Available online at www.sciencedirect.com
SCIENCE DIRECT®
Energy and Buildings 37 (2005) 529–544
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

Modeling energy efficiency of bioclimatic buildings

A.F. Tzikopoulos, M.C. Karatza, J.A. Paravantis*

Department of Technology Education and Digital Systems, University of Piraeus, 80 Karaoli and Dimitriou Street, Piraeus 185 34, Greece

Received 20 July 2004; received in revised form 10 September 2004; accepted 23 September 2004

Abstract

The application of bioclimatic principles is a critical factor in reducing energy consumption and CO_2 emissions of the building sector. This paper develops a regression model of energy efficiency as a function of environmental conditions, building characteristics and passive solar technologies. A sample of 77 bioclimatic buildings (including 45 houses) was collected, covering Greece, other Mediterranean areas and the rest of Europe. Average energy efficiency varied from 19.6 to 100% with an average of about 68%. Environmental conditions included latitude, altitude, ambient temperature, degree days and sun hours; building characteristics consisted in building area and volume. Passive solar technologies included (among others) solar water heaters, shading, natural ventilation, greenhouses and thermal storage walls. Degree days and a dummy variable indicating location in the Mediterranean area were the strongest predictors of energy efficiency while taller and leaner buildings tended to be more energy efficient. Surprisingly, many passive technologies did not appear to make a difference on energy efficiency while thermal storage walls in fact seemed to decrease energy efficiency. The model developed may be of use to architects, engineers and policy makers. Suggestions for further research include obtaining more building information, investigating the effect of passive solar technologies and gathering information on the usage of building.

Keywords: Bioclimatic architecture; Sustainable architecture; Energy efficiency; Passive solar technologies; Regression model

1. Introduction

The term bioclimatic (or sustainable) architecture refers to an alternative way of constructing buildings so that local climatic conditions are taken into account and a number of passive solar technologies are utilized in order to improve energy efficiency; the term passive solar technologies refers to heating or cooling techniques that passively absorb (or protect from, e.g. natural shading) the energy of the sun and have no moving components. Bioclimatic structures are built in such a way that, during winter months, exposure to cold temperatures is minimized and solar gains are maximized; during the summer, bioclimatic structures are shaded from the sun and various cooling techniques are employed [1–3], often with the aid of renewable energy sources [4]. In addition, locally available building materials may be used.

It is estimated that 4.5 out of 6 billion tones of carbon emitted worldwide from human activities may be attributed to industrialized countries [5]. Approximately half of this is due to buildings (in one form or another). Building more energy efficient houses may reduce carbon emissions by 60% or more, which translates to 1.35 billion tones of carbon, an amount equal to the savings proposed by the environment conferences in Rio and Berlin; as a side benefit, building more bioclimatic homes will conserve conventional energy sources and possibly reduce dependence on oil imports. Because of this potential for significant savings in energy consumption and reduction in greenhouse gas emissions, bioclimatic architecture has received a fair amount of attention all over the world in the last few years (e.g. [6–9]) and is regarded as an important parameter in contemporary architecture [10]. In Greece, for instance, the Rule for Rational Use and Energy Savings (RRUES) that was enacted in 1998, stipulates that energy consumption reduction measures be made compulsory for all buildings by 2007 [11,12].

Although there exist numerous case studies that examine isolated bioclimatic projects or buildings (such as [13–16] as well as model codes that predict energy consumption of a

* Corresponding author. Tel.: +30 210 4142771; fax: +30 210 4142753.
E-mail address: jparav@unipi.gr (J.A. Paravantis).

0378-7788/$ – see front matter
doi:10.1016/j.enbuild.2004.09.002

single building (see [17] for a brief but complete review) based on either energy parameters or physical laws or performance data, little effort has been invested in analyzing a larger sample of bioclimatic structures using statistical techniques. This paper attempts to build a regression model in order to understand how energy efficiency of bioclimatic buildings depends on environmental (including climatic) conditions, building characteristics and passive solar technologies that are commonly utilized.

2. Background

Orientation of buildings so that they could utilize solar input more efficiently, first took place in Greece 2500 years ago [18]. A few centuries later, Rome bathhouses were built so that their windows faced the south to let in the warmth of the sun [19]. In 1200 A.D., the Anasazi (regarded as ancestors of Pueblo Indians in North America) built cliff dwellings that captured the winter sun [20]. More recently, in 1891, Clarence Kemp, a Baltimore inventor, patented the first commercial solar water heater [21]. In 1940, the Sloan Solar House in Chicago, designed by Keck, became the first contemporary building making use of passive solar heating [18]. In 1953, Dan Trivich of Wayne State University, made the first theoretical calculations of the efficiencies of various materials based on the spectrum of the sun [20]. In 1977, the U.S. Department of Energy launched the National Renewable Energy Laboratory of the Solar Energy Research Institute, a federal facility dedicated to harnessing power from the sun [22]. Finaly, in 1994, the National Renewable Energy Laboratory (formerly known as the Solar Energy Research Institute) completed a construction of its Solar Energy Research Facility, which was recognized as the most energy-efficient of all U.S. Government buildings worldwide [23].

Energy consumed in the building sector constitutes a significant proportion of total energy consumption. Sources place the amount of energy expended in the building sector in Europe to about 40–45% of total energy consumption [24]; about two thirds of this amount is used in private buildings. Other sources claim, that in industrialized countries, energy usage in buildings is responsible for approximately 50% of carbon dioxide emissions [25–27]. Solar energy, for example, covers 13% of primary energy used in buildings; this percentage could increase to 50% by 2010 while in some cases it could even reach 57% [28].

In Greece, the use of energy in buildings such as public and private buildings, schools, hospitals, hotels and athletic facilities, constitutes 30% of total national energy demand and contributes about 40% of carbon dioxide emissions [29]. Heating and refrigeration of buildings consume the largest part of energy expended in domestic uses [30]. Taking into consideration that only about 3% of buildings in Greece have been constructed after 1981 (when heat insulation regulations were put into effect), it may be concluded that the limited application of insulation in the majority of residences causes significant energy losses in Greece [31].

A bioclimatic building may be so economically efficient that it consumes even 10 times less energy for heating compared to a conventional European building [32]. The additional cost of a typical bioclimatic structure is usually around 3–5% and in most cases less than 10% [33]; this cost is usually returned within a few years [34]. Bioclimatic technologies (such as passive solar systems) may also be retrofitted to existing structures although, in such cases, the cost is typically a little higher. In addition to conservation of energy, bioclimatic architecture may improve day lighting and indoor comfort conditions. For instance, in a natural ventilation design project for houses in Thailand, it was found that, although total energy saving in the winter months was less than 20%, indoor air quality was significantly improved and this was an important feature justifying the design [35].

The total amount of energy used for a building includes [36]:

- Production energy (also known as embedded energy), which is the energy expended during production, assembly, maintenance, alteration, demolition and recycling of building materials.
- Induced energy, which is the energy consumed for construction; architects, civil engineers and construction crews control the consumption of energy during the construction phase.
- Operation energy, which is the energy necessary to maintain required levels of comfort; obviously, energy consumed for the operation of a building represents a more or less steady amount for a longer period of time.
- Grey energy, which refers to conversion losses incurred during transport of materials, construction of building, heating etc.

Two important observations may be made. On one hand, energy required for a building is not only the amount used during its operation; production energy, induced energy and grey energy are also needed and they increase consumption of non-renewable energy resources as well as carbon emissions. On the other hand, operation energy (which, along with the part of grey energy that concerns operation, is the only group that keeps increasing during the lifetime of a structure) may be significantly reduced if bioclimatic principles are applied during design and construction.

Energy efficiency of a building based on bioclimatic principles is determined by a set of environmental, technical and usage factors. First of all, the location of a building is a major determinant; geographic latitude that is related to mean temperature (with lower temperatures in places of greater latitude) should be a major influence. Also, location of a building in an area with continental climate increases dryness and thermal variation while location in the Mediterranean implies mild winters and relatively cool