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Low-rise Office Retrofit: Prerequisite for Sustainable and Green Buildings in Shanghai

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Abstract. Commercial buildings comprise of 25% office blocks, largest proportion in commercial sector with highest energy consumption in Shanghai. Nevertheless, the demand for office space is still rising, driven by state-owned enterprises. Unfortunately, these existing buildings are energy inefficient as they barely adapt to present varying climate conditions of the province. Owing to aggravated climate change and rising urbanization rate of Shanghai, attention should be directed towards upgrade of office buildings to meet set sustainable building standards. 3-dimensional spatial characterization using vector topographic mapping posits low-rise buildings account for more than 50% of total buildings in Shanghai. Hence, retrofitting existing low-rise office buildings will significantly contribute to building sustainability. Subsequently, a retrofit package guideline suitable for sporadic energy use mode in rapidly expanding cities like Shanghai should be established. This nascent study postulates an updated correlation between climate change and building energy consumption in Shanghai. Based on the postulation, it is recommended that the best energy conserving building retrofit package is that which can mitigate the impact of both societal factors (like urbanization rate) and climate change to building energy consumption. In general, this study defines a foundation framework for building researchers and decision-makers to effectively evaluate retrofit measures for existing buildings become sustainability in Shanghai.

1. Introduction

1.1. Background on Shanghai

Shanghai had a population of 23.02 million in 2010. It covers an area of 6340.5 km² extending 120km from south to north, and 100 km from east to west. It is located within the 'hot summer and cold winter (HSCW) climate zone (East China), where winters are normally cool and damp, and summers are hot and humid [1]. As a result, existing buildings in this city are required to meet with anti-overheating, shading and cooling requirements in summer and anti-cold requirements during winter simultaneously. However, this is not the case as old existing buildings were constructed based on designs for northern China buildings (severe cold climate regions). Consequently, building energy consumption in this city is quite high due to the complex climate variation through out the year and



also impact of high urbanization rate. Urbanization trend is considered to be a major contributor to internal oscillation resulting to deteriorating environmental condition. In 1978, 58% of residents in Shanghai lived in urban area; However, it is currently estimated that about 90% of the population are urban with a population density of 3,854 persons/km² [2]. The development of this city can bring the citizens much benefits, but it also sacrifices the environment to deteriorating conditions like local climate variation caused by urban heat island (UHI) effects. This coupled with dense and complex urban structures, and high population density will escalate the energy consumption of the city. Without adequate mitigating measures and policies, the average energy consumption in Shanghai may experience further growth according to recent growth pattern. Consequently, this will exacerbate the natural environment, climate condition and human living quality. Based on the city's climate and societal complexities, series of questions arise as to the reasons behind its record climate variation. Globally, climate change is attributed to anthropogenic activities in collaboration with natural variations. However, can this be the same reason for climate change in Shanghai? Or is it simultaneously associated with localized societal activities like urbanization and population shift? And if so, to what magnitude? These are crucial points to be considered before determining optimum solutions for climate change and sustainability problems in such cities. Prominent solution that addresses both of these issues is by adopting building retrofit measures.

1.2. Building Retrofit Measures

Buildings are major energy consumers and account for 20-40% of energy consumption in most countries [3]. Consequently, smart and economic buildings are developed to circumvent the upsurge in energy consumption. One way to reduce the impact of buildings on huge energy consumption and environmental pollution is through retrofits. Retrofitting buildings have the tremendous potential to reduce building energy consumption by 30-40% [4]. Building retrofits can be defined as the renovation of old buildings with facilities for ease of operation, improvement of efficiency and reduction of environmental disturbance. Therefore, building retrofit measures can be stated to be any form of strategy to attain this set objectives. Recently, they are classified into 3 management classes: demand-side, supply-side and energy conserving managements. This is summarized in Table 1.

2. Shanghai Buildings: Types, Energy Consumption and Associated Contributors

2.1. Shanghai Building Types

Shanghai Bureau of Statistics states that non-residential buildings accounts for 50% of total buildings in Shanghai in 2016 [2]. Non-residential buildings include plants, schools, and commercial (public) buildings which contains offices, stores, hospitals, hotels and cinemas, and other types. Commercial building comprises of 25% office building block, largest proportion in commercial sector with highest energy consumption in Shanghai. In terms of total non-residential buildings, office building block has the second largest share with a 13 percentage. Nevertheless, the demand for office space is still rising (as shown in Figure 1), driven by state-owned enterprises and firms benefitting from the free trade zone. 3-dimensional spatial characterization using vector topographic mapping posits low-rise buildings account for more than 50% of total buildings in Shanghai [5]. As shown in Figure 2a, low rise, high rise and mixed buildings are represented by yellow, red and orange colors respectively. It can be observed that the city centre, marked within the black box, is dominated by high rise and mixed buildings with sparse amount of low rise buildings. Contrarily, outside the black box, indicating the outskirts of Shanghai, is mostly occupied with low rise buildings and sparse amount of mixed buildings, with few high-rise buildings scattered around. Empty lands are also found available within the outskirts for future plan. Figure 2b shows the spatial development of the city. The figure presents the age of buildings within the city centre to date back before 1950. After this year, the city tends to expand sequentially towards its borders with each passing year. In general, it can be deduced that low rise building blocks dominated most of the border space of Shanghai and are sparsely distributed across the city centre.

Table 1. Classification of building retrofit measures.

Building Retrofit Classification ◦		Building Retrofit Technologies ◦
Demand-side Management ◦	Building Envelope ◦	- Building fabric insulation (i.e. ceiling, wall, etc) ◦ - Windows retrofits (i.e. multiple glazing, low-E coatings, shading systems, etc) ◦ - Air-tightness ◦ - Cool roofs and coatings ◦ - Floor retrofits, etc. ◦
	Equipment System ◦	- Natural ventilation ◦ - Control upgrade ◦ - Lighting upgrade ◦ - Energy efficient equipment (HVAC, water heating, lift, etc) ◦ - Thermal storage and heat recovery, etc. ◦
Energy Conserving Management ◦	Energy Conserving Behaviors ◦	- Occupancy regimes, schedules and activities ◦ - Comfort requirements ◦ - Staff training ◦ - New management scheme ◦ - Monitoring strategies, etc. ◦
	Energy Management and Control System ◦	- Management and maintenance ◦ - Access to control (i.e. automatic control systems, optimization control strategies, etc) ◦
Supply-Side Management ◦	New/Renewable Technology ◦	- Solar PV/PVT systems ◦ - Solar thermal systems ◦ - Biomass systems ◦ - Electric system retrofits ◦ - Geothermal power systems ◦ - Wind power systems, etc. ◦

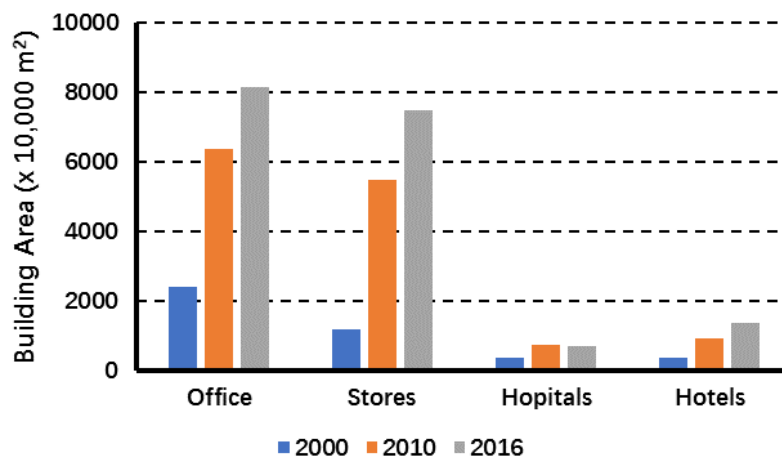


Figure 1. Composition of Different Commercial building types in 2000, 2010 and 2016.

Furthermore, these building blocks are mostly historical buildings and are estimated to account for over 50% of the buildings in this city [6]. Given that the non-residential building blocks has almost the same percentage as residential blocks [2], it can be reasonably implied that low-rise non-residential buildings, which are old, account for about 50% of the entire non-residential building types in Shanghai. Unfortunately, this vast existing low-rise buildings are energy inefficient as they lack the potential to adapt to present varying climate conditions and sporadic energy use mode of the province. Hence, attention should be directed towards the upgrade of these building blocks, amidst the aggravating climate change and rising urbanization rate. Moreover, due to the high share of energy

consumption of low-rise office buildings, it is paramount to promote the retrofitting of existing low-rise office buildings as a stride to attaining urban sustainability in this city. Subsequently, a retrofit package guideline (RPG) suitable for this purpose should be established.

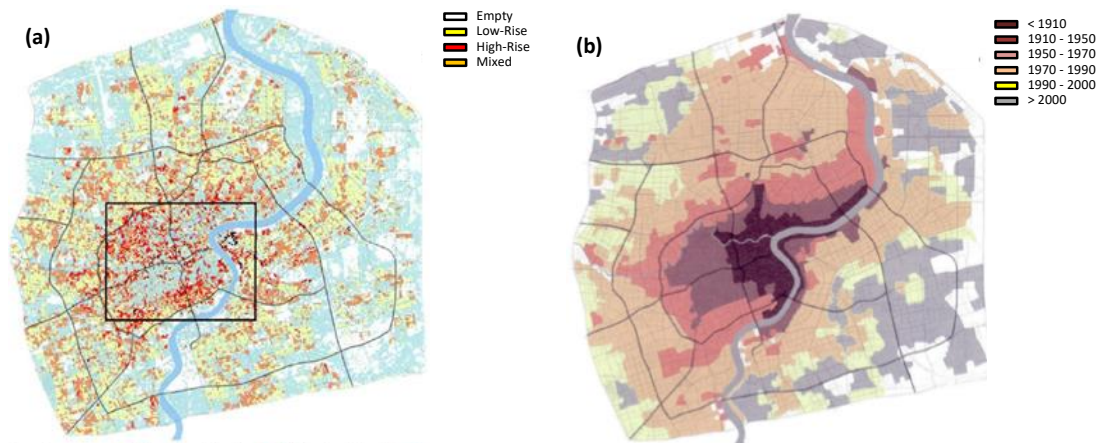


Figure 2. Spatial characterization of building's (a) height [5] and (b) age [6] in Shanghai.

2.2. Building Energy Consumption in Shanghai

Buildings provide an interface between indoor and outdoor environment in order to maintain indoor temperature within a comfortable range for its users. As a result, buildings consume a lot of energy for occupants' activities, facilities, comfort and lighting. Data from Shanghai Municipal Statistics Bureau [2] shows the trend of annual energy consumption of Shanghai as shown in Figure 3. The figure depicts a continuous growth in total building energy consumption of Shanghai in the past 46 years. From 1970 to 2000, the growth rate was slow; however, this became rapid after 2000 until 2013, when it gradually slowed down. This can be partly attributed to the significant net increase in population of Shanghai resulting from migratory purposes. Before 2010, Shanghai witnessed a net migration influx 8 folds that of 1990 baseline, which suggests a reason for the exponential growth in energy consumption within this period. Afterwards, net migration reduced to about 50% of 2010 baseline and has remained so till date. This elucidates the slow energy consumption rate beyond 2013.

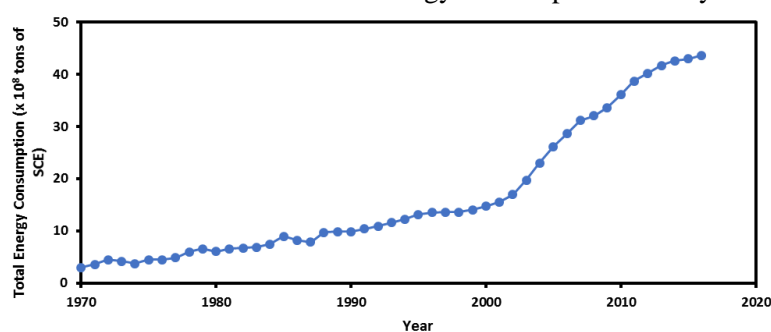


Figure 3. The Annual Energy Consumption from 1970 to 2016 in Shanghai [2].

2.3. Interaction between Energy Consumption, Climate Change and Urbanization in Shanghai

A summary of climate data (expressed as annual temperature) and annual building energy consumption of Shanghai is shown in Figure 4a, extracted from China Meteorological Administration document from 1970 to 2016 [7]. It is evident that annual average temperature of Shanghai showed an ascending trend within the stipulated period, with a more rapid ascent after 1990 until 2010. In 1970, the annual average temperature was about 15°C, but in 2007, it increased significantly to above 18 °C indicating approximately 3°C in the past 40 years [8]. Accordingly, it is expected that building energy

consumption will also increase due to net cooling load in this region [9]. However beyond 2010, total energy consumption kept rising despite the decrease in annual average temperature. It is contended that the slight reduction in temperature results from the large-scale erection of urban green systems, which has reduced UHI effects [10]. This hypothesizes that increase in building energy consumption in Shanghai is not entirely attributed to the worsening impact of climate change but is simultaneously affected by some societal factors like urbanization. Associated with urbanization is increasing population density, which tends to escalate building energy consumption, partly due to the large share of old and energy-inefficient buildings in this city. This hypothesis is validated by the 10% decrease in regression coefficient between energy consumption and annual temperature post 2010. Wang and Elnimeiri [8] estimated a 77.4% relationship between these variables from 1970–2010. However, updated analysis as shown in Figure 4b indicates a 69.3% relationship from 1970-2016. This updated decrease in correlation despite the continuous rise in energy consumption suggests that climate change is not the only factor contributing towards rising energy consumption.

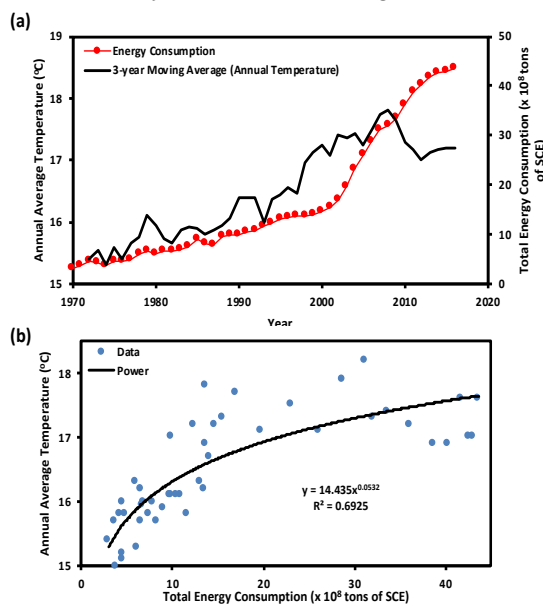


Figure 4. Energy consumption vs. annual average temperature in Shanghai (a) Annual variation of total energy consumption against average temperature, and (b) regression relationship between energy consumption and annual temperature from 1970-2016.

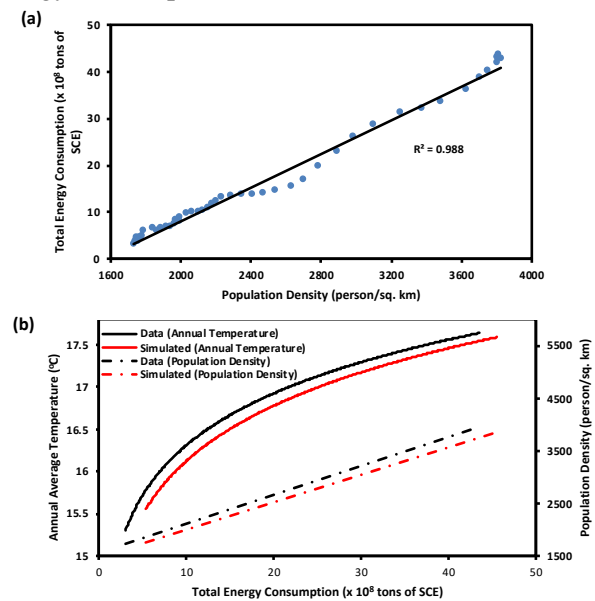


Figure 5. (a) Energy consumption vs. population density in Shanghai, (dots are actual data and line is the regression plot) and (b) Variation of estimated energy consumption from actual, from 1970-2016.

Other factors, as earlier suggested, like urbanization rate also plays a role in energy consumption. This is further investigated and shown in Figure 5. Figure 5a shows the impact of population density, indicative of urbanization rate, on building energy consumption from 1970-2016 with by R^2 -value of 0.988. This depicts that building energy consumption is highly associated with population density in Shanghai. As a result of urbanization, it is estimated that about 90% of residents in Shanghai are living in urban areas when compared to 58% in 1978 [2]. On one hand, this results from the influx of people into the city; and on the other hand, the development of rural lands to urban areas. This plays a key role in energy consumption as a result of UHI effect, which contributes to the local climate variation. Recent studies show that the climate change in this region is significantly affected by both external climate variability and internal oscillation [11]. To express this relationship mathematically, an equation relating energy consumption ($E \times 10^8$ tons of SCE), population density (P) and average annual temperature (T) for Shanghai was generated using basic statistical tools, *ceteris paribus*:

$$E (\times 10^8 \text{ tons of SCE}) = 0.02P - 1.18T - 10.96 \quad (1)$$

where P is measured in persons/km² and T in °C. Equation (1) has an R²-value of 0.9904 with all predictors having significance value less than 0.05. Disparity in estimated energy consumption from the actual is shown in Figure 5b. This shows that the estimated values exhibit same trend and are within close proximity with actual values. The mathematical expression will be adopted in further simulation studies of building energy consumption incorporating climate and urbanization indicators. However, this equation is limited to total building energy consumption owing to the unavailability of data for office buildings in Shanghai. Nonetheless, we can assume that the same trend applies to office buildings, given that office buildings account for a set percentage of total building blocks.

3. Building Retrofit Technologies and Related Challenges: Study on Low Rise Office Buildings

Different retrofit technologies have different effect on different building types. A proposed technology for a given building type in a particular city might not be applicable to the same/other building types in a different/same city. Hence, it is crucial to review retrofit technologies for various low rise office buildings, mainly in cities with high urbanization rate in order to deduce a suitable retrofit mix for this building type in Shanghai [12]. However, owing to limited studies on low-rise office buildings, a comprehensive review on low rise commercial buildings, with similar function as office buildings is consulted and their outcomes are shown in Table 2. From the results of Table 2, the adopted measures are rated based on their degree of applicability to various building types (Figure 6). This is computed from the average of their normalised impact to the building energy performance, using the equation:

$$D_i(\%) = \frac{\sum_{x=1}^p \left(\frac{n_i}{\sum_i^N n_i} \times 100\% \right)}{p} \quad (2)$$

where D_i is the degree of application of the retrofit measure (i), n_i is the impact of the retrofit technology on building energy saving in building type x, p is the number of a particular building type reviewed, and N is the number of retrofit measures adopted. Globally applied retrofit technologies for commercial buildings, as elucidated in Figure 6 and Table 2, can be summarized into:

Table 2. Summary of building retrofits on low-rise commercial buildings.

Building Type	Major Retrofit Measures	Methodology	Major Results	Ref
Office Buildings				
1979 disused wine storage building, Taiwan	Installing roof garden, water meters, rainwater capture system, waterless toilets & urinals, blanket insulation, solar shading, interior glazing, HVAC upgrade, IEQ control, and management plan.	hybrid approach combining A* graph and genetic algorithms (GA)	Energy consumption reduction: 39–43%, reduction in life cycle energy cost and CO ₂ emissions	[13]
Office building in Edmonton, Ottawa and Vancouver	heat recovery, day-lighting, boiler efficiency economizer, preheat upgrade, and lighting load reduction.	EnergyPlus Simulation tool	Energy savings: 20% in electricity consumption, and 30%, 32% and 19% reduction in natural gas for Edmonton, Ottawa and Vancouver respectively.	[14]

Office building situated in Pretoria, South Africa	Windows and lighting upgrade, insulation of walls and roof, upgrade of HVAC system, and PV power supply installation.	multi-objective optimization was solved by genetic algorithm (GA)	Within 6 years, energy savings: 761.6 MWh; cost savings: \$81,003. Lighting retrofit is the most cost-effective followed by HVAC retrofit. Long payback period for PV system and building envelope retrofit.	[15]
66 office buildings in Hong Kong	Insulations of walls, roof and floors, upgrade of windows, shading, chiller units and air-conditioners, use of energy efficient lightings and improvement of ventilation	Monte Carlo and regression analyses	higher efficiency chiller units and fresh water cooling tower (FWCT) systems significantly reduced cooling energy demand.	[16]
University Buildings				
5 buildings in Melbourne University	Upgrade of lighting systems with some magnetic and electronic ballasts and triphosphor globes (T8 32W & T5 21W)	simple energy and cost estimations	10% reduction in CO ₂ emission and 13-65% energy saving depending on lighting retrofit option. However, the retrofit technology is quite expensive.	[17]
Partially-retrofitted university building Ireland	replacing windows with double-glazing windows, upgrade of heaters and thermostatic radiator valves (TRVs), and additional wall insulation.	Occupant surveys (ASHRAE 55 and CBE IEQ) and physical IEQ measurements	ad-hoc retrofitting of the façade did not make any significant difference to IEQ and occupants continued to adapt personally to the existing conditions	[18]
School Buildings				
Nursery school building in Athens, Greece	green roof system	experimental investigation and simulation using TRNSYS 15.1	building energy consumption reduction: 6-49% and for its top floor: 12-87%	[19]
Secondary school building in Pisa, Italy	NZEB retrofit: windows replacements external insulations of walls and roofs, installation of venetian blinds, solar thermals and PV systems, and water-source heat pump	energy simulation (EC700 Edilclima and SEAS 3 (ENEA – University of Pisa)) and economic evaluation	Reduction in thermal energy by 48%, with an annual consumption of 129,454 kWh. Long payback periods of the retrofit measures, due to low yearly energy uses in the existing configuration.	[20]
Public Building				
6 public buildings across Europe	new thermal insulation, renovating old facades and roof, solar assisted heating systems, high-efficiency windows, HVAC and light bulbs, installing wind turbines, condensing gas boilers and PV panels	coupling field data with referenced eco-profiles and inventory data	thermal insulation (high-efficiency windows, and thermal insulating boards) had the most significant benefits (energy and emission savings).	[21]

Historical Buildings

<i>Elmi-Pandolfi</i> building, Italy	smart carbon fibre reinforced polymers (CFRP) with embedded fibre optic sensors	real-scale experimentation and basic calculations	'smart' composite technology is effective for detecting crack openings.	[22]
<i>Palazzo dell'Aquila Bosco-Lucarelli</i> building, Italy	change of indoor set temperatures, better air-tightness, replacement of traditional gas boiler with condensation methane heater, adopting efficient fenestration systems, and upgrade of lighting devices	in-field analysis and numerical modeling using EnergyPlus	22% reduction in building energy demand with a discounted payback period of 11 years	[23]

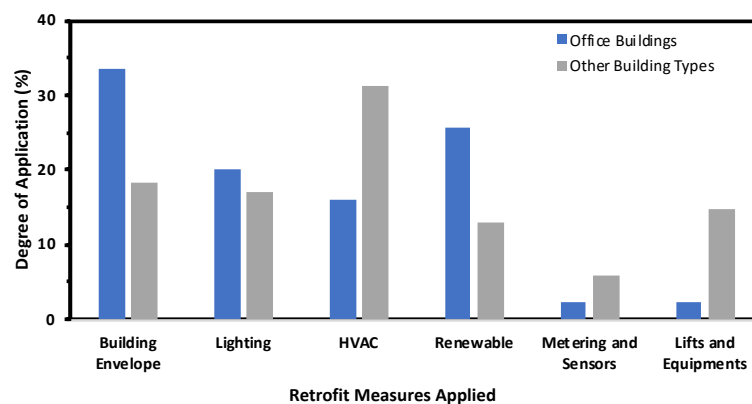


Figure 6. Degree of application of different retrofit measures to low-rise commercial building types.

Building Envelope Insulations: Upgrading building envelopes have proven to be a great energy conserving measure for all building types [21], particularly green roofs and walls [19]. Furthermore, high reflective windows with double glaze/thermal frames are recommended. They are more soundproof, air-tight, safe and can prevent heat losses thereby improving air conditioning efficiency. Costing, long payback periods [15] and introduction of other environmental effects [18] are common challenges met by this measure.

Heating & Cooling Systems: Installation of new and efficient air conditioning systems, evaporative coolers and adequate ventilation means will enhance indoor air quality and temperature [24,25]. This is very important in buildings where indoor air condition is paramount. However, it is not as beneficial as the aforementioned retrofit technologies in office buildings. In addition, this technology is also posed with high cost, quality and durability of the system [16,24].

Low-carbon/Renewable Energies: These are likely more impactful retrofit technologies than HVAC and lighting in office buildings. It can be attributed to the benefits of daylighting, ventilation and workers behaviour during office hours. Solar/PV systems and integrated wind turbines are prominent low-carbon energy retrofit systems [25]. Despite its benefits, only a few percentage of existing buildings have adopted this measure. This is attributed to its high costs and long payback period [15,20].

Lighting: Upgrade to a more energy-efficient lighting systems and installation of suitable monitor and control systems (motion and daylight sensors) are also prominent means of saving energy in buildings [15,25]. However, it ranks after insulation and renewable sources in office buildings. This measure is suggested to be the first step to green building retrofit. Although it is relatively costly, has questionable quality, short lifetime and low luminosity in comparison to conventional systems [17].

Energy regeneration systems (Lifts and Equipments): Use of energy regeneration systems such as variable-frequency and variable-voltage drive systems can improve energy efficiency [25]. For

instance, when applied to elevators, they convert the mechanical energy of gravity-driven motors to electricity. Cost and maintenance measures are the greatest challenges faced by this system [24].

Sensors and Maintenance Measures: Sensors, most especially temperature, motion, daylight and smoke sensors are considered resourceful for improving building performance [22]. They aid in monitoring, detecting and regulating operations of a system based on the desired set values. Subsequently, preventing excesses in energy consumed by these systems [25]. Challenges include lack of technical know-how, building energy management system data and maintenance measures along side costing.

4. Conclusion

In summary, it can be deduced that climate change is not the only factor causing increased energy consumption in Shanghai, as erroneously deduced by most studies. Urbanization rate, among others is another relevant factor. For purpose of predicting the most suitable retrofit measures for buildings in Shanghai, the evaluating methodology should include urbanization indicators among others in its assessment. Due to the strong affiliation of buildings energy consumption to urbanization rate (indicated by population density), we predict that the most suitable retrofit measure for Shanghai should be one that mitigates the contribution of societal factors (like high urbanization rate) to building energy consumption. Existing non-residential buildings in Shanghai are classed into low-rise, high-rise and super high-rise buildings, with low rise buildings having the dominant share of existing non-residential buildings. Moreover, these are historical buildings and as a result are energy inefficient unless rebuilt or retrofitted. Among all the building types, existing office blocks accounts for the highest share in non-residential building energy consumption. Hence, it is recommended that low-rise office buildings should be prioritized for retrofitting pending when rebuilt or demolished, as this will contribute significantly to green and sustainable built environment in Shanghai. Review of global sustainable building retrofit measures, their application, performance evaluation and challenges for low rise commercial buildings reveals that:

1)The most impactful retrofit technology for low-rise office buildings is the building envelope, which comes second after heating and cooling systems for other commercial building types. Renewable sources of energy and lighting are also important retrofit measures for low-rise office buildings.

2)For optimum improvement in building performance, a whole building ('deep') retrofit is recommended. However, further studies on economical evaluation are needed in this regard.

3)Optimal retrofit package should account for indoor environmental quality, occupancy requirement, energy efficiency and cost-effectiveness.

4)Coupled with this, it is recommended that promoting and implementing necessary regulations in this regard; and establishment of maintenance and management measures are necessary to ensure retrofitted buildings are continually sustainable, both environmentally and energy-wise.

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