Energy for Sustainable Development 31 (2016) 170–177

Contents lists available at ScienceDirect

Energy for Sustainable Development

Impact of orientation of residential neighborhoods on optimizing sustainable and equitable exposure of insolation—Case study of Sulaimani, Iraq

Shazad Jamal Jalal, Rawand K. Bani *

Faculty of Engineering, Department of Architectural Engineering, University of Sulaimani, Sulaimani 46001, Iraq

ARTICLE INFO

Article history:
Received 4 July 2014
Revised 18 October 2015
Accepted 12 December 2015
Available online 2 March 2016

Keywords:
Residential buildings' orientation
Gridiron system
Opposite facades
Insolation inequity index
Sulaimani
Iraq

ABSTRACT

In the northern hemisphere, neighborhoods are often preferred to be laid out in a rectilinear gridiron pattern with half of the houses in double-lot blocks having south-facing facades for optimal use of available solar energy. Adjoining houses, with north-facing facades, receive minimal insolation, leading to an overall inequitable use of available insolation. This paper presents a method of determining the overall optimal block orientation using 3ds Max software with linear regression models. The city of Sulaimani, Iraq, is used to illustrate. Obtaining the optimal orientation is essential for guiding planners in the land subdivision process, before the lots are designed. To optimize sustainable and equitable exposure to insolation in the city of Sulaimani, the annual insolation value (AIV) was calculated based on the algebraic sum of the amount of insolation energy for each double facade at each 5°, then factored by the cooling and heating degree-day ratio for each month. These values represent the annual energy required for cooling and heating for each orientation. The insolation inequity index (III) was proposed to measure the inequity between various opposite orientations. Accordingly, the value of (III) is equal to one for the ideal case (zero inequity). All orientations were examined, and the (0°–180°) demonstrated the highest inequity (III = 0.60), which indicates 40% inequity while the highest equity (III = 0.98) was (110°–290°). Nevertheless, the last orientation was not the most sustainable because its total (AIV) was not the minimum. The optimal direction was determined to be (100°–280°), which has the minimum total (AIV) of 484 kWh (maximum sustainability) with the largest value of (III = 0.92) (maximum equity). It was found that if this optimal orientation was applied in Sulaimani, the inequity would have been reduced by 22% from III = 0.70 in 1955 to III = 0.92 in 2003.

Introduction

The Rectangular or Rectilinear Gridiron System (RGS) is a land subdivision method that offers a good connection and eases the orientation of residential blocks (Tasker-Brown et al., 2002). A certain recession is imperative in this system, for planting trees and aesthetical purposes (De Chiara et al., 1969, 1995). The general aspects of this system encompasses; large built areas, wide streets and it is easy to locate addresses, but very limited open spaces, promotes through traffic and out of limit speed (Galaty et al., 2001, 2002; Sendich 2006) (see Figs. 1 and 2).

Considering a residential unit, maximum insolation energy received is about 1 kWh/m^2 (Tasker-Brown et al., 2002), and because the angle of the sun changes throughout the day, Iraq typically gets an annual average of 5.3 kWh/m^2.day (Abdul- Wahid et al., 2010). The orientation of a building is an important factor in determining the building's ability to absorb solar energy and, hence, on the amount of supplemental heating or cooling required to keep the interior comfortable (Lechner, 2009) (Wong and Chow, 2001). Orientation of buildings starts from the land subdivision process, especially in the RGS where the lots are small and each lot (residential unit) have only one facade. In this system the designer is not free to orient the building appropriately. Instead the land subdivision determines the orientation from the direction of the residential blocks. This research investigates an issue in double-sided residential blocks in the RGS, which is commonly used. In such systems, the buildings face opposite directions allowing one of the buildings in the pair to receive much more insolation than the other, therefore creating a state of inequity (see Fig. 1).

The objective is to address the excess of insolation that creates a heating load in summer, and at the same time, the shortage of insolation on the opposite facade that results in heating load in winter. The research focuses on delivering guidelines on how to orient residential blocks with balanced exposure on both opposing facades not only for the direct facade. This will assist in a fair utilization of direct insolation energy throughout the whole year.

* Corresponding author at: Faculty of Engineering, University of Sulaimani, New Campus, Kirkuk-Main Road, Sulaimani 46001, Iraq. Tel.: +964 7701440188.
E-mail address: Rawand.jalal@univsul.edu.iq (R.K. Bani).

http://dx.doi.org/10.1016/j.esd.2015.12.004
0973-0826/

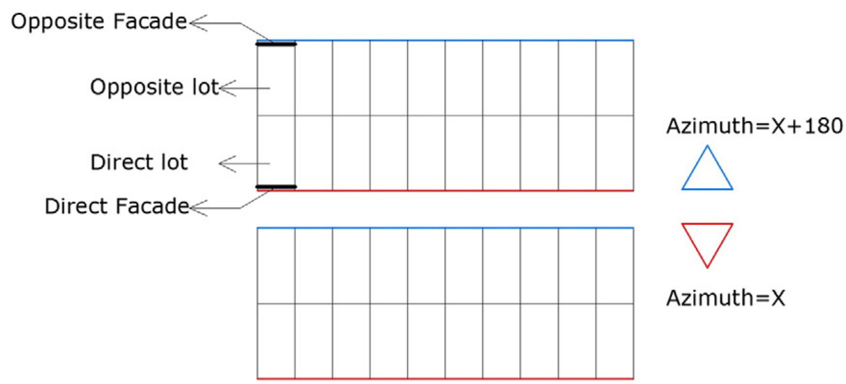

Fig. 1. Typical residential blocks' layouts in the Gridiron System land subdivision.

Research approach

The research implemented the descriptive analytical and comparative method to deliver its objectives. Necessary plans and layouts have been obtained from Sulaimani's municipal administration, to assess a number of districts throughout different time series. This assessment will be based on the evaluated indicators inferred for the residential units' orientations in the research.

A brief account of Sulaimani

Sulaimani city is located in the Iraqi-Kurdistan region, at 350 km northeast of the Iraqi capital Baghdad. The city is 220 km distant to the South East of the capital of Iraqi-Kurdistan region Erbil (see Fig. 2). Sulaimani is the center district of the Sulaimani Governorate (province). Sulaimani province is of 17,023 km^2 in area with a population of 2 million people (Ministry of Planning, 1998).

The city of Sulaimani was founded in 1784. As of 2013, its population has reached 750,000 (Ministry of Planning, Censuses of Accommodations, 2013). It is located on latitude 35° 33′ north and longitude 45° 25′ east, with an average height of 850 m from mean sea level (MSL) (Sulaimani Governorate, 1989).

Starting from the 1950s and still, the residential blocks' subdivision is based on the RGS in the majority of Sulaimani's neighborhoods (except the historic downtown). The RGS has been always problematic with steep slopes in the streets and pathways of the city, beside the existence of numerous hills. The essential problem (in the research) is the absence of consideration for the opposite sides of double-sided residential blocks. The administrative authorities of the subdivision process in Sulaimani overlooked the fact that the blocks are double sided, as its apparent from the map of the city the RGS blocks are oriented in all directions randomly without prioritizing any specific one (see Fig. 2C).

Four different neighborhoods from four different generations were selected as samples for a case study: Akary built in 1955 (Akary—1955), Rzgary built in 1961(Rzgary—1961), Bekhtiyary built in 1980 (Bekhtiyary—1980), and Kurdsat built in 2003 (Kurdsat—2003) (see Fig. 2). The orientation of the blocks in these samples were examined for optimality. It was found that 96% of all residential blocks in Akary—1955 were on the 29°–209° orientation. The majority of the residential blocks in Rzgary—1961 were on the 146°–326°, by 28%. In Bekhtiyary—1980, the majority (33%) were on 117.5°–297.5°, and in Kurdsat—2003, 52% were on 101°–281° (see Fig. 2D, E, F and G). These orientations later will be evaluated for optimality based on the results of the research. Optimality is a reference to a double lot RGS block that has the maximum equitable exposure to direct insolation and simultaneously has the minimum required energy for cooling and heating throughout the year.

Methods

This section describes the calculation method of the value of insolation energy in Sulaimani and how the data taken from the sunlight diagram in 3ds Max were used as inputs to formulate linear regression models to compute the value for each 5° orientation over a year.

Magnitude of direct insolation in Sulaimani

The average insolation for the city was calculated per square meter of horizontal surface at two different time periods; the first one for 30 years (1961–1991) by Mahdi and Wissam (2011), the second one is for 22 years (1983–2006) by NASA Atmospheric Science Data Center (2005) (see Table 1). The monthly averages of insolation vary by a small margin between the two data sets (see Table 2). The maximum average monthly variations occurred at May and September by 18.58 kWh/m^2 increase and 9.64 kWh/m^2 decrease, respectively. The total average annual variation is at 7.39 kWh/m^2 (recession), which translates to 0.45% when comparing the two data sets. To convert the amount of direct insolation from the horizontal surface to the vertical plane (facades), 10% reduction was applied to each value (Al-Rawahi and et al., 2011) (see Table 2).

The average of the daily minimum and maximum temperatures varied from −1.2 °C in January to 51.6 °C in July between the years of 1983–2006 (see Table 3). The average daily hours of sunlight also varied accordingly. The longest day reached to 13.5 h/day in July, whereas the shortest day reached 9 h/day in December and January (from 3ds Max).

Calculating the total hours of direct insolation on residential facades in Sulaimani

This research relied on the 3ds Max sun diagram to estimate the actual number of hours that a virtual two story residential building's facade is exposed to direct insolation throughout a year in Sulaimani. The geographical coordinates of Sulaimani were inserted in the software, and the four cardinal directions (N, E, W, and S) in addition to 45° intervals (NE, SE, SW, and NW) were evaluated regarding the entire range of direct insolation exposure (see Table 4).

The appropriate linear regression model was derived based on the maximum value of R^2 for data given by the 3ds Max for each 45°, in order to interpolate the amount of insolation energy for each 5° for all directions for each month (see Table 5). The sampling of directions was semicircular (representing frontal direction) instead of the circular sampling (frontal and opposite directions). The reason behind selecting the semicircular sampling is the simple linear mathematical relation required to calculate it. The time range of insolation exposure for each direction (at 5° intervals) is equal to number of the average sunlight hours in that month minus number of hours of front facade's insolation