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Daylightophil High-Performance Architecture: Multi-Objective Optimization of Energy Efficiency and Daylight Availability in BSk Climate

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Abstract

This paper introduces parametric modeling and optimization analysis. By using Rhinoceros, Grasshopper and its plug-in ladybug and honeybee, we decided to find the optimized fillet angle of the curved facade office building to maximize the useful daylight illuminance and minimize the energy consumption of the building in Tehran Iran. This can improve the design quality and has a major participant to decrease the energy consumption and improve the daylight exploitation.

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Keywords: Optimized Fillet Angle; Useful daylight illuminance; Energy consumption; Grasshopper; Ladybug and Honeybee;

1. Introduction

Daylighting refers to the use of natural light, to support the visual and thermal demands of building occupants. Daylight and views provide a strong connection to place and time. They promote healthy circadian rhythms, reduce stress, and improve productivity, attentiveness, and mood. Although many studies have attempted to quantify the human benefits (employee retention, reduced absenteeism, and improved student testing scores), definitive research is still lacking. Daylighting is the simple concept that seeks to control natural light in a space and reduce or eliminate electric lighting. Not only is electrical lighting responsible for a significant amount of the electrical load on a commercial building, but it can also cause excessive cooling loads. Utility costs for a building can be decreased when daylighting is properly designed to replace electrical lighting. Good daylighting design means using strategies that address the climatic conditions of the building location. In climate zones with more cooling requirements, designers should employ strategies that reduce solar and conductive heat gain while maximizing natural light [1]. In contrast, strategies for zones with more heating requirements should balance the heat loss from reduced artificial lighting and conduction with potential heat gains from daylighting [2]. Nowadays energy is a challenging issue in developing countries which made new era in energy efficient architecture in contemporary architecture of developing countries such as Iran. Considerable amount of energy consumptions in building sector, have gained more attention and consumers have to do their best to improve their performance and prevent energy waste [3].

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The limitation of energy resources and the remarkable growth of use them in Iran compare with universal average has doubled the necessary of optimizing energy consumption in this country. Considering that in recent years the housing and commercial sector has allocated the largest ratio (37%) of energy consumption to itself; design the optimum pattern is one of the appropriate strategies [4]. There are some attributes which effect on the daylighting ratio of the building, such as orientation, size and material of windows, etc. But there is a significant attribute as “Fillet Angle" that describes the angle of the fillet in curved facade building. These attributes could be varied parametrically, through as a parameter. And a parametric representation of a design is on where selected values within the design model are variable. So the objective of this study is to analyze the use of parametric design method in an office building, which has variable facade fillet angle. To effectively design daylight in buildings, daylight availability data are necessary. Although there is a great potential of daylight energy in Iran, its use is hindered by absence of measured data [6,7]. So the design is to find the optimized facade fillet angle to minimize the energy consumption and maximize the useful daylight illuminance in the climatic condition of Tehran region [8,9]. It is very important to explain that energy efficient adoption on natural ventilation [10,11], recombinant materials [12] and new geometry [13] have a lot to do with architectural design process [14] especially building form and composition.

Tehran features a semi-arid climate with continental climate characteristics and a Mediterranean climate precipitation pattern. Tehran's climate is largely defined by its geographic location, with the towering Alborz Mountains to its north and the central desert to the south. It can be generally described as mild in the spring and autumn, hot and dry in the summer, and cold and wet in the winter [15].

The following graph (Fig. 1) shows the monthly average high and low temperature of Tehran.

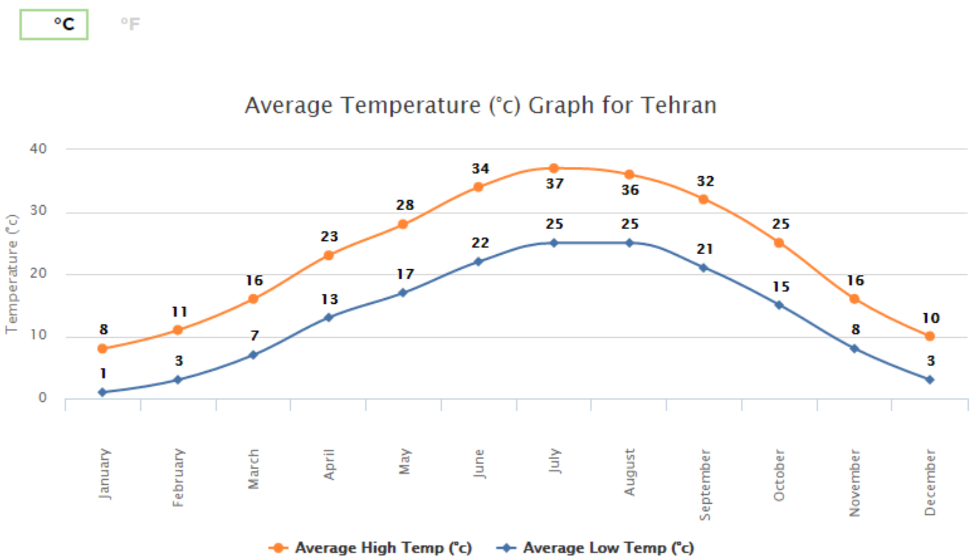

Fig. 1. Average Temperature (°c) Graph for Tehran [16].

2. Methodology

This research is introduced as a simulation and modeling research. We select Rhinoceros, an architectural modeling program, Grasshopper to parametrize a Rhino Model and its plug-in ladybug and honeybee for energy and daylighting simulation and use Galapagos to achieve the optimized value.

Grasshopper 3D is a graphical parametric form generating tool, integrated into Rhinoceros 3D. It allows the architects & designers to generate complex parametric forms. An open source parametric plugin called “Ladybug” is used to support further environmental analysis inside the Rhinoceros/Grasshopper Interface. Ladybug imports standard “Energy Plus Weather” files (.EPW) into Grasshopper 3D and brings with it, a wide variety of 2D and 3D interactive graphics to conduct accurate environmental studies for the form generation of the building. It simplifies the process of analysis and automates the calculations, whilst providing easy to understand graphical visualizations in the 3D modeling interface of Grasshopper. It further allows users to work with validated energy and daylighting engines such as “EnergyPlus”, “Radiance” and “Daysim”, effectively allowing to the architect to make better design choices. The “Honeybee” is another parametric plugin for Grasshopper which also connects Grasshopper3D to “EnergyPlus”, “Radiance”, “Daysim” and “OpenStudio”, for building energy consumption & daylighting simulation [17]. And the first solver publically released within Grasshopper is Galapagos which implements a genetic algorithm for goal seeking and multiple objective optimizations [18].