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Design-Build-Operate Energy Information Modeling (DBO-EIM) for Green Buildings: Case Study of a Net Zero Energy Building

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Design-Build-Operate Energy Information Modeling (DBO-EIM) for Green Buildings: Case Study of a Net Zero Energy Building

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ABSTRACT

The concept of Design-Build-Operate Energy Information Modeling (DBO-EIM) is proposed. The DBO-EIM aims at creating a detailed and persistent energy model that can be used to reduce energy consumption and improveoccupant comfort throughout the life-cycle of a building. Within the framework, the model is builtto supportdecision makingin the design phase, validated and tuned during construction and commissioning phases, and then continuously used for environmental control in operation.

To illustrate the first stage of the DBO-EIM process, an office buildinglive projectis used as a test bed. Itis designed to be “a net zero energy building” by its integrated building system design and on site renewable energy generation. Detailed whole-building energy simulation models are developed by using DesignBuilder and EnergyPlus programs. Baseline models are built based on U.S. ASHRAE 90.1-2007energy standard.Design alternatives and the proposed design case (PDC) modelsare created by employingvarioussustainable design strategies for comparing and decision making purpose.

Load and energy reduction potentials of different sustainable strategies are compared, such as high performance building envelope, alternativeHVAC systems, and daylightresponsive lighting controls. The simulation results suggest that annual energy use intensity (EUI) for the PDC model is 86.0kWh/m^2, which is 59.5% less than the 2003 Commercial Building Energy Consumption Survey (CBECS) median office national average data, 43.2% less than the 2008 Department of Energy new construction median office reference building, and 39.8% less than the ASHRAE 90.1-2007 baseline model. With 101.3kWh/m^2 annual photovoltaic (PV) electricity generation, which is predicted based on 4 months of actual measured data, the CSL is expected to achieve net zero site energy goal.The thermal performance results are examined to comply with the energy code. The building has just been completed. In the next phase,commissioning and operation data will be collected, analyzed and employed to complete the demonstrative study of the DBO-EIM framework.

KEYWORDS

Design-Build-Operate, Energy Information Modeling, Green Buildings, Net Zero Energy

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INTRODUCTION

The concept of Building Information Modeling (BIM) has beengaining widespread interest in the building industry. It is recognized that BIM canpotentially be used as an effective collaboration platform to reduce cost and effort during the Design-Build-Operate process.Similarly, green building concept is well accepted and its market is growing rapidly. For instance, the Leadership in Energy and Environmental Design (LEED) building market enjoys a 103% growthover the past 11 yearsin the U.S. (Zhao & Lam, 2012). Green buildings advocate for saving land, energy, water, and materials, as well as creating a healthy and comfortable environment for occupants throughout the building life-cycle.

Both these concepts pursue a common objective to improve performance and reduce cost by various means.However, they have not been practiced on a common platform. Specifically, as an essential criterion to evaluate green buildings, building energy performance has not been considered from the life-cycle perspective, although a few research have been conducted based oncommonly-used BIM standards, such as IFC (Industry Foundation Classes), to perform energy simulation(Bazjanac, 2008)(Kim & Anderson, 2012). At present,building energy models are createdafter designs have been made and the main purpose is to demonstrate compliance for codes and standards (USGBC, 2011). After the code evaluation has been achieved, the energy model is discarded.

The "Design-Build-Operate Energy Information Modeling (DBO-EIM)" platform is proposed, advocating that a detailed whole building energy model (1) should be createdduring the design phase to assist design decision making and to be used for code compliances; (2) should be modified during the construction and validated during the commissioning phases to become the as-built and well-tuned energy model; (3) and should be continuously used during the operation phase to be integrated with building automation systems (BAS) to conduct advanced building controls to reduceenergy consumption and improveoccupant comfort. The DBO-EIM is a "living" building energy information model that evolves through the entire building Design-Build-Operate process.

As a test-bed of the DBO-EIM concept, the Phipps Conservatory Center for Sustainable Landscapes (CSL) in Pittsburgh, Pennsylvania,USA is studied. The CSL is a 2-story, 2,262m^{2}office building, which is expected to achieve "net zero site energy" goal, as defined byTorcellini, et al (2006). In this paper, the design stage of the DBO-EIM schema is presented. Detailed whole-building energy simulation models are developed by using DesignBuilder(DesignBuilder Software Ltd, 2012)and EnergyPlus(Crawley, et al., 2001)programs. Results are compared for decision making purpose. Future work is discussed to provide a complete vision for the DBO-EIM.

RESEARCHAPPROACH

DBO-EIM framework

The framework of the DBO-EIM is shown in Figure 1. At the design stage, the baseline model isfirst built based on preliminary design according to applicablebuilding energy codes.

Then alternative sustainable design optionswould be proposed, which typically include building envelope, HVAC and daylight/lighting considerations. The energy simulation results of the alternativeswould be compared and optimized to determinethe final PDC. The PDC model would then begenerated based on the final detailed design drawings, which could employ one or several effective design options of the alternative models.

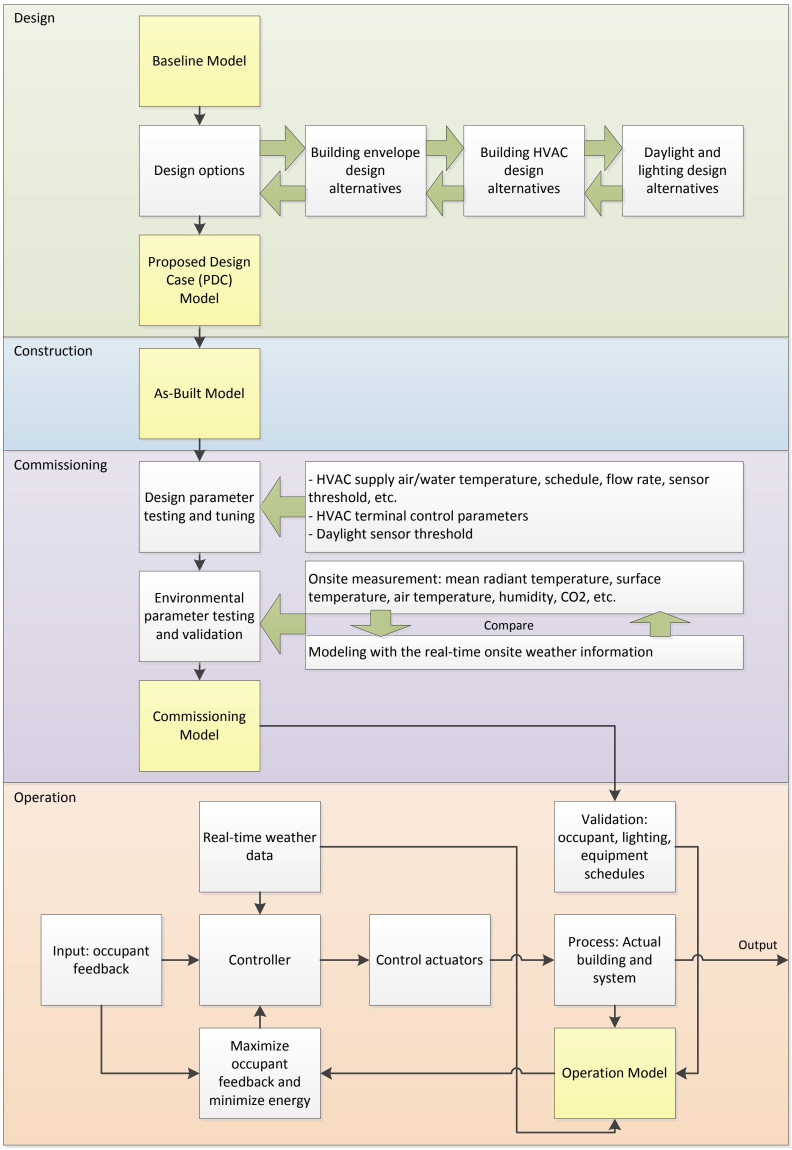

***Figure 1**. The DBO-EIM framework*

At the construction stage, the PDCmodel would be modified based on the as-built drawings to form the "as-built model".At the commissioning stage, the HVAC, lighting and other system design parameters, such as HVAC supply air temperature, schedule, and flow rate, etc. are first testedand tuned. Then the thermal environmental aspects of the as-built model would be validatedby comparing the on-site measurements and modeling results based on real time weather information, which is collected from the on-site weather station. The parameters include mean radiant temperature, dry bulb temperature, relative humidity, and other variables.

At the operation stage, occupant, equipment, and lighting schedules, as well as other model assumptions should be adaptedfirst, based on the real in-use situation, so the commissioning model becomes the "operation model". Advanced building control system can then be developed by using environmental data mining (Dong, et al., 2010), model predictive control, and subjective feedbacks from occupants. The preliminary schematic control diagram is shown in Figure 1.

CSL case study for the design stage

Since the building construction has just been completed, this paper will reportonly the design stage work. At this stage, all the models share the same assumptions on schedules and zone parameters based on ASHRAE 90.1-2007 energy standard (ASHRAE, 2007)and design specifications. The baseline model, and design alternative (DA) models are created for comparison purpose. The PDC model isfinalized according to construction drawings, which employs the all of the most effective design options. Table 1 shows design strategies used in different models. Details can be found in the project report(Lam & Zhao, BUILD - NSF/EFRI Annual Report, 2012). Figure 2 shows the baseline and the PDC model in the DesignBuilder program.

Table 1. *Baseline, design alternative, and PDCmodel inputs*

Model	*Envelope*	*HVAC*	*Daylight/Lighting*
Baseline	ASHRAE 90.1-2007	ASHRAE 90.1-2007 System 4: Packaged rooftop heat pump	ASHRAE 90.1-2007
DA #1	ASHRAE 90.1-2007	HVAC #1: Variable air volume ceiling-based air distribution	ASHRAE 90.1-2007
DA #2	ASHRAE 90.1-2007	HVAC #2: VAV with under floor air distribution (UFAD) for south zones and CBAD for north zones	ASHRAE 90.1-2007
DA #3	Design case (fenestrations, shades, green roof, surroundings, etc.)	HVAC #1	ASHRAE 90.1-2007
DA #4	Design case	HVAC #3: VAV integrated with energy recovery ventilator (ERV) and ground source heat pump (GSHP) with UFAD for south zones and CBAD for north zones without terminal reheat systems	ASHRAE 90.1-2007
PDC	Design case	HVAC #3	ASHRAE 90.1-2007 with daylight responsive controls

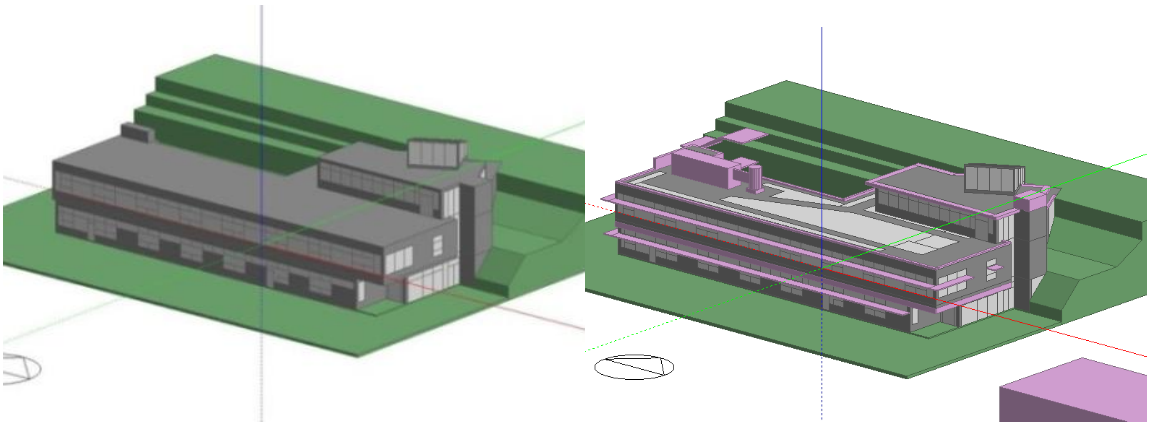

Figure 2. *Baseline (on the left) and PDC (on the right) DesignBuildermodels*

RESULTS AND DISCUSSION

Building load analysis

Figure 3 shows the building cooling and heating design loads of different models, which are calculated by auto-sizing routines of EnergyPlus based on design day data from TMY3 weather files(Seo, Huang, & Krarti, 2009). First, the Baseline is compared with the DA #1. Given the same envelope design, the change of HVAC system does not influencecooling and heating design peak loads.

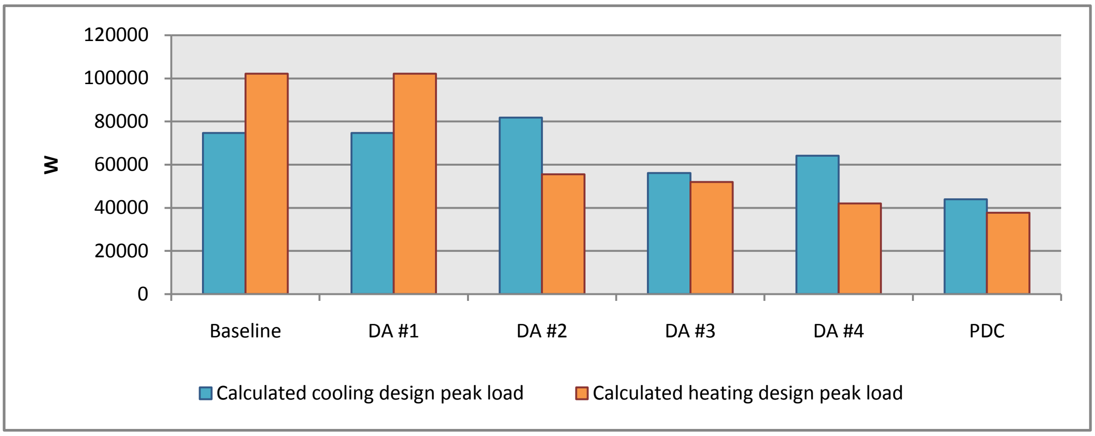

Figure 3*. Calculated building cooling and heating design loads*

Second,the DA#1 and the DA#2, the DA#3 and the DA#4 are compared, respectively. It can be seen thatthe DA#1 and the DA#3 have higher cooling peak load and lower heating peak load, given the same envelope designs. However, the first finding suggests that HVAC system change does notinfluencebuilding peak load. So the load change is likely due todifferences of room air model set-upin the EnergyPlus program. The DA #1 and the DA#3 use the UFAD room air model for the south zones, which is a two nodes room air model with floor plenum air supply (Buhl, 2007). The default room air model for other zones is a well-mixed one node air model(Crawley, et al., 2001). The result of the higher cooling load is contradictory to the design expectation in practice. Generally, under floor air distribution (UFAD)is considered to havehigher cooling supply air temperature and lower supply air pressure, which implies lower cooling loads comparing to ceiling-based air distribution system. The reason is that in the EnergyPlus program, the design cooling load of a UFAD room not only includes the occupied zone, but also contains its supply plenum and return plenum. So the "calculated cooling design load" is the overall cooling load of the three spaces. According to Schiavon et al. (2010)'s simplified UFAD cooling load calculation method,"UFAD has a peak cooling load 19% higher than an overhead cooling load, and 22% of the total zone UFAD cooling load goes to the supply plenum in the perimeter." (Schiavon, Lee, Bauman, & Webster, 2010)

Third, the models with different envelope designs (the DA#1 and the DA#3) are compared. Given the same HVAC #1, the CSL PDC envelope can result in 24.8% reduction in cooling design load and 49.2% reduction in heating design load comparing to the baseline envelope design.

Fourth, the load implication of daylight-responsive lighting control is analyzed by comparing the DA #4 and PDC. In this model, given the same envelope and HVAC designs, the daylight responsive lighting controls can reduce the building cooling load by 31.5%.

Building energy use intensity analysis

Figure 4 shows the annual EUI of all the models and the predicted on-site PV electricity generation (conditioned floor area is 1775.9m^2).First, with the same baseline envelope design, the models with different conventional HVAC systems result in similar annual energy consumptions (142.8kWh/m^2, 135.0kWh/m^2, 135.6kWh/m^2 for the Baseline, the DA #1, and the DA #2, respectively).By comparing the DA #1 and the DA #3, with the same HVAC #1, the improvement of building envelope design shows a 28.3% reduction in HVAC (including heating, cooling, fan, and pump) energy consumption and a 12.0% reduction in total energy consumption. By comparing the DA #3 and the DA #4, with the same PDC envelope, for HVAC #3, the annual HVAC energy consumption reduction is 25.0% and annual total energy consumption reduction is 6.1%.By comparing the DA #4 and the PDC, by employing daylight responsive lighting controls,the lighting energy consumption reduction is 56.2% and the HVAC reduction is 16.4% and the total energy consumption reduction is 22.9%.Given the fact thatglare is not considered, the daylight impact might be overestimated. In practice, when blinds are closed to control glare issues, the electric lighting useand cooling energy usewould likely be higher than the simulation results.

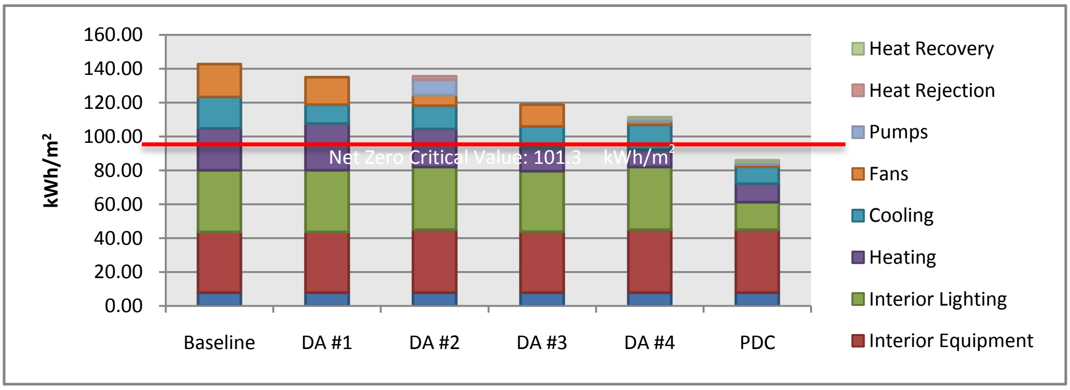

Figure 4*.Annul EUI*and *the predicted on-site PV electricity generation*

CSL installed a 125kW PVsystem. The net zero critical line represents the predicted on-site PV generation by using the National Renewable Energy Laboratory (NREL)'s solar energy prediction tool – "In My Backyard"(NREL, 2012), which has been adjusted based on the actual generation measurement inthe four month (December, 2011, and February 2012 – April 2012). The total annual electricity generation and the EUI are expected to be 179,906kWh and 101.3kWh/m^2, respectively.Thereforewith an 82.0kWh/m^2 predicted annual energy consumption, the CSL's net zero energy goal should be met.

Figure 5 shows the annual energy use intensity (EUI) of the benchmark building and the CSL PDC models. The U.S. 2003 CBECS(USEIA, 2012) data and ASHRAE 90.1-2004 DOE Reference Building (Torcellini, et al., 2008) data are used. Comparing to the 2003 CBECS national average EUI (revised in 2008) for median office buildings (929m^2 – 2,323m^2), the CSL PDC can save 59.5% of the annual energy use. Comparing to the DOE reference building for median office buildings (4,982m^2), by using Pittsburgh TMY3weather file (ASHRAE Climate Zone 5A), the CSL PDC can save 43.2% of the annual energy use.

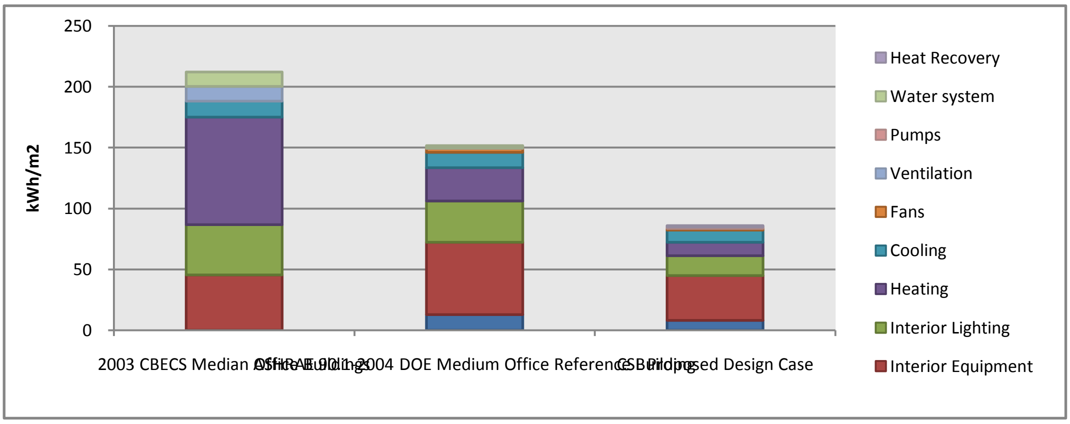

Figure 5. *Annual energy use intensity (EUI) of the benchmark and the CSL PDC models*

Temperature analysis

Dual temperature setpoints(with a band between 23.0 ℃ and 24.0 ℃ anda tolerance of 2.0 ℃)are used as the zone operation temperature. To ensure the models have "comfortable" indoor thermal conditions, "hour temperature setpoint not met" as an important thermal performance indicator has been analyzed. The highest number of "occupied hour temperature setpoint not met" of the PDC model is 122 hours, which meets the ASHRAE 90.1-2007 requirement of "not exceeding300 hours." (USGBC, 2011).

CONCLUSION AND FUTURE WORK

At the design stage, the detailed models are built following the DBO-EIM framework. The current work is the foundation of the overall DBO-EIM framework, which illustrates the process of building energy modeling process, as well as the decision making process based on the energy performance of different system design strategies. Results show that the CSL PDC model can meet the net zero site energy objective.

In future work,following the actual project schedule, the model will be validated and tunedon the basis of the as-built and commissioning results, and the building control model will be developed based on the schema shown in Figure 1. The overall DBO-EIM framework will then be complete and continuously used in the CSL. The performance of the total DBO-EIM will be evaluated by both objective and subjective methods.

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