ENERGY SAVINGS ASSESSMENT FOR THE ROBERT E. JOHNSON STATE OFFICE BUILDING IN AUSTIN, TEXAS

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ABSTRACT

U.S. businesses and institutions spend an estimated $175 billion per year for energy. Of that, the fraction under performance contracts and energy service agreements is currently growing, aided by cheaper monitoring technology and integration with EMCS systems. Energy simulation programs are used both for estimating potential savings as well as to help verify savings from retrofits actually installed. The potential accuracy afforded by today's energy simulation programs is high. Yet the reliability of the results is frequently compromised by a lack of certainty that the simulations reflect actual conditions. Although there is little documentation on current methods to verify energy savings in buildings, the International Performance Measurement and Verification Protocol (IPMVP), developed by the Department of Energy (DOE), provides best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects. This paper presents a method for verifying the energy savings of a newly constructed building using a baseline simulation model calibrated to the measured whole-building energy consumption to determined the independent and combined effect of the stated efficient components installed in the building. In this paper the results show that the energy savings resulting from the new design reduced the energy use by 46% when compared to similar state office buildings.

INTRODUCTION

Supplementing tedious manual energy calculations, computers have been used to predict heating, ventilating, and air-conditioning (HVAC) loads. More importantly, simulation models have also been compared and adjusted to match metered energy data since the early 1970's (Ayers and Stamper 1995; Kusuda 1999).

To guide the development of energy simulations, ASHRAE Guideline 14P and the International Performance Measurement and Verification Protocol (IPMVP) have been developed (IPMVP, 1997; IPMVP, 2001). While Guideline 14 defines protocols for measurement of energy and demand savings for energy conservation retrofits at technical level, the IPMVP establishes a general framework and terminology to assist buyers and sellers of metering and verification (M&V) services.

Although some studies have been conducted to provide guidance when evaluating the energy performance of new building (Anon, 1980; Stein and Eley, 2000), to date there is no consensus guidelines have been published to guide comparisons of measured and simulated data. Thus, the objective of this study is to determine the energy savings in the newly constructed Robert E. Johnson State Office building and to bring clarity to the use of metered and measured data.

CASE STUDY

The Robert E. Johnson State Office building is a 5-story, 303,389 square foot office building for state legislative support staff, such as House Committees, Legislative Council, State Auditor, the Legislative Reference Library, the Senate Print Shop and the Sunset Commission.

Overall the building is divided into three sections with divisions created by a ground level breezeway and vehicular access area. Upper floors extend above these areas. The building's northern facade is approximately 14 degrees west of north, which exposes it to direct sunlight during the afternoon hours. It is also important to note that the building contains over 50% glazing in the façade consisting of two types of glazing and that deciduous trees line a significant portion of the south façade up to the 3rd level.

Overall, to develop and calibrate the energy simulation the following interview procedures were conducted.

- Meet with the systems' engineer and review the buildings intended and actual operation
- Meet with the architect and review the building intended and actual material specifications, especially glazing.
- Conduct building walkthroughs to verify the existing architecture and systems
- Conduct targeted systems audits to determine the actual operation and parameters of selected systems.
- Acquire relevant building documentation such as the construction documents, change orders, systems specifications, relevant metered and sub-metered data, and the buildings utility bills.
- Identify and verify systems and their performance
- Document system through photographs for review by other personnel.

To analyze the sustainability of the Robert E. Johnson Building, this study: 1) analyzed the monthly utility bills over 9 months (Reedy, et al, 1995), 2) created a calibrated energy simulation matched to the whole-building energy consumption (Bou-Saada and Haberl, 1994), 3) compared the annual energy consumption of the Robert E. Johnson building with selected state buildings in the LoanSTAR database (Turner et al, 1992) and 3) isolated the energy use of the stated efficient components of the building. Specific tasks included the following:

- Task #1 – Simulate the As-Built Building and assume the inclusion of all energy conservation measures (ECMs),
- Task #2 – Calibrate the As-Built Simulation to the measured data,
- Task#3 – Compare the Robert E. Johnson State Office Building with similar state office buildings,
- Task #5 – Identify the ECMs installed within the building that can be simulated, and
- Task #6 – Modify calibrated As-Built simulation to exclude individual ECMs for an disaggregated affect and to exclude all simulated ECMs representing the base case building.

Energy Conservation Design Measures

Despite the many building systems and components that are considered energy efficient or conserving, many of them are not quantifiable without extensive simulation effort and sub-metering of the operational building system. As a result, it is important to warn researchers to take caution when setting ambitious goals that also have short timelines. For this research, the following energy conserving measures were studied (Eley and Tathagat. 1998): 1) HVAC air handling system, 2) efficient chillers, 3) T-8 fluorescent lamps for lighting, 4) motion sensors for lighting control, and 5) low-E window glazing.

In addition to the above list ECMs many other features exits within the building but were not factored in the savings calculations. They are: 1) low NOX boiler, 2) daylighting sensors, 3) enthalpy heat recovery, 4) low head pumping, dual path HVAC system, 5) run-around coil on preconditioning units, 6) light shelves, 7) the building's shape, 8) a high albedo roof, tree shading, 9) static pressure supply and return differences, 10) air foil HVAC fans, 11) dual path economizer, 12) chiller operation, 13) condenser tower operation, and 14) heating system operation.

A review of the mechanical equipment indicated that the building contained high efficiency centrifugal chillers, an oversized cooling tower, and two 20 horsepower pumps used to circulate water through the tower. Primary-secondary chilled water loops are used to distribute the chilled water to the building. Variable frequency drives are installed on the secondary loop. In addition, a low NOX boiler and secondary flue is installed. For the majority of the conditioned area, the HVAC system is a dual duct system utilizes preconditioned outside air containing run-a-round coil (before and after the preconditioning coil) controlled by an energy management system. VAV systems are used in all areas except the basement, which is primarily constant volume.

AS-BUILT ENERGY SIMULATION

In this paper, the As-Built simulation refers to the existing building conditions, including all energy efficient features. To create the simulation model, the As-Built energy simulation was based on pre-construction data provided by a previous study (Eley and Tathagat. 1998) and adjusted to match the system data of the constructed building. Please note that

TMY2 weather data for Austin, Texas was used in all simulations. Overall, the collected data from the interview process was entered into the DOE-2 program (LBL, 1993), (Figure 1). An analysis of sub-metered data of a typical floor was used to determine the lighting and equipment schedules of the simulated building. More information regarding the development of typical building data is discussed in the following section. To further calibrate the module, the whole-building electricity use of the building was analyzed and used to adjust equipment schedules and to account for the variance in the systems' operation. Lastly, the simulation was adjusted to match the selected energy saving features. In some cases, the DOE-2 model was simplified due the program's limitations, which include: 1) lack of program coding to simulate the exact features of the air handling systems, 2) codeword limitations, 3) and incomplete building data.

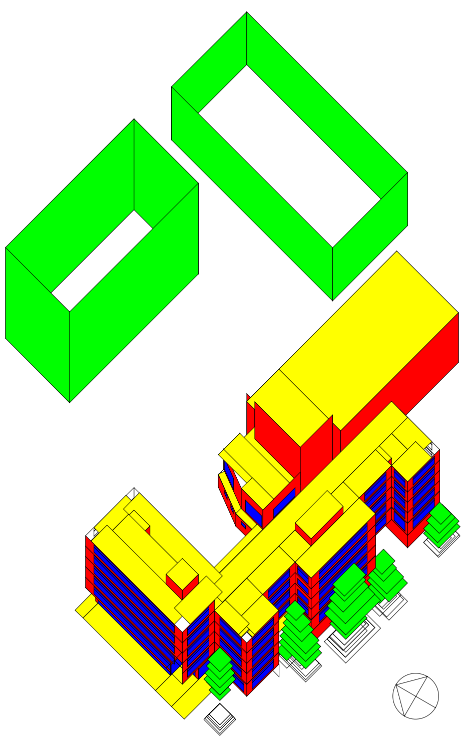
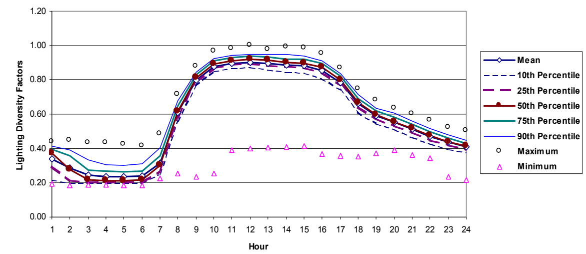


Figure 1. Draw BDL View of the DOE-2 Simulation Model

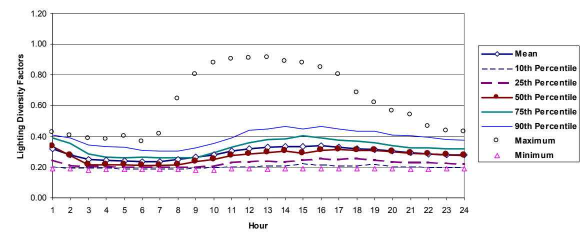
<u>Developing Typical Building Data</u>

An analysis of the fourth floor (approximately 44,100 sq.ft.) was used to determine typical lighting and equipment schedule. Specifically, the fourth floor day type profiles were developed using methods defined in the ASHRAE 1093RP. The resulting profiles were use entered into the DOE-2 program as typical internal loads (Figure 2). To further calibrate the model to match the measured data, the whole-building electricity of the building was analyzed and used to adjust equipment schedules due their higher degree of variance in system operation, types, and use. Other hidden loads such as the parking, exterior lights, and the Legislative Computer Center were identified and added to the DOE-2 simulation.



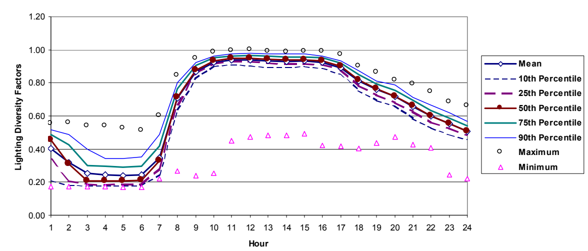
(a)

Weekday types: 4th Floor Lights & Receptacles



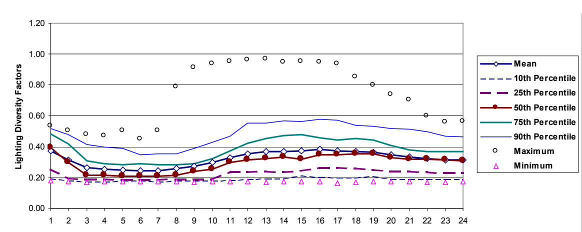
(b)

Weekend Day types: 4th Floor Lights & Receptacles



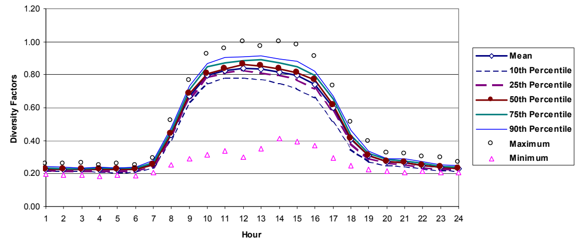
(c)

Weekday types: 4th Floor Lights

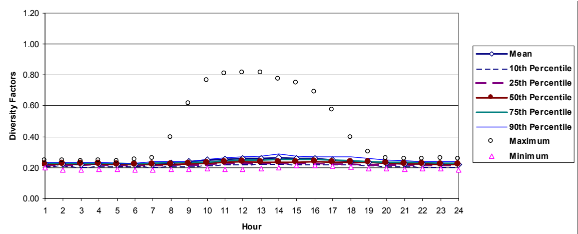


(e)

Weekend types: 4th Floor Lights



(e)
Weekday types: 4th Floor Receptacles



(e)
Weekend types: 4th Floor Receptacles

Figure 2. Typical Load Shapes

Development of Window Properties

In this study, optical data of the Low-E and clear glazed window systems, reported by Lawrence Berkley Laboratory (LBL, 2001), were used in this study to create window library entries for the two existing window types and the base case system using Window 4.1 (LBL, 1997). The window library of the DOE-2 program was then appended. A plot of the glazing properties for each window is shown in Figure 4 Figure 4, and Figure 5.

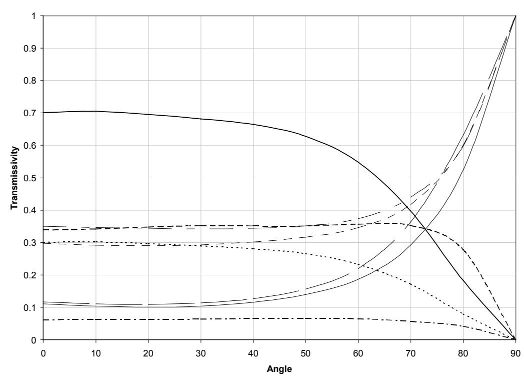


Figure 3. Transmissivity vs. Angle of Incidence for Upper Window Clerestory

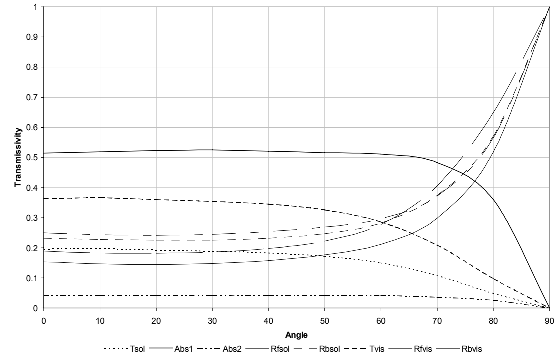


Figure 4. Transmissivity vs. Angle of Incidence for Lower Window System

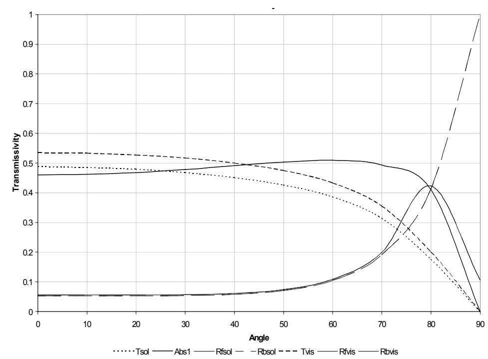


Figure 5. Transmissivity vs. Angle of Incidence for Base-Case Building

The DOE-2 energy simulation software, solar transmission coefficients are used to describe the relationship between transmittance of the window and the incidence angle of the sun. In addition to the physical description of the window, the thermal properties such as conductance, spectral properties, emissivity, and the solar heat gain coefficient are input in the energy software. Table 3 provides a general comparison of the various window systems used in this study.

Table 1. Total Window Thermal Values

Glazing	U-value[a] Btu/hr-ft²-F (W/m²-C)	SC[b]	SHGC[c]	Vt[d]
Single Bronze Clear	1.12 (6.38)	0.71	0.61	0.51
REJ Upper Window	.56 (3.18)	0.47	0.40	0.60
REJ Lower Window	0.39 (2.19)	0.33	0.28	0.35

[a] U-value is the total heat transfer coefficient for the window system (W/m^2-C : Btu/ft^2-F)
[b] SC is the shading coefficient for the total window system representing the ration f the solar heat gain through the window system relative to that through 3 mm (1/8") clear glass at normal incidence.
[c] SHGC is the solar heat gain coefficient of the total window system representing the solar heat gain through the window system relative to the incident solar radiation.
[d] Vt is the total window system's visible transmittance at normal incidence.

To consider the simulation calibrated, good agreement between the measured and simulated data were obtained. These comparisons included analysis of:

- the whole building annual electric energy use (Figure 6)
- the annual cooling energy use (Figure 7),
- the annual heating energy use, (Figure 8), and
- the annual chiller efficiency (**Error! Reference source not found.**).

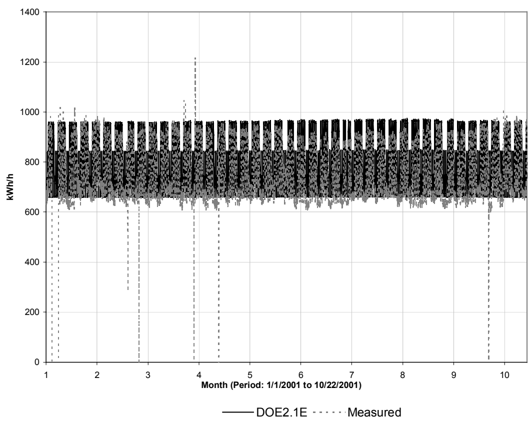


Figure 6. Comparison of Measured and DOE-2 System Electricity Use for the As-Built Building

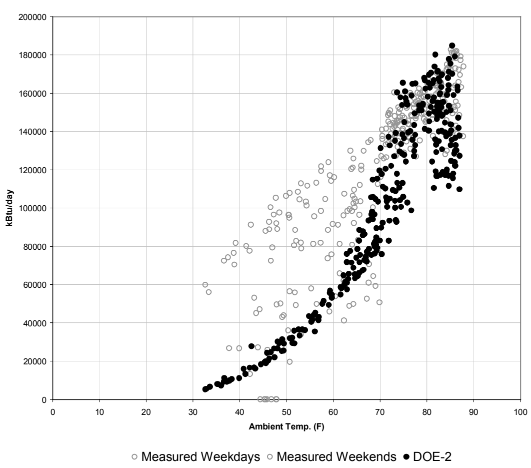


Figure 7. Comparison of Measured and Simulated Whole Building Cooling Energy Use for the As-Built Building

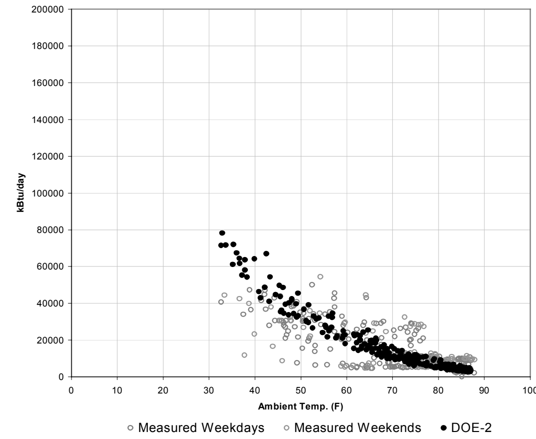


Figure 8. Comparison of Measured and DOE-2 Whole Building Heating Energy Use for the As-Built Building

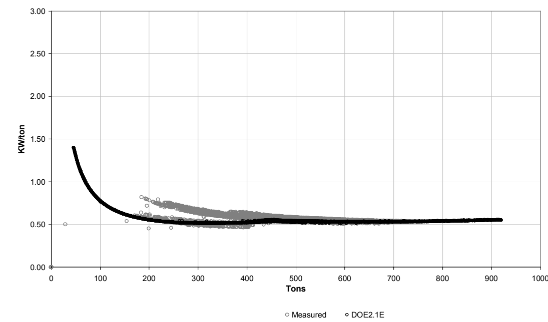


Figure 9. Comparison of Measured and DOE-2 Chiller Efficiency for the As-Built Building

DATA ANALYSIS

To determine the buildings sustainability, results of the calibrated simulation were first compared to similar buildings within the LoanSTAR database. Secondly, each selected energy conserving measure (ECM) was varied to determine an isolated effect for each condition and then combined to determine an aggregated effect that is considered to be the base-case building.

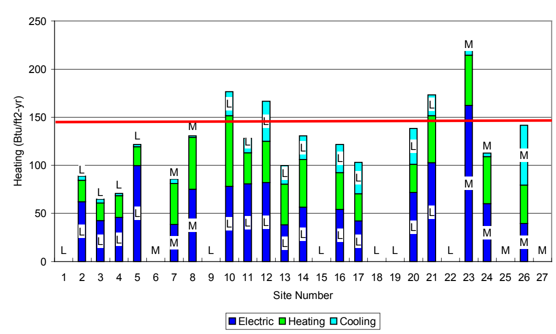


Figure 10. Comparison to Typical Buildings in Texas

Comparison with Similar Buildings

Figure 10 illustrates the energy consumption of comparable buildings in Texas with the Robert E. Johnson State Office building. Of importance to this research are columns numbered 11 - the John H. Reagan building, 12 – the Insurance building, 13 – Archives building, 14 – W.B. Travis building, 15 – L.B. Johnson building, 16 – Price Daniels building, 17- Tom C. Clark building, 20 – Capitol building, 21 – Sam Houston building, 23 – James E. Rudder building, 24 – Insurance Annex building, 25 – Central Services building, and 26 – Supreme Court building. In comparison, the Robert E. Johnson building, which has a simulated annual energy intensity of 148.26 kBtu per square foot compares well with the Supreme Court Building (Haberl, 2001).

Analysis of ECM's

In the final analysis, the calibrated model was used to create a base-case condition by removing all quantifiable energy efficient features of the building (Table 2).

Table 2. Quantifiable ECM's for As Built and Base-Case

Component	As-Built	Base-Case	Variable
Glazing	Low-E Glass	Single Pane Bronze	glass-type-code
HVAC	Variable Air Volume	Constant Volume	min-cfm-ratio
Chiller	0.5 kw/ton	0.75 kw/ton	elec-input-ratio
Lighting	T-8 Lamps	T-12 lamps	lighting-w/sqft
Motion Sensors	On	Off	Lighting schedule

As indicated earlier in this paper, five energy conservation measures were analyzed to determine the base case conditions. Overall, two low-E glazing types were simulated for the As-Built case and single pane bronze glazing was used for the base case condition. For the HVAC system, the system was varied between variable-air-volume (VAV) and constant volume. Based on performance data the as-build chiller performed at approximately 0.5 kW/ton while historical data from other sites indicate a standard performance of 0.75 kW/ton (Haberl et al., 1997).

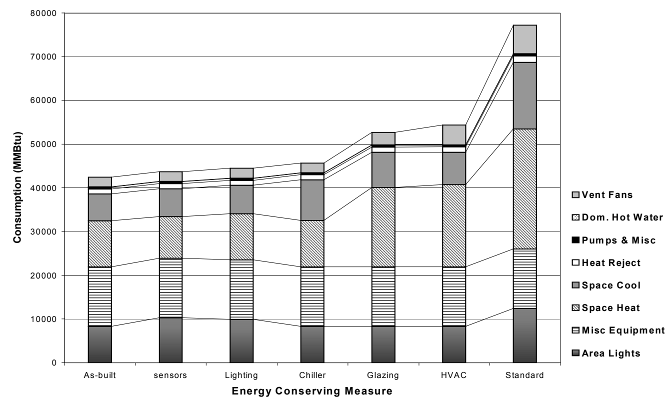


Figure 11. Simulated Building Energy Performance Summary

The results show that the low-E glazing and the VAV system have the greatest impact on the energy saving of the building, with the VAV system having the greatest effect. In contrast, the sensors, lighting, and the chiller have a smaller effect, with sensors having the least. Overall, the base-case simulation shows a 182% increase (i.e. a 45% decrease in energy use) in the energy consumption of the building if the selected energy efficient systems were installed based on standard industry systems and practices (Table 3) (Figure 11). Note that SPACE HEAT is the sum of electricity and natural gas for space heating and that SPACE COOL is the electricity used for space cooling.

Table 3. Annual Building Energy Performance Summary in MBtu.

CATEGORY OF USE	As-built	Sensors	Lighting	Chiller	HVAC	Glazing	Base-Case
AREA LIGHTS	8326.8	10311.9	9923.9	8326.8	8326.8	8326.8	12405.9
MISC EQUIPMT	13625.1	13625.1	13625.1	13625.1	13625.1	13625.1	13625.1
SPACE HEAT	10530.8	9499.7	10532.4	10622.5	18769.1	18123.8	27464.2
SPACE COOL	6171.9	6393.4	6511.1	9291.6	7417.2	8025.3	15249
HEAT REJECT	1097.2	1114.6	1121.9	1107	1197.3	1217.9	1391.1
PUMPS & MISC	424.3	424.2	423.5	423.5	426.5	423.4	426.4
VENT FANS	2149.2	2213.4	2276.8	2156.9	4532.9	2813.7	6514.8
DOMHOT WATER	82	82	82	82	82	82	82
Total	**42407.3**	**43664.3**	**44496.7**	**45635.4**	**54376.9**	**52638**	**77158.5**

SUMMARY

This research has shown that the energy savings of newly constructed energy-efficient building can be determined us an aggregated and disaggregated analysis. However, many questions still need to be answered such as which ECM's do we simulate, and the time and cost constraints to conduct such simulations.

Future studies must be guided by criterion that insure the validity and reliability of such assessments. They are: 1) the building design criterion that includes the development of building features, process for communication between consultants, and material selection, 2) the simulation criterion that includes the development of standards for conducting and reviewing the energy simulation, and 3) monitoring and verification criterion which includes the evaluation of the design strategies and the long-term analysis of owning and operating costs of the building to verify the predicted energy savings.

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