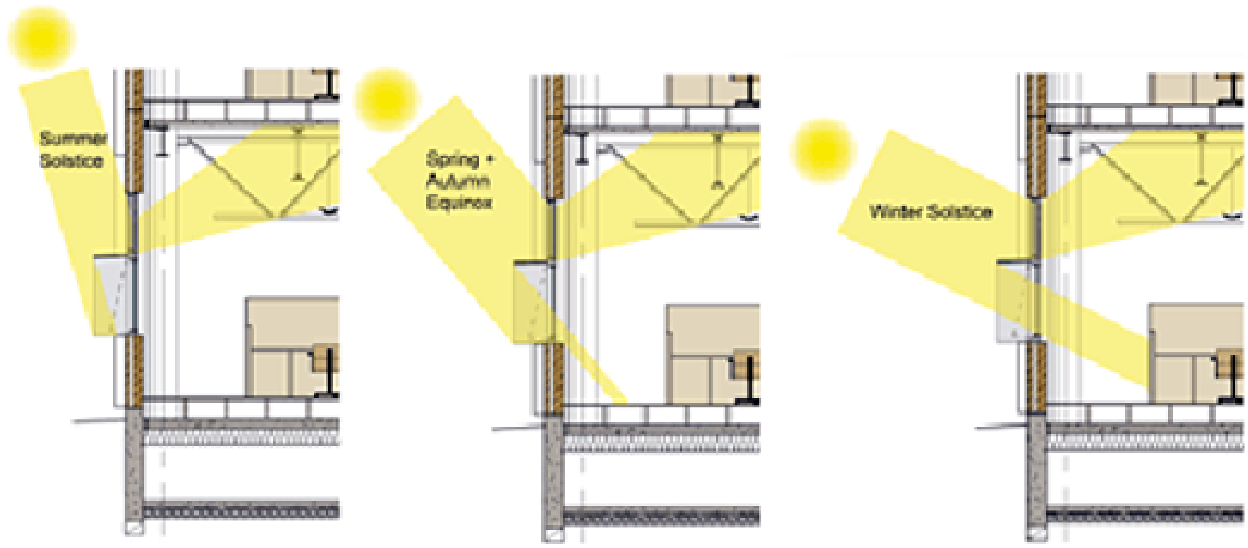

Figure 52: Seasonal performance of shading, redirection devices.

is not a simple line item, and can vary tremendously in scope and cost. Many elements of a daylighting implementation will likely already be part of a building design or retrofit (e.g. windows and light fixtures), but a successful daylighting system will make use of the following technology types and construction methods:

· **Exterior shading and control devices.** In hot climates, exterior shading devices often work well to both reduce head gain and diffuse natural light before entering the work space. Examples of such devices include light shelves, overhangs, horizontal louvers, vertical louvers, and dynamic tracking of reflecting systems.

· **Glazing materials.** The simplest method to maximize daylight within a space is to increase the glazing area. However, three glass characteristics need to be understood in order to optimize a fenestration system:

- U-value: represents the rate of heat transfer due to temperature difference through a particular glazing material.
- Shading coefficient: a ratio of solar heat gain of a given glazing assembly compared to double-strength, single glazing. (A related term, solar heat gain coefficient, is beginning to replace the term shading coefficient.)
- Visible transmittance: a measure of how much visible light is transmitted through a given glazing material.

Glazings can be easily and inexpensively altered to increase both thermal and optical performance. Glazing manufacturers have a wide variety of tints, metallic and low-emissivity coatings, and fritting available. Multi-paned lites of glass are also readily available with inert-gas fills, such as argon or krypton, which improve U-values. For daylighting in large buildings in most climates, consider the use of glass with a moderate-to-low shading coefficient and relatively high visible transmittance.

· **Aperture location.** Simple sidelighting strategies allow daylight to enter a space and can also serve to facilitate views and ventilation. Typically, the depth of daylight penetration is about two and one-half times the distance between the top of a window and the sill.

· **Reflectances of room surfaces.** Reflectance values from room surfaces will significantly impact daylight performance and should be kept as high as possible. It is desirable to keep ceiling reflectances over 80%, walls over 50%, and floors around 20%. Of the various room surfaces, floor reflectance has the least impact on daylighting penetration.

· **Integration with electric lighting controls.** A successful daylighting design not only optimizes architectural features, but is also integrated with the electric lighting system. With advanced lighting controls, it is now possible to adjust the level of electric light when sufficient daylight is available. Three types of controls are commercially available:

- Switching controls: on-and-off controls that simply turn the electric lights off when there is ample daylight.
- Stepped controls: control individual lamps within a luminary to provide intermediate levels of electric lighting.
- Dimming controls: continuously adjust electric lighting by modulating the power input to lamps to complement the illumination level provided by daylight.

Any of these control strategies can, and should, be integrated with a building management system to take advantage of the system's built-in control capacity. To take full advantage of available daylight and avoid dark zones, it is critical that the lighting designer plan lighting circuits and switching schemes in relation to fenestration. The following figure shows control scheme types.

· **Other lighting control schemes.** In addition to daylight controls, other electric lighting control strategies should be incorporated where they are cost effective, including the use of:

o Occupancy controls: using infrared, ultrasonic, or micro-wave technology, occupancy sensors respond to movement or object surface temperature and automatically turn off or dim down luminaries when rooms are left unoccupied. Typical savings have been reported to be in the 10% to 50% range depending on the application.

Timers: these devices are simply time clocks that are scheduled to turn lamps or lighting off on a set schedule. If spaces are known to be unoccupied during certain periods of time, timers are extremely cost-effective devices.

Chapter 3. Examples of climate responsive architectures

3.1 Case of study: Bayt El-Suhaymi

Location: Cairo, Egypt, North Africa

Climate: Dry-hot. Little rain and high daily temperature range

Description: Suhaymi house is a traditional islamic/vernacular architecture house that was built in the year 1648, with a floor area of 2000 m2. It lies in the heart of Cairo city, and is now owned by the Egyptian government and used as a museum

Materials: Stone, bricks.

Strategies: It has heavy bearing walls of brick & stone and roofs that are marked with their thermal resistance properties. Openings to the outside are very small and shaded, which protect the building from the strong sun. The decorated wooden grillage (Mashrabiya) allows the needed amount of light to penetrate without overheating. The means of cross-ventilation exist, while being able to trap the cool airflow through the water fountain and courtyard garden. Balconies are facing the inside, which are mostly shaded during the day, allowing the cooled air in through pressure difference. Different Halls were used for winter and summer according to their orientation(pla)

3.2 Case of study: New AUC Campus

Location: Cairo, Egypt, North Africa

Figure 53: Bayt El-Suhaymi internal hall view (wik, b)

Figure 54: Bayt El-Suhaymi envelope composition with local materials(stone-bricks) (wik, b)

Climate: Dry-hot. Little rain and high daily temperature range

Description: The American University Campus in Cairo (AUC) is designed based on traditional architecture criteria. It was built in the year 2008, covering 46,000 acres of land, and lies on the outskirts of Cairo.

Materials: Stone, marble and granite

Strategies: Sandstone walls reduce the cooling demand through their high thermal mass. All offices have the possibility to be naturally ventilated, and also have natural daylighting. The mechanical ventilation uses a chilled water system, which is 40% provided by co-generation power method. 27 water fountains increase the relative humidity, cooling the dry micro-climate of the campus. Even though studies have been conducted to install renewable energy on the buildings, all of the energy is from fossil fuels. The building orientation and density is also doubted and could have been improved.(pla)

3.3 Case of study: Malvern Hills

Figure 55: New AUC envelope configuration view (arc, a)

Figure 56: New AUC campus natural daylighting sources (cai)

Location: Worchestershire, United Kingdom

Climate: Temperate oceanic climate

Description: Malvern Hills Science Park, located in picturesque rural Worcestershire, is the unlikely home to Qinetiq, a leading international defence and security technology company and supplier of defence research to the UK Government. As a reection of the parks commitment to cutting-edge technology and to accommodate growing interest in its facilities, a groundbreaking sustainable energy building, Phase , was completed in June . Supported by funding from Advantage West Midlands, the Regional Development Agency, and the European Regional Development Fund, Phase is a benchmark for low carbon development in the West Midlands. It won the Excellence in Property Design Award, including contribution to environmental sustainability and innovation in design, from the UK Science Park Association.

Materials: Concrete, Aluminium Facades.

Strategies: Externally, the buildings envelope has a homogenous skin, sealed and insulated with an aluminium rainscreen facade. An array of Colt exterior sun louvres are mounted as brise soleil, shading the south elevation during the heat of the day, while allowing full outward views.In addition to the brise soleil, Colt designed and installed a sun-tracking louvre system adjacent to the bistro. This creates both visual impact and an energy efcient way to provide solar shading, harnessing the power of the sun to keep the building cool.

Six enormous vertical fins, each measuring 2.5 m wide x 10.5 m high, rotate slowly through the day to track the movement of the sun. Each blade consists of an upper section made of Shadotex louvre comprising. Ferrari fabric, stretched over an aluminium support frame, which absorbs and repels up to of the heat of the suns rays, thereby reducing cooling loads. The lower section is made of Shadometal perforated metal louvres. In the Malvern Hills Science Park in the UK, where large fins rotate slowly through the day to track the movement of the sun using thermo-hydraulic drives.

Figure 57: Malvern Hill Science Park

3.4 Case of study: Glaxo Wellcome House West

Location: West London, United Kingdom

Climate: Temperate oceanic climate

Description: A new building was required on the Greenford campus of Glaxo Welcome to consolidate operations, and serve as a headquarters building for the newly merged company. The architects were commissioned in August 1995, with a start on site in March 1996, and occupation in December 1997.

Materials: Reinforced concrete frame with terracotta tiles

Strategies: Occupant glare is reduced by automatic roller blinds that are activated by daylight sensors. Motorized dampers, which open and close automatically according to weather conditions and the desired thermal effect, moderate temperatures in the ventilated double skin. In the winter, the sun is low and the heat produced, if any, is beneficial. The dampers at the top and bottom of the double skin are kept closed and the cavity acts as a warm 'blanket' to the building for increased thermal insulation. The cloak of warm air also reduces heat loss at nighttime.

In the summer, air is let into the double skin cavity at the bottom, and out at the top, through motorized dampers that ventilate the cavity and keep temperatures down. The summertime effect creates a cavity that

Figure 58: Close up of the sun tracing aluminium fins

Figure 59: View from inside the Malvern Hill building

intercepts solar gain and protects office spaces from direct insolation. It encloses and protects additional shading devices, louvres and walkways. These fixed elements absorb heat from solar gain, creating air currents, which draw in cool air from low level. Cool air is warmed as it extracts heat from the louvres and walkways and heat gains through insolation are expelled from the cavity at high level.

Figure 60: The thermo-hydraulic drivers animating the fins

Figure 61: Glaxo Wellcome House West

Figure 62: Double skin facade

Figure 63: Facade control system

Figure 64: View of the facade from outside

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