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Quantifying Energy Consumption in Skyscrapers |of Various Heights

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Abstract

With world population becoming progressively urbanized, approximately 55% to date, the typology of the skyscraper is promoted as potentially socially and economically successful solution. However, an important challenge set on a worldwide basis is how to reduce their high-energy demands, environmental and social imbalances to meet growing strict regulations on carbon emissions and sustainable development. This paper looks at the challenges of skyscraper development in relation to energy efficiency, and investigates strategies towards achieving reducing its energy consumption. A 100m tall model is simulated using the climatic characteristic of Tel Aviv, and energy consumption is studied according to two parameters: the thermal advancement of the building envelope, and the effect of the changing microclimate in relation to altitude. The model is then simulated at 200m-400m high (60 – 125 stories high) and energy consumption is compared in relation to altitude.

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Keywords: skyscraper typology; energy efficiency; environmental variable; simulations at different heights

1. Introduction

Population migration towards the cities on a worldwide basis, has promoted the typology of the skyscraper as an important high-density living solution to the already dense urban centers. According to a research report by the Council of Tall buildings and Urban Habitat (CTBUH) the distribution of skyscrapers of 200m tall-and more, around the globe to date is as follows: China (348), South Korea (48), Rest of Asia (140), Australia (27), Europe

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(37), Middle East (120), USA (169) [1]. Except for the USA, where skyscraper construction is distributed evenly across the 20th century, China's boom on skyscrapers was initiated in the 1990's, reflecting the country's fast pace of urbanization, and in the Middle East from 2000 onwards as a tool for advancing economic and political influence. In addition, other places like Tel Aviv, in Israel, changed their planning policies to allow for future skyscraper construction. More specifically, Tel Aviv's Planning and Construction Committee issued the 2025 city master plan that has set new guidelines on skyrise development.

As world population is becoming progressively urbanized, a sustainable approach needs to be established that lessens the environmental impact of cities. Contemporary high-rise buildings do not present an all-around successful solution either to an increasing population or as examples of economic prosperity, as they are linked to high-energy demands, environmental and social imbalances [2]. This is a general observation of 20th century's architecture that is characterized by a deviation from climatic considerations and reliance on mechanical means for the building's operation, a reflection that does not only affect the typology of the skyscraper. However, skyscrapers are very large buildings and their impact on the urban fabric, and the environment in general, is much greater. At present, the building industry is regarded as the most energy intensive sector with buildings accounting for close to 50% of carbon dioxide (CO2) emissions, created through the combustion of fossil fuels for the building's operations (Embodied Energy – EE and Operational Energy – OE). However, emissions produced from the energy used to operate the building (OE), form the largest source of building-related GHG emissions, according to UNEP SBCI [3]. So, in the process towards reducing GHG emissions it becomes critical to advance the energy efficiency of buildings. Renewable energy economy will be an important part for future energy reserves, with the only constraints being how quickly and efficient transition from fossil fuels will be. However, in regards to a building's energy consumption and energy efficiency the most economical and environmentally friendly solutions, exist while the building is still on the drawing board, forming a design strategy according to the special climatic and regional conditions and taking advantage of passive heating and cooling techniques to satisfy the building's needs. Any additional technologies used at a later stage, ideally should be there to assist the building's thermal equilibrium in extreme weather conditions. Low energy consumption as a result combats climate change and atmospheric pollution, by reducing the production of GHG emissions.

The large-scale volume of the skyscraper and its increased energy consumption levels, in relation to low-rise buildings, dictate for an in-depth study of its operations and a focus on quantifying its energy requirements. In this process it becomes important to study skyscraper's from a climatically responsive perspective by taking into consideration three main variables: first, a design strategy according to the building's immediate environment (orientation, prevailing winds); second, the thermal properties of the building envelope; third, the effect of height in energy performance. The building envelope becomes the most important building component in achieving thermal equilibrium between indoor and outdoor climate according to thermal comfort conditions. Its form and thermal behavior of the chosen materials must interact appropriately with the ambient climatic conditions to reach healthy, comfortable indoors [4].

This paper studies the energy efficiency of a 100m tall residential model in relation to thermal properties of the building envelope by advancing the structure thermally in stages, and in relation to height by conducting simulations on ground, middle level and top floor. The advanced thermal envelope is then simulated to 200m, 300m and 400m high, a height that is considered a threshold to date in skyscraper construction within urban environments. The differences in energy consumption between the consecutive heights present information on the relationship between the building envelope and its microclimate, in relation to altitude. The study of the variations in energy consumption of the different levels provides the base towards advancing the skyscraper's energy efficiency. The chosen location is Tel Aviv, a city that is expected to raise its skyscraper construction in the following years. Also, studying skyscraper construction in the Mediterranean climate of Tel Aviv will provide information for many other Mediterranean cities, as well as other Middle Eastern cities, that undergo a similar process [5]. The simulation software used in this study is EnergyPlus for the structure's energy consumption and Ecotect Analysis for the design of optimum shading devices according to orientation. Indoor thermal comfort conditions are calculated in line with ASHRAE Standard 55 and the local weather file.