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Sustainability Index Measurement of Energy Efficient Skyscrapers: Present Indian Perspective

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Abstract: *During last century development of skyscraper have been rapidly increasing worldwide. The present fifth generation skyscrapers are influenced by the energy conservation and sustainable strategies. This paper brings out the list of such techniques and design principles used in tall building. A comprehensive literature study has been made to classify and characterize the innovative sustainable techniques. A comparative analysis is worked out in a weighted scale for the classified sustainable and energy conservation technologies and design principles. During analysis, present techno-socio-economic Indian scenario is given prime importance. Final phase of the paper measures the sustainability index of the above said technology and principles. This index and the ranking ultimately reveal that the passive design criteria with some selective energy generation techniques are the key features of modern sustainable skyscrapers in India.*

Keywords: *Energy generation, Facade design, Passive system, Skyscrapers, Sustainability index*

I. Introduction

Over the passage of time a considerable amount of changes and reforms in design of building and the use of building material are identified. The change in building design with respect to its space and volume is mainly due to the socio-economic shift. The new structural materials and the innovative use of building materials also imparted to the change in building vocabulary. The high cost of land price and the advancement in the field of structural engineering initiated to adopt vertical development in the core urban areas. Over the past hundred years the high-rise building has also undergone an array of development. The parametric changes in design and practices of tall building are influenced by various factors like, development of new material and technology, regulatory changes by civil bodies, change in demography in urban areas and modern economic and commercial impact to the society.

Generally, Skyscrapers are not considered as an ecological building. The Skyscrapers require more energy and material resources to build, to operate and eventually, to demolish. Tall buildings require high strength structural material to withstand the heavy superstructure and lateral loads. It requires greater energy demands to transport and pump materials to the upper floors. Until we have an economically viable alternative built form, the skyscraper as a building type will continue to be built particularly to meet the demands of urban and city growth and increasing rural-to-urban migration. UN report, in the year 2010 estimated that, urban population will exceed rural population within next twenty years. Sixty percent of the world population will live in urban areas by 2030. These changes will be clearly visible in Asian countries along with India, where the economy is increasing rapidly. In modern context the climate change and global warming are the burning issues. It is a fact that, the built environment made a significant contribution on the global green house effect. UNEP environmental programme, 2007 found that, the building materials and its present system are accountable for 30-40 percent of the primary energy used in the world [1].

So as a whole, particularly from the building type point of view, skyscrapers can never be considered as an eco-friendly building as it has certain negative environmental impact. But a positive improvement has been noticed regarding the thermal performance and the energy efficiency of the high rise buildings since their birth (1885) [2].

II. Energy Generation In High Rise Buildings

Historically, the development of high rise building can be clustered into five energy generations. These five generations are separated by each other with a connecting event. Four such connecting events are recognised as (i) Introduction of 1916 New York zoning law, (ii) Innovation and use of curtain wall as building façade, 1951 and (iii) The energy crises in 1970s. (iv) Rise of an environmental consciousness in 1997 [3].

After the zoning law was implemented, the bulky nature of first generation building became slender to incorporate the vertical setback. The energy requirement for heating and air-conditioning increases proportionally with the increase of building surface area [4] the third generation buildings maximized the use of single-glazed dark colour curtain glass wall at their building facade. Rectangular dark glass facade buildings (known as black skyscrapers) quickly became popular around the world, regardless of building's site location and climatological considerations. The use of dark curtain wall increases the building's primary energy consumption in two folds. The black skyscrapers fully rely on HVAC system and have increased dependence on artificial lighting; hence increased energy consumption. The popularity of the single-glazed curtain wall facade high rise building construction was abruptly interrupted by the energy crises that evoked in 1973 and 1979. The mass people gradually became conscious of using energy in buildings. Many developed nations brought in building energy performance codes, forcing a widespread switch to double-glazing. The construction of single-glazed curtail wall was strongly criticized. The black skyscrapers in general became increasingly unpopular and the construction of black skyscrapers in American cities drastically went down.

Finally, the first significant tall building reflecting new environmentally conscious principles was the Commerzbank in Frankfurt (1997) by Norman Foster. The building is also considered the first 'ecological' skyscraper due to its use of sky gardens and energy-saving technologies [5]. It includes a full height central atrium to provide natural light and ventilation, open to sky gardens in various vertical levels, air movement through operable windows and water based ceiling cooling system.

An environmental consciousness started playing a role in all over the world. Many climate sensitive and energy efficient design features are introduced in the built environment to reduce the energy consumption. But all the features may not be feasible to incorporate in the Indian high rise building perspective. A comprehensive literature survey produces a list of the energy conservation features applicable to buildings and that are discussed in the next chapter.

III. Sustainable Features Of Modern High Rise Buildings

Built in 1956, Frank Lloyd Wright’s Price Tower in Oklahoma shows many features and was in future rationalized as sustainable one. Some literature would of course, claim that the early work of Geoffrey Bowa in Sri Lanka (Mahaweli office tower, Colombo, 1976), Charles Correa in India (Kanchenjunga Apartments, Bombay, 1983), or Harry Seidler in Australasia (Riverside Centre, Brisbane, 1986) are more indicative of the first prototypes for eco-skyscrapers [6]. The majority of the tall building presently constructed tries to follow some typical requirement of sustainability. The practice of the sustainable features and technologies has many bifurcations. In this present study, the sustainability and the energy conservation approach are grouped into five classifications: Façade Design, Passive System, Generation of Electricity, Visual Comfort and Renewable System. Based on the literature review and application in the modern buildings for last thirty years, the sustainable and energy conservation technologies and design principles are listed under the five groups as below:

III.1 Façade Design

1. A typically designed facade allows for natural ventilation for over half the year through **operable windows**. This system can be adopted for low rise building of height maximum 20 floors.
2. **Balconies and overhangs** usually provide sufficient amount of shading to the direct solar radiation. But very few high rise building incorporates the shading devices into its façade due to monotony in building elevation. The portion of the building without any shading devices is rendered with high-quality solar glass panels which minimize solar gain.
3. **High performance curtain wall** reduces solar heat gain through low-emissivity (low-e) glass.
4. **Internally ventilated double wall system** keeps the interior thermal environment under control.
5. Façade on the sides of maximum heat gain (eastern and western) is made of **triple glazed glass** which insulates the building’s interior.

III.2 Passive System

1. A **central atrium** can be designed to provide natural lighting and ventilation to internal office spaces. A temperature gradient can be set up to execute ventilation due to stack effect. But in sufficiently high buildings natural stack effect must be supported by mechanical ventilation.
2. **Buffer spaces** should be created between the external outdoor and internal air conditioned spaces. Buffer zone reduces the conductive solar heat gain. [For example, buffer space can be of car park deck, entrance lobby, service floor, storage areas]
3. A local **evaporative cooling** is well executed by the reflection pools at building entrance. The efficiency of the evaporative cooling will enhance if the building is placed at upstream side of the breeze passing the pool.
4. Extensive **site landscaping** reduces the direct solar reflection.
5. A **water-based cooling system** has been designed for chilled ceilings. A radiant cooling ceiling system is designed to circulate cool air in the office floors. Perimeter “chilled beams” are provided in the ceiling level instead of normal air-conditioning and ventilation duct. These perimeter chilled beams carry the cold water (approximately 14^0 C) through concealed copper pipes. Floor-by-floor air handling units provide more even, efficient, and healthy cooling and fresh air.
6. An **inverted design concept**, where the maximum opening are given in the interior courtyard side.

III.3 Generation of Energy

1. **Wind turbine** can be set up in certain vertical level to generate electricity. The aerodynamic shape of the building envelop with typical floor plan become the key feature to enhance the air draft. The wing-like towers assist to accelerate the wind velocity and create pressure differences. The funnel condition allows sufficient air flow that imparts to the electricity generation.
2. **Small wind turbines** of the size of a window, sometimes designed and placed in strategic maximum wind locations to generate local level of back-up power.
3. **Photovoltaic cells** can be employed in the building façade to generate electricity.
4. Installation of **Building Integrated Photovoltaic cells**. Building integrated photovoltaic (BIPV) are the photovoltaic material that are used to replace conventional building material (such as cladding tiles or roof tiles) in parts of the building envelope such as roof, wall and skylight. They are increasingly being incorporated into the construction of new buildings as an ancillary source of electrical power.

III.4 Visual Comfort

1. Open to sky, large gardens can be accommodated in differential vertical levels to increase the natural light quantity in interiors. These are known as **Sky Courts**. Sky courts at different intermediate levels allow occupants to enjoy greenery, as well as creating a passive cooling.
2. **Spiral vegetation** and landscaping planter boxes can be designed **along with the ramp**. The continuous vegetated areas occupy a surface area of productive biomass. The planting contributes to the ambient cooling of the façades through evaporation and transpiration. The landscaped ramp results in a built form with a vertical landscape.
3. **Energy-efficient, high-efficacy, lighting** with zonal control minimize the electrical load. Road and amenity lighting are also designed with solar-powered.
4. **Day light responsive controls**: maximizing the use of natural light by the use of lighting controls that respond to daylight, integrated into the system of the blinds.

III.5 Renewable System

1. **Twofold drainage system** is designed to separate the waste and soil water. The water treatment also allows the gray water recycling.
2. **Recycle of rain water** through a sophisticated rain water capture system can be designed so that, it can be aimed for nearly zero storm water discharged to city sewer system.
3. **Dual-flush for the closets** and **electronic taps** controls the flow of excess water use.
4. **High efficient office equipment**: Sophisticated equipment that yield water and power conservation.
5. **Using recycled / industrial byproduct** as prime building materials.

These sustainable and energy conservation technologies and design features are further assessed through selected sustainable parameters and discussed in subsequent paragraphs.

IV. MEASUREMENT OF SUSTAINABLE INDEX AND DISCUSSIONS

The features of sustainable and energy conservation technology and design are finally assessed through five sustainable parameters. This point system assessment ultimately measures the suitability index. The index will rank the applicability of the features (mentioned in previous chapter) in Indian condition. Following five sustainability index measurement parameters (appeared as P1 to P6 in Table1) are considered during comparative analysis:

1. Energy Saving Potential (it is based on the relative amount of energy conservation in the tropical climate of India)
2. Impact on environment (It includes the direct and indirect impact on the environment in a long term basis. It also takes account of the embodied energy of the used material)
3. Application and Technical Feasibility (many features may not be readily applicable and may require technological or engineering up-gradation. Sometimes some of the features are not feasible to adopt in socio-economic circumstances)
4. Degree of Maintenance (it takes the regular and extent of required maintenance affair of the adopted technology)
5. Initial Cost (it gives the capital investment on the installation of energy conservation technological features)
6. Return on Investment (it estimates the return period and the amount of yearly return on the capital investment)

Point (1 to 5) is awarded to each of the parameters for entire features. Better potential and appropriateness of the technology with respect to the parameter is given lower points. Whereas the higher point of any parameter indicates the relatively adverse scenario. Around twenty modern eco-skyscrapers of fifth energy generation are thoroughly studied as a part of the case study. The point is given to each category according to the latest literature survey and the review articles along with the explanation and narration given by the prime electronic media. The approach to the adopted technology and the suitability in the Indian environment is considered. Both in terms of technological feasibility and socio-economic structure of present Indian scenario is taken care of. Two statistical properties, the "mean" and the "range" of the overall point marking are considered to finalize the sustainable index measurement. As the minimum value of the "mean" recognize the best fitted performance and the minimum "range" gives more confidence for adoptability, the product of the two is calculated. The minimum value of the product signifies the best suitability. Sustainable index (SI) can finally represent in mathematical form as:

$$\mathrm{SI} = \left(P_{avg}\right) \times \left[\left(P_{\max}\right) - \left(P_{\min}\right)\right]$$

Table1. Sustainability Index Analysis and Measurement

Sustainability & Energy Conservation Features		Sustainability Index Measurement Parameters							
Façade Design		**P-1**	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**SI**	**Rank**
1	Operable Windows	4	1	3	1	1	4	7.00	1
2	Balconies & Overhangs	5	1	3	2	2	3	10.67	4
3	High Performance Curtain Wall	1	3	4	3	4	2	8.50	2
4	Internally Ventilated Double Wall System	1	4	5	4	5	1	13.33	5
5	Triple Glazed Glass	1	4	4	3	4	2	9.00	3
Passive System		**P-1**	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**SI**	**Rank**
1	Central Atrium	3	1	2	2	2	3	4.33	1
2	Buffer Spaces	4	1	3	2	3	2	7.50	3
3	Evaporative Cooling	2	1	3	2	2	4	7.00	2
4	Site Landscaping	3	1	2	3	3	4	8.00	4
5	Water-based Cooling System	1	2	3	3	5	1	10.00	5
6	Inverted Design Concept	3	1	3	2	2	4	7.50	3
Generation of Energy		**P-1**	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**SI**	**Rank**
1	Wind Turbine	1	3	5	4	5	2	13.33	4
2	Small Wind Turbines	3	3	3	3	4	2	6.00	1
3	Photovoltaic Cells	1	1	3	2	4	2	6.50	2
4	Building Integrated Photovoltaic Cells	2	1	4	2	5	1	10.00	3
Visual Comfort		**P-1**	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**SI**	**Rank**
1	Sky Courts	2	1	4	3	3	3	8.00	3
2	Spiral Vegetation	3	1	3	2	2	4	7.50	2
3	Energy-Efficient, High-Efficacy, Lighting	1	2	2	2	4	1	6.00	1
4	Day Light Responsive Controls	1	3	3	3	5	2	11.33	4
Renewable System		**P-1**	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**SI**	**Rank**
1	Twofold Drainage System	3	2	4	4	4	2	6.33	3
2	Recycle of Rain Water	2	1	2	3	3	3	4.67	2
3	Dual-flush for the Closets	3	3	5	4	4	2	10.50	4
4	High Efficient Office Equipment	2	3	4	5	5	1	13.33	5
5	Using Recycled / Industrial By-product	2	1	3	1	1	1	3.00	1

The Table 1 shows the complete analysis and the rank of the sustainable and energy conservation technologies and design features for Indian condition.

The final outcome of the analysis can be categorized into three parts.

(i) The traditional solar passive design features like central atrium with stack effect, buffer spaces, facade treatment with overhang are best suitable to control over the thermal heat gain (and to minimize the cooling load) of the building.

(ii) Miniature form of wind turbine and the photovoltaic cell along with energy efficient artificial lighting can be well fitted for Indian condition high rise building. A spiral split level interior garden concept can also be adopted for visual comfort.

(iii) Using recycled material and a comprehensive rain water harvesting scheme can be adopted in buildings.

V. Conclusion

The climatic change and global warming have presently become a burning issue worldwide. The requirement of environmental sustainability and further reduction in primary energy demand in buildings was noticed in late twentieth century buildings. In the present study, the sustainability index is measured for some selected energy conservation technology and design principles. The judgment was carried out in Indian context. The analysis finally reveals that the traditional solar passive design principles with a building surface solar and wind energy generation technology could be the appropriate solution at present. Using recycled and industrial by-product material with rain water capturing system will enhance the overall sustainability of the Indian tall building.

REFERENCES

[1] UNEP, Buildings and Climate Change: Status, Challenges and Opportunities, Nairobi, United Nations Environmental Programme, 2007.
[2] R.G. Stein, Observations on Energy Use in Buildings, Journal of Architectural Education, 30 (3), 1977, 36-41.
[3] P. Oldfield, D. Trabucco, and A. Wood, Five energy generations of tall buildings: an historical analysis of energy consumption in high-rise buildings, The Journal of Architecture, 14 (5), 2009, 591-613.
[4] D. Arnold, Air Conditioning in Office Buildings after World War II, ASHRAE Journal, 1999,33–41.
[5] A. Wood, Sustainability: A New High-Rise Vernacular, the Structural Design of Tall and Special Buildings, 16, 2007, 401-410.
[6] K. Yeang, and R. Powell, Designing the Eco-Skyscrapers: Premises for Tall Building Design, The Structural Design of Tall and Special Buildings, 16, 2007, 411-427.