



A holistic approach to energy efficient building forms

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ARTICLE INFO

Article history:

Received 2 October 2009
Received in revised form 10 March 2010
Accepted 14 March 2010

Keywords:

Holistic design
Energy efficiency
Solar exposure
Building form
City climate
Urban heat island
Green roofs
Air flow

ABSTRACT

Minimizing energy consumption in buildings has become an important goal in architecture and urban planning in recent years. Guidelines were developed for each climatic zone aiming at increasing solar exposure for buildings in cold climates and at reducing solar exposure for buildings in hot climates. This approach usually plans for the season with the harshest weather; often forgetting that temperatures in cities at latitude 25° can drop below thermal comfort limits in winter and that temperatures in cities at latitude 48° often rise above thermal comfort limits in summer. This paper argues that a holistic approach to energy efficient building forms is needed. It demonstrates a generic energy efficient building form derived by cutting solar profiles in a conventional block. Results show that the proposed building form, the Residential Solar Block (RSB), can maximize solar energy falling on facades and minimize solar energy falling on roofs and on the ground surrounding buildings in an urban area in winter; thus maximizing the potential of passive utilization of solar energy. The RSB also supports strategies for mitigating the urban heat island through increased airflow between buildings, the promotion of marketable green roofs and the reduction of transportation energy.

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1. Introduction

1.1. Background

The interrelationship between built up form and climate has been the subject of many publications. Early publications can be categorized into three main groups. The first group focuses on issues of human thermal comfort as a basis for formulating building design utilizing passive strategies [1–3]. The second group focuses on issues of solar access as a prerequisite for utilization of solar energy for passive heating and daylighting purposes [4]. The third group focuses on understanding the effect of urbanization on city climatology [5]. More recent research appears to follow the same categorization.

As a result of research conducted in the first group, knowledge now exists that can help increase energy efficiency at the building level through application of passive heating, cooling, ventilation, and daylighting strategies. Comfort and energy consumption concerns are better addressed today through building design codes as well as voluntary schemes.

In the second group a growing body of literature indicates that there is a great need for solar indicators to provide city planners with tools to help them make informed decisions on how best to

deploy solar energy technology to utilize the huge solar resource available within cities. These solar indicators include “Repartition Maps” [6], “Orientation Rose” [7], “Iso-shadow” [8], “Shadow Density” [9], and the “Sky View Factor” [9].

Another growing body of literature looks at the energy performance at the city level and investigates factors such as urban density, urban texture, and urban randomness [7,10–14]. Studies at the block level are still scarce [15].

Distribution of solar energy on different surfaces in a built environment was the focus of few investigations. Leveratto [16] sought solar access for an open space rather than a neighboring building as the ‘Solar Envelope’ suggested. Stasinopoulos [17] compared the potentials of solar energy falling on roofs vs. solar energy falling on equatorial facades.

In the third group a growing body of literature is looking at the mitigation of the urban heat island effect with special focus on vegetation, green roofs, cool roofs and airflow between buildings. The interactions between vegetation, the microclimate, and the urban environment have been studied by many authors [18,19]. Studies by Niachou et al. [20], Köhler et al. [21] and Takebayashi and Moriyama [22] indicate the potential of improved thermal performance of buildings with green roofs. Studies by Baskaran and Kashef [23], Pospisil et al. [24], and Bozonnet et al. [25] help understand the characteristics of airflow between buildings as a method for preventing heat from being trapped in open urban spaces.

The above review of the literature raises the following questions:

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- Design guidelines to minimize heat gain and promote heat loss in summer are available. Also available are design guidelines to minimize heat loss and maximize heat gain in winter. So what kind of building form can follow both sets of guidelines to achieve higher performance all year round not just in one season?
- Studies on energy efficient building forms are in a fragmented state. Investigations usually focus on one indicator, factor or strategy. So can synergy be created if a holistic approach is adopted?
- More studies are needed at the urban block level where neither planning nor building design guidelines are effective. So how can the form of a few blocks be optimized to increase the block's performance and that of the entire city, if enough such blocks are built?

1.2. Methodology

In order to answer the questions mentioned above, this paper provides a systematic comparison and an evaluation of the relationships between urban built form and energy efficiency of three generic forms: two conventional forms and one proposed energy efficient form. The basic scale of the study is the urban block scale. The study comprises simulations of the three forms followed by a discussion of synergies created by the proposed form. The design research is divided into two distinct research sections. The first section is concerned with solar exposure in winter and the second section is concerned with reduced heat gain in summer via the support of strategies for mitigating 'the urban heat island effect'.

2. Increased winter solar exposure

Solar energy could be utilized actively to generate electricity with photo-voltaic panels and to provide solar heated water. Solar energy could also be utilized passively for heating living spaces and providing daylight. Solar energy falling on an urban area is received either by buildings or by the ground between buildings. The component falling on buildings is received either by roofs or by facades. The state of the art in utilizing solar energy differs for each type of these urban surfaces.

Although attempts do exist to extract heat from paved streets, with the technologies available today it is hard to utilize solar energy falling on the ground in an urban open space to heat surrounding buildings. This portion of solar energy could be seen, depending on the climatic zone and time of year, as a positive or negative contribution for improving or deteriorating the bioclimatic quality of the open space itself.

Solar energy falling on roofs could be easily utilized to heat water or air and to produce electricity using PV panels. Collecting this portion of solar energy should be followed by a system to store the collected energy and a system to distribute it to different zones of the building. In multistory buildings, which form the biggest part of most urban areas, the energy distribution system has a special importance to transfer the collected energy to the lower parts of the building. One disadvantage of this scheme is that a percentage of the collected energy gets lost in the storage and distribution systems. Another disadvantage is that the annual pattern of radiation on roofs does not match the annual pattern of heating needs. This means that more energy could be gained in summer due to the high sun path when this energy is not really needed. In winter, when the heating needs rise, the radiation values on the roof drop due to the low sun path. This again requires a seasonal energy storage system and could therefore be utilized using active systems.

Solar energy falling on facades is the only portion of solar energy that could be easily used passively without complicated mechanical equipment and expensive installations. The annual pattern of solar radiation on SE, S and SW facades matches with the annual pattern

of heating needs. This, together with recent developments in high performing building envelopes, shows that the utilization of this part of solar energy is the most promising.

2.1. Urban forms

2.1.1. The linear urban form

Utilization of the constant amount of solar energy falling on a certain urban area could be improved by minimizing the percentage of solar energy falling on the ground and on roofs which automatically led to an increase in the percentage of solar energy falling on building facades of this urban area. This could easily be achieved by avoiding mutual shadowing and orienting the buildings to the sun. Most planners would apply these two recommendations by planning an urban form consisting of a row of houses one apartment deep and facing the equator. This urban form has the following disadvantages:

1. Functionally, it is difficult to fit into most infrastructures which require a grid iron street pattern.
2. Visually, it is a monotonous form in which it is difficult to well define open spaces and to differentiate between different categories of open spaces.

2.1.2. The block urban form

In projects where solar energy utilization is not given great weight, city planners tend to use the residential block as a unit for their designs. The two main reasons for implementing the residential block are that it could fit in most existing or planned grid iron street patterns and it produces two different types of well defined open spaces. Streets running in both directions offer a good pattern for transportation and facilities. Backyards offer a quiet and safe place for semi-private outdoor living, which allows neighbors to meet and helps to build community. From the solar point of view the residential block could be seen as an inefficient form for the following reasons:

1. Some of its sides are either unfavorably oriented to the sun and/or suffer from mutual overshadowing.
2. The solar energy falling on the facade is poorly distributed leaving many areas in the building with extremely low solar radiation with other areas receiving most of the solar energy.

2.1.3. The Residential Solar Block

The Residential Solar Block (RSB) is a building form developed with the aim of achieving the functional, spatial, social and visual advantages of the conventional residential block with the energy efficiency advantages of the linear urban form. It is an attempt to generate the maximum built-up volume of the block after putting overshadowing restrictions on the site. It could be derived from a conventional block with sides facing NE, SE, SW and NW using the method of cutting solar profiles in December for the selected latitude. This is simply a matter of extruding the block plan very high upwards, and then cutting several solar profiles through the vertically extruded planes for a range of selected points on the line where façades on the opposite side of the open space meet the ground. The resulting shadows fit almost exactly in the open spaces between buildings. Fig. 1 shows the resulting form and the range of shadows in December for a block optimized for latitude 48.00.

2.2. Solar exposure calculations

The computer program CITY SHADOWS, developed by the author, was used to carry out solar exposure calculations. The program is able to model urban forms and to study them under selected

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