Building energy index and morphology: Critique on urban office building stock of Colombo Municipal Council region

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Abstract

Rapid urbanization exaggerates the urban building stock in cities and enhances the formations of Urban Heat Islands (UHI). City of Colombo is an evidence for existence of an UHI with an increasing trend in expansion of its boundaries. In the year 2005, the extent of Colombo's UHI was 42% and an annual increase of 1.75% was predicted. Moreover, a burgeoning trend is apparent in the extent of built-up area from 74% in the year 2005 to 97.3% by the year 2013.

Expansion of built-up area and emergence of compact urban milieus increases energy indices of the building stock. With the present urban development strategy of the country towards a mega-polis initiation, it is significant to explore urban building stock and its status of energy consumption.

In this study a walkthrough field investigation was performed in 35 Grama Niladhari (GN) divisions in Colombo Municipal Council region. The structure of the survey was organised in relation to geographical information system (GIS) data and land use maps of the CMC region. Data was collated to formulate a comprehensive database on morphology of office building stock comprising major physical parameters and energy indices.

Results revealed the office building stock is primarily composed of Air-conditioned office spaces and of which 78% contains naturally ventilated common spaces. In this stock 53% and 13% of the office buildings have an annual average building energy index above 200KWhm^{-2} and 300KWhm^{-2} respectively. Moreover 75% of the office buildings are attached with another built structure and fenestration details of the critical west façade is composed of glazed, Aluminium cladding and combination of Aluminium cladding with glazed. Office buildings with Aluminium cladding facades and combination of glazed surfaces are evident for 42% and 35% of heat transferring west facades of the building stock. Thus the findings reveal a significant relationship between the morphology and high energy indices of the office building stock.

Introduction

Urban heat island (UHI) phenomenon describes the excess warmth of the urban atmosphere and surfaces compared to the non-urbanized rural surroundings[1]. urbanization inflates the urban building stock in cities and enhances the formations of UHI. City of Colombo is an evidence for existence of an UHI with an increasing trend in expansion of its boundaries. In the year 2005, the extent of Colombo's UHI was 42% and predicted for an annual increase of 1.75%. Moreover, an increasing trend is apparent in the extent of built-up area from 74% in the year 2005 to 97.3% by the year 2013[2]. Buildings are considered to be one of the main reasons for the UHI effect. Building masses increase the thermal capacity which increases the city temperature. Further anthropogenic heat sources such as air conditioners and road traffic add to the rise in temperatures in urban areas[3]. Moreover, Expansion of built-up area and emergence of compact urban milieus increases energy indices of the building stock. This is due to the increased use of air conditioning and artificial lighting of the building interiors. With the present urban development strategy of the country towards a mega-polis initiation, it is significant to explore urban building stock and its status of energy consumption.

Many studies have performed to identify the relationship between energy consumption and the characteristics of the existing building stock[4-6]. In addition, the energy consumption of the building stock has been explored in relation its geometric features such as building shape, compactness and orientation. Moreover, the energy consumption of the office buildings have been explored with the energy performance of the building envelop and fenestration details.

Limited research attention had given to the energy consumption of the building stock in Sri Lanka. Few studies have focused on lighting energy efficiency and indoor environment quality of the office buildings in Colombo. Another study has analysed the building performance in terms of

energy, indoor environment, environment degradation and economic aspects by using building. These studies have specifically focused on analysing one aspect of the building stock in terms of energy consumption. With the present urban development strategy of the country towards a mega-polis initiation, it is important explore urban building stock and its status of energy consumption.

Moreover, many researches on energy consumption and the building stock has followed a common research approach by analysing the available information of the buildings stock such as mapping databases, floor space statistics, energy benchmarks and measured energy consumption reported in display energy certificates. However the actual characteristics of the existing building stock have not been taken into consideration in analysing the energy consumption of the building stock.

Thus it is vital to investigate the actual building stock in tropics as 70% of the global urbanization will be concentrated in developing countries of Asia and Africa by the year 2030[7]. Hence this study is focused on mapping a nexus between building morphology and building energy index of office building stock in Colombo Municipal Council region, which represents the highest building density of the country.

Colombo Municipal Council Region

Colombo Municipal Council Region which is the focus area of this study is located in the Colombo District (6°55' N, 79°51' E at a latitude of 8m), in Western province of Sri Lanka. This district represents the highest population density of the country within the range of 2001 to 4000 persons/Km2. Colombo as the commercial capital is composed of a residential population of 647,000 with 700,000 floating population. Approximately 50% of the floating population commute for employment. The maximum office building stock of the Colombo district is concentrated in the Colombo Municipal Council region which contains 35 Grama Niladhari (GN) divisions. Thus the study investigates the office building stock distributed among 35 GN divisions of the CMC region.

Characteristics of office building stock in the study focus

Office building stock of CMC region is primarily composed of air-conditioned office spaces and of which 78% contains naturally ventilated common spaces. In this stock 52.80% of the office buildings have annual energy use intensity more than 200KWhm.$^{-2}$ of which 12.64% of the buildings are more than 300KWhm.$^{-2}$ Moreover only 25.84% of the office buildings have annual energy intensity less than 150KWm.$^{-2}$. The average Building Energy Intensity of CMC is 211.59 KWhm^{-2} per annum and the average building height is 6 floors.

Data related to office building characteristics were collected based on the building orientation, physical configuration, building form, fenestration details, number of floors, working hours, space conditioning system and construction materials.

Morphology of Office building stock in CMC region

a. Building geometry and Physical configuration

Building form influences energy consumption. Thoughtful articulation of shape and form is needed to minimize the energy consumption of the buildings[8]. Hence it is significant to understand the existing plan forms of the office building stock. Six types of office building plan forms were identified and these plan forms can be generalized as basic plan forms and composite plan forms.

The basic plan forms consist of square, linear, and circular plan forms. Composite plan forms derived from a combination of basic plan forms and they demonstrate L, U shapes and trapezium plan forms. Within this stock 85.05% of the buildings demonstrates a combination of linear and square plan forms. In these basic plan forms 62.07% and 22.98% are with linear and square plan forms respectively. Circular and trapezium plan forms are equal percentage of 2.30% in the building stock. These composite plan forms in CMC region consists of 2.29% of U and 8.045% of L shape plan forms respectively. Graphical representation of the basic and composite plan forms and its combinations are shown in Fig 1

When considering the positioning of these buildings, the building stock represents a combination of attached and detached building forms. Of which 63.22% of the buildings are detached buildings and 36.78% of the buildings are attached with another structure at least from one side. Buildings with both sides attached to another building have an average energy index of 210.04 KWhm-^{2}.

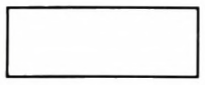
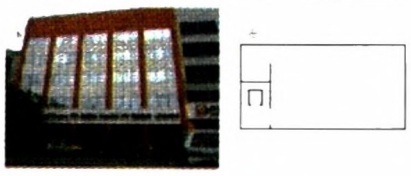
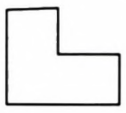
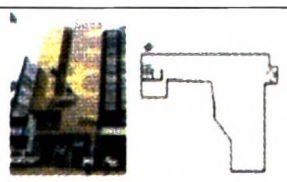
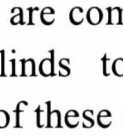
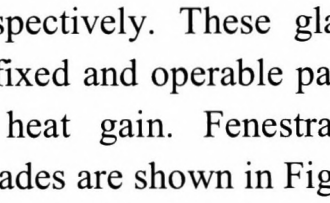
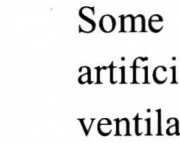
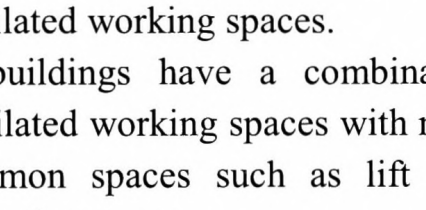
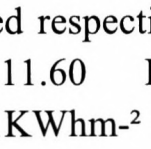
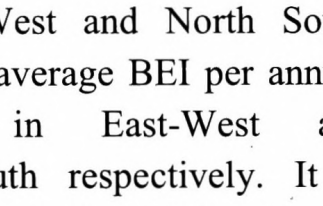
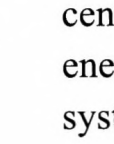
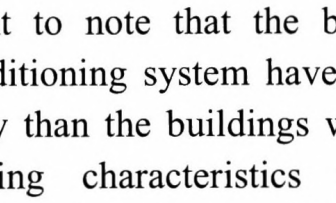
Basic plan forms		**Composite plan forms**	
Linear plan forms 		L shape Plan form 	
62.07%		8.045%	
Square Plan form 		U shape plan form 	
22.98%		2.29%	
Circular plan form 		trapezium plan form 	
2.30%		2.30%	

Fig. 5 Existing Building Geometry of the office building stock in CMC Region

b. Building orientation and building façade

East and west facades in the tropics are affected by direct solar radiation and influence the solar heat gain into the building interiors. Thus these facades denote critical facades for tropical climates. East and West front facades were found to represent different compositions of glazed and Aluminium cladding. Of which 17%, 26%, 57% are evident for glazed, Aluminium cladding and Aluminium cladding with glazed respectively. These glazed facades are composed of fixed and operable panels with blinds to control heat gain. Fenestration details of these critical façades are shown in Fig. 2. In addition, 41.38% and 13.79% of the office building stock is East West and North South oriented respectively. The average BEI per annum is 211.60 KWhm-² in East-West and 200.21KWhm-² North-South respectively. It is evident that buildings facing East and West facades have higher energy intensity due to the increased cooling load as a result of the direct solar gain.

Building Energy Index and morphology of the office building stock

Building Energy Index is a quantitative measure to evaluate the energy consumption of a building within a period of a year in relation to its floor area. The unit of this index is kWh/m2/annum. Corresponding building energy indices of stock were calculated and the Fig. 3 represents the building with the highest Energy Index of this building stock. It is evident that the Building Energy Index of this stock varies within the range of 100 – 400 kWh/m2/annum. Of which 52.8% and 12.84% corresponds to 200 and 300 kWh /m2/annum respectively.

Building energy intensity of the office buildings vary with factors such as number of occupied hours, air conditioning system, amount of equipment used. Office buildings with BEI more than 300 kWh/m2/annum have extended working hours. All the office buildings in CMC region have artificially ventilated working spaces.

Some office buildings have a combination of artificially ventilated working spaces with naturally ventilated common spaces such as lift lobbies, corridors and services areas.

It is significant to note that the buildings with central air conditioning system have less building energy intensity than the buildings with split type system. Building characteristics were further analysed based on the selected office buildings in different building energy intensity ranges as shown in Fig. 4. Office building stock of CMC region was categorized based on the BEI per annum. The segregated BEI ranges were 100-150 KWhm-²,150-200 KWhm-² and 250-300 KWhm-². The selected buildings of A, B, C, D and E represents the office buildings stock of the categorized BEI range. The selected buildings have the same number of occupational hours and occupants. Further the selected representative office buildings denote the combination of fenestration details of cladded Al, fixed Glass panels, combination of fixed glass and Al panels and operable windows.

Orientation	Percentage	Average BEI
East-West	41.38%	211.60KWhm-^{2}
North-South	13.79%	200.21KWhm-^{2}
North East-South West	25.59%	200.08KWh-^{2}
North West-South East	19.24%	205.69KWhm-^{2}
Building fenestration details of front facade		
57% of buildings are cladded with Aluminium and glass.	26% of the buildings are Aluminium cladded throughout the façade	17% of buildings have full length glass openings.
		

Fig. 6 Building Orientation and Buiding Fenestration details

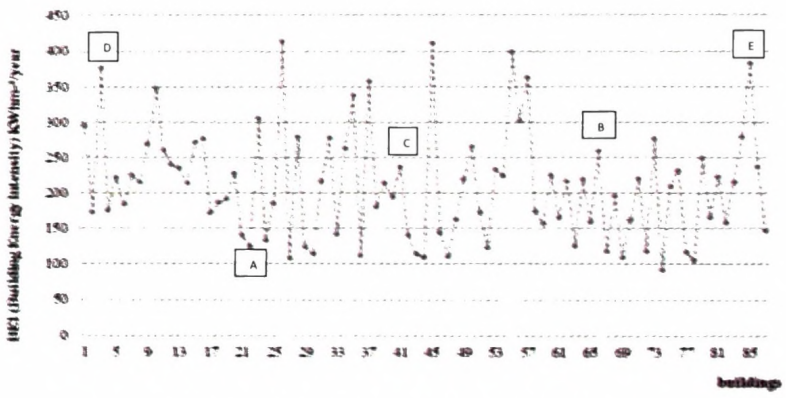


Fig. 7 Building energy Intensity

he plan form of the representative office buildings consist of square and linear plan forms. The selected buildings have a combination of naturally and mechanically ventilated buildings. Representative building within the range 100-150 KWhm-^{2} has both mechanical and natural ventilation to condition the space. Selected buildings of D and E which represents BEI category of above 300KWhm-^{2} per annum use split type air conditioners to condition the spaces. Whereas, B and C representative buildings of BEI category of 200-250 KWhm^{-2}/per annum and 250-300 KWhm-^{2} use central air condoning system to condition the space mechanically.

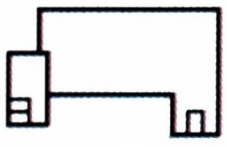
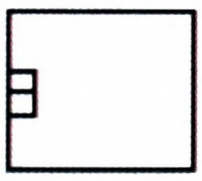
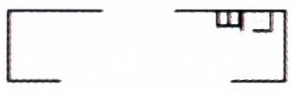
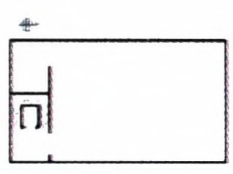
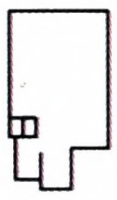
Moreover, B, D and E buildings which represents the BEI category above 250KWhm-^{2}/per annum is east west oriented and the front building façade has a combination of fixed glazed panels, Al and glass claddings. This denotes the building façade and orientation of the buildings has a significant influence on building energy intensity.

5.0 Conclusion

Aim of this study is to develop a comprehensive data base of the morphology of office building stock in CMC region, which represent the highest built density in the country. The office building stock of CMC region is comprised of basic and composite plan forms. Basic plan forms consist of linear, square and circular plan forms. Within the building stock 85.05% of the buildings demonstrates a combination of linear and square plan forms and the average energy intensity per annum is 211.59 KWhm-^{2}.

Based on the collected data it was revealed that the majority of the office buildings are facing East-West orientation of 41.38% and NE-SW orientation of 25.59%. Moreover, buildings facing east west orientation have the highest average building energy intensity per annum of 211.60KWhm-^{2} which is due to the direct solar heat gain.

Fig. 8 Office Building Characteristics in CMC

BEI 100-150 KWhm^{-2}/ per annum	**BEI 200-250 KWhm^{-2}/ per annum**	**BEI 250-300 KWhm^{-2}/ per annum**	**BEI 300KWhm^{-2}/per annum above**	**BEI 300KWhm^{-2}/per annum above**
BUILDING A	**BUILDING C**	**BUILDING B**	**BUILDING D**	**BUILDING E**
 **111.95KWhm^{-2}/per annum**	 **218.70KWhm^{-2}/per annum**	 **262.14KWhm^{-2}/per annum**	 **376.25 KWhm^{-2}/Per annum**	 **381.64 KWhm^{-2}/per annum**
 Square plan form	 Rectangular plan form	 Rectangular plan form	 Rectangular plan form	 Rectangular plan form
NW-SE	NE-SW	East-West Orientation	East-West Orientation	East-West Orientation
Glass operable windows	Operable glass windows	Fixed glass panels	Al cladded with glass operable windows	Al cladded with glass operable windows
Detached building	Detached building	Detached building	Attached from one side	Detached building
Mix mode building	Mechanical ventilation	Mechanical ventilation	Mechanical ventilation	Mechanical ventilation
Artificial lighting and natural lighting	Artificial lighting and natural lighting	Artificial lighting	Artificial lighting	Artificial lighting
Split type A/C and Natural ventilation	Central A/C	Central A/C	Split type A/C	Split type A/C
2 lift	2 lift	2 lift	1 lift	2 lift
normal working hours week days:	normal working hours week days:	normal working hours week days:	normal working hours week days: Saturday	normal working hours week days: 8.00a.m-5.30p.m
120 people	110 people	140 people	170 people	100 people
16years old	15 years old	24 years old	32 years old	18 years old

The majority of the office building stock of CMC region consist of detached buildings of 63.22% and 36.78 % of buildings are attached with another structure from one side or both sides. Buildings which are attached to another structure from both sides have relatively high BEI per annum (211.07KWhm-^{2}) than the buildings attached to another structure from one side (210.04 KWhm-^{2}). This is due to the limited exposure of the direct solar gain from outside.

Conventional wisdom reveals that the detached buildings have higher building energy intensity than the buildings with attached buildings due to the larger exposed area for solar heat gain. Moreover, factors such as orientation, number of occupied hours, level of occupancy, and fenestration detail of the front facades and method of ventilation influence the energy consumption of the building. Furthermore critical facades represent the front of the building due to easy access from the road. These East and West facades represent different compositions of glazed and Aluminium cladding. Of them, 17%, 26%, 57% are respectively glazed, Aluminium cladded and Aluminium cladded with glazing. Fenestration details along with the window orientation, window area, room dimensions, size and position of shading needs to be detailed further in this study.

This study will be a platform to develop a fundamental database matrix, focusing on existing office building stock of CMC. Thus the findings reveal a significant relationship between the morphology and high energy indices of the office

building stock. Moreover this will provide an outline of the office building stock and its characteristics in relation to its energy intensity.

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