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Passive Architectural Design Index applied to vernacular and passive buildings

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Abstract

Vernacular architecture's use of passive building techniques has been developed in response to the prevailing climatic conditions of the past. Today, buildings are designed with complete indifference to the climate and materials. Energy consumption in buildings is mainly connected to space cooling, supply of hot water, lighting, cooking and, use of appliances. Space cooling and lighting are directly influenced by the design of the building. Energy codes should be concerned with 'sufficiency' as well as 'efficiency'. A more economic and ecological approach to building design is needed.

Keywords: Vernacular, Climate, Passive, Building Codes, Efficiency

Introduction

A Passive Architectural Design Index, capable of evaluating vernacular and passive (modern) structures in the Indian sub-continent is desirable for several reasons. At present the Bureau of Energy Efficiency's star rating for office buildings and popular green building rating systems like LEED and GRIHA stimulate attempts to gain energy efficiency in buildings and sets out targets for energy consumption [1 - 4]. All three rating systems adhere to the Energy Conservation Building Code of India [4] that prescribes allowances for building envelope such as U-Values for building envelope, wall-window ratio (WWR), ventilation rates, etc. and MEPS standards for air conditioning equipment and lighting.

Although these rating systems and ECBC (Energy Conservation Building Code) serve to reduce energy consumption in buildings, they still face some unresolved issues, which require thoughtful solutions. For example, it is well established that buildings in India require a WWR (glazing) of about 10-30% to provide optimum daylight levels within the buildings, whereas the code permits the use of glazing up to 60% [4]. Similarly, the existing standards do not question the necessity for air conditioning in buildings and exhaustive technical solutions and guidelines have not been laid out for the development of passive designs.

Energy Ratings and Limitations

Preliminary results from a baseline study on commercial buildings in India show energy consumption in typical daytime operated office buildings ranges from 115 kWh/m2/yr in public sector buildings to 349 kWh/m2/yr in three shift operated buildings. Residential energy consumption ranges from (below) 20 – (above) 70 kWh/m2/yr with a mean consumption of 48 kWh/m2/yr and 43 kWh/m2/yr in composite climate and warm humid climate respectively[5].

LEED rates energy performance of buildings in terms of percentage energy savings obtained by comparing LEED rated building against energy consumption of a representative typical building [1].Without an absolute energy consumption index, this kind of purely 'relative' index cannot provide tangible targets for long-term energy goals. GRIHA has set a specific energy consumption index, the Energy Performance Index (EPI), for both conditioned and un-conditioned buildings based on climate [2]. The minimum EPI for conditioned commercial/institutional buildings is 140 kWh/m2/yr and for residential buildings it is 100 kWh/m2/yr at indoor temperature in the range of 23 – 26 °C; and a lower value for un-conditioned buildings with an adaptive thermal comfort range [2]. The Bureau of Energy Efficiency has developed an EPI based star-rating (1 star to 5 star) programme for office buildings falling under three different climate zones [3]. According to this, the EPI for office buildings with more than 50 percent conditioned area of the total floor area ranges from 80 (below) - 200 kWh/m2/yr and the EPI for office buildings with less than 50 percent conditioned area of the total floor area ranges from 35 (below) - 85 kWh/m2/yr.

The total floor area of buildings in India is projected to increase five times from approximately 1,940 million m2 in 2005 to about 9,675 million m2 in 2030. Residential buildings occupy the lion's share of 67 percent followed by commercial buildings (19%), hospitality sector (8%) and retail (6%) [6]. Another estimate by the International Energy Agency (IEA) [7] shows an increase in the construction of the floor area by about 80 percent from 2010 to 2030. The report expects the residential sector to rise from 12,435 million m2 to 22,300 million m2 with about 32% (15,636 million m2) of floor area to be "cooled floor area" [7]. Of the total energy consumption in India during the year 2013-2014, 22.5% is consumed by the residential sector and 8.7 percent is consumed by the commercial sector: a total consumption by building related uses of approximately 31 percent [8]. Heating, ventilation and air conditioning accounts for up to 55 percent of energy consumption in commercial buildings in India, followed by lighting (25%) and the rest is taken by plug loads (15%) and other minor loads. The use of appliances consumes energy in residential buildings in India. Major consumption is for lighting (36%), fans (18%), television (11%), refrigerators (14%), air conditioner (4%) and water heating; stand-by-power etc. comprises the rest (excluding cooking related energy) [9].

With an urban household market saturation of about 3% in 2010, room air conditioners (ACs) constitute the bulk of air conditioning purchases in India (about 99% of sales). The market grows by 20 percent p.a. Peak electricity demand from ACs is estimated to be 5 GW in 2010,about 4 percent of total peak electricity demand of 122.2 GW at a shortage of 9.8 percent.The AC energy take is expected to reach 83 GW in 2030.The total peak electricity demand in India during the year 2013-14 was 136 GW. Thus, at an installed capacity of 248.5 GW of peak demand only from ACs of about 83 GW, in an energy-efficient scenario, by 2030

India could face potential peak demand shortage unless power generation capacity is increased manifold [10]. Scarce energy resources have also to be shared between other major sectors such as agriculture, transport and industry, which support the country's fast growing economy.

Therefore, it is imperative that the rating systems should also focus on containing the potential increase in cooled floor area by encouraging the use of passive design principles. Emphasis should be laid on separately assessing air conditioning energy consumption and the total final energy consumption of the building while developing EPI.

Vernacular and Passive Architecture – Merits and Challenges

Vernacular buildings use little or no energy. They manifest the reality of the climate, culture and material of the place and time. For example, Radhakrishnan et al. [11] show how decades-old climate responsive buildings provide better thermal comfort than do poorly designed mainstream modern buildings. Most of the historical and modern principles for passive and energy conscious design are well documented with a degree of technical rigour in several books, handbooks, charts and tables [12 - 17].

Despite considerable research in passive building principles, they have been little applied in modern times. There are several reasons for this, technical, social and economic.[11]. Passive design for enhanced thermal comfort and indoor air quality is offset by the available plot of urban land and the constraints imposed by the surrounding urban built form and environmental conditions, constraints of building cost and building regulations. Besides, as Gupta notes, "there is no point in trying to sell the idea of greater thermal comfort to someone who has no money to pay for it, just as there is no point in trying to sell a less than comfortable building to someone who needs air-conditioning and can pay for it"[18]. Comfort conditions in vernacular buildings seldom match those of air-conditioned buildings. They match adaptive thermal comfort standards for a large percentage of the annual duration [19, 20].

Need for codes based on passive design potential

India's Planning Commission has estimated that energy use in the residential sector will reach about 2,250 TWh by 2047, in a moderate efficiency scenario and 1,200 TWh in an aggressive efficiency scenario [6, 9]. In a GBPN (Global Building Performance Network) study report based on the field studies of households in four Indian cities, the annual energy consumption per household is projected to increase from 650 kWh in 2012 to 2,750 kWh by 2050 in a 'business as usual' scenario. This level of consumption could be cut to 1,170 kWh in a very aggressive efficiency scenario [21]. By assuming conservative figures based on the floor area projections by IEA, [7] if all of the new commercial buildings are built and old ones are suitably retrofitted to BEE 5star, 3star and 1 star [3]or GRIHA minimum EPI Equivalent [2], the commercial sector alone would consume from176 TWh to 352 TWh.

From this, 50 TWh to 110 TWh would be consumed for air conditioning and lighting[1]. Similarly residential buildings built to GRIHA EPI standards [2] would consume energy of about 710 TWh of which air conditioning and lighting accounts for about 75 TWh to 250 TWh [2]. Even going by extremely conservative figures, the total energy consumption for air conditioning and lighting in the building sector would be in the range of 125 TWh to 360 TWh.

Unfortunately, growth in demand will negate the savings through efficiency measures, even if electricity generation is increased by 20 percent. It is estimated that as compared to 31 percent usage in 2014, energy consumption in 2030 by the building sector will be in the range of 10 percent -28.8 percent. This shows that energy codes based on EPI alone are not sufficient to save energy because along with the efficiency, there is also an increase in usage. Curbing the consumer's idea of the right to use available resources is a general problem.

It is therefore, very important to incorporate the concept of 'sufficiency' along with 'efficiency' in building energy codes. There is a need for building codes that include means to indicate building's 'passive design potential' using research from vernacular and passive designs to bridge the gaps in energy codes. Building energy codes seldom address passive building techniques with the same technical rigour adopted for active measures.

Moreover, the concept of fully closed air conditioned buildings if applied improperly/partly can have adverse impacts. For example, a study done by Mathur et al. [22] shows that Energy Conservation Measures prescribed by ECBC [4] when applied to unconditioned buildings do not always produce intended results. This is because, for an unconditioned building, matters such as thermal mass, thermal lag and ventilation schedule play an important role in achieving thermal comfort, which are often overlooked in ECBC in which the envelope is prescribed only in terms of its R-Value. Most energy modelling studies focus only on the energy efficiency measures as outlined in the national building energy code, which mainly concerns fully air-conditioned buildings. Determining factors that affect performance of envelope load dominate the analysis. Intermittently operated, mixed-mode buildings in India are largely unknown.

Today, there are two kinds of low energy buildings in India: vernacular architecture which incorporates passive techniques (sufficiency) and green building ones for which the ratings emphasize energy savings through increase in equipment 'efficiency' [23]. Yet, there exists an experimental area for work on passive-hybrid buildings, avoiding both extremes. Buildings can be broadly described as passive, active and hybrid buildings: non-air conditioned, air conditioned, and a mix of both. The building typologies etc of these three categories differ immensely [11]. Few realize what potential exists for economic and ecological benefits from a passive-hybrid approach.

[1]assuming 20% for cooling and 10% for lighting
[2]assuming cooling energy and lighting energy consumption in the range of 10-35%

The need for a strategic research

This paper emphasizes the need to explore the gap pertaining to vernacular, passive and low energy architecture. There are four main heads under which the work can be advanced.

Qualitative Analysis of Various Attributes of Passive Architecture

Qualitative analysis has been the first step in understanding principles of passive and vernacular architecture and in the formulation of guidelines. Nevertheless, these theoretical observations are always in a context of time and use with limited relevance to modern buildings. Mofidi has done a chronological analysis of climate responsive architectural elements. He has analysed, qualitatively, design strategies for passive architecture in arid climates, examining geometrical, morphological, spatial and textural merits in their response to the climate, to form guidelines for climate responsive design [24]. Similar observations in city planning, extensive use of shading elements, effective use of thermal mass, and building designs allowing for varying ventilation patterns according to seasons have been made for the hot arid climate of Jaisalmer, India [25]. Ahuja and Rao [26]have discussed the key climate responsive design strategies in a hot-dry climate based on qualitative observation. Passive-cooling techniques such as down draught evaporative cooling, night time ventilation, ground coupled pre cooling of air, and wind catchers have been in use in the Middle East and Central Asia and are well documented. The element of quantitative measurement is often absent from such studies. Adapting such findings in modern buildings is always a process of discovery and experiment, because of the variations in scale and use.

Data logging and on-field experimental analysis

Advances in the field of building sciences provided tools that helped researchers measure all the tangible aspects of passive building techniques. Temperature, humidity and wind data have been recorded using data loggers. One such study conducted by Shanti Priya et al [19] has compared the indoor temperature and relative humidity in a vernacular dwelling to a typical modern dwelling. The data were collected over a period of time during summer and winter months and have also been compared against thermal simulation results. It has been deduced that the traditional building is more naturally comfortable compared to modern building [19]. Doctor-Pingel et al. [27] studied the thermal performance of domes and vaults in brick masonry in a residence cum office building and obtained quantifiable information to analyse the performance of passive design buildings constructed with local materials. Kubota et al [29] conducted field monitoring of indoor and outdoor temperature and relative humidity in two rural vernacular Malaysian raised timber houses and a typical urban brick terrace house. The field measurements pointed to the merits and drawbacks of both the schemes. Kubota et al also discuss the implications of microclimate on lightweight timber structures in urban areas compared to rural areas [29]. Das in a more comprehensive study [30] examined not only bioclimatic but also typological and socio-cultural aspects of courtyard houses of Kolkata, India. The conclusions of the study have provided insight into bioclimatic design components such as the orientation, dimensions of the courtyards, the usage within the space, design of adjacent spaces in relation to the courtyard, temperature and air movement around the spaces etc.

Quantified and recorded data support empirical observations on passive design principles with their practical effectiveness. Quantification also reveals any critical shortcomings in executing the design or the applicability of the design principles. Most research in this category strengthens the prospect of using the data for better bio climatic design of modern buildings. The data need to be validated, for example, through calibrated computational building models, in order to aid effective design of new buildings.

Numerical/computational validation, calibrated models and parametric simulations

Numerical, experimental and computational methods aid in adapting results, discussed above, to functional building design. Recent developments in the field of building thermal and airflow simulation have opened the way to better design of passive and bio-climatic buildings [31]. Sophisticated hygrothermal and ventilation simulation tools have made it possible to evaluate designs without complex experiments [32]. Scott has examined sustainable urban housing in China[33], discussing low-energy building design with the help of various design tools. Pollock et al [34] have shown that parametric simulations conducted at the initial design stage helps to optimize building form and orientation, building materials, shading, and wall widow ratio. These authors have used a coupled, transient simulation approach to model heat transfer and airflow in a generic six-storey apartment in Shangahi and another in Beijing to evaluate the potential of some wind driven cooling techniques [34]. Several studies concern Passive Downdraught Evaporative Cooling (PDEC), the wind catcher or solar chimney. Simulation techniques of analysis and modelling show that thermal, wind and moisture transfer can be made possible by this mode of design [35 - 38].

The technology and literature for passive architecture are not sufficiently well applied at present, but it is probably a question of time. Computer tools for design studies need to be tried out by people with inquiring minds and an interest in environment-friendly architecture. Vernacular architecture offers approaches which can meet the needs of society as a whole.

Indices and Design Guidelines for Passive Buildings

Passive buildings provide thermal comfort without the aid of conventional air-conditioning. They are un-conditioned, naturally ventilated, or bio-climatic buildings. Their time has come and architecture needs to recognize its responsibility. An application manual by CIBSE[39] for naturally ventilated non-domestic buildings lays down strategies for natural ventilation and also provides technical specifications to design openings in such buildings for acceptable Indoor Air Quality. Design guidelines, although they may provide required technical support, cannot be indices to measure the passive potential of a building.

One method of rating passive buildings is to quantify thermal comfort, which in fact offers alarge degree of flexibility in design, and choice of materials, unlike fully insulated air-conditioned buildings. The static model based on PMV/PDD developed by Fanger and the adaptive thermal comfort model by Humphrey have been widely accepted to validate comfort conditions[40]. Singapore's Building Construction Authority's rating system called Green Mark [42] rates conditioned and un-conditioned buildings separately. The conditioned buildings are assessed in terms of envelope thermal transfer value in W/m2. Un-conditioned buildings are rated on their potential for natural ventilation which can be demonstrated using wind tunnel tests or computational analysis [42]. Singapore also has prescribed elaborate guidelines for the same. It has to be noted that natural ventilation is only part of a strategy to achieve comfort conditions in un-conditioned buildings. Other elements in conjunction include thermal mass, controlling natural ventilation, building usage etc.

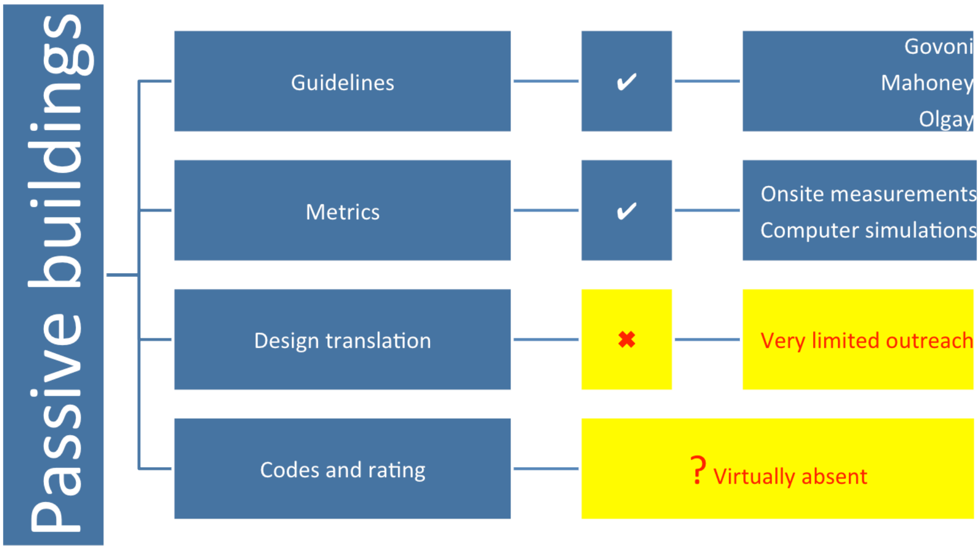

Figure 1: The need for strategic research

Recommendations and Strategies Suggested For Passive Design

There is a need to understand existing building typologies and techniques to develop effective ways to aid the design rating of passive and low energy buildings as opposed to closed air-conditioned buildings.

- A broad data collection and field analysis (where data are not already available) should be done in the geographical area of study. The study should include such matters as climate, building typologies, building materials, housing density, local building byelaws, land usage, building materials, housing density, etc.
- Key technical parameters which have a strong bearing on a building's energy consumption should be identified; including function, usage, occupancy, internal loads and thermal comfort.
- The construction industry is affected by costs related to material supply chain, pace of construction and space requirements to incorporate passive design principles. Therefore, the impact of these factors on infrastructure and the economy needs to be studied in detail.

- The passive design techniques obtained from the research data would be further segregated. The first level would be individual passive techniques and technologies based on first principles or technologies such as e.g., shading, orientation, thermal mass, cross ventilation, ground coupled pre-cooling of air, etc. The second level would be combined technologies adaptable to different building typologies.
- Computational methods would be used to develop calibrated models from the selected tools to validate the data at both levels against the empirical data.

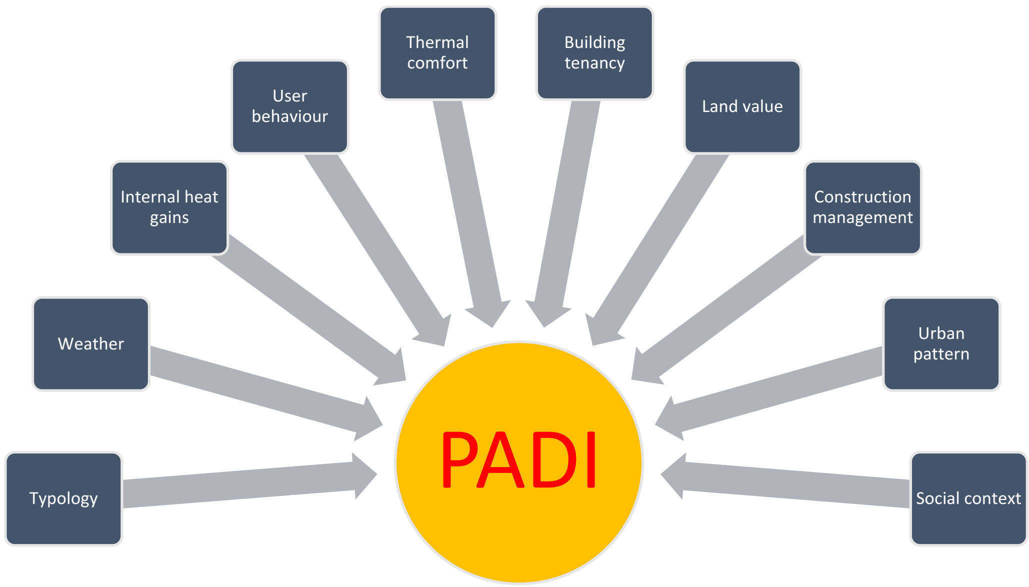

Figure 2: Interpretation of arrival at a Passive Architectural Design Index

- The outcomes from the design and technical studies will form a novel approach of rating the building efficiency, the Passive Architectural Design Index (PADI). PADI establishes a critical threshold limit beyond which the usage of air conditioning in buildings becomes indispensable to achieve thermal comfort (adaptive) indoors.

- Finally a tool can be developed based on "design approach" by the virtue of its passive techniques and technologies encouraging designers to be more ecologically responsible in the way they design. Further, different simulation tools can be used at various stages of design such as dynamic simulation tools for detailed temperature and energy analysis, daylight simulation, and computational fluid dynamics for ventilation design etc. It will help in developing means to use these tools more intuitively rather than to limit them only for obtaining energy certifications.

Development of relevant scale and tools

At present there is a void of such kind of database that integrates design, evaluation and energy standards at the same time. There is a need for establishing reliable methodologies to evaluate innovative passive and low energy techniques. This data can then be used to complement national energy codes like ECBC. Then every other building designed can successfully incorporate trustworthy passive architectural features at its capacity. A new Passive Architectural Design Index (PADI) has to be developed in the following four tentative categories.

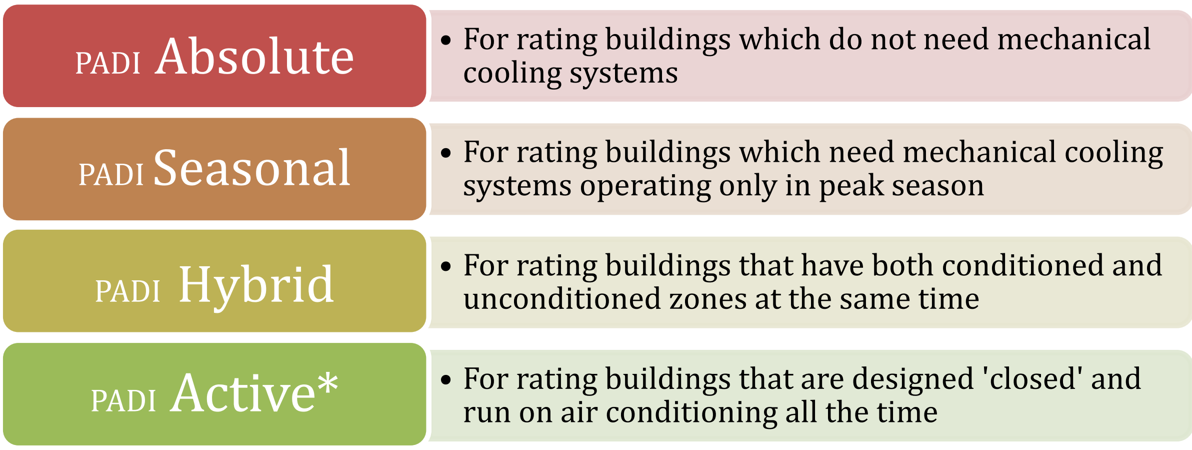

Figure 3: PADI Classification

*Not focus of this research except for the development of a threshold index for such buildings

- The passive building guidelines and bio-climatic charts to aid the design of modern buildings should be reinterpreted in the context of contemporary technical, social and economic factors.
- Development of a model PADI tool that contains a comprehensive database of passive techniques and technologies for select climates, geographical locations, and building types.
- Achieving passive buildings that provide thermal comfort without the use of conventional air conditioning systems in the context of developing cities in the tropics by identifying these buildings and finding means to improve them before converting them into complete air-conditioned buildings.
- Remove the technical, social and economic barriers in order to realize truly passive and low energy buildings.

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