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Trends in observable passive solar design strategies for existing homes in the U.S.

Kelly Kruzner*, Kristin Cox, Brian Machmer, Leidy Klotz

Civil Engineering Department, Lowry Hall, Clemson University, Clemson, SC 29634, United States

HIGHLIGHTS

- GoogleMaps to examine implementation of cost-effective, observable passive solar strategies in U.S. houses.
- No national trends toward passive solar design in U.S.—a missed opportunity.
- Some regional passive solar trends in U.S. for house orientation, roof color.

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ABSTRACT

Passive design strategies are among the most cost-effective methods to reduce energy consumption in buildings. However, the prevalence of these strategies in existing U.S. homes is not well understood. To help address this issue, this research evaluated a nationally-representative sample of 1000 existing homes distributed geographically across the U.S. Using satellite images, each building was evaluated for three passive design strategies: orientation, roof color, and level of shading. Several statistically significant regional trends were identified. For example, existing homes in the High Plains, Ohio Valley, Northwest, and Southern regions show a statistically significant trend towards orientation in the East–West direction, an effective passive design strategy. Less intuitively, in terms of what would seem to be optimal passive design, buildings in the High Plains and Ohio Valley generally have lighter roof colors than buildings in the warmer Southwest region. At the national level, no statistically significant trends were found towards the passive design strategies evaluated. These trends give us no reason to believe they were a major consideration in the design of existing homes. Policy measures and education may be required to take advantage of the opportunity for cost-effective energy savings through more widespread passive solar design.

1. Introduction

In passive solar building design, the architectural elements of a building are designed to collect, store, and distribute solar energy as light and heat (Anderson and Michal, 1978; Nervegna, 2003). Unlike active solar heating and electric systems, passive solar design does not involve the use of mechanical and electrical devices. Some examples of passive solar design strategies include: extending the building dimension along the east/west axis to maximize solar light gain on the elongated south wall; sizing and shading windows to face the midday sun in the winter and be shaded in the summer; using shading elements (e.g. shrubbery, trees, trellises) to protect against solar heat gain in the summer while promoting it in the winter; and using insulation to reduce heat gain or loss.

Passive solar design in residential buildings offers great promise to reduce energy consumption as well as the associated costs and climate-changing emissions. Plans for energy security and stabilization of climate rely on drastic reductions in the energy consumption of our residential buildings, which account for 22.5% of overall energy consumption in the U.S., corresponding to almost 240 billion USD in 2009 (U.S. Department of Energy, 2011a). Real-world applications of passive solar design have been able to reduce residential buildings' energy consumption by 25%–40% with little additional up front cost (Walker, 2010). If passive solar design was used to realize these reductions in just 10% of U.S. homes, projected energy and cost savings would be 531 trillion btu/year and 6 billion USD/year, respectively. The ENERGY STAR® rebate program, by comparison, has saved an estimated 1.7 trillion btu/year, or approximately 150 million USD/year (U.S. Department of Energy, 2011b).

While passive design strategies can be cost-effective methods to reduce energy consumption in buildings, competing design considerations (e.g. current styles, the status-quo) may receive more priority. Moreover, the widespread adoption of air-conditioning and other strategies to mechanically control the indoor environment

* Corresponding author. Tel.: +1 864 384 7663.
E-mail addresses: kesprague@gmail.com (K. Kruzner), kristinanncox@gmail.com (K. Cox), bmachme@clemson.edu (B. Machmer), leidyk@clemson.edu (L. Klotz).

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mean that passive design is not necessarily a requirement for occupant comfort. Rather than optimize the passive design of a home in a hot climate, for example, a designer can just specify a more powerful air conditioning unit. Even homes built prior to the invention of air conditioning may be retrofitted in ways that negate any original passive design strategies. For example, homeowners may replace natural ventilation through open windows in favor of closed windows and air conditioning.

Researchers recognizing the potential of passive solar design are investigating topics including insulations, building orientations, solar heat storage and ventilation, and energy efficiency modeling methods for various types of buildings (Hassanain et al., 2011; Khanal and Lei, 2011; Mahajan, 1989; Morrissey et al., 2011; Wittwer, 1989). Policy-makers recognizing the potential of passive solar design are mandating specific passive design strategies in other regions of the world (Chandel, 2009). Improving our overall understanding of current passive solar design implementation in the U.S. is a necessary step to begin identifying ways to make implementation more widespread. In response to this need, *the objective of this research is to examine existing homes in the U.S. for national and regional trends which are consistent with recognized strategies for geometric passive solar design.*

2. Theory

This research examines geometric strategies for passive solar design in existing homes in the U.S. These strategies, selected because they are high-impact in terms of energy savings (Anderson and Michal, 1978; Walker, 2010) and observable from Google Earth satellite images, include:

- *Orientation*, which refers to the axis along which the house is elongated. One technique for passive solar design includes orienting windows toward the equator. Therefore, houses in the U.S. elongated on the east–west axis, which have more space available for south-facing windows, have greater potential for passive solar heating (English and Walker, 2000).
- *Roof color*, either light or dark. Lighter roof colors will absorb less heat and therefore can reduce energy required for cooling in hot summer months. Darker roof colors, which absorb more heat, will increase the need for cooling in the summer but can decrease heating loads in the wintertime (Rosenfeld, 1995). Roof ventilation is also an important consideration in passive solar design, but is not observable from satellite images, and roof color alone can still provide significant savings in heating and cooling energy (Akbari et al., 1999).
- *Level of shading*, from trees or other objects. Full shading, especially with deciduous trees, can ease cooling loads in the summer while allowing indirect heat and light from the winter sun (Rosenfeld, 1995).

Regional climate must be considered for passive solar design in the U.S.; the design which takes best advantage of solar heating for New England winters is not necessarily best for the Southeastern states, where summer cooling loads are of larger concern. To account for regional climate differences in this research, the U.S. was divided into the seven regions shown in Fig. 1[1], which also shows the average summer and winter temperatures and the average annual precipitation from 1971 until 2010 (US. National Climatic Data Center, 2012). The figure shows climate differences among the regions. Generally, the southern regions tend to have higher temperatures than the northern regions. The eastern portion of the U.S. tends to get more rainfall, while the western portion is typically drier.

Aspects unique to the U.S. may influence the prevalence of passive solar design, when compared to other countries. Heating and cooling equipment here are powered primarily by either gas or electricity and we have relatively low electricity costs. For example, in 2008, the average household electricity cost in the U.S. was 0.113 USD/kwh, while in Japan this cost was 0.206 USD/kwh, and in the United Kingdom it was 0.231 USD/kwh (U.S. Energy Information Administration, 2010). In 2007, the average household natural gas price in the U.S. was 500.70 USD/10^7kilocalories, while in Japan the cost was 1236.90 USD/10^7kilocalories, and in the United Kingdom it was 753.70 USD/10^7kilocalories (U.S. Energy Information Administration, 2012). So, while passive solar design offers just as much potential to save energy in the U.S. as it does in other countries, the monetary value of this saved energy is less in the U.S. than it would be elsewhere. Less cost savings means less motivation to implement passive solar design strategies. Another unique aspect that may influence the prevalence of passive design in the U.S. is the culture of individual autonomy. Federal or state regulations mandating specific passive solar design strategies or setting general limits on energy use per household would influence the prevalence of passive design strategies. However, these types of regulations would likely face strong resistance in the U.S. Low energy costs and a culture of autonomy both would seem to decrease the likelihood of our research finding statistically significant trends towards passive solar design in the U.S.

3. Method

To pursue the research objective we examined a nationally-representative sample of 1000 existing homes, evenly distributed geographically across the contiguous U.S. Home locations included in the sample were identified using randomly generated latitude and longitude coordinate pairs. Buildings at these coordinates were then evaluated using satellite images from Google Earth. For each building, we examined the high-impact and observable passive solar design techniques; orientation, roof color, and level of shading. We also collected information on density, state, and road orientation for each building to help answer some of the secondary questions described in the results, discussion, and analysis section.

To generate a random sample of houses, a coordinate system was established over the contiguous U.S. First, we determined the eastern- and western-most longitude coordinates and northern- and southern-most latitude coordinates. These coordinates form a rectangle with edges at 25°N, 65°W, 125°W, and 50°N. A random number generator formula in the Microsoft Excel spreadsheet program was used to determine a four-digit decimal number between zero and one. This random decimal was multiplied by the total number of longitude degrees in the grid system (60°) to determine a displacement from the eastern-most longitude point. This process was repeated for latitudes, with the reference latitude at the southern-most point, to create a coordinate pair. For example, if the random number generated was.3305, to find the latitude coordinate we would multiply.3305 by the total number of latitude degrees, 25°, and add it to the southern-most boundary (in our case, 25°N). This would yield a coordinate for our sample of 33.2636°N. Similarly, a random number for longitude of.4245 would be multiplied by total longitudinal degrees, 60°, and added to the eastern-most boundary, 65°W, to get 90.4732°W. This point (33.2636°N, 90.4732°W) becomes part of the random sample.

[1] Regional boundary distinctions were adapted from Weatherye.com (accessed in February, 2011).