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Evidence of the 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.

Keywords

energy efficiency; green buildings; LEED; Heating Degree Days; energy use intensity

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1.0 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 (CDD), 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. However, it appears that high performance buildings may be weakening that correlation. 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 through examples of green construction worldwide that demonstrates energy use intensity (EUI) does not correlate with climate in lower energy buildings. This leads to the conclusion that if the net-zero energy buildings are to be accomplished within the boundary of the building site, improvements must focus on occupant-specific energy reductions.

2.0 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, depending on climate [1]. Correlation between building energy use and HDD is well established, both within climatic zones and globally [2-4]. In conducting a comparison of urban carbon inventories, [5] showed that this relationship is relevant on aggregate for international cities as well. As presented in Figure 1, there is a significant correlation between heating fuel consumption and HDD, with most of the variation likely due to levels of industrial activity.

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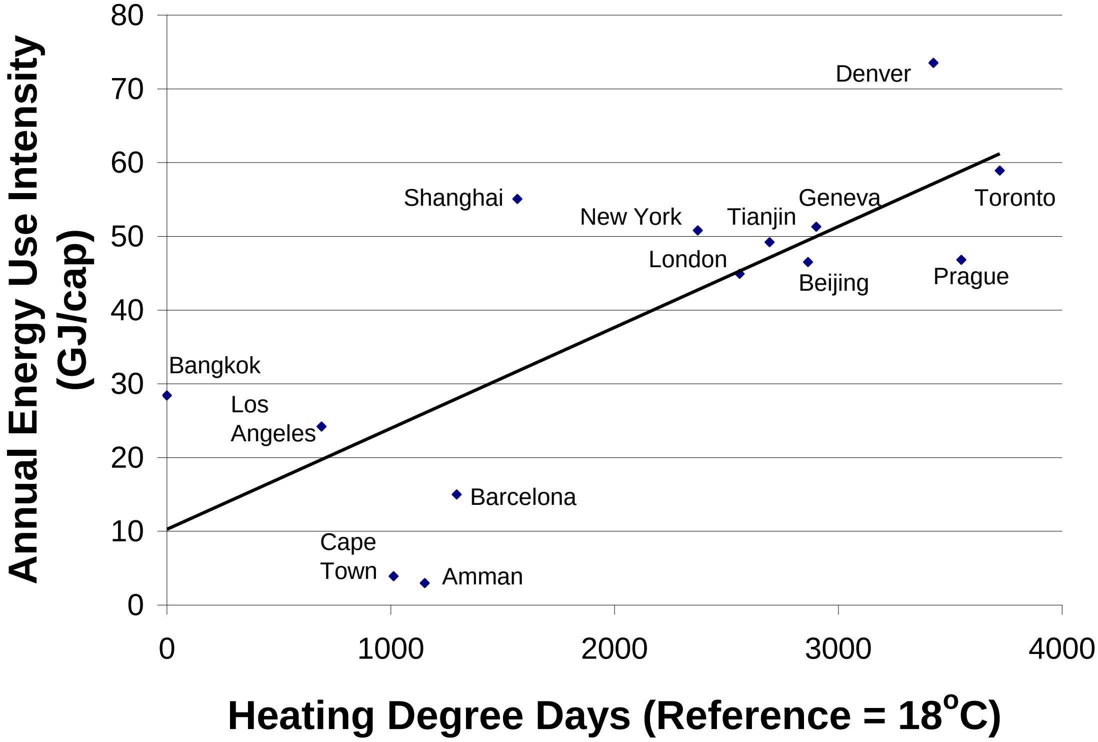

Figure 1: Urban heating fuel consumption vs HDD (n = 14; adapted from [5])

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.

3.0 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 and distribution and employing 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 crises of the 1970's, 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); these standards provide energy use benchmarks as a key certifying requirement. 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 – 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.

4.0 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. These technologies lower temperature requirements for cooling/heating media, and the quality and quantity of primary energy 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 requirement. 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 achieve significantly lower energy requirements.

We have analyzed actual and modeled building data from various sources [11-15] to determine the impact on the relationship between HDD and EUI internationally. The buildings examined (many of which are LEED certified) use an array of technologies (passive and active, electricity- and fuel-based) to lower EUI. Examples of the features found in some top performers are found in Table 1.

Our analysis shows that high performance buildings have been successful in reducing energy demand to the point that, for both modeled estimates and measured data, energy consumption no longer shows a correlation with heating degree days. If all end use types are aggregated, no significant correlation was apparent from a regression analysis of measured EUI of high performance buildings versus heating degree days (at a reference temperature of 18^{o}C; t-stat = -0.022, R^2 = 8.63x10^{-6}, n=59). However, laboratories were distinct outliers, where all EUIs exceeded 800 kWh m^{-2} (versus the average of 200 kWh m^{-2} observed in all other building uses). If outliers are removed (Figure 2), and buildings are further subdivided into residential, commercial and educational end-users, some correlation is observed for educational and residential buildings; however, the sample sizes are relatively small (n=12 and 9, respectively) when compared to commercial buildings (n=36). Commercial buildings still did not demonstrate any correlation, with a data set that spanned over a larger number of climatic zones. Examining the data used above obtained from [14] and [15], a correlation is observed between hours of building occupancy per week and energy consumption (t=2.52, n=20). Overall, the evidence suggests that the end use and occupant characteristics have become greater predictors of energy intensity for green buildings than climate.

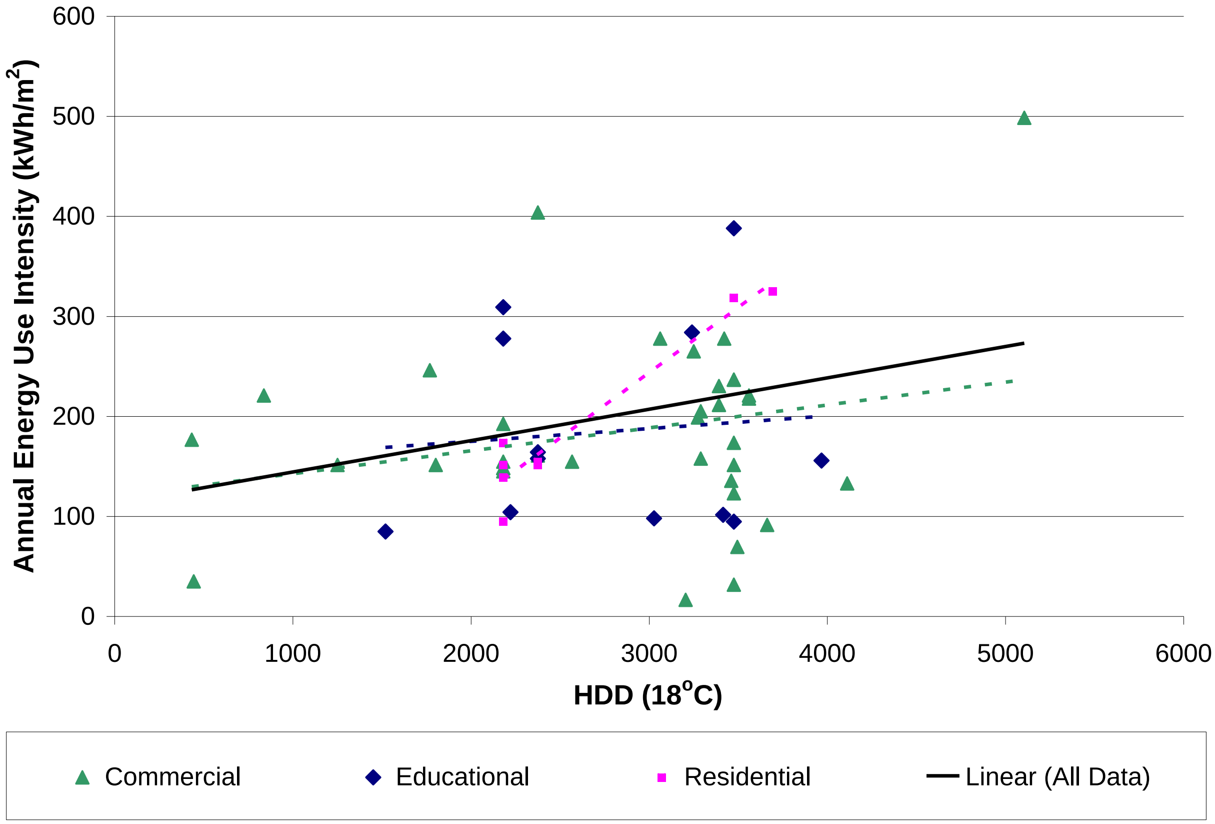

Figure 2: Actual Building Energy Consumption vs HDD (n = 57)

Modeled data is also analyzed since the geographic and climatic scope of the buildings assessed is broader than what was available from measured cases. These did not demonstrate a relationship in any of the three categories (see Figure 3). Even when the HDD reference temperature is lowered to adjust for improvements in thermal performance (15, 12 and 10^{o}C are applied), p-values and t-statistics for modeled EUI suggest that the relationship between energy consumption and HDD is not significant. The same observation was made with the measured

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EUI data.

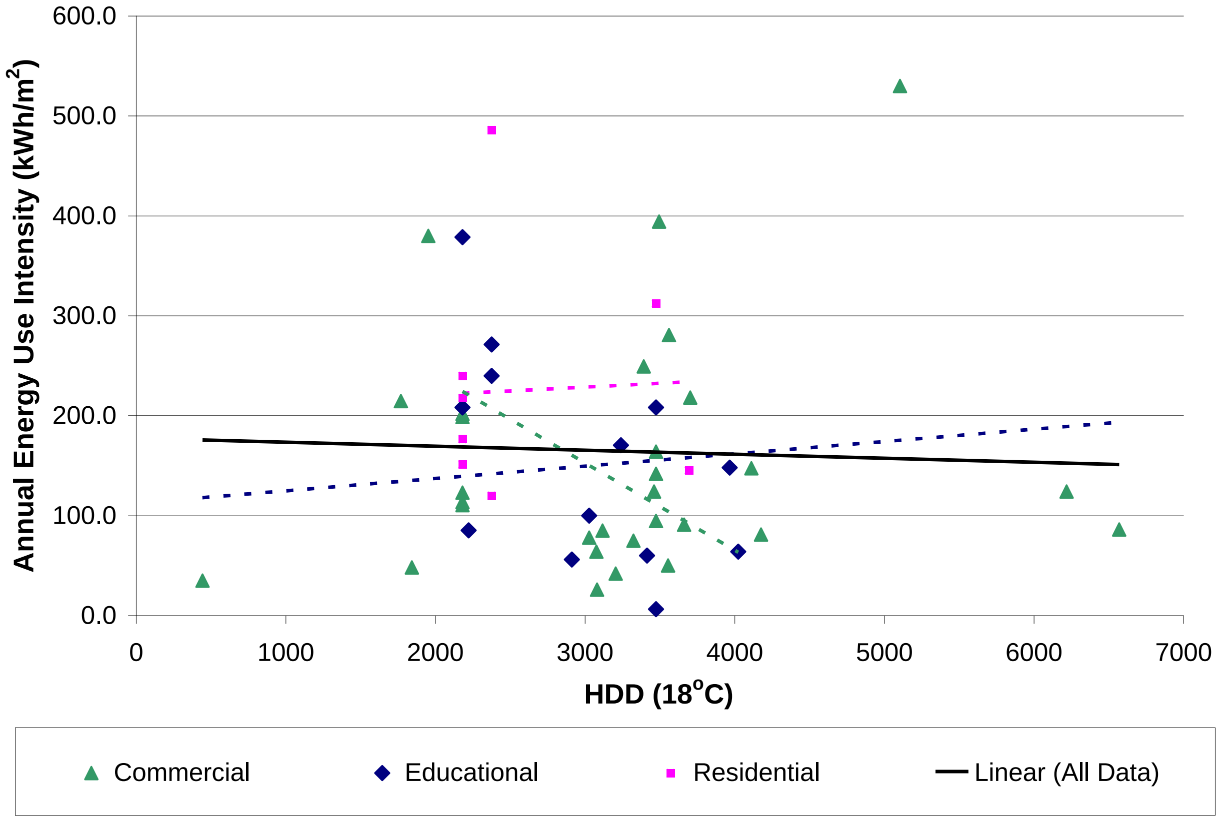

Figure 3: Modeled Energy Use Intensity vs HDD (n = 52)

5.0 Future Energy Demand Reduction Options

Building EUI may have been decoupled from climate for high performance buildings, but there is still work to be done if buildings are to become net zero energy consumers. It is important for energy managers to understand and examine the factors that matter most in pushing for this higher level of energy performance. Many of the greatest outliers of the buildings assessed in the complete data set presented in Figures 2 and 3 are government labs and office buildings, end-users whose behavior can vary considerably based on our analysis of data from [9] (EUI standard deviations of 162 and 25 kWh/m^2, respectively, compared with 8 kWh/m^2 for multi-unit residential).

Factors related to building occupancy (as will other factors that drive non-regulated energy uses) will need to be assessed for opportunities for efficiency gains to move further down the path to net-zero energy buildings. Domestic hot water usage, unregulated plug loads, lighting systems, appliance/equipment efficiency, occupant behavior and energy consumption culture will all need to be addressed to provide further significant reductions in building energy consumption. Embodied energy will also comprise a greater share of lifecycle building energy consumption, and must also be reduced in the greater context of a lower energy (and lower carbon) economy. Finally, on-site/decentralized energy generation also plays an important role in the path to net-zero energy consumption, including building integrated photovoltaics, micro-turbines, trigeneration technology, and district energy. The net-zero building will ultimately require more rigorous energy management to achieve reductions, taking advantage of sophisticated monitoring and building information systems.

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