Chapter 24
A Building Energy Performance Model and Advisor System

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Abstract The *AFRESH* home is an *a*ffordable, *f*lexible, *r*esilient, *e*nergy efficient, *s*ustainable, and *h*ealthy home designed and built to integrate different technologies that help improve energy efficiency. The home is located at BCIT (British Columbia Institute of Technology, Burnaby, BC, WWW.bcit.ca) campus and is constructed with energy efficient, nontoxic, and environmentally friendly materials and features: photovoltaic (solar roof panel), wind turbine, fuel cell, energy storage, and distributed energy generation. The home is also fitted with a heat-recovery and geo-exchange HVAC system. This article explains the characteristics of AFRESH home under study and its energy performance model, followed by a description of the actual design and implementation of the home energy management system. Results of the research and the analysis of the results are also included in the paper.

24.1 Introduction

In collaboration with BCIT's School of Energy research teams, Group for Advanced Information Technology (GAIT), and Products and Process Applied Research Team (PART), we are developing methods to monitor, simulate, and estimate the power consumption, generation, and storage of the AFRESH. Using this data we will simulate common home appliance usage scenarios in order to predict daily electric energy consumption costs. For this purpose a prototype Home Energy Advisor System is designed [1]. For the first prototype, a limited amount of automated control is considered; instead, there is a greater emphasis on human control to verify the simulation. Ideally the prototype would be used to provide homeowners with sustainable and practical power consumption habits.

Appliances used in the home are intelligent and can communicate via a home area network with a load control system. The AFRESH home (Fig. 24.1) is a collaboration of green technologies that help the homeowners make informed

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Fig. 24.1 AFRESH home in BCIT Burnaby campus

decisions to decrease their energy consumption. The AFRESH home energy performance was modeled using the eQuest (Quick Energy Simulation Tool), version 3.64. The model inputs were based upon the information gathered during a site review and conversations with the building operator on the building systems and typical use. In general, the energy performance model focused on the building's total energy usage. Energy production systems were not included in the model; the performance of these systems was calculated separately and can be subtracted from the total energy usage to evaluate the building's "net-energy" performance [2].

24.2 Modeling Project Scope

Beginning in January 2013, a project was undertaken to investigate the energy performance of AFRESH home, located at the BCIT Burnaby campus. The objectives of the project are summarized as follows:

- Develop an understanding of the AFRESH home, including the building enclosure assemblies, mechanical systems, and power generation systems.
- Perform energy performance modeling based on the current configuration and usage of the AFRESH home.
- Validate the performance model using actual building data.
- Identify opportunities for improvements in building design (dependent upon modeling results and available data).
- Identify opportunities for modeling improvement.
- Model AFRESH home assuming residential occupancy.
- Provide recommendations for using AFRESH home designs in residential houses.

24.3 Building History

Originally designed as "Home 2000," AFRESH home was featured at the 2001 BC Home Show to demonstrate best practices in affordable, sustainable residential construction and energy systems. Following the Home Show, AFRESH home was relocated to BCIT.

In 2008, retrofits were conducted to allow for research into a Distributed Power Connections study by BC Hydro. This study intended to "transform the AFRESH Home to become a net energy producer and to study the way that energy migrates to and from the grid." Building retrofits included installing a new externally mounted photovoltaic panel array on the south building face, incorporating a natural gas fuel cell and a geo-exchange heating system, and integrating an energy management system (including wireless thermostats and smart meters). The controls for these systems are housed in a mechanical room addition located in the southeast corner of the building.

In 2011, a vertical-axis wind turbine, on the northwest corner of the property, and new south-facing photovoltaic panels were installed as part of a project from the GAIT research group. The purpose of this project is to research integration issues of renewable energy sources into grid-connected and off-grid scenarios.

24.4 Building Description

24.4.1 Structure, Enclosure, and Systems

ARESH home is a three-story, wood-framed house located at the BCIT Burnaby campus. The lower two floors are designed as living space, while the upper floor is intended to be an attic. The house has an interior floor area of about 185 m^2 (approximately 2,000 ft^2). There is a second floor balcony on the south elevation that the building drawings indicate to be an interior storage area.

There is a single-level addition on the west elevation that houses the majority of the mechanical equipment. This space is insulated but only heated by the mechanical equipment it houses.

The windows are vinyl-framed with awning and casement operable unit. The double-glazed insulated glazing units (IGUs) have metal spacers with low-e coatings.

The building has sloped metal roofs with claristory windows on the west elevation. There are single- glazed skylights on the east elevation with building-integrated photovoltaic panels. The building is serviced by multi-zone mechanical systems. A ground-source heat pump, consisting of 4 loops buried on the north side of the property, provides the heat for space heating and hot water. There are heat-recovery ventilation systems on each floor to capture heat from the exhaust air to heat the fresh makeup air.

There is an air-conditioning unit on the west side of the property; from our discussions with the building operator, it's unclear what the system's frequency of use is. The building's interior environment is controlled automatically by a wireless thermostat system. Building users are also able to control the system manually via the online GridPoint energy management system (EMS).

The building's electrical systems are sub-metered per device through the online GridPoint system. However, the summation of the device loads breakdown is less than the total annual consumption recorded both through EMS and through BCIT's data, indicating that some devices are consuming power but are not connected to the sub-metering monitoring system. The difference in energy usage each month was between 500 and 800 kWh, for a total of 7,000 kWh over the year.

24.4.2 Appliances

The building is equipped with LED lights and ENERGY STAR (efficient) appliances. The building contains a refrigerator, stove and range, microwave, clothes washer and dryer, dishwasher, and television, although many of these devices are seldom used by the current commercial occupants.

24.4.3 Power Generation Systems

The building has several alternative power generation systems; however, some of them are not currently being utilized. For clarity, the systems are categorized as either "active" (currently in use) or "inactive."

24.5 Active Power Generation Systems

24.5.1 Photovoltaic Panels

There are building-integrated photovoltaic (BIPV) panels incorporated into the east skylights, with 1 cm by 1.6 cm glass spacers to allow daylight into the attic. The capacity of this system is approximately 2 kW. These skylights were originally intended to be south facing; however, when the house was relocated to BCIT, the site geometry required orienting the building such that the panels were east facing.

There are externally mounted photovoltaic panels on the south-facing roof. The capacity of the six-panel array is approximately 1.2 kW. The south-facing panels were installed to take advantage of the great solar insolation and were tilted at an optimum angle for the local latitude.

24.5.2 Ground-Source Heat Pump

There is a "geo-exchange" ground-source heat pump system, discussed in the previous section. This system is reported to have a 3:1 production ratio (COP = 3), producing three units of heat energy for every one unit of electrical energy consumed. Although capable of providing heating and cooling, the system is currently only being used for space heating and hot water.

24.6 Power Generation Systems

24.6.1 Natural Gas Fuel Cell

The building is equipped with a natural gas fired fuel cell, intended to be used to reduce the electric grid loads during peak hours. However, the building operators have had difficulties maintaining and operating the fuel cell and it is not currently being used. Information on its performance was not made available to us for this project.

24.6.2 Vertical-Axis Wind Turbine

A 50 ft tall vertical-axis wind turbine is located in the northwest corner of the property. The turbine has the capacity to produce a maximum of 5 kW at a peak wind speed of 12 m/s and can generate power at a reduced efficiency at wind speeds as low as 2 m/s. The wind turbine is part of a research project by the GAIT research group and is not currently being used.

24.6.3 Actual Power Consumption

The building's energy consumption data was obtained from the online GridPoint monitoring system and compared to BCIT's microgrid energy management system data available. The total average annual energy purchased from the grid is about 15,850kWh. In addition, AFRESH home produced about 1,330 kWh from the photovoltaic panels in 2012. Figure 24.2 shows yearly energy generation consumption of AFRESH home.

24.7 Building Performance Modeling

The AFRESH home was modeled using the eQuest (Quick Energy Simulation Tool), version 3.64. The model inputs were based upon the information gathered during a site review and conversations with the building operator on the building systems and typical use.

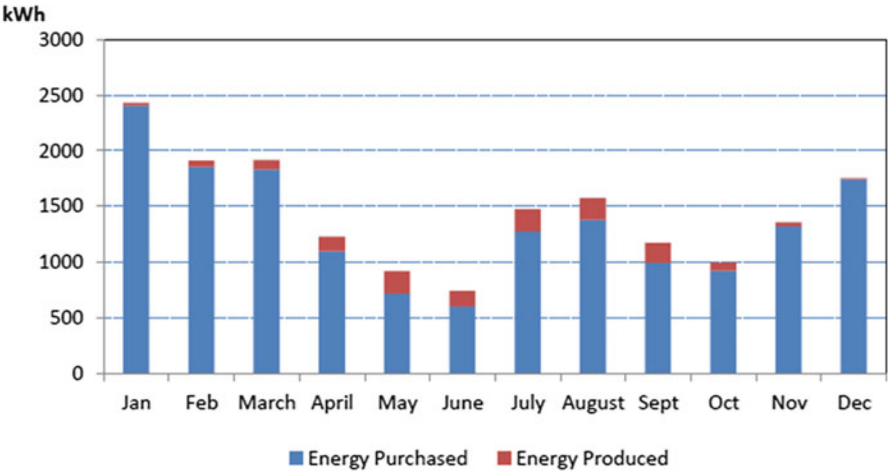

Fig. 24.2 Energy generated and consumed in AFRESH

In general, the energy performance model focused on the building's total energy usage. Energy production systems were not included in the model; the performance of these systems was calculated separately and can be subtracted from the total energy usage to evaluate the building's "net-energy" performance.

24.7.1 Modeling Approach

The modeling approach was to capture the essential elements relevant to energy performance. The following criteria were used to produce an effective energy model:

- The model should accurately represent heat load paths.
- The model should provide an estimate of interior heating and cooling loads.
- The model should provide the analyst with a clear understanding of the building's behavior under heating and cooling loads.
- The model should be relatively easy to modify so it can be used to investigate a building's sensitivity to changes in various input parameters.

These criteria were adopted from the course notes [3] for effective structural modeling and modified for energy modeling.

24.7.2 Model Design

Following the adopted modeling principles, a two-story, rectangular building shell was created in eQuest to represent AFRESH home. The actual building footprint consists of two offset rectangles, as illustrated in Fig. 24.3, which may introduce solar shading effects not encountered in the model.

Further, the attic floor plan is altered from the lower floors. However, the effects of the staggered floor plans were considered to be negligible on the load analysis in this case. A simplified building floor area was created with an equivalent footprint size to the original building and the mechanical room was not considered. The isometric representation of the energy model is shown in Fig. 24.4.

24.7.3 Loads

AFRESH home is currently being used as an office space, so the energy model was first designed to reflect office loads, to allow for calibration with the actual performance data. The building's actual occupancy scheduling was inconsistent and not accurately recorded, so the model inputs assumed that the building was occupied from 8 am to 5 pm on weekdays and closed weekends and holidays.

Fig. 24.3 Actual building footprint

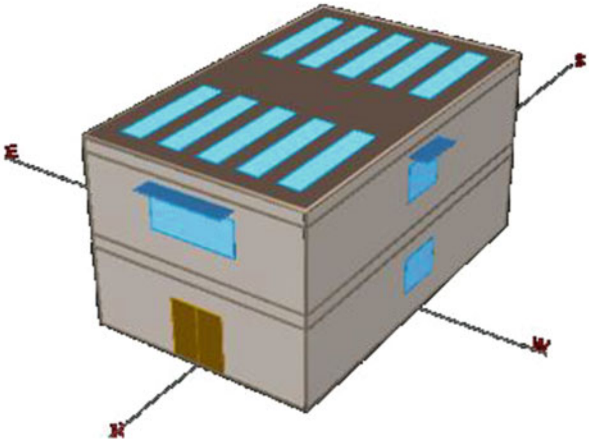

Fig. 24.4 The isometric representation of the energy model

These values were based on typical energy modeling schedules and assumed constant throughout the year.

Internal loads were dependent on the building's occupancy type, based on the default values in eQuest and modified to reflect the actual occupant density of the home.

24.7.4 Model Calibration

The building performance model was calibrated using measured energy data, so changes in the model can reflect expected changes in actual building performance. Model calibration is used to produce a model that accurately predicts energy consumption

For this project, the level of calibration was limited to whole building performance, due to a lack of resolution in energy usage data and unknowns in the mechanical system design and interior loads.

Interestingly, the occupant densities and occupant schedules had a more significant effect on the whole building energy performance than mechanical system adjustments.

The model was well calibrated, and the final predicted energy usage closely matched the actual energy usage. The modeled usage is compared to the actual energy usage in Fig. 24.5.

24.7.5 Modeling Result and Suggestions

Strategies for improving the power generation of the photovoltaic system and wind turbine were evaluated to identify opportunities for reducing the building's grid energy usage. These strategies are discussed below.

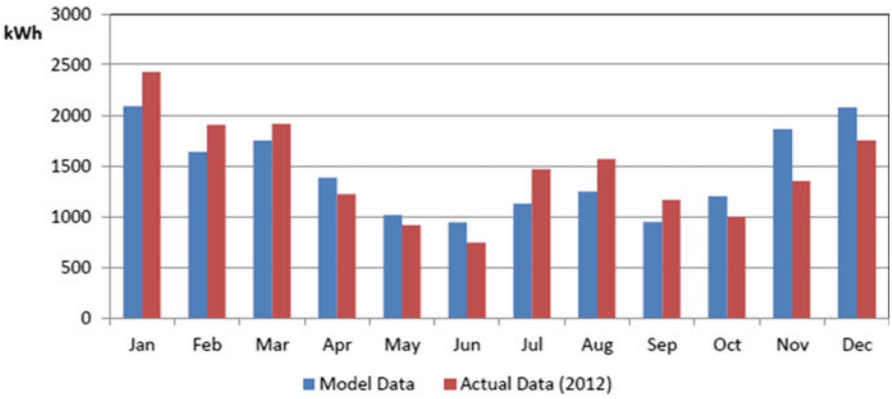

Fig. 24.5 Actual data vs. calibrated performance model outputs

24.8 Photovoltaic Improvements

The current configuration of the photovoltaic panels (2 kW east-facing BIPV and 1.2 kW south-facing externally mounted PV) was evaluated to assess the potential energy generation currently possible. The results are summarized in Table 24.1.

There is a large discrepancy between the potential energy generation and the actual generation of the solar panels, the cause of which was not immediately apparent. The historical energy production of the panels was reviewed. The energy production of the photovoltaic panels has been decreasing regularly every year, likely due to dust/debris build up on the panels. However, the total energy production in 2010 was only about 1,750 kWh, which is still significantly less than the energy production potential summarized in Table 24.1.

The photovoltaic energy production capacity was evaluated to consider the effects of orienting the BIPV system to the south. In this example, additional externally mounted PVs were still included to further increase the energy production. The results are summarized in Tables 24.1 and 24.2.

The energy modeling part of this project consisted of an energy performance analysis of the AFRESH home on BCIT Burnaby campus, summarizing the existing building systems, developing a calibrated whole building energy performance model based on the building's current usage as an office space, estimating the building's energy performance when used as a single-family house, and reviewing the building's current alternative energy production and identifying strategies for improvements. Based on the obtained results, AFRESH home achieves its goal of being an affordable, high-performing home. However, there is currently a considerable amount of "untapped" power generation potential that could be utilized to further reduce the home's reliance on grid energy.

Table 24.1 Summary of current and optimum configuration of AFRESH PVs

	Current configuration-potential energy output	Optimum configuration
2 kW BIPV	1,300 kWh (east facing)	2000 (south facing)
1.2 kW externally mounted PV	1,200 kWh (south facing)	856 (east facing)
Total	2,500 kWh	2,856 kWh

Table 24.2 Summary of potential and actual energy output of AFRESH PVs

	Current configuration-potential energy output (kWh)	Current configuration-actual energy output
2 kW BIPV (east facing)	1,300	1,330 kWh (combined, 2012)
1.2 kW externally mounted PV (south facing)	1,200	
Total	2,500	1,330 kWh

AFRESH home design principles can be affordably implemented in typical residential house construction to improve the stock of residential buildings and reduce the grid energy demand.

24.8.1 The Low Cost Home Energy Advisor

The Low Cost Power Advisor (LCPA) Simulation [1] was designed to provide the user with a tool to effectively determine optimum strategies for appliance power consumption. It does this by integrating what is known about the power consumption of various appliances and when they are being used. This can be done for as many appliances as you want, making it possible to simulate multiple use case environments. Consumption power is then converted into a cost which is dependent on the price scheme being implemented by the electricity provider. An analysis on this cost can help answer questions such as:

- How much will I save if I hold off activating the dishwasher until off peak hours?
- What will be the annual return for an installation of a 1 kW solar panel?
- What control can be implemented by appliance manufacturers to reduce the electric bills for the appliance users?
- What control can be implemented by appliance manufacturers to reduce power consumption during peak loads for electricity providers?
- Which control strategy should you implement in a fixed tariff vs. real-time based power pricing strategy?

The appliance model may either be analytical or numerical. Implementing an analytical model requires a good understanding on what impacts the appliances power consumption/generation. The analytical model may require some advanced math which may or may not be supported by the simulation. This may not always be viable due to a lack of theory and data available for the given appliance. In numerical model we can take the numerical data we collect, through monitoring the appliance, and map it onto its corresponding simulation counterpart.

Whether we want to verify the analytical model or input numerical models, we needed to acquire appliance power consumption data from the AFRESH home as shown in Fig. 24.6. The data we used was taken from:

- The Energy Storage System
- Electric Energy Meter
- Appliance specifications
- Energy consumption averages
- PLC data acquisition system

A block diagram of the LCPA is shown in Fig. 24.7. The system measures the power consumption data using sensor, takes feedback from the homeowner (user), and suggests optimum appliance adjustment to the user.

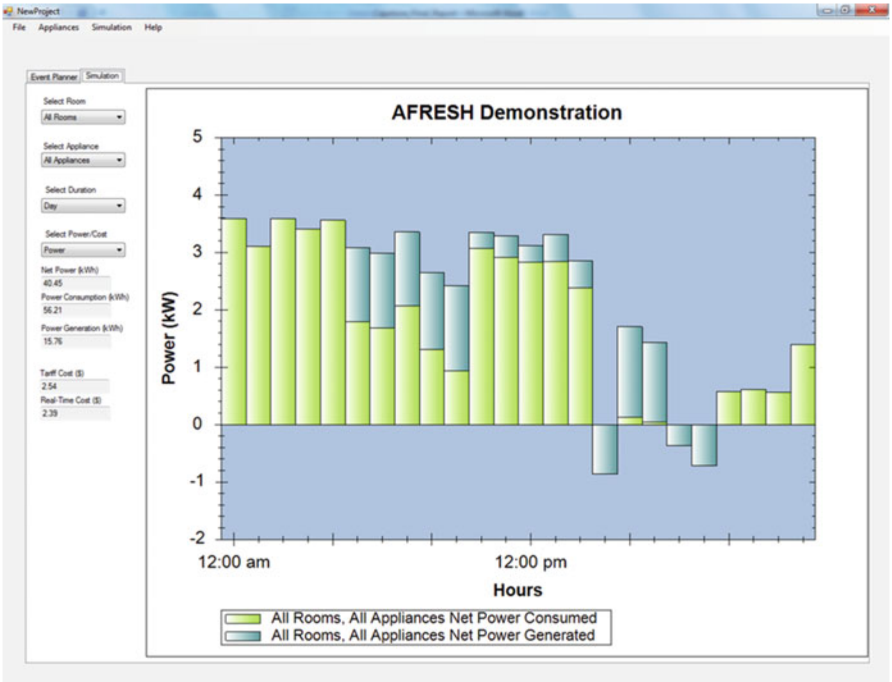

Fig. 24.6 LCPA user interface tab

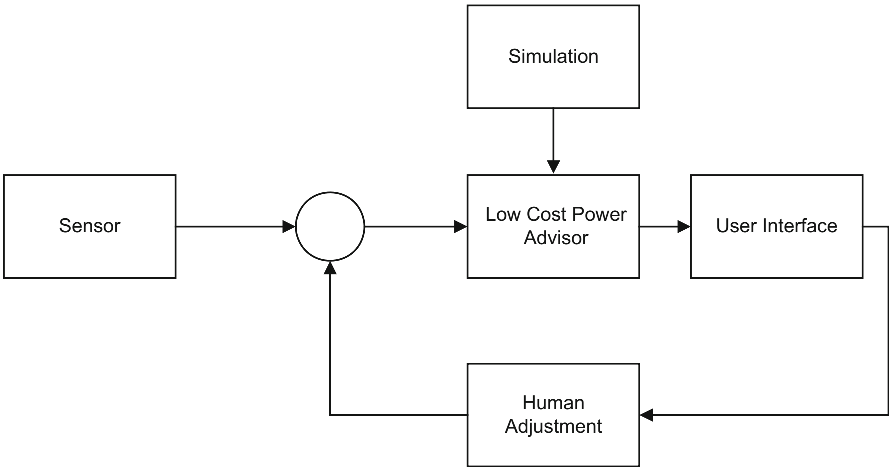

Fig. 24.7 Overall high-level design flow chart

24.8.2 Application of the Home Energy Management System

The Prototype Home Energy Managements system with the simulation software provided the user with the ability to evaluate control implementations and appliance usage scenarios. The simulation software was able to evaluate:

- Real-time pricing scenarios
- Tariff pricing scenarios
- Appliance control strategies
- Power and cost savings

Overall the Low Cost Power Advisor was successful in providing a proof of concept solution to reduce homeowner power consumption following British Columbia Hydroelectric Company guidelines [4]. The LCPA provides the AFRESH home owner insight of:

- Current power consumption
- Detailed consumption list of individual appliances
- Appliance record of total and high-tariff period activations with associated extra cost
- User settable consumption alarm set points
- Consumption trend

24.9 Conclusion

This paper discussed the development of energy performance analysis model of the AFRESH home on BCIT Burnaby campus, summarizing the existing building systems, developing a calibrated whole building energy performance model based on the building's current usage as an office space, estimating the building's energy performance when used as a single-family house, reviewing the building's current alternative energy production, and identifying strategies for improvements. AFRESH home achieves its goal of being an affordable, high-performing home. However, there is currently a considerable amount of "untapped" power generation potential that could be utilized to further reduce the home's reliance on grid energy.

In addition to energy analysis, a Low Cost Power Advisor was built and tested on the house. The system was successful in providing a proof of concept solution to reduce homeowner power consumption. LCPA is a prototype solution for a consumer that clearly and simply demonstrates the energy savings that can be achieved using the simulator by adjusting power-consuming habits or implementing automated control with the appliance. It will be necessary to have this tool for consumers to reliably make positive long-term decisions regarding their energy-consuming habits.

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