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MAPPING A NEXUS BETWEEN URBAN BUILT FORM AND ENERGY INTENSITY: CASE OF OFFICE BUILDING STOCK IN COLOMBO MUNICIPAL COUNCIL OF SRI LANKA

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Abstract

Residential and commercial buildings consume one fifth of the world's total energy and accounts for one third of the global greenhouse gas emissions. Annual Energy consumption in Sri Lanka has rapidly increased over the past years. Building accounts for 64.7% of the total national energy consumption in 2013 and 26.1% of the energy is consumed by non-domestic buildings. Thus highlights the importance of investigating the energy consumption of urban office building stock.

Majority of the office buildings in Colombo are dominated by air-tight envelopes with glazed facades. . Thus demands for active systems to condition the indoor environments. This trend in the office building stock has originated energy intensive office interiors with an average annual building energy index of 250 KWh/m2.Although 80% of the urban building stock in Colombo Sri Lanka is composed of office buildings there is a limited research attention on the energy behavior of this building stock. Thus this study focuses on mapping a nexus between urban built form and energy intensity of the office building stock in Sri Lanka.

Physical configuration of the building stock varies along the main arteries of the study focus area. Of which 53% and 47% of the buildings have a shallow and a deep plan form respectively.75% of the office buildings are attached with another structure and these physical configurations have a direct impact on the Building Energy Index. Further fenestration details of the critical façade have different compositions of glazed and Aluminum cladding Of which 17%, 26%, 57% are evident for glazed, Aluminium cladding and Aluminium cladding with glazed respectively. Results indicated that the energy intensity of the buildings associated with the orientation, fenestration detailing of the critical faced and building form.

Keywords: *office buildings, energy consumption, building form typologies*

1. Introduction

Residential and commercial buildings consume one fifth of the world's total energy and accounts for one third of the global greenhouse gas emissions (IEO, 2010). During the past half a century new building construction has increased and consequently affected the energy demand from buildings due to the present practice on energy intensive artificially conditioned building interiors with mechanically ventilated, artificially lit and air conditioned mechanisms.

In office buildings, energy is mainly used for lighting, cooling and heating. Cooling energy demand of a building is affected by heat gain internally (electrical lighting, building equipment, and people) and externally (solar radiation, air temperature, and wind) and also heating energy demand is affected by heat loss through facades (Susorova et al., 2013). Many studies have investigated the thermal performance of building forms in respective to climates (Steadman et al., 2000, Steemers et al, 2003).

The research on building shape proposes the shape Coefficient is directly proportionate to its external wall surfaces. The relationship between the building shape and energy consumption changes with the climatic conditions. In rigorous climates a linear correlation is evident. However, there is no significant relationship in mild climates (Depecker et al. 2001).

Other influencing building configuration factors on energy consumption are focused on façade formations such as window orientation, window to wall ratio (WWR) and geometric factors on internal spaces such as a ratio of room width to depth. These design strategies were investigated using energy stimulations for different climate zones. A model room of a typical office building has been simulated to identify the annual energy consumption and the results show that energy consumption in hot climates are significantly affected by the façade formations and geometric factors (Susorova et al., 2013).

Most of these studies on the impact of building form on energy consumption have followed a common research approach focusing on different climates, seasonal changes with simplified built forms. However a less research focus towards actual office built forms and existing building stock is evident.

Although few studies represent the energy consumption patterns of the built forms in tropical climates (Charde et al., 2013, Fasi et al., 2015, Steemers et al., 2010), it is vital to investigate the actual building stock in tropics as the 70% of the global urbanization will be concentrated in developing countries of Asia and Africa by the year 2030 (UNFPA, 2007).

Since the current urban expansion of the city of Colombo is planning towards the implementation of Megapolis development, which will initiate a burgeoning trend in the construction of more and more urban office buildings in the Colombo Municipal Council Region. However a limited research attention is evident on the impact of the office building forms and energy consumption pattern. Thus it is vital to explore the existing office building stock to comprehend a relationship between the physical configuration of the built forms and its energy demand.

Current building stock in Sri Lanka accounts for 64.7% of the primary energy consumption, of which 26.1% is consumed by non-domestic building sector (SSEA, 2013). Office building stock dominates the urban built forms in the city of Colombo. However unavailability of actual data of this building stock has become a prime restriction in future research. Thus this study focuses on developing a nexus between urban built forms and energy intensity of the existing office building stock in Colombo Municipal Council region.

2. Colombo Municipal Council Region

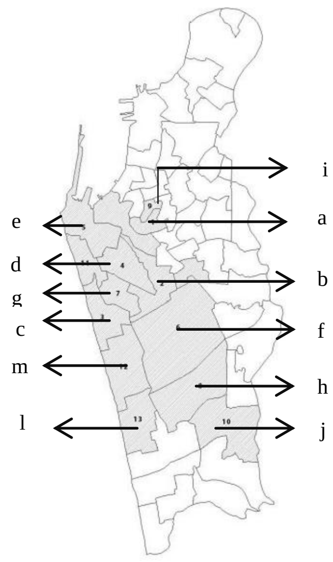
Colombo Municipal Council region which is the focus area of this study is situated in the Colombo district (6°55' N, 79°51' E at a latitude of 8m), in the Western province of Sri Lanka. This district represents the highest population density of the country within the range of 2001 to 4000 persons/Km^2. Colombo as the commercial capital is composed of a residential population of 647,000 with 700,000 floating population (Urban Transport System Development Project for Colombo Metropolitan Region and Suburbs CoMTrans Urban Transport Master Plan). 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.

*2.*1 IT'S CLIMATE

Climate of Colombo is characterised as a tropical monsoon climate with uniformly high temperatures with high humidity. Mean monthly temperature over the year varies from 26°C to 29°C with the highest average in March to April (Maximum temperature 36°C). Mean monthly relative humidity varies from 60% -80% during a year. Colombo experience long hours of sunshine and mean hourly global horizontal radiation varies from 398 to 350 W/m^2 within a year with the highest in the month of March (Maximum hourly global radiation, 1030 W/m^2).

2.2 OFFICE BUILDING STOCK IN CMC REGION

Figure 1 shows the percentage distribution of office building stock in the CMC region. The GN divisions such as, Keselwatte (18.92%), Suduwella (16.19%), Kollupitiya (15.02%) and Fort (11.42%) represent the highest building stock in this region. In these GN divisions the location of the office buildings are predominately along the major traffic arteries which represents Galle road, Dharmapala Mawatha, Sangharaja Mawatha, Sir James Peiris Mawatha and D.R Wijewardana Mawatha.



GN Divisions	Percentage of office buildings
a. Kesellwatte	18.92%
b. Suduwella	16.19%
c. Kollupitiya	15.07%
d. Hunupitiya	12.25%
e. Fort	11.42%
f. Cinnamon Gardens	9.94%
g. Wekanda	9.38%``
h. Thibirigasyaya	7.46%
i Aluthkade West	6.92%
j. Kirula	6.93%
k. Kompannaweediya	5.77%
l. Millagiriya	5.05%
m. Bambalapitiya	4.39%

Figure 21 Percentage of office buildings in Colombo Municipal Council (CMC)

2.1 JUSTIFICATION FOR SELECTION OF THE STUDY FOCUS

East-West orientation is one of the significant design strategies on heat gain of tropical buildings. Among the 35 GN divisions of CMC region, 13GN divisions have a concentration of office buildings more than 4%. Within the 13 GN divisions, the highest office building stock of 75% of the East-west orientation is evident in the GN division of Kollupitiya. These buildings are predominantly located along Galle Road and R.A De Mel Mawatha. Thus the study represents the critical office building stock for heat gain in the CMC region and this paper presents physical configuration and energy indices of the office building stock in the Kollupitiya GN Division.

3.0 Characteristics of the office building stock in the study focus

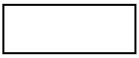
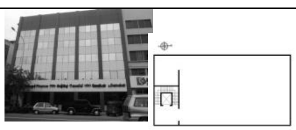
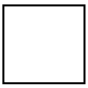
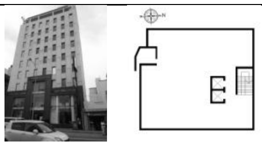
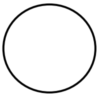
Major characteristics of this office building stock are that 90% are fully air-conditioned and mean number of floors is within the range of 5 to 7 storeys. However 10% of the stock has amalgamated air conditioned working spaces and naturally ventilated common areas like lobbies and corridors. Mean building energy index (BEI) of this office building stock is 243.12 KWh/m²/annum.

Five types of office building plan forms were identified and these plan forms can be generalised 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 and U shapes. Within this stock 75% of the buildings demonstrates a combination of linear and square plan forms distributed along the Galle Road and R.A De Mel Mawatha. In these basic plan forms 58% and 17% are with linear and square plan forms respectively. Circular plan forms are not evident in this office building stock.

Composite built form of L shape is a combination of two linear plan forms or a linear and a square plan form. Moreover the amalgamation of three linear plan forms represents the U shape. These composite plan forms along the Galle Road and R.A De Mel Mawatha are consists of 16% of L and 9% of U shape plan forms respectively. Graphical representation of the basic and composite plan forms and its combinations are shown in figure 2a.

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. Furthermore these facades represent the front of the building due to easy access from the road. These East and West front facades 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 openable panels with blinds to control the heat gain. Fenestration details of these critical façades are shown in figure 2b.

When considering the positioning of these buildings this stock represents 75% of attached built forms and the balance is free standing. Thus the figure 3 shows a combination of the positioning of the built form in relation to two main types of plan forms with the East West orientation.

Basic plan forms		
Linear plan forms 		58% of the buildings has a rectangular plan form
Square Plan form 		17% of the buildings has a square plan form
Circular plan form 		Non of the buildings have a circular plan forms facing east west orienation

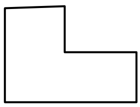
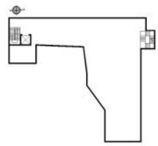
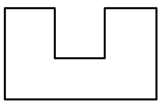
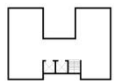
Composite plan forms		
L shape Plan form 	 	16% of the buildings are with a L shape plan form
U shape plan form 	 	9% of the buildings are with a L shape plan form

Figure 2a Categorization of buildings according to the plan forms

Critical façade characteristics		
Buildings with glaze and Aluminium	Buildings with aluminum facades	Buildings with fixed/non fixed glaze panels
		
57% of the buildings are cladded with Aluminium and glasses in the front faced	26% of the buildings are Aluminium Cladded throughout the front façade.	17% of the buildings have full length glass openings in the front façade.

Figure 2b Categorization of the critical façade

3.1 NEXUS BETWEEN THE BUILDING ENERGY INDEX (BEI) AND THE BUILT FORM

Building Energy Index is a quantitative measure to evaluate the energy consumption of a building within a period of an year in relation to its floor area. The unit of this index is kWh/m2/annum. Corresponding building energy indices of the stock was calculated and the Figure 4 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 150 – 300 kWh/m2/annum. Of which 68% and 16% corresponds to 200 and 300 kWh/m2/annum respectively. Figure 5 shows the physical configuration in relation to positioning and plan forms of the 5 buildings which represents the maximum BEI of this building stock.

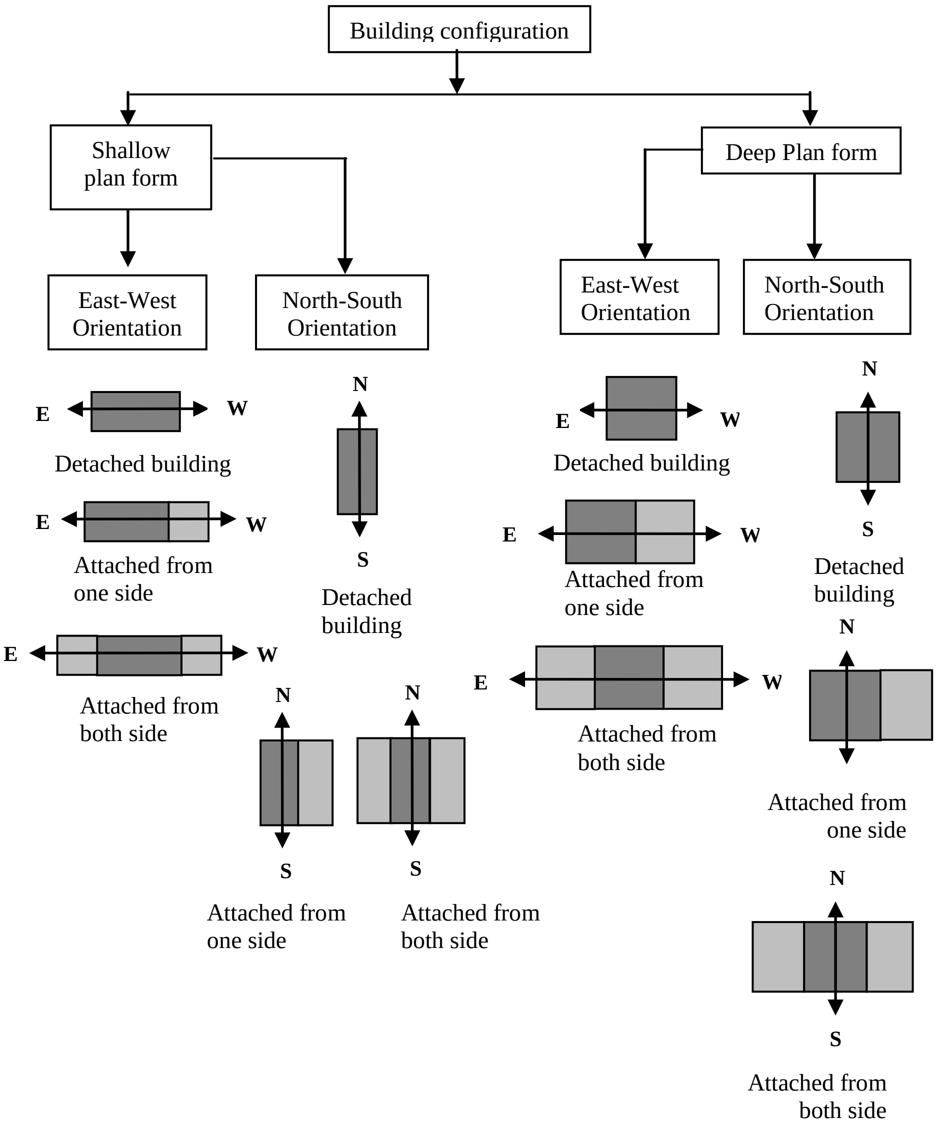


Figure 3 office building typology

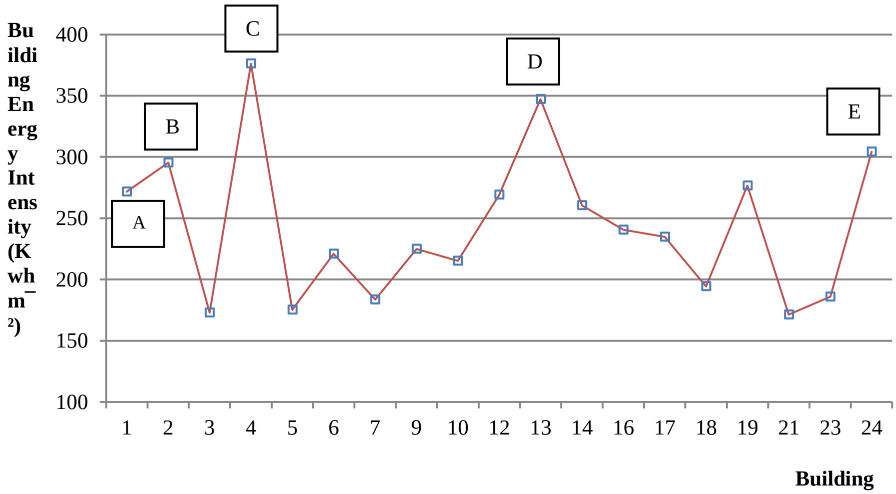


Figure 4Buildings Energy Index of the office building stock

Buildings with the highest Building Energy Index have a configuration of basic and composite plan forms. Buildings with basic plan forms has a higher building Energy Index than composite plan forms. Furthermore buildings with glazing in the critical façade have a higher Building Energy Index than the other fenestration details.

3.2 NEXUS BETWEEN THE BEI AND ASPECT RATIO

Aspect ratio of a building is a ratio between length and width. Literature has informed a building with an aspect ratio above 2 with an East West orientation consumes more energy due to the increasing demand in the operation of cooling plant (Geoffrey J et al., 2004). Moreover the buildings where the long side of the building facing east-west orientation has more energy use intensity as a result of the direct heat gain. Buildings with an aspect ratio (length/width) above one have a shallow plan form. A deep plan form has an aspect ratio less than one. Buildings with deep plan forms consume more energy due to artificial lighting and air conditioning. Figure 6 shows the relationship between the BEI and aspect ratio.

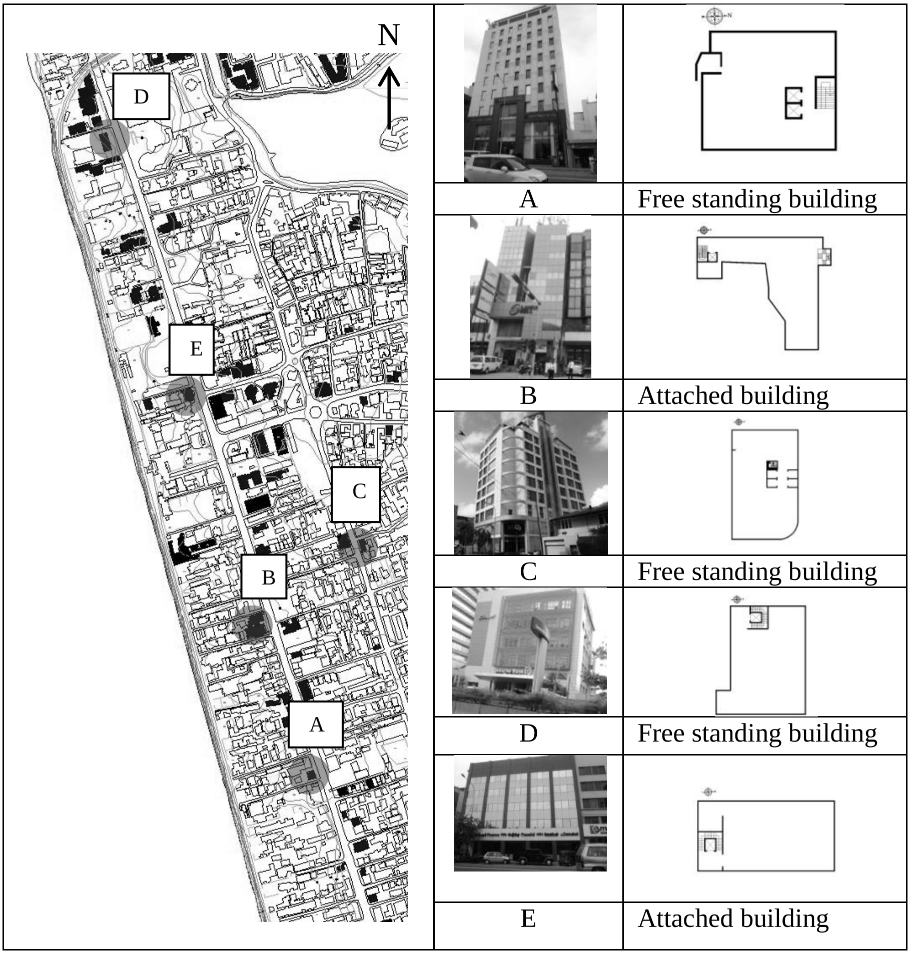


Figure 5 Physical configurations of the buildings with the highest BEI

It is evident that the physical configuration of the building stock varies along Galle Road and R.A De Mel Mawatha. Of which 53% and 47% of the buildings have a shallow and a deep plan form respectively. Critical façade of the shallow plan forms are East-West oriented. Thus these plan forms get direct solar radiation. Critical façade of the deep plan forms are North-South oriented. Conventional wisdom reveals that the shallow plan forms consume less energy than deep plan forms. In contrary some buildings with shallow plan forms had higher building energy index than the deep plan forms. Thus denote that these buildings are attached with another structure from one side or both sides. In addition fenestration details of the building envelop influence the energy consumption of the building.

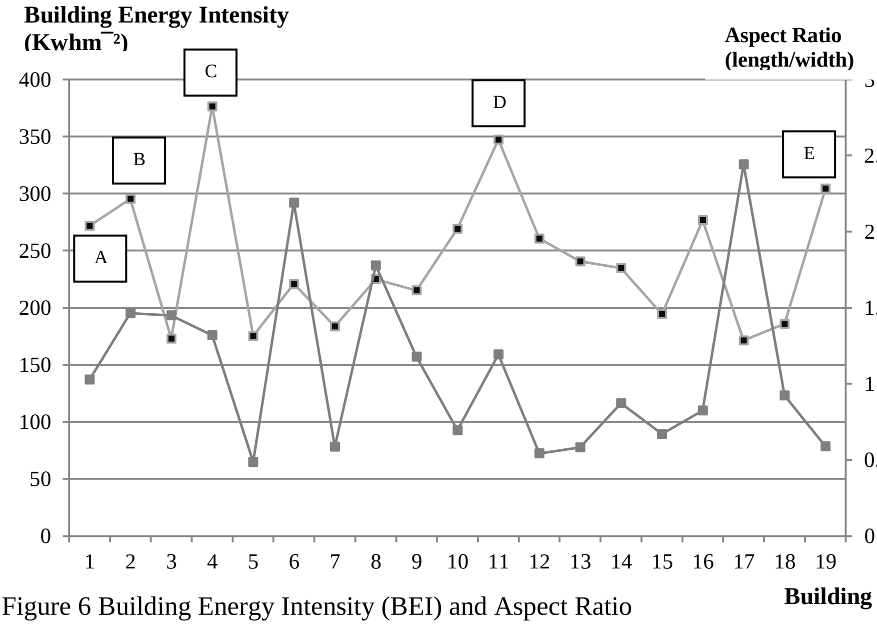


Figure 6 Building Energy Intensity (BEI) and Aspect Ratio

4.0 Conclusion

Analysing the office building stock with respect to its energy intensity is a prime importance to enhance energy consumption especially in a tropical climate. In addition this analysis is the beginning of developing a data base for the existing building stock which will be a foundation for the construction of new building with low energy consumption.

, The highest office building stock of 75% of the East-west orientation is evident in Kollupitiya.GN Division and they are predominantly located in Galle Road and R.A De Mel Mawatha. 90% of the building stock has sealed envelopes with air conditioned building interiors. Building Energy Index of this stock varies within the range of 150 – 300 kWh/m2/annum. Five types of office building plan forms were identified and these plan forms are generalized as basic and composite plan forms. Within the building stock 75% and 25% of the buildings demonstrates a combination basic plan forms and composite plan forms respectively.

Further more 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 which 17%, 26%, 57% are evident for glazed, Aluminium cladding and Aluminium cladding with glazed respectively. These fenestration details of the critical facade have an impact on the building energy index of the building.

The positioning of this buildings stock represents 75% of attached built forms and the balance is free standing. Thus a typology of building configuration was developed based on the building plan form. Of which 53% and 47% of the buildings have a shallow and a deep plan form respectively. It is evident that the Energy used index has an impact on the positioning of the critical façade and the building plan configuration.

Factors such as window orientation, window area, room dimensions, size and position of shading, and floor plan configurations have a significant impact on the building energy consumption. Majority of the office buildings in Colombo are dominated by air-tight envelopes with glazed facades. Thus demands for active systems to condition the indoor environments. Subsequently the office building stock has originated energy intensive office interiors. This study will help to set out a holistic approach of new future town planning, on setting out of new roads and cutting of geometry for fabric of new sites in reference to more “energy optimized” building volumes.

In addition this will be a platform to develop a fundamental database matrix, focusing on enhancing the screened office buildings with more specific research on façade renovation by means of energy conscious replacing of worn out façade materials, and creating or optimizing positioning and size of shading devices. Thus further studies for Colombo office building renovation or construction of new structures could be fired positively by proposed matrix typology.

References

[1] Susrova, Irina;Meysam Tabibzadeh, Anisur Rahman, Herek L. Clack, Mahajoub Elnimeiri, "the effect of geometry factors on fenestration energy performance and energy savings in office buildings," *Energy and Buildings*, vol. 57, pp. 6-13, 2013.

[2] P. Depecker, C. Menezo, J. Virgone, S. Lepers, "Design of Buildings shape and energetic consumption ," *Building and Environment* , vol. 36, pp. 627-635, 2001.

[3] Philip Steadman, Ian Hamilton, Stephen Evans, "Energy and Urban Built Form," *Building Research & Information* , vol. 42:1, pp. 17-31, 2014.

[4] Koen Steemers, Carlo Ratti, Dana Raydan, "Building Form and Environmental performance: archetypes, analysis and an arid climate," *Energy and Buildings* , vol. 35, pp. 49-59, 2003.

[5] N.D Mortimer, A. Ashley, M. Elsayed, M.D. Kelly, J.H.R. Rix, "Developing a database of energy use in the UK non-domestic Building Stock," *Energy Policy*, vol. 27, pp. 451-468, 1999.

[6] Bruhns H, Steadman P, Herring H A, "A database for modeling energy use in the non-domestic building stock of England and Wales," *Building and Environment* , vol. 51, pp. 243-254, 2012.

[7] Steadman P, Bruhns HR, Rickaby PA., "An Introduction to the National Non-domestic Building Stock Database," *Environ Plann B*, vol. 27, no. 1, pp. 3-10, 2000.

[8] Jones P, Williams J, Lannon S, "Planning for a Sustainable City: an energy and nvironmental prediction model," *J environ Planing Manage 1*, vol. 43, no. 18, pp. 855-72, November 2000.

[9] Yamagachi Y, Shimoda Y, Mizuno M., "Proposal of a modeling approach considering urban form for evaluation of city level energy management," *Energy Buildings* , vol. 39, no. 5, pp. 580-92, 2007.

[10] Coffey B, Borgeson S, Selkowitz S, Apte J, Mathew P, Haves P, "Towards a very low energy building stock: modeling the US commercial building stock to support policy and innovation planning," *Build Ref Inf*, vol. 37(5-6), pp. 610-24, 2009.

[11] Koen Steemers, "Energy and the city: density, buildings and transport," *Energy and Buildings*, vol. 35 , pp. 3–14, 2003.

[12] Cisco L. Valentine PE, CEM Geoffrey J Glig ETI, "The Effect of Building Geometry on Energy Use," *Engineering*, vol. 101, no. 2, pp. 70-80,
UNFPA Report, (July 2007), 'State of the World's Population 2007' NY