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COST EFFECTIVENESS IN HVAC BY BUILDING ENVELOPE OPTIMIZATION

EFECTIVIDAD EN FUNCIÓN DE LOS COSTOS EN SISTEMAS HVAC A PARTIR DE LA OPTIMIZACIÓN DE LA ENVOLVENTE ARQUITECTÓNICA

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Abstract_

The increased need for thermal comfort in buildings has increased the energy demand for HVAC systems. Building envelope and air conditioning system are closely interrelated; hence building envelope optimization should be the most crucial step towards HVAC load reduction. Building envelope optimization for minimizing heat gains and resultant energy demand involves optimization of building orientation, window-to-wall ratio (WWR), roof, wall, glass and shading devices. This study considers a Net Zero energy Home, a building that matches on-site energy production (through renewable sources such as solar photovoltaic) with on-site energy consumption, located in Delhi (India). For the purpose of analysis a simulation model of the building, created on eQuest energy analysis software, was run parametrically with incremental improvement in envelope parameters to evaluate their impact on building envelope load. The study revealed that, starting from a conventional base model to optimized design case, through step-by-step optimization of building orientation, window-to-wall ratio (WWR), roof, wall, glass and shading devices, percentage reduction in heat load through envelope was approx. 71%. This reduction resulted in lower HVAC load, thus a smaller energy efficient HVAC system was able to cater to the cooling/heating needs of the house.

Resumen_

La creciente necesidad de disfrutar de temperaturas adecuadas al interior de las construcciones ha aumentado la demanda de energía de los sistemas HVAC (sigla en inglés de calefacción, ventilación y aire acondicionado). La envolvente arquitectónica y el sistema de aire acondicionado están estrechamente vinculados; por lo tanto, la optimización del primer factor debe ser la medida de mayor importancia a la hora de reducir la carga de HVAC. La optimización de la envolvente arquitectónica para reducir al mínimo la ganancia de calor y la consiguiente demanda de energía requiere optimizar la orientación del edificio, la relación lleno-vacío (WWR, por sus siglas en inglés), el techo, los muros, los ventanales y los elementos de control solar. Este estudio trata sobre una vivienda "con energía neta cero", una edificación que equipara la producción de energía in situ (mediante fuentes renovables como células solares fotovoltaicas) con el consumo de energía in situ, y que está ubicada en Delhi (India). Para efectos del análisis, un modelo de simulación de la vivienda –creado con el software de análisis de la energía eQuest– se ejecutó en forma paramétrica con mejoras incrementales en los parámetros de la envolvente, con el fin de evaluar su impacto en la carga de la envolvente arquitectónica. El estudio reveló que –a partir de un modelo base convencional hasta el caso del diseño optimizado– la optimización gradual de la orientación del edificio, la relación WWR, el techo, las paredes, los ventanales y los elementos de control solar, redujo la carga térmica en aproximadamente 71% gracias a la envolvente. El resultado de esta disminución fue una menor carga de HVAC, con lo cual se lograron satisfacer las necesidades de calefacción/enfriamiento de la vivienda con un sistema HVAC más pequeño y eficiente en materia de energía.

Palabras clave: construcción con energía neta cero, optimización de la envolvente arquitectónica, reducción de la carga de HVAC
Key words: net zero energy building, building envelope optimization, HVAC load reduction.

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Introduction_

The building sector is one of the largest consumers of energy, consuming almost 45% of global energy for heating, cooling, ventilation and lighting. The ever increasing demand for installation of heating, ventilation & air-conditioning (HVAC) system can be attributed to the increased need for providing thermal comfort in buildings. This has resulted in increased energy demand and higher electricity bills. The increased demand is catered to by conventional sources of energy which is harmful for the environment. In any building, lighting, equipments and HVAC are the primary consumers of energy. The overall energy consumption determines the electricity bill for a building, of which HVAC is the highest component (Fig.1). Hence it is essential to reduce the HVAC load which will not only result in lower energy consumption but also reduced electricity bill.

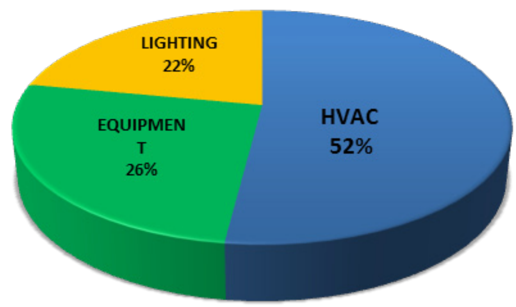

Figure 1: Energy consumption of a building (source: Nishita Badeira).

HVAC load can be classified into two fundamental categories: Internal and external. Internal loads are due to release of heat from heat sources like lights, equipments and occupants, in a conditioned space, while external loads are due to heat gain in a conditioned space from external sources like building envelope and infiltration of outdoor air (Fig.2).

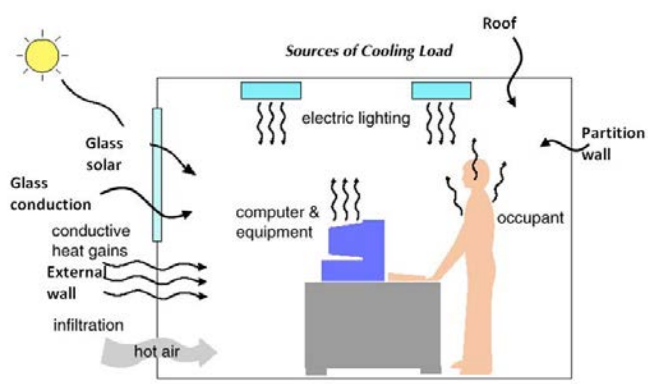

Figure 2: HVAC load components (source: http://www.hku.hk).

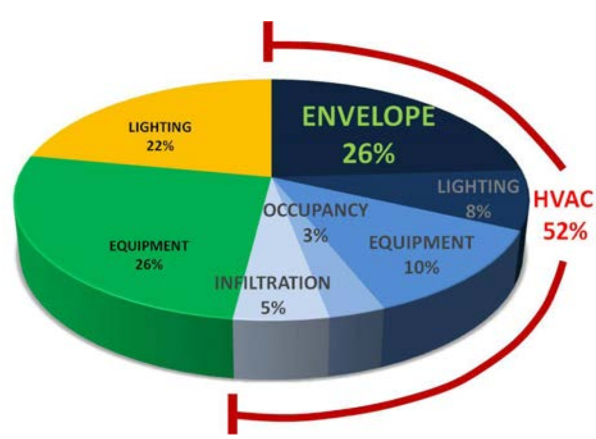

Figure 3: HVAC load breakdown (source: Nishita Badeira).

HVAC load can be decreased by reducing internal loads i.e. using energy efficient lighting, equipments and HVAC system. However, this is not enough. The building envelope is the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating interior temperatures and helps determine the amount of energy required to maintain thermal comfort (Climate Techbook- Building Envelope, 2011).

The pie chart shown in Fig. 3 demonstrates the various components contributing to HVAC load in a residential building. From the pie chart it is clear that building envelope is the largest contributor of heat gains in a building, hence, for reduction of HVAC loads, it is crucial to optimize the envelope.

Total heat gain through envelope is due to conduction gains from roof, wall and windows and solar gains from window glass. Therefore, building envelope optimization for minimizing heat gains involves optimization of building orientation, window-to-wall ratio (WWR), roof, wall, glass and shading devices. The optimization procedure is further explained through a case study of a hypothetical net zero home located in Delhi, India (design based on Shunya, the first net zero energy home of India), (Baderia & Khandelwal, 2011).

Net Zero Concept & Building Envelope_

Energy use can be measured by various methods (relating to cost, energy, or carbon emissions). However, irrespective of the definition, the main objective is to achieve net energy balance between energy consumed and energy harvested. The U.S. Department of Energy defines a net zero site energy building as "one which produces as much energy onsite through renewable sources as it uses in one year" (Logan & Klaassen, 2010).

To some, the above definition would mean that a Net zero energy building is achievable, provided that renewable energy equivalent to its energy requirement is generated. However, the fundamental objective of the net zero concept is to reduce energy demand to the lowest possible level first, then address energy supply. Therefore all possible cost-effective energy-efficiency strategies must be incorporated in the design before installing expensive renewable energy sources (Torcellini & Pless, 2011). Although energy efficiency is attainable through efficient building design, efficient lighting systems & equipments and high performance HVAC system, for a net zero energy building, minimizing energy use through an optimized building envelope should be of highest priority (Magee, 2011)

The hypothetical net zero home, assumed for the purpose of this study, is visualized to be self sufficient in terms of its electricity requirement. It is designed with an array of solar panels on its roof top to generate electricity equivalent to its annual electricity demand. Due to high initial investment and large area requirement of solar panels, focus is on reducing the electricity demand of the house so as to reduce the solar panel requirement.

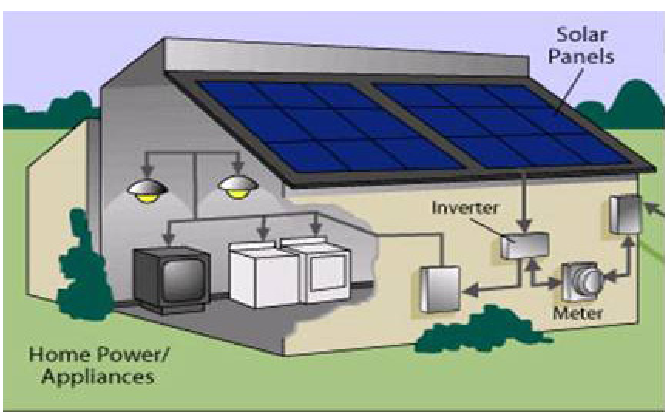

Figure 4: Net Zero Energy Concept (Source: http://www.redhookgreen.com).

However, as discussed earlier, various strategies like efficient envelope, lighting and equipment etc. can be explored to reduce the energy consumption, this paper will only focus on the measures taken for envelope optimization (Baderia & Khandelwal, 2011). The hypothetical net zero home, assumed for the purpose of this study, is visualized to be self sufficient in terms of its electricity requirement. It is designed with an array of solar panels on its roof top to generate electricity equivalent to its annual electricity demand. Due to high initial investment and large area requirement of solar panels, focus is on reducing the electricity demand of the house so as to reduce the solar panel requirement. However, as discussed earlier, various strategies like efficient envelope, lighting and equipment etc. can be explored to reduce the energy consumption, this paper will only focus on the measures taken for envelope optimization (Baderia & Khandelwal, 2011).

Analysis & results_

For the purpose of analysis, the project has been modeled in eQuest simulation software. eQuest uses the DOE-2 building energy simulation engine which is a widely used and accepted building energy analysis program that can predict energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, usage, along with weather data, to perform an hourly simulation of the building and to estimate envelope loads.

To assess the impact of building envelope optimization on HVAC load reduction, the simulation model of the net zero home, located in Delhi, was run parametrically with incremental improvement in envelope parameters. For the purpose of comparison, the building with the longer axis oriented North/South is considered as the base model which has the following envelope parameters:
_Roof: 0.088 Btu/hr.ft^2°F
_Wall: 0.194 Btu/hr.ft^2°F
_Glass: U-Value: 0.581 Btu/hr.ft^2°F
_Shading Coefficient: 0.348
_Shading devices: None
Each strategy used for envelope optimization is discussed in detail in the subsequent paragraphs.

*Weather file of Delhi available on Energyplus website has been used for this analysis.

Figure 5: Plan, Net Zero Home (source: Nishita Badeira).

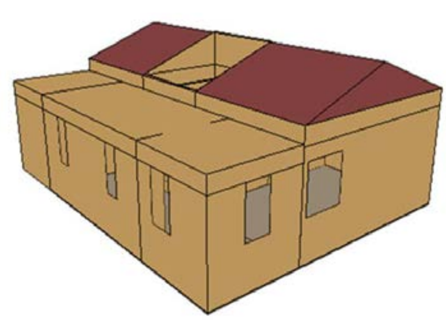

Figure 6: View of Base Model, Net Zero Home (source: Nishita Badeira).

Orientation: The orientation of a building directly relates it to its natural environment i.e. the sun, wind, weather patterns, topography, landscape, and views. Therefore, decisions made in site planning and building orientation during the design stage have major implications on the energy performance of the building over its entire life cycle. Moreover, correct choices made during site planning would result in physically and psychologically comfortable conditions in the building. Building orientation provides opportunities for passive solar heating when needed, solar heat gain avoidance during cooling time, natural ventilation, and daylighting throughout the year (Nayak & Prajapati, 2006).

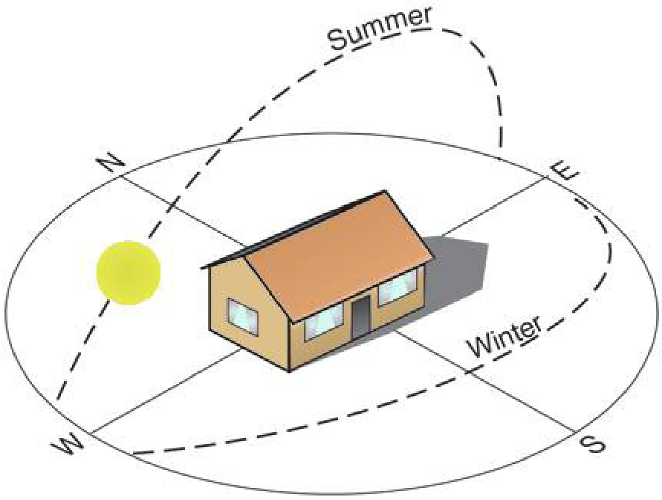

Figure 7: : Optimum orientation (source: http://www.ecowho.com).

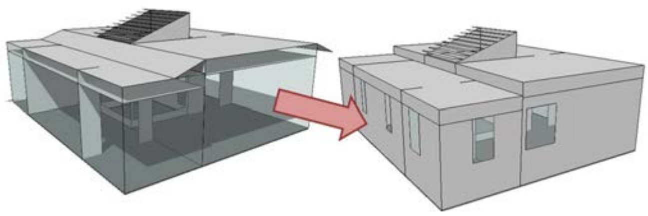

Figure 8: WWR Optimization for Net Zero Home (source: Nishita Badeira).

As a general guide, long, narrow buildings facing north/south with their longer axis running east/west have lower peak cooling loads, while buildings facing east/west with their longer axis running north/south have higher peak cooling loads (Fig. 7), (Baderia & Khandelwal, 2011). For optimizing orientation of the net zero home, it was analyzed for every 45° rotation. The optimized orientation (Longer axis oriented East/west) demonstrated 5% reduction over the worst orientation (Longer axis oriented North/South).

Window to wall ratio (WWR): Windows are a source of daylight, fresh air and views for a building. However, window size and placement, if based entirely on views and facade composition, may negatively impact a building's energy efficiency, comfort and indoor air quality. Hence, HVAC loads can be further reduced by optimally sizing & placing the windows. As a thumb rule, maximum windows must be placed on North and south facades, as they can be easily shaded and can also provide useful daylight. East and west facing windows are very difficult to shade. Window sizing and placement in the net zero energy home is based completely on its effect on energy efficiency through passive solar and daylighting strategies. The WWR for the house was optimized to 25% with maximum windows placed on north and south façade and minimum on east and west façade. (Fig.8)

Roof & Wall: As maximum solar radiation is received by a roof of any building, it contributes greatly to internal heat gain. The roof should be protected against excessive heat gain by over-deck insulation to achieve the appropriate U-value (thermal conductance value), (refer Fig.9). Similarly external wall must be externally insulated so that conduction gains from wall are minimized (Fig.10), (Eco-housing Assessment Criteria - Version II, 2009).

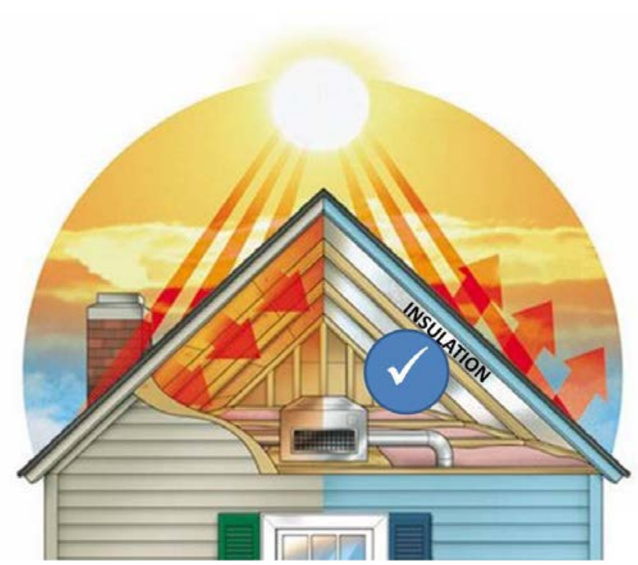

Figure 9: Roof Insulation (source: Nishita Badeira).

Figure 10: Wall insulation (source: Nishita Badeira).

Some commonly used roof/wall insulation types are mineral wool slabs, glasswool, rockwool expanded/extruded polystyrene, polyurethane foam etc. In the net zero home, the wall and roof for conditioned spaces were assumed to be insulated with 120mm Polyurethane (PU) panels with U value of 0.033 Btu/hr.ft^{2}°F, while the naturally ventilated spaces were insulated with 50mm PU panel.

The provision of insulation in natural ventilated spaces decreases the surface temperature of the inside walls and increases thermal comfort by reducing the mean radiant temperature. The partition walls between the conditioned and unconditioned spaces were insulated with 40mm rockwool to prevent heat gain from unconditioned spaces to conditioned spaces. The provision of over-deck roof insulation and external wall insulation further reduced the heat gain through envelope by 21% and 52% respectively.

Window assembly: In addition to WWR optimization, for further reduction in heat load, mainly conduction gains and solar heat loads, proper selection of window assembly is equally important.

Heat flow into and out of the building can be reduced by incorporating a high performance window assembly which subsequently minimizes the need for heating and cooling and allows high levels of natural light into the space (refer Fig. 11). High performance glass constitutes multi-layered glazing with solar control coating, low-e coating etc. For the purpose of analysis high performance window assemblies of double glazed unit and UPVC frame with the following specifications were assumed for the net zero home:
U-Value: 0.19 Btu/hr.ft^{2}°F
Shading Coefficient: 0.34
Visible Light Transmission: 57%
This resulted in 67% reduction in heat load from the base model.

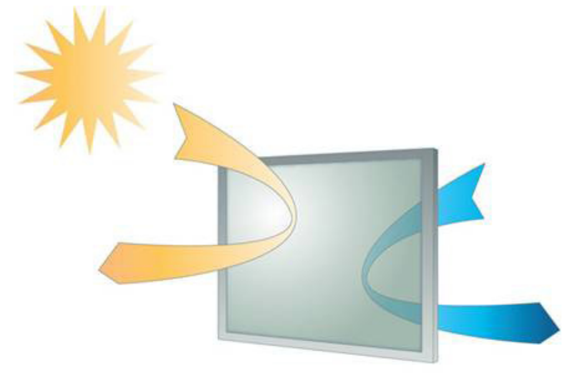

Figure 11: High Performance Glass (source: http://www.veradewindows.com).

Shading devices: Solar shading helps to block the incident solar radiation from penetrating into living spaces, consequently reducing heat gain. It can be achieved by self-shading building form, adjacent buildings, trees and shading devices such as overhangs/fins.

Solar Shading devices should be designed such that they minimize unwanted solar gain in summer completely while allowing winter sun into the building to facilitate passive solar heating. Unwanted glare and high contrast ratios should also be dealt with to avoid visual discomfort. North/South facing windows can be easily shaded with the help of overhangs and light shelf, while east/west facing windows, though difficult to shade due to very low angle sun, can be dealt with by providing a combination of horizontal and vertical shading devices (Fig.12).

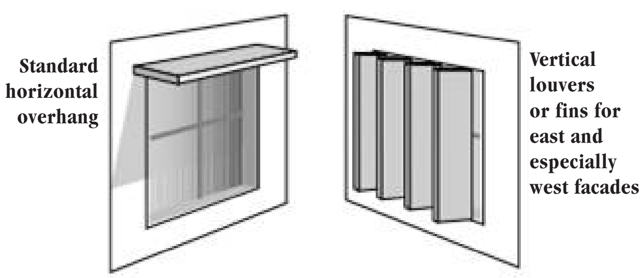

Figure 12: Window shading (source: : Shading Strategy, Section 5).

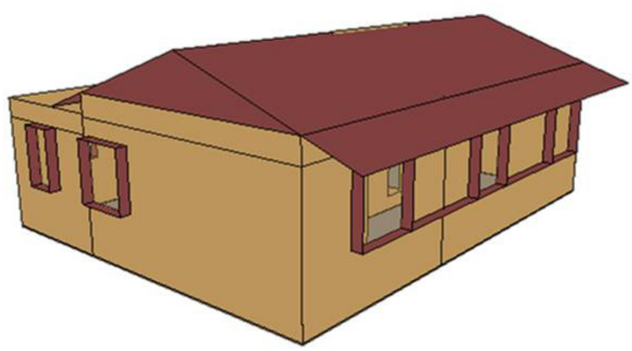

Figure 13: : Shading devices for Net Zero Home (source: Nishita Badeira).

Shading has been designed for the net zero home with the help of roof overhangs, fixed shades in courtyard and overhangs & automated sandwich screen in windows (Fig.13). The complete window assembly with the shading screen between the two glass panes can be operated manually or can be programmed such that it operates automatically based on the solar radiation incident on it. Heat load from envelope further reduced from 67% to 71% by the use of shading devices.

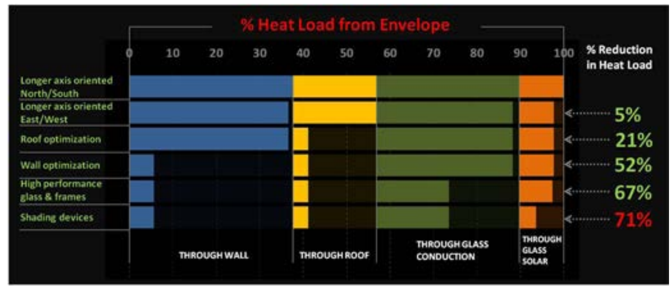

Figure 14: % Reduction in heat load from envelope (source: Nishita Badeira).

Conclusion_

A building's envelope continuously interacts with the outside environment, and its performance has a strong influence on the HVAC load, indoor environment and comfort conditions. Through this study, various steps involved in reducing heat gain through building envelope were analyzed. It was observed that from base design case to optimized design case, percentage reduction in heat load through envelope is about 71%. The resultant reduction in heat load results in lower HVAC load, thus a smaller energy efficient HVAC system is able to cater to the cooling/heating requirements of the house. With a decreased system size, the initial investment on HVAC system reduces. Due to an optimized envelope and energy efficient system, the electricity bills are lowered resulting in a cost effective HVAC system.

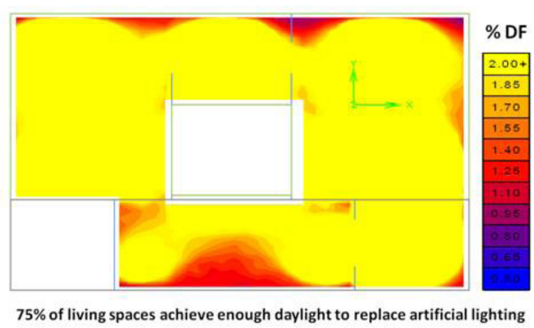

Figure 15: Daylighting for Net Zero Home (Analysis performed on ecotect software)
(source: Nishita Badeira).

Moreover, due to typically high cost of renewable energy sources, effective incorporation of energy efficiency measures in a building reduces the size of the renewable energy system required to achieve net-zero energy. (Logan & Klaassen, 2010). It is also worth noting that the benefits of careful envelope designing are not restricted to reduction in HVAC load. During favorable outside conditions, careful envelope designing can provide thermal comfort by natural ventilation. In an appropriately designed building, natural light can be utilized for all day-to-day tasks, thus reducing the need for artificial lighting during daytime which further helps in reducing lighting load associated with artificial lights. Therefore, proper building design can optimize air conditioning system performance, minimize energy costs and improve comfort. auS

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