Long Term Relationships: When Design Teams Engage in Multi-Year Building Performance Monitoring

Z Smith, Eskew+Dumez+Ripple

ABSTRACT

The widely observed gap between predicted and measured energy performance is a key disincentive to convincing clients or designers to pursue high-performance techniques. When post-occupancy performance studies are done, the design teams are often involved only tangentially, reducing the opportunities for designers to learn what went wrong. However, recent changes in the reward structure for architects have led to a sea-change in the profession, where measured energy use intensity results are increasingly contractual requirements or requested as part of awards submissions. Some firms are now compiling performance results on most of their portfolio, and working with building owners, operations staff, occupants, engineers and contractors to help understand why some projects achieve high performance and others do not. This session will feature three case studies drawn from portfolio performance inventories and describe efforts in multi-year post-occupancy engagement documenting occupant comfort, energy performance, and operational lessons learned across a wide range of building types including single- and multi-family housing, libraries, houses of worship, commercial offices, and research laboratories. One key result from these studies is that buildings don't use too much energy because too much comfort is being provided—rather, allowing occupants to modify conditions and report comfort & discomfort on an ongoing basis is a cheap tool to identify problems and improve energy performance. Comfort complaints are the canary in the coal mine; we ignore them at our peril. As building systems become increasingly complex, the process of getting everything working well can take far longer than the typical commissioning period. This session will show how Architecture & Engineering firms can develop long-term relationships with all players to achieve high performance and profit.

Introduction

The use of energy modeling during the design of buildings is based on the premise that such models can successfully predict the energy use of buildings once constructed, operated, and occupied. If models work, then designers can trade off various measures—say, a more efficient heating system for less insulation—with no change in anticipated energy consumption, or help evaluate which design measures would reap the greatest savings for the least investment. However, studies (Turner and Frankel 2008) and anecdotal reports (Navarro 2009, 2012b) have noted that the measured energy use is typically quite different than predicted, and sometimes not in a good way. Perhaps the most depressing chart in a report on the post-occupancy performance of 121 LEED New Construction buildings shows that a plot of measured vs. predicted energy use exhibits a regression correlation coefficient r^2=0.33, which could be interpreted as indicating that only 1/3 of the observed variation in measured energy use is attributable to variations in design (Turner and Frankel 2008, 25). Subsequent analysis (Newsham, Mancini, and Birt 2009) explored the finer details of baselines and comparison benchmarks, but the question remains:

Why spend so much attention optimizing design, if 2/3 of the variation in energy use is due to other factors?

Every anecdotal report of a building that didn't perform as predicted hurts the argument of those looking to reduce energy usage in buildings and makes it that much harder for a design team to advocate to a client that they should invest in measures calculated to improve performance. With predicted Energy Use Intensity (EUI) data now required in all submissions for design excellence awards of the American Institute of Architects [AIA] (Pearson 2014), there is a higher level of exposure for these predictions, and some design firms have begun compiling data on the performance of their portfolio of built work, and when possible, performing diagnostics to understand what went right or what went wrong (Holdridge, Rashed-Ali, and Young 2011; Thomas 2014).

This paper will relate one design firm's experiences with "closing the loop" between design and performance, and how this is changing their practice. This case-study approach is necessary anecdotal, but helps illustrate the dynamics emerging in design firms across the country.

Approach

This gap between prediction and performance is like a good murder mystery with an abundance of plausible suspects. The best detectives are cautious not to jump to conclusions, and consider the possibility that more than one suspect may have had a hand in the victim's demise. Table 1 lists the usual suspects.

Table 1. Potential causes of gaps between predicted and measured building energy use

Suspect	What they may have done wrong	Examples
Architect	Design errors such that the building built differs from what was communicated	Thermal bridging Severe infiltration due to poor detailing
Engineer	Design errors that cause unexpected operation	Oversized systems with high cycling Simultaneous heating and cooling
Energy Modeler	What was modeled was not what the design team intended	Actual occupancy schedules different from information provided during modeling Thermal bridging not accounted for Partial-load operation info unavailable Software limitations: e.g., ground coupling
Contractor	What was built was not what was drawn	Substitutions of alternate materials or systems components than those used during modeling. Sloppy installations where building components meet.
Building controls	Operation sequencing not what the engineer intended Schedule not what was intended	Some systems 'off' when building unoccupied, but not all When in doubt, run it 24/7
Building	Not following maintenance	Failure to replace filters

Operator	schedules Overriding control systems to stay in their technical comfort zone	Bypassing unfamiliar systems Locking setpoints Dealing with system alarms by dismissing them
Occupants	‘End-run’ around faulty systems	Tape over the daylight sensor Electric space heater under the desk to compensate for overcooling

Some of these mismatches can be caught by a good commissioning agent or would be accounted for by a team following the International Performance Measurement and Verification Protocol (EVO 2012) called for under the LEED rating system Measurement and Verification credits. However, even fully commissioned buildings will wander off from their design optimum. The following case study provides an effective illustration.

Case Study 1: Unforced error

The Dr. Nancy Foster Florida Keys Environmental Complex, a 30,000 sf project composed of a visitor’s center, labs, and offices opened in 2006, earning LEED Silver certification with energy consumption predicted 27% below the ASHRAE reference building. Commissioning during construction caught some obvious errors; for example, a DC motor within a large air-handling unit had been wired backwards, causing the ventilation system to deliver all conditioned air to a single return duct while drawing return air from all supply registers. After the building’s opening, the design team signed off with all systems apparently running as intended. In 2009, some three years after opening, the design architecture firm Eskew+Dumez+Ripple contacted the facility manager as part of an energy inventory of its portfolio and learned a cautionary tale of what had transpired in the interim.

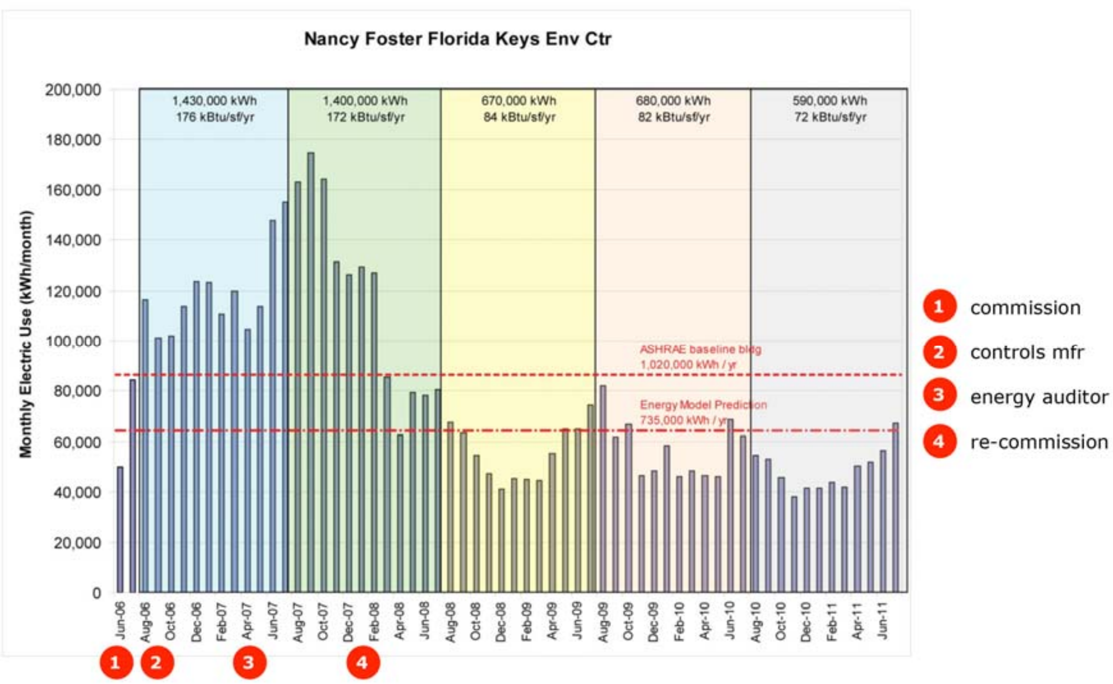


Figure 1. Monthly electricity use of the Dr. Nancy Foster Florida Keys Environmental Complex

For the first two months of operation, the building's energy consumption fell within the range anticipated by the design-phase energy model. However, three months into occupancy, the local representative of the building management system (BMS) manufacturer appeared on site to helpfully install a new release of the BMS software, inadvertently overwriting many systems settings and schedules. As shown in Figure 1, energy use shot up.

After several months of energy bills double what had been anticipated, the facility manager contacted the commissioning agent (based 800 miles away) to seek advice. The commissioning agent offered to come and investigate for only the cost of travel reimbursement, but the facility manager had no budget for travel. Instead, the facility did have access to the services of a local energy auditor under a contract already in place. Subsequent to the auditor's manipulations of settings (such as raising the supply air temperature, raising the moisture content of air delivered) the building experienced another 50% increase in energy consumption and a mold bloom.

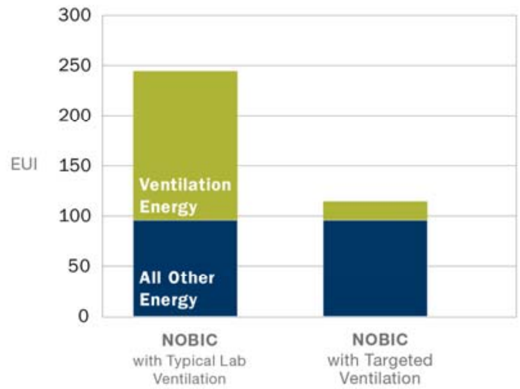
At this point, the facility manager was able to obtain funds for the air ticket for the commissioning agent to return and re-commission the systems. Almost immediately, building performance began to match expectation. Indeed, as the facility manager refined operational strategies, energy consumption in subsequent years has averaged 13% below model predictions. In retrospect one notes that the building suffered over $150,000 of excess utility bills for want of funds for a regional air ticket.

After reviewing the events that transpired, the architect, mechanical engineer (Newcomb&Boyd), and commissioning agent (another division of Newcomb & Boyd) agreed that on all subsequent joint projects they would check in quarterly after occupancy, and work more to train local facilities operators to recognize signs of when systems were going astray.

Case Study 2: Empowering occupants with occupant choice

In 2009, the same team of architect, mechanical engineer, and commissioning agent were completing design of the New Orleans BioInnovation Center (NOBIC), a 4-story 65,000 sf incubator complex including biotech labs, offices, and conference facilities for downtown New Orleans (Eskew+Dumez+Ripple 2013c). The project rents space to entrepreneurs 'by the yard', from 3 feet of bench space to labs 600sf at a time. As construction documents approached completion, favorable cost estimates prompted the Owner to request that the design team look for investments that might lower long-term operating costs and, while they were at it, "pursue that LEED thing." After a six-week exploration, the Owner approved package of investments totaling $600,000 that were anticipated to save up to $150,000 per year in utility costs while allowing the project to earn LEED Gold certification.

Some of the measures proposed were obvious enough (higher-performance glazing & framing, a more efficient electrical transformer and chiller). Some were measures that, as far as energy modeling for LEED certification was concerned, saved no energy at all, but provided a highly granular approach to thermal control, ventilation, and electrical monitoring. Each lab was also separately sub-metered to allow the facility operator the flexibility of billing heavy users separately. Because there was no way to know what type of research might be done in any given lab, the 'safe' strategy would be to ventilate all to the highest common denominator bulk air change rate, 12 Air Changes per Hour (ACH) being a typical choice. Due to the high latent loads of dehumidifying outdoor air in the local climate, the energy impact of such a default choice would be huge. Instead, the design team developed a system whereby each 600 sf lab could have its own ventilation policy, varying air flush rates from 2ACH to 12ACH, with occupancy control and a 'Panic' button that took the lab and any fume hoods to maximum in case of an accident. See Figure 2.



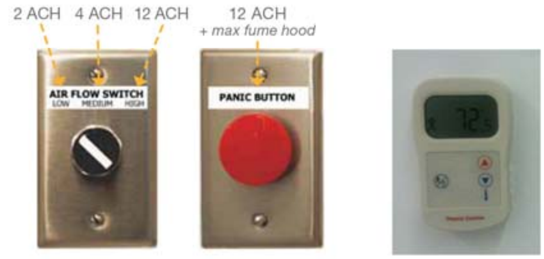


Figure 2: NOBIC: (left): Predicted savings in Energy Use Intensity allowed by a targeted ventilation strategy (right) Occupant controls provided in each 600sf lab for independent control of temperature and ventilation rate.

Given reasonable assumptions of the diversity of tenant ventilation needs, this strategy was predicted to result in significant energy savings. However, under the standard guidance for energy modeling under ASHRAE 90.1, ventilation rates are assumed to be an externally imposed requirement, and so whatever mix of ventilation rates are being used in the 'proposed' building, the same mix must be used in the 'reference' building against which one is being scored. The ironic consequence is that although this building was only predicted to use 22% less energy than its ASHRAE baseline this predicted Energy Use Intensity was 65% less energy than comparable lab/office buildings in the Labs21 benchmarking database (giving it a lower Energy Use Intensity than 92% of such lab/office buildings). As illustrated in Figure 3, saving this much energy in a high-energy-use building type such as labs saves as much energy as achieving net-zero performance in other common building types

The design team has stayed involved with the project on a regular basis, checking actual energy use against the original model. Measured EUI has tracked predictions within a few percent as the building has leased out space ahead of its original business plan since first opening in 2011. Within this general agreement, there are still discrepancies where gas use has been running higher than predicted and electric use lower, as expected for some lab spaces which have lower plug loads and consequently higher re-heat needs than assumed during design.

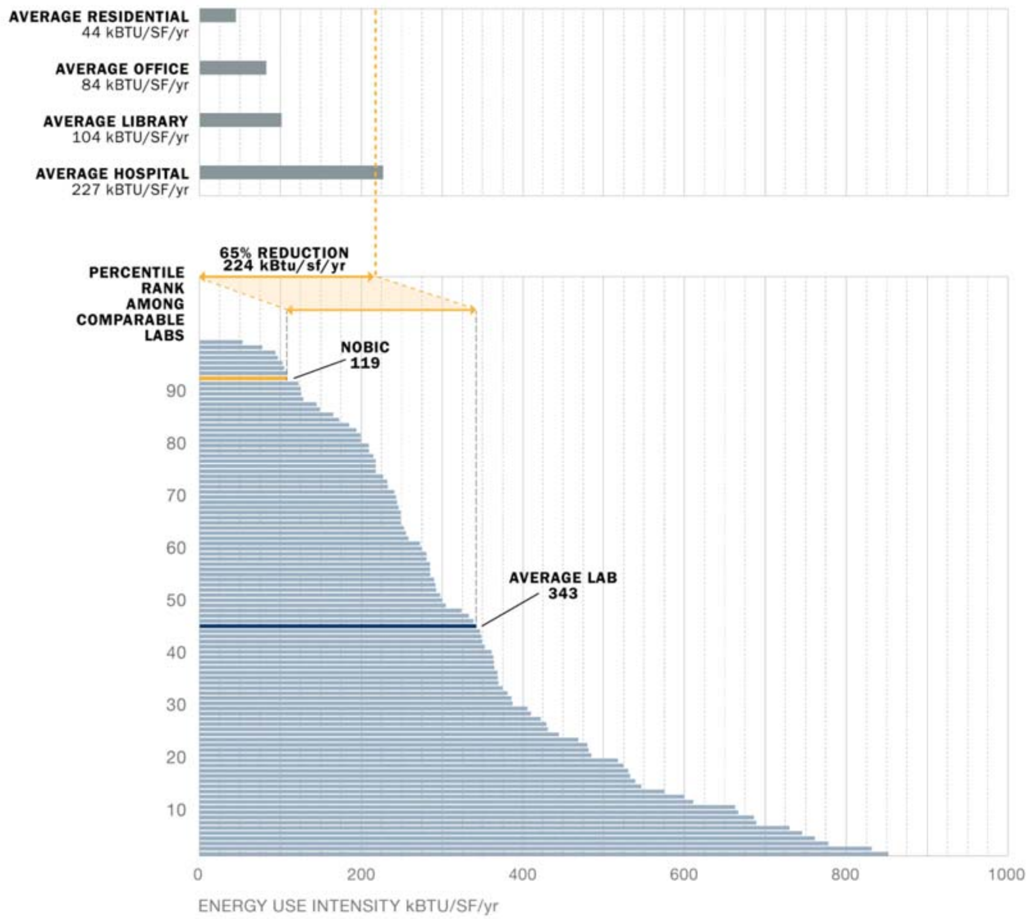


Figure 3: EUI for NOBIC in context. Lab data from Labs21; others from CBECS (EIA 2003a) & RECS (EIA 2003b).

One anecdote: During post-occupancy monitoring, it was learned that while comfort scores averaged over the building were quite high, one lab in particular was the source of complaints as running too hot. The tenant attributed it to the large amount of equipment his growing business was using. The building management system remote monitoring display showed all re-heat shut down, so the building operator also concluded there was inadequate cooling capacity. However, a member from the Architect's team visited the lab, pointed an infrared thermometer at the air supply register, showing that air was being supplied at 90°F. It turned out that despite what the BMS showed (that it had issued a command to close the re-heat valve), the valve was in fact stuck open. Sometimes remote monitoring systems can be too remote. Since repairing the valve, comfort has been re-established and energy use for the lab has gone down.

This illustrates a principle the team has seen on other projects: when buildings use too much energy, it's not that occupants are consuming too much comfort. Rather, malfunctioning systems often use too much energy while delivering poor comfort. Comfort complaints are the canary in the coal mine, and we ignore them at our peril.

Case Study 3: Variation in energy use due to occupant choice

Recent moves towards greater disclosure of energy consumption, such as New York City's Local Law 84, have demonstrated the huge variation in energy use among 'similar' buildings (Navarro 2012a, NYC 2012). Within any given building type—say, multifamily housing or high-rise office buildings—the worst 20% of buildings may use 3 times as much energy per square foot as the best 20%. This hints at huge potential savings. However, such aggregated data sets don't tell us how much of this variation is due to building design, to maintenance, to operator competence, or to occupant choices.

Seryak and Kissock explored the sources of the variation over a portfolio of 350 houses owned by the University of Dayton and rented to groups of students of varying sizes (Seryak and Kissock 2003). While variations due to building construction had substantial effects, household size and occupant behavior were shown to be key drivers of overall energy use.

Other studies have provided further hints: A study of 50 Toronto school buildings all constructed within a decade of each other to similar plans demonstrated a 3:1 range in EUI (McIntyre 2007). Even more telling was the anecdote offered by the study's author: When the principal of the worst-performing school was informed of her ranking, within 6 months of low-cost / no-cost operational changes, her school had moved to the middle of the pack. Similarly, a study of 11 tract homes built to similar PV-enhanced designs by a single homebuilder in a single neighborhood of Sacramento showed annual electric bills ranging from $0 to $1,200 (Crosbie 2005). In both these cases, building designs were similar, but not identical, with varying building orientation and construction crews. So how much of the variation is attributable to operator and occupant choices is still open to dispute.

Data from a single large multifamily apartment building with a central plant but individual control and metering of heating, cooling, and plug loads allows us to separate affects due to occupant choices. The 930 Poydras Residential Tower, comprised of 250 studio, 1- and 2-bedroom apartment units and townhouses plus ground floor retail, opened in early 2010 in New Orleans (Eskew+Dumez+Ripple 2013a). Each unit is heated and cooled by an individual water-source heat pump connected to a recirculating water loop kept at a neutral temperature by a rooftop boiler and cooling tower. Each unit is individually metered, so that tenants pay for the electricity to run their heat pump, water heater, lights and plug loads; the building owner incorporates the central plant costs into rent. Starting in 2012, the Architect has compiled monthly utility consumption data for all units and performed energy modeling and analysis. Typical results are shown in Figure 4.

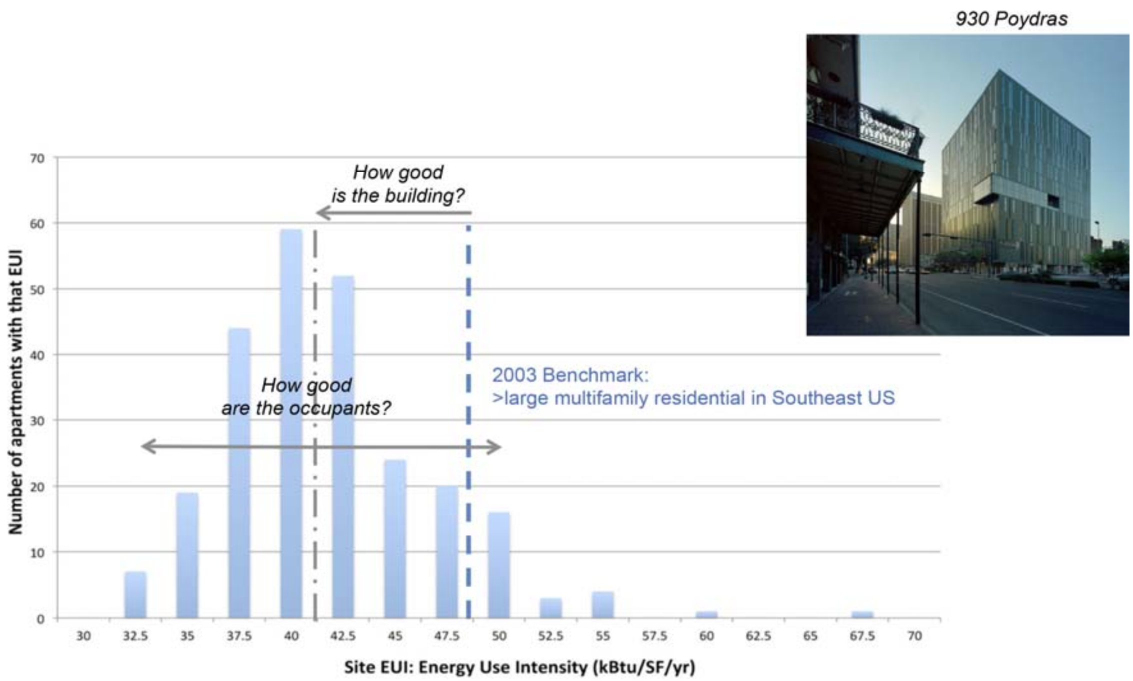


Figure 4. Variation in EUI among tenants of a single 250-unit multifamily residential building.

In this analysis, 'Common' energy consumption for corridors, lobby, recreation areas, elevators, and the operation of the central plant are pro-rated by apartment area and added to their individual energy use. In this way, the sum of all individual tallies matches the energy consumption of the entire residential portion of the building. Figure 4 shows that the median EUI is about 20% lower than the 2003 average for large multifamily residential buildings in the Southeast, but that some units use significantly less and others significantly more. In fact, analysis aggregating all units of a given orientation showed that unit orientation was responsible for less than 10% of the variation in actual energy consumption. This result was consistent with results from energy modeling. For high-rise residential, the project is relatively restrained in its use of glazing, with a window/wall ratio of 30%, and uses low solar-heat-gain glass, helping to explain this small variation of energy use with unit orientation.

To those who are quick to blame poor energy performance entirely on either 'bad design' or 'bad occupants', the data in Figure 4 speak loud and clear: both matter.

Conclusions

This paper has given the results from three buildings by a single architectural firm—Eskew+Dumez+Ripple—that has undertaken performance monitoring of buildings in its portfolio. Three case studies—an environmental center, a research laboratory, and a high-rise residential tower, have illustrated the components that contribute to overall energy performance, from variation in design to variation in construction to variation in operation and occupancy patterns.

An increasing number of leading architectural firms, including Lake|Flato, Kirksey, SmithgroupJJR, EHDD, RTKL, SHW, and LMN, are now looking at their portfolios in a similar fashion. At present, firms generally perform these investigations without additional fees from the Owner. If they are not being paid directly, why do they do it? One partner in a leading architectural firm explained, “Projects with repeat clients tend to be our most profitable, because we get to re-use the time spent understanding their organization and their unique needs; investing in long-term performance demonstrates our commitment to them and keeps us in the top of their mind when another project comes up.” Over half of the firms recently surveyed by Design Intelligence magazine now engage in what they describe as ‘thought leadership, research, and innovation’ programs (Walter 2013). With the AIA requiring reporting of predicted EUI with award submissions, and the LEED rating system now requiring reporting of energy and water performance data for at least 5 years post construction (USGBC 2011), both claims and results are increasingly being scrutinized by third parties. New project delivery systems such as that used in the National Renewable Energy Laboratories’ Energy Systems Integration Facility (Brettman and Denmark 2013), where achieving energy performance goals were part of the fee incentive structure hint at new reward structures to come.

These studies are examples of a new level of commitment to architectural practice as a long-term relationship, where designers maintain connections to projects long after they are built, creating opportunities for long-term learning while demonstrating to clients their commitment to long-term service. It creates opportunities for new kinds of partnerships between those who design buildings and those who care how they perform.

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