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Short communication

Decoupling of building energy use and climate

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ABSTRACT

Energy use intensity (EUI) and climate have a well documented correlation, which is generally applied in building energy management. Green buildings have sought to greatly reduce energy consumption and a number of examples are documented in the literature. A sample of high performance buildings constructed in a variety of global locations is analyzed here, and provides evidence that measures to reduce energy consumption have reduced EUI to the point where its correlation with heating degree days is no longer apparent. This result suggests that end-user behaviour is the next major hurdle in lowering the energy consumption of greener buildings.

1. Introduction

The correlation between climate and building energy use is an intuitive one. There is an expectation that with an increase in heating degree days (HDD), or cooling degree days, modified by humidity, building energy consumption will rise. This has been a commonly applied principle for energy managers as a means to normalize energy consumption with respect to weather severity in a given year. Global climate change, as well as energy price concerns, has stimulated actions to reduce energy demands, resulting in the emergence of examples of green construction in many countries. We provide empirical evidence that energy use intensity (EUI) no longer correlates with climate for a sample of international green buildings.

2. Climate and energy use

Building energy use has conventionally been mostly through the provision or removal of low-grade heat. Space conditioning is the largest building energy demand fraction, amounting to 42–68% of end-use energy for residential buildings and 48–55% for office buildings [1]. Correlation between building energy use and HDD is well established, both within climatic zones and globally [2–4]. For a further example, in conducting a comparison of urban carbon inventories, Kennedy and others [5], showed that this relationship holds on aggregate for international cities as well. As Fig. 1 shows, there is a significant correlation between heating fuel consumption and HDD, with most of the variation likely due to levels of industrial activity.

Conventional heating, ventilation and air conditioning systems have used active means of converting and redistributing energy, but this has changed in green building construction. Space conditioning, at the most basic level, involves an initial conversion (typically through combustion or mechanical means) and distribution of the conditioning medium (generally convection or radiative), although heat pumps, electric radiative heat and air conditioning have an additional external convert-distribute step through an electrical grid. This has involved employing motors, boilers, furnaces and compressors to achieve a comfortable indoor environment. High performance buildings, however, attempt to exploit passive energy distribution before relying on equipment that require significant entropy generation.

3. High performance buildings

Modern high performance buildings moderate the interface between the interior and exterior "climate" more efficiently. Green buildings aim to reduce heating/cooling loads, improve the efficiency of conversion/distribution and employ passive designs where possible for lower input and higher quality conditioning. Interest in low-energy building design can be linked to eras of perceived energy scarcity and volatility in prices. The modern era of low-energy building construction originated during the energy

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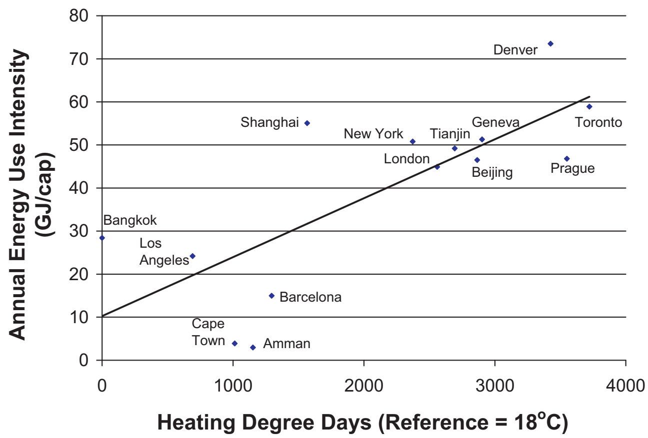

Fig. 1. Urban heating fuel consumption vs heating degree days ($n = 14$; adapted from [5]).

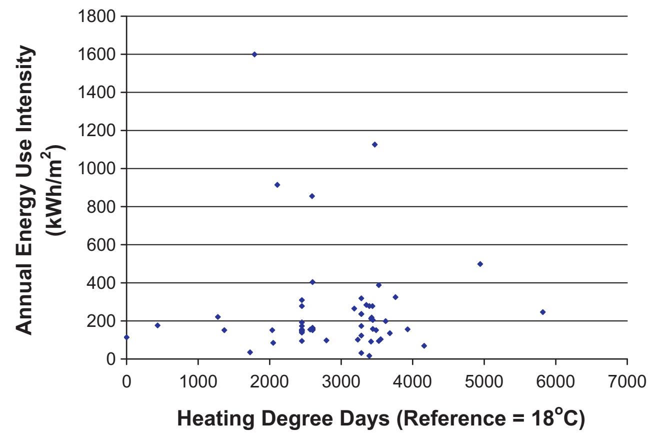

Fig. 2. Actual building energy consumption vs heating degree days ($n = 57$).

crises of the 1970s, which saw the promotion of photovoltaic technology and passive solar design as a means to improve resiliency against energy price shocks [6].

The resurgence of interest in high-performance buildings within the past two decades, due in part to concerns over energy price, climate change and sustainability in general, has spawned numerous certification programs including BREEAM (UK), Green Globes (USA) and LEED (USA). Many of these standards have been adopted globally, with LEED having 18 international member organizations and BREEAM assessors listed in over 30 countries [7,8]. Concurrently, interest in application of green building practices has grown tremendously in recent years, with the number of LEED certifications increasing by an order of magnitude from 2004 to 2008, to nearly 20% of non-residential new construction in the US [9]. More recently, the Living Building Challenge, a next-generation certification scheme developed by the Cascadia Green Building Council, is based on mandatory standards (or "imperatives") rather than credits; certification requires on-site food production, operational water and energy independence, carbon-neutrality, geographic limitations on construction material sources, and construction waste diversion rates greater than 80% [10]. More rigid certification schemes are likely to further raise the standards for what defines a green building.

4. Breaking the climate – energy use link

The current trend in high performance building design strategies employ conditioning systems which are more efficient in the conversion and redistribution of energy (Table 1). These technologies lower temperature requirements for cooling/heating media, and the quality and quantity of primary energy used is reduced. As a result of the decreased energy demand, systems in high performance buildings are able to provide much of their energy demand from high entropy sources, e.g., via ground source heat pumps, solar thermal and heat recovery. As well, active and passive ventilation can be employed to reduce cooling requirements. Finally, reduction in heating/cooling loads is largely achieved by installing high performance building envelopes as well as temperature moderating elements providing thermal mass. When taking these strategies into account to meet certification standards, builders have been able to significantly lower energy demand.

We have analyzed actual green building performance data from various sources [11–15] to determine the impact on the relationship between HDD and energy use intensity (EUI). The buildings examined (many of which are LEED certified) use an array of the technologies discussed above (passive and active, electricity- and fuel-based) to achieve reduced energy requirements. Our analysis shows that high performance buildings have been successful in reducing energy demand to the point that, energy consumption no longer shows a correlation with heating degree days (Fig. 2). If all end use types are aggregated, no significant correlation was apparent from a regression analysis of measured EUI of high performance buildings versus HDD (at a reference temperature of 18 °C; t-stat = −0.265, $R^2 = 1.27 \times 10^{-3}$, $n = 57$).

Table 1
Measures employed in high performance buildings (adapted from [13]).

Building system	Energy efficiency measures employed
Ventilation	Passive/hybrid systems, operable windows, displacement ventilation, heat recovery, variable speed drives, night time ventilation
Envelope	Triple-paned, low-e, argon filled windows, high *R*-value walls (>3 RSI), high R-value roofs (>5 RSI), double-skin façades, air tightness
Lighting	Skylights, T5 fluorescents, reduced lighting density, automated lighting controls
Heating/cooling	Passive solar with thermal mass, ground source heat pump, optimized orientation for shading/heat gains, evaporative cooling, absorption chillers, solar thermal collectors

5. Conclusion

The decoupling of building energy use from climate, as exhibited by recent green buildings, is in many ways an impressive human achievement. Using a range of passive, active and other technologies, we are able to construct buildings in a range of relatively harsh climates, from hot to cold, with operational energy use performance that is independent of temperature gradients. Of course, such gradients still largely determine the building energy use in contemporary cities, as show in Fig. 1; retrofitting and rebuilding our cities to achieve lower levels of energy consumption remains a huge task. The performance of green buildings will hopefully continue to improve too; the link with climate has been decoupled, but energy use related to other factors such as end use and occupant characteristics, can still perhaps be improved.

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