DESIGN TECHNOLOGIES FOR HIGH PERFORMANCE ENERGY EFFICIENT BUILDINGS

Ar. Shikha Aggarwal, Ph.D. scholar, I.K.G. Punjab Technical University, Jalandhar Kapurthala road, Punjab, India,

Dr. Prabhjot Kaur, Professor and Director, I.K.G. Punjab Technical University, Mohali campus-2, Punjab,

Dr. P.S. Chani, Professor and Head of the Department, Department of Architecture, I.I.T. Roorkee, Uttarakhand, India.

ABSTRACT

Designing high performance energy efficient buildings involves passive as well as active strategies. It is also important to involve the active and passive strategies at the early stage of design itself. This stage involves use of modelling, simulation and analytical software. It involves not only high costs but also the degree of uncertainty of decision making is also high [2]. Designing a net zero-energy buildings (NZEBs) has many complex parameters and is also largely dominated by mandatory codes and standards like ASHRAE (2008, IEA) [1].

Keywords: Building technology, Zero energy buildings, zero carbon buildings, Energy efficient buildings

INTRODUCTION

The three main components that need to be integrated in design at early stages of project development of a NZEB are as follows:

- **Passive design strategie**s: They include orientation of building, building block design (geometry/ ratios), building envelope design, geothermal cooling / heating, insulation, etc.
- **Energy Efficient equipment**: They include HVAC, hot water, lighting, appliances, transportation, building automation and control, other plug load equipment, etc.
- **Electricity generation**: They include on-site (building integrated electrical generation or on site separate / independent electricity generation using renewable sources of energy like solar cells, wind turbines , bio0diesel,etc.) or off site (purchased from state electricity board) [3].

DESIGN & TECHNOLOGIES OF NZEB

NZEBs have low energy requirements by use of energy efficient measures and meet those demands by generating energy from available abundant renewable energy sources such as direct solar radiation, wind and the earth’s thermal storage capacity. This section reviews design solutions for office buildings in composite climate and list multiple passive and active climate-responsive strategies and solutions.

Incomposite climate, hot weather pertains for more than 6 months. So it is necessary to avoid sensible and latent heat gains to achieve thermal comfort with minimum energy consumption. Thus, the passive design strategies involve low heat gain and more of heat dissipation. Passive cooling strategies lower the energy requirement of a building and reduce heat gain by thermal zoning of areas and installing protection devices. Active designs aim to minimise heat gain and maintain the comfort conditions by mechanical methods.

I.**Passive Design Strategies**

a. **Solar Control:** The building envelope receives the maximum solar radiation and transfers heat toward the interior buildings. This heat gain can be controlled by designing appropriate orientation, building form, building volume and window to wall ratio (WWR), light coloured and reflective external finishes and providing shading devices. Provision of large green areas and shade trees also help in blocking the Sun and reduce the reflection of sun ray towards the building [6].

b.**Thermal Control:** The thermal exchange between the indoor and the outdoor environment varies according to the extent of exposure and thermal properties of the building envelope. Construction elements like cavity walls, thermal mass, thermal insulation and external reflective materials influence the incoming heat flux inside the building.

c. **Thermal Zoning:** Provision of buffer spaces between the inner areas and the external areas, active multiple skins decrease the heat exchange through the building envelope.

d. **Passive Cooling:** Passive and low energy cooling strategies dissipate heat through architectural elements and natural heat sinks through like natural ventilation, nocturnal/night ventilation ,direct evaporative cooling, indirect evaporative cooling and ground cooling. Though these strategies are low energy consuming but they are insufficient during peak loads. The cooling performance of these systems can be improved by integrating them with active systems like slab radiant cooling with embedded chilled pipes, evaporative coolers and geothermal bore hole heat exchangers [7].

i.**Natural Ventilation**: Work productivity is directly affected by ambient temperature and prevalent natural ventilation. Night (nocturnal) ventilation removes the heat gained by the building structure (due to thermal properties) during the day. This nocturnal cooling cools down the internal temperature also of the building. This effect of night ventilation with an exposed thermal mass could reduce the cooling loads leading to reduction incapacity of cooling equipment. Night ventilation is more effective in dry climates with large diurnal range of15ºC– 20ºC and night temperature below20ºC [8]. Effectiveness of nocturnal ventilation depends on diurnal temperatures , humidity ,wind speed and direction.

ii.**Direct Evaporative Cooling:** During evaporation sensible heat is converted into latent heat at a constant wet-bulb temperature and can be enhanced by adding water body and vegetation. Or sprinklers in integrated wind scoops (Passive Down draught Evaporative Cooling (PDEC).

iii.**Indirect Evaporative Cooling:** This type of cooling is done by cooling the building structure by water evaporation from the exterior surface e.g. roof sprays, water curtains, etc.

iv.**Ground Cooling:** The heat from a building can be dissipated to the ground (heatsink). The effectiveness of this system depends on the difference between ambient air and ground temperatures, the soil materials; conductivity, heat capacity and density.

It is also most effective during summer time (high temperature outside) when there is maximum difference in temperature between the ambient air and the ground exists.

v. **Hybrid (Mixed mode) Cooling:** It is a combination of natural and mechanical systems of ventilation to achieve good indoor air quality IAQ and thermal comfort of the users along with reducing energy consumption. They involve features like low pressure ductworks, variable speed fans and heat recovery systems. Many BIM software and simulation softwares are used for early design decision and regular monitoring.

II. **Passive Strategies For High Performance Buildings** [9]

vi. **Site selection: The site should have ample** renewable energy opportunities. It should be so located so as to reduce transportation costs. [10]

vii. **Orientation:** example TERI RETREAT Building, Gurgaon has adopted orientation as an important tool in its "solar architecture design ". [11]

viii. **Building Form**: Punjab Energy Development energy [PEDA] office complex in Chandigarh is a climate responsive building, with an innovative concept of architectural design.

ix. **Daylight integration**: The ITC, Green Centre in Gurgaon has an effective daylight integration while cutting down the heat gain. [12].

x. **Landscaping**: The SOS Tibetan children's village at Rajpur, Dehradun has provided landscaping planning so that the large playground is in wind sheltered zone with clear winter sun access. [11]

xi. **Water bodies**: The transportation Corporation of India, Ltd. (TCIL) building, Gurgaon uses re-circulating system in which a large body of water flows over extensive surfaces to maximise evaporation. The water trickles down along the tall solid concrete columns and creates a large heat sink. The thin sheet of overflow on the sides of the pool creates a large heat sink. This controls the air temperature. [11]

xii. **Solar chimney**: A central evaporative cooler located above the staircase well at the residence of a family in Panchkula helps in providing good and natural ventilation.

xiii. **Courtyards and verandas**: The American Institute of Indian studies, Gurgaon has provided spaces with different thermal characteristics through verandas and courtyards. The two courtyards have been diagonally placed. First courtyard is ornamental and has water pool, vegetation and sitting areas and the second courtyard is open ended.

xiv. **Insulation** : [13]

xv. Reduction in energy demand, water use in conjunction with reducing the demand for hot water.

xvi. **Materials:** Select materials that have low embodied energy.

xvii. Reduce energy use in all areas of the building The balance between energy efficiency and renewable is an important issue. It is essential not to apply excessive renewables to buildings with poor energy efficiency [10].

III. Design Methodology and Guidance

NZEB can be successful by using less technical involvement also if planned in early stages of design and involving all multi-disciplinary engineers at the early stage itself.

Architectural Approach: As defined by RIBA, there are five main phases–Pre design, Design, Pre-Construction, Construction and Use. There are 11subcategories(A-L).

Bioclimatic Approach: A climatic approach consists of four main design stages; climate data, biological evaluation, technological solutions and architectural application. Climate data of a particular location is plotted on a bioclimatic chart–based on the psychometric chart–and strategies are designed for appropriate site selection, building form, orientation ,shading devices, construction and air movement[14].

Engineering Approach: It is a 7-stage process adopted by engineers. It involves feasibility studies, concept design stage, design brief, scheme design stage, detail design stage, construction design information, construction, and design feedback.

CIBSE Approach: The Chartered Institution of Building Services Engineers seeks optimum design of building components using passive strategies, active strategy, trade-offs and specifications.

IEA-Annex40 Approach: International Energy Agency has carried out various projects. The project in annex 40 presents NZEB design approach based on reducing the energy requirement, achieving maximum building energy efficiency and meeting the energy requirements through active systems. In this approach more time is spent in early design stages. [18]

IV. Design Guides

There are many types of design guides based on international/ national/regional best practices and research findings. These design guides are for reference only and may not be mandatory. They are classified into three main categories; energy codes,design standards and general publications.

Energy Codes: International energy codes and standards offer minimum/maximum acceptable values for energy-efficient design and minimum carbon emission. These codes are mainly for residential and commercial buildings. These codes have three compliance approaches; prescriptive, trade-off or performance approaches. The prescriptive approach has minimum/maximum acceptable limits of different building properties such as U-values and SHGC. The commonly used energy codes/standards in hot climates are:

- ASHRAEStandard189.1: Standard for the Design of High-Performance Green Buildings(ASHRAE2011)
- Performances EnergétiquesdesbâtimentsàLaRéunion (PERENE2009)
- ASHRAE Standard 90.2-2007: Energy Standard for Low-Rise Residential Buildings (ASHRAE 2007)
- Building Code of Australia BCA 2006 (ABCB 2006)
- International Energy Conservation Code IECC (ICC2006)
- Indian Energy Conservation Building Code (BEE 2006)
- Egyptian Energy Efficiency Residential Building Code EERBC (HBRC2006)
- Commercial Building Energy Standard for Mexico (Huang*et al.* 1998)

The active design strategies include electric and thermal energy generation(photovoltaic panels, wind turbines, thermosyphons, etc.), movable sun protection, active cooling (solar assisted or conventional Heating Ventilation and Air Conditioning (HVAC)), artificial lighting and mechanical ventilation. One of the most important factors concerning active strategies for NZEBs is the efficiency of the equipment and appliances that achieve those strategies. This includes efficient HVAC equipment ,efficient household appliances and high performance ceiling fans. Therefore, this chapter aims to review the current technologies, identify the most important design parameters, strategies and technologies through parametric analysis and suggest the most suitable solutions for NZEBs in hot climates.

V. Active Cooling Technologies

The use of active cooling technologies consumes electricity and if they are grid connected, they will emit GHG as well. So technologies have to be building integrated and carbon emission free as well.

Conventional Air Conditioning Systems: They include Window Units, split units, Packaged Systems and Units, VRF(VRV) systems and central air conditioning systems. The window units and packaged systems have high electricity costs and the effective average life cycle is very short up to 10 years. The Variable Refrigerant Flow (VRF) or Variable Refrigerant Volume has a compact air-cooled condensing unit located outdoor and is connected to several dozen so fin door fan coil units less than 100 tons. The system regulates the refrigerant flow rate to the terminals individually according to the cooling demand of the particular zones. VRF is more expensive than split system and has average life cycle of 15 years. The central air conditioning system is used for cooling loads more than 100 tons. The chilled water system is connected to multiple air handling units distributed throughout the large buildings and the main chiller plant is located at one central location. Since the COP of chillers in this system is high thus energy consumption is also very high. The duct sizes are also large and occupy a lot of space along the ceiling/ floor thus leading to increase in floor- floor height of a building. This system is effective only with well insulated and air tight buildings. The exhaust air flowing through the ducts carries various gases, odours and other particulate matter exhausted from the rooms. So to maintain the quality of indoor air, number of air changes have to be controlled and fresh air has to be introduced at entry level after filtration and dehumidification.

1) **Non-Conventional Air Conditioning Systems**

a) **Radiant Cooling:** This system is very effective as it helps in controlling indoor air quality and thermal comfort in a building. The only problem is about the control of condensation on inner surfaces of cavity walls or interiors and collection and disposal of the condensate.

b) **Evaporative Cooling:** These systems include evaporative cooling methods like fans, fogging system and roof evaporative cooling.

VI. Impact on environment: Air-conditioning systems consume a large amount of electricity and also increase the peak load. These systems also emit greenhouse gases due to use of CFC and HCFC refrigerants.

Renewable Technologies: A building can easily achieve the zero energy objectives by use of renewable energy.

I. **Solar power** is the most easily available source to meet its energy demand.

a. Solar Thermal Systems: These systems use solar thermal energy to heat water for various uses in a building There are many types of solar collectors available in the market nowadays.

b. Solar Thermosyphon: This system works on the principle of heating the water using solar heat and then collecting it in the tank above itself once it reaches an equilibrium temperature.

c.Solar Collector: Solar collectors are of three types i.e. flat plate, air and evacuated tube collectors. They are used for solar assisted air-conditioning systems.

d. Solar Electrical Systems: The solar modules mounted on buildings capture solar energy and convert it into electricity. These solar modules are available as crystalline silicon and amorphous silicon. The Crystallinesiliconcellsaremadefromslicesofalargesinglecrystalingot(monocrystalline) whereas multi-crystalline cells have an efficiency of 14 %. They are covered with tempered glass on top and a tough ethylene vinyl acetate material at the back to protect the solar cells from moisture. The back of modules should be kept cool with the help of good ventilation.

The amorphous silicon cell can be applied as a thin film to glass or plastic layer in multiple module sizes. The efficiency of thin film modules is lower (3-7%) than that of crystalline modules but are less expensive than them.

VII. Wind Turbines System

The wind turbines require minimum wind speed constantly to ensure stable electricity supply. They also need an inverter (to turn wind generated electricity from DC to AC). The turbine should produce between 0 and 10kW hours per day. Some studies mention that the wind turbine could generate 660 kWh/year.

Uncertainty of Decision Making

Designing of a building involves multidisciplinary aspects and is an exploratory process with the architectural model being the base plan. Decisions taken in early design stage influence 80% of all detailing decisions throughout the rest of the project till its completion. [16]. For small scale projects it is not very difficult to take decisions by an architect but for large scale projects, engineering solutions are required at every stage. Hence there is high uncertainty regarding performance of NZEB design particularly in environmental impact of the building.

When we define a base model, we also have to give specification of various construction components. These include the following;

1. External walls
2. Roofs
3. Floors
4. Partitions
5. Internal / external doors
6. Air-tightness
7. Thermal mass
8. Glazing details- construction, frames, opening area for external and internal glazing, roof glazing, shading systems.
9. Facade types: types of facade layouts, frame definitions, glazing data (opening/no opening, continuous, height, width.

The walls and partitions can be external /internal and can have exposed/semi-exposed surfaces. Specifications of the construction component that has to be provided includes thickness of the component and properties of the material like transmittance values, thermal resistance, etc.

When we specify a wall, cladding systems have also to bedefined. They are integral part of the construction. There are two types of cladding systems. They are as follows:

a. The built up metal cladding systems involving rail and bracket or z-spacer systems with insulation within the panels. For example, metal twin skin systems having 0.4 mm to 1.2 mm thick metal skins and an insulation layer between them

b. The composite panel metal cladding systems with insulation inside the panels.

However, a rain screen is not considered as metal cladding for calculation purposes as they provide only protection from external weather conditions. We can add up to10 layers to the external wall specification. Properties to be defined:

1. The convection properties of the outer and inner surfaces have also to be defined. For this we need the convective and radiative heat transfer coefficients (W/m^{2-} k) for all the surfaces. If any construction component (e.g. wooden joists) are being used to bridge the inner and outer walls, then their transmittance values (U-value) and Thermal Resistance (R-value) with the upper and lower limits have also to be defined.
2. The construction components also include the internal heat sources like heated floors, chilled ceilings, etc. These systems have pipes/tubes embedded in the construction components. If the hydronic tube heating/

cooling systems are being used then their position, size, thermal properties of the tubes have to be defined for this.

CONCLUSION

The high performance buildings incorporate the above discussed technologies . There are various design guides, energy codes, energy ratings systems, etc. that can be referred to in the early stages of design itself. There are various parameters of evaluation of performance like Metrics of evaluation, User Comfort, Building integrated Passive Strategies, Energy Efficiency, Innovative Solutions and Technologies, etc. The effects of uncertainties have to be considered at the design stage itself so as to avoid non-optimal design of energy systems.

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