GREEN BUILDINGS IN MASSACHUSETTS: COMPARISON BETWEEN ACTUAL AND PREDICTED ENERGY PERFORMANCE

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ABSTRACT

Conventional buildings consume a significant amount of energy which is about one third of the total annual energy requirement in the US. We assess energy use in 19 (new and/or renovated) green buildings in Massachusetts (MA) that have adopted an array of Energy Conservation Measures (ECMs) and on-site renewable energy generation to reduce building energy consumption. The predicted energy use of the buildings estimated during the pre-construction design phase is compared with actual energy use (electricity and natural gas) for each of the buildings with one year or more of occupancy. Also performance of photovoltaic (PV) systems deployed in several of these buildings has been analyzed.

We find that most green buildings are consuming on an average 40% more energy than predicted, but are still consuming less than a building designed to MA baseline building code. The average PV system performance is above 80% of predicted monthly values.

1. INTRODUCTION

Buildings consume a significant amount of energy and water. In general, buildings in both residential and commercial sectors use electricity and heating oil/natural gas for lighting, ventilation, air conditioning, operating appliances and electronic equipment, space and water heating. According to IEA (2004) residential and commercial buildings consume 51% of the world’s electricity generation (1). The corresponding value for heat use in buildings is 55%. Another estimate by the Pittsburgh Green Building Alliance (GBAPGH) shows that worldwide, buildings consume nearly 40% of the world's energy, 25% of its wood, and 15% of its water (2).

Buildings in general not only consume large amounts of energy and resources, but also have significant impact on occupant health and productivity. Considerable attention has been focused over the last decades on enhancing energy efficiency and improving the quality of life in buildings.

Green buildings are designed to minimize on-site environmental impacts. This is achieved by selecting appropriate materials used in their construction and maximizing the performance of the installed systems to create healthy environments for people to live and work.

2. US BUILDING’S ENERGY PROFILE

In the last decades there has been a general shift from industrial to service oriented economy, and also from heavy to light industry. These have affected the energy use pattern in US leading to an increase in energy consumption in the commercial and residential sectors. Practically most of this energy is consumed in residential homes and commercial buildings. The Pittsburgh Green Building Alliance (GBAPGH) estimates that buildings in United States are responsible for about one-third of the country’s total energy consumption (2). In addition, the Environmental Protection Agency (EPA) states that people in United States spend around 80% of their time in buildings, and the indoor air quality is two to five times worse than the outside air (3).

Electricity and natural gas are the final forms of energy sources most consumed indoors in the country. The Energy Information Administration (EIA) estimates that almost 70 percent of the retail sales of electricity and 38 percent of the natural gas delivered to ultimate customers went to both residential and commercial sectors during 2005 (4).

TABLE 1: ENERGY INTENSITY PER BUILDING ACTIVITY IN THE US

Activity	kBtu/sq-ft
Education	83.05
Office	92.89
Public Assembly	93.93
Mercantile Total	91.23
Lodging	100.08
Health Care	187.80
Food Service	258.30
Service	77.00

In 2003 the Commercial Building Energy Consumption Survey (CBECS) estimated that almost 55 and 32 percent of the total building energy consumption was in-site electricity and natural gas with a national average energy intensity of 91 kBtu per square feet (5). A breakdown of energy end-use per principal building activity determined that office, mercantile (retail and malls) and educational buildings together consumes 45 percent of the total building energy with an average energy intensity of 93, 91 and 83 kBtu per square feet respectively (Table 1).

For the Northeast region, the commercial and residential energy intensities are estimated as 99.75 and 48 kBtu per square feet which are higher than that for other US regions (Table 2). The energy intensity of commercial buildings in New England is 99.94 kBtu per square feet, with in-site electricity and natural gas consumption of 41 and 25 percent of the total New England's building energy consumption (CBECS) (5).

TABLE 2: ENERGY INTENSITY PER REGION IN US

	kBtu/sq-ft	
Region	Commercial (year 2003)	Residential (year 2001)
Northeast	99.75	48
Midwest	99.38	49
South	84.71	42
West	82.92	40

3. GREEN BUILDINGS CASE STUDY IN MASSACHUSETTS

Massachusetts is one of the leading states in the rapidly growing green building movement in the US. National and State programs have been providing financial and technical support for adoption of clean energy technologies in green buildings. In addition, incentives and the rebates from the utilities companies are provided for adopting energy efficiency improvement measures in buildings. Green buildings are designed based on Massachusetts Energy and Building Code as well as the LEED and Massachusetts CHPS (MA-CHPS) Standards. LEED is a guideline and rating system that merit energy efficient features, and CHPS is similar to LEED except that is geared toward schools.

The Energy Engineering Program of the University of Massachusetts Lowell has conducted case studies on 19 green buildings in Massachusetts. The goal of the Green Buildings Case Study was to assess effectiveness of green features in reducing energy consumptions in the respective green buildings. Comparisons were made between the energy consumption predicted during the design phase of a project and the actual energy consumed in buildings with occupancy for one year or more. In addition, issues were identified common to several buildings that would help in future green building designs.

Two categories of buildings were defined for the case study: Green Schools and Green Buildings. These categories were chosen due to the different rating systems: MA-CHPS design standards were used for Green Schools, and LEED rating system for Green Buildings (6, 7).

Most of the schools and buildings were either newly constructed or renovated from existing buildings (Table 3). They all received grants from the Massachusetts Technology Collaborative (MTC) to aid in their design and construction (9).

3.1 Energy Conservation Measures

The green features in each building were based on Energy Conservation Measures (ECMs) which are a group of several high-efficiency and energy saving strategies identified and addressed starting from the design process, pursued during the project construction and put into operation during occupancy. For each building, the project team consisted of architects, engineers, consultants, owners. The ECMs implemented in each building were similar (but not the same) with an objective to reduce the consumption of electricity, gas, and improve the indoor air quality and comfort.

The most important ECMs were:

- Daylight harvesting system: Optimal building orientation, use of skylights, clerestory windows and translucent walls.
- High efficiency lighting system: Light fixtures controlled by occupancy sensors and time of day.

TABLE 3: GREEN SCHOOLS AND GREEN BUILDINGS IN THE STUDY.

	Location	Area (ft^2)	Construction Type	Year of Operation	Cost (million $)
Green Schools					
Berkshire Hills Regional Middle School	Great Barrington	78,000	New	2005	15.6
Blackstone Valley High School	Upton	300,000	30% new and 70% renovated	2005	35.7
Dedham Middle School	Dedham	130,464	New	2006	26.1
Ashland High School	Ashland	202,465	New	2006	
Gill Montague	Montague	196,096	16% new and 84% renovated	2004	33.3
Holten Richmond Middle School	Danvers	148,000	60% new and 40% renovated	2005	29.7
MATCH School	Boston	31,500	10% new and 90% renovated	2002	6.2
Michael E. Capuano	Somerville	80,200	New	2003	18.3
Newton South High School	Newton	387,200	27% new and 63% renovated	2005	50
William Stanley Elementary	Waltham	95,000	New	2003	17.5
Williamstown Elementary School	Williamstown	89,000	New	2002	14.3
Woburn High School	Woburn	340,000	New	2006	66.8
Green Buildings					
Allston-Brighton CDC	Allston	74,474	New	2005	21
Artists for Humanity – EpiCenter	Boston	23,500	New	2004	6.8
Cambridge City Hall Annex	Cambridge	33,216	Renovated	2004	8
Genzyme Corporate center	Cambridge	344,450	New	2003	140
Trustee of Reservations: Doyle Conservation Center	Leominster	22,000	82% new and 18% renovated	2004	5
Woods Hole Gilman Ordway Campus	Falmouth	19,300	62% new and 38% renovated	2003	6.2

- Dimming control systems: Controllers to balance the amount of natural and electrical light through light sensors.
- Optimized windows glazing: Control of the incident amount of sunlight into the building for natural illumination and heat collection.
- Optimized boiler plant: Condensing boiler that that uses the heat in the exhaust gases from the boiler to preheat the water.
- Heat recovery system: Heat recovery ventilators (HRV) with heat exchangers to heat or cool incoming fresh air.
- Optimized wall insulation and use of thermal mass wall/floor system.
- Demand ventilation: Motors for fan powered boxes and variable air volume (VAV) systems to supply only the volume of conditioned air needed to satisfy the load
- Variable flow pumping: Pump motors with variable frequency drive (VFD) for delivery of hot and chilled water.
- Renewable systems: Solar PV arrays, wind generators, and biofuel boilers to reduce fossil fuel consumption and for educational purposes.

In addition, selection of materials and water conservation measures were also implemented. Special preferences were made to low/non-toxic materials, high recycled content and easily recyclable materials, and low embodied energy certified materials with long lasting characteristics. In relation to water, some buildings made use of low-flow fixtures with controlled activation, composting toilets, and stormwater /grey water management systems that collects and storage rain water that is used to flush toilets and for irrigation. Transportation issues were also addressed.

3.2 Actual Buildings Consumption

The study here focuses on comparing actual energy bills to the results obtained from predictions of the building energy performance provided before building construction. Prediction data was obtained mainly from applications to the MTC for funding. Several interviews with the owners, project team, managers and end users were conducted. In addition, occupancy surveys were conducted with some of the buildings to understand the usage and operation based on: goals met, obstacles encountered, and changes made during all the process (design-construction-occupancy); issues that affect the end performance of the buildings.

A summary table of energy consumption of each building is presented in Table 4. The average designed energy consumption of most of the buildings is less than the "base case", or the same building designed according to the minimum requirements of the energy code, but actual energy consumption is higher than designed case. Energy data collected and compared for most of buildings show that even though, in the first few years of operation, they are consuming on average 40% more than they were designed, but they are still consuming less than a building designed to code.

The annual average electricity consumption of the green schools shows that for the MATCH School and the Ashland High School the actual electricity consumption is around 10% higher than predicted for "as designed" case (Table 4). However, for the remaining schools the actual electricity consumption is much higher than predicted (Table 4), which in the case of the Holten Richmond Middle School is 89%. The actual annual average natural gas consumption for most of the schools is much higher than the designed with the exception of the Michael E. Capuano School, which is 21% less than the designed case.

The comparison of designed versus actual electricity and natural gas consumptions for different schools may yield anomalous inferences. For instance, the electricity consumption for the Michael E. Capuano School is 50% higher than the designed case; however, its actual annual natural gas consumption is 21% less the designed case. This led us to assess the total energy consumption (electricity and natural gas combined) of each school. Michael E. Capuano School's total annual actual energy consumption is 1.5% less than the design case. However, for all the other schools the actual energy consumption is more than 35% than the designed case, with the difference as high as 86% for the Holten Richmond Middle School.

For green buildings, annual actual electricity consumption for the Trustees of Reservation Doyle Conservation Center is only 9% more than the designed case. That for the Woods Hole Gilman Ordway Campus building is 27% less than the designed case (Table 4). The total actual energy consumption for the Artist for Humanity – Epicenter and City Hall Annex buildings are 27% and 30% higher than the designed case, respectively. The overall energy consumption for the Woods Hole building is 27% less then the designed case. Some of the reasons for large difference between the predicted versus actual energy use are:

- Energy modelers appear to use incremental energy saving resulting from the proposed energy efficiency measures adopted in the building and the on-site renewable energy generation, according to several modelers interviewed. Therefore, the predicted energy use does not capture the characteristics of the building in its entirety.
- Limitations in the building modeling can not predict the human behavior in the buildings related to the use of plug loads, levels of occupancy and building's operation hours.
- Modifications in the original design made in the buildings during the construction phase due to limitations in the budget and/or changes in the type of materials used.

- Some buildings have experienced high rates of energy consumption in their first months of operation due to not all the systems installed being completely operative or commissioned. The delay in the task of contractors and sub-contractors, the correct settings of the systems, and the process of learning and adaptation by the users have influenced the energy consumption.

3.3 PV Systems Performance

Most of the generated energy data by photovoltaic systems (PV) in green schools and green buildings was provided by the owners of the systems who periodically performed readings of the Wh-meters or was from Data Acquisition Systems (DAS), some of which were available on-line.

The approach to perform the analysis was based on the next steps:

- Preference was given to the local data, i.e. incident solar irradiation and ambient temperature obtained from weather stations installed on-site or around the area and recorded by the DAS, or by private institutions or weather forecast companies.
- If local data was not found or was not sufficient or reliable, the data was taken from TMY2 database (1961-1990) for Boston (MA), Worcester (MA), Concord (NH) and Albany (NY) depending of the building location in MA (8).
- Predicted energy generated monthly and annually by the PV system was obtained first with the local data, TMY2 data and/or by PV systems design software available.
- The results are compared with the energy generation data recorded by the DAS or obtained from direct reading from the wh-meters.
- Due to several factors (weather conditions, failures, maintenance works, etc.) there were months in which the records of energy production data were completely or partially missing. Only months with reliable or few missing data were taken into consideration for the analysis, and in that case the comparison was made over the period of time determined by the months selected.

The results show that most of the PV systems energy production was above 80% of the energy predicted. The performance was expected to be higher if there was a complete data record and if there was appropriate maintenance and monitoring of the PV modules.

Most of the PV modules have a flat or lower tilt angle, so the energy generation during the winter season is sometimes reduced due to snow covering. In some cases the maintenance work on the PV systems is difficult to achieve as it appears that these tasks were not considered in the original design of the building and the PV system. For example some PV systems lack a faucet nearby for cleaning purposes, or there is a difficult or limited access to the PV modules because of security concerns.

Better performance values were reached when local weather data was used (Table 5). The use of historical TMY2 data increased the difference between the actual and estimated energy generation.

Outstanding cases are the 47.7 kW PV system installed in Artist for Humanity in South Boston and the 20 kW PV system installed in Genzyme Center which have an actual performance of 95 percent and 93 percent, respectively. For these cases almost a complete record of data was available.

4. ARTISTS FOR HUMANITY – EPICENTER CASE STUDY

One of the more interesting case studies is the Artists for Humanity Epicenter. Located in South Boston and occupied in October 2004, the Epicenter is a 23,500 square foot steel and concrete structure that serves as a facility for the Artists For Humanity organization (AFH). Considered in the category of commercial buildings, this four-story structure is comprised of studios, a large gallery, and offices. Awarded with a LEED platinum certification, the Epicenter is an outstanding example of sustainable and high-efficient green building design. Within all the ECMs, the most remarkable characteristics are:

- Maximum utilization of daylighting.
- Environment friendly and recyclable materials.
- Passive heating and cooling (heat-recovery system and natural ventilation that replaced air-conditioning systems)
- A 47.7 kW PV system

From Oct. 2004 to Nov 2006 the Epicenter reached the energy savings and environmental achievements:

- Reduction of the peak load demand to 33.5 percent when is compared to the baseline case. Average summer peak load reduced to 27 percent and average winter peak load reduced to 59 percent.
- The PV system contributed 51 percent of the total electricity consumption. Performance of 95 percent of predicted, with a high contribution up to 74 percent of total building electricity during summer time.
- Grid electricity and gas consumption reduced to 10 and 59 percent of the baseline case.
- Carbon dioxide emissions reductions of 96 tons per year.

The energy intensity has been reduced to 34 kBtu/ft^2, which is 33 percent of the baseline case and is much less that the 99.9 kBtu/ft^2 for a typical commercial building in New England (CBECS).

TABLE 4: ANNUAL ENERGY INTENSITY OF GREEN SCHOOL AND GREEN BUILDINGS

	Electricity				Natural Gas				Total
Green Schools	Base case (kWh/ft^2)	Designed (kWh/ft^2)	Actual (kWh/ft^2)	% Change: Actual minus designed	Base case (Therms/ft^2)	Designed (Therms/ft^2)	Actual (Therms/ft^2)	% Change: Actual minus designed	Energy Intensity (kBtu/ft2)
Berkshire Hills Middle School	9.32	7.78	9.39	21%	0.41	0.11	0.25	127%	57.04
Blackstone Valley High School	9.57	5.55	NA	-	0.32	0.22	NA	-	-
Dedham Middle School *	5.54	4.33	NA	-	0.5	0.32	NA	-	-
Ashland High School	9.01	7.16	7.77	9%	0.43	0.26	0.43	65%	69.51
Gill Montague	NA	6.83	10.46	53%	NA	NA	NA	-	-
Holten Richmond Middle School	6.75	5.37	10.15	89%	0.41	0.3	0.55	83%	89.63
MATCH School	23.66	13.34	15.04	13%	0.1	0.07	0.25	257%	76.32
Michael E. Capuano	NA	5.8	8.69	50%	NA	0.53	0.42	-21%	71.65
Whitman Hanson	NA	5.48	NA	-	NA	NA	NA	-	-
William Stanley Elementary	NA	4.82	7.17	49%	NA	0.38	0.5	32%	74.46
Woburn High School *	10.03	7.66	NA	-	0.3	0.31	NA	-	-

Green Buildings	Base case (kWh/ft2)	Designed (kWh/ft2)	Actual (kWh/ft2)	% Change: Actual minus designed	Base case (Therms/ft^2)	Designed (Therms/ft^2)	Actual (Therms/ft^2)	% Change: Actual minus designed	Energy Intensity (kBtu/ft2)
Artists for Humanity - EpiCenter	20.97	3.28	4.08	24%	0.32	0.16	0.22	27%	33.92
Cambridge City Hall Annex	11.69	10.9	14.16	30%	0.2	na	na	na	48.3
Genzyme Corporate center	NA	NA	15.3	-	NA	NA	NA	-	-
Trustee: Doyle Con. Center	NA	6.25	6.83	9%	NA	0.03	NA	-	-
Woods Hole - GOC	24.52	4.66	3.39	-27%	na	na	na	na	11.6

NA- Not Available; na- not applicable, *The schools opened in fall 2006 therefore actual data were not available

TABLE 5: MASSACHUSETTS PV SYSTEMS PERFORMANCE IN GREEN SCHOOLS AND BUILDING

Location	System Size (kW)	Tilt Angle (degrees)	Azimuth Angle (degrees)	Evaluation Period	Weather and Solar Data Used	Predicted Energy (kWh)	Actual Energy (kWh)	Performance (*)
Green Schools								
Ashland High School	33.6	5	160	Dec. 2005 - Nov. 2006	TMY2 Boston	36,829	28,885	78.43%
Match School	19.44	Flat	NA	Oct 2004 - Nov 2006 (1)	Local Data	36,991	26,806	72.46%
Michael E. Capuano School	34.96	Flat	NA	Jan. 2004 - Oct. 2006 (2)	Local Data	94,463	79,716	84.39%
Woburn High School	33.6	5	180	Sep. 2006 - Nov 2006	TMY2 Boston	7,105	4,591	64.62%
Green Buildings								
Artist for Humanity	47.7	8	195	Oct. 2004 - Nov. 2006	Local Data	111,577	105,780	94.80%
Cambridge City Hall Annex Building	26.5	Flat	NA	Apr. 2005 - Dec 2006	Local Data	53,760	44,957	83.62%
Genzyme Center	20	Flat	NA	Jan. 2005 - Dec 2006	Local Data	43,272	40,208	92.92%
Maverick Landing	33.6	28	210	Apr. 2005 - Mar. 2006	TMY2 Boston	43,137	35,828	83.06%
Trustees for Reservations (3)	9.12 / 18.24	30	90 / 270	Jun. 2004 - May. 2006	TMY2 Worcester	59,078	48,422	81.96%
					Total	**486,212**	**415,192**	**85.39%**

NA: Not Applicable, (1) No Data Recorded in Jun. and Jul. 2005, (2) System not operative from Sep. 2005 to Mar. 2006
(3) Two PV systems , (*) Performance in relation to the Predicted Energy

The actual success of the Epicenter is not only due to the ECMs implemented, but also to the educational component and behavior by the owners and occupants in terms or recycling and energy conservation.

5. CONCLUSIONS, LESSONS LEARNED

The results show considerable energy savings in electricity mainly because of the high efficiency lighting fixtures integrated with daylighting strategies. Even though, in the first few years of operation, the buildings studied are consuming on average 42% more than they were designed to, they are still consuming much less than the comparable buildings designed to code or the typical building in New England.

The contribution of renewable energy system installed on-site, on the other hand, has been performing reasonably well compared to expected levels when modeled with actual weather data. Despite PV systems contributing on average less than 5 percent of the electricity in green schools, they are useful tools for educational purposes and for gaining design and construction experience.

Gas bills were collected and compared for 6 buildings. Gas consumption was 56% more than designed. Heating energy penalties of some of the ECMs like the lighting strategies reduced the amount of heat by the use of electric lights.

The average energy consumption of most of the buildings is less than the "base case", or the same building designed according to the minimum requirements of the energy code, but energy consumption is higher than predicted. Other factors that have attributed to the increase in energy include: budget problems, changes in end use, increase in occupancy, building modifications, energy management systems not being maximized, and selection of materials.

Use and integration of lighting and daylighting strategies are considered the most important green features for most of the occupants not only for the energy savings but also for the rebates offered for their installations. By other hand, the stormwater/grey water management systems are not subject to grants or rebates, but are also considered as an important conservation measure for buildings where they are installed.

Education and training to the end-users (occupants, owners and maintenance staff) are keys to the success of the green features in buildings.

The use of energy monitoring systems and sub-metering to really explore and analyze the effectiveness of some of the ECMs may help evolve strategies for designing aspects of green schools and green buildings.

Commissioning helps uncover devices and systems that are inappropriately designed, installed, and/or used.

In general, based on the results of this study, green buildings are contributing in very positive ways to reducing the energy and environmental impacts relative to existing buildings and minimum code buildings. But the frustration in stakeholders based on the difference between predicted and actual paid-for energy use should be addressed mainly by communicating uncertainties in design predictions, by better training in the use of the technologies in the buildings, and by commissioning.

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