Energy Saving Potential in Building Envelopes through Energy Conservation Building Code and Design Alternatives in Warm and Humid Climate

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Abstract: Energy usage in commercial buildings significantly adds to the total annual energy consumption of the building sector in India which is growing at a fast pace. A large fraction of energy consumed in buildings is attributed to space cooling systems. Heat transfer through the building envelope leads to higher demand for space cooling and increased electricity usage for space cooling systems which further leads to higher levels of emissions enabling climate change. In this study, the energy savings potential for commercial buildings through the implementation of Energy Conservation Building Code (ECBC) of India has been studied for commercial building envelope in the warm and humid climate zone of India. The existing building envelope is analysed through documentation and a simulation model is created towards the baseline case. A second model is then simulated with ECBC prescriptive requirements using Energy Conservation Measures (ECM) and is evaluated based on energy consumption to analyse the relative performance of building envelope components. The implementation of ECBC prescriptive requirements is found to reduce energy consumption by 15.86% in the baseline case. Further implementation of Design Alternatives (DA) in the building envelope achieved a reduction in overall annual energy consumption by 32.31%.

1 INTRODUCTION

Mass urbanization and expanding population has brought tremendous growth in the building sector in the warm & humid climate of India and it is poised for greater growth in the future. It is estimated that 75% of the buildings required in the upcoming decade is yet to be built, and a study conducted in 2010 estimates that 700-900 million square metres of commercial and residential spaces are expected to be built every year in India (McKinsey and Company, 2010). This large-scale development is resulting in an increasing demand for energy. The building sector in Warm & humid climatic zones of India contributes to approximately one third of the total annual electrical energy consumption in the region (McKinsey and Company, 2010).

Commercial buildings that are being developed in the warm and humid regions consume a significant amount of energy. In the year 2016-17, the commercial sector consumed a total of 98333 GWh which constitutes to about 9.22% of the total energy consumption in India (Central Electricity Authority, 2017). Figure 1 shows the growth in energy consumption in the commercial sector in India.

A major part of the required electrical energy in India is generated through thermal power plants where coal is used as a major source of energy for production. 76.08 % of total power generation in India is based on thermal power plants using coal (Central Electricity Authority, 2018). Generation of power using such fossil fuels leads to emission of GHGs and harmful particulate matter which affect the local as well as global environment, leading to climate change. According to a data collected in 2017 the annual growth rate of CO_2 emissions in India from 2005 to 2016 was 6% with a total emission of 2271.1 million tonnes of CO_2 (U.S. Energy Information Administration, 2012). A study conducted in 2012 estimated that India's net annual CO_2 emission value would reach 2.2GT by 2035, making it the world's second largest emitter of GHGs (U.S. Energy Information Administration, 2012).

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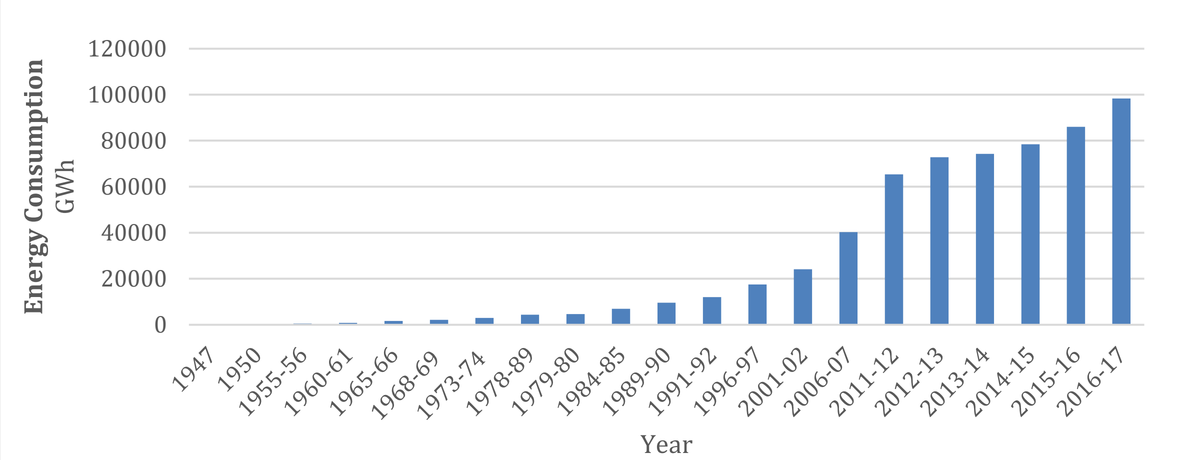

Figure 1: Electrical Energy Consumption growth in Commercial Sector in India (Source: Central Electricity Authority).

Studies have shown that the building sector, which contributes to about 30% of the total national energy consumption, has the potential to control the effect of energy consumption on climate change through the implementation of energy conservation measures. In commercial buildings, energy consumed by HVAC for space cooling, lighting and use of office equipment are major contributors to the total energy consumed. The space cooling in commercial buildings contributes to nearly 50% of the total commercial building energy consumption (International Energy Agency, 2011). In India, air conditioning systems sales has increased from 2.8 million units in 2009 to approximately 30 million units in 2017 (TERI, 2018).

In order to mitigate the harmful effects caused by such large-scale growth on the environment and to promote energy efficiency in the built environment, the energy conservation building code was formulated by the Bureau of Energy Efficiency (BEE). These building codes aim to conserve energy and operation costs to the building owner over time, relative to the building energy performance and operation costs of a conventionally designed building. The Energy Conservation Building Code (ECBC) focuses on energy conservation in commercial buildings due to their high share of energy consumption in the nation.

Several studies have been carried out to analyse the energy conservation potential through the implementation of various energy conservation codes and advanced energy efficiency measures in different climatic zones in India. Chedwal et al. reported that the application of ECBC strategies on the existing hotels in Jaipur, Rajasthan could lead to an annual savings of 27.9 GWh. Furthermore, the application of advanced EEMs resulted in an annual energy savings potential up to 67.04 GWh (Chedwal, Mathur, Agarwal and Dhaka, 2015). In a study conducted for energy conservation potential in the hot and dry climate of Ahmedabad, Gujarat, Jayswal et al. estimated a 31% reduction in space cooling load through the implementation of ECBC for building envelope design (Jayswal, 2012). Another study conducted by Tulsyan et al. focused on six different typologies of commercial buildings in the city of Jaipur, Rajasthan. This study resulted in understanding the variation of energy saving potential with the type of building usage. Energy conservation through ECBC implementation ranges from a minimum of 17% in the case of an institutional building to the highest of 42% in the case of a hospital building in the hot and dry climate of Jaipur (Tulsyan, Dhaka, Mathur and Yadav, 2012). A study was conducted on the practical implementation of energy conservation measures like cool roofs and roof whitening for air-conditioned commercial buildings in warm & humid climatic zone, in the city of Hyderabad which estimated a reduction in space cooling energy requirement by 14-26% (*Xu, Sathaye, Akbari, Garg, Tetali,* 2011).

A number of studies in different climatic zones, have proven the effectiveness of the implementation of energy conservation codes and advanced energy efficiency measures for energy savings in commercial buildings. However, there are limited number of studies related to the implementation of ECBC on commercial buildings in warm and humid climate. The aim of this study is to understand the factors leading to increased electrical energy consumption in a conventional commercial building and to estimate the energy savings potential of an ECBC-compliant building compared to the energy consumption in a conventional commercial building in warm and humid climate. Energy saving potential through ECBC recommended parameters and advanced energy efficiency measures for the building envelope has been studied for the demonstration building.

2 ENERGY CONSERVATION BUILDING CODE OF INDIA

2.1 Overview

The Bureau of Energy Efficiency (BEE) is an agency initiated by the government of India under the ministry of power. The role of BEE is to introduce codes and standards for the efficient use of energy in India. One such initiative was the launch of Energy Conservation Building Code (ECBC) in 2007 with the objective of reducing the impacts of increasing energy consumption and carbon emissions which ultimately leads to a larger problem of climate change. ECBC provides nominal guidelines and requirements for energy efficient design of buildings through several approaches.

A building with commercial use is classified as per the functional requirements of its design, construction, and use into the following categories such as Hospitality, Healthcare, Assembly, Business, Educational, Shopping Complex, and Mixed-use Building. The energy efficiency criteria in commercial buildings is achieved by implementing certain energy efficiency measures in the design of building systems. The code specifications are broadly applicable to four main building systems; Building envelope, HVAC and mechanical systems, lighting (interior and exterior), and electrical power generators and motors.

ECBC sets a few mandatory requirements and provides two approaches for compliance; Prescriptive Method and Whole Building Performance Method. The Prescriptive Method requires a building to meet all prescribed minimum or maximum values for all building systems whereas in the Whole Building Performance Method, the building is said to be ECBC-compliant when the net annual energy consumption value of the proposed simulation model is lower compared to that of the standard design model. Under this approach, it is not necessary for the design to follow the individual ECBC prescribed requirements.

2.2 Implementation of ECBC

Implementation of ECBC in commercial buildings in India can be proved instrumental in energy conservation and energy efficient design. While the Central Government has powers under the Energy Conservation Act, 2001 to notify standards energy consumption in commercial buildings, the state governments can amend the code to suit local or regional needs and notify the same.

In the state of Karnataka, mandatory Energy Conservation Building Code compliance was adopted for commercial buildings in 2014 by the Karnataka Renewable Energy Department Limited under the Energy Department of the Government of Karnataka. Several modifications were made to the code by The Energy Department to suit the local requirements in Karnataka.

2.3 ECBC for Warm and Humid Climate Zone

All prescriptions given by the code are specific to the climate zone in which the proposed building is situated. All regions of the country have been classified into the following five climatic zones: warm-humid, composite, temperate, hot and dry, and cold. The varying profile of each climate zone demands different code prescriptions to facilitate the thermal comfort requirements. ECBC prescribes material requirements for each component of the building envelope, specifically for ECBC compliance in the warm and humid climate zone. For instance, the maximum permissible U-value of a roof assembly in the warm and humid climate zone is prescribed as 0.33 W/m^2K and that of an opaque external wall is 0.40 W/m^2K. The maximum allowed Energy Performance Index (EPI) ratios for all ECBC-compliant buildings in warm and humid climate is 1.

3 METHODOLOGY

A five-storey commercial building has been chosen for detailed analysis and demonstration which is located in Manipal, Karnataka. The demonstration building envelope has extensive glazed facade and the heat gain conditions can be well understood in such a layout. The data of energy consumption due to each building envelope component is studied for further understanding of the factors that influence variation in energy consumption. Implementation of ECBC on commercial building envelopes has been studied and this study aims to contribute towards the energy saving potential especially for the warm and humid climatic zone in India.

3.1 Climate at Study Location

Figure 2 shows the monthly temperature variation for Manipal where the demonstration building is situated and is a broad representative sample for this climate.

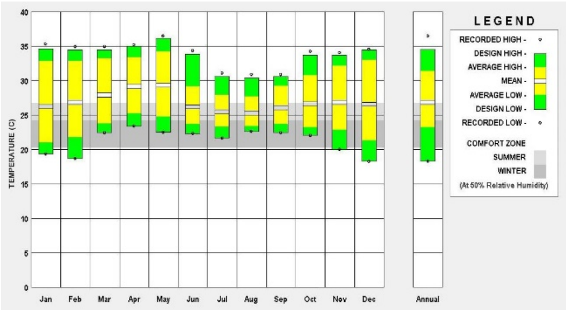

Figure 2: Monthly temperature variation in Manipal.

Manipal lies in the district of Udupi in southern coastal Karnataka which experiences tropical warm and humid climate. The temperature reaches a maximum of 37°C with an average humidity of 72% during the summer months from March to May. Heavy rainfall of over 4000 mm is experienced in the months of June to September with peak humidity level up to 90%. The average annual humidity is 77% and the and mean annual temperature is 29°C. Heavy winds are common during the monsoon, reaching a peak wind speed of over 12m/s.

3.2 On-site Documentation of Demonstration Building

Figure 3: Exterior view of demonstration building.

On-site documentation of the building was carried out to collect data on the building dimensions, annual energy consumption, occupancy, building materials etc. Figure 3 shows the exterior view of the demonstration building.

Table 1: Lists details of the demonstration building that have an impact on the energy consumption.

Building Information	Details
Location	13°20'48.4"N 74°47'03.1"E
Site area	910 m^2
Building size	G + 4
Total built-up area	2190 m^2
Ground coverage	38.5%
First floor carpet area	500 m^2
Building facing	North-West
Operating schedule	9:00 AM – 9:00 PM
WWR - NW	0.85
WWR - NE	1.00
WWR - SW	0.71
WWR - SE	0.00

The demonstration building is a G+4 shopping centre majorly occupied by departmental stores. The building has a ground coverage of 350m^2, total built up area of 2190m^2 and total carpet area of 1900m^2 which is majorly occupied by departmental stores.

The stores have an operation time of 12 hours, from 9:00AM to 9:00PM. The upper floors have a larger floor plate area compared to the ground floor which is achieved by a 3-meter cantilever on all sides. The longer front façade of the building faces the north-west direction and the structure incorporates complete glass facades on two sides with an average window-to-wall ratio of 0.62. A small central atrium from the ground floor to the third-floor acts as a good source of daylighting. Table 2 lists the material specifications for each of the building-envelope component.

The building envelope majorly consists of the opaque walls, roof slab and vertical fenestrations. The opaque walls have an overall u-value of 2.03 W/m^2K and are constructed with 150mm thick concrete masonry units with interior and exterior plaster thickness of 10mm. The building roof and floors are 150mm thick reinforced concrete slabs with a thermal transmittance (u-value) of 2.97 W/m^2K. Exterior glazing curtain wall is used as vertical fenestration with clear glass of 10mm thickness and SHGC of 0.86.

Table 2: Building Material Specifications.

Building component	Material(s)	Detailing
Wall	Concrete masonry U-value 2.03 W/m²K	200mm thick masonry (concrete block) wall + 10mm cement plaster in interior(s) and exterior(s).
Vertical Fenestration	Exterior glazing U-value 5.54 W/m²K SHGC 0.76	Full height exterior clear glass glazing 10mm thickness
Floor	RCC flat slab U-value 1.8 W/m²K	Reinforced concrete slab 100mm thick
Roof	RCC flat slab U-value 1.8 W/m²K	Reinforced concrete slab 100mm thick

The building plan follows a symmetrical layout with a simple grid for columns placement. The building entrance is on the north-west facade of the building. A central atrium of 3.0m x 7.8m divides the plan into two equal rentable areas while also serving as a good source of daylight. The building consists of one elevator and one staircase that reaches up to the 4th floor. The average floor-plate area is 320m^2 on the ground floor and 500m^2 on all above floors. Figure 4 shows the typical floor plan of the demonstration building.

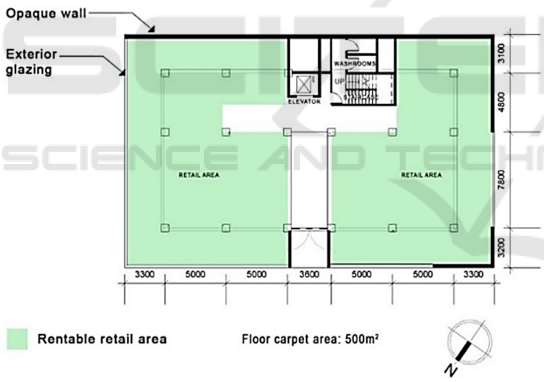

Figure 4: Typical floor plan.

3.3 Building Energy Simulation

In this study, the annual energy consumption of the simulated model of the proposed design following ECBC recommendations is compared to that of the existing energy consumption value of the demonstration building. Building energy simulation is carried out using a BEE approved simulation software, eQUEST, which enables detailed building energy analysis. The software utilizes a DOE-2 simulation engine and it also includes a building creation wizard, a graphical result display, and an EEM wizard. The 3D simulation model of the demonstration building made on e-QUEST is shown in Figure 5.

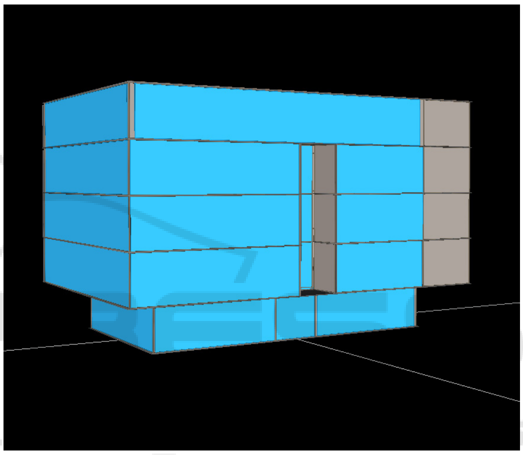

Figure 5: eQUEST simulation model of demonstration building.

As per the onsite documentation of the building envelope and the utility bills of the building, the baseline case with all parameters of the building envelope and material specifications is used as input and modeled. The simulation model is calibrated with the onsite documentation and validated towards ECBC compliance and ECM Design Alternatives for building envelopes in warm & humid climatic zone. The prescriptive requirements are achieved by implementing design strategies such as increasing the thickness and addition of insulating materials to the roof(s) and opaque walls, utilising glazing with lower SHGC in vertical fenestrations and so on. Table 3 lists the prescriptive requirements for building envelope components of ECBC compliant retail buildings in warm & humid climatic zone of India.

Table 3: ECBC prescriptive requirements for building envelope in warm and humid climate.

Building Envelope Component	Parameter	Prescriptive Requirement
Opaque External Wall	Maximum U-Value	0.40 (W/m^2K)
Roof	Maximum U-Value	0.33 (W/m^2K)
Vertical Fenestration	Maximum SHGC	0.27
	Maximum U-Value	3.00 (W/m^2K)

The second model is simulated after the implementation of ECBC prescriptive requirements on e-QUEST to arrive at the new energy consumption value. The difference between the energy consumption values of the first model and the second model gives the total energy saved through the implementation of the energy efficiency measures used to attain the ECBC requirements.

4 RESULTS AND DISCUSSION

On simulating the first model with existing building parameters as a baseline, an annual electrical energy consumption value of 547,230 kWh with EPI of 249.8 $kWh/m^2/y$ was obtained. Majority of the consumed energy could be attributed to space cooling which constitutes to 35.44% of the net building energy consumption. Energy conservation measures for the building envelope presents potential for reduction in energy consumption due to space cooling. Furthermore, it was noticed that maximum energy consumption occurs in the months of March, April and May which are the hottest months of the year for this climatic region which leads to maximum requirement for space cooling through HVAC systems.

On obtaining these values and identifying the major factors that cause an increased consumption of energy during several months of the year, certain energy conservation measures (ECMs) specific to the building envelope were implemented as prescribed by ECBC in order to reduce the energy demand by HVAC systems. The ECMs included aspects such as change in the U-value of opaque walls, glazing and roof which are achieved by altering the material or the building component specifications. Once the changes were applied to the second model, the building performance was simulated on eQUEST. The changes made in the second model resulted in reduction in energy consumption compared to the model simulated with existing parameters. The percentage of energy conserved through the implementation of each ECM was calculated. Table 4 lists the percentage of reduction in energy consumption achieved through each ECBC prescriptive requirement change in the building envelope and the cumulative energy consumption.

Table 4: Energy savings through each ECBC prescriptive building envelope ECM.

Parameter	Baseline Case	ECBC Prescriptive ECM	Energy Savings (%)
Wall thickness – U-value	200mm thick concrete masonry wall U-value 2.03 W/m^2K	300mm thick aerated concrete block wall U-value 0.40 W/m^2K	7.28%
Roof slab thickness – U-value	100mm thick reinforced concrete slab U-value 1.8 W/m^2K	115mm thick reinforced concrete slab with 60mm thick over-deck extruded polystyrene insulation U-value 0.32 W/m^2K	4.78%
Glazing type – U-value	10mm single glazing U-value 5.54 W/m^2K	20mm double glazing - 6mm glass with 8mm air cavity U-value 3.0 W/m^2K	5.84%
Glazing type – SHGC	10mm single glazing SHGC 0.76	20mm double glazing - 6mm glass with 8mm air cavity SHGC 0.27	5.84%
Cumulative Total			**Total 15.86%**

It is observed that change in the properties of opaque walls lead to maximum reduction in energy consumption due to space cooling requirement. For instance, reduction of U-value by using 300mm thick aerated concrete blocks in opaque walls leads to reduction of building energy consumption by 7.28%

and addition of insulation in the roof slab to reduce the U-value, reduced energy consumption by 4.78%. Similarly, since nearly half of the building incorporates a glass façade, changing the vertical fenestration to a double-glazed unit to reduce both the U-value and SHGC achieved a reduction in building energy consumption by 5.84%. However, the glass façade of the demonstration building faces the north and north east directions and naturally receives a lower amount of direct sunlight and hence a building receiving direct sunlight could benefit more from such lowering of the U-value and SHGC of glazing. A total of 15.86% savings in energy is achieved through the implementation of ECMs based on ECBC prescriptive requirements leading to a reduced annual energy consumption of 460,439 kWh compared to 547,230 kWh in the baseline case. The results obtained can be viewed in terms of the classification of building envelope component where opaque walls seem to have a higher effect of heat gain compared to the transparent glazing. This result, however, is specific to this demonstration building and is dependent on the type of building, orientation and overall window to wall ratio. Figure 6 shows the comparative effect of each ECBC prescriptive ECM for the building envelope.

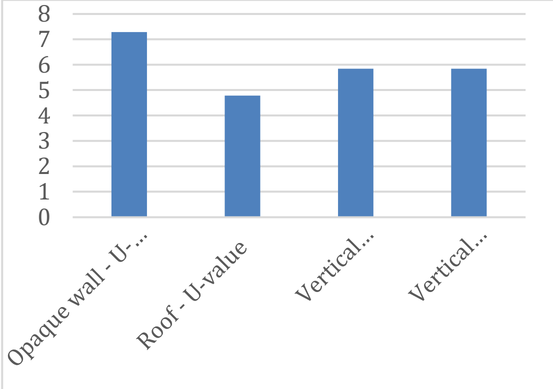

Figure 6: Comparative effect of ECBC prescriptive ECM for building envelope.

Further implementation of Design Alternatives (DA) for building envelops on the demonstration building model such as the introduction of cool roof, thermal insulation of walls and reduction of window-to-wall-ratio yielded savings in energy in addition to the savings through ECBC prescribed ECMs. Percentage of energy savings through each DA and cumulative total savings of DAs along with ECBC prescriptive ECMs is listed in Table 5.

Table 5: Energy savings through each DA for building envelope and cumulative savings.

Parameter	**Baseline Case**	**ECBC Prescriptive ECMs Implemented**	**Design Alternatives**	**Energy Savings (%)**
Wall thermal insulation	200mm thick concrete masonry wall - U-value 2.03 W/m^{2}K	300mm thick aerated concrete block wall - U-value 0.40 W/m^{2}K – No insulation	300mm thick aerated concrete block wall with 60mm thick thermal insulation	13.62%
Cool Roof	100mm thick reinforced concrete slab - No coating - U-value 1.8 W/m^{2}K	115mm thick reinforced concrete slab with 60mm thick insulation - U-value 0.32 W/m^{2}K - No coating	115mm thick reinforced concrete slab with 60mm thick insulation and reflective coating - Solar reflectance 0.65	8.22%
Window-to-Wall-Ratio	Overall WWR of 0.62	Overall WWR of 0.62	Overall WWR of 0.40	10.47%
DA + ECBC Prescriptive ECM Cumulative total				**32.31%**

Addition of thermal insulation to the west and south-west facing walls reduces internal heat gain and consequently reduces annual energy consumption by 13.62% and the increase in roof solar reflectance to create a cool roof resulted in 8.22% savings. To reduce the amount of heat-gain due to direct sunlight through vertical fenestrations, reduction in the over WWR of the building envelope to 0.40 reduces energy consumption by 10.47%. Simulating the model with the combined effect of both the ECBC prescriptive ECMs and DAs gives an overall annual electricity consumption of 401,502 kWh with 32.31% annual savings.

5 CONCLUSIONS

Through this study, it is evident that there is a significant potential for energy conservation through the implementation of ECBC in commercial buildings. The research is carried out for a demonstration building situated in the warm and humid climate zone in Karnataka, India and is a broad representative sample for this climate and a similar methodology can be followed for any Indian city with similar climatic conditions. Changes made to the building envelope by following ECBC recommendations for the building envelope achieved a reduction in annual energy consumption by 15.86% and additional implementation of DAs lead to an overall annual savings of 32.31%. It is concluded that the building envelope is a key determinant factor in the energy consumed in commercial buildings mainly required for space cooling. With a large part of the building stock in India yet to be built, it is important to implement energy conservation measures in all upcoming buildings to achieve healthy growth and a sustainable development of cities in the country.

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