Energy Efficiency in Building Design

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Abstract

Energy is the prime mover of life. It is the core of any activity in buildings. Although energy production and building technology have made great achievements in energy efficiency, today we have still come to use more and more energy in buildings than our forefathers. Today's improved quality of life comes at a 'price'. In general greater environmental concern is being expressed for global warming and the security of energy supply for generations to come. Developed countries - although admittedly the greater energy consumers - have also made great steps in this direction, with significant results for the community - but what about Malta?

Introduction

This paper gives an overview of potential energy losses in modern buildings in Malta as it points out some DO's and DON'Ts in construction and energy management. It highlights the importance of cavity insulation, double glazing and planning norms among other parameters, distinguishing between embodied energy and energy in use in buildings. Finally the use of alternative sources of energy is advocated, which when combined with passive solar design, would yield to a holistic energy efficient building.

1. Thermal Comfort & Life style

Today we spend 80% of our lives indoors. We are also verging to spend 100% of this time in controlled environments. Nowadays we work in air conditioned offices, live in air conditioned houses, driving from one to the other in air conditioned cars. It is often claimed that we may be gradually loosing our sense of adaptation as we demonstrate a narrower tolerance range for varying indoor environmental conditions. This is more typically the case with the colder countries on the globe. Higher expectations in thermal comfort standards verge towards energy wastage.

However in a Mediterranean lifestyle living outdoors is part of our social well being. This is nourished by mild winters and hot summers with long cool evenings. The fairly predictable summers, combined with availability of local material are the grammar for vernacular architecture. This is typically represented by the sun-drenched courtyard and shaded loggia. Traditionally there has always been an accent on keeping buildings cool in summer rather than warm in winter. Average daily temperatures *are* truly increasing over all months. This may be confirmed from Meteorological data analysed over thirty year periods.

With an aim towards retaining a broader adaptation range, a healthier lifestyle and enhanced natural thermal comfort conditions in the design of buildings it is wise to start with some research about our forefathers' understanding of the external environment. In particular this relates the use of indoor spaces with immediate outdoor ambient conditions, better known as the microclimate. This is important for new buildings and just as important when reviving character houses or designing additions to them. It is equally important to understand early construction methods that often expressed both structural requirements as well as latent environmental concerns.

An open courtyard should not be simply covered without careful consideration of its microclimate. This could have adverse effects on the surrounding rooms, namely temperature build-up, retention of high RH (relative humidity) levels and the lack of sufficient ventilation through the building.

In the '60s and '70s the environmental control strategy was to strive for a *climate exclusive* approach, opting for active (energy consuming) environmental systems. Sparked by the energy crisis in the '70s, architects and developers alike became energy conscious in the '80s and '90s. This has inverted the overall strategy in architectural design concepts. Today, instead of a *climate exclusive* approach most architects opt for a *climate inclusive* design, relying on natural ventilation, building shape and orientation as the salient features to control the indoor environment.

Malta's land resource has long been on a one-way road, diminishing the natural countryside, converting it into a solid building mass, consuming yet another natural resource – globigerina limestone. Considering that more than a staggering 22% of our Island is already built up, politicians and town planners need to be more vigilant on land use. Gone should be those days when every citizen demanded, almost by right, a plot of land from the Government of the day, the patch where he spends all his time, energy and savings, to build his life-long abode. Private speculation has also contributed to the present sprawl of development, merging towns into one building mass. This has in turn brought with it a high degree of embodied energy in construction and later in use.

New building schemes should place an accent on higher density of development. These are to include more flats, maisonettes and terraced houses as opposed to bungalows on single *tumolos* of land. Apart from the erosion of our land resource, the lower height to width ratio of our street sections has eliminated sheltered walkways. This also increases surface temperatures calling for greater cooling loads. The same may be said in winter when greater heat losses occur through unsheltered walls and large glazed areas. In general compact planning should also be encouraged.

Excessively broader streets should be avoided in new town planning schemes. The car has become the central planning parameter. This has brought about the introduction of wider streets, combined with front gardens, which are seldom landscaped. All this has sadly eliminated any possible shading from our streetscape, so typical in village cores. We are gradually loosing the notion of thermal comfort by natural means.

2. *Concept Design Approach*

The environmental design strategy should be the springboard of architectural concepts. New ideas can only germinate through an all round awareness of energy use in buildings, both to construct and to run, benefiting both the developer and the end-user alike.

When building on a green site or refurbishing an existing building for re-use, site orientation needs to be given its due importance. Planning disposition should be considered with respect to standard bearings. Consideration is to be given to north - south exposure for enhancing adequate ventilation and solar gains for summer and winter respectively.

Indoor spaces need to be oriented with a sensitivity to their light level requirements relative to the use of the space, with openings adequately sized accordingly. Natural lighting is also influenced by depth of plan and internal planning. Any space deeper than 6m in plan will require an artificial lighting supplement during daytime.

Large glazed areas facing south should be avoided, especially for habitable spaces. When subject to excessive solar gains these quickly fall for air conditioning. This is particularly critical for showrooms and other ‘state of the art’ commercial buildings or large voluminous spaces (e.g./ hotel foyer). Environmental concerns should override aesthetic and prestige priorities.

Heights of surrounding buildings cannot be ignored. These may have an influence on the quality of light and desirable solar gains replenishing habitable rooms with sunny spells across the short but cold winter season. Size and position of openings relative to the immediate environment is therefore very important.

Adjacent buildings can also give a good forecast of indoor conditions. Studies of similar buildings are also a design aid. A good starting point would be to compare building type, footprint area, number of occupants and energy consumption per annum. This is better known as the *energy rating* of a building. Most international design competitions are today judged by this criterion. It is already an indication of the energy consumption in operation. Similar buildings should give an indicative benchmark for budgeting *energy running costs* of the new building.

For any building one critical parameter affecting its energy consumption is the surface area to volume ratio, since energy gains/losses (cooling and heating) are dependent on the overall exposed wall and roof surface areas.

3. Embodied Energy

Buildings consume energy in two phases. Initially energy is needed to fabricate a building's components and erect it on site. This is termed as the *embodied energy* of the building, considered as that phase which includes constructing, servicing and finishing until commissioning. The second phase is the *energy in use* where the energy consumed to run the building is considered. Through a greater awareness of potential energy losses, today architects have realised that a nominal capital investment in construction results in a greater long-term saving in running costs.

3.1 Building Construction

Energy-sensitive detailing in construction needs careful consideration at an early design stage. This is particularly important in the local scenario. In general energy losses through a standard dwelling occur as follows:

Building Component	***% Energy Losses***
Roofs:	35%
Walls :	25%
Floors:	15%
Windows:	15%
Draughts:	10%

This naturally varies according to site parameters and volume to surface area ratio among other factors. A basic understanding of elemental heat transfer mechanism is therefore important. This is outlined herewith.

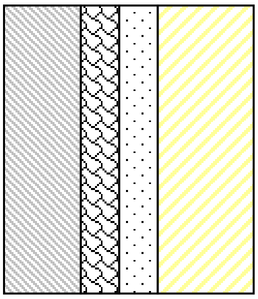
The rate with which heat H, flows over time t, through a material depends on the type of material k, its area A and thickness l, and the temperature difference δT:

$$dH / dt = kA\delta T / l$$

where k is the thermal conductivity of the material. In practice architects deal with a material of known thickness l, hence it is easier to look at the U-value of that material [units: $W/m^2{}^{\circ}C$]. When combining different materials we simply add the Resistances R (1/U), but not the U-values. This characteristic also determines the rate of energy (heat) flow. This is given by :

$$Q = UA\delta T \qquad \text{[units: Watts]}$$

A simple U-value calculation is illustrated as follows:



SUMMER: External: 35°C Internal: 21°C
WINTER: External: 07°C Internal: 21°C

180 / 50 / 50 / 230mm
blockwork / insulation / air / masonry

respective thermal conductivity values are:

k = 0.19 / 0.04 / 0.84 / 0.696 W/m°C

blockwork resistance, $R_b = \frac{0.180}{0.190} = 0.947\ m^2{}^\circ C/W$

insulation resistance, $R_i = \frac{0.050}{0.040} = 1.25\ m^2{}^\circ C/W$

air resistance, R_a (standard) $= 0.18\ m^2{}^\circ C/W$

masonry resistance, $R_m = \frac{0.230}{0.696} = 0.331 m^2{}^\circ C/W$

TOTAL WALL Resistance, $R_{wall} = \Sigma [R_b + R_i + R_a + R_m]$
$= 2.708\ m^2{}^\circ C/W$

TOTAL WALL Transmittance, $\mathbf{U_{wall} = 1 / R_{wall} = 0.369\ W/m^2{}^\circ C}$

UNIT energy gained,

$Q = UA\delta T$
$Q = 0.369*1.0*(14)$
$= 5.17\ W / m^2$

For a typical terraced house the front room's external wall could be 5.80 x 3.0m. This results in an energy loss/gain of **90W** from the wall alone as a first approximation. Similarly this could be worked for different components for each different space of the building to estimate the aggregate energy losses.

Typical U-values for the local globigerina limestone skins are shown in the following table(different combinations may be worked as illustrated above):

Wall Construction	**Composite U-value**
150 / 25 / 230mm, cavity unventilated	1.11 W/m^2 °C
150 / 25 / alum foil / 230mm, cavity unventilated	0.74 W/m^2 °C
150 / 25 exp.polystyrene / alum foil / 25 / 230mm	0.47 W/m^2 °C
150 / 25 exp.polystyrene / alum foil / 25 150mm	0.52 W/m^2 °C

Note the significant difference in the U-value by using a reflective aluminium foil

Based on the above calculations and earlier research by the author, the following general recommendations may be picked up as design cues by the discerning architect:

DO insulate external double walls with a minimum of 50mm high density expanded polystyrene or equivalent. Thickness decision should be calculated for each case. This is predominantly based on building material/s used, its thickness, cavity size as well as the surface texture.

DO NOT assume same insulation levels throughout a building. Do not ignore the use of the adjoining indoor and outdoor spaces as these all have an effect on the overall thermal performance of the building. Circulation corridors and other secondary spaces can have a mediating effect on principal usable spaces. Shading and sheltering devices can also influence the surface temperature of a wall by reducing solar gains in summer and convective heat losses in winter.

DO insulate concrete roofs, typically flat in Malta, with a minimum of 100mm high density expanded polystyrene or an equivalent material. Same conditions for walls apply.

DO NOT cast a concrete roof slab *across* a cavity into the external wall surface. This induces thermal bridging of heat through the butt end of the slab. It also gives rise to water penetration and spalling concrete. Bridging the cavity reduces its effect apart from breaking up any insulation present.

DO plant evergreen trees close to south walls or creepers. Landscaping reduces the surface temperature of external walls which in turn has an effect on immediate spaces, apart from appraising the natural environment.

DO not exclude the possibility of having an additional temporary roof structure such as a trellis with vegetation or some other device forming an air gap to shade the roof finish, yet allowing air movement. Once more this reduces surface temperatures on a critical surface, since roofs are exposed to solar radiation for the best part of a sunny day unlike walls, which are normally subject to solar exposure for only a portion of the day, depending on their orientation or shading from surrounding buildings.

3.2 Elements & Finishes

Careful detailing is necessary, particularly for openable elements and at joints where different materials meet. For improved energy efficiency there should be an underlying awareness towards draft proofing against thermal losses. This also helps to reduce unwanted noise levels from external environments.

Good quality finishes, apart from their aesthetic appraisal of the building, can also have a significant effect in curtailing energy losses. This could occur indirectly through rising damp, cold bridging and rain water ingress. Careful detailing at transition joints between different materials or around elements is equally important in determining such losses.

DO design and specify a rubber gasket around timber and aluminium doors and windows. This reduces heat ingress into air-conditioned spaces in summer and cuts down on cold air infiltration in heated spaces in winter.

DO NOT however ignore minimum ventilation requirements. These are subject to the use of the building or its individual spaces. Specifications exist for air change rates for different uses. A minimum air infiltration is required in all cases to ensure a constant supply of fresh air for basic human needs.

DO detail and specify seals around frames of retrofitted doors and windows. Air gaps are often left unsealed or simply pointed or sealed with silicone as a filler. Non-uniform dimensions between the masonry and the element are often irregularly filled.

DO NOT choose dark coloured finishes for external south facing walls. A white or light coloured surface does not only reflect heat but also enriches the quality of reflected light. The same may be said for roof finishes, particularly for the choice of a roof protection membrane.

DO aim to minimise the moisture content of local stone and any other building material. Sanitary laws dictated the use of hot bitumen to isolate masonry below and above ground floor, today replaced by improved materials with minimum site labour involved. At ground floor the damproof course should be properly detailed with a skirting using an impermeable bonding agent. Rising damp reduces surface and air temperatures in winter. Exposed party walls requiring an impermeable treatment should not have the odd bituminous coating applied throughout as this acts as a ‘black body’ attracting the much unwanted heat gains in summer. A carefully selected finish should be applied or an alternative weather protection considered.

DO specify double-glazing for an air-conditioned environment. This is particularly important where large glazed areas are a design prerequisite (ex/ showrooms or commercial premises). The tendency is that the large spans of today’s frame structures increase the permissivity of large glazed areas, often considered as a prestige upmarket corporate image for an upmarket company. High-tech reflective glass still transmits a good degree of solar gains/losses, increasing the cooling/heating loads on environmental systems.

DO NOT design for large glazed areas for office buildings, especially for south and west facing elevations. Apart from the greater capital costs there is also a notable increase in the running costs of such buildings. Integrating these office buildings as per upcoming trends will eventually cause an indelible demand on the national grid.

DO consider the use of shading devices. These could be either fixed as part of the building (cantilevered overhang, louvers), or temporary, fitted after the building is finished and occupied (awning, blinds). The latter often come as an afterthought. These should not only be used in extreme cases where large glazed areas are absolutely necessary (showrooms) but generally for south facing openings. Ideally this should be thought of at an early design stage. A careful study of orientation should quickly reveal the problem areas, such as the setting sun on a west elevation. Vertical protection is then needed.

DO NOT opt for glazed elements that are flush with the external building line. These give no solar protection from the depth of the wall. Avoid internal shading devices; these are often improvised as an afterthought (louvers on the inside, vertical blinds, curtains). These only give nominal protection, as the heat would have already entered the space.

4. Energy in Use

4.1 Building Services

Services are normally considered as sub-ordinate to buildings, as the name implies, serving the indoor environmental needs of the occupants. However it is common practice nowadays that architects and engineers get together at an early design stage to determine the principal design criteria, with other professions running in parallel. Architects have also become wiser in providing for basic requirements for services in their design. This includes provisions for renewable sources of energy just as much as energy conserving measures in construction technology, as outlined above.

DO provide for reasonable space for services in any building. After consulting with the building services engineer/s allowance should be made in the initial planning stage to cater for shafts, under-floor trenches, cable trays in false ceilings, and vertical recesses for ducting or other engineer-specified riser stacks. (The latter will certainly deter the use of passive stacks for services).

DO NOT ignore advice from past users of similar buildings (or the same building in a retrofit). This is often priceless in terms of laying out services. Similarly do not blindly remove or ignore present services. Apart from adopting a recycling principle, these may provide a good guide to new requirements.

DO call in a mechanical/electrical engineer in due time. This is particularly important if the building is not just for domestic use. With today's complex environmental systems, low and high voltage circuits and data systems, it is wise to seek advice from day one of the project. This saves local masonry atrocities in chasing and punctured holes, particularly affecting insulation and the quality of finishes thereafter.

DO NOT design for the minimum sanitary law requirements. Although these seem to be more of a rule of thumb or a necessary evil today, especially with narrowing planning constraints as developers demand more for their own expensive 'slice of Malta'. Always strive for lighting and ventilation parameters to be marginally over and above minimum requirements, otherwise these will have to be remedied at the expenditure of energy.

DO refer to standards and specifications for lighting requirements for different spaces and respective uses. If in doubt seek expert advice such that window sizing for natural light is not overdone. Excess light may result in discomfort or disability glare. In worst cases artificial lighting may then be preferred during daytime, calling an additional energy demand which could have been avoided at design stage. [This is typically the case with school buildings and open plan offices in Malta].

DO insulate all hot water pipe work leading from the hot water heater to all discharge points including roof installations. This should include both covered pipes under tiles and plastering as well as in shafts. Heat losses occur in both instances. Such insulation should be to the right specifications and regular inspections and preventive maintenance should be encouraged.

4.2 Energy Management

Energy audits are not too different from financial audits. Essentially these involve regular energy monitoring, typically annually or quarterly if there is a seasonal use of energy. Energy bills in Maltese Liri (and consumption in kWh) are compared and charted to closely analyse trends in energy demand such that forecasts can be made for the same quarter next year or beyond.

This is being done regularly on a national level by Enemalta to forecast demand and the fuel supply needed to energise the grid. There is no reason why this cannot be done at a local level within a building, be it industrial, commercial or domestic, be it complex or simple. After a reasonable period of monitoring, trends can be observed - ideally over a number of years - and energy wastage can be localised such that timely action may be taken. This is energy management at its best.

It is very important to research precedent studies of similar buildings, observing their energy demands over the years. These normally have a story to tell in terms of changes of use and the respective lifecycles. Historic buildings also give an indication as to lifestyle and comfort standards and the respective environmental considerations of the day. Energy wastage and past mistakes may be observed, to be avoided in refurbishments or new build.

DO NOT lump all the energy consumption beyond the 'doorstep' under one meter. If this is the case there is no way that one can identify space heating loads from hot water systems, or lighting from power loads. Ideally one should fit an energy meter on every circuit (this measures units consumed directly in kWh). Knowing the rate of electricity, particularly in Malta where to date we have a flat day and night rate, one can easily identify where most of the electrical energy is going. Very often the decisions involved will not call for any strenuous sacrificial changes to comfort and lifestyles.

DO NOT simply buy household appliances at lowest prices. Very often the cheapest *buying* price carries with it the dearest *running* cost. Do look for energy labels, located at the back, giving the 'Wattage' of the appliance. EU standards require classification of manufacturers own products to standard 'colour coded energy labels'. This aims to ensure high quality products with high energy efficiency at competitive prices on the market.

Appliances may also be metered individually to compare their label-specified Wattage with actual consumption. This may alert us to rectify any anomalous drops in efficiencies.

DO seriously consider the use of different fuel types. Primary sources of energy have different calorific values. The choice should be made to have such sources to produce energy *in the form we need it* and *when we need it*. A case in point would be gas for cooking and space heating, electricity for lighting. *The key to energy efficiency is to limit the number of energy transfers to cut down on losses between the primary source and its end use.*

5. Alternative Sources of Energy

Alternative sources of energy refer to all those sources that are an *alternative* to fossil fuels. These include renewable sources. Admittedly some forms, such as photovoltaics, are still considered as 'space technology', often beyond the family budget, yet their unit price is dropping sharply as demand for production increases with the increase in the cost of fossil fuels.

Considerations for their applications are listed in order of feasibility and reachable budget.

DO consider a sloping roof slab for the washroom or stairwell to face a true south orientation where possible. This would be ready to take a solar water heater or photovoltaic panels. This facilitates their installation, which normally takes place at roof level within the same washroom or stairwell area. It will also be easier to have the water tank of the solar water heater indoors thus reducing night losses in winter.

DO NOT limit the hot water plumbing from the conventional electrical water heater to only the bathrooms. Such plumbing should be taken up to roof level foreseeing the option of installing a solar water heater, even if at a later stage. It should ideally be included at the initial stage given the high return for a nominal increase in capital costs (especially when compared to mahogany balustrades on marble staircases in hollow halls).

DO work out payback periods for each model on the market before deciding on which solar water heater to buy. The final decision should not be based on cost but moreover on its efficiency and payback period. This is where earlier energy audits come in handy. Ideally one should have monitored his isolated energy demand for hot water heating as kWh/capita (i.e. energy use per family member). The greater the number of members in a family, the more efficient is the system and the greater is the return on investment.

Once the annual figure is known, given the cost of a SWH, it is easy to work out the number of years over which this will be redeemed. Beyond that date, hot water comes *free* from the sun.

DO NOT choose a model that has a back-up element, otherwise it is very difficult to determine the electricity saved when monitoring. Since such an electric element comes on with a thermostat switch it may either be too sensitive or kept on for most of the time, thus self-defeating the original purpose. The element should either come as an option, be removed or switched off. Locally, given the hours of sunshine in winter a three-day autonomy is guaranteed, i.e. over three consecutive days with an overcast sky, warm water is still ensured. Specifications should till be checked from country of origin to local conditions.

DO NOT shrug off the possibility of having a photovoltaic system. PV arrays are becoming cheaper as production increases. New brands are coming on the market in smaller mountable arrays, which give higher efficiencies at competitive prices. Technological development has also improved the battery bank giving less storage space, less maintenance and longer autonomy. The internet is a good place to start from.

DO therefore consider having a separate DC installation for, say, lighting only. In the event of the installation of a photovoltaic system this works more efficiently on *direct current* where a pre-determined load facilitates the design of the PV system. Although this may not be included in the original design stage a tilted roof structure provides a homogeneous aesthetically pleasing structure.

DO consider a small wind turbine as an option. This may suffice to draw water out of a well. It may complement a PV system across seasonal requirements. While a PV array performs at its best in mild summer conditions, wind turbines are most receptive in winter.

6. Conclusion

Traditional building methods have today made way to modern building technology. Earlier energy conservation measures in buildings were often ingenious and simplistic. These were also robust and hence effective as they required minimal human intervention - if at all - involving zero energy use (e.g./ ventilation stacks). Today’s technology has introduced systems that are intricate and complex which require an ‘expert’ to run and maintain (ex/ Building Maintenance System).

Architects are today faced with a greater challenge. They need to learn how to master the elements to their favour, as our forefathers did, rather than struggle against them as their enemy. At the same time today architects need to marry this knowledge through precedence with today's rapid growing technology, so as to build energy efficient yet comfortable buildings.

Energy demand is ever on the increase. Through globalisation, travel and merging lifestyles people tend to use energy abundantly and expect it to be readily available on demand, at the flick of a switch, yet unaware of its day-to-day implications on the environment and nature's bio-cycles. In general buildings, in construction and use, consume over half of the nation's energy supply.

Energy conservation is however not merely about reducing energy demands from the national infrastructure or energy bills, but it is more about preserving the environment for our offspring. This is the tune of sustainable development.

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