ABSTRACT

EXPERT SYSTEM FOR ENERGY OPTIMIZATION OF BUILDINGS USING SUSTAINABLE AND RESILIENT STRATEGIES

by
Victoria Ann Scala

An expert system is developed using the science of heuristics to better model energy usage in existing commercial buildings and to predict future improvements more accurately. The software performs an initial audit analysis of all the major building systems including building envelope, HVAC, lighting, office equipment and appliances, water and hot water, and waste handling. A novel feature of the expert system is that it analyzes energy flow within the building more interactively and cohesively, as opposed to looking at each system individually as do most energy analysis tools on the current market. Both forward and backward chaining strategies are used to accomplish this.

During the auditing process, the software queries user habits and system controls to understand occupant behavior, which can have a significant effect on actual energy usage. Responses are analyzed using Bayesian functions to develop heuristic factors, which are then applied to the results of the audit analysis. This ensures that energy usage is modeled as it is used and operated, as opposed to how it was designed, which can differ significantly.

Once the heuristic factors are applied to audit results, the expert system performs a synchronization step with a forcing function to converge the calculated energy usage with actual consumption from the utility bills, so that energy efficiency may be optimized in the target building. The software then generates a list of recommended upgrades that are prioritized by cost, ease of implementation, and projected energy savings.

Sustainable and resilient strategies are also recommended by the system, since it is becoming increasingly important that a building not only be “green” but also be resilient in the face of a disaster, natural or otherwise.

The expert system is validated and calibrated with ten schools selected from the Newark Public Schools District in New Jersey. The test group of K-12 buildings proved ideal in that they all had similar usage but also represented a wide range of building age, size, and construction type. They were also subject to the temperature extremes of the Northeast climate. Although the expert system is calibrated for Newark school system, the data libraries are easily modified to model any number of building types and climates.

In general, the model shows very good convergence with actual energy consumption for the ten schools as evidenced by an average synchronization adjustment of -0.9% for electric usage and 0.0% for natural gas. A key finding for the Newark study was the wide range of the heuristic index, which measures how occupant behavior and system controls affect the energy usage within a target building. The heuristic index for the “best” test case is 29%, while for the “worst” test case is 54%, or nearly double. Detail model results show that a well-trained staff and good building management are the most influential factors in reducing the heuristic index and thus energy consumption for a given school. The impacts of factors such as HVAC system type and construction materials on energy efficiency are found to be less significant for this test group. The overall model results suggest that a 17% average reduction in energy usage is achievable by improving building management and custodial staff training, and savings of 10% or more can be realized by implementing modest cost upgrades with rapid payback, such as replacing weather stripping, appliance timers, and filter maintenance.

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by
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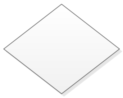
LIST OF SYMBOLS

A	Area (ft^2)
A_C	Annual Cost per Appliance Type
$a_{n,1}$	Lighting Loads Calculated Using Basic and Heuristic Analysis
$a_{m,2}$	Office Equipment and Appliances Loads Calculated Using Basic and Heuristic Analysis
$a_{m,3}$	Hot Water Loads Calculated Using Basic and Heuristic Analysis
$a_{m,4}$	Cooling Loads Calculated Using Basic and Heuristic Analysis
$a_{1,n}$	Winter Loads Calculated Using Basic and Heuristic Analysis
$a_{2,n}$	Spring Loads Calculated Using Basic and Heuristic Analysis
$a_{3,n}$	Summer Loads Calculated Using Basic and Heuristic Analysis
$a_{4,n}$	Fall Loads Calculated Using Basic and Heuristic Analysis
B_O	Total energy billed percentage for original building
B_R	Total energy billed percentage for building with recommendations applied
B_W	Actual electric energy usage from the utility bills for winter season
b_1	Actual Electrical Usage from Utility Bill for Winter Season
b_2	Actual Electrical Usage from Utility Bill for Spring Season
b_3	Actual Electrical Usage from Utility Bill for Summer Season
b_4	Actual Electrical Usage from Utility Bill for Fall Season
c	Specific Heat Capacity $\left(\frac{Btu}{lb \times {}^\circ\mathrm{F}}\right)$
CDD	Number of Cooling Degree Days for Given Period
D	Number of Days the School was in Operation in the Given Month
DD	Number of Degree Days for Given Period
E	Enrollment

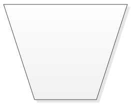
E_{CC}	Energy Consumption for Cooling of the Estimated Period (kWh)
E_{CH}	Energy Consumption for Heating of the Estimated Period (units of fuel)
F_{sa}	Lighting Special Allowance Factor (dimensionless)
F_{ul}	Lighting Use Factor (dimensionless)
H_{AC}	Heuristic Factor for Equipment and Appliances System Controls
H_{AU}	Heuristic Factor for Equipment and Appliances User Habits
H_{BC}	Heuristic Factor for Building Envelope System Controls
H_{BU}	Heuristic Factor for Building Envelope User Habits
HDD	Heating Degree Days
H_{ET}	Heuristic Factor for Education and Training
HF_{O}	Heuristic Factor percentage for original building
HF_{R}	Heuristic Factor percentage for building with recommendations applied
H_{G}	General Heuristic Factor
H_{H}	Heuristic Factor for HVAC
H_{LC}	Heuristic Factor for Lighting System Controls
H_{LU}	Heuristic Factor for Lighting User Habits
H_{OI}	Heuristic Factor for Occupancy Information
H_{WH}	Heuristic Factor for Waste Handling
H_{WU}	Heuristic Factor for Water User Habits
HV	Heating Value of Fuel (Btu/ units of fuel)
h	Hours of Operation per Week
h_{P}	Hours of Operation per Week the Appliance is Turned off but Plugged in
IAA_{O}	Initial Audit Analysis percentage for original building
IAA_{R}	Initial Audit Analysis percentage for building with recommendations applied

IAC	Interior Solar Attenuation Coefficient (dimensionless)
m	Mass (lbs)
P	Annual Phantom Load per Appliance Type (kWh)
P_C	Annual Phantom Cost per Appliance Type
Q	Heat (Btu)
Q_A	Heat Given off by Appliances (Btu/hr)
Q_D	Heat Infiltrating through Doors (Btu/hr)
Q_L	Heat Given off by Lighting (Btu/hr)
Q_P	Heat Given off by People (Btu/hr)
Q_R	Heat Transfer due to Conduction through the Roof (Btu/hr)
Q_S	Heat Transfer due to the Sun’s Radiant Energy (Btu/hr)
Q_{WL}	Heat Transfer due to Conduction through Walls and Floors (Btu/hr)
Q_{WN}	Heat Infiltrating through Windows (Btu/hr)
Q_2	Solar Radiation (Btu/ft^2)
q	Heat Gain from Appliance (Btu/hr)
q_A	Heat Gain from Adults (Btu/hr)
q_C	Heat Gain from Children (Btu/hr)
q_g	Design Cooling Load (Btu/h)
q_L	Design Heat Loss Including Infiltration and Ventilation (Btu/h)
qt	Quantity of Appliance
ΔT	Outdoor Average Temperature – Indoor Average Temperature (^oF)
Δt	Temperature Difference (^oF)
S	Number of Staff and Teachers
SEER	Seasonal Energy Efficiency Ratio (Btu/h/W)
SHGC	Solar Heat Gain Coefficient (dimensionless)

SM_E	Synchronization matrix for electric load of given school
SS	Synchronization Step percentage
U	Conductance of the Material (Btu/hr/ft^2/^{o}F)
W	Total Wattage per Fixture Type (Watt)
W_{HE}	Hot Water Usage for Elementary Schools (gal/mo)
W_{HH}	Hot Water Usage for High Schools (gal/mo)
W_P	Total Phantom Wattage per Appliance (kWh)
W_{WE}	Water Usage for Elementary Schools (gal/mo)
W_{WH}	Water Usage for High Schools (gal/mo)
wk	Weeks of Operation per Year
x_f	Convergence Factor for Fall Electric Loads
x_{sm}	Convergence Factor for Summer Electric Loads
x_{sp}	Convergence Factor for Spring Electric Loads
x_w	Convergence Factor for Winter Electric Loads
x_1	Convergence Factor for Lighting Usage
x_2	Convergence Factor for Office Equipment and Appliance Usage
x_3	Convergence Factor for Hot Water Usage
x_4	Convergence Factor for Cooling Usage
η	Efficiency of Heating System (dimensionless)



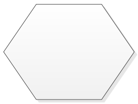
Analysis



Analysis Found in Another Flowchart

Data

Document/Output



Heuristic Function

Input/Process

Input Sub-process

Start/End

CHAPTER 1

INTRODUCTION

1.1 General Background on the Problem

Sustainability has risen over the years as a forefront concern of designers, engineers, governments and building owners. Sustainability is the idea that people should live in a way that considers the environment, the economy, and society. With the rise of this idea, came the rise of new technologies and rating systems. A prominent rating system is the Leadership in Energy and Environmental Design, more commonly known as LEED (US Green Building Council, 2012). However, the system has been criticized for not meeting expected energy usage. Often, LEED certified buildings use more energy than comparable counterparts that are not certified (Ryan, 2012). Some attribute the disparity to the fact that the rating is based on models and not actual energy consumption. Such models also drastically underestimate the influence that user behavior has on energy consumption. This failure has cast a shadow on the idea and is leading people away from the "green gadgets" sustainability approach. Along with recent natural disasters, it is leading people towards the idea of resilience, that a building should be operable and help people survive during times of crisis or simply when the power goes out. Often the suggestions for sustainability and resiliency are similar, but people come to the recommendation from different perspectives, one of social responsibility, the other of life safety.

Energy efficiency is still an idea pursued by most, whether to be socially responsible or merely to reduce costs. Energy audits can be extremely helpful with this, showing where the energy is being consumed and where the waste is coming from

(Thumann, 2010). After an audit, recommendations can be made to retrofit systems, conduct proper maintenance, install controls and increase awareness of occupant behavior. Occupant behavior is a key aspect when considering energy efficiency. For instance, lighting controls may be installed to limit when lights are on, but if users override these, the retrofit will not be energy efficient at all. Whereas, if users are in the habit of turning the switch off, there is no need to install controls because the users are the control. This idea may sound simple, but before these technologies were created, things were done this way because it was the only option.

Another example of the inefficiency of some modern building design trends can be found in glazing systems. Before air conditioning was widely applied, operable windows were necessary for ventilation. Over the past several decades, however, fully glazed exteriors have become increasingly popular. It would seem obvious that glazed buildings are inherently inefficient due to their poor insulation quality. Also, that these buildings are totally reliant on air conditioning demonstrate that they are not resilient. Several studies have even shown that older buildings are more energy efficient than more recent ones (Navarro, 2012). In some ways, one may say, society just needs to re-learn how to be energy efficient and resilient.

1.2 Research Overview

An expert system has been developed to model energy usage of commercial buildings in order to determine current energy consumption and to recommend where energy improvements can be made. The expert system audits and analyzes all major building systems including building envelope, HVAC, lighting, office equipment and appliances, water and hot water, and waste handling. In addition, a survey of user habits and system controls is made to understand occupant behavior, which can drastically affect energy usage in the target building. After the initial audit analysis is complete, heuristic factors are then computed and applied to better model actual usage. Then, the expert system synchronizes the audit analysis with actual consumption, so that energy efficiency in the building is optimized.

The expert system then generates recommendations on ways to improve energy efficiency, ranking them by cost, ease of implementation, and projected savings. The recommendations are broken down into three levels: (1) immediate improvements, which include quick fixes with no or low cost; (2) gradual improvements, which include recommendations with a simple payback of two years or less and should be fixed when possible; and (3) capital improvements, which will require longer implementation, higher investment and, therefore, a longer payback period.

The expert system also considers sustainable and resilient strategies, since it is becoming increasingly important that a building not only be ‘green’ but also resilient in the face of a disaster, natural or otherwise. After Hurricane Irene in 2011 and Hurricane Sandy in 2012, it is more pertinent than ever that buildings continue to run during prolonged power outages, whether it be school buildings serving as shelters or businesses continuing to operate.

The program was calibrated using selected school buildings from the Newark Public School District. The choice was appropriate, given that “America’s schools spend more than $7.5 billion annually on energy – more than they spend on textbooks and computers combined…[These] energy costs are the largest operating expense for school districts after salaries and benefits” (Energy Star Building Manual, 2006). Certainly, more money can be used for education if the buildings could become more energy efficient. Other factors which made the Newark system a good choice included the northeast weather conditions, and the fact that the school system already has some efficiency measures in place, which were key during the calibration to see how well they work. The 79 buildings in the Newark System also vary widely in age, being built as early as 1848 and as recent as 2007.

CHAPTER 2

LITERATURE REVIEW

2.1 General Introduction

Sustainable or green buildings have been on the forefront of the energy conservation trends. Over the past few decades, numerous devices have emerged to make buildings friendlier to the environment. However, the problem is identifying ones that are reliable and actually conserve energy. In parallel with rising interest in this area, energy rating systems have also emerged. The United States Green Building Council's (USGBC) Leadership in Energy and Environmental Design is arguably one of the most well-known, as it encompasses more than 14,000 projects (US Green Building Council, 2012). With the rise of rating systems, also came realization that some were not living up to their energy saving expectations. Many are based on models and not actual energy usage or real life conditions, leading some to believe that they are merely a marketing scheme.

Recent disasters have taken their toll on many cities, and it is becoming more important to not only be sustainable but to be resilient in the face of these disasters. Society is realizing that buildings with operable windows and good insulation helped people withstand these disasters. These buildings are still habitable when the power goes out because they do not rely on elevators or forced ventilation to be occupied. In some ways, it seems society is simply re-learning how to be resilient.

Energy audits have often been used in order to make buildings more energy efficient. Some popular auditing tools on the market today include the Department of Energy's EnergyPlus, TREAT and ENERGY STAR® Portfolio Manager. These programs have some commendable capabilities, but also some limitations. For instance, the Department of Energy's EnergyPlus is a powerful program, but the unfriendly graphical interface requires an experienced user. TREAT has an extensive data library and friendly user interface, but the program can only calculate energy differences between the original structure and the improvement of the user's choice. It cannot suggest areas of improvement. ENERGY STAR® Portfolio Manager is helpful in tracking energy efficient measures. It is known for its ranking features, where the program rates the target building against comparable buildings to see how the building is using its energy as compared to others. However, this program does not perform an audit but rather looks only at usage.

2.2 Energy Conservation Trends and Progress

A green building, according to ASTM International, is "a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life… A green building optimizes efficiencies in resource management and operational performance; and minimizes risks to human health and the environment" (Burnett, 2007). Green buildings should be considered from a holistic approach in order to achieve sustainability from design through operation (Wu, 2010). A key way to achieve green buildings, in new construction, is through the use of life cycle assessment. Life cycle assessment is the quantitative assessment of environmental impacts from cradle to grave, which should be used from the beginning of the project so that materials and systems are selected to use environmentally friendly resources and to match performance expectations (Mora, 2011). Heating and cooling loads account for the largest amount of energy usage; 48-55% in office buildings and 42-68% in residential (Mohareb, 2011). Green buildings aim to reduce heating and cooling loads to improve efficiency, mostly by using passive designs for lower energy input while still maintaining quality conditioning. The main way to do this is to minimize energy loss through the buildings enclosure (Mora, 2011).

Building energy efficiency has evolved over the years to an integrated system approach by analysis of whole building energy design concepts rather than as simple additions of disconnected parts (Pisello, 2012). Designers are able to do this by integrating all of the building properties in the early design stages to optimize the building performance through all seasonal conditions particular to a given building. In general, energy regulations aim at minimizing final energy consumption without compromising the comfort or the productivity of the occupants (Perez-Lombard, 2011).

In New York City, the office of Long-Term Planning and Sustainability has completed the first comprehensive study of energy use of the city’s largest buildings. The city began tracking buildings under a law by Mayor Michael Bloomberg in 2009, which applies to buildings over 50,000 square feet or multiple properties that are more than 100,000 square feet (Navarro, 2012). Although the law only covers 2% of the city’s buildings, these account for 45% of all energy use by buildings in the city. The buildings will begin undergoing audits this year, but the data has revealed some trends already. Older buildings, even dating back to 1900s, performed better than most structures from recent decades; green-building experts say it is likely because they have fewer windows and thicker walls, which provide better insulation. Another study from Norway reached similar findings that new office buildings were less efficient than older ones (Ryghaug, 2009).

The office of Long-Term Planning and Sustainability is not stopping with just the initial findings. The City wants to publicly assign scores to buildings, similar to what is currently done with restaurants (Navarro, 2012). They hope that such a public announcement will encourage owners, occupants and builders to aim for higher efficiency.

While the United States is aiming to standardize green building programs to increase efficiency based on baseline energy codes, Japan has already implemented such measures. Japanese codes require owners of buildings larger than 2,000 square meters to submit a report on energy conservation to local authorities to show the improvements for energy efficiency that have been made (Perez-Lombard, 2011).

Benchmarking systems like these can be used as a public yardstick and can encourage poor performers to do so. Performance indicators, such as ‘kWh/ft^2/yr’ would provide information that makes building users, owners, or whoever pays the utility bills accountable for their energy use performance (Chung, 2012).

2.3 Focus of Energy Conservation

Proponents of energy efficiency promote the idea that higher performance leads to a better occupant experience and lower operating costs, which are significant when looking at the life-cycle cost (Andrews, 2009). Joelsson and Gustavsson in their study found that as energy efficiency measures were implemented into each of the various buildings, the primary energy usage was notably reduced (Gustavsson, 2009). Considering that the

HVAC component in a building accounts for approximately 65% of the total building's energy usage, reducing this factor alone through energy efficient technologies can drastically lower utility bills (Liu, 2009).

Over the past several decades, many energy efficient technologies have emerged. The problem has now shifted towards finding ones that are reliable and durable. Various measures, which may be considered for the improvement of energy efficiency, can be broken down into the following basic categories: building envelope; reducing heating and cooling loads; use of renewables; use of intelligent energy management; indoor comfort; energy efficient appliances; and lighting. With the numerous technologies available, one has to consider the environmental, financial, energy and social aspects to determine the best choice that will still maximize the energy efficiency and satisfy the occupant or owner (Diakaki, 2008).

General building features like the year of construction, architectural style and region influence which technologies are best to implement (Andrews, 2009). The budget available to operate the building, as well as the operators themselves, can impact technology adoption. Buildings with larger budgets are more likely to select advanced technologies, whereas others with smaller budgets are more likely to select easier retrofits like lighting. Operators' experience and cost to learn new technologies should also be considered. No technology, other than fluorescent lighting has yet to dominate in buildings (Andrews, 2009). This is most likely due to the fact it is inexpensive, easily installed, and has low maintenance. Newer, larger buildings that are owner-occupied often see the most energy efficient technologies applied because they can afford the upfront costs of research, learning and installation; therefore, these energy efficient technologies are unlikely to spread swiftly beyond the current users (Andrews, 2009).

The design and construction phases are key times to optimize the energy efficiency of a building and estimate future usage. The insulation and orientation, for example, do not alone ensure energy efficiency, as the management of the equipment is a key factor as well (Escriva, 2011). While every building cannot implement the newest 'green' technologies, there are actions that every building can take to be proactive in energy efficiency. These basic actions include the following steps: accurately measure and store operational data; properly schedule units' operation; automatically monitor electricity and alert management if use is in excess; assign a person responsible for energy use; define pro-active actions taken by all users; modify facilities for easier management; and establish communication between users and managers (Escriva, 2011).

2.4 Introduction of Energy Rating Systems

Numerous rating systems have emerged over recent years as the popularity of 'green' buildings has spread. The Leadership in Energy and Environmental Design (LEED) was developed by the United States Green Building Council (USGBC) in 2000. LEED certification is a third party verification that looks at five areas of performance: sustainable site, water savings, energy efficiency, material selection and indoor environmental quality (US Green Building, 2012). Points are assigned to various items within these categories. The total points awarded leads to four types of accreditation: LEED Certified, LEED Silver, LEED Gold, and the highest, LEED Platinum. LEED has grown to encompass 14,000 projects and is estimated to have a value of $60 billion in green building construction projects (Fortunato, 2011). Several factors driving the market include: (1) numerous government mandates and incentives; (2) growing availability of green building supplies has decreased construction costs; (3) private sector firms recognizing the long term value resulting in improved marketing; (4) reduction in maintenance costs; and (5) enhanced quality of life (Fortunato, 2011).

The United States isn't the only one creating rating systems. Green Globes was developed in 1996 by the Canadian Standards Association, which produced BREEAM, the Building Establishment's Environmental Assessment Method (Green Globes, 2012). Within the United States, Green Globes is operated under the Green Building Initiative. The Hong Kong Building Environmental Assessment Method, HK-BEAM, was created in the same year. Since then, Australia's Green Star was created in 2003, Singapore's Building and Construction Authority, Green Mark, in 2005, and New Zealand's Green Star, most recently in 2007.

One of the newest guidelines to emerge is the Living Building Challenge, which was created in 2006 by the International Living Features Institute based in Portland, Oregon. The Living Building Challenge "calls for buildings to not only have net-zero energy and water systems, but to use half the energy required to get LEED platinum certification" (Newcomb, 2012). Living Building Challenge is a much more intensive accreditation process. So far it has recognized six buildings as 'living.' Projects must be in operation for a minimum of twelve months before they can become eligible to participate as it is based on actual performance. This is unlike the LEED accreditation, which is based on model estimates during the design stage.

2.4.1 Shortcomings of Rating Systems

As has been noted, LEED buildings often do not live up to their energy saving expectations. One theory is that designers are too optimistic in their estimates of occupancy behavior, which leads to less energy savings than expected (Ryan, 2012). As John Scofield, Professor of Physics at Oberlin College, testified to the House of Representatives, "What LEED designers deliver is what most LEED building owners want – namely, green publicity, not energy savings" (Roudman 2013). The major issue with building energy models is the lack of validation and verification studies. These models typically assume ideal conditions and exclude actual conditions like the effects that building occupants have on energy use (Ryan, 2012). In addition, the models may be used by non-technical people, like policy makers, leading to skewed results. LEED has been criticized for certifying buildings before they are occupied and for not revoking certification when the buildings do not live up to expectations (Roudman, 2013).

One of the most prominent failures of the LEED rating system has been the Bank of America Tower located at New York City's Bryant Park. The 55-story tower was the first skyscraper to receive LEED Platinum certification for Core & Shell in 2010. The tower includes low flow plumbing fixtures, gray water storage, under-floor air delivery system and a 5.1 megawatt cogeneration system (Bank of America, 2013). It was praised by Mayor Bloomberg and its own tenant Al Gore for working to solve the climate crisis (Crawford, 2010). However, according to data released by New York City in the fall of 2012, the Bank of America Tower uses more energy per square foot and releases more greenhouse gases than any other comparably sized building in the City (Roudman, 2013). In fact, it uses twice as much energy per square foot as the Empire State Building, which is 80 years older than the tower. It also performs worse than the lower rated LEED Gold Goldman Sachs Building, which is the most comparable tower. “It’s not just an embarrassment; it symbolizes a flaw at the heart of the effort to combat climate change” (Roudman, 2013).

Two other examples of actual energy usage being significantly higher than predicted energy usage were explained by Lawrence Spielvogel, consulting engineer (Post, 2012). The first example was the Pennsylvania Department of Environmental Protection’s Cambria Office, which was claimed to use 25,000 Btu per square foot per year. But electric bills for the second year showed 41,900 Btu or 67% more energy than predicted. The other, the Adam Joseph Lewis Center for Environmental Studies at Oberlin College, was designed for net zero energy use, but the second year it consumed a total of 46,000 Btu per square foot per year.

Some have claimed that LEED accredited buildings are merely a marketing scheme, or rather a branding technique. One study found that an increase of 10% in energy efficiency is associated with a 2% increase in selling price, but a certified LEED building has a premium sale price between 11% and 25% in addition to a rental premium of 5% (Sabapathy, 2010). In order to achieve these premium rental and sale prices, accreditation must be acquired. One study found that first time users of LEED-New Construction find the cost and complexity of the LEED registration and certification processes to be a deterrent as well (Issa, 2010).

Criticism has also been leveled at certain green building features. For example, Lawrence G. Spielvogel, consulting engineer, stated “Ground source heat pumps, chilled beams and radiant floors don’t work as well as claimed. Under floor air supply is too expensive and not better than conventional systems." So if the systems do not work as well and the buildings are not performing as promised, how come this isn't better known? "Nobody wants to admit something doesn't work so we can learn from mistakes and move on. At ASHRAE, we used to share our war stories and publish them. That stopped about 20 years ago because of fear of getting sued" (Post, 2012).

LEED isn't the only building rating system with flaws. Hugh Byrd and Paola Leardini discuss New Zealand's issues (Byrd, 2011). Most of the accredited buildings in New Zealand are sealed, highly glazed, thermally light weight, and dependent on air conditioning, which are not generally considered 'green' design features since they do not follow architectural science principles. The authors point out that although 'green' rating systems consider many aspects, including land use and transportation, one of the main aspects of both architectural science and sustainability, namely energy, is not effectively addressed. Designing buildings that are dependent on air conditioning cannot be 'green' when there is no guarantee of unconditional energy supply in the country and a strong likelihood of rationing in the future. The authors point out that it is possible to achieve New Zealand's highest rating while the building envelope is almost breaking the law. Since windows lose ten times the amount of energy compared to insulated walls, in general, it is difficult to justify glazing more than 50% of the exterior surface (ASHRAE, 2000). Many of the 'green' buildings in New Zealand exceed 50% glazing.

2.5 Rise of Resiliency from Sustainability

Sustainability is often used in a vague manner, an idea that people agree with, but one that is not well defined. As Dr. Karl-Henrik Robert, founder of the organization, The

Natural Step, stated, “Everyone talks about sustainability, but no one knows what it is” (Keller, 2003). Some definitions suggest that ‘green design’ and ‘sustainability’ cannot be defined in absolutes but rather as a mindset, or process, to achieve a certain goal (Grumman, 2003). The Design Ecology Project, which specializes in ecological design, has perhaps articulated the best definition: sustainability can only be maintained indefinitely when three elements are considered, the environment, the economy and society (Keller, 2003). Each aspect must be applied in order to have a working system of sustainability. One could think of each aspect as a gear, where each has to properly turn in order to have a sustainable system, as depicted in Figure 2.1.

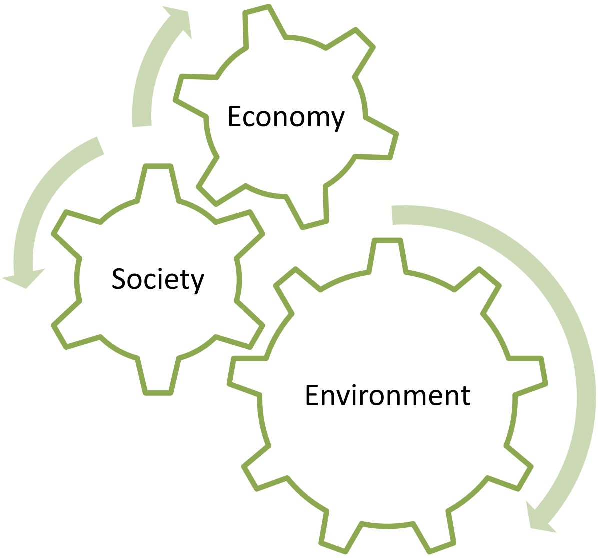


Figure 2.1 The principle of sustainability.

Source: Adapted from Keller, J. (2003). *ASHRAE GreenGuide* (D. Grumman, Ed.). Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Following Hurricane Irene in 2011 and Hurricane Sandy in 2012, there has been recognition that green or sustainable designs alone are not enough. “Where sustainability aims to put the world back into balance, resilience looks for ways to manage an imbalanced world" (Zolli, 2012). This movement towards resilience is also growing due to the dissatisfaction with the green gadgets approach to sustainability (Alter, 2011). After September 11th, downtown Manhattan had the largest amount of LEED certified buildings, which allowed them to produce lower environmental impacts but not to respond to impacts from the environment like redundant power systems (Zolli, 2012). Resilience is not just about how buildings withstand these impacts, but also how people do.

Although 'green' infrastructure is often associated with devices and gadgets, it is often simplicity that makes infrastructure resilient. For instance, walking communities and bicycles make it possible to go to the store when the power goes out (Alter, 2011). Glass enclosed skyscrapers, which depend on elevators and forced ventilation, are typically uninhabitable when the power goes out, whereas, walk up apartments with operable windows can still be used. Some of the strategies that promote resilience are the same as those that promote sustainability. For example, better insulation in a building would be sustainable by reducing the energy required to heat and cool the space. On the same note, this insulation is resilient when the power goes out so the space is still habitable. One just focuses on life safety, whereas the other focuses on doing the right thing (Alter, 2011). To some extent, society is just re-learning how to be sustainable and resilient.

2.6 Energy Efficient Schools

Many schools across the United States have implemented retrofits and new technologies to promote energy efficiency. One such school is the Richardsville Elementary School within the Warren County Public School District in Richardsville, Kentucky. This school is the first full-scale “net zero energy” school in the United States. The building is 72,285 square feet and was constructed at a cost of $206.50 per square foot totaling $14,927,000. The projected simple payback is 15 years. The engineers and architects incorporated various green design elements, including a solar photo voltaic system on the roof and a shaded structure in the parking lot area. An energy usage monitoring system is used to measure trends in HVAC, lighting, plug load and kitchen load. Insulated concrete form walls increase thermal performance, and the school’s rectangular shape minimizes heat transfer through the exterior envelope. All classrooms are located on the north and south sides to capture the best day lighting, and T8 lamps are installed within each classroom to reduce energy consumption. A reduction in water consumption was achieved with permeable pavers and low flow fixtures. Maintenance costs were reduced by installing stained concrete floors. Non-standard kitchen equipment that consumes less energy was also installed, necessitating staff to learn different ways to cook (Seibert, 2012).

Smaller scale examples include the Andover Public School District located in Andover, Massachusetts, which linked all of their district’s 10 schools together with an energy management system. The system controls the building lights, so when the janitors engage the security system at night, all of the other lights automatically turn off. Interestingly, the school system reported a decrease in energy consumption as well as vandalism (Guide, 2012). Another example is the Kent Intermediate School District located in Grand Rapids, Michigan, which used a building automation system to screen for conditions approaching emergency levels and automatically opens pre-emptive work orders (Guide, 2012). Another, the Poudre School District located in Fort Collins, Colorado, participates in a utility partnership called ‘Energy Rules’ that gives back ten percent of energy savings to the school as an incentive to conserve energy (Guide, 2012).

2.7 Expert Systems

2.7.1 Origins of Artificial Intelligence

Two researchers of artificial intelligence are credited with laying the foundation concepts: Alan Turing, a British mathematician and Claude Shannon, an American mathematician (Negnevitsky, 2005). In 1950, Turing wrote the influential paper, ‘Computing Machinery and Intelligence’. In the same year, Claude Shannon also published a paper about chess playing machines, which demonstrated the need for heuristics in determining the solution due to the numerous possible moves and the time it would take to evaluate each move. Heuristics is a series of rules of thumb that limit the search for a solution.

The official birth of artificial intelligence came in 1956 at a small IBM conference at Dartmouth College, where computer scientists, including Shannon, discussed their research efforts in automatic theorems and how it could be used to simulate human reasoning (Durkin, 1994). The new science would be dominated by these ten researchers and their students for the next two decades. The collective efforts led to great expectations in the field of artificial intelligence. However, due to the limited capabilities of computers at the time and the limited methods available for solving broad problems, performance was poor and the field declined (Negnevitsky, 2005).

It wasn't until almost two decades later that the most important development in artificial intelligence occurred; researchers realized the problem domain had to be restricted (Negnevitsky, 2005). In 1965, NASA engaged Stanford University to develop a program that could determine the molecular structure of soil for an unmanned spacecraft sent to Mars (Durkin, 1994). The Stanford team knew specific expertise was needed but also rules of thumb, or heuristics, in order to narrow down the millions of possible molecular structures. The result was a program, called DENDRAL, which worked as an expert chemist in recognizing molecular structures of unknown compounds; it became the first expert system.

A more famous expert system was PROSPECTOR, developed by Stanford Research Institute for mineral exploration (Negnevitsky, 2005). While creating this program, it lead researchers to discover that the knowledge one has to reason with was more important than the reasoning method itself. The program used Bayes' rules of evidence, when knowledge was unknown, to propagate uncertainties through the system, making it easy to transition from the laboratory to commercial use. When the personal computer or PC hit the markets in the 1980s, it was possible for researchers and engineers in all disciplines to take up creating expert systems.

2.7.2 Characteristics of Expert Systems

Expert systems are a branch of artificial intelligence set to a specific domain. In simplest terms, an expert system reasons about how to solve a problem rather than calculating the solution. Experts use their experiences to problem solve by using certain rules of thumb to shortcut to the solution. The differences between conventional programming, as compared to expert system development, are mainly that conventional programming focuses on the solution and is done in sequential development, whereas an expert system development focuses on the problem in an iterative development (Durkin, 1994).

Expert systems contain two major parts, knowledge and inference. The knowledge base contains facts, rules, concepts and relationships about the problem, while the inference engine is developed from the experts' reasoning to draw conclusions (Durkin, 1994). The inference engine then combines facts from the working memory with rules from the knowledge base to come to a conclusion. This concept is illustrated in Figure 2.2.

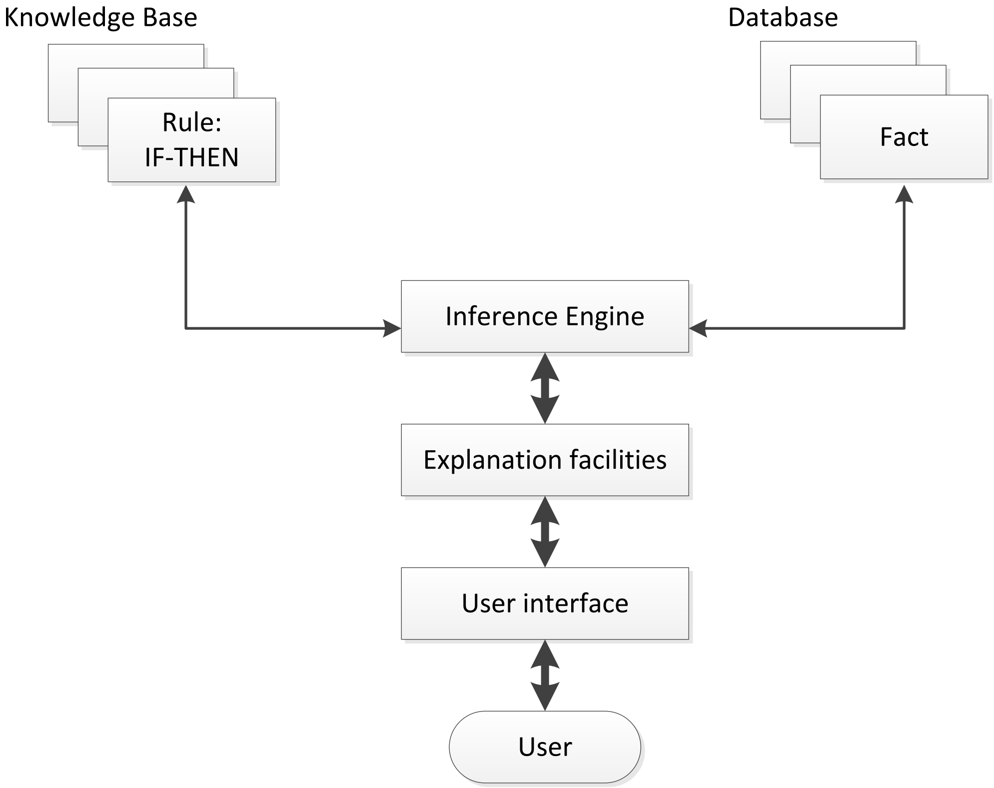


Figure 2.2 Basic structure of a rule-based expert system.

Source: Adapted from Durkin, J. (1994). *Expert Systems Design and Development*. New York, NY: Macmillan.

The inference engine is made up of *if (cause) then (effect)* statements to reason a result through either deduction, abduction or induction (Hopgood, 2001). Deduction is when a cause and a rule result in a conclusion. Abduction is when an effect and a rule result in a cause. Finally, induction is when a cause and effect result in a rule. An inference engine performs the task by scanning the rules of the working memory and the knowledge base for a match; when a match occurs, it adds the conclusion to the working memory and then keeps scanning for more matches as seen in Figure 2.3.

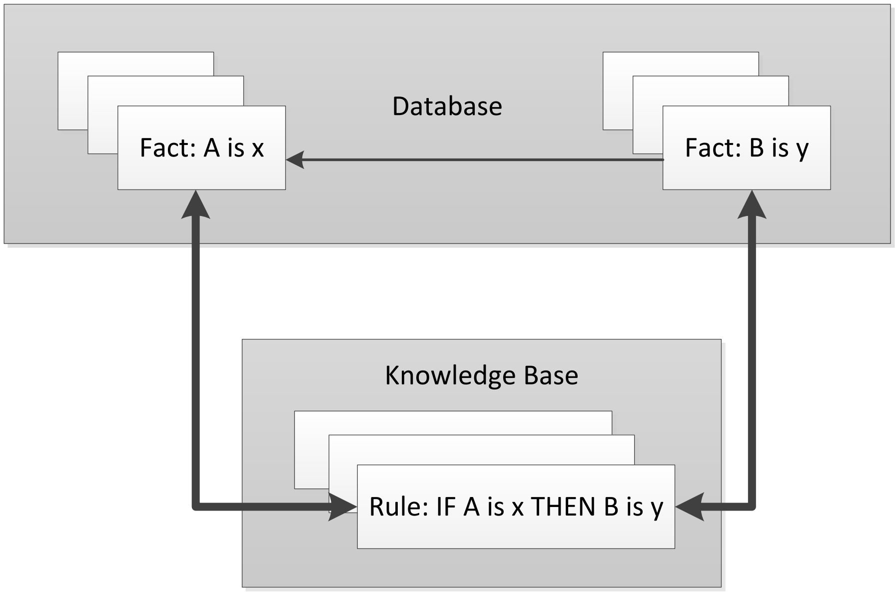


Figure 2.3 Inference engine cycles via a match-fire procedure.

Source: Adapted from Durkin, J. (1994). *Expert Systems Design and Development*. New York, NY: Macmillan.

There are two types of inference engines, also known as control modules: forward chaining, which is data driven, and backward chaining, which is goal driven (Hopgood, 2001). In forward chaining the rules are applied in response to the current fact base, which includes facts that are supplied or derived. In contrast, backward chaining looks to establish or refute the existence of a goal.

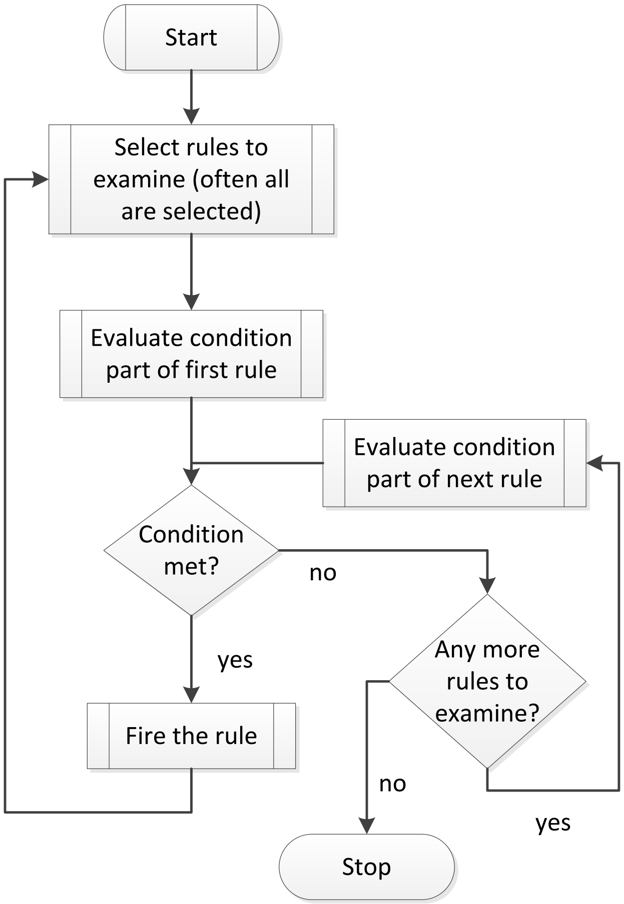


Figure 2.4 Forward-chaining with "first come, first served" conflict resolution.

Source: Adapted from Hopgood, A. (2001). *Intelligent Systems for Engineers and Scientists* (2nd ed.). Boca Raton, FL.: CRC Press.

As stated previously, forward chaining is a data driven search. Forward chaining is similar to the idea of Modus Ponens, which is a valid argument in the field of logic. It can be simply written as *if P then Q, or given P therefore Q*. In an expert system, the information from the user is placed in the working memory (Durkin, 1994). The inference engine then scans the rules looking for a match; when a match is found, the rule is fired, meaning it adds the rule's conclusion to the working memory. It then cycles again looking for new matches until no more matches are found. A diagram of how forward chaining progresses can be seen in Figure 2.4. Some advantages of forward-chaining are that it works well when problems naturally begin by gathering information, and it can also provide much information from a small amount of data. However, one drawback of forward-chaining is that it does not know which information is important, so it spends the same amount of time looking for significant information as well as insignificant information, which can lead to the program asking unrelated questions to the user (Durkin, 1994).

Backward-chaining is a goal driven search that begins with a hypothesis and then searches for facts to support it (Durkin, 1994). In this method, the inference engine firsts checks the working memory to ensure the goal has not already been added, which is performed incase another knowledge base already proved it. If it has not been, then it searches the *THEN* part of the rules in search of the goal. When it finds a *THEN* statement that has its goal, it proceeds to check if the sub goals have been added to the working memory. If not, they become new goals to prove. The inference engine continues to do this until it finds a statement that is not concluded by any rule, which is called a primitive. A diagram of how the process progresses, is illustrated in Figure 2.5. Some advantages of backward-chaining is that it works well when the problem begins with a hypothesis and assesses if it can be proven; since it is goal driven the questions stay on the related topic, which means it searches only relevant parts of the knowledge base. A drawback, however, is that it follows one line of reasoning until it fails where it is then dropped, and starts another line of reasoning.

An important aspect of an expert system is the explanation facility, since the solution is reasoned and not purely calculated. As an expert would be able to justify how they came up with the conclusion, the system needs to be able to show its logic, or justification, for a given conclusion to the user (Durkin, 1994).

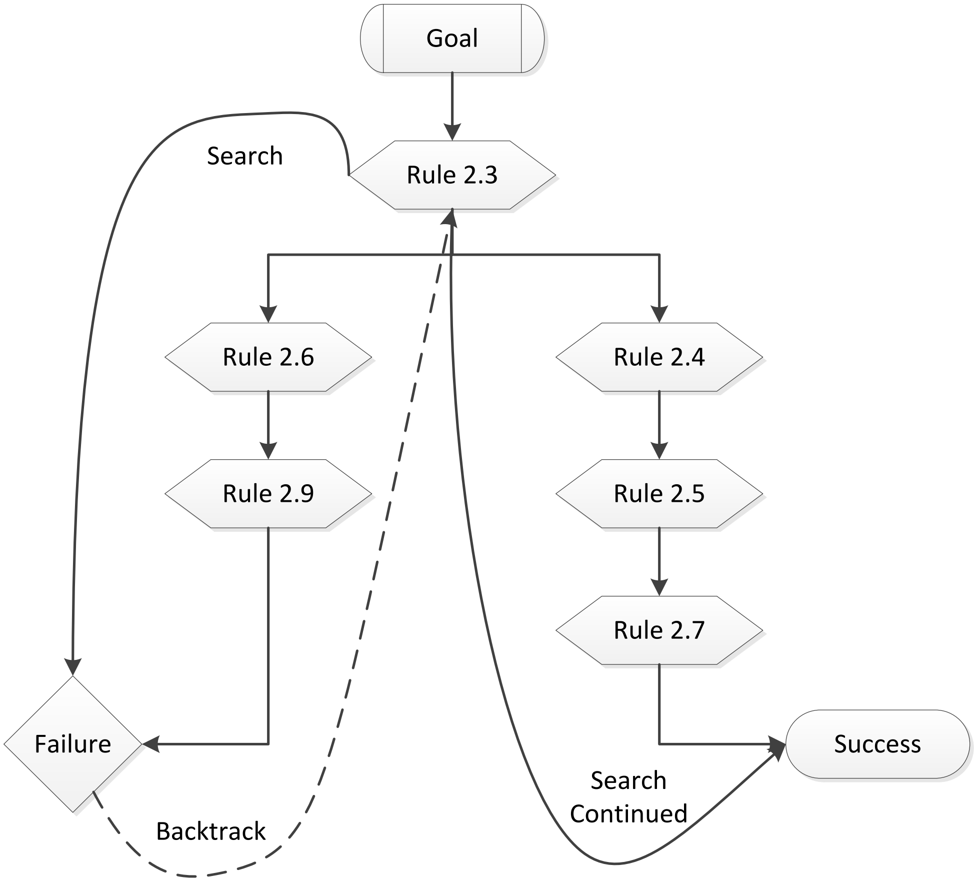


Figure 2.5 Backward chaining process.

Source: Adapted from Hopgood, A. (2001). *Intelligent Systems for Engineers and Scientists* (2nd ed.). Boca Raton, FL.: CRC Press.

2.7.3 Problem Solving: Bayesian Theory and Networks

Probability calculus was invented by Pascal and Fermat in the 17th century for the purpose of gambling and dealing with physical uncertainty (Korb and Nicholson, 2004). Two common probabilities are conditional and posterior. Conditional probability allows the probability of an event A, given event B occurred. Posterior probability is finding the probability of an earlier event given a later one has occurred. In simple terms, conditional probability is forward in time, while posterior probability is backward in time (Durkin, 1994).

Other mathematicians soon realized that these probabilities could be used to deal with other uncertainties, like ignorance (Korb and Nicholson, 2004). The 18th century British mathematician, Thomas Bayes, formulated Bayes Theorem, to explain this probability (Durkin, 1994). “Bayesianism is the philosophy that asserts that in order to understand human opinion as it ought to be, constrained by ignorance and uncertainty, the probability calculus is the single most important tool for representing appropriate strengths of belief” (Korb and Nicholson, 2004). The main goal in Bayesian modeling is to find the most accurate representation of a system, even though it may be based on inconsistent advice from experts (Korb and Nicholson, 2004).

The theorem states that the probability a given hypothesis is true given evidence, $P(H|E)$, is equal to the probability that the hypothesis is true, $P(H)$, times the probability of observing evidence when the hypothesis is true, $P(E|H)$, divided by the probability of evidence, $P(E)$.

In equation form this is written, $P(H|E) = \frac{P(H)*P(E|H)}{P(E)}$

where $P(H|E)$ is the probability a hypothesis H is true, given evidence E;

$P(H)$ is the probability a hypothesis H is true;

$P(E|H)$ is the probability of observing evidence E when hypothesis H is true;

$P(E)$ is the probability of evidence E (Durkin, 1994).

Bayes Theorem can be expanded using prior probabilities to understand the present situation. This is expressed by the formula

$$P(H|E) = \frac{P(E|H) \times P(H)}{P(E|H) \times P(H) + P(E|{\sim}H) \times P({\sim}H)}$$

where P(H) is the prior probability hypothesis H is true;

P($E|H$) is the probability the hypothesis H is true and will result in evidence E;

P(~H) is the prior probability hypothesis H is false;

P($E|{\sim}H$) is the prior probability of evidence E even when hypothesis H is false (Negnevitsky, 2005).

Bayes' theorem relies on knowing prior probabilities of an event to comprehend a current situation (Durkin, 1994). This is especially useful in expert systems when one thinks of the *IF THEN* statements as *IF* evidence *THEN* hypothesis. Bayesian artificial intelligence aims to create a thinking mechanism which does better than or at least equal to humans. It can also adapt to changing conditions, recognize limited knowledge, and cope well with uncertainties (Korb and Nicholson, 2004).

Two ratios used with Bayes Theorem are the likelihood of sufficiency and likelihood of necessity. The term likelihood of sufficiency is the value of the expert's belief in hypothesis H for given evidence E, represented by $LS = \frac{P(E|H)}{P(E|{\sim}H)}$. The likelihood of necessity, on the other hand, is the value of discredit of the hypothesis H if evidence E is absent, represented by $LN = \frac{P({\sim}E|H)}{P({\sim}E|{\sim}H)}$. The expert decides the likelihood of the ratios of LN and LS independently. In ruled based expert systems the probability of a hypothesis P(H) is converted into prior odds, $O(H) = \frac{P(H)}{1-P(H)}$. To obtain the posterior odds the previous statement is updated by LS, if the evidence is true, and LN, if the evidence is false, $O(H|E) = LS \times O(H)$ and $O(H|{\sim}E) = LN \times O(H)$ (Negnevitsky, 2005). From the posterior odds you can then get the posterior probabilities, which are $P(H|E) = \frac{O(H|E)}{1 + O(H|E)}$ and $(H|{\sim}E) = \frac{O(H|{\sim}E)}{1 + O(H|{\sim}E)}$, respectively. In this way, the Bayesian theory uses rules in the form of: *IF* E is true {LS, LN} *THEN* H is true {prior probability} (Negnevitsky, 2005).

2.7.4 Heuristics

The concept of heuristics originated in the 1950s and was well known by the early 1960s (Durkin, 1994). Instead of using algorithms, which perform the same operations in the same order every time, heuristics reason the answer using *IF THEN* statements. Since heuristics do not calculate the answer, the solution cannot be guaranteed to be correct, but it is a reasonable solution (Durkin, 1994). A formal definition of heuristics was given by Feigenbaum and Feldman in *Computers and Thought*, 1963.

> "A heuristic is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large search spaces. Heuristics do not guarantee optimal solutions; in fact they do not guarantee any solution at all; all that can be said for a useful heuristic is that it offers solutions which are good enough most of the time" (Feigenbaum and Feldman, 1963).

Consider the following example to illustrate the concept of heuristics. Suppose that one wants to determine if a person has a fever. The 'algorithm' approach would be to get a thermometer and measure the person's temperature. This would guarantee a solution, the temperature, and will tell whether they had a fever or not. The heuristic approach would be done in an *IF THEN* statement format. *IF* the person's head feels warm *THEN* the person has a fever. This does not guarantee a solution. For instance, the person may have been lying in the sun and that is why their head feels warm. However, the heuristic approach is a reasonable solution.

In order to solve a problem using heuristics in artificial intelligence, the problem must be broken down into: the global database, which is the main data structure; the rules, which operate on the global database; and the control strategy, which decides which rule to apply (Tzeng, 1988). In the example of a 'search-tree method', using basic algorithms, the control strategy continually searches until a goal is met. However, in many problems the domain of possible combinations for a solution can become exponential as the size of the problem increases. With an uninformed control strategy, the time to solve the solution can become considerable and the solver rendered unusable. To avoid this problem, a heuristic search method called the 'evaluation function' is used. At a given node in the search-tree, the evaluation function gives an estimate of the path from start to goal, constrained through the given node. This is the sum of the minimum path already found from start to the given node, and the estimate of the minimum path from the given node to the goal. The evaluation function therefore ranks the node at each step so the minimum path is expanded. Heuristics can be used in numerous methods as a simplification to limit the search for a solution.

2.8 Building Systems

2.8.1 Building Envelope

When analyzing buildings for energy consumption, the various buildings components are traditionally divided into systems. However, such building systems cannot be examined individually, but rather need to be looked at collectively, as each will affect the others. For example, consider the heating and cooling systems for a building. This requires a consideration of weather conditions in conjunction with the lighting, building envelope, ventilation, and occupant usage (Thumann, 2010). This is illustrated in Figure 2.6, which shows the process of heat gain in a building. Heat gains are due to: conduction through walls and roofs; transfer from the sun's radiant energy; heat infiltrating through building openings, or fenestration, like windows and doors; heat given off by appliances and lighting; and heat given off by people. In a similar way, Figure 2.7 shows the process of heat loss in a building. The difference is that now the heat exits due to conduction through walls and roofs, as heat moves from a warm body to a cold body. Also, heat is now escaping through the building openings, or through the fenestration. Both heat gain and heat loss are described in more detail in Section 4.2, Building Envelope.

The building envelope is defined as elements that enclose conditioned spaces and through which thermal energy may be transferred. Heat exchange between the envelope and the environment occurs when a temperature gradient exists across the wall. Therefore, energy is saved when the rate of heat exchange between the envelope and environment is reduced.

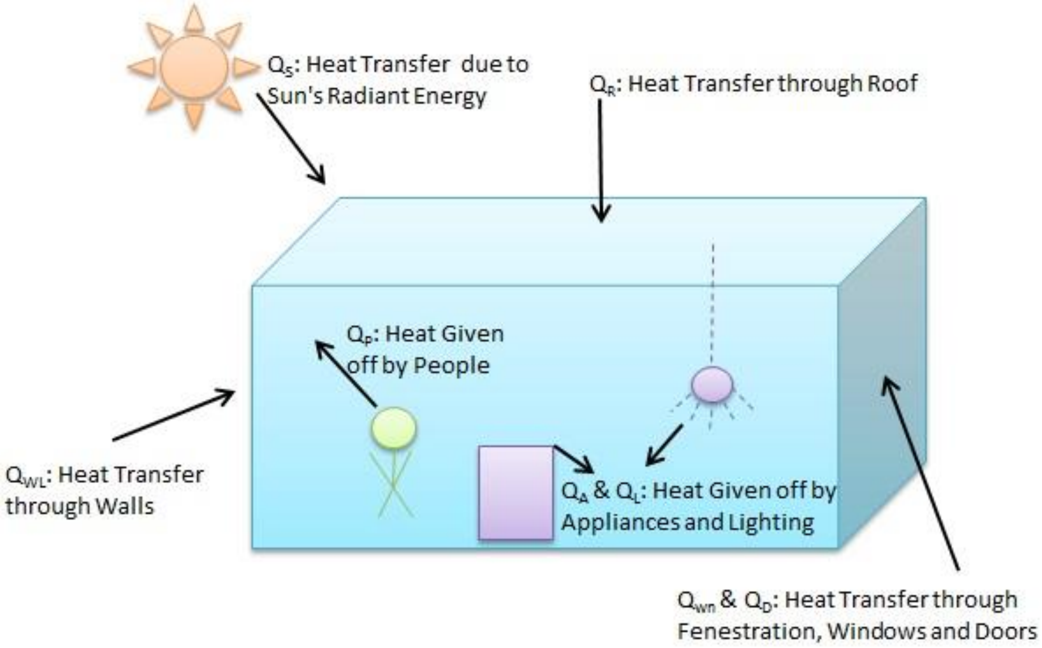


Figure 2.6 Heat gain of a building.

Source: Adapted from Thumann, A., Younger, W., & Neihus, T. (2010). *Handbook of Energy Audits* (8th ed.). Lilburn, GA: Fairmont Press.

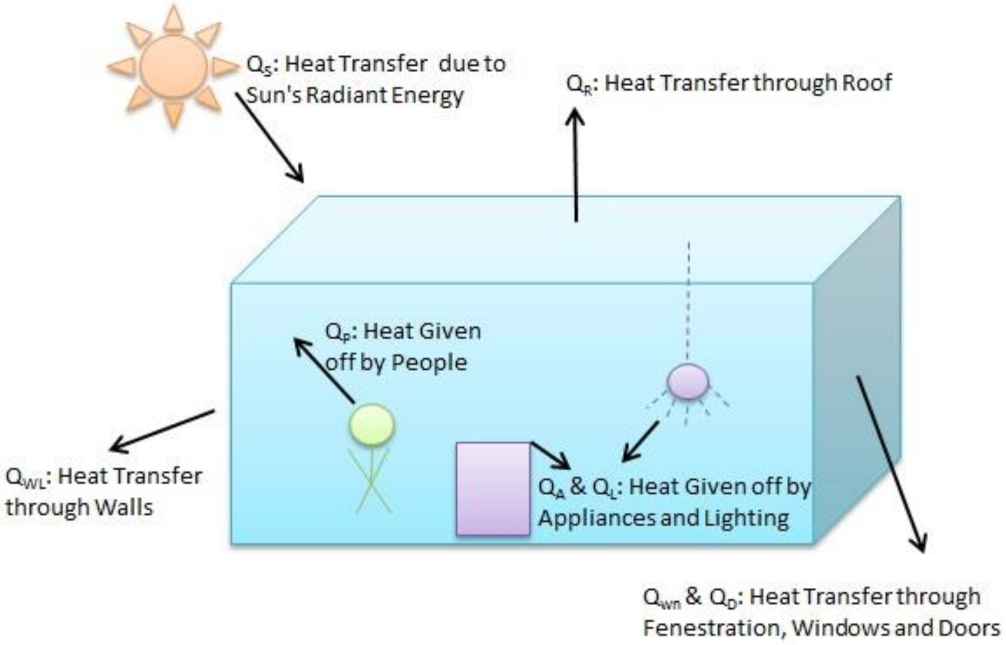


Figure 2.7 Heat loss of a building.

Source: Adapted from Thumann, A., Younger, W., & Neihus, T. (2010). *Handbook of Energy Audits* (8th ed.). Lilburn, GA: Fairmont Press.

Heat flow always moves from the hot side to the cold side. In order to compute heat gain and losses, the thermal resistance for each component, or R values, are required, as well as their square footage. The basic envelope components include the roof, walls, doors, and windows. Weather data for the area is needed as well, including the average temperature for the solar radiation. Infiltration through openings must be assessed since it can lead to a significant waste of energy (Thumann, 2010).

2.8.2 Electrical: Lighting and Appliances

A building is continually gaining heat generated by lights, appliances, and people. Therefore, one way to conserve energy is to reduce heat output of lighting and appliances. However, in colder climates, lowering this will increase your heating load. It is also important to consider the energy wasted due to inefficient lights and appliances. Switching to energy efficient lighting not only saves energy, but it reduces heat gains and maintenance costs. Installing system controls like occupancy sensors can reduce hourly usage by 30%, and daylight controls can reduce usage by 50% (Thumann, 2010).

Appliances should be turned off when not in use to reduce energy waste, as well as heat gains. For example, installing timer setbacks on vending machines ensures they are not running when the building is closed. Many appliances with a quick start feature, like televisions, are not fully off even when they have been powered off. This is called a “phantom load”, which means the device is still drawing power while it is plugged in, even though it is in the off position. To eliminate such waste, devices should be either unplugged or plugged into a power strip that turns everything off at the end of the day, thus eliminating the phantom load. Another example is to use vending machines with timer setbacks, so that they are not running when the building is closed.

2.8.3 Mechanical

The mechanical systems in a building control the heating, ventilation, and air-conditioning, or HVAC. The HVAC system maintains the desired environmental conditions within the enclosed space, including temperature, humidity, and ventilation. This is done not only for occupant comfort but also to ensure equipment does not freeze in cooler climates. HVAC systems typically include a primary and secondary system. The primary converts energy, either fuel or electricity, into heating or cooling, while the secondary delivers the heated, cooled, or ventilated air to the specified zone (ASHRAE, 2000).

Heating, ventilation and air-conditioning can account for anywhere between 45 and 80 percent of energy use in a school with the norm at 65 percent (Thumann, 2010). Energy efficiency measures, including maintenance, controls, and proper training of facilities staff, can reduce this usage and lead to significant savings.

2.8.4 Water

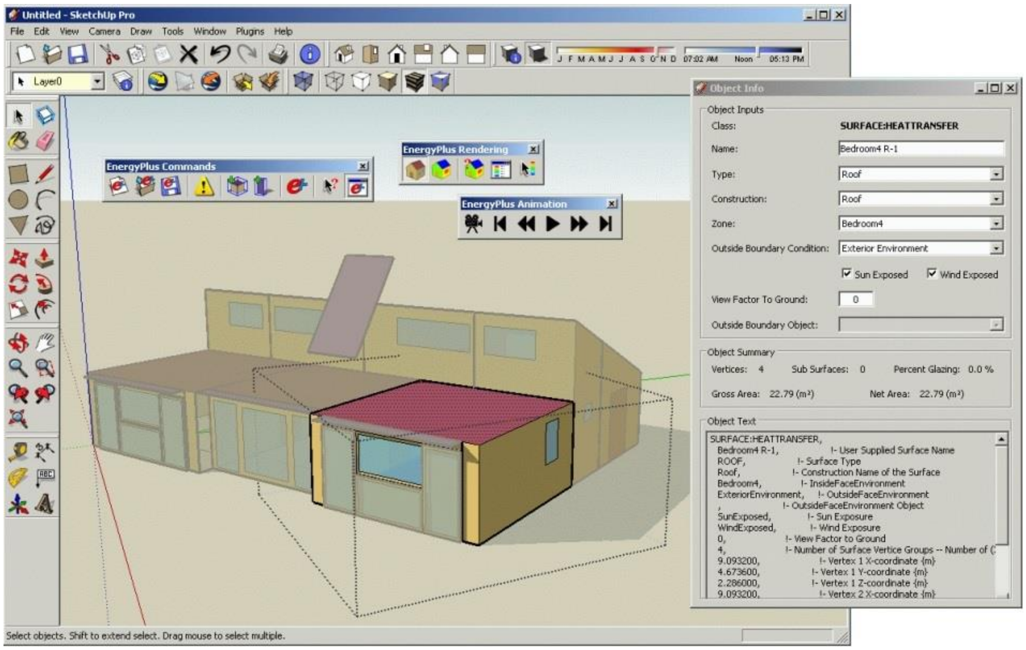
Reducing water consumption not only results in cost saving, but is an important part of achieving sustainability. Water is easily wasted through leaks and running fixtures, and maintenance is crucial to minimize such waste. Low flow plumbing fixtures also reduce the amount of water used. For example, the flow rate of non-conserving shower heads range from 3.4 to 8 gal per minute, while low flow models range from 1.9 to 2.75 gallons per minute. The average payback of low flow fixtures is just two years (Thumann, 2010). On average, a school with a cafeteria, gym and showers uses 25 gallons per student per day, while a school with only a cafeteria uses only 15 gallons per student per day (Thumann, 2010). An elementary school uses 0.6 gallons of hot water per student per day on average and high school uses 1.8 gallons of hot water per student per day (ASHRAE, 1991).

2.9 Similar Works

2.9.1 EnergyPlus

This section will discuss six computer programs that have some similarities to the proposed expert system in this research. The first is the Department of Energy's EnergyPlus program, which was originally released in April of 2001 (Crawley, 2010). The EnergyPlus program fully integrates the building envelope, HVAC, water and renewable energies and was based on earlier programs, specifically BLAST and DOE-2.1E. EnergyPlus has been used in the design of the Freedom Tower and the New York Times Building for energy simulation alternatives and energy use impacts. The program can simulate loads and perform an analysis of energy performance with low-energy technologies, including photovoltaic, at time steps of less than an hour. It can also interface with CADD, Google SketchUp 3-D and OpenStudio, as illustrated in Figure 2.8. This allows a user to create a model, or import a preexisting model. EnergyPlus does not have a 'friendly' user interface, as can be seen in Figure 2.9; instead it takes input from programs such as Google SketchUp and outputs a text file as seen in the black window with text.

EnergyPlus can approximate a building's heating, cooling, lighting, ventilation, water usage and carbon emissions. The program is primarily used during the design phase of new buildings to predict energy flow in a building. Although it is a powerful program, it can only tell the differences between the current system and a proposed change by the user. It cannot suggest a proposed system or fix a current one. The unfriendly graphical interface also requires an experienced user.



Object Inputs

Class: SURFACE:HEATTRANSFER

Name: Bedroom4 R-1

Type: Roof

Construction: Roof

Zone: Bedroom4

Outside Boundary Condition: Exterior Environment

☑ Sun Exposed ☑ Wind Exposed

View Factor To Ground: 0

Outside Boundary Object:

Object Summary

Vertices: 4 Sub Surfaces: 0 Percent Glazing: 0.0 %

Gross Area: 22.79 (m²) Net Area: 22.79 (m²)

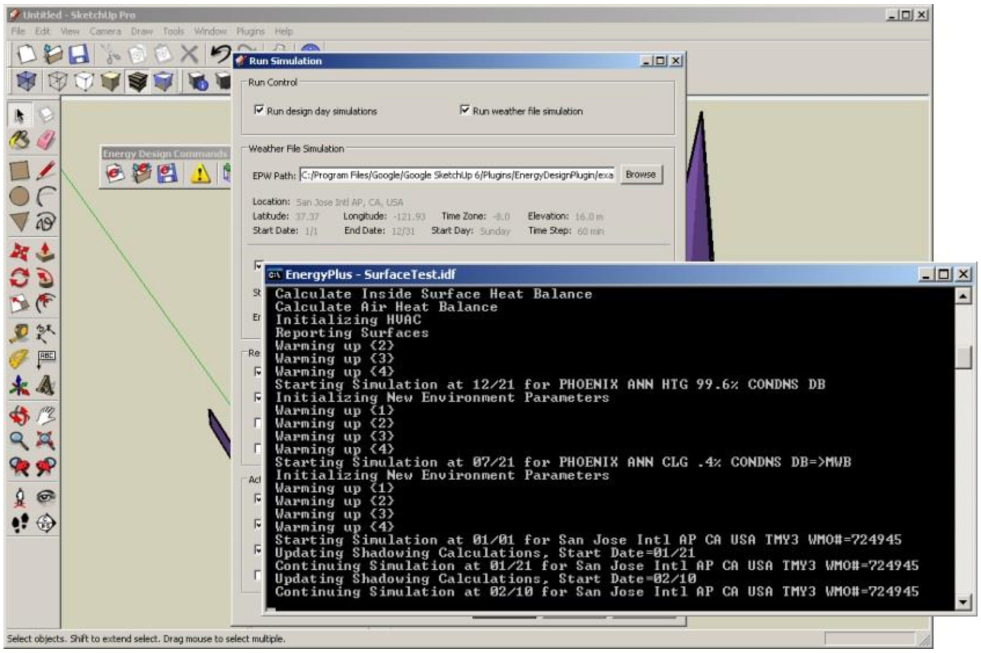
Object Text

```
SURFACE:HEATTRANSFER,
  Bedroom4 R-1,            !- User Supplied Surface Name
  ROOF,                    !- Surface Type
  Roof,                    !- Construction Name of the Surface
  Bedroom4,                !- InsideFaceEnvironment
  ExteriorEnvironment,     !- OutsideFaceEnvironment
  ,                        !- OutsideFaceEnvironment Object
  SunExposed,              !- Sun Exposure
  WindExposed,             !- Wind Exposure
  0,                       !- View Factor to Ground
  4,                       !- Number of Surface Vertice Groups -- Number of (
  9.093200,                !- Vertex 1 X-coordinate {m}
  4.673600,                !- Vertex 1 Y-coordinate {m}
  2.286000,                !- Vertex 1 Z-coordinate {m}
  9.093200,                !- Vertex 2 X-coordinate {m}
```

Select objects. Shift to extend select. Drag mouse to select multiple.

Figure 2.8 Google SketchUp used as an interface to then run the EnergyPlus program.

Source: Crawley, D. (2010, February 16). EnergyPlus: DOE's Next Generation Simulation Program. Retrieved August 31, 2013, from https://www1.eere.energy.gov/buildings/pdfs/eplus_webinar_02-16-10.pdf.



☑ Run design day simulations ☑ Run weather file simulation

EPW Path: C:/Program Files/Google/Google SketchUp 6/Plugins/EnergyDesignPlugin/exa

Location: San Jose Intl AP, CA, USA
Latitude: 37.37 Longitude: -121.93 Time Zone: -8.0 Elevation: 16.0 m
Start Date: 1/1 End Date: 12/31 Start Day: Sunday Time Step: 60 min

```
Calculate Inside Surface Heat Balance
Calculate Air Heat Balance
Initializing HVAC
Reporting Surfaces
Warming up {2}
Warming up {3}
Warming up {4}
Starting Simulation at 12/21 for PHOENIX ANN HTG 99.6% CONDNS DB
Initializing New Environment Parameters
Warming up {1}
Warming up {2}
Warming up {3}
Warming up {4}
Starting Simulation at 07/21 for PHOENIX ANN CLG .4% CONDNS DB=>MWB
Initializing New Environment Parameters
Warming up {1}
Warming up {2}
Warming up {3}
Warming up {4}
Starting Simulation at 01/01 for San Jose Intl AP CA USA TMY3 WMO#=724945
Updating Shadowing Calculations, Start Date=01/21
Continuing Simulation at 01/21 for San Jose Intl AP CA USA TMY3 WMO#=724945
Updating Shadowing Calculations, Start Date=02/10
Continuing Simulation at 02/10 for San Jose Intl AP CA USA TMY3 WMO#=724945
```

Figure 2.9 Google Sketchup with EnergyPlus program running.

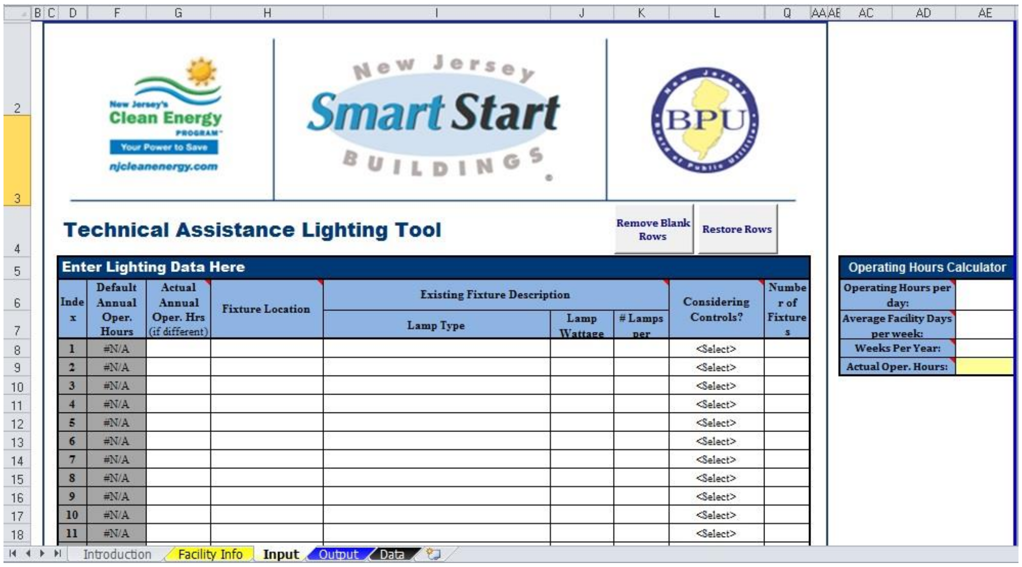
Source: Crawley, D. (2010, February 16). EnergyPlus: DOE's Next Generation Simulation Program. Retrieved August 31, 2013, from https://www1.eere.energy.gov/buildings/pdfs/eplus_webinar_02-16-10.pdf.

2.9.2 ESIP

Under New Jersey law, government agencies can make energy improvements to their facilities and seek reimbursement for initial installation costs of the upgrades. All local government agencies are eligible, including administrative units, schools, universities, and non-profits. To participate, the agency hires an energy auditing firm from the list of pre-qualified firms, who follow the New Jersey's Clean Energy Program guidelines (Energy, 2013). New Jersey's Clean Energy Program then covers 100% of the cost of the audit. When the audit is complete, the participant receives a list of recommended energy efficient upgrades that reduce expenses, as well as improve health and productivity. Some of the upgrades are eligible for incentives though the NJ SmartStart Buildings Program, Direct Install or Pay for Performance. Participants of the Clean Energy

Program can then take advantage of the initiatives up to an annual incentive cap at $100,000 per year, per agency (Energy, 2013).

New Jersey's Clean Energy Program has sector specific technical assistance tools to aid in the analysis of lighting, motors, HVAC, and variable frequency drives. These technical assistance tools, which are available on the ESIP website, calculate energy use and cost savings for replacing these pieces of equipment with energy efficient technologies (Energy, 2013). A screenshot of the lighting tool can be seen in Figure 2.10. A limitation of this program it that is considers components of the building individually and does not analyze the total building system. For example, it will indicate that energy efficient lamps reduce heat gain. But, it does not analyze the effect on the total heat gain and loss of the building.



Technical Assistance Lighting Tool

Enter Lighting Data Here

Index	Default Annual Oper. Hours	Actual Annual Oper. Hrs (if different)	Fixture Location	Existing Fixture Description			Considering Controls?	Number of Fixtures
				Lamp Type	Lamp Wattage	# Lamps per		
1	#N/A						<Select>	
2	#N/A						<Select>	
3	#N/A						<Select>	
4	#N/A						<Select>	
5	#N/A						<Select>	
6	#N/A						<Select>	
7	#N/A						<Select>	
8	#N/A						<Select>	
9	#N/A						<Select>	
10	#N/A						<Select>	
11	#N/A						<Select>	

Operating Hours Calculator	
Operating Hours per day:	
Average Facility Days per week:	
Weeks Per Year:	
Actual Oper. Hours:	

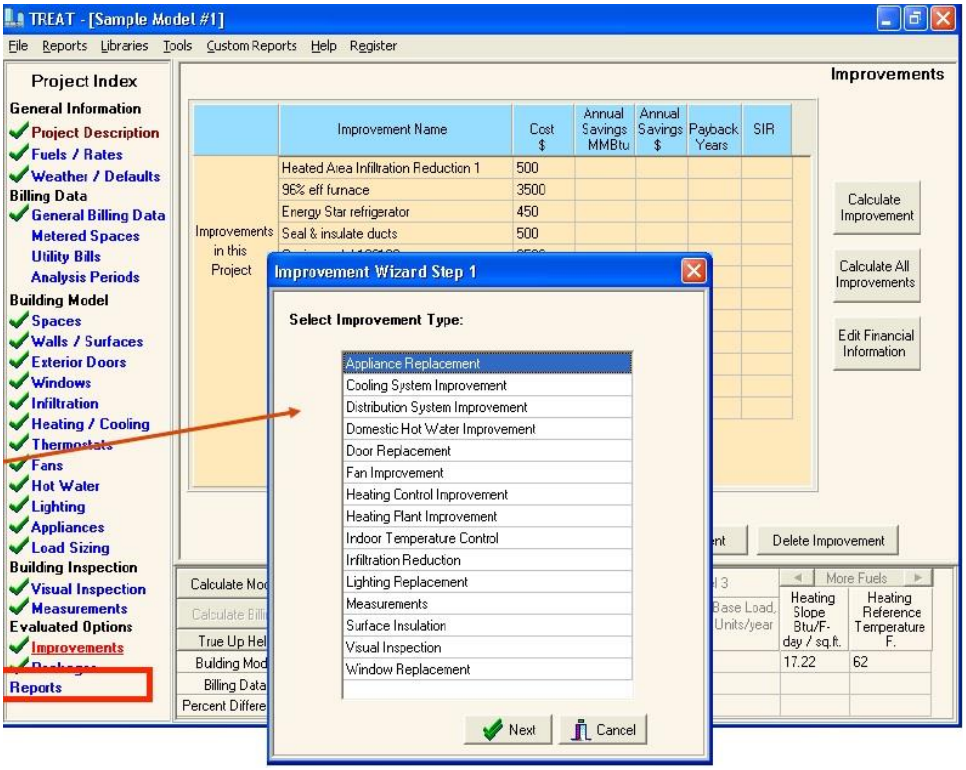
Figure 2.10 ESIP screenshot run through Microsoft Excel program.

Source: Energy Savings Improvement Program. (n.d.). Retrieved February 25, 2013, from http://www.njcleanenergy.com/commercial-industrial/programs/energy-savings-improvement-program.

2.9.3 TREAT

The company, Performance Systems Development, created the program TREAT, which stands for Targeted Retrofit Energy Analysis Tool. It performs residential audits for energy analysis and building modeling. The program has won numerous awards, including the 2005 R&D 100 Award from R&D Magazine (TREAT, 2012). TREAT has been approved by the HERS BESTEST and the Department of Energy. HERS BESTEST is a verification procedure developed by the National Renewable Energy Laboratory to determine the accuracy and effectiveness of the energy prediction software. TREAT is the only energy audit software approved by the Department of Energy for residential housing. It includes extensive material libraries for single and multi-family housing and features the ability to project savings for combined retrofits.

While the program has an extensive library of materials and can complete a very thorough audit of a home, it is limited when considering improvements. The user has to select them from a general improvement library as shown in Figure 2.11. The program then calculates the difference between the original and the improved building. It does not suggest areas for improvement, however. This is the same limitation as the EnergyPlus program. It is a powerful program to complete an audit and compare retrofits, but it does not have the intelligence to suggest applicable retrofits.



	Improvement Name	Cost $	Annual Savings MMBtu	Annual Savings $	Payback Years	SIR
Improvements in this Project	Heated Area Infiltration Reduction 1	500				
	96% eff furnace	3500				
	Energy Star refrigerator	450				
	Seal & insulate ducts	500				

Select Improvement Type:

- Appliance Replacement
- Cooling System Improvement
- Distribution System Improvement
- Domestic Hot Water Improvement
- Door Replacement
- Fan Improvement
- Heating Control Improvement
- Heating Plant Improvement
- Indoor Temperature Control
- Infiltration Reduction
- Lighting Replacement
- Measurements
- Surface Insulation
- Visual Inspection
- Window Replacement

Heating Slope Btu/F-day / sq.ft.	Heating Reference Temperature F.
17.22	62

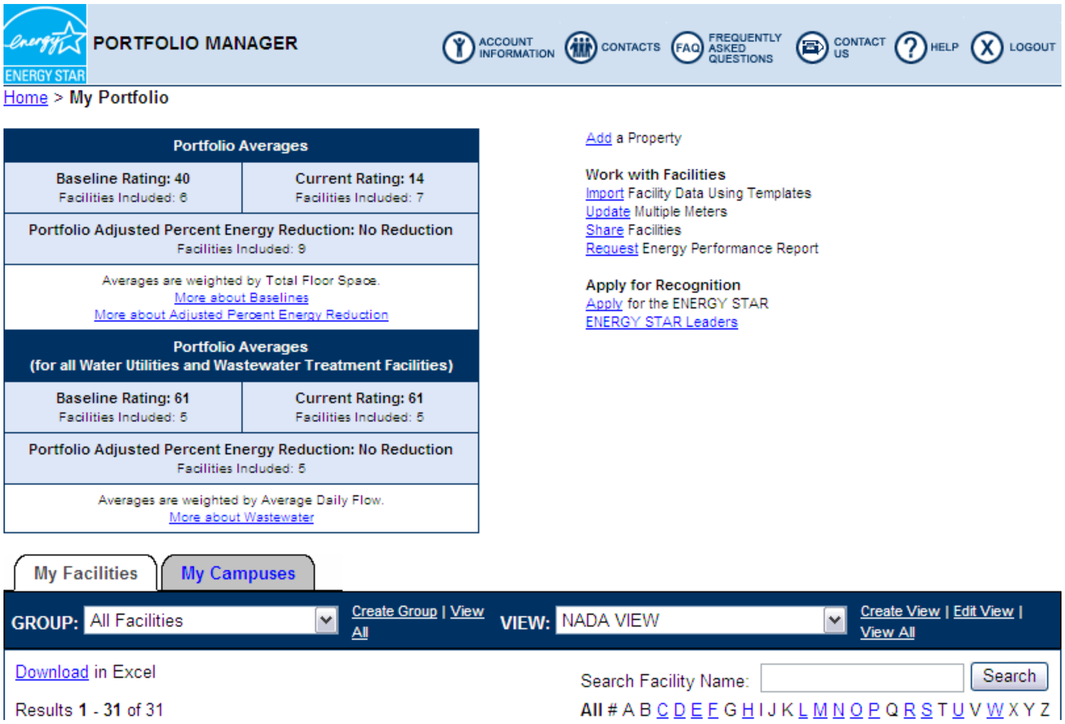
Figure 2.11 Screenshot of the TREAT program.

Source: Treat Software: Performance Systems Development. (n.d.). Retrieved December 14, 2012, from http://psdconsulting.com/software/treat/.

2.9.4 ENERGY STAR® Portfolio Manager

The Department of Energy has created a program called ENERGY STAR® Portfolio Manager, which allows a user to track and asses energy and water consumption. The program establishes a baseline of energy performance, sets goals for energy performance, ranks investments, and measures and verifies improvements, financially and environmentally. It has earned recognition from the Environmental Protection Agency and Building Owners and Managers Association (Benchmark, 2013). The program benchmarks where a building currently stands as compared to similar buildings by generating a score or “rating” as seen in Figure 2.12. The rating ranges from 0-100 and states where the building's energy use stands as compared to similar buildings. A rating of 50 is average, while a 75 and above signifies top performance. The DOE's rating system takes into account the building's size, location, occupancy and number of computers (Benchmark, 2013).

This program is a valuable tool for comparing energy efficiency of various buildings to determine which buildings offer the best opportunities for improvement. Also, it is helpful in tracking energy efficient measures to see how well they are working. It does take into account size, location and other properties in order to assure that comparisons are made to equivalent or very similar buildings. However, this program does not perform an energy audit, but rather it tracks usage from utility bills.



Portfolio Averages	
Baseline Rating: 40 Facilities Included: 6	Current Rating: 14 Facilities Included: 7
Portfolio Adjusted Percent Energy Reduction: No Reduction Facilities Included: 9	
Averages are weighted by Total Floor Space. More about Baselines More about Adjusted Percent Energy Reduction	

Portfolio Averages (for all Water Utilities and Wastewater Treatment Facilities)	
Baseline Rating: 61 Facilities Included: 5	Current Rating: 61 Facilities Included: 5
Portfolio Adjusted Percent Energy Reduction: No Reduction Facilities Included: 5	
Averages are weighted by Average Daily Flow. More about Wastewater	

Add a Property

Work with Facilities
Import Facility Data Using Templates
Update Multiple Meters
Share Facilities
Request Energy Performance Report

Apply for Recognition
Apply for the ENERGY STAR
ENERGY STAR Leaders

GROUP: All Facilities | Create Group | View All
VIEW: NADA VIEW | Create View | Edit View | View All

Download in Excel
Search Facility Name:
Results 1 - 31 of 31
All # A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

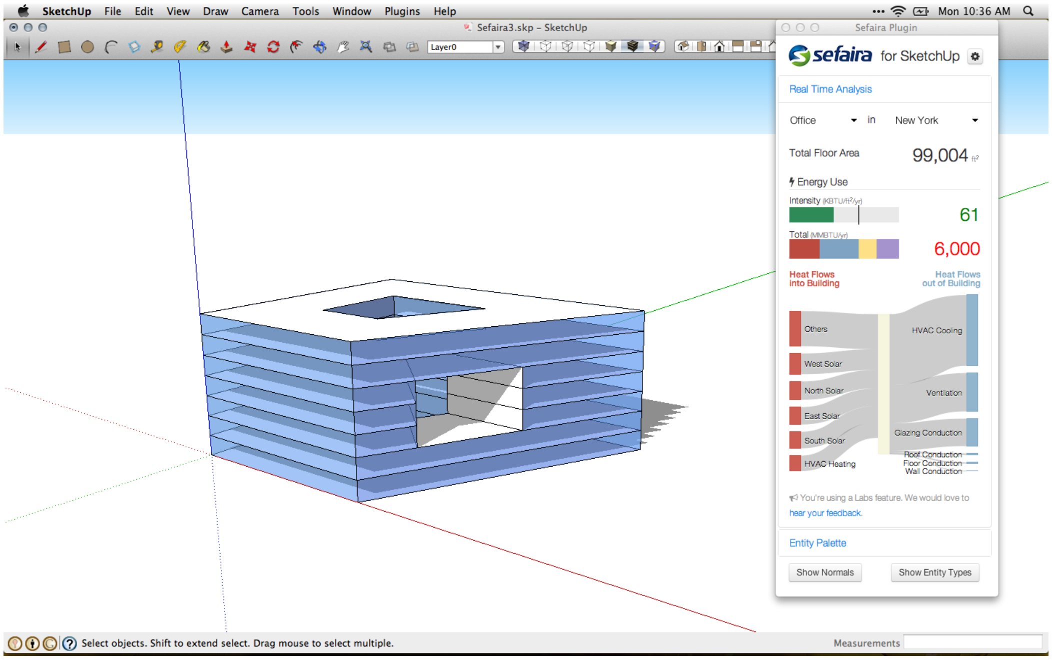
Figure 2.12 Screenshot of ENERGY STAR® Portfolio Manager program.

Source: Benchmark with EPA's Energy Star Portfolio Manager. (n.d.). Retrieved February 25, 2013, from http://www.energystar.gov/ia/partners/reps/ci_program_sponsors/downloads/Portfolio_Manager_Fact_Sheet.pdf.

2.9.5 Sefaira

Sefaira is a program that provides constant feedback on energy usage while creating a design in either Revit or Google's Sketchup. Computing is performed in the cloud to allow for faster results and allow access by multiple users. Built primarily for architects in the early design stages, the friendly user interfaces allows non-experts an ease of results.

Some of the parameters are shown in bar charts to allow quick feedback to the user. For example, Energy Use Intensity, or EUI, bar chart allows the user to see how it would compare to other buildings if the user has the respective EUI. Another is the Energy Use Breakdown bar chart, which allows the user to identify the biggest energy consumer in the designed building. Lastly, the Heat Flow Diagram can be used to modify the design to improve building performance (Sterner, 2013).



Office in New York

Total Floor Area 99,004 ft²

Intensity (KBTU/ft²/yr) 61

Total (MMBTU/yr) 6,000

You're using a Labs feature. We would love to hear your feedback.

Select objects. Shift to extend select. Drag mouse to select multiple.

Figure 2.13. Google's Sketchup platform with the Sefaira window showing energy usages.

Source: Sterner, C. (2013, October 30). Sefaira for SketchUp: Three Steps to Better Performance. Retrieved January 24, 2014, from http://sefaira.com/resources/sefaira-for-sketchup-three-steps-to-better-performance.

Although the tool can be very helpful during the design stage of a building, it is not recommended for existing construction. For example, the tool can evaluate which side of a building should have less glazing, improved glazing or even whether the building should be rotated. These, of course, would not be feasible strategies for an existing building. Also the software does not suggest areas of improvements or where the improvements could be made.

2.9.6 BuildingIQ

BuildingIQ is cloud based software to reduce HVAC costs in commercial buildings. It delivers between 10 and 25 percent savings which can add up to 20 points on a LEED score. BuildingIQ was founded by Michael Zimmerman in 2009. The software uses data from past meter reads or building management systems (BMS). If field measurements cannot be made, the evaluators can use historical data or engineering judgment. The cloud based software allows for real time analyses of sensors, meters and weather data, which are normalized for weather, occupancy and day type (i.e. weekend vs workday). It then makes small changes to the HVAC settings that result in financial gains without affecting occupant comfort. It has a monthly subscription fee which is based on owners expenses (Measurement, 2013).

BuildingIQ has received numerous awards including the 2013 Global Cleantech 100 Report, which recognizes the top 100 innovative and promising companies. The program was also the 2013 New Energy Pioneer Winner - Bloomberg New Energy Finance for innovative proven technologies, and it also receives the 2010 AIRAH Award for Excellence in Innovation, which recognizes achievements in the industry of HVAC (Measurement, 2013).

Building IQ is a strong software that accomplishes a reduction in HVAC costs by allowing a third party to alter HVAC setting and optimize usage. It does not, however, recommend areas to improve efficiency. It also does not look into other building factors to make a building more sustainable.

	Energy Cost ($)	Energy Usage (kWh)
Baseline	$ 94,045.29	783,711
Actual	$ 79,349.12	661,243
Savings	$ 14,696.17	122,468
Percentage		**15.63 %**

Figure 2.14 Screenshot of the BuildingIQ online savings dashboard.

Source: Measurement and Verification Functionality of the BuildingIQ System. (2013, January 1). Retrieved January 24, 2014, from http://www.buildingiq.com/wp-content/uploads/2013/10/BIQ_MeasurementVerification_WP.pdf.

CHAPTER 3

RESEARCH OVERVIEW

3.1 Research Objectives

The objective of this research was to develop an expert system using the science of heuristics to better model energy usage in buildings and to predict the benefit of future energy improvements more accurately. The software performs an initial audit analysis of all the major auditing categories including building envelope, HVAC, lighting, office equipment and appliances, water and hot water, and waste handling (see Figure 3.1). A novel feature of the expert system is that it analyzes energy flow and usage within the building more interactively and cohesively, as opposed to looking at each as individual parts.

During the auditing process, the software queries about user habits and system controls, during this process, to understand occupant behavior, which can have a significant effect on actual energy usage. Responses are analyzed to develop heuristic factors which are applied to the results of the audit analysis. This ensures that energy usage is modeled as it is used and operated, as opposed to how it was designed, which can differ significantly. The end goal is to achieve a more realistic and sustainable total building system.

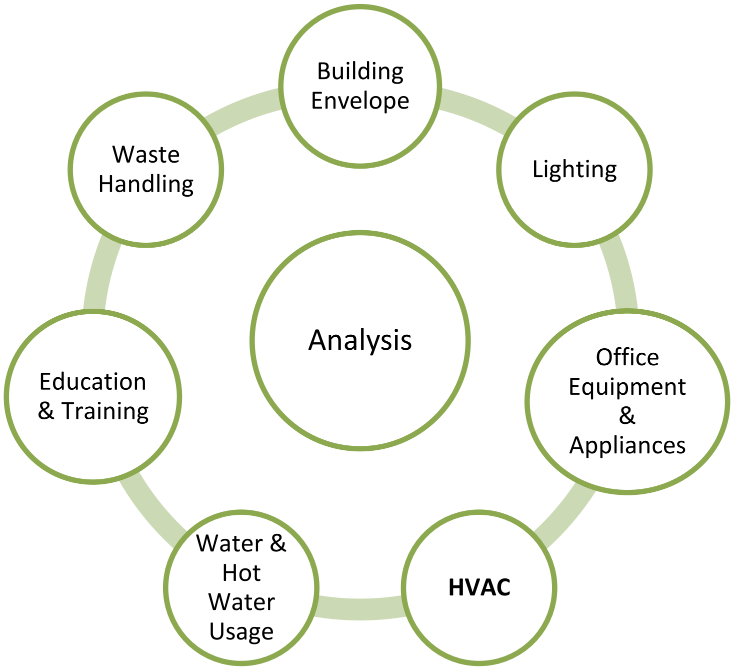


Figure 3.1 Diagram showing major category components of the Expert System.

Once all the audit data are input, the expert system performs a synchronization step to converge calculated energy with actual consumption from the utility bills, so that energy efficiency is optimized in the target building. The software generates a list of recommended upgrades that are prioritized by cost, ease of implementation, and projected energy savings. These recommendations are then broken down into three levels. The first level includes immediate quick fixes with no or low cost. The second level includes recommendations with a simple payback of two years or less that should be fixed when convenient, like over a summer closure or when a majority of the maintenance occurs. The third recommendation level includes capital improvements that require longer implementation, higher investment, and, therefore, a longer payback period.

Sustainable and resilient strategies are also recommended by the system, since it is becoming increasingly important that a building not only be “green” but also be resilient in the face of a disaster, natural or otherwise. It also identifies and directs the education and training needs for the building occupants.

The expert system has been tested and calibrated with selected buildings in the Newark Public Schools district. The Newark district, which includes 79 schools, provided ideal test cases given the wide range of building age, size, and construction type, as well as extremes of heating and cooling loads associated with the Northeast climate.

3.2 Research Significance

Evaluating the energy efficiency of an existing building is in some ways more complex than for new construction. An energy audit needs to be performed first. Audits consist of information gathering, analysis, and proposed actions that have been evaluated for technical and economic feasibility (Escriva, 2012). Optimally, energy audits should be completed over the course of one year, not just a particular moment in time. At a minimum, the methodology should cover the main energy consuming services in buildings including: the envelope, HVAC systems, lighting and equipment (Perez-Lombard, 2011). Other factors that should be considered are the building type and environmental conditions (Escriva, 2012).

Audits are helpful, but many experts believe there needs to be a better method to decipher the energy efficiency of buildings. According to Martinaitis (2007), there is a need for “an appraisal methodology for building renovation and energy efficiency improvement projects (or a set of methods) which makes sense for most stakeholders and at the same time takes into account societal interests such as protection of the environment, public health and social cohesion."

This research aimed to not only create a more effective and accurate energy auditing tool for a building, but also to suggest areas of improvements which leads to a more sustainable and resilient building. No other program currently known is able to recommend and rank improvements by ease of implementation, initial cost and payback period, thus allowing building owners and operators to make better decisions.

3.3 Originality of Research

There are three significant aspects of this work that make it original. These are the cohesiveness of the energy flow analysis, the use of heuristics to model building energy systems, and synchronization of calculated with actual energy usage. Each of these original aspects will now be described.

A novel feature of the expert system is the ability to model all systems of the building interactively and more cohesively. This allows a more accurate characterization of the energy flow throughout the building, as opposed to looking at each individual system. This approach also leads to better energy efficiency through sustainable and resilient strategies. In addition, the data libraries in the program are easily modified to model to any number of weather regions and building types.

The second original aspect of the research is the use of heuristics, which have a two-fold role in the analysis. First, heuristics are able to evaluate current user habits and systems controls to develop better estimates of future savings from improvements. For example, a query might reveal what controls are in place and, even more importantly, how the controls are used, if at all. Heuristics also help determine how the energy is being consumed. For instance, a query of the user habits may reveal leaks in the building envelope, e.g., windows left open leading to higher heating loads. The results of such queries are used to generate heuristic factors for the target building. A detailed discussion of how heuristics are used in the expert system is presented in Chapter 5.

The third aspect of research originality is a synchronization step that converges the calculated energy usage with actual consumption form the utility bill. The synchronization adjustments are weighted heuristically among the various building systems. The result is a realistic model of actual energy consumption throughout the building, which allows for more accurate energy savings predictions from improvements. The synchronization process is discussed in further detail in Chapter 6.

3.4 Model Overview of the Expert System

The model that drives the expert system is shown schematically in Figure 3.2. There are eight basic components that require input data to perform the initial audit. The first component is ‘General Features’ which includes occupancy information, utility billing data, address, and enrollment. ‘Building Envelope’ addresses walls, roofing and fenestration, as well as the R values associated with each. ‘HVAC’ involves an equipment inventory of heating, cooling, ventilation and exhaust equipment along with distribution types and ages. ‘Lighting’ includes fixture wattage, quantity and location. ‘Office Equipment and Appliances’ includes equipment quantity and wattage. ‘Water and Hot Water’ includes types and quantity of plumbing fixtures, as well as swimming pools and lawn irrigation. ‘Waste Handling’ examines various categories of recycling and waste collected and the frequency at which they are collected. Finally, ‘Education and Training’ evaluates ongoing programs for students and staff. Data necessary for each of

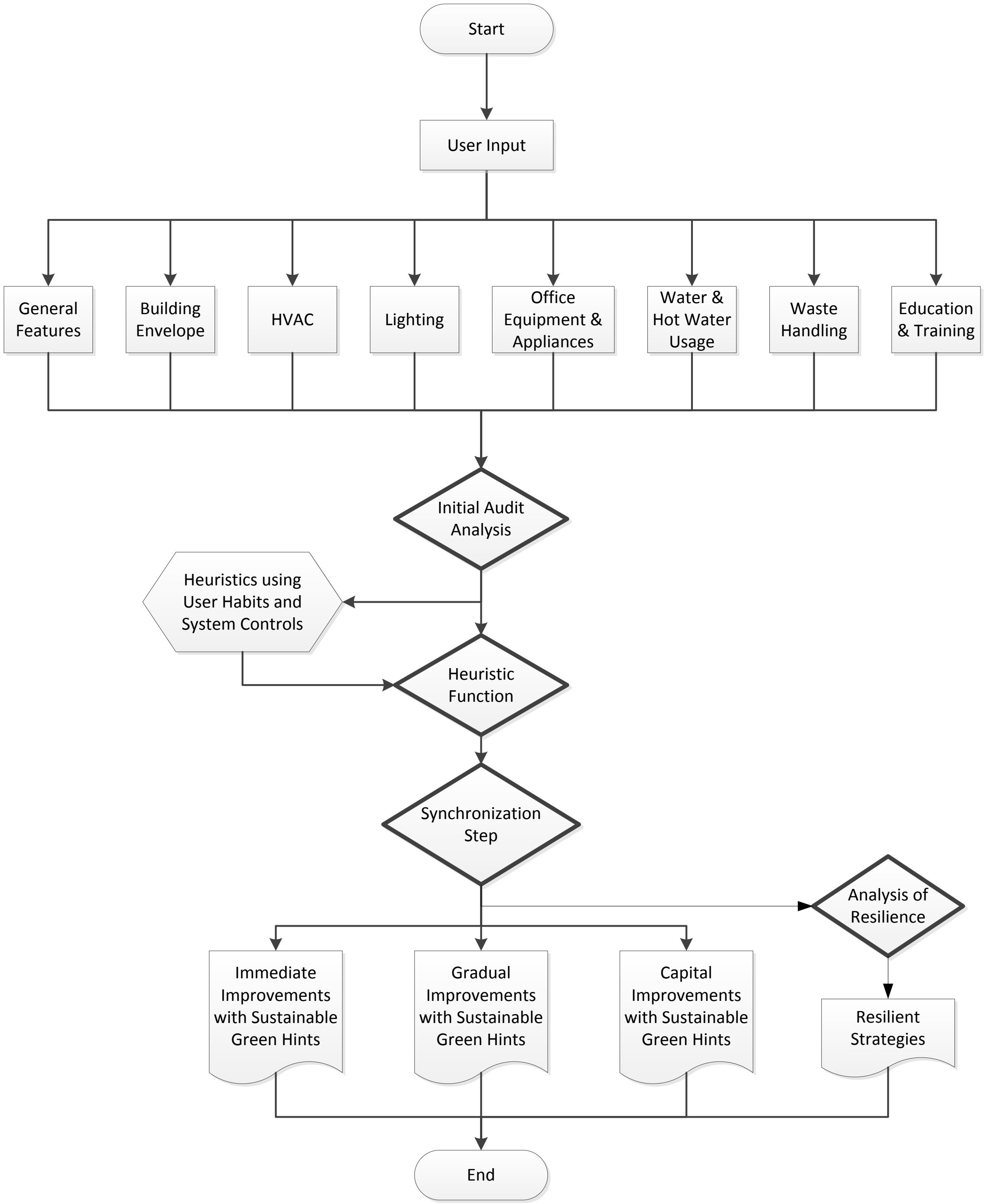


Figure 3.2 Model overview of Expert System.

these components is input by the user on successive screens. The user is able to print data sheets to facilitate data input since the sheets match the program format exactly.

After all the necessary data are entered, the model then performs the ‘Initial Audit Analysis’. This includes an analysis of each component, as well as an overall comparative analysis. For example, lighting component will yield computed current total usage, how the building compares to average usage, and heat generated by the system for input into other systems. In this way, everything in the building and the building itself is accounted for.

Most component categories also involve a query of user habits and system controls. This input is required for the ‘Heuristic Function’ to better gauge how building users affect energy usage. This allows a more accurate prediction of future usage, as well as the performance of recommended improvements.

Once the ‘Initial Audit Analysis’ and ‘Heuristic Function’ are completed, a ‘Synchronization’ step is performed. The purpose of this step is to resolve inevitable differences between estimated energy usage from the audit and actual energy usage from the billing data. This assures for more accurate prediction of energy savings.

Finally, after all analyses and synchronizations are completed, the expert system generates a summary energy consumption analysis and recommendations of ways to increase energy efficiency within the building. The summary energy consumption analysis includes the utilities followed by the modules. Each module can then be expanded for monthly view. The usage, cost, and percent cost are shown, as well as, a comparison of use per square foot to industry standards. These are broken down into three categories based on cost and ease of implementation. The three categories are immediate, gradual and capital improvements. Selected improvements are accompanied by “green hints,” which are aimed at achieving more sustainable solutions. In addition, “resilient strategies” are given, to make the building more able to function in times of emergency.

3.5 Programming Language Structure

A few different programming softwares were considered to code the expert system. Microsoft’s Visual Studio 2012 was initially investigated. However, after some development time, it was determined that successful use the software requires a significant background in computer programming.

Microsoft Excel 2013 was then chosen to program the expert system. Excel 2013 is a powerful spreadsheet program with macro programming capabilities. These key features proved very satisfactory to support the numerous forward and backward chaining calculations required for the expert system to perform properly. Several other features that made excel a good choice include:

- A data validation tool that ensures proper values are entered by the user. The program also gives data input instructions.
- Drop down menus that facilitate user choices in various system areas including lighting fixtures, material properties and queries of user habits and system controls.
- The ‘vlookup’ tool that matches the numerous data libraries with the drop down menus. In addition, the data libraries, which are shown in Appendix A, can be easily modified by the user to account for various building types and regions.
- Pivot tables that allow the user to easily look through numerous views of the model results, e.g., utility type, module, and yearly and monthly summaries.
- Filter features that lead the user to view recommendations by module or level of improvement.

CHAPTER 4

MODEL DEVELOPMENT

4.1 Global Computational Analysis for Optimization

The Expert System evaluates and optimizes energy usage in a building using a global computational analysis which is comprised of three major subprograms: Initial Audit Analysis; Heuristic Function; and Synchronization Step (refer to Figure 4.1). These subprograms initially receive and analyze input data separately to produce interim results. The global analysis routine then takes over, guiding each of the subprograms to interact and recompute as needed to achieve an optimized model of current energy usage of all building systems in the facility. The global analysis also generates recommendations for reducing energy usage, including hints for enhancing sustainability and resilience.

The various system components of the Initial Audit Analysis subprogram are described in the remaining sections of this chapter. The Heuristic Function is next detailed in Chapter 5, and the Synchronization Step follows in Chapter 6.

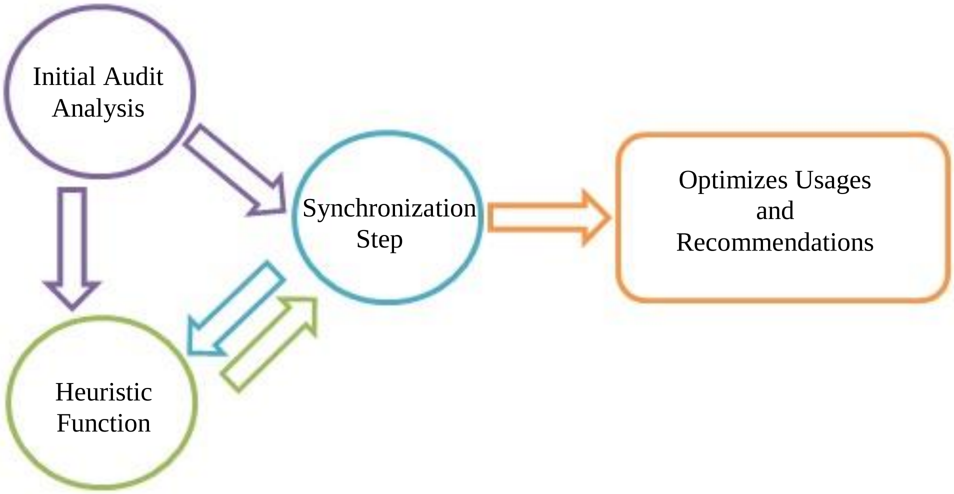


Figure 4.1 The global computational analysis for optimization process.

4.2 Building Envelope

The building envelope component is the most complex building system to analyze given the numerous factors that it encompasses. Diligence is warranted, though, since this component has a large effect on the energy requirement for the HVAC system. The building envelope component takes into account all of the heat transfer between the outside environment and the conditioned space.

The heat mechanisms involved can be seen in Figure 4.2, which are heat transfer through walls and roofs, heat transfer due to the Sun's radiant energy, heat transfer through fenestration, heat gain from lighting and appliances, and heat given off by people. The total heat gain of a building may be defined by summing the heat generated by each of these mechanisms as given in Equation 4.1(adapted from Thumann, 2010). Note that total heat gain is used to determine cooling loads for HVAC.

$$Total\ Heat\ Gain = Q_G \tag{4.1}$$

$$= (Q_{WL} + Q_R) + Q_S + (Q_{WN} + Q_D) + (Q_L + Q_A) + Q_P$$

where Q_{WL}: heat transfer due to conduction through walls and floors (Btu/hr)

Q_R: heat transfer due to conduction through the roof (Btu/hr)

Q_S: heat transfer due to the Sun's radiant energy (Btu/hr)

Q_{WN}: heat infiltrating through windows (Btu/hr)

Q_D: heat infiltrating through doors (Btu/hr)

Q_L: heat given off by lighting (Btu/hr)

Q_A: heat given off by appliances (Btu/hr)

Q_P: heat given off by people (Btu/hr)

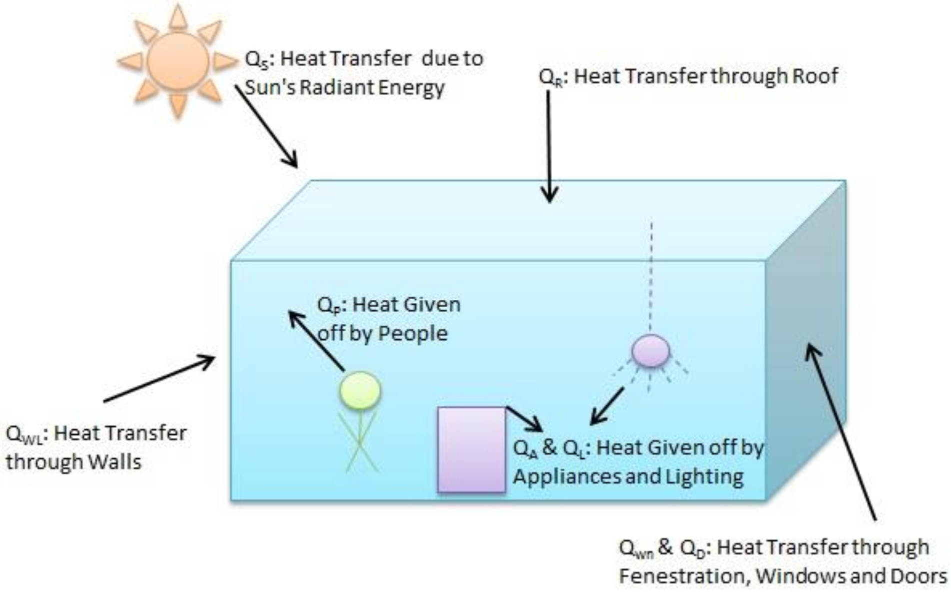


Figure 4.2 Heat gain of a building.

Source: Adapted from Thumann, A., Younger, W., & Neihus, T. (2010). *Handbook of Energy Audits* (8th ed.). Lilburn, GA: Fairmont Press.

Heat loss through the building envelope is also of interest and is used to estimate heating loads. Total heat loss is defined using the same mathematical terms, except some terms such as lighting are subtracted since they contribute heat, thereby reducing heating requirements.

$$Total\ Heat\ Loss = Q_O$$

$$= (Q_{WL} + Q_R) - Q_S + (Q_{WN} + Q_D) - (Q_L + Q_A) - Q_P \qquad (4.2)$$

The solution of Equations 4.1 and 4.2 requires that the heat for each of the component terms be determined. These are computed using the following equations:

Heat gain through walls:

$$Q_{WL} = U \times A \times \Delta T \qquad (4.3)$$

where U: conductance of the material (Btu/hr/ft^2/^{o}F)

A: wall area (ft^2) = Gross Surface Area – fenestration

ΔT: outdoor average– indoor average temperature (^{o}F)

Heat gain through roof:

$$Q_R = U \times A \times \Delta T \tag{4.4}$$

where U: conductance of the material (Btu/hr/ft^2/^{o}F)

A: area of the roof (ft^2)

ΔT: outdoor average – indoor average temperature (^{o}F)

Heat transfer due to the Sun's radiant energy:

$$Q_S = Q_2 \times 0.6A \times \frac{1\,month}{days\ in\ month} \times \frac{1\,day}{24\ hours} \tag{4.5}$$

where Q_2: solar radiation (Btu/ft^2)

A: surface area of the building (ft^2)

Heat gain through windows:

$$Q_{WN} = U \times A \times \Delta T \times SHGC \times IAC \tag{4.6}$$

where U: conductance of the material (Btu/hr/ft^2/^{o}F)

A: window area (ft^2)

ΔT: outdoor average– indoor average temperature (^{o}F)

SHGC: Solar Heat Gain Coefficient (dimensionless)

IAC: Interior Solar Attenuation Coefficient (dimensionless)

Heat gain through doors:

$$Q_D = U \times A \times \Delta T \tag{4.7}$$

where U: conductance of the material (Btu/hr/ft^2/^{o}F)

A: door area (ft^2)

ΔT: outdoor average– indoor average temperature (^{o}F)

Heat given off by lighting:

$$Q_L = 3.41W \times F_{ul} \times F_{sa} \tag{4.8}$$

where 3.41: (Btu/hr / 1 Watt)

W: total wattage per fixture type (Watt)

F_{ul}: lighting use factor (dimensionless)

F_{sa}: lighting special allowance factor (dimensionless)

Heat given off by appliances:

$$Q_A = qt \ \times q \tag{4.9}$$

where qt: quantity of appliance

q: heat gain from appliance (Btu/hr)

Heat given off by people:

$$Q_P = q_A \times Staff + \ q_C \times Enrollment \tag{4.10}$$

where q_A: heat gain from adults (Btu/hr)

q_C: heat gain from children (Btu/hr)

The flowchart for Building Envelope component of the model is shown in Figure 4.3. First, the user inputs the material type and area for each of the envelope elements. (The Building Envelope input screenshots are shown in the Appendix B.) In order for the expert system to perform the analysis of the Building Envelope, it will need input from other modules including the General Building Features, Lighting, and Office Equipment & Appliances. The General Building Features module furnishes the zip code of the building, operation hours, and occupancy. This allows the expert system to call needed values of outside temperature and heat from people from a Data Library. For the

Lighting input, the program calls from the Data Library the total wattage per fixture type to compute heat gain from the lamps, with corresponding safety allowance and lighting use factors. Finally, the Office Equipment and Appliances input requires the quantity of each type of fixture, so the expert system can call for particular energy for each appliance. The System Controls and User Habits component will work with the Heuristic Function in order to better determine the actual usage and recommended improvements.

Once all the data has been input and information received from the other input modules and data libraries, the building envelope analysis is performed using Equations 4.1 through 4.10. The output document for the Building Envelope analysis will provide total heat gain, total heat loss and estimate of building leakage.

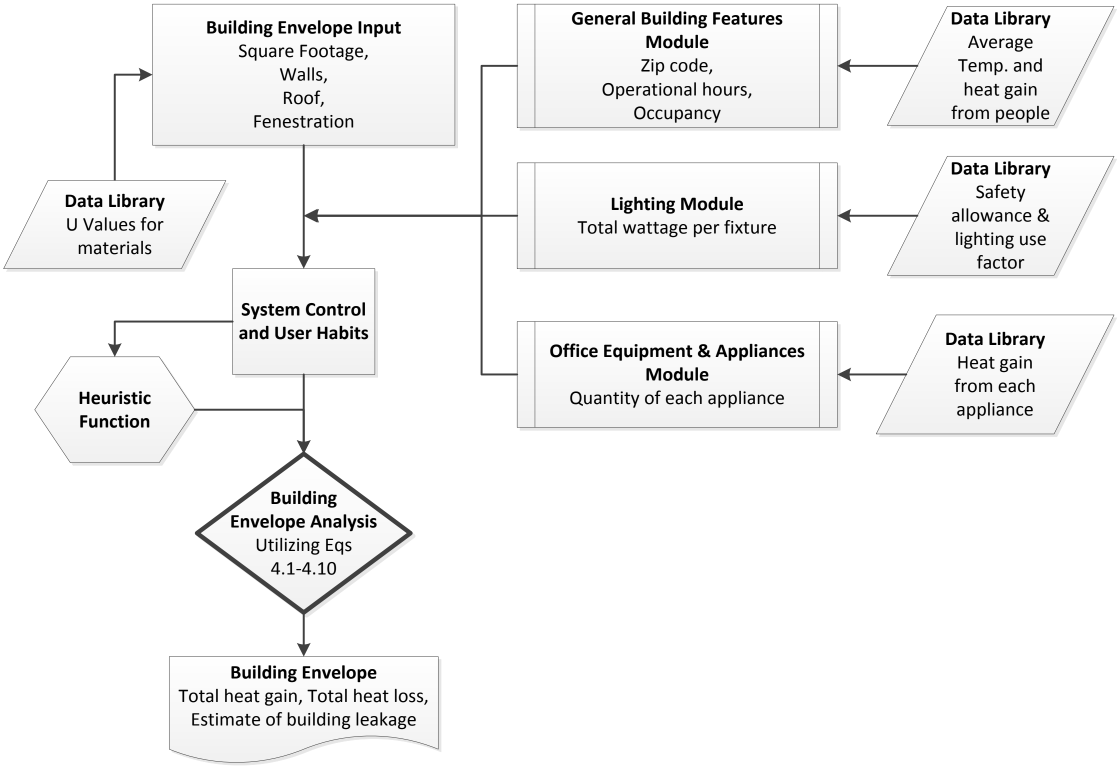


Figure 4.3 Flowchart of the building envelope module.

4.3 HVAC

Heating, ventilation and air conditioning (HVAC) consumes more energy in buildings than any other single system, accounting for approximately 65 percent of total usage. There are two general approaches to achieving energy savings with HVAC systems. The first is to design and install a major retrofit, which involves major capital investment. Payback periods for such upgrades can be lengthy, and they are often coupled with a major building renovation or addition, if they are done at all.

The second approach to achieve energy savings is to focus on things like improved system controls and maintenance. The cost of such upgrades is much more modest, although noticeable reductions in energy usage may still be realized. For instance, annual maintenance on the hot water boiler by a technician typically results in a 10 to 20 percent reduction in HVAC energy consumption (Thumann, 2010). The expert system will focus on this latter kind of system improvement.

ASHRAE (2000) provides some useful relationships for estimating energy requirements for HVAC systems. The Heating Degree-Day Method is used to estimate the theoretical seasonal energy requirement of heating systems. The method is straight forward and assumes that the efficiency of the system is constant regardless of temperature (Howell, 2005). The Heating Degree Day equation is shown below:

$$E_{CH} = 1.77 \frac{q_L(DD)24}{\eta(HV)\Delta t} \tag{4.11}$$

where E_{CH}: energy consumption for the estimated period (units of fuel)

q_L: design heat loss including infiltration and ventilation (Btu/h)

DD: number of degree days for given period

24: (hours/day)

Δt: temperature difference (^{o}F)

η: efficiency of heating system (dimensionless)

HV: heating value of fuel (Btu/ units of fuel)

Similarly, Cooling Degree Day Method can be used to estimate the energy requirements for cooling using the following equation (Howell, 2005):

$$E_{CC} = \frac{q_g(CDD)24}{1000(SEER)\Delta t_d} \tag{4.12}$$

where E_{CC}: energy consumption for the estimated period (kWh)

q_g: design cooling load (Btu/h)

24: (hours/day)

CDD: number of cooling degree days for given period

1000: (W/kWh)

SEER: seasonal energy efficiency ratio (Btu/h/W)

Δt_d: temperature difference (^{o}F)

Temperature change over point depends on room temperature, air quantity and sensible heat gain and is computed using the following equation:

$$t_{co} = t_r - \frac{q_{is}+q_{es}-1.1Q_p(t_r-t_p)}{\Delta q_{td}} \tag{4.13}$$

where t_{co}: temperature of changeover point (^{o}F)

t_r: room temperature at time of changeover, normally 72^{o}F, (^{o}F)

t_p: primary air temperature at unit after system is changed over

Q_p: primary air quantity (cfm)

q_{is}: internal sensible heat gain (Btu/h)

q_{es}: external sensible heat gain (Btu/h)

Δq_{td}: heat transmission per degree of temperature difference between room and outdoor air (Btu/h)

Another useful relation is given in Equation 4.14, which calculates the energy lost monthly due to air flow, ventilation and exhaust (Capehart, 2012):

$$\frac{Btu}{Month} = V \times (E + S) \times 1440 \times 0.075 \times 0.24 \times (HDD + CDD) \tag{4.14}$$

where V: volume of air entering or leaving (CFM)

E: enrollment

S: staff and teachers

1440: number of minutes per day (min)

0.075: pounds of dry air per cubic foot (lb/cf)

0.24: specific heat of air (Btu/lb/°F)

HDD: heating degree days per month, (days × °F)

CDD: cooling degree days per month, (days × °F)

The flowchart for the HVAC component of the expert system is shown in Figure 4.4. The first step is to input a description of the current system. It is broken down into five categories: heating, cooling, heating/cooling - heat pump, supplementary equipment and air quality. For the first three categories involving heating and cooling, the user inputs the type and age of the primary system, as well as the type of distribution system. For supplementary equipment the user will choose if any of the equipment is present in their facility. Data are also input for systems to maintain air quality, including both ventilation and exhaust. Maintenance log books can also be used for HVAC trends and information for the data input.

Once all the HVAC system data are input, the program next obtains from the General Building Features other relevant data, including operational hours to determine the running hours, zip code for average temperatures, and square footage for comparisons. The program then calls the Data Library to determine the corresponding rated efficiencies for the equipment. The System Controls and User Habits are then queried and analyzed by the Heuristic Function. The expert system next analyzes the overall HVAC system using necessary steps and equations. The final output of this system includes estimation of current usage and how the building compares with average usage of similar buildings.

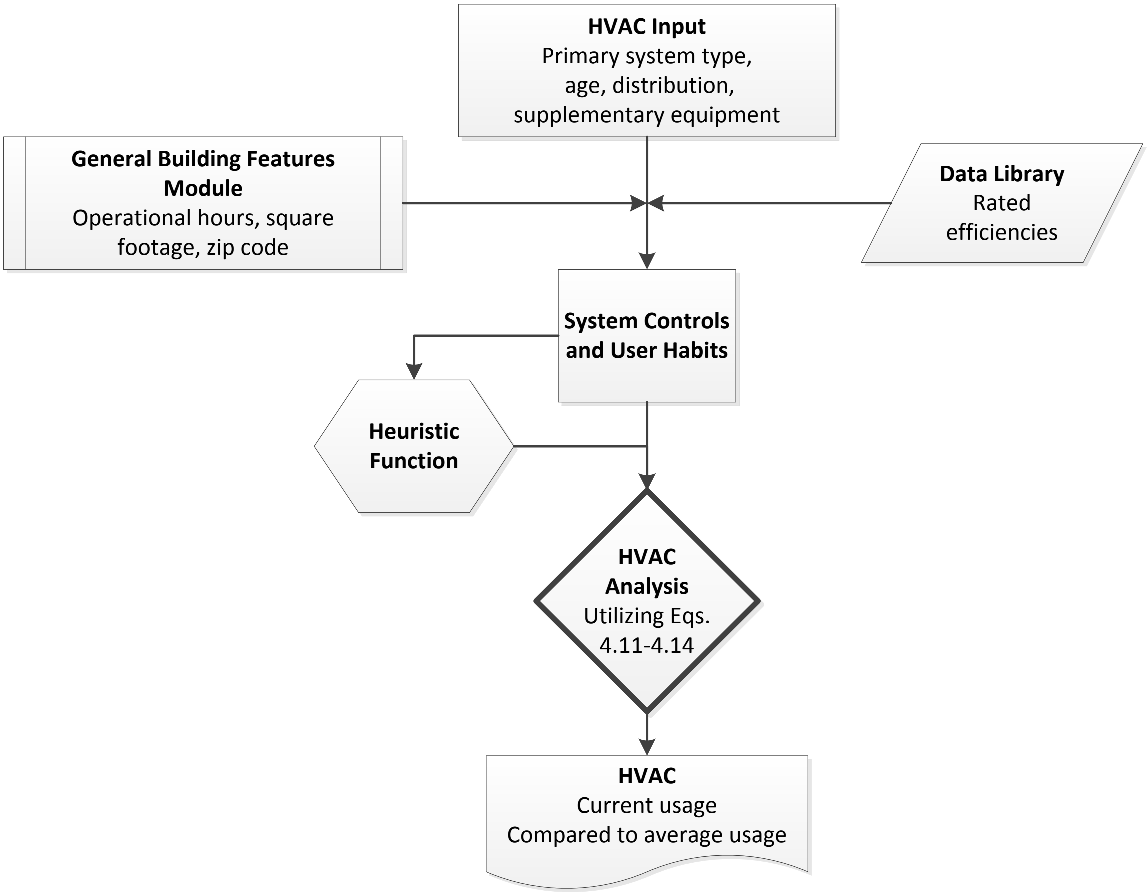


Figure 4.4 Flowchart of the HVAC module.

4.4 Lighting

Lighting accounts for approximately 15 percent of energy use in schools. It is generally considered to be one of the easier aspects to retrofit. In order to calculate the lighting usage, the quantity of each fixture type and the associated wattage and usage must first be determined. Lighting usage can then be calculated using the following equations:

$$Annual\ kWh\ per\ fixture\ type = \frac{W}{1000} \times h \times wk \times qt \tag{4.15}$$

where W: total wattage per fixture

h: hours of operation per week

wk: weeks of operation per year

qt: quantity of fixtures

$$Annual\ kWh\ of\ lighting = \sum Annual\ kWh\ per\ fixture\ type \tag{4.16}$$

$$Annual\ cost\ per\ fixture\ type = \tag{4.17}$$

$$\frac{cost}{kWh} \times Annual\ kWh\ per\ fixture\ type$$

$$Annual\ cost\ of\ lighting = \sum Annual\ cost\ per\ fixture\ type \tag{4.18}$$

Note that heat gain from lighting must be included in the building envelope analysis. The instantaneous rate of heat gain from electrical lighting can be calculated by:

$$Q_L = 3.41 W F_{ul} F_{sa} \tag{4.19}$$

where Q_L: heat gain (Btu/h)

W: total light wattage (Watt)

F_{ul}: lighting use factor (dimensionless)

F_{sa}: lighting special allowance factor (dimensionless)

The flowchart for the lighting component of the expert system is shown in Figure 4.5. Analysis begins with the lighting input where the user enters the fixture type, total wattage per fixture type and quantity. (The Lighting input screenshots are shown in the Appendix B.) The program then accesses the General Building Features to determine the operational hours. Next, the program calls the Data Library to obtain the corresponding safety allowance and lighting use factors. The User Habits are then entered for eventual use by the Heuristic Function. The expert system then performs the Initial Audit

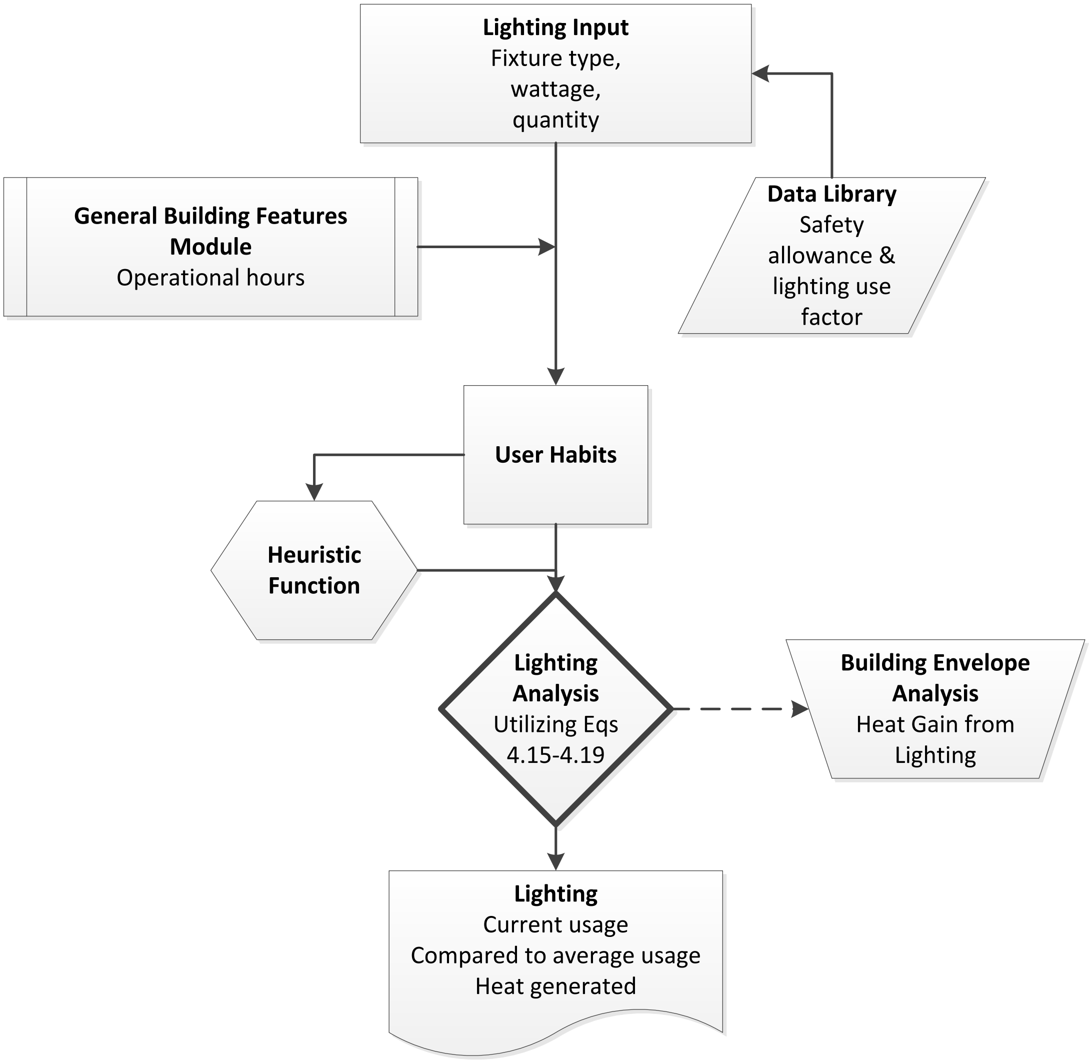


Figure 4.5 Flowchart of the lighting module.

Analysis of the Lighting module. The final output will provide current estimated kWh usage and compares it to average industry standards for the same building type. The heat generated by the lamps is also given. Note, that these same data are also made available to the Building Envelope component to determine the heat gain from lighting for the building envelope potential.

4.5 Office Equipment and Appliances

The office equipment and appliances component of the expert system analyzes all plug loads in the building. These range from computers and printers to coffee makers and vending machines. In addition to plug load, the program also considers "phantom load." Phantom load refers to the power that a device draws when it is switched off but is still plugged in. Such loads can be high for appliances with a quick start feature or with a clock device inside, like a television. Even devices with small phantom loads can waste significant amounts of energy over long periods of time.

The annual energy usage of each appliance can be calculated using the following equation:

$$A = \frac{W}{1000} \times h \times wk \times qt \tag{4.20}$$

where A: annual standard kWh per appliance type

W: total wattage per appliance

h: hours of operation per week

wk: weeks of operation per year

qt: quantity of appliances

In a similar way, annual energy usage due to phantom loads can be determined as follows:

$$P = \frac{W_P}{1000} \times h_P \times wk \times qt \tag{4.21}$$

where P: annual phantom kWh per appliance type

W_P: total phantom wattage per appliance

h_P: hours of operation per week the appliance is off but plugged in

In order to determine the total annual kWh usage of all office equipment and appliances in the building, the standard and phantom loads must be totaled. The annual costs associated with each usage type can then be determined using Equations 4.22-4.25:

$$Annual\ kWh\ of\ appliances = \sum(A + P) \tag{4.22}$$

$$A_C = \frac{cost}{kWh} \times A \tag{4.23}$$

where A_C: annual cost per appliance type

$$P_C = \frac{cost}{kWh} \times P \tag{4.24}$$

where P_C: annual phantom cost per appliance type

$$Annual\ cost\ of\ appliances = \sum(A_C + P_C) \tag{4.25}$$

The total heat gain from office equipment and appliances, which is used in the building envelope component, is calculated using the following equation:

$$Q_A = qt \times q \tag{4.26}$$

where Q_A: heat gain from office equipment and appliances (Btu/hr)

qt: quantity of appliances

q: heat gain of type of appliance (Btu/hr)

The flowchart for the Office Equipment and Appliances module of the expert system is shown in Figure 4.6. First, the appliance types and quantities are input. (The

Office Equipment and Appliances input screenshot is shown in Appendix B.) Then the program obtains the operational hours from the General Building Features module. Adjustments to the stated hours may then be made based on the User Habits screen. The program next calls the Data Library to determine the corresponding wattage and phantom load for each of the appliances, as well as the heat gain. These data are then made available to the Building Envelope analysis to determine the heat gain from appliances for the Building Envelope. The System Controls and User Habits information is then

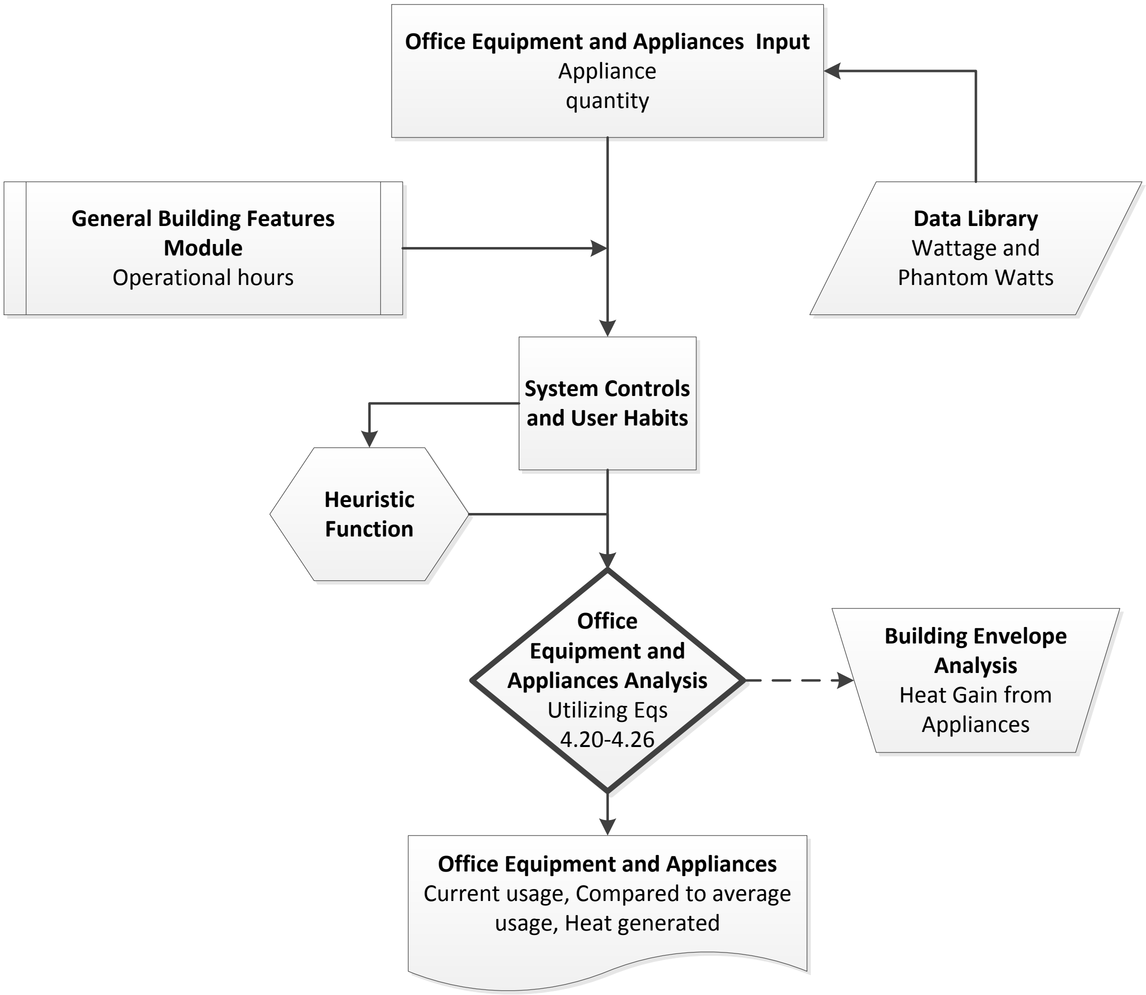


Figure 4.6 Flowchart of the office equipment and appliances module.

analyzed by the Heuristic Function to better predict actual energy usage. The expert system next performs the Initial Audit Analysis for the Office Equipment and Appliances module. The final output provides current estimated kWh usage and compares it to the average industry standards. The heat generated by the receptacle loads is also given, which is made available to the Building Envelope component.

4.6 Water and Hot Water Usage

The water and hot water usage component of the expert system analyzes all of the water being consumed in the building, including plumbing, drinking, cooking, swimming, and cleaning. Water usage can be determined one of two ways. The first is by fixture audit, which involves recording all fixtures and then using industry standards to estimate usage. The second way is to employ standard industry ratios based on the number of building occupants. The latter approach involves use of the following equations:

$$W_{WH} = 15 \times E \times D \tag{4.27}$$

where W_{WH}: water usage for high schools (gal/mo)

E: enrollment

D: number of days the school was in operation in the given month

$$W_{WE} = 12 \times E \times D \tag{4.28}$$

where W_{WE}: water usage for elementary schools (gal/mo)

E: enrollment

D: number of days the school was in operation in the given month

Hot water is most often estimated using standard ratios as well, as shown in Equation 4.29 for high schools or Equation 4.30 for elementary schools. Once the total usage per month is found, then the energy required to heat the water can be calculated using Equation 4.31.

$$W_{HH} = 1.8 \times E \times D \tag{4.29}$$

where W_{HH}: hot water usage for high schools (gal/mo)

E: enrollment

D: number of days the school was in operation in the given month

$$W_{HE} = 0.6 \times E \times D \tag{4.30}$$

where W_{HE}: hot water usage for elementary schools (gal/mo)

E: enrollment

D: number of days the school was in operation in the given month

$$Q = cm\Delta T \tag{4.31}$$

where Q: heat (Btu)

m: mass (lbs)

c: specific heat capacity $\left(\frac{Btu}{lb\times°\mathrm{F}}\right)$

ΔT: change in temperature (^{O}F)

The flowchart for the Water and Hot Water component is shown in Figure 4.7. Initially, the quantities of fixtures are input (The Water and Hot Water input screenshots are shown in Appendix B.). Then the program obtains the occupancy and operational hours from the General Building Features and utility usage from the Water and Sewer Utility input. Adjustments to the stated hours may then be made based on the user habits screen. The program will then call the Data Library to determine the average gallons per flush or gallons per minute. The User Habits is then analyzed by the Heuristic Function to better predict actual usage. The expert system next performs the Initial Audit Analysis for Water and Hot Water Usage. The final output provides the current estimated usage and compares it to the average industry standards. The estimated hot water usage and estimated energy required to heat the hot water are also generated.

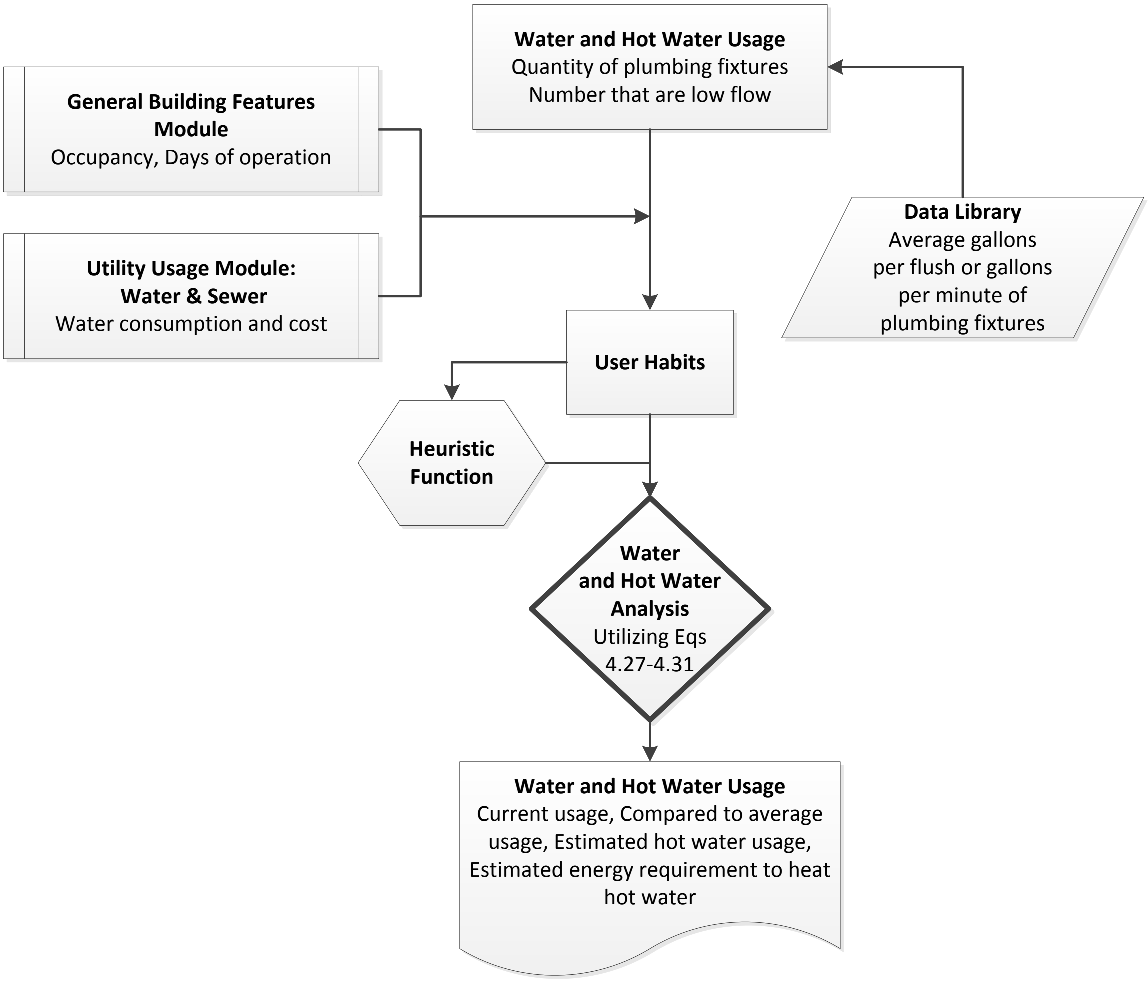


Figure 4.7 Flowchart of water and hot water usage module.

4.7 Waste Handling

Responsible waste handling plays an important role in achieving sustainability for the target building. This requires that the occupants both think and act 'green.' It is also essential that the buildings facilities staff have adequate receptacles to encourage and remind occupants of what can be recycled. On average, people recycle only 1.53 pounds of the 4.40 pounds of generated waste per person per day, so there is almost always room for improvement (Municipal, 2013).

The flowchart for the Waste Handling component of the expert system is shown in Figure 4.8. First, the amount of each category of recycling, location frequency, estimated monthly quantities and cost are input into the program (The Waste Handling input screenshots are shown in the Appendix B). Next, the expert system calls occupancy data from the General Building Features and recommended best practice percentages for each category of recyclables and trash. The expert system then analyzes these data with the aid of the Heuristic Function to determine the usage and improvements. Finally, the output will display current usage and target minimum goals for each category of recyclables, as well as suggestions for achieving these goals.

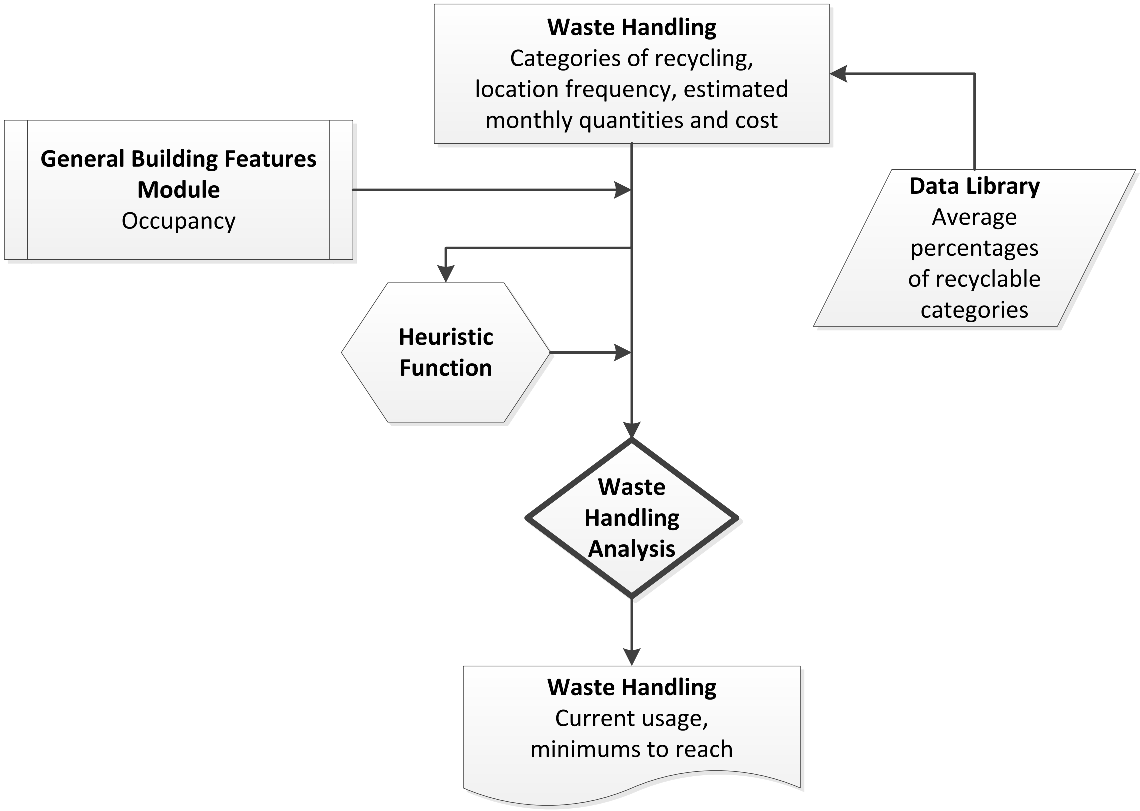


Figure 4.8 Flowchart of waste handling module.

4.8 Education and Training

Education and Training of building occupants and facilities staff play a key role in achieving energy savings. The idea is to create and maintain an awareness of energy and resource conservation. In support of this, a study by the University of British Columbia, suggested that being in a sustainable environment induces pro-environmental behavior based on the cognition effect. That is, the environment affects how people act and feel (Morales, 2013).

The flowchart for the Education and Training module of the expert system is shown in Figure 4.9. The user first inputs various data about the education of the students regarding sustainability, recycling and resilience (The Education and Training input screenshot is shown in Appendix B.). It also queries about the level of staff training in these same areas. The expert system then analyzes these data to generate two principle results. The first is to produce heuristic factors based on current Education and Training levels that will be utilized by other components of the expert system. The other results are suggested improvements for the education of students and the training of the facilities staff in the areas of energy and resource conservation.

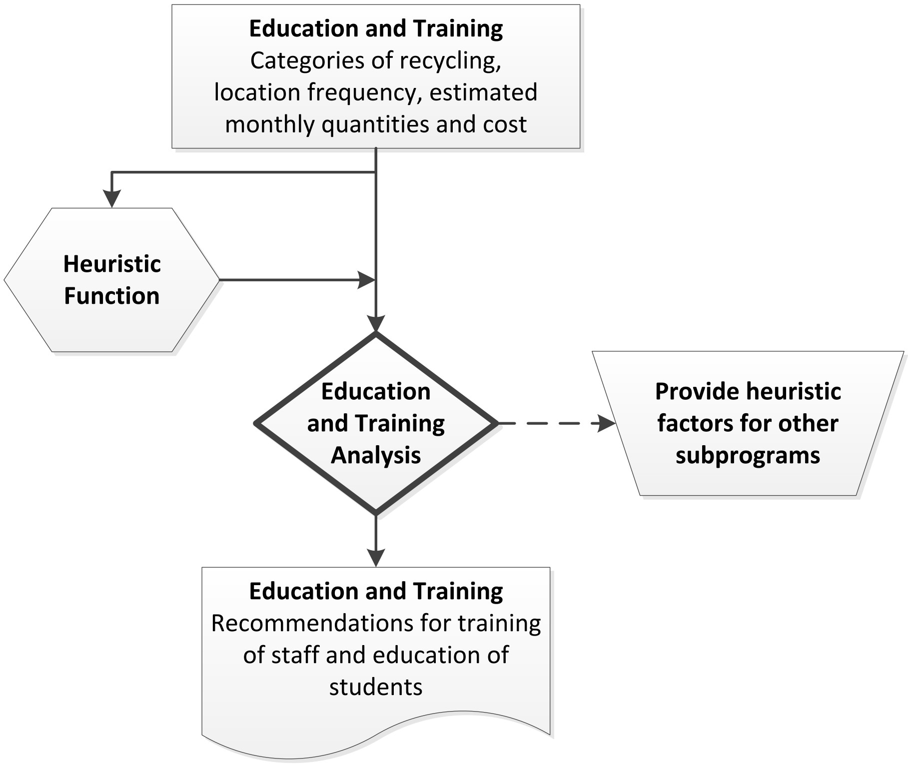


Figure 4.9 Flowchart of the education and training module.

CHAPTER 5

HEURISTIC ANALYSIS

A key feature of the expert system is that it evaluates occupant behavior and its likely influence on current and future energy usage. This is accomplished by incorporating a Heuristic Function into the expert system. In essence, heuristics elevates the analysis of a building from a traditional energy audit to a more realistic depiction of current and future conditions.

The influence of occupant behavior is evaluated by first querying current user habits and installed system controls. Based on the answers, a ranking or grade is generated that is then used to adjust the results of the Initial Audit Analysis. For instance, stronger user habits and/or more extensive system controls the closer the audit results will be to actual consumption. Similarly, the building will probably see more payback from future improvements, just because the occupants are more likely to fully implement them. In addition, there will be better Synchronization between estimated and billed energy consumption.

Whereas, a building that does not have sustainable user habits and is wasting energy will have billed energy amounts, and it may see lower payback and smaller improvements. Thus, for these facilities, the Heuristic Function can help to identify specific areas where improvement is needed. It can also recommend education and training measures targeted at reducing future energy usage.

In a similar way, the Heuristic Function will help the building system to achieve a higher level of sustainability and resilience. For example, when an improvement can be done in a more sustainable or green manner, a ‘green hint’ will appear showing how the improvement could be implemented in a more socially responsible way. Heuristics can also help determine resiliency of a building, and if there are areas for improvement, these will be suggested. This is important, considering that schools often become shelters during disasters.

The range of heuristic factor was initially determined to be 0.9 to 1.4. In essence, a perfectly operated building would earn a heuristic factor of 0.9. This is then applied to the Initial Audit Analysis modifying it to result in 90% of the Initial Audit Analysis. Similarly, a very poorly run building would earn a heuristic factor of 1.4 which would result in 140% of the Initial Audit Analysis.

The equation for the General Heuristic Factor is shown in in Equation 5.1. The General Heuristic Factor, which is applied to all of the components from Chapter 4, is based off of the answers from the Occupancy Information, Waste Handling, as well as, Education and Training. This factor is done to gain an understanding of general occupant behavior within the target building.

$$H_G = \frac{(H_{WH} + H_{ET} + H_{OI})}{3.0} \tag{5.1}$$

where H_G: general heuristic factor

H_{WH}: heuristic factor for waste handling (See 5.11)

H_{ET}: heuristic factor for education and training (See 5.15)

H_{OI}: heuristic factor for occupancy information (See 5.18)

The factors that make up the General Heuristic Factor are explained in further detail later in the chapter.

The General Heuristic Factor is then applied to the natural gas, water, and electrical estimated audit analyses in order to get a more accurate representation of actual usage. Each of these components, in turn, also has its own heuristic factor depending on the answers to the System Controls and or User Habit queries within that component. The basic equations for natural gas, water and electricity are shown in Equations 5.2 to 5.5 below.

$$Total\ Natural\ Gas\ Required = H_G[H_B(Q_{WL} + Q_R + Q_{WN} + Q_D) - H_LQ_L - H_AQ_A] - Q_S - Q_P + H_HE_{CH} \tag{5.2}$$

where $H_B = H_{BU} + H_{BC}$ (See 5.8 and 5.16)

$$Total\ Water\ Usage = H_G[(H_W \times Total\ Water\ Hot\ and\ Cold, ft^3)] \tag{5.3}$$

where $H_W = H_{WU}$ (See Eq. 5.9)

$$Total\ Electrical\ Energy\ Required = H_G[(H_L \times Base\ Lighting, kWh) + (H_A \times Office\ Equipment, kWh) + (H_W \times Hot\ Water, kWh)] + H_HE_{CC} + (H_B \times Cooling\ Load) \tag{5.4}$$

The last term is expanded as follows,

$$H_B \times Cooling\ Load = H_G[H_B(Q_{WL} + Q_R + Q_{WN} + Q_D) + H_LQ_L + H_AQ_A] + Q_S + Q_P \tag{5.5}$$

where $H_L = \frac{H_{LU}+H_{LC}}{2}$ (See 5.7 and 5.18)

$H_A = \frac{H_{AU}+H_{AC}}{2}$ (See 5.12 and 5.13)

$H_W = H_{WU}$ (See 5.9)

$H_B = \frac{H_{BU}+H_{BC}}{2}$ (See 5.8 and 5.16)

In order to determine the various heuristic factors for each component, input from the User Habits and System Controls queries need to be analyzed. This analysis incorporates Bayesian Theory to reflect the probabilities associated with each factor. The general form of the equation to solve for the heuristic factors of the User Habits for Lighting, Building Envelope and Water is given in Equation 5.6 below. The table provides the specific variables for each respective component.

$$H = \left[\left(\frac{100 - I + (\sum_{n=0}^{a}(\alpha \times n) + \sum_{n=0}^{a}(\beta \times n) + \sum_{n=0}^{a}(\gamma \times n))}{100}\right) \times 0.50\right] + 0.90 \tag{5.6}$$

Table 5.1 Variables to Use in Equation 5.6 to Determine Lighting, Building Envelope, and Water User Habits Heuristic Factors

Heuristic Factor	**H**	**A**	**β**	**γ**	**Equation**
Lighting User Habits	H_{LU}	N_V	O	A	(5.7)
Building Envelope User Habits	H_{BU}	N_N	F_W	M	(5.8)
Water User Habits	H_{WU}	N_N	F_W	M	(5.9)

where N_V: points for answer ‘Never’, 0 points neutral

O: points for answer ‘Occasionally’, $\frac{1}{2} \times \frac{1}{q} \times I$

A: points for answer ‘Always’, $\frac{1}{q} \times I$

N_N: points for answer ‘None’, 0 points neutral

F_W: points for answer ‘Few’, $\frac{1}{2} \times \frac{1}{q} \times I$

M: points for answer ‘Many’, $\frac{1}{q} \times I$

I: initial Score, 80 points

a: number of times that answer was selected

q: number of questions

The general form of the equation to compute the heuristic factors for Waste Handling and Equipment and Appliances components is given in Equation 5.10 below. The accompanying table is used to determine the specific variables.

$$H = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(\alpha\times n)-\sum_{n=0}^{a}(\beta\times n)-\sum_{n=0}^{a}(\gamma\times n)]-[\sum_{n=0}^{a}(\delta\times n)+\sum_{n=0}^{a}(\varepsilon\times n)+\sum_{n=0}^{a}(\theta\times n)]}{100}\right)0.50\right]+0.90 \qquad (5.10)$$

Table 5.2 Variables to Use in Equation 5.10 to Determine Waste Handling, Equipment and Appliances System Controls and User Habits Heuristic Factors

Heuristic Factor	**H**	**A**	**B**	**γ**	**δ**	**ε**	**θ**	**Equation**
Waste Handling	H_{WH}	Y	D	N_O	-	-	-	(5.11)
Equipment and Appliances System Controls	H_{AC}	Y	N_A	N_O	N_N	F_W	M	(5.12)
Equipment and Appliances User Habits	H_{AU}	Y	N_A	N_O	N_{Nu}	F_{Wu}	Mu	(5.13)

where Y: points for answer 'Yes', $\frac{1}{q}\times 20$

D: points for answer 'Don't Know', 0 points neutral

N_A: points for answer 'Not Applicable', 0 points neutral

N_O: points for answer 'No', $\frac{1}{q}\times I$

N_N: points for answer 'None', 0 points neutral

N_{Nu}: points for answer 'None', $-\frac{1}{q}\times I$

F_W: points for answer 'Few', $\frac{1}{2}\times\frac{1}{q}\times I$

F_{Wu}: points for answer 'Few', $-\frac{1}{2}\times\frac{1}{q}\times 20$

M: points for answer ‘Many’, $\frac{1}{q} \times I$

Mu: points for answer ‘Many’, $-\frac{1}{q} \times 20$

I: initial Score, 80 points

a: number of times that answer was selected

q: number of questions

The general form of the equation to determine heuristic factors for Building Envelope System Controls, as well as Education and Training components, is given below in Equation 5.14. The table provides the specific variables for each component.

$$H = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(\alpha\times n)-\sum_{n=0}^{a}(\beta\times n)-\sum_{n=0}^{a}(\gamma\times n)]}{100}\right)\times 0.50\right]+0.90 \qquad (5.14)$$

Table 5.3 Variables to Use in Equation 5.14 to Determine Education and Training, HVAC, and Building Envelope System Controls Heuristic Factors

Heuristic Factor	**H**	**A**	**β**	**γ**	**Equation**
Education and Training	H_{ET}	Y	N_O	-	(5.15)
HVAC	H_H	Y	N_O	-	(5.16)
Building Envelope System Controls	H_{BC}	T	N_R	L	(5.17)

where Y: points for answer ‘Yes’, $\frac{1}{q} \times 20$

N_O: points for answer ‘No’, $\frac{1}{q} \times I$

T: points for answer ‘Tight’, $\frac{1}{q} \times 20$

N_R: points for answer ‘Normal’, 0 points neutral

L: points for answer ‘Leaky’, $\frac{1}{q} \times I$

I: initial Score, 80 points

a: number of times that answer was selected

q: number of questions

Finally, the heuristic factor for Occupancy Information and Lighting System Controls are solved using the Equations 5.18 and 5.19 below.

$$H_{OI} = \sum_{n=0}^{a}(I_F \times n) + \sum_{n=0}^{a}(O \times n) + \sum_{n=0}^{a}(F_R \times n) \tag{5.18}$$

where H_{OI} = heuristic factor for occupancy information

I_F: points for answer ‘Infrequently’, 1.1

O: points for answer ‘Occasionally’, 1.2

F_R: points for answer ‘Frequently, 1.3

a: number of times that answer was selected

$$H_{LC} = \left[\left(\frac{100-\left(I+20\left(\frac{\sum R_C}{R}\right)\right)}{100}\right) \times 0.50\right] + 0.90 \tag{5.19}$$

where H_{LC}: heuristic factor for lighting system controls

R_C: rooms with controls

R: total number of rooms

I: initial Score, 80 points

CHAPTER 6

SYNCRONIZATION

The Initial Audit analyzes the various building systems individually and as a whole to estimate energy usage. It is based upon building material properties, equipment specifications, industry standards, and "ideal" occupant behavior. The Heuristic Function of the expert system attempts to adjust the audit results to reflect "actual" occupant behavior, based upon queries of user habits and installed system controls. But given the considerable complexities of the building energy systems, the actual energy consumed based on billing data may be higher or lower than the adjusted audit results.

The purpose of the Synchronization process is to resolve the inevitable differences between estimated energy usage from the audit results and actual energy usage from the billing data. The Synchronization Step is performed after the heuristic factors have been applied in order to build the best possible model of actual energy usage in the target building. It is an essential step for optimizing future energy usage and savings.

The general approach for Synchronization was to first express energy usage as a series of linear equations in the form of $Ax=B$. The 'A' coefficient represents the energy load calculated from the Initial Audit as modified by the Heuristic Function. The 'B' value is the actual energy usage from the utility bills. And 'x' is a convergence factor which is determined during the Synchronization Step.

Depending on the number of building systems being synchronized, an entire system of first order linear equations may be written as follows:

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = B \tag{6.1}$$

$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = B$$

$$\ldots.$$

$$a_{n1}x_1 + a_{n2}x_2 + \cdots + a_{nn}x_n = B$$

A number of solution strategies are available to solve systems of linear equations. For the current study, it was decided to use Gaussian transformation, also known as "elimination." This method was chosen since the systems of equations generated by the expert model appeared to meet the Gaussian conditions of independence and consistence for a unique solution set. Using this method, a solution is obtained by transforming Equation 6.1 into matrix form as shown here:

$$Ax = B$$

$$\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} \tag{6.2}$$

Solution is then straight forward by multiplying matrix B by the inverse of A:

$$x = A^{-1}B \tag{6.3}$$

As an example, a Synchronization matrix for electrical usage may be constructed of coefficient "a_{mn}", where "m" represents the four seasons and "n" represents the electrical categories of lighting, office equipment and appliances, hot water, and cooling:

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} \tag{6.4}$$

where $a_{1,n}$: Winter loads calculated using basic and heuristic analysis

$a_{2,n}$: Spring loads calculated using basic and heuristic analysis

$a_{3,n}$: Summer loads calculated using basic and heuristic analysis

$a_{4,n}$: Fall loads calculated using basic and heuristic analysis

$a_{m,1}$: Lighting loads calculated using basic and heuristic analysis

$a_{m,2}$: Office equipment and appliances loads calculated using basic and heuristic analysis

$a_{m,3}$: Hot Water loads calculated using basic and heuristic analysis

$a_{m,4}$: Cooling loads calculated using basic and heuristic analysis

x_1: Convergence factor for lighting usage

x_2: Convergence factor for office equipment and appliance usage

x_3: Convergence factor for hot water usage

x_4: Convergence factor for cooling usage

b_1: Actual electrical usage from utility bill for winter season

b_2: Actual electrical usage from utility bill for spring season

b_3: Actual electrical usage from utility bill for summer season

b_4: Actual electrical usage from utility bill for fall season

When the Gaussian solver was applied to actual electrical energy data from an audited Newark school, the convergence factor matrix was found to be lumped rather than distributed. Specifically, some values of x_m were found to be zero, while others were either very large or very small. Further investigation revealed that while the equations were theoretically independent, some were much too similar. Distinct independence is a necessary condition for satisfactory solutions using Gaussian Transformation.

It was then decided to try an alternate method to solve the system of linear equations shown in Equation 6.5. This second approach involved the use of a forcing function. As before, the 'a_{mn}' coefficient represents the energy load calculated from the Initial Audit as modified by the Heuristic analysis. The 'B' value is the actual energy usage from the utility bills and the 'x' is a convergence factor which is determined during the Synchronization Step. A new factor 'Δ' is introduced as the difference between 'B', utility bill and 'a_{mn}', energy load calculated from the initial audit analysis as modified by the heuristic function. A matrix of convergence factors, 'x_m,' one for each of the seasons, may then be determined. As an example, the convergence factor for lighting is defined as:

$$x_m = \frac{\left(\frac{a_{m1}}{\sum_{n=1}^{4}(a_{1n})}\Delta\right)+\sum_{n=1}^{4}(a_{1n})}{\sum_{n=1}^{4}(a_{1n})} \tag{6.5}$$

where x_m: Convergence factor for lighting load

a_{m1}: Energy load for lighting using initial audit as modified by heuristic factor for a given season

$\sum_{n=1}^{4}(a_{1n})$: Sum of energy load using initial audit as modified by the heuristic factor for all four component loads in a given season

Δ: Difference between 'B' utility bill for electric during the given season and $\sum_{n=1}^{4}(a_{1n})$

An inspection of Equation 6.5 indicates that the convergence factor, x_m, will be the same for all four system components e.g., lighting, office equipment, hot water, cooling loads, during a given season.

By multiplying each component by the season convergence factor and repeating the process for all of the four seasons, the result will be a revised system of synchronized linear equations that effectively model total electrical energy consumption in the target building using forcing functions:

$$x_1 a_{11} + x_1 a_{12} + x_1 a_{13} + x_1 a_{14} = B_1 \tag{6.6}$$

$$x_2 a_{21} + x_2 a_{22} + x_2 a_{23} + x_2 a_{24} = B_2 \tag{6.7}$$

$$x_3 a_{31} + x_3 a_{32} + x_3 a_{33} + x_3 a_{34} = B_3 \tag{6.8}$$

$$x_4 a_{41} + x_4 a_{42} + x_4 a_{43} + x_4 a_{44} = B_4 \tag{6.9}$$

Finally, it is convenient to define a synchronization matrix for electrical systems that summarizes the seasonal variations as shown in Equation 6.10. Note that this solution form is more satisfying than the Gaussian approach in that each convergence factor is connected with a season rather than a system component.

$$SM_E = \begin{bmatrix} x_W \\ x_{Sp} \\ x_{Sm} \\ x_F \end{bmatrix} \tag{6.10}$$

where SM_E: Synchronization matrix for electric load of given school

x_W: Convergence factor for winter electric loads (formally x_1)

x_{Sp}: Convergence factor for spring electric loads (formally x_2)

x_{Sm}: Convergence factor for summer electric loads (formally x_3)

x_F: Convergence factor for fall electric loads (formally x_4)

A similar process is used to find the synchronization matrix to model natural gas energy consumption.

CHAPTER 7

MODEL VALIDATION, CALIBRATION, AND TESTING

7.1 Test Group Selection

In order to validate and calibrate the expert system, a test group of buildings was needed. The Newark Public Schools District was chosen for this purpose. Contact was established with Mr. Rodney Williams, Manager of Energy Facilities, who granted permission and access for the research. Audit visits and interviews of facilities staff were conducted in the Spring of 2013 and again in the Spring of 2014. This included collecting various building information including: building age, square footage, utility bills, number of occupants, HVAC system, hours of operation, and energy efficient measures already installed. Interviews with staff, administration, and teachers were key to determine answers to the queries of user habits and system controls.

The Newark School System was chosen for several reasons. The weather conditions in Newark, New Jersey are representative of the Northeast, experiencing extremes of both heating and cooling. Also, the Newark School System already has some energy efficiency improvements in place, such as energy monitoring systems, which will be key during the calibration process to see how well the improvements work. Finally, the wide range in age of the 79 school buildings in the district provided a variety of construction details, as the Newark schools were built from as early as the 1848 to as recent as 2007.

The Newark Public Schools District also stands to benefit from the calibration process. Not only will the district have a detailed audit and log of energy usage in a number of schools, but it will also receive recommendations on how to make each building more energy efficient.

A total of 14 schools were visited and initially audited. All inspections were made in cooperation with consulting firms who were also conducting energy audits. Following a review of the collected data, four schools were eliminated from the test group for calibration purposes, namely Barringer High School, Camden Street Elementary, Weequahic High School and Chancellor Avenue Elementary. The reasons for exclusion ranged from missing utility data to excess complexity in the heating and cooling systems, e.g. multiple additions, installed solar panels.

The ten schools finally selected for testing are listed in Table 7.1 along with their basic data. This test sample comprises 12.7% of the total number of district schools and is considered significant. The schools also provide a range of key building characteristics including: type (elementary vs. high school), size (40,813 sf to 316,828 sf), age (1906 – 1976), and with or without additions. In addition, the test sample included some apparent 'duplicates' to check model reliability. The principal comparator subgroups for model validation and calibration are indicated in Table 7.1 by a superscript letter.

Table 7.1 Newark Public Schools Selected for Expert System Testing

School Name	**Type**	**Square Footage**	**Building**	**Addition**
Thirteenth Ave [a]	Elementary	202,762	1971	
Louise A Spencer [a]	Elementary	192,189	1976	
GW Carver [a]	Elementary	210,384	1972	
Arts	High School	172,163	1931	1996
Technology [b]	High School	172,163	1912	1974

School Name	Type	Square Footage	Building	Addition
Chancellor Ave Annex [c]	Elementary	40,813	1959	
Fourteenth Ave [c]	Elementary	57,965	1906	
Quitman	Elementary	122,269	1963	
Mount Vernon	Elementary	110,289	1955	1996
Malcolm X Shabazz [b]	High School	316,828	1913	1976

[a] represents duplicates that were used for initial calibration and repeatability.
[b] represents comparators of similar use and age but difference in size.
[c] represents comparators of same use and size but over 50 years apart in age.

7.2 Validation and Initial Calibration Step

Once the model program was fully debugged, the raw data for the school test group were input into the expert system model. The uncalibrated model results for the initial runs are shown in Figures 7.1 and 7.2 for both electric and gas. The bars for each schools show the relative proportions of the audit calculations, heuristic function, and synchronization adjustment. Some general trends are worth noting. On average, the magnitude of the audit calculation for electric and gas was determined to be 63% and 69%, respectively. These were deemed to be ‘reasonable’ based upon literature trends and personal experience, and thus provided a general validation of the model. It was clear, however, that the required average synchronization percentages to converge with the initial audit and heuristic function seemed high. For electric it ranged from 10% to 57% with an average of 24%, while for natural gas it ranged from 2% to 25% with an average of 11%. The synchronization step is thought to be a fine adjustment only, ranging between ±10%. It was also clear that there were some outlier schools that could be improved such as Quitman for electric and Chancellor Annex for natural gas.

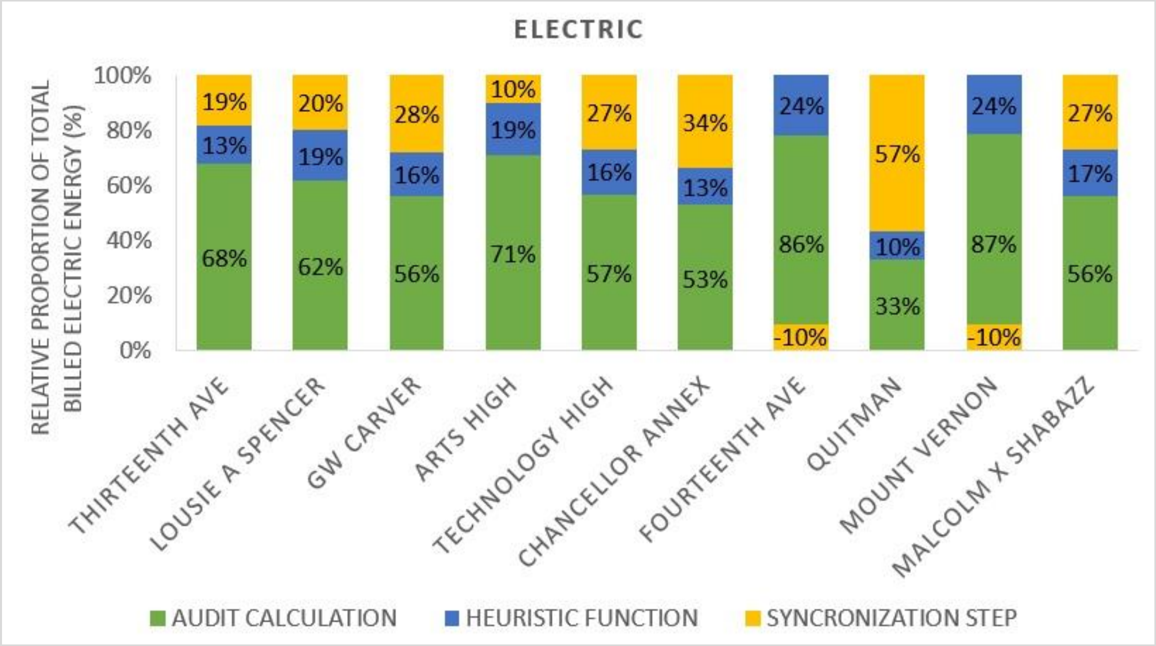


Figure 7.1 Uncalibrated electrical energy data for school test group.

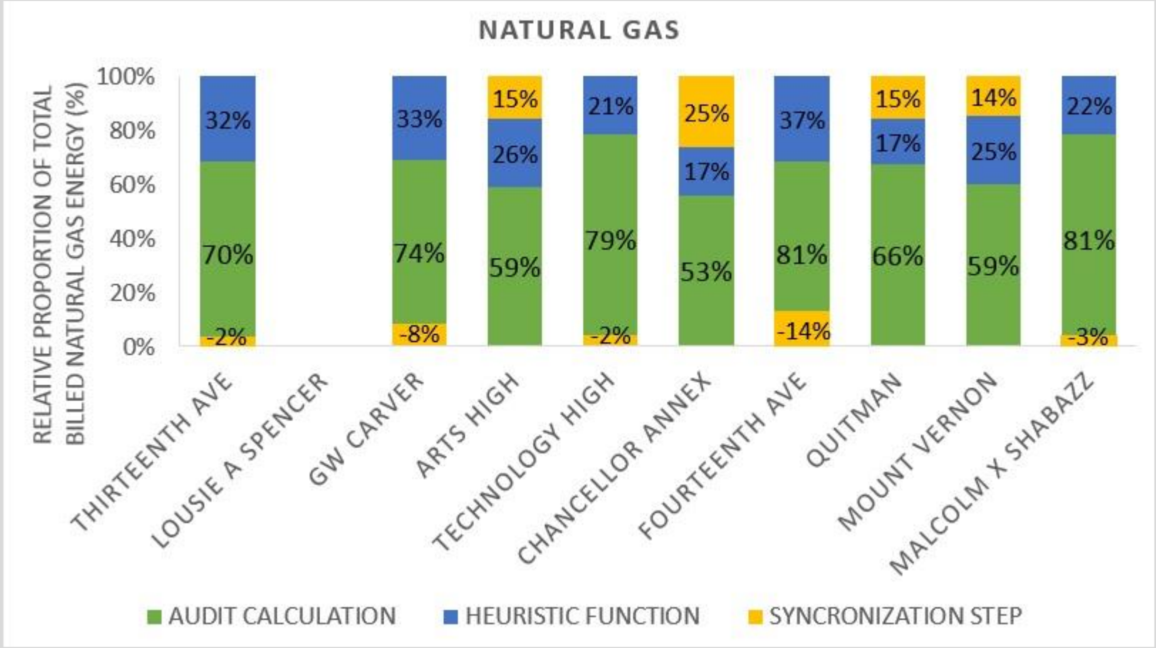


Figure 7.2 Uncalibrated natural gas energy data for school test group.

For the initial calibration step, it was decided to reexamine certain assumptions and algorithms within the initial audit analysis. For example, the lighting hours had originally been assumed to be on from the time the building opens until the time the custodial staff closes the building at 11pm. The lighting hours were reduced to reflect the fact that most lighting was turned off around 6pm, when most students and staff have left (with the exception of hallway lighting). Another adjustment to the model was the addition of walk-in coolers and freezers in the cafeteria. Originally, kitchen loads were excluded because schools are increasingly shifting to warming and prep rather than full cooking facilities. However, refrigeration is still needed and it adds a significant electric load. The efficiency of the HVAC equipment were also examined, as well as the air exchange rate by forced and natural ventilation.

The results of the model following the initial calibration step for electric and natural gas are presented in Figures 7.3 and 7.4. As indicated, the range of initial audit calculations for electric have improved considerably to 70%. The heuristics now account for 23-34%, with an average of 26%, which is as expected for normal system controls. The synchronization percentage has also tightened to a range of -8% to 18% with an average of 4%. Natural gas usage shows similar results, with an average audit of 70%, average heuristic of 25%, and average synchronization of 4%.

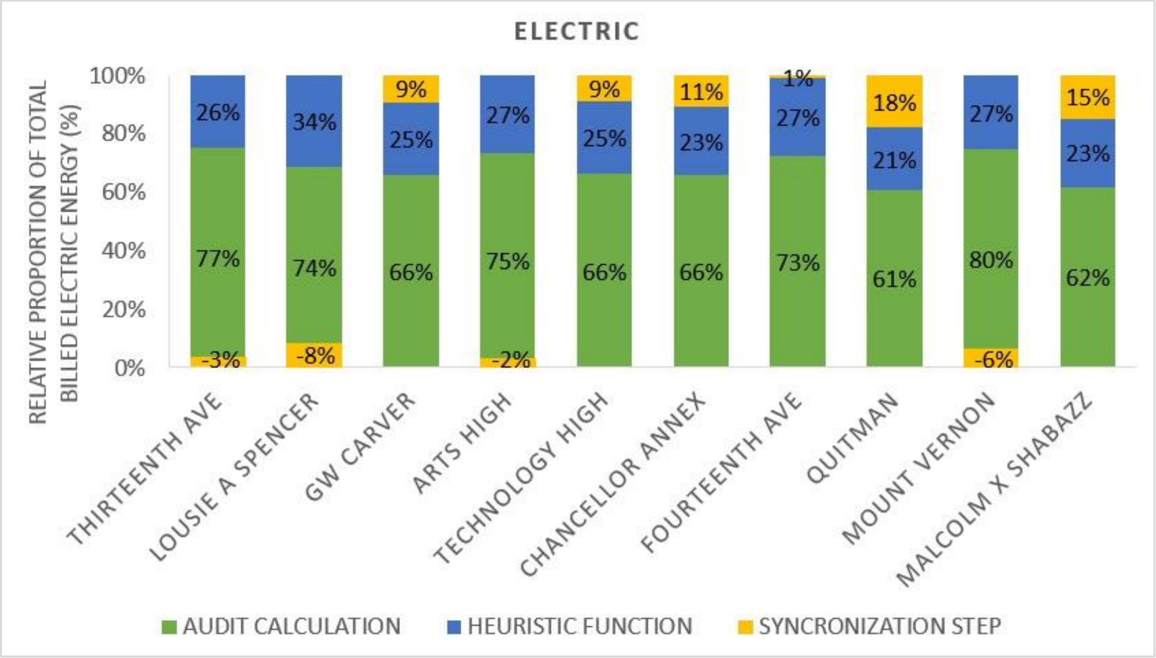


Figure 7.3 Initial calibration of electrical energy data for school test group using optimized audit calculations.

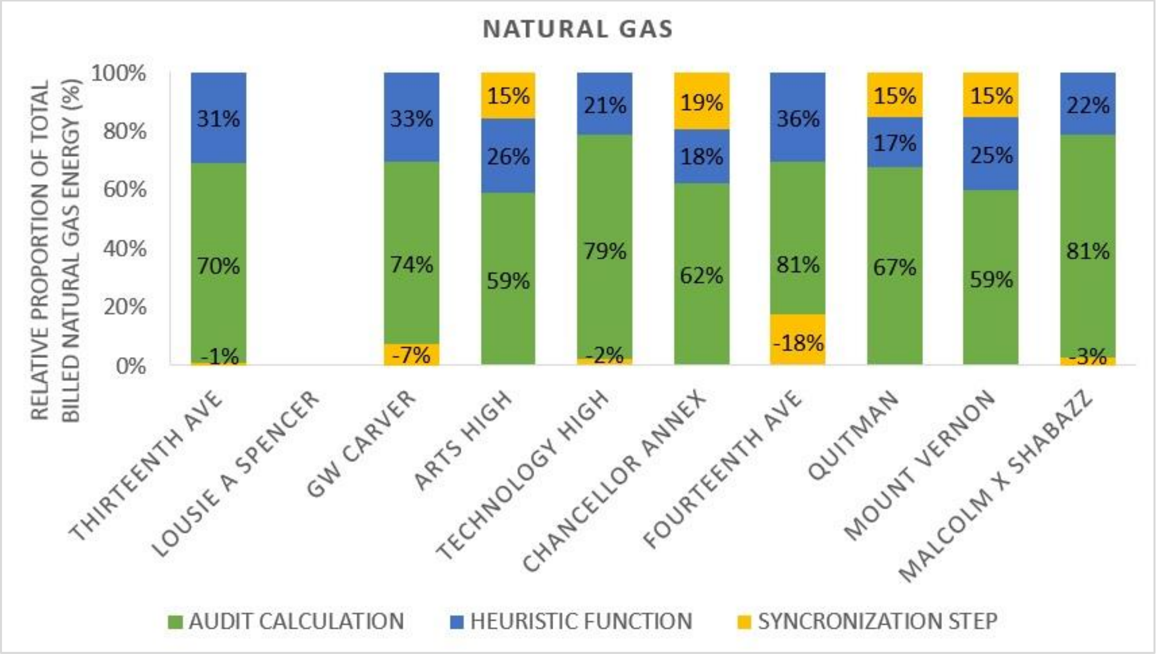


Figure 7.4 Initial calibration of natural gas energy data for school test group using optimized audit calculations.

7.3 Final Calibration Step

The final calibration of the expert system was performed by fine tuning the heuristic factors. This procedure is illustrated by recalling Equation 5.6, which is used to compute the heuristic factor, H, for lighting, building envelope, and water user habits:

$$H = \left[\left(\frac{100 - I + \left(\sum_{n=0}^{a}(\alpha \times n) + \sum_{n=0}^{a}(\beta \times n) + \sum_{n=0}^{a}(\gamma \times n)\right)}{100}\right) \times \boxed{0.5}\right] + \boxed{0.9} \tag{5.6}$$

This relationship, based upon Bayesian Theory, generates a heuristic multiplier that depends on the responses to queries of the users and operations of the audited facility. For this equation, the external range of heuristic factors that can be generated ranges from 0.9 for a building that is perfectly operated to 1.4 for a building that is very poorly operated (0.9 + 0.5 = 1.4). The heuristic factor is then multiplied by calculated energy from the initial audit to estimate actual or billed energy. In essence, a perfectly operated building would be consuming 90% of the energy calculated by the Initial Audit Analysis. Similarly, a very poorly run building would be consuming 140% of the energy calculated by the Initial Audit Analysis.

By performing a series of trial and error model runs, it was decided to extend the total range of the heuristic factor from 0.5 to 0.525 with lower and upper limits of 0.925 and 1.45 respectively, resulting in 92.5% to 145% of the Initial Audit Analysis. The revised equation for the factor then becomes:

$$H = \left[\left(\frac{100 - I + \left(\sum_{n=0}^{a}(\alpha \times n) + \sum_{n=0}^{a}(\beta \times n) + \sum_{n=0}^{a}(\gamma \times n)\right)}{100}\right) \times \boxed{0.525}\right] + \boxed{0.925} \tag{7.1}$$

This relatively modest adjustment substantially improved convergence of the model with billing data. An examination of Figures 7.5 and 7.6 clearly shows better consistency for most schools among the audit and heuristic parts of the model, accompanied by substantial reduction in synchronization percentages.

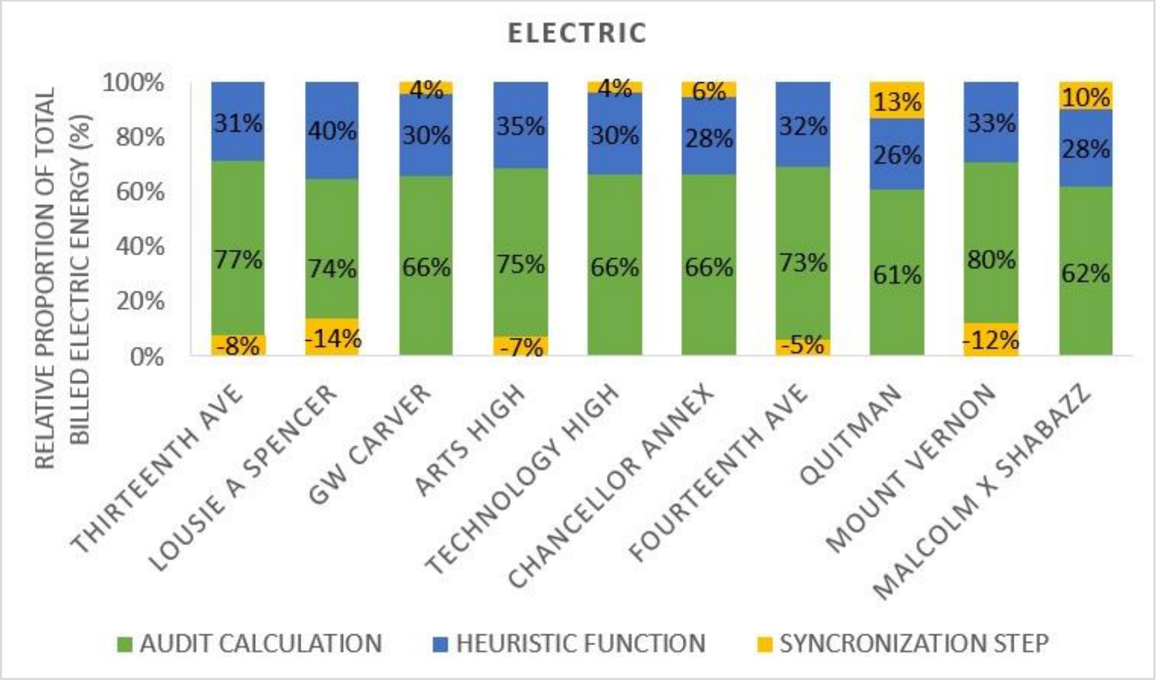


Figure 7.5 Final calibration of electrical energy data for school test group using optimized heuristic factors.

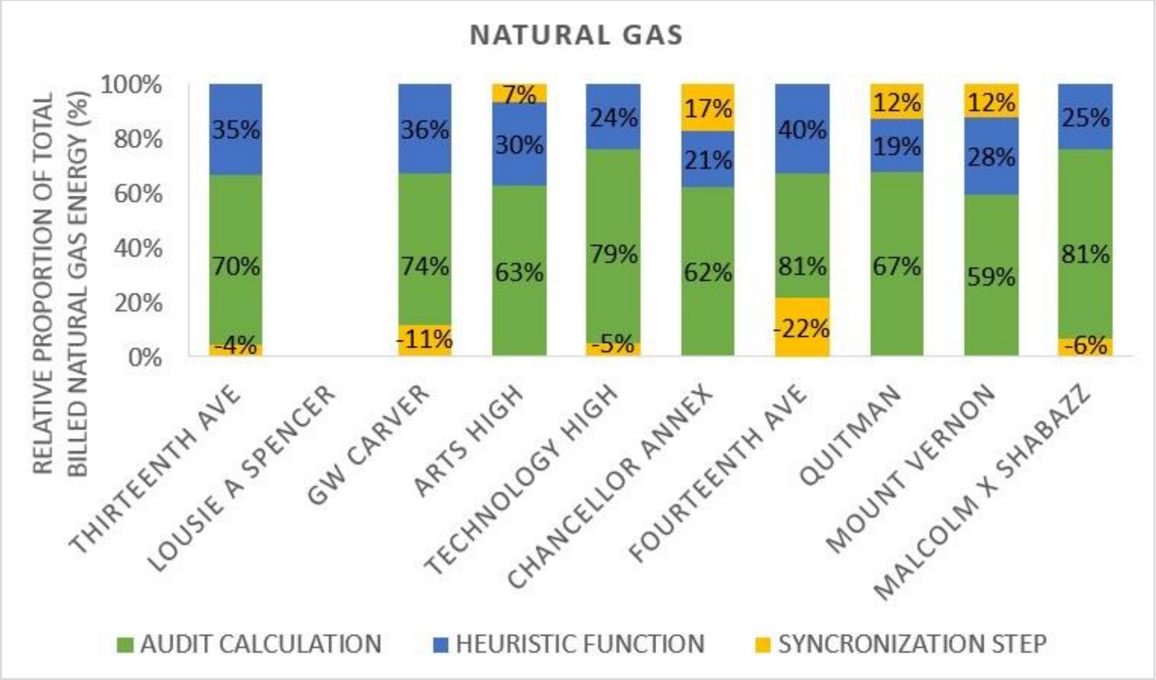


Figure 7.6 Final calibration of natural gas energy data for school test group using optimized heuristic factors.

The influence of this final calibration step is also shown in Table 7.2, which summarizes the synchronization matrices for each tested school. In the ‘perfect’ case, the sum of the initial audit and heuristic factor would exactly equal the billed energy amount, thereby making the synchronization factor zero. The ‘practical’ goal of calibration is to minimize the synchronization factor to a very limited range, which was in fact achieved as indicated in Table 7.2. The average synchronization adjustment for electrical energy ranges from -14% to 13%, with a mean net value of -0.90%. For natural gas, the average synchronization adjustment ranges from -22% to 17%, with a mean net value of 0.00%.

An examination of Table 7.2 shows seasonal variations of synchronization factors, even for the duplicate schools. It is speculated that these variations may be explained by differences in the kinds of HVAC systems and their control mechanisms. The largest variation was found for the summer season, when the occupancy and cooling loads vary widely among buildings in the school system.

While it is clear from the previous discussion that the overall calibration of the model is satisfactory, comparisons of model results between individual schools are also worth examining. Such comparisons indicate the robustness of the expert system and its applicability to a range of situations.

7.3.1 Model Repeatability

The first three schools in Table 7.1, Thirteenth Ave, Louise A Spencer, and GW Carver provided an opportunity to evaluate model repeatability in that they are all similar in type, size, and age. Reference to Figure 7.6, good agreement is apparent for natural gas between Thirteenth Ave and GW Carver with an audit calculation of 70% and 74%,

Table 7.2 Synchronization Matrices of Electric Analysis for Tested Schools.

	Thirteenth Ave	Louise A Spencer	GW Carver	Arts High	Technology High	Chancellor Annex	Fourteenth Ave	Quitman	Mount Vernon	Malcolm X Shabazz
Winter	1.20	1.01	1.37	1.05	1.28	1.09	1.24	1.18	1.18	1.27
Spring	0.94	0.72	1.20	0.90	1.03	1.05	1.02	1.11	0.91	1.01
Summer	0.66	0.89	0.87	0.89	0.92	0.96	0.57	1.05	0.59	1.01
Fall	0.89	0.83	0.72	0.87	0.94	1.15	0.98	1.16	0.84	1.10
Average	0.92	0.86	1.04	0.93	1.04	1.06	0.95	1.13	0.88	1.10
Net	-8%	-14%	4%	-7%	4%	6%	-5%	13%	-12%	10%

heuristic adjustment of 35% and 36%, respectively. Similarly as shown in Figure 7.5, the model showed good repeatability for electric usage between Thirteenth and Louise A Spencer, with audit calculation values of 77% and 74% and heuristic values of 31% and 40%, respectively. Louise A Spencer had to be excluded due to faulty utility bill data.

A second repeatability check was made by comparing Technology High with Malcolm X Shabazz, because both have the same use, same year of original construction, and both also have additions. For electric usage, the model yielded 66% and 62% for calculated, and 30% and 28% for heuristic values, respectively. Agreement of results for natural gas was similarly good, with calculated energies of 79% and 81%, and heuristic adjustments of 24% and 25%, respectively.

7.3.2 Comparing Building Age

Another interesting comparison was made between Fourteenth Avenue (built 1906) and Chancellor Ave Annex (built 1959), since they are the same use and similar size, but were built more than 50 years apart. For the electric usage, Fourteenth Avenue, which was the older, had a higher calculated result of 73% compared to Chancellor Avenue Annex’s 66%. This is as expected. The trend for natural gas was similar: Fourteenth Avenue had a calculated usage of 81% whereas Chancellor had a calculated of 62%.

Some interesting trends in the heuristic index with regard to building age were also noted between these two schools. The heuristic index is defined as the proportion of Heuristic Function to Initial Audit Analysis. A summary of the heuristic indices related to electric and natural gas for all the schools is provided in Figures 7.7 and 7.8. The heuristic index of electric usage for Fourteenth Avenue and Chancellor Avenue Annex are 44% and 43%, respectively, and so are comparable. However, the natural gas heuristic indices are 49% and 33%, respectively, meaning that the newer school, Chancellor Ave Annex is operating more efficiently with regard to the heating system. This is interesting considering that both schools have the same primary heating source, a steam boiler with radiator distribution. The same trend is apparent in the unit energy consumption, with Fourteenth Avenue at 0.4657 Therms/SF compared to Chancellor Avenue Annex at 0.3568 Therms/SF. Both building envelopes are also very similar with the same U-value for walls and windows. This leads to the conclusion that occupant behavior and system controls can have a more significant effect on usage than the age of the building.

7.3.3 Heuristic Index

In general, the heuristic index provides insight into how well or poor a building is operating. The heuristic index is defined as the proportion of Heuristic Function to Initial Audit Analysis. The significant influence of the heuristic index on energy usage is clearly seen in Figures 7.7 and 7.8. As indicated, for electric the 'best citizen' is Quitman with a heuristic index of 29%, mostly due to good occupant behavior and better system controls. The 'worst citizen' was Louise A Spencer with an index of 54%, which is nearly double. The remaining schools have results that range between 41% and 46%.

For natural gas, the 'good citizens' have a heuristic index under 35%, while the 'poor citizens' exceed 35%. The overall range for natural gas is from 29% to 50%. The best case is Quitman with 29%, while the worst case is Thirteenth Ave with 50%. It can be concluded that Quitman is the most efficiently run school of the ten schools in the test group, due to its low heuristic index for both electric and natural gas usage.

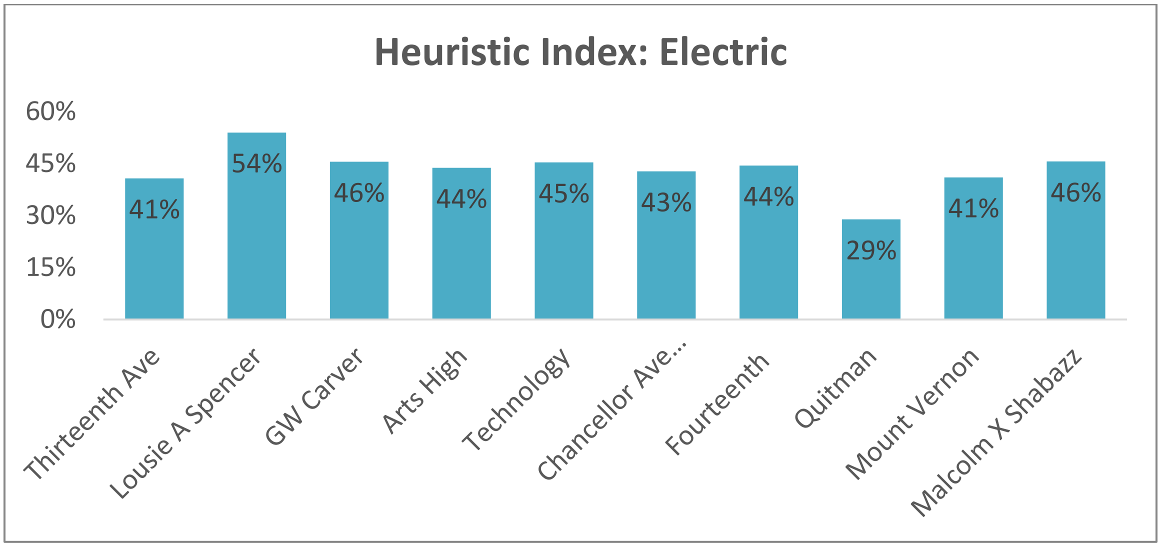


Figure 7.7 Heuristic index for electric usage.

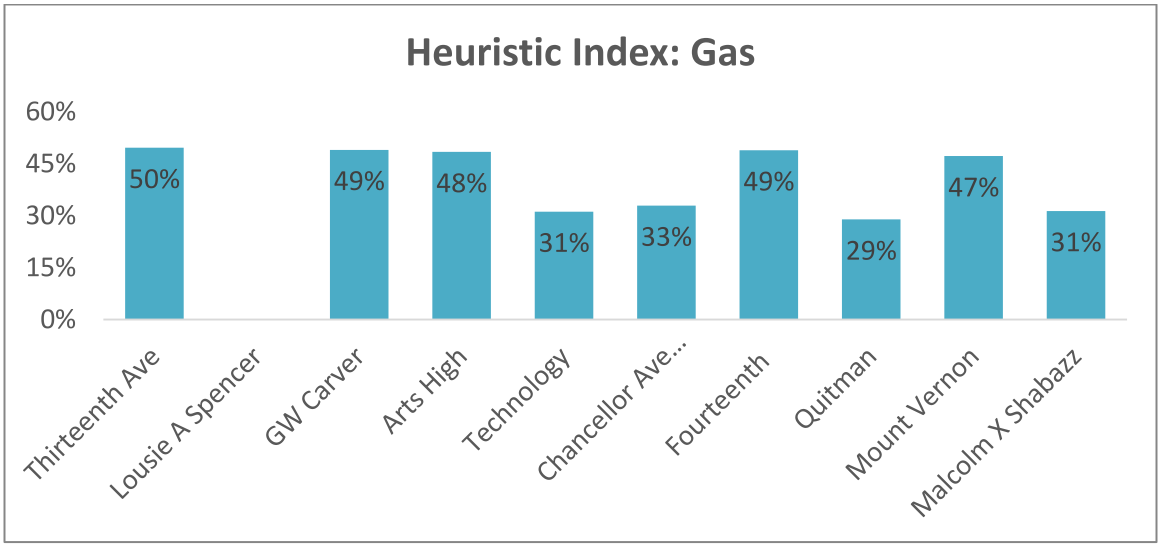


Figure 7.8 Heuristic index for natural gas usage.

7.3.4 Comparative Unit Cost Analysis

A comparison was made of the unit cost of energy per square foot for the buildings in the test group, as shown in Figure 7.9. This reveals which buildings could benefit the most by implementing energy improvements from the recommendations. It also indicates the average unit cost for both electric and natural gas usage. For electric usage, Quitman and Chancellor Annex have the highest cost per square foot and for natural gas, GW Carver and Mount Vernon are the highest. It is speculated that variations in building envelope may play a significant role in the unit cost within this test group. Thus, these several schools could see the highest savings by implementing energy saving strategies.

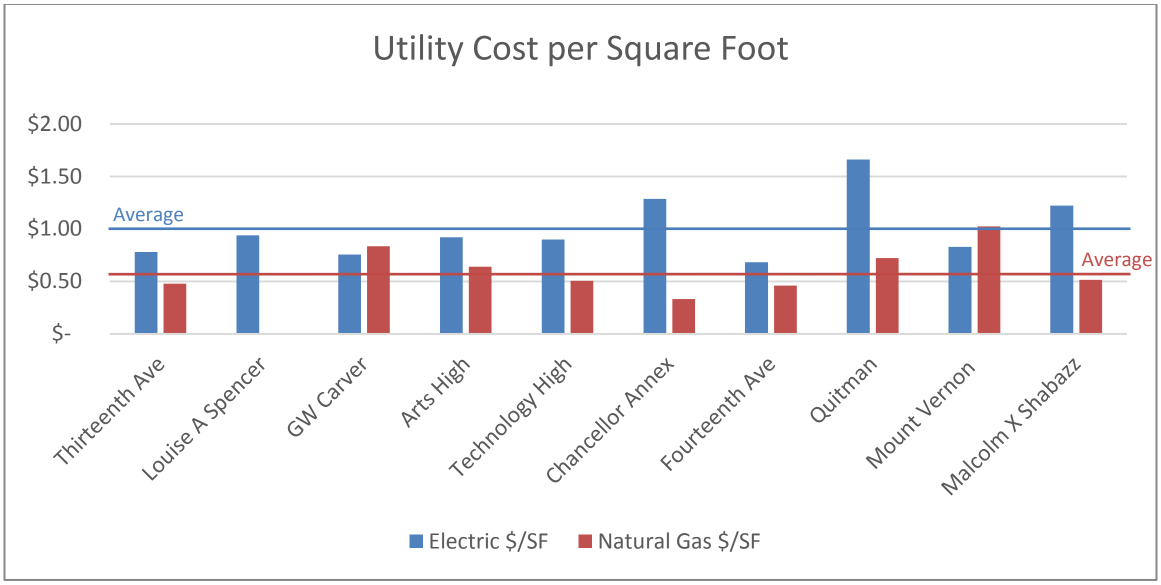


Figure 7.9 Electric and natural gas cost per square foot.

7.4 Predictive Mode

Up until this point in the study, the expert system has been used in an ‘audit’ mode to create an optimized energy model of existing conditions in the building. The expert system can also be applied in a ‘predictive mode’ to estimate savings by implementing various improvements. This is accomplished by first analyzing the building in its existing condition, followed by a second model run that includes one or more recommended upgrades.

Analysis using the predictive mode begins by running the model and calculating the total energy billed from the original building, ‘B_O.’ B_O is the sum of the percentages from the Initial Audit Analysis (IAA_O), Heuristic Function (HF_O) and Synchronization Step (SS) as described in Equation 7.2. In standard applications of the model, B_O will equal 100%. Next, a second run is made with the recommended improvements integrated into the expert system. This yields new values for the various terms as shown in Equation 7.3, including ‘B_R’, which is the new predicted billed energy following the improvement. Note that the Synchronization Step is assumed to remain the same for a single building upgrade. But for multiple upgrades, the Synchronization Step should be revaluated by backward chaining and rerunning the model for the new predicted billed energy. Finally, the difference between B_O and B_R is calculated to estimate the predicted energy savings as shown in Equation 7.4. Actual monetary savings can be found by applying these results to the yearly utility bill corresponding with the energy type.

$$B_O = IAA_O + HF_O + SS \tag{7.2}$$

$$B_R = IAA_R + HF_R + SS \tag{7.3}$$

$$Predictived\ Energy\ Savings = B_O - B_R \tag{7.4}$$

where B_O: Total energy billed percentage for original building

B_R: Total energy billed percentage for building with recommendations applied

IAA_O: Initial Audit Analysis percentage for original building

IAA_R: Initial Audit Analysis percentage for building with recommendations applied

HF_O: Heuristic Factor percentage for original building

HF_R: Heuristic Factor percentage for building with recommendations applied

SS: Synchronization Step percentage

A number of model runs were made for the test group to evaluate predicted savings for the more common energy improvements. The results show that on average a 17% reduction in energy usage is achievable by improving building management and custodial staff training. The model runs also demonstrated that energy savings range from 10% up to 19% can be realized by implementing modest cost upgrades with rapid payback, such as replacing weather stripping, appliance timers and filter maintenance.

CHAPTER 8

RESULTS AND CONCLUSIONS

8.1 General Conclusions

The objective of this study was to develop an expert system to model energy usage of commercial buildings to determine energy consumption and to recommend where energy improvements can be achieved. This research aimed to not only create a more effective and accurate energy auditing tool for a building, but also to allow owners and operators to make better decisions so that their buildings can be more sustainable and resilient. The following is a summary of the results and conclusions of the current study:

1. The software performs an Initial Audit Analysis of all the major building systems including building envelope, HVAC, lighting, office equipment and appliances, water and hot water, and waste handling. A novel feature of the expert system is that it analyzes energy flow within the building more interactively and cohesively, as opposed to looking at each system individually as do most energy analysis tools on the current market. This was accomplished by using both forward and backward chaining strategies. The result is a more accurate characterization of energy usage throughout the building.
2. During the auditing process, the software queries user habits and system controls to understand occupant behavior, which can have a significant effect on actual energy usage. Responses are analyzed using Bayesian functions to develop heuristic factors, which are then applied to the results of the Initial Audit Analysis. This ensures that

energy usage is modeled as it is used and operated, as opposed to how it was designed, which can differ significantly.

3. Once the heuristic factors are applied to audit results, the expert system performs a Synchronization Step with a forcing function to converge the calculated energy usage with actual consumption from the utility bills. This establishes a realistic model of actual energy consumption throughout the building, which allows energy efficiency to be optimized.
4. The software then generates a summary of energy consumption for each building system. The summary analysis includes usage, cost, and percent of total cost, as well as a comparison of usage per square foot to industry standards. The program also generates a list of recommended upgrades that are prioritized by cost, ease of implementation, and projected energy savings. Sustainable and resilient strategies are also recommended by the system, since it is becoming increasingly important that a building not only be "green" but also be resilient in the face of a disaster, natural or otherwise. It also identifies and directs the education and training needs for the building occupants.
5. The expert system was validated and calibrated with ten schools selected from the Newark Public Schools District in New Jersey. The test group comprised 12.7% of the total number of schools in the district and is considered significant. These K-12 buildings proved ideal in that they all had similar usage but also represented a wide range of size (40,813 sf to 316,828 sf), age (1906 – 1976), and construction type. They were also subject to the extremes of heating and cooling loads associated with the Northeast climate. Although the expert system was calibrated for the Newark

school system, the data libraries are easily modified to model any number of building types and weather regions.

6. On average, the magnitude of the initial audit calculation for electric and natural gas was determined to be 63% and 69% of the billed energy, respectively. These were deemed to be ‘reasonable’ based upon literature trends and personal experience, and thus provided a general validation of the model. As an initial calibration step, it was decided to reexamine certain assumptions and algorithms within the initial audit analysis. After the initial calibration, the range of initial audit calculations for electric and gas shifted slightly to 70%, although the ranges of the heuristic and synchronization percentages tightened and improved.
7. The final calibration step of the expert system was performed by fine tuning the heuristic factors. In general, these final adjustments substantially improved consistency among the audit and heuristic parts of the model for the ten schools. For example, the results for electric and natural gas showed average audit values of 70.0% and 70.7% with an average heuristic of 31.3% and 28.7%, respectively. The calibrated model also showed very good convergence with actual energy consumption for the ten schools as evidenced by an average synchronization adjustment of -0.9% for electric usage and 0.0% for natural gas.
8. The expert system can also be applied in a predictive mode to estimate savings by implementing various improvements. This is accomplished by first analyzing a building in its existing condition, followed by a second model run that includes one or more recommended upgrades. This typically lowers the energy usage of both the audit and heuristic analyses, which are then summed along with the original

synchronization to find the new predicted billed energy for the building. The estimated savings are simply the difference between the ‘original’ energy bill and the new ‘predicted’ energy bill.

9. A key finding for the Newark study was the wide range of the heuristic index, which measures how occupant behavior and system controls affect the energy usage within a target building. The heuristic index for the “best” test case is 29%, while for the “worst” test case it is 54%, or nearly double. Detail model results show that a well-trained staff and good building management are the most influential factors in reducing the heuristic index and thus energy consumption for a given school. The impacts of factors such as HVAC system type and construction materials on energy efficiency are found to be less significant for this test group, however.
10. Applying the expert system in the predictive mode for the Newark test group identified some specific areas of future energy improvement. Overall model results suggest that, on average, a 17% energy usage reduction is achievable by improving building management and custodial staff training. The expert system also showed that energy savings ranging from 10% up to 19% can be realized by implementing modest cost upgrades with rapid payback, such as replacing weather stripping, appliance timers, and filter maintenance.

8.2 Recommended Future Research

The first area of future research is to extend this research nationally to include other areas of the country and to various kinds of commercial buildings. This will require modifying data libraries to accurately represent climate conditions and building types. Data libraries can also be adjusted as new technologies emerge. As more buildings are analyzed with the model, further observations and comparisons of building types, uses and ages can be made.

A second area of future research is to expand the recommendations feature of the expert system to include cost analysis. So, in addition to the level of a recommendation, specific installation cost and payback will also be given. Over time, these costs would then be calibrated based on actual costs to ensure better accuracy of expected savings.

Programming language is another area of future research which is being considered. It is anticipated to transform the program from Microsoft Excel to a more advanced program such as Visual Studio. Such software features an integrated development environment (IDE) to create applications, Windows Forms, and a website interface. This would allow for easier and more widespread use.

The heuristic factors, as well as seasonal synchronization factors, are other areas that should reviewed. Developing further questions for the heuristic factor queries ought to lead to more precise results for the modules, in particular HVAC. Further investigation of the synchronization factors should also be examined to confirm the reason for seasonal variation.

It is recommended that two tools could be used to increase the accuracy of the Initial Audit Analysis. The first is a static pressure gauge, which determines negative and positive pressures within the building. This allows better quantification of building infiltration and leakage, which can be a significant factor within the building envelope module. Similarly, an infrared camera could also be used to evaluate leakage and specific areas of the building where insulation is substandard or damaged.

APPENDIX A

DATA SETS

Data sets used for the expert system are provided in the following tables.

Table A.1 Insolation and Temperature Data for Newark, New Jersey

	Max Daily Temp (°F)	Min Daily Temp (°F)	Avg Monthly Temp (°F)	Heating Degree Days Base 65°F	Cooling Degree Days Base 65°F	Total Global Radiation Btu/sq.ft.
Jan	38.5	24.3	31.4	1040	0	551.7
Feb	40.2	24.9	32.6	905	0	793
Mar	48.8	32.4	40.6	756	0	1108.7
Apr	61.2	42.2	51.7	398	0	1448.6
May	71.6	52.1	61.9	142	47	1687.1
Jun	81.1	61.6	71.4	0	196	1795.3
Jul	85.6	67.2	76.4	0	353	1759.9
Aug	83.7	65.5	74.6	0	297	1564.8
Sep	77.0	58.6	67.8	32	117	1272.9
Oct	66.9	48.1	57.5	243	11	950.9
Nov	54.2	38.2	46.2	563	0	596.2
Dec	41.5	27.4	34.5	945	0	454.4
Annual	62.5	45.2	53.9	5033	1022	1165.3

Source: (Knapp, 1980)

Table A.2 Wall Conductance for Various Wall Combinations

	Wall Combination	U factor Btu/hxft^{2}x°F	Total R
Curtain Walls	Spandral Glass, R-10 insulation board, gyp board	0.075	13.3
	Metal Wall Panel, R-10 Insulation board, gyp board	0.076	13.2
	1 in stone, R-10 insulation, gyp board	0.075	13.3
Stud Walls	Metal Wall Panel, sheathing, R-11 batt insulation, gyp board	0.074	13.6
	1 in stone, sheathing, R-11 batt insulation, gyp board	0.074	13.6
	Wood siding, sheathing, R-11 batt insulation, 1/2 in wood	0.071	14.0
	1 in stucco, sheathing, R-11 batt insulation, gyp board	0.073	13.8

	Wall Combination	U factor Btu/hxft^{2}x°F	Total R
EIFS	EIFS finish, R-5 insulation board, sheathing, gyp board	0.118	8.5
	EIFS finish, R-5 insulation board, sheathing, R-11 batt insulation, gyp board	0.054	18.6
	EIFS finish, R-5 insulation board, sheathing, 8 in LW CMU, gyp board	0.092	10.8
Brick Walls	Brick, R-5 insulation board, sheathing, gyp board	0.101	9.9
	Brick, sheathing, R-11 batt insulation, gyp board	0.066	15.1
	Brick, R-5 insulation board, sheathing, R-11 batt insulation, gyp board	0.050	20.1
	Brick, R-5 insulation board, 8 in LW CMU	0.102	9.8
	Brick, 8 in LW CMU, R-11 batt insulation, gyp board	0.061	16.3
	Brick, R-5 insulation board, 8 in HW CMU, gyp board	0.111	9.0
	Brick, R-5 insulation board, brick	0.124	8.1
	Brick, R-5 insulation board, 8 in LW concrete, gyp board	0.091	11.0
	Brick, R-5 insulation board, 12 in HW concrete, gyp board	0.102	9.8
	Brick, 8 in HW concrete, R-11 batt insulation, gyp board	0.068	14.6
Concrete Block Wall	8 in LW CMU, R-11 batt insulation, gyp board	0.067	14.8
	8 in LW CMU with fill insulation, R-11 batt insulation, gyp board	0.059	16.9
	1 in stucco, 8 in HW CMU, R-11 batt insulation, gyp board	0.073	13.7
	8 in LW CMU with fill insulation	0.186	5.4
	8 in LW CMU with fill insulation, gyp board	0.147	6.8
	12 in LW CMU with fill insulation, gyp board	0.121	8.2
Precast and Cast-in-Place Concrete Walls	4 in LW concrete, R-5 board insulation, gyp board	0.118	8.4
	4 in LW concrete, R-11 batt insulation, gyp board	0.074	13.6
	4 in LW concrete, R-10 board insulation, 4 in LW concrete	0.076	13.1
	EIFS finish, R-5 insulation board, 8 in LW concrete, gyp board	0.115	8.7
	8 in LW concrete, R-11 batt insulation, gyp board	0.068	14.7

	Wall Combination	U factor Btu/hxft^{2}x°F	Total R
	EIFS finish, R-10 insulation board, 8 in HW concrete, gyp board	0.082	12.2
	8 in HW concrete, R-11 batt insulation, gyp board	0.076	13.1
	12 in HW concrete, R-19 batt insulation, gyp board	0.047	21.4
	12 in HW concrete	0.550	1.8

Source: (Sauer, 1998)

Table A.3 Roof Conductance for Various Roof Combinations

	Roof Combination	U Factor Btu/h*ft^2*F	Total R
Sloped Frame Roofs	Metal roof, R-19 batt insulation, gyp board	0.044	22.8
	Metal roof, R-19 batt insulation, suspended acoustical ceiling	0.040	25.0
	Metal roof, R-19 batt insulation	0.045	22.2
	Asphalt shingles, wood sheathing, R-19 batt insulation, gyp board	0.041	24.1
	Slate or tile, wood sheathing, R-19 batt insulation, gyp board	0.042	23.7
	Wood shingles, wood sheathing, R-19 batt insulation, gyp board	0.041	24.6
Wood Deck	Membrane, sheathing, R-10 insulation board, wood deck	0.690	14.5
	Membrane, sheathing, R-10 insulation board, wood deck, suspended acoustical ceiling	0.058	17.2
Metal Deck Roofs	Membrane, sheathing, R-10 insulation board, metal deck	0.080	12.6
	Membrane, sheathing, R-10 insulation board, metal deck, suspended acoustical ceiling	0.065	15.4
	Membrane, sheathing, R-15 insulation board, metal deck	0.057	17.6
	Membrane, sheathing, R-10 plus R-15 insulation boards, metal deck	0.036	27.6
	2 in concrete roof ballast, membrane, sheathing, R-15 insulation board, metal deck	0.052	19.1
Concrete Roofs	Membrane, sheathing, R-15 insulation boards, 4 in LW concrete	0.054	18.6
	Membrane, sheathing, R-15 insulation boards, 6 in LW concrete	0.052	19.2
	Membrane, sheathing, R-15 insulation boards, 8 in LW concrete	0.051	19.7
	Membrane, sheathing, R-15 insulation boards, 6 in HW concrete	0.056	18.0
	Membrane, sheathing, R-15 insulation boards, 8 in HW concrete	0.055	18.2
	Membrane, 6 in HW concrete, R-19 batt insulation, suspended acoustical ceiling	0.042	23.7

Source: (Sauer, 1998).

Table A.4 Rates of Heat Gain from Occupants

	Total Heat Btu/h		
Degree of Activity	Adult Male	Adjusted M/F	Child
Seated, very light work	450	400	338
Moderately active office work	475	450	356
Standing, light work, walking	550	450	413
Athletics	2000	1800	1500

Source: (Sauer, 1998).

Table A.5 Typical Non-Incandescent Light Fixtures

		Description	Ballast	Watts per Lamp	Lamps per Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Compact Fluorescent Fixtures		Twin, (1) 5W lamp	Mag-Std	5	1	5	9	1.80
		Twin, (1) 7W lamp	Mag-Std	7	1	7	10	1.43
		Twin, (1) 9W lamp	Mag-Std	9	1	9	11	1.22
		Quad, (1) 13W lamp	Mag-Std	13	1	13	17	1.31
		Quad, (2) 18W lamp	Mag-Std	18	2	36	45	1.25
		Quad, (2) 22W lamp	Mag-Std	22	2	44	48	1.09
		Quad, (2) 26W lamp	Mag-Std	26	2	52	66	1.27
		Twin, (2) 40W lamp	Mag-Std	40	2	80	85	1.06
		Quad, (1) 13W lamp	Elec.	13	1	13	15	1.15
		Quad, (1) 26W lamp	Elec.	26	1	26	27	1.04
		Quad, (2) 18W lamp	Elec.	18	2	18	38	1.06
		Quad, (2) 26W lamp	Elec.	26	2	26	50	0.96
		Twin or multi, (2) 32W lamp	Elec.	32	2	32	62	0.97
Fluorescent Fixtures	1	18 in., T8 lamp	Mag-Std	15	1	15	19	1.27
	1	18 in., T12 lamp	Mag-Std	15	1	15	19	1.27
	2	18 in., T8 lamp	Mag-Std	15	2	30	36	1.2
	2	18 in., T12 lamp	Mag-Std	15	2	30	36	1.2
	1	24 in., T8 lamp	Mag-Std	17	1	17	24	1.41
	1	24 in., T12 lamp	Mag-Std	20	1	20	28	1.4
	2	24 in., T12 lamp	Mag-Std	20	2	40	56	1.4
	1	24 in., T12 HO lamp	Mag-Std	35	1	35	62	1.77
	2	24 in., T12 HO lamp	Mag-Std	35	2	70	90	1.29
	1	24 in., T8 lamp	Elec.	17	1	17	16	0.94
	2	24 in., T8 lamp	Elec.	17	2	34	31	0.91
	1	36 in., T12 lamp	Mag-Std	30	1	30	46	1.53
	2	36 in., T12 lamp	Mag-Std	30	2	60	81	1.35
	1	36 in., T12 ES lamp	Mag-Std	25	1	25	42	1.68

		Description	Ballast	Watts per Lamp	Lamps per Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Fluorescent Fixtures	2	36 in., T12 ES lamp	Mag-Std	25	2	50	73	1.46
	1	36 in., T12 HO lamp	Mag-Std	50	1	50	70	1.4
	2	36 in., T12 HO lamp	Mag-Std	50	2	100	114	1.14
	2	36 in., T12 lamp	Mag -ES	30	2	60	74	1.23
	2	36 in., T12 ES lamp	Mag -ES	25	2	50	66	1.32
	1	36 in., T12 lamp	Elec.	30	1	30	31	1.03
	1	36 in., T12 ES lamp	Elec.	25	1	25	26	1.04
	1	36 in., T8 lamp	Elec.	25	1	25	24	0.96
	2	36 in., T12 lamp	Elec.	30	2	60	58	0.97
	2	36 in., T12 ES lamp	Elec.	25	2	50	50	1
	2	36 in., T8 lamp	Elec.	25	2	50	46	0.92
	2	36 in., T8 HO lamp	Elec.	25	2	50	50	1
	2	36 in., T8 VHO lamp	Elec.	25	2	50	70	1.4
	1	48 in., T12 lamp	Mag-Std	40	1	40	55	1.38
	2	48 in., T12 lamp	Mag-Std	40	2	80	92	1.15
	3	48 in., T12 lamp	Mag-Std	40	3	120	140	1.17
	4	48 in., T12 lamp	Mag-Std	40	4	160	184	1.15
	1	48 in., T12 ES lamp	Mag-Std	34	1	34	48	1.41
	2	48 in., T12 ES lamp	Mag-Std	34	2	68	82	1.21
	3	48 in., T12 ES lamp	Mag-Std	34	3	102	100	0.98
	4	48 in., T12 ES lamp	Mag-Std	34	4	136	164	1.21
	1	48 in., T12 ES lamp	Mag-ES	34	1	34	43	1.26
	2	48 in., T12 ES lamp	Mag-ES	34	2	68	72	1.06
	3	48 in., T12 ES lamp	Mag-ES	34	3	102	115	1.13
	4	48 in., T12 ES lamp	Mag-ES	34	4	136	144	1.06
	1	48 in., T12 lamp	Mag-ES	32	1	32	35	1.09
	2	48 in., T12 lamp	Mag-ES	32	2	64	71	1.11
	3	48 in., T12 lamp	Mag-ES	32	3	96	110	1.15
	4	48 in., T12 lamp	Mag-ES	32	4	128	142	1.11
	1	48 in., T12 ES lamp	Elec.	34	1	34	32	0.94
	2	48 in., T12 ES lamp	Elec.	34	2	68	60	0.88
	3	48 in., T12 ES lamp	Elec.	34	3	102	92	0.9
	4	48 in., T12 ES lamp	Elec.	34	4	136	120	0.88
	1	48 in., T8 lamp	Elec.	32	1	32	32	1
	2	48 in., T8 lamp	Elec.	32	2	64	60	0.94
	3	48 in., T8 lamp	Elec.	32	3	96	93	0.97
	4	48 in., T8 lamp	Elec.	32	4	128	120	0.94
	1	60 in., T12 lamp	Mag-Std	50	1	50	63	1.26
	2	60 in., T12 lamp	Mag-Std	50	2	100	128	1.28
	1	60 in., T12 HO lamp	Mag-Std	75	1	75	92	1.23

		Description	Ballast	Watts per Lamp	Lamps per Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Fluorescent Fixtures	2	60 in., T12 HO lamp	Mag-Std	75	2	150	168	1.12
	1	60 in., T12 ES VHO lamp	Mag-Std	135	1	135	165	1.22
	2	60 in., T12 ES VHO lamp	Mag-Std	135	2	270	310	1.15
	1	60 in., T12 HO lamp	Mag-ES	75	1	75	88	1.17
	2	60 in., T12 HO lamp	Mag-ES	75	2	150	176	1.17
	1	60 in., T12 lamp	Elec.	50	1	50	44	0.88
	2	60 in., T12 lamp	Elec.	50	2	100	88	0.88
	1	60 in., T12 HO lamp	Elec.	75	1	75	69	0.92
	2	60 in., T12 HO lamp	Elec.	75	2	150	138	0.92
	1	60 in., T8 lamp	Elec.	40	1	40	36	0.9
	2	60 in., T8 lamp	Elec.	40	2	80	72	0.9
	3	60 in., T8 lamp	Elec.	40	3	120	106	0.88
	4	60 in., T8 lamp	Elec.	40	4	160	134	0.84
	1	72 in., T12 lamp	Mag-Std	55	1	55	76	1.38
	2	72 in., T12 lamp	Mag-Std	55	2	110	122	1.11
	3	72 in., T12 lamp	Mag-Std	55	3	165	202	1.22
	4	72 in., T12 lamp	Mag-Std	55	4	220	244	1.11
	1	72 in., T12 HO lamp	Mag-Std	85	1	85	120	1.41
	2	72 in., T12 HO lamp	Mag-Std	85	2	170	220	1.29
	1	72 in., T12 VHO lamp	Mag-Std	160	1	160	180	1.13
	2	72 in., T12 VHO lamp	Mag-Std	160	2	320	330	1.03
	2	72 in., T12 lamp	Mag-ES	55	2	110	122	1.11
	4	72 in., T12 lamp	Mag-ES	55	4	220	244	1.11
	2	72 in., T12 HO lamp	Mag-ES	85	2	170	194	1.14
	4	72 in., T12 HO lamp	Mag-ES	85	4	340	388	1.14
	1	72 in., T12 lamp	Elec.	55	1	55	68	1.24
	2	72 in., T12 lamp	Elec.	55	2	110	108	0.98
	3	72 in., T12 lamp	Elec.	55	3	165	176	1.07
	4	72 in., T12 lamp	Elec.	55	4	220	216	0.98
	1	96 in., T12 ES lamp	Mag-Std	60	1	60	75	1.25
	2	96 in., T12 ES lamp	Mag-Std	60	2	120	128	1.07
	3	96 in., T12 ES lamp	Mag-Std	60	3	180	203	1.13
	4	96 in., T12 ES lamp	Mag-Std	60	4	240	256	1.07
	1	96 in., T12 ES HO lamp	Mag-Std	95	1	95	112	1.18
	2	96 in., T12 ES HO lamp	Mag-Std	95	2	190	227	1.19
	3	96 in., T12 ES HO lamp	Mag-Std	95	3	285	380	1.33
	4	96 in., T12 ES HO	Mag-Std	95	4	380	454	1.19

		Description	Ballast	Watts per Lamp	Lamps per Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Fluorescent Fixtures	1	96 in., T12 ES VHO lamp	Mag-Std	185	1	185	205	1.11
	2	96 in., T12 ES VHO lamp	Mag-Std	185	2	370	380	1.03
	3	96 in., T12 ES VHO lamp	Mag-Std	185	3	555	585	1.05
	4	96 in., T12 ES VHO lamp	Mag-Std	185	4	740	760	1.03
	2	96 in., T12 ES lamp	Mag-ES	60	2	120	120	1.03
	3	96 in., T12 ES lamp	Mag-ES	60	3	180	210	1.17
	4	96 in., T12 ES lamp	Mag-ES	60	4	240	246	1.03
	2	96 in., T12 ES HO lamp	Mag-ES	95	2	190	207	1.09
	4	96 in., T12 ES HO lamp	Mag-ES	95	4	380	414	1.09
	1	96 in., T12 ES lamp	Elec.	60	1	60	69	1.15
	2	96 in., T12 ES lamp	Elec.	60	2	120	110	0.92
	3	96 in., T12 ES lamp	Elec.	60	3	180	179	0.99
	4	96 in., T12 ES lamp	Elec.	60	4	240	220	0.92
	1	96 in., T12 ES HO lamp	Elec.	95	1	95	80	0.84
	2	96 in., T12 ES HO lamp	Elec.	95	2	190	173	0.91
	4	96 in., T12 ES HO lamp	Elec.	95	4	380	346	0.91
	1	96 in., T8 lamp	Elec.	59	1	59	58	0.98
	1	96 in., T8 HO lamp	Elec.	59	1	59	68	1.15
	1	96 in., T8 VHO lamp	Elec.	59	1	59	71	1.2
	2	96 in., T8 lamp	Elec.	59	2	118	109	0.92
	3	96 in., T8 lamp	Elec.	59	3	177	167	0.94
	4	96 in., T8 lamp	Elec.	59	4	236	219	0.93
	2	96 in., T8 HO lamp	Elec.	86	2	172	160	0.93
	4	96 in., T8 HO lamp	Elec.	86	4	344	320	0.93
Circular Fluorescent Fixtures		Circlite, (1) 20W lamp	Mag-PH	20	1	20	20	1
		Circlite, (1) 22W lamp	Mag-PH	22	1	22	20	0.91
		Circlite, (1) 32W lamp	Mag-PH	32	1	32	40	1.25
		(1) 6 in. circular lamp	Mag-RS	20	1	20	25	1.25
		(1) 8 in. circular lamp	Mag-RS	22	1	22	26	1.18
		(2) 8 in. circular lamp	Mag-RS	22	2	44	52	1.18
		(1) 12 in. circular lamp	Mag-RS	32	1	32	31	0.97

		Description	Ballast	Watts per Lamp	Lamps per Fixture	Lamp Watts	Fixture Watts	Special Allowance Factor
Circular Fluorescent Fixtures		(2) 12 in. circular lamp	Mag-RS	32	2	64	62	0.97
		(1) 16 in. circular lamp	Mag-Std	40	1	40	35	0.88
High Pressure Sodium Fixtures	1	35W lamp	HID	35	1	35	46	1.31
	1	50W lamp	HID	50	1	50	66	1.32
	1	70W lamp	HID	70	1	70	95	1.36
	1	100W lamp	HID	100	1	100	138	1.38
	1	150W lamp	HID	150	1	150	188	1.25
	1	200W lamp	HID	200	1	200	250	1.25
	1	250W lamp	HID	250	1	250	295	1.18
	1	310W lamp	HID	310	1	310	365	1.18
	1	360W lamp	HID	360	1	360	414	1.15
	1	400W lamp	HID	400	1	400	465	1.16
	1	1000W lamp	HID	1000	1	1000	1100	1.1
Metal Halide Fixtures	1	32W lamp	HID	32	1	32	43	1.34
	1	50W lamp	HID	50	1	50	72	1.44
	1	70W lamp	HID	70	1	70	95	1.36
	1	100W lamp	HID	100	1	100	128	1.28
	1	150W lamp	HID	150	1	150	190	1.27
	1	175W lamp	HID	175	1	175	215	1.23
	1	250W lamp	HID	250	1	250	295	1.18
	1	400W lamp	HID	400	1	400	458	1.15
	2	4000W lamp	HID	400	2	800	916	1.15
	1	750W lamp	HID	750	1	750	850	1.13
	1	1000W lamp	HID	1000	1	1000	1080	1.08
	1	1500W lamp	HID	1500	1	1500	1610	1.07
Mercury Vapor Fixtures	1	40W lamp	HID	40	1	40	50	1.25
	1	50W lamp	HID	50	1	50	74	1.48
	1	70W lamp	HID	75	1	75	93	1.24
	1	100W lamp	HID	100	1	100	125	1.25
	1	175W lamp	HID	175	1	175	205	1.17
	1	250W lamp	HID	250	1	250	290	1.16
	1	400W lamp	HID	400	1	400	455	1.14
	2	400W lamp	HID	400	2	800	910	1.14
	1	700W lamp	HID	700	1	700	780	1.11
	1	1000W lamp	HID	1000	1	1000	1075	1.08

Source: (Sauer, 1998).

Table A.6 Heat Gain from Typical Commercial Appliances

Appliance	Size	Energy Rate Rated (Btu/h)	Recommended Rate of Heat Gain, (Btu/h) Sensible	Latent	Total
Microwave Oven (residential type)	1 ft^3	2050 to 4780	2050 to 4780	-	2050 to 4780
Refrigerator (small)	6 to 25ft^3	1670	665	-	655
Toaster (small pop-up)	4 slices	8430	4470	3960	8430

Source: (Sauer, 1998).

Table A.7 Recommended Heat Gain from Miscellaneous Office Equipment

Appliance	Max Input Rating (Btu/h)	Recommended Rate of Heat Gain, (Btu/h)
Vending Machine cold beverage	3924 to 6551	1962 to 3275
Microwave oven, 1 ft^3	2047	1365

Source: (Sauer, 1998).

Table A.8 Recommended Heat Gain from Typical Computer Equipment

Computers	Continuous (Btu/h)	Energy Saver Mode (Btu/h)
Average value	188	68
Conservative value	222	85
Highly conservative value	256	102
Monitors (not flat screen)		
Small (13 to 15 in.)	188	0
Medium (16 to 18 in.)	239	0
Large (19 to 20 in.)	273	0

Source: (Sauer, 1998).

Table A.9 Recommended Heat Gain from Typical Laser Printers and Copiers

Laser Printers	Continuous (Btu/h)	1 page per min (Btu/h)	Idle (Btu/h)
Small Desktop			
Desktop	734	341	119
Small Office	1092	546	239
Large Office	1877	938	427
Copiers			
Desktop	1365	290	68
Office	3753	1365	1024

Source: (Sauer, 1998).

Table A.10 Glazing and Window Systems

	Glazing System				Center of Glazing Properties Incidence Angle	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing			Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Single Glazing	1/8	CLR	0.9	SHGC	0.86	0.75	0.78	0.64	0.75	0.77	0.8	0.66	0.78
				T	0.83								
				Rf	0.08								
				Rb	0.08								
				Afn	0.09								
	1/4	CLR	0.880	SHGC	0.81	0.71	0.74	0.6	0.71	0.75	0.79	0.64	0.77
				T	0.88								
				Rf	0.08								
				Rb	0.08								
				Afn	0.16								
	1/8	BRZ	0.680	SHGC	0.73	0.64	0.67	0.54	0.64	0.58	0.61	0.5	0.59
				T	0.65								
				Rf	0.06								
				Rb	0.06								
				Afn	0.29								
	1/4	BRZ	0.540	SHGC	0.62	0.54	0.56	0.46	0.54	0.45	0.48	0.39	0.47
				T	0.49								
				Rf	0.05								
				Rb	0.05								
				Afn	0.46								

	Glazing System				Center of Glazing Properties	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing		Incidence Angle	Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Single Glazing	1/8	GRN	0.820	SHGC	0.7	0.62	0.64	0.52	0.61	0.7	0.73	0.6	0.71
				T	0.61								
				Rf	0.06								
				Rb	0.06								
				Afn	0.33								
	1/4	GRN	0.760	SHGC	0.6	0.53	0.55	0.45	0.53	0.65	0.68	0.55	0.66
				T	0.47								
				Rf	0.05								
				Rb	0.05								
				Afn	0.47								
	1/8	GRY	0.620	SHGC	0.7	0.62	0.64	0.52	0.61	0.52	0.55	0.45	0.54
				T	0.61								
				Rf	0.06								
				Rb	0.06								
				Afn	0.33								
	1/4	GRY	0.460	SHGC	0.59	0.53	0.54	0.44	0.52	0.39	0.41	0.34	0.4
				T	0.46								
				Rf	0.05								
				Rb	0.05								
				Afn	0.49								
	1/4	BLU GRN	0.75	SHGC	0.62	0.55	0.57	0.46	0.54	0.64	0.67	0.55	0.65
				T	0.49								
				Rf	0.06								

	Glazing System				Center of Glazing Properties	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing		Incidence Angle	Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
				Rb	0.06								
				Afn	0.45								
Reflective Single Glazing	1/4	SS on CLR 8%	0.08	SHGC	0.19	0.18	0.18	,15	0.17	,07	0.07	0.06	0.07
				T	0.06								
				Rf	0.33								
				Rb	0.5								
				Afn	0.61								
	1/4	SS on CLR 14%	0.14	SHGC	0.25	0.23	0.24	0.19	0.22	0.12	0.12	0.1	0.12
				T	0.11								
				Rf	0.26								
				Rb	0.44								
				Afn									
	1/4	SS on CLR 20%	0.2	SHGC	0.31	0.28	0.29	0.24	0.27	0.17	0.18	0.15	0.17
				T	0.15								
				Rf	0.21								
				Rb	0.38								
				Afn	0.64								

	Glazing System				Center of Glazing Properties	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing		Incidence Angle	Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Reflective Single Glazing	1/4	SS on GRN 14%	0.12	SHGC	0.25	0.23	0.24	0.19	0.22	0.1	0.11	0.09	0.1
				T	0.06								
				Rf	0.14								
				Rb	0.44								
				Afn	0.8								
	1/4	TI on CLR 20%	0.2	SHGC	0.29	0.27	0.27	0.22	0.26	0.17	0.18	0.15	0.17
				T	0.14								
				Rf	0.22								
				Rb	0.4								
				Afn	0.65								
	1/4	TI on CLR 30%	0.3	SHGC	0.39	0.35	0.36	0.3	0.34	0.26	0.27	0.22	0.26
				T	0.23								
				Rf	0.15								
				Rb	0.32								
				Afn	0.63								

	Glazing System				Center of Glazing Properties	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing		Incidence Angle	Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Double Glazing	1/8	CLR CLR	0.81	SHGC	0.76	0.67	0.69	0.56	0.66	0.69	0.72	0.59	0.7
				T	0.7								
				Rf	0.13								
				Rb	0.13								
				Af1	0.1								
				Af2	0.07								
	1/4	CLR CLR	0.78	SHGC	0.7	0.61	0.63	0.52	0.61	0.66	0.69	0.57	0.68
				T	0.61								
				Rf	0.11								
				Rb	0.11								
				Af1	0.17								
				Af2	0.11								
	1/8	BRZ CLR	0.62	SHGC	0.62	0.55	0.57	0.46	0.54	0.53	0.55	0.45	0.54
				T	0.55								
				Rf	0.09								
				Rb	0.12								
				Af1	0.3								
				Af2	0.06								
	1/4	BRZ CLR	0.47	SHGC	0.49	0.44	0.46	0.37	0.43	0.4	0.42	0.35	0.41

	Glazing System				Center of Glazing Properties Incidence Angle	Total Window SHGC at Normal Incidence				Total Window Tv at Normal Incidence			
	Glass		Center Glazing			Aluminum		Other Frames		Aluminum		Other Frames	
Type	Thickness	Color	Tv		Normal 0.00	Operable	Fixed	Operable	Fixed	Operable	Fixed	Operable	Fixed
Uncoated Double Glazing				T	0.38								
				Rf	0.07								
				Rb	0.1								
				Af1	0.48								
				Af2	0.07								
	1/8	GRN CLR	0.75	SHGC	0.6	0.53	0.55	0.45	0.53	0.63	0.66	0.54	0.65
				T	0.52								
				Rf	0.09								
				Rb	0.12								
				Af1	0.34								
				Af2	0.05								
	1/4	GRN CLR	0.68	SHGC	0.49	0.43	0.45	0.37	0.43	0.57	0.6	0.49	0.59
				T	0.39								
				Rf	0.08								
				Rb	0.1								
				Af1	0.49								
				Af2	0.05								

Source: (Sauer, 1998).

Table A.11 Interior Solar Attenuation Coefficients (IAC) for Single or Double Glazings Shaded by Interior Venetian Blinds or Roller Shades

Glazing System	Nominal thickness each pane, (in)	Glazing Solar Transmittance		Glazing SHGC	IAC				
					Venetian Blinds		Roller Shades		
		Outer Pane	Single or Inner Pane		Medium	Light	Opaque Dark	Opaque White	Translucent Light
Single Glazing Systems									
Clear, residential	1/8		.87 to .80	0.86	0.75	0.68	0.82	0.4	0.45
Clear, commercial	1/4 to 1/2		.80 to .71	0.82					
Clear, pattern	1/8 to 1/2		.87 to .79						
Heat absorbing, pattern	1/8			0.59					
Tinted	3/16, 7/32		.74, .71						
Above glazings, automated blinds				0.86	0.64	0.59			
Above glazings, tightly closed vertical blinds				0.85	0.3	0.26			
Heat absorbing	1/4		0.46	0.59	0.84	0.78	0.66	0.44	0.47
Heat absorbing, pattern	1/4								
Tinted	1/8, 1/4		.59, .45						
Heat absorbing or pattern			.44 to .30	0.59	0.79	0.76	0.59	0.41	0.47
Heat absorbing	3/8		0.34						
Heat absorbing or pattern			0.24	0.37	0.99	0.94	0.85	0.66	0.73
Reflective coated glass				.26 to .52	0.83	0.75			
Double Glazing Systems									
Clear double, residential	1/8	0.87	0.87	0.76	0.71	0.66	0.81	0.4	0.46
Clear double, commercial	1/4	0.8	0.8	0.7					
Heat Absorbing double	1/4	0.46	0.8	47	0.72	0.66	0.74	0.41	0.55
Reflective Double				.17 to .35	0.9	0.86			

Source: (Sauer, 1998).

Table A.12 Representative Fenestration Frame U factors in (Btu/h×ft^2×°F) - Vertical Orientation

		Operable			Fixed			Garden Window	
Frame Material	Type of Spacer	Single	Double	Triple	Single	Double	Triple	Single	Double
Aluminum without thermal break	All	2.38	2.27	2.2	1.92	1.8	1.74	1.88	1.83
Aluminum with thermal break	Metal	1.2	0.92	0.83	1.32	1.13	1.11		
	Insulated	n/a	0.88	0.77	n/a	1.04	1.02		
Aluminum-clad wood/reinforced vinyl	Metal	0.6	0.58	0.51	0.55	0.51	0.48		
	Insulated	n/a	0.55	0.48	n/a	0.48	0.44		
Wood/Vinyl	Metal	0.55	0.51	0.48	0.55	0.48	0.42	0.9	0.85
	Insulated	n/a	0.49	0.4	n/a	0.42	0.35	n/a	0.83
Insulated fiberglass / vinyl	Metal	0.37	0.33	0.32	0.37	0.33	0.32		
	Insulated	n/a	0.32	0.26	n/a	0.32	0.36		
Structural glazing	Metal								
	Insulated								

	Type of	Plant Assembled Skylight			Curtain Wall			Sloped/Overhead Glazing		
Frame Material	Spacer	Single	Double	Triple	Single	Double	Triple	Single	Double	Triple
Aluminum without thermal break	All	7.85	7.02	6.87	3.01	2.96	2.83	3.05	3	2.87
Aluminum with thermal break	Metal	6.95	5.05	4.58	1.8	1.75	1.65	1.82	1.76	1.66
	Insulated	n/a	4.75	4.12	n/a	1.63	1.51	n/a	1.64	1.52
Aluminum-clad wood/reinforced vinyl	Metal	4.86	3.93	3.66						
	Insulated	n/a	3.75	3.43						
Wood/Vinyl	Metal	2.5	2.08	1.78						
	Insulated	n/a	2.02	1.71						
Insulated fiberglass / vinyl	Metal									
	Insulated									
Structural glazing	Metal				1.8	1.27	1.04	1.82	1.28	1.05
	Insulated				n/a	1.02	0.75	n/a	1.02	0.75

Source: (ASHRAE, 2001).

Table A.13 Representative Fenestration Frame U Factors (Btu/hxft^{2}x°F)

Door Type	No Glazing	Single Glazing	Double Glazing with 1/2 in. Air Space	Double Glazing with e=.10, 1/2 in. Argon
SWINGING DOORS (Rough Opening - 38 in. x 82 in.)				
Slab doors				
Wood Slab in Wood Frame	0.46			
6% glazing (22in x 8in lite)	-	0.48	0.46	0.44
25% glazing (22in x 36in lite)	-	0.58	0.46	0.42
45% glazing (22in x 64in lite)	-	0.69	0.46	0.39
More than 50% glazing				
Insulated Steel Slab with Wood Edge in wood frames	0.16			
6% glazing (22in x 8in lite)	-	0.21	0.19	0.18
25% glazing (22in x 36in lite)	-	0.39	0.26	0.23
45% glazing (22in x 64in lite)	-	0.58	0.35	0.26
More than 50% glazing				
Foam insulated steel slab with metal edge in steel frame	0.37			
6% glazing (22in x 8in lite)	-	0.44	0.41	0.39
25% glazing (22in x 36in lite)	-	0.55	0.48	0.44
45% glazing (22in x 64in lite)	-	0.71	0.56	0.48
More than 50% glazing				
Cardboard honeycomb slab with metal edge in steel frame	0.61			
Stile-Assembled-Stile -and-Rail doors				
Aluminum in aluminum frame	-	1.32	0.93	0.79
Aluminum in aluminum frame with thermal break	-	1.13	0.74	0.63
REVOLVING DOORS (rough opening - 82 in. x 84 in.)				
Aluminum in aluminum frame				
Open	-	1.32	-	-
Closed	-	0.65	-	-
SECTIONAL OVERHEAD DOORS (Nominal - 10 ft x 10 ft)				
Annunciated Steel (nominal U=1.15)	1.15	-	-	-
Insulated Steel (nominal U=0.11)	0.24	-	-	-
Insulated Steel with thermal break (nominal U=.08)	0.13	-	-	-

Source: (ASHRAE, 2001).

Table A.14 Hot Water Demand and Use for Various Types of Buildings

	Max. Hour (gal/student)	Max. Day (gal/student)	Average Day (gal/student) per day of operation
Elementary School	0.6	1.5	0.6
High School	1	3.6	1.8

Source: (ASHRAE, 1999).

Table A.15 Hot Water Demand per Fixture for Various Types of Buildings

Fixture	(gal/hour/fixture)
Basins, private lavatory	2
Basins, public lavatory	15
Dishwashers	20-100
Foot basins	3
Kitchen sink	20
Pantry sink	10
Showers	225
Service sink	20
Circular wash sinks	30
Demand Factor	0.4
Storage Capacity Factor	1

Source: (ASHRAE, 1999).

Table A.16 Water Conserving Plumbing Fixtures

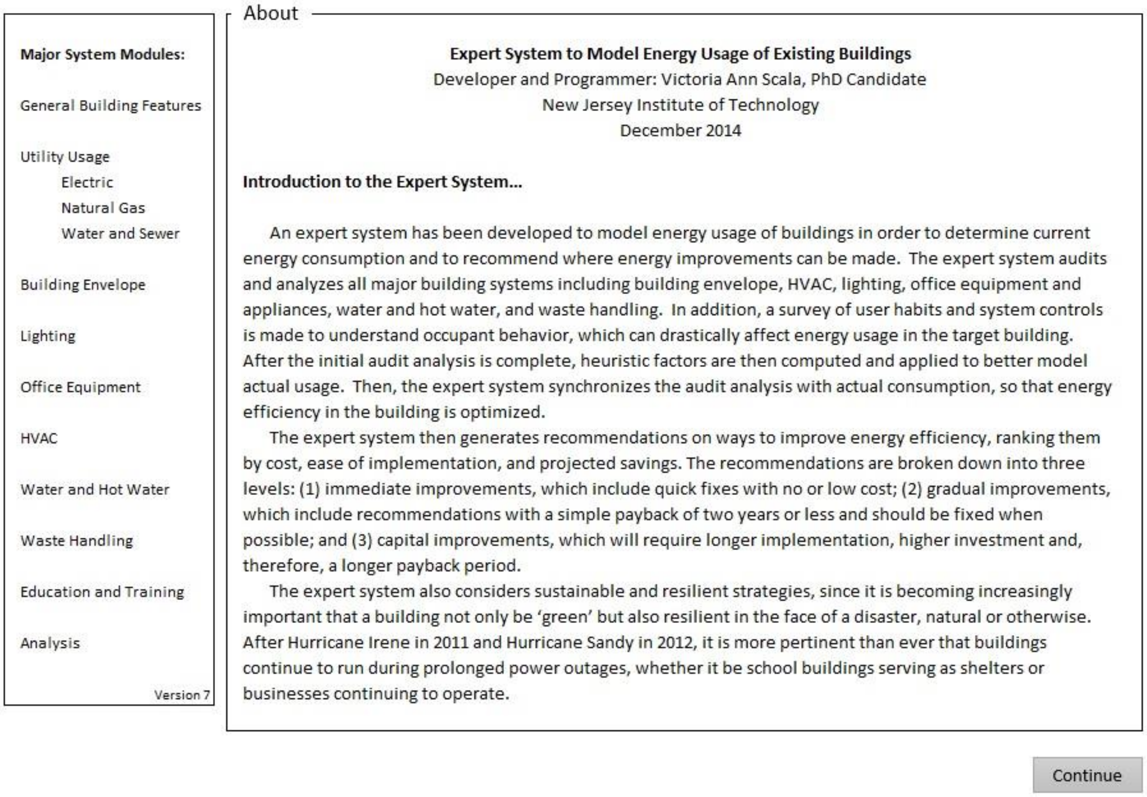
Flush Fixture Type	Water Use (Gallons/ Flush)	Flow-Fixture Type	Water Use (Gallons/ Minute)	Fixture Type	Energy Policy Act of 1992 Max Water Usage
Conventional Water Closet	1.6	Conventional Lavatory	2.5	Water Closets (GPF)	1.6
Low-Flow Water Closet	1.1	Low-Flow Lavatory	1.8	Urinals (GPF)	1.0
Ultra-Low Flow Water Closet	0.8	Kitchen Sink	2.5	Showerheads (GPM)	2.5
Composting Toilet	0.0	Low-Flow Kitchen Sink	1.8	Faucets (GPM)	2.5
Conventional Urinal	1.0	Shower	2.5	Replacement Aerators (GPM)	2.5
Waterless Urinal	0.0	Low-Flow Shower	1.8	Metering Faucets (gal/cycle)	0.25
		Janitor Sink	2.5		

Source: (Keller, 2003).

APPENDIX B

SCREENSHOTS OF PROGRAM

The following are screenshots of the program. The data included is for Arts High School.



Expert System to Model Energy Usage of Existing Buildings
Developer and Programmer: Victoria Ann Scala, PhD Candidate
New Jersey Institute of Technology
December 2014

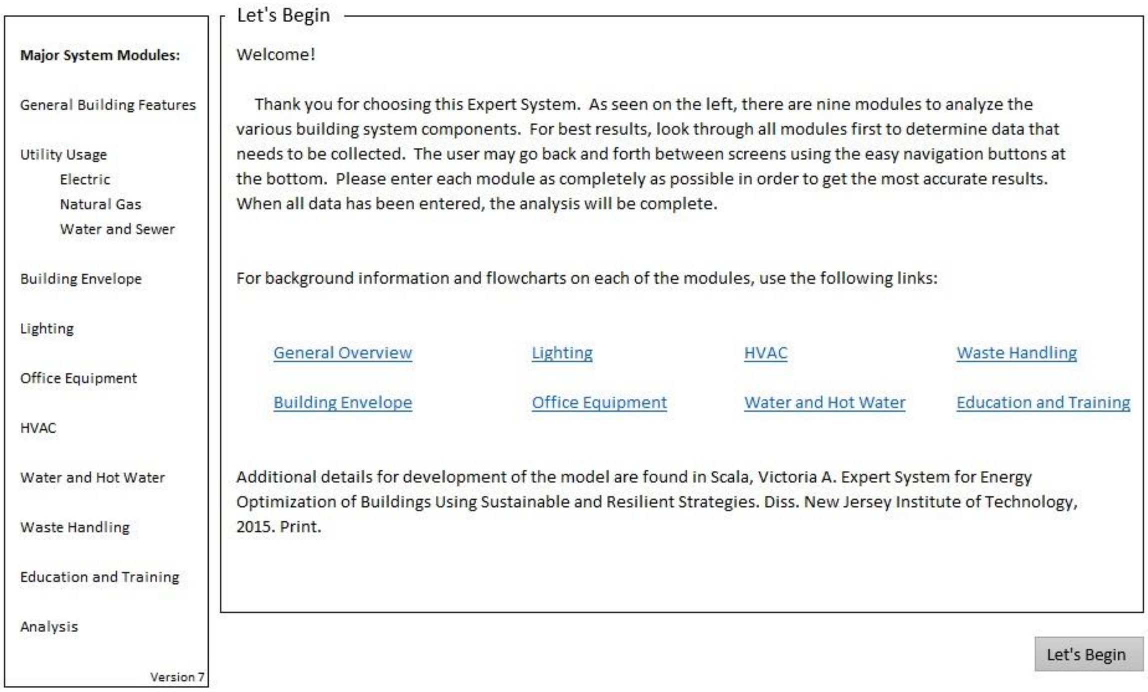
Introduction to the Expert System…

An expert system has been developed to model energy usage of buildings in order to determine current energy consumption and to recommend where energy improvements can be made. The expert system audits and analyzes all major building systems including building envelope, HVAC, lighting, office equipment and appliances, water and hot water, and waste handling. In addition, a survey of user habits and system controls is made to understand occupant behavior, which can drastically affect energy usage in the target building. After the initial audit analysis is complete, heuristic factors are then computed and applied to better model actual usage. Then, the expert system synchronizes the audit analysis with actual consumption, so that energy efficiency in the building is optimized.

The expert system then generates recommendations on ways to improve energy efficiency, ranking them by cost, ease of implementation, and projected savings. The recommendations are broken down into three levels: (1) immediate improvements, which include quick fixes with no or low cost; (2) gradual improvements, which include recommendations with a simple payback of two years or less and should be fixed when possible; and (3) capital improvements, which will require longer implementation, higher investment and, therefore, a longer payback period.

The expert system also considers sustainable and resilient strategies, since it is becoming increasingly important that a building not only be 'green' but also resilient in the face of a disaster, natural or otherwise. After Hurricane Irene in 2011 and Hurricane Sandy in 2012, it is more pertinent than ever that buildings continue to run during prolonged power outages, whether it be school buildings serving as shelters or businesses continuing to operate.

Figure B.1 Screenshot of the initial screen when opening the exert system which describes what the program is about.



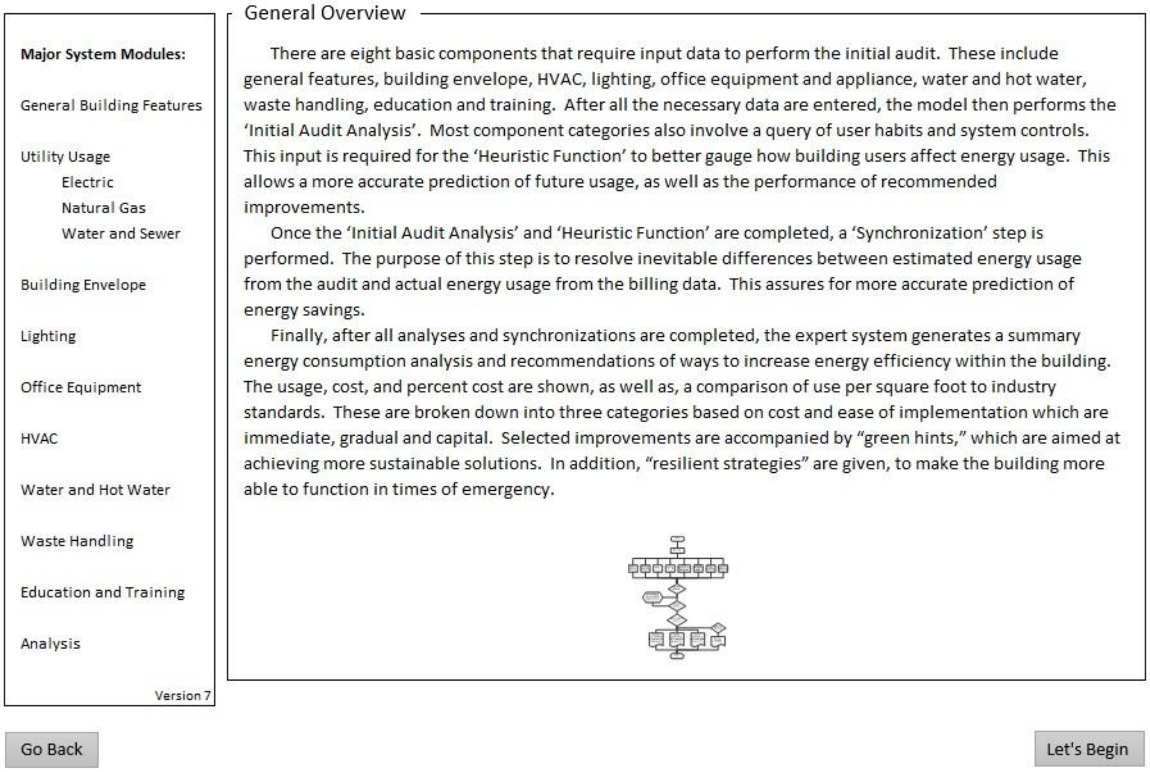
Welcome!

Thank you for choosing this Expert System. As seen on the left, there are nine modules to analyze the various building system components. For best results, look through all modules first to determine data that needs to be collected. The user may go back and forth between screens using the easy navigation buttons at the bottom. Please enter each module as completely as possible in order to get the most accurate results. When all data has been entered, the analysis will be complete.

For background information and flowcharts on each of the modules, use the following links:

Additional details for development of the model are found in Scala, Victoria A. Expert System for Energy Optimization of Buildings Using Sustainable and Resilient Strategies. Diss. New Jersey Institute of Technology, 2015. Print.

Figure B.2 Welcome screen showing the modules and where to get background information on each of them.



There are eight basic components that require input data to perform the initial audit. These include general features, building envelope, HVAC, lighting, office equipment and appliance, water and hot water, waste handling, education and training. After all the necessary data are entered, the model then performs the 'Initial Audit Analysis'. Most component categories also involve a query of user habits and system controls. This input is required for the 'Heuristic Function' to better gauge how building users affect energy usage. This allows a more accurate prediction of future usage, as well as the performance of recommended improvements.

Once the 'Initial Audit Analysis' and 'Heuristic Function' are completed, a 'Synchronization' step is performed. The purpose of this step is to resolve inevitable differences between estimated energy usage from the audit and actual energy usage from the billing data. This assures for more accurate prediction of energy savings.

Finally, after all analyses and synchronizations are completed, the expert system generates a summary energy consumption analysis and recommendations of ways to increase energy efficiency within the building. The usage, cost, and percent cost are shown, as well as, a comparison of use per square foot to industry standards. These are broken down into three categories based on cost and ease of implementation which are immediate, gradual and capital. Selected improvements are accompanied by "green hints," which are aimed at achieving more sustainable solutions. In addition, "resilient strategies" are given, to make the building more able to function in times of emergency.

Figure B.3 General overview of the modules and how they interact.

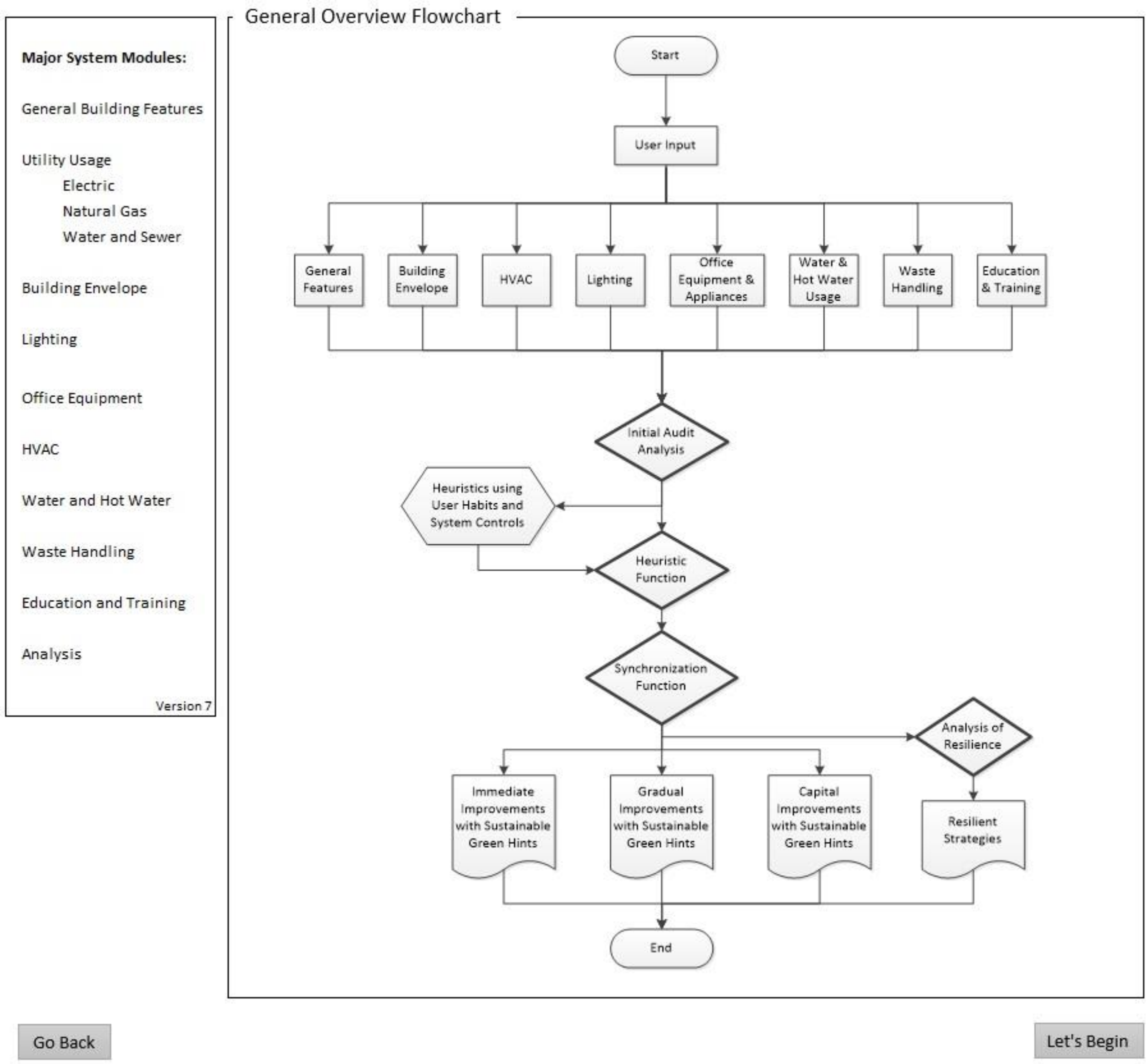
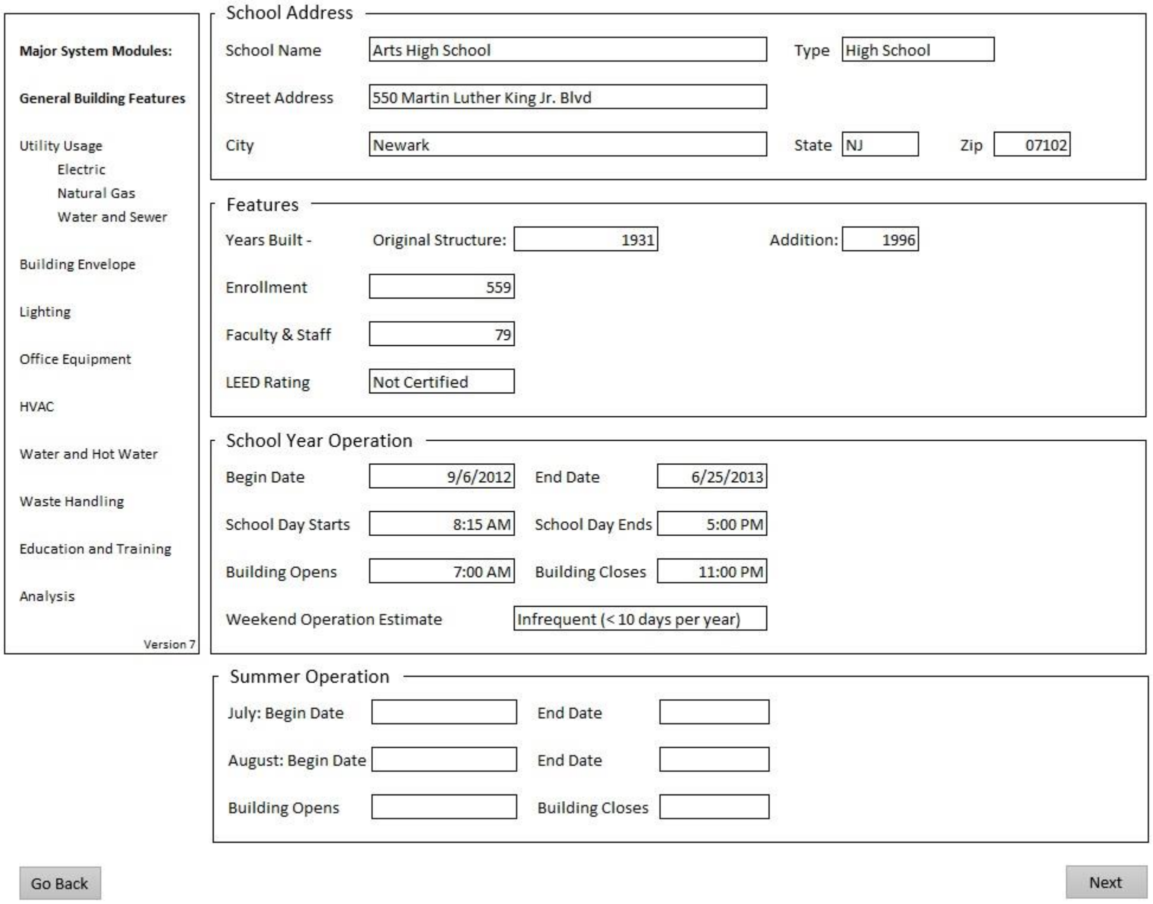


Figure B.4 General overview flowchart of the modules and how each interacts.



School Address

School Name: Arts High School
Type: High School
Street Address: 550 Martin Luther King Jr. Blvd
City: Newark
State: NJ
Zip: 07102

Features

Years Built - Original Structure: 1931
Addition: 1996
Enrollment: 559
Faculty & Staff: 79
LEED Rating: Not Certified

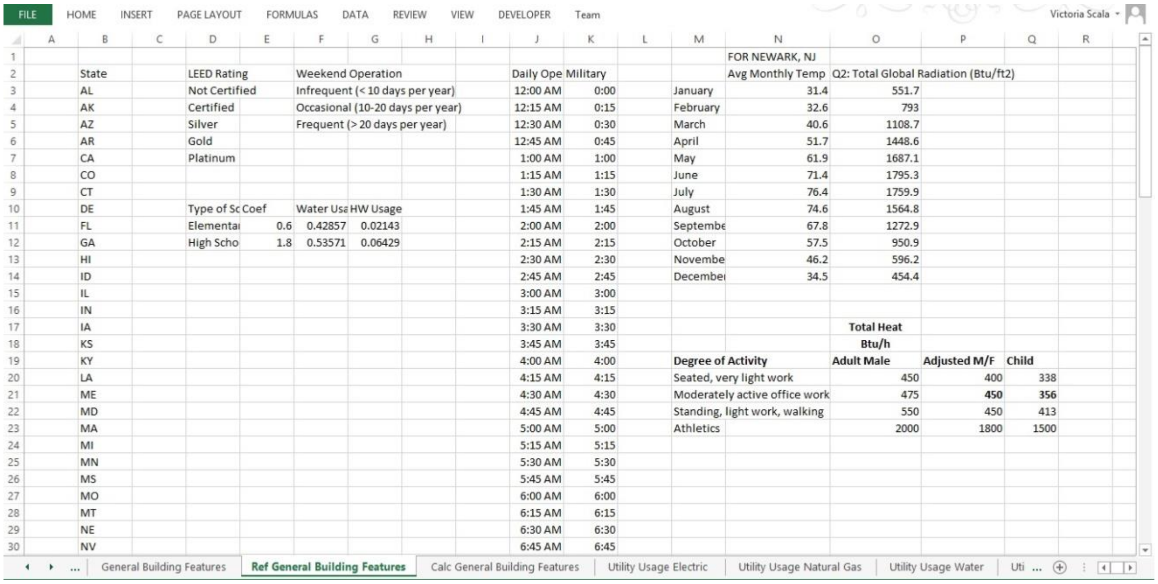
School Year Operation

Begin Date: 9/6/2012
End Date: 6/25/2013
School Day Starts: 8:15 AM
School Day Ends: 5:00 PM
Building Opens: 7:00 AM
Building Closes: 11:00 PM
Weekend Operation Estimate: Infrequent (< 10 days per year)

Summer Operation

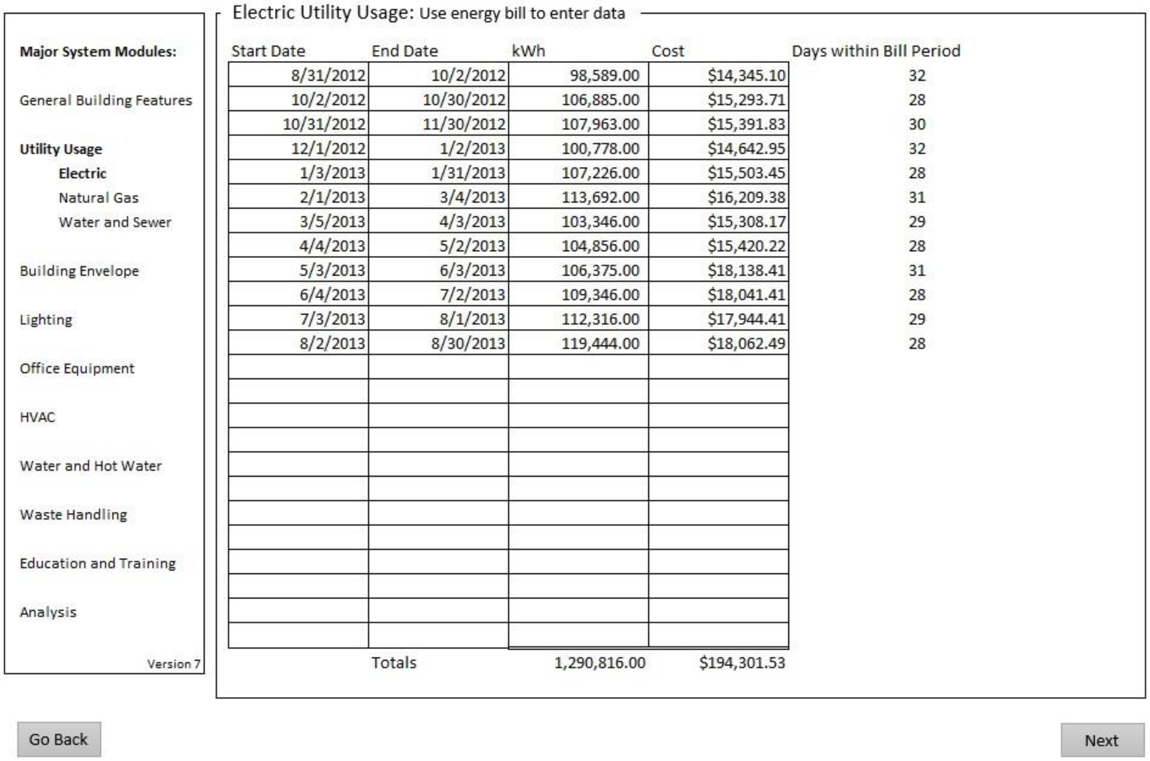
July: Begin Date:
End Date:
August: Begin Date:
End Date:
Building Opens:
Building Closes:

Figure B.5 Screenshot of general building features module. Numerous helpful hints are imbedded within the input options to aid the user.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1														FOR NEWARK, NJ				
2		State		LEED Rating		Weekend Operation				Daily Ope	Military			Avg Monthly Temp	Q2: Total Global Radiation (Btu/ft2)			
3		AL		Not Certified		Infrequent (< 10 days per year)				12:00 AM	0:00		January	31.4	551.7			
4		AK		Certified		Occasional (10-20 days per year)				12:15 AM	0:15		February	32.6	793			
5		AZ		Silver		Frequent (> 20 days per year)				12:30 AM	0:30		March	40.6	1108.7			
6		AR		Gold						12:45 AM	0:45		April	51.7	1448.6			
7		CA		Platinum						1:00 AM	1:00		May	61.9	1687.1			
8		CO								1:15 AM	1:15		June	71.4	1795.3			
9		CT								1:30 AM	1:30		July	76.4	1759.9			
10		DE		Type of Sc	Coef	Water Usa	HW Usage			1:45 AM	1:45		August	74.6	1564.8			
11		FL		Elementai	0.6	0.42857	0.02143			2:00 AM	2:00		Septembe	67.8	1272.9			
12		GA		High Scho	1.8	0.53571	0.06429			2:15 AM	2:15		October	57.5	950.9			
13		HI								2:30 AM	2:30		Novembe	46.2	596.2			
14		ID								2:45 AM	2:45		Decembei	34.5	454.4			
15		IL								3:00 AM	3:00							
16		IN								3:15 AM	3:15							
17		IA								3:30 AM	3:30				**Total Heat**			
18		KS								3:45 AM	3:45				**Btu/h**			
19		KY								4:00 AM	4:00		**Degree of Activity**		**Adult Male**	**Adjusted M/F**	**Child**	
20		LA								4:15 AM	4:15		Seated, very light work		450	400	338	
21		ME								4:30 AM	4:30		Moderately active office work		475	**450**	**356**	
22		MD								4:45 AM	4:45		Standing, light work, walking		550	450	413	
23		MA								5:00 AM	5:00		Athletics		2000	1800	1500	
24		MI								5:15 AM	5:15							
25		MN								5:30 AM	5:30							
26		MS								5:45 AM	5:45							
27		MO								6:00 AM	6:00							
28		MT								6:15 AM	6:15							
29		NE								6:30 AM	6:30							
30		NV								6:45 AM	6:45							

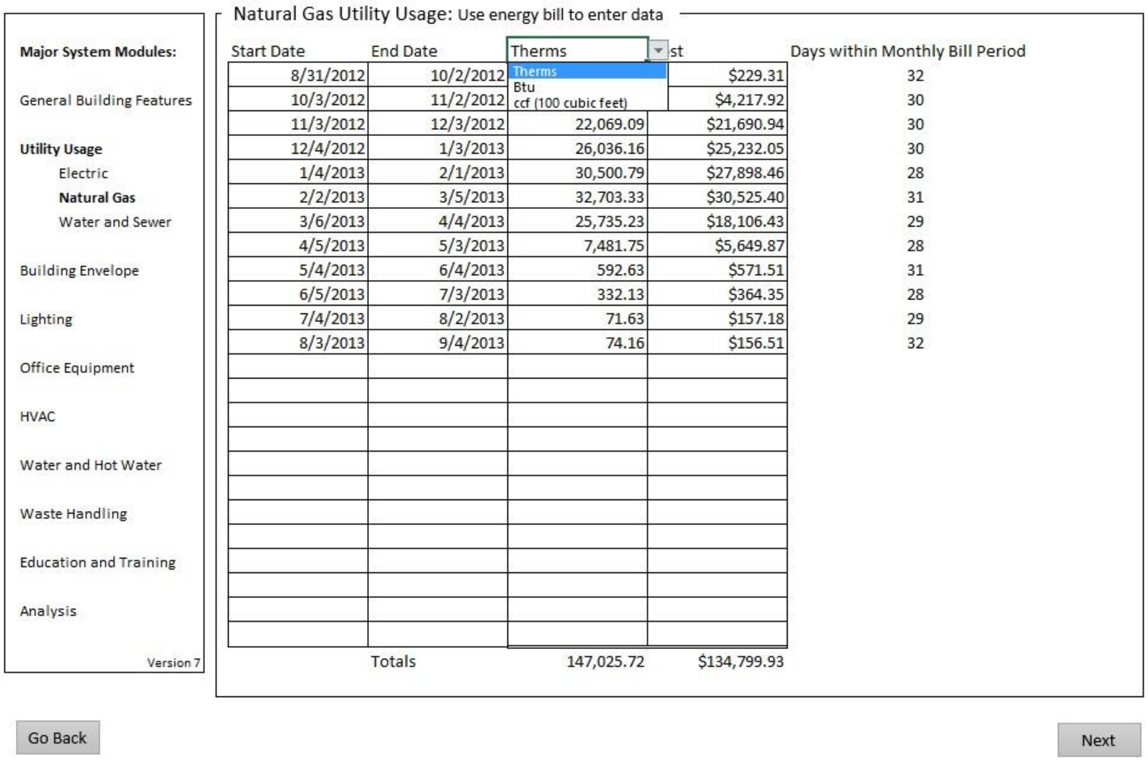
Figure B.6 General building features reference, or data library, screen for drop down menus in the general building features input screen.



Electric Utility Usage: Use energy bill to enter data

Start Date	End Date	kWh	Cost	Days within Bill Period
8/31/2012	10/2/2012	98,589.00	$14,345.10	32
10/2/2012	10/30/2012	106,885.00	$15,293.71	28
10/31/2012	11/30/2012	107,963.00	$15,391.83	30
12/1/2012	1/2/2013	100,778.00	$14,642.95	32
1/3/2013	1/31/2013	107,226.00	$15,503.45	28
2/1/2013	3/4/2013	113,692.00	$16,209.38	31
3/5/2013	4/3/2013	103,346.00	$15,308.17	29
4/4/2013	5/2/2013	104,856.00	$15,420.22	28
5/3/2013	6/3/2013	106,375.00	$18,138.41	31
6/4/2013	7/2/2013	109,346.00	$18,041.41	28
7/3/2013	8/1/2013	112,316.00	$17,944.41	29
8/2/2013	8/30/2013	119,444.00	$18,062.49	28
	Totals	1,290,816.00	$194,301.53	

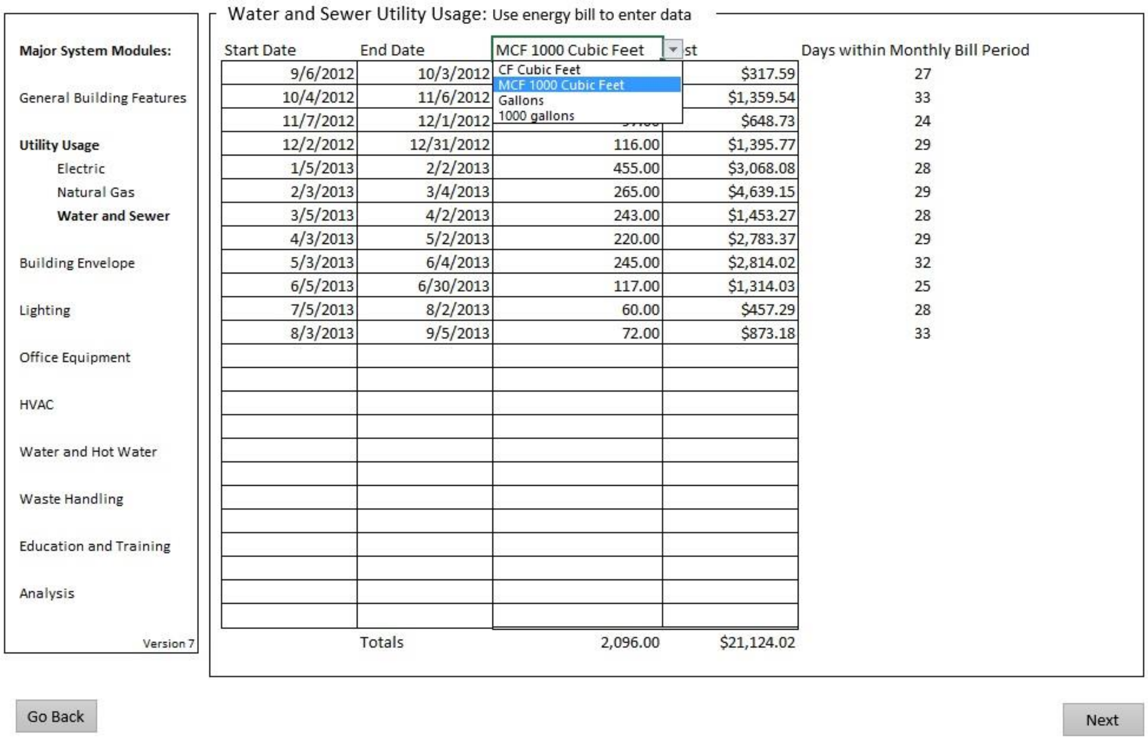
Figure B.7 Electric utility usage input screen.



Natural Gas Utility Usage: Use energy bill to enter data

Start Date	End Date	Therms	st	Days within Monthly Bill Period
8/31/2012	10/2/2012		$229.31	32
10/3/2012	11/2/2012		$4,217.92	30
11/3/2012	12/3/2012	22,069.09	$21,690.94	30
12/4/2012	1/3/2013	26,036.16	$25,232.05	30
1/4/2013	2/1/2013	30,500.79	$27,898.46	28
2/2/2013	3/5/2013	32,703.33	$30,525.40	31
3/6/2013	4/4/2013	25,735.23	$18,106.43	29
4/5/2013	5/3/2013	7,481.75	$5,649.87	28
5/4/2013	6/4/2013	592.63	$571.51	31
6/5/2013	7/3/2013	332.13	$364.35	28
7/4/2013	8/2/2013	71.63	$157.18	29
8/3/2013	9/4/2013	74.16	$156.51	32
	Totals	147,025.72	$134,799.93	

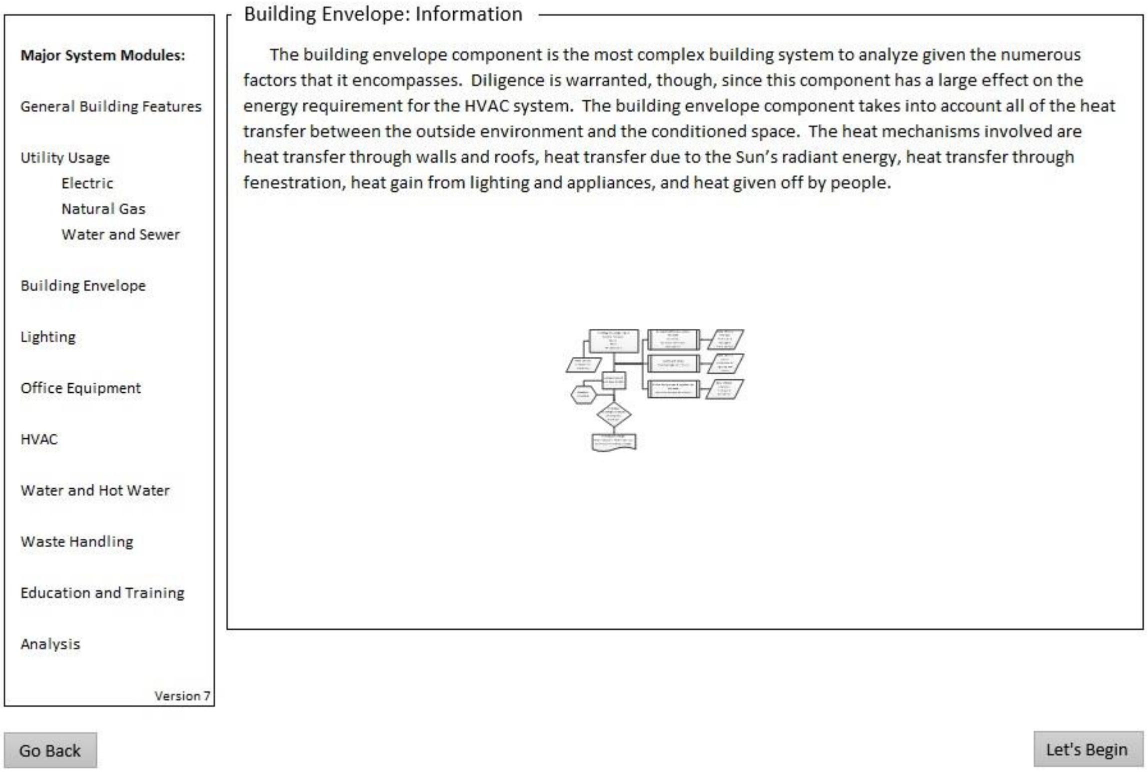
Figure B.8 Natural gas utility usage input screen.



Water and Sewer Utility Usage: Use energy bill to enter data

Start Date	End Date	MCF 1000 Cubic Feet	st	Days within Monthly Bill Period
9/6/2012	10/3/2012		$317.59	27
10/4/2012	11/6/2012		$1,359.54	33
11/7/2012	12/1/2012	[illegible]	$648.73	24
12/2/2012	12/31/2012	116.00	$1,395.77	29
1/5/2013	2/2/2013	455.00	$3,068.08	28
2/3/2013	3/4/2013	265.00	$4,639.15	29
3/5/2013	4/2/2013	243.00	$1,453.27	28
4/3/2013	5/2/2013	220.00	$2,783.37	29
5/3/2013	6/4/2013	245.00	$2,814.02	32
6/5/2013	6/30/2013	117.00	$1,314.03	25
7/5/2013	8/2/2013	60.00	$457.29	28
8/3/2013	9/5/2013	72.00	$873.18	33
	Totals	2,096.00	$21,124.02	

Figure B.9 Water utility usage input screen.



Building Envelope: Information

The building envelope component is the most complex building system to analyze given the numerous factors that it encompasses. Diligence is warranted, though, since this component has a large effect on the energy requirement for the HVAC system. The building envelope component takes into account all of the heat transfer between the outside environment and the conditioned space. The heat mechanisms involved are heat transfer through walls and roofs, heat transfer due to the Sun's radiant energy, heat transfer through fenestration, heat gain from lighting and appliances, and heat given off by people.

Figure B.10 Information on the building envelope module.

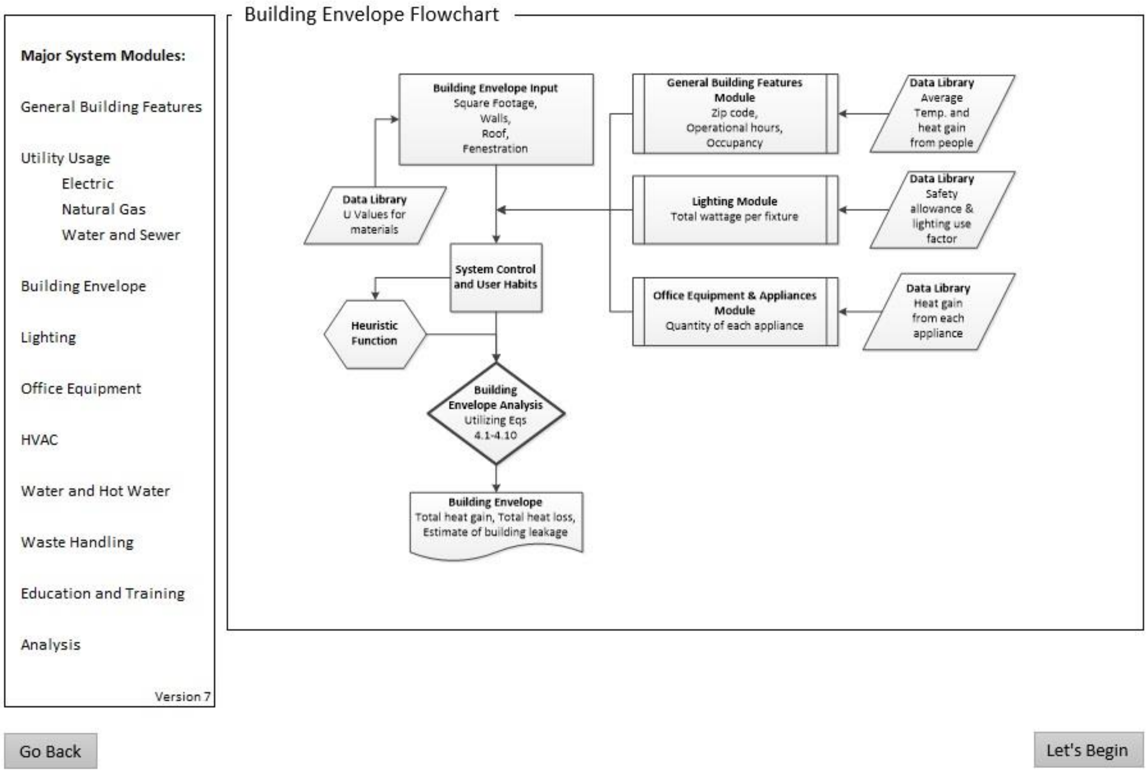
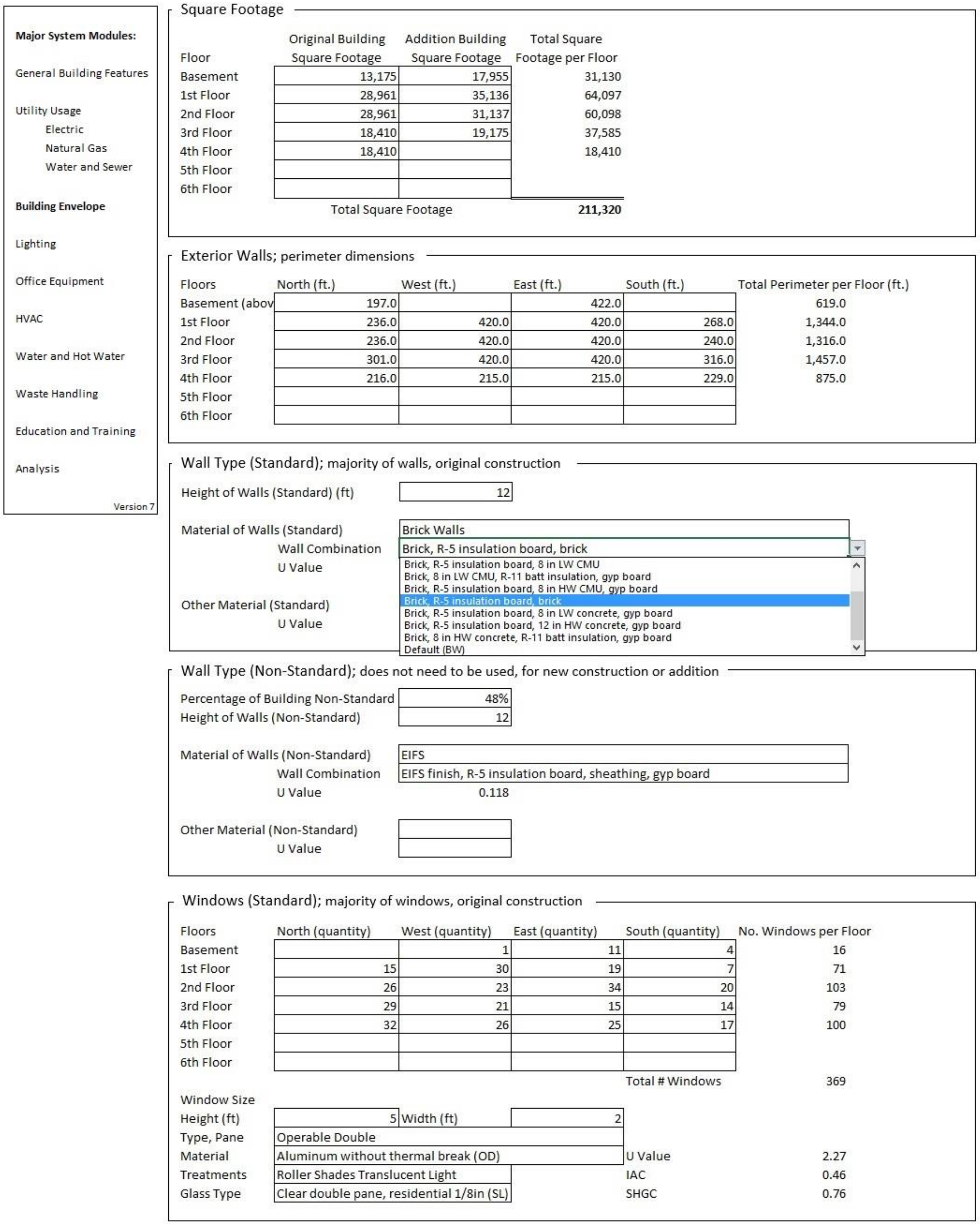


Figure B.11 Flowchart of the building envelope module.



Square Footage

Floor	Original Building Square Footage	Addition Building Square Footage	Total Square Footage per Floor
Basement	13,175	17,955	31,130
1st Floor	28,961	35,136	64,097
2nd Floor	28,961	31,137	60,098
3rd Floor	18,410	19,175	37,585
4th Floor	18,410		18,410
5th Floor			
6th Floor			
	Total Square Footage		211,320

Exterior Walls; perimeter dimensions

Floors	North (ft.)	West (ft.)	East (ft.)	South (ft.)	Total Perimeter per Floor (ft.)
Basement (abov	197.0		422.0		619.0
1st Floor	236.0	420.0	420.0	268.0	1,344.0
2nd Floor	236.0	420.0	420.0	240.0	1,316.0
3rd Floor	301.0	420.0	420.0	316.0	1,457.0
4th Floor	216.0	215.0	215.0	229.0	875.0
5th Floor					
6th Floor					

Wall Type (Standard); majority of walls, original construction

Height of Walls (Standard) (ft)	12
Material of Walls (Standard)	Brick Walls
Wall Combination	Brick, R-5 insulation board, brick
U Value	
Other Material (Standard)	
U Value	

Wall Type (Non-Standard); does not need to be used, for new construction or addition

Percentage of Building Non-Standard	48%
Height of Walls (Non-Standard)	12
Material of Walls (Non-Standard)	EIFS
Wall Combination	EIFS finish, R-5 insulation board, sheathing, gyp board
U Value	0.118
Other Material (Non-Standard)	
U Value	

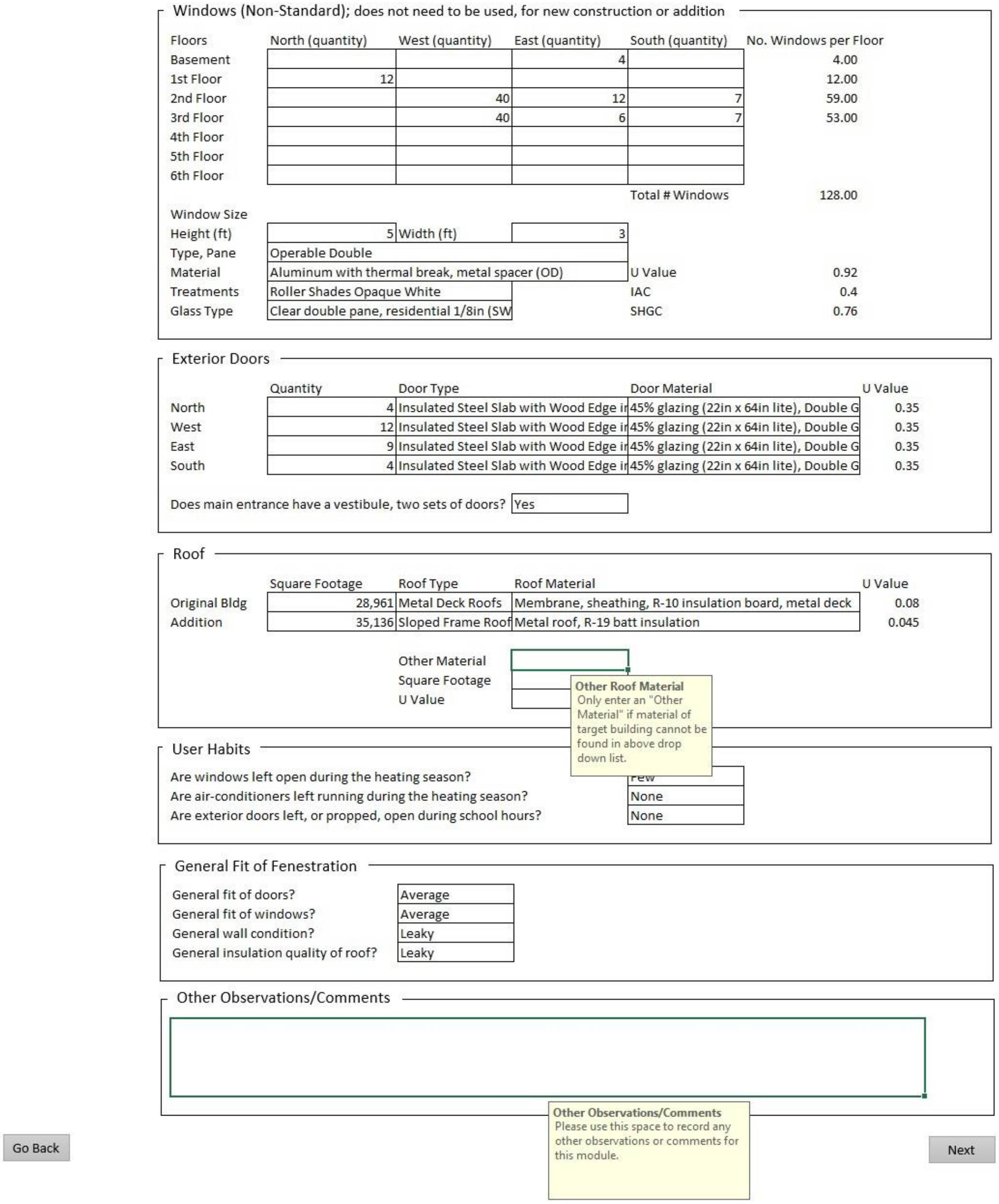
Windows (Standard); majority of windows, original construction

Floors	North (quantity)	West (quantity)	East (quantity)	South (quantity)	No. Windows per Floor
Basement		1	11	4	16
1st Floor	15	30	19	7	71
2nd Floor	26	23	34	20	103
3rd Floor	29	21	15	14	79
4th Floor	32	26	25	17	100
5th Floor					
6th Floor					
				Total # Windows	369

Window Size

Height (ft)	5	Width (ft)	2
Type, Pane	Operable Double		
Material	Aluminum without thermal break (OD)	U Value	2.27
Treatments	Roller Shades Translucent Light	IAC	0.46
Glass Type	Clear double pane, residential 1/8in (SL)	SHGC	0.76

Figure B.12 Screenshot of building envelope module, continued in Figure B.13.



Windows (Non-Standard); does not need to be used, for new construction or addition

Floors	North (quantity)	West (quantity)	East (quantity)	South (quantity)	No. Windows per Floor
Basement			4		4.00
1st Floor	12				12.00
2nd Floor		40	12	7	59.00
3rd Floor		40	6	7	53.00
4th Floor					
5th Floor					
6th Floor					
				Total # Windows	128.00

Window Size

Height (ft)	5	Width (ft)	3	
Type, Pane	Operable Double			
Material	Aluminum with thermal break, metal spacer (OD)		U Value	0.92
Treatments	Roller Shades Opaque White		IAC	0.4
Glass Type	Clear double pane, residential 1/8in (SW		SHGC	0.76

Exterior Doors

	Quantity	Door Type	Door Material	U Value
North	4	Insulated Steel Slab with Wood Edge ir	45% glazing (22in x 64in lite), Double G	0.35
West	12	Insulated Steel Slab with Wood Edge ir	45% glazing (22in x 64in lite), Double G	0.35
East	9	Insulated Steel Slab with Wood Edge ir	45% glazing (22in x 64in lite), Double G	0.35
South	4	Insulated Steel Slab with Wood Edge ir	45% glazing (22in x 64in lite), Double G	0.35

Does main entrance have a vestibule, two sets of doors? Yes

Roof

	Square Footage	Roof Type	Roof Material	U Value
Original Bldg	28,961	Metal Deck Roofs	Membrane, sheathing, R-10 insulation board, metal deck	0.08
Addition	35,136	Sloped Frame Roof	Metal roof, R-19 batt insulation	0.045

Other Material
Square Footage
U Value

Other Roof Material
Only enter an "Other Material" if material of target building cannot be found in above drop down list.

User Habits

Are windows left open during the heating season?	Few
Are air-conditioners left running during the heating season?	None
Are exterior doors left, or propped, open during school hours?	None

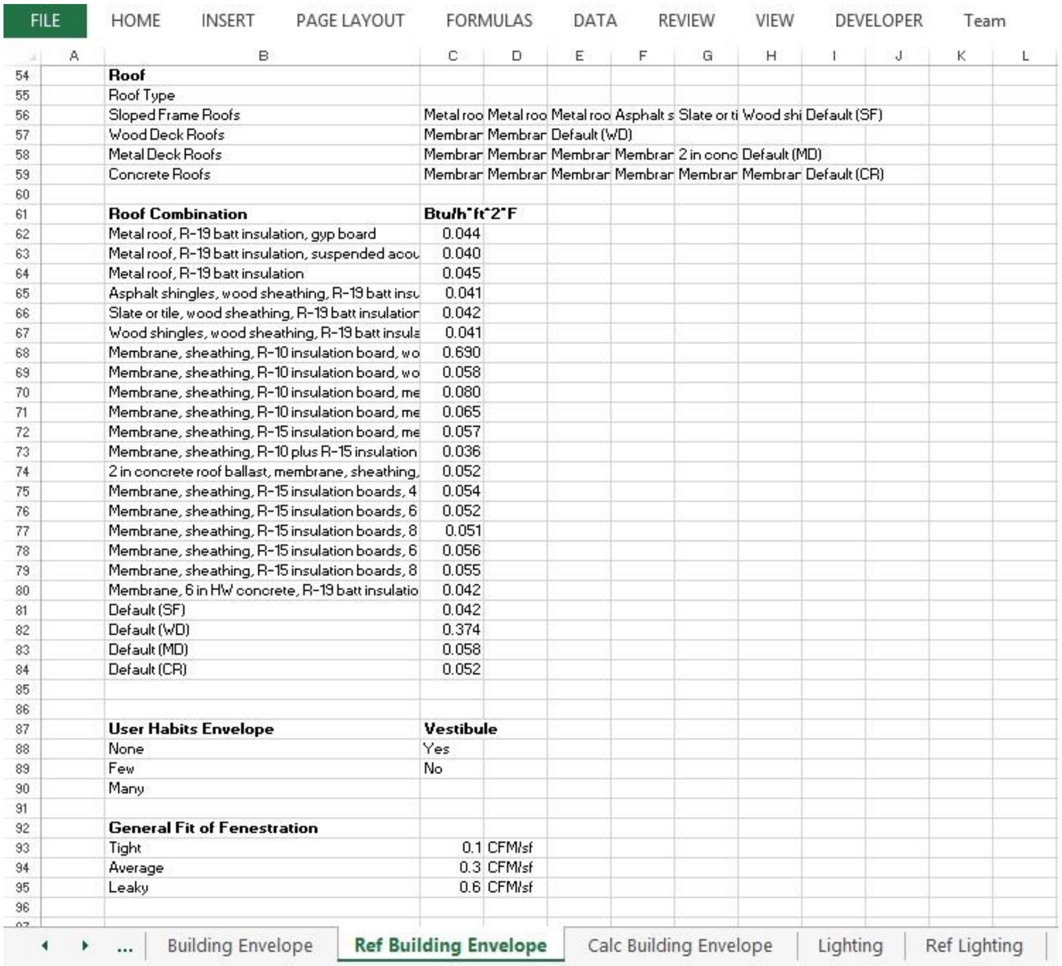
General Fit of Fenestration

General fit of doors?	Average
General fit of windows?	Average
General wall condition?	Leaky
General insulation quality of roof?	Leaky

Other Observations/Comments

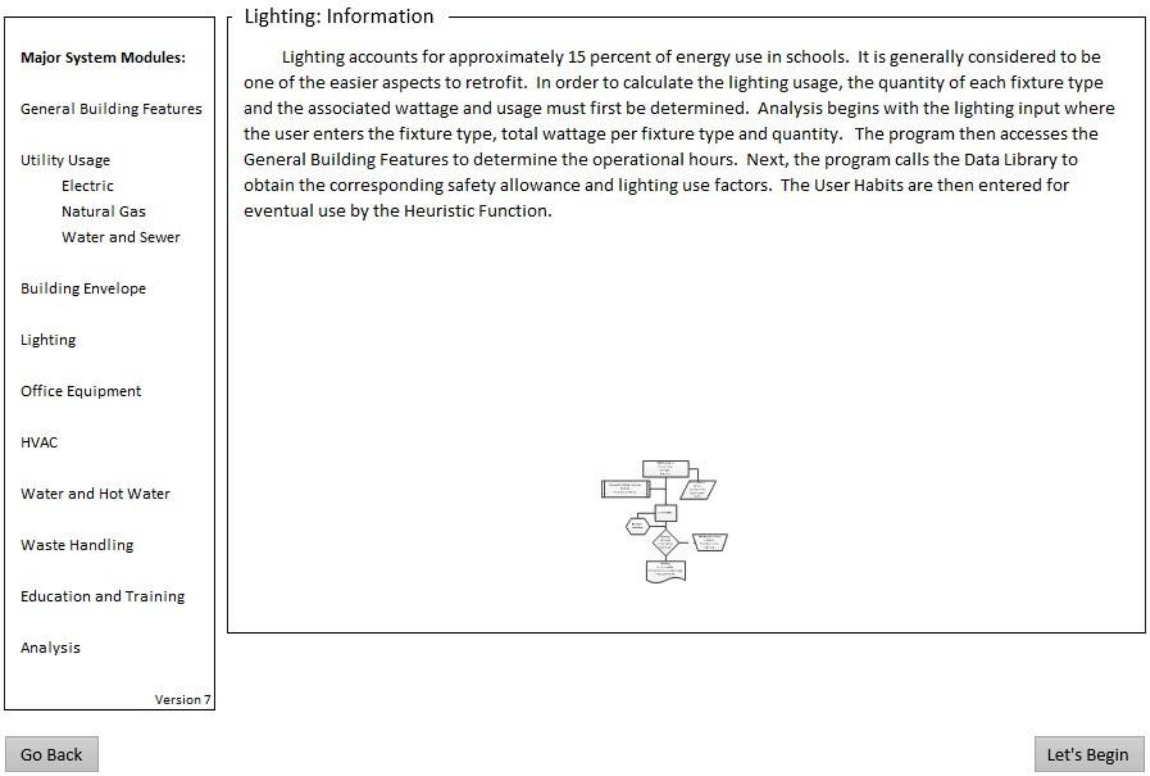
Other Observations/Comments
Please use this space to record any other observations or comments for this module.

Figure B.13 Continuation of the building envelope module input screen. Helpful hints are shown for other roof material and other observations. There are numerous aids embedded within the program.



	A	B	C	D	E	F	G	H	I
54		**Roof**							
55		Roof Type							
56		Sloped Frame Roofs	Metal roo	Metal roo	Metal roo	Asphalt s	Slate or ti	Wood shi	Default (SF)
57		Wood Deck Roofs	Membrar	Membrar	Default (WD)				
58		Metal Deck Roofs	Membrar	Membrar	Membrar	Membrar	2 in conc	Default (MD)	
59		Concrete Roofs	Membrar	Membrar	Membrar	Membrar	Membrar	Membrar	Default (CR)
60									
61		**Roof Combination**	**Btu/h*ft*2*F**						
62		Metal roof, R-19 batt insulation, gyp board	0.044						
63		Metal roof, R-19 batt insulation, suspended acou	0.040						
64		Metal roof, R-19 batt insulation	0.045						
65		Asphalt shingles, wood sheathing, R-19 batt insu	0.041						
66		Slate or tile, wood sheathing, R-19 batt insulatior	0.042						
67		Wood shingles, wood sheathing, R-19 batt insula	0.041						
68		Membrane, sheathing, R-10 insulation board, wo	0.690						
69		Membrane, sheathing, R-10 insulation board, wo	0.058						
70		Membrane, sheathing, R-10 insulation board, me	0.080						
71		Membrane, sheathing, R-10 insulation board, me	0.065						
72		Membrane, sheathing, R-15 insulation board, me	0.057						
73		Membrane, sheathing, R-10 plus R-15 insulation	0.036						
74		2 in concrete roof ballast, membrane, sheathing,	0.052						
75		Membrane, sheathing, R-15 insulation boards, 4	0.054						
76		Membrane, sheathing, R-15 insulation boards, 6	0.052						
77		Membrane, sheathing, R-15 insulation boards, 8	0.051						
78		Membrane, sheathing, R-15 insulation boards, 6	0.056						
79		Membrane, sheathing, R-15 insulation boards, 8	0.055						
80		Membrane, 6 in HW concrete, R-19 batt insulatio	0.042						
81		Default (SF)	0.042						
82		Default (WD)	0.374						
83		Default (MD)	0.058						
84		Default (CR)	0.052						
85									
86									
87		**User Habits Envelope**	**Vestibule**						
88		None	Yes						
89		Few	No						
90		Many							
91									
92		**General Fit of Fenestration**							
93		Tight	0.1	CFM/sf					
94		Average	0.3	CFM/sf					
95		Leaky	0.6	CFM/sf					
96									

Figure B.14 Building envelope reference, or data library, screen for drop down menus within the building envelope input screen. This particular worksheet has over four hundred lines of data, only a portion is shown above.



Lighting accounts for approximately 15 percent of energy use in schools. It is generally considered to be one of the easier aspects to retrofit. In order to calculate the lighting usage, the quantity of each fixture type and the associated wattage and usage must first be determined. Analysis begins with the lighting input where the user enters the fixture type, total wattage per fixture type and quantity. The program then accesses the General Building Features to determine the operational hours. Next, the program calls the Data Library to obtain the corresponding safety allowance and lighting use factors. The User Habits are then entered for eventual use by the Heuristic Function.

Figure B.15 Background and interaction information on the lighting module.

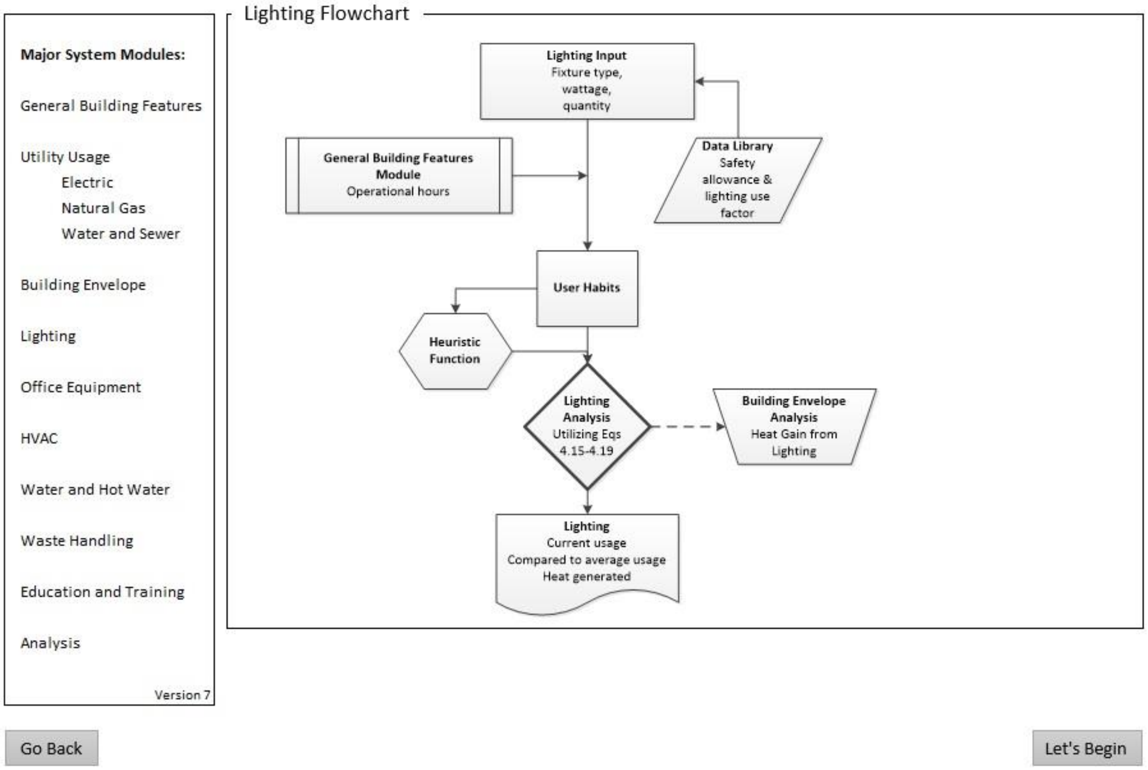
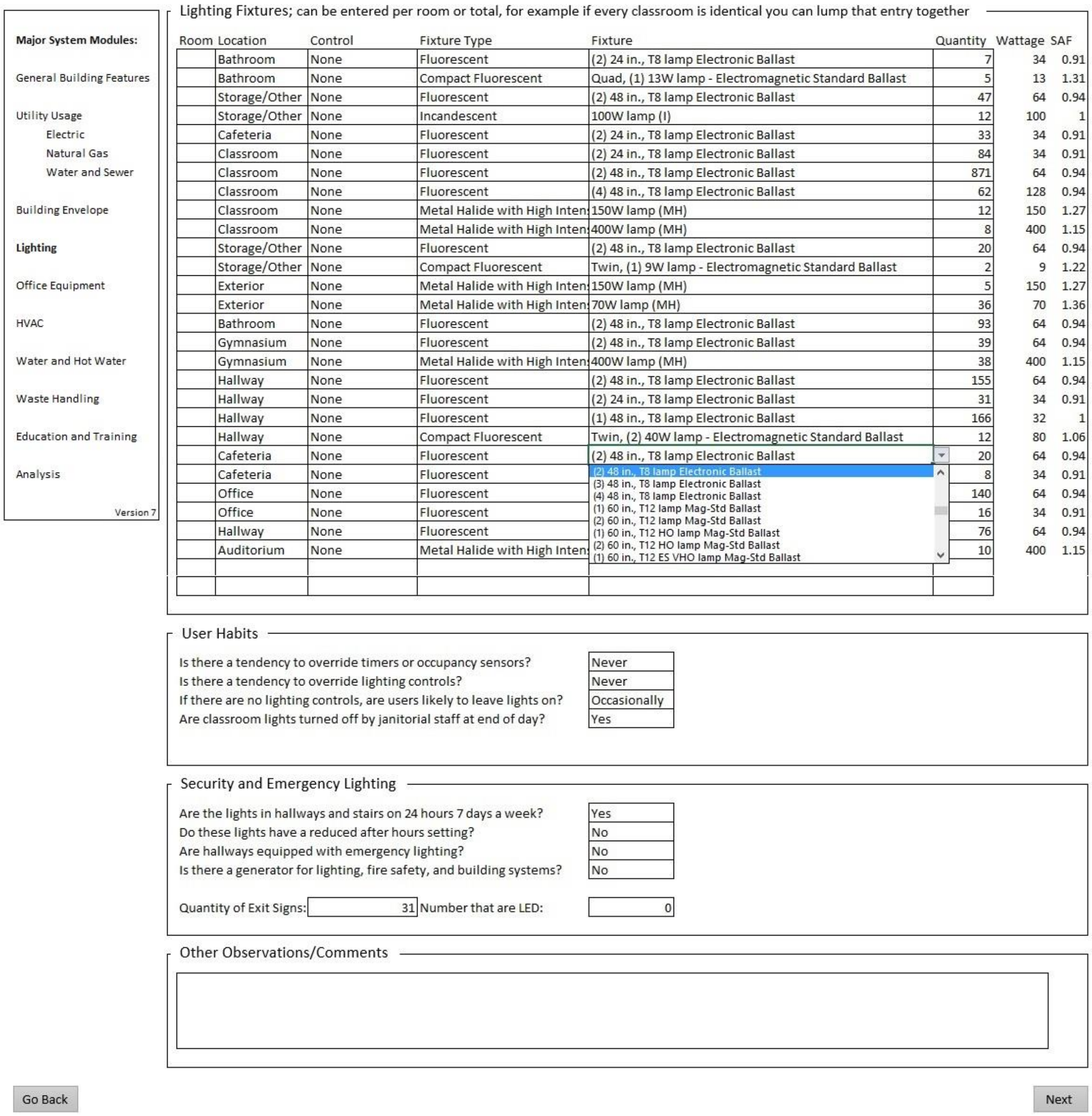


Figure B.16 Lighting module interaction shown in flowchart.



Lighting Fixtures; can be entered per room or total, for example if every classroom is identical you can lump that entry together

Room	Location	Control	Fixture Type	Fixture	Quantity	Wattage	SAF
	Bathroom	None	Fluorescent	(2) 24 in., T8 lamp Electronic Ballast	7	34	0.91
	Bathroom	None	Compact Fluorescent	Quad, (1) 13W lamp - Electromagnetic Standard Ballast	5	13	1.31
	Storage/Other	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	47	64	0.94
	Storage/Other	None	Incandescent	100W lamp (I)	12	100	1
	Cafeteria	None	Fluorescent	(2) 24 in., T8 lamp Electronic Ballast	33	34	0.91
	Classroom	None	Fluorescent	(2) 24 in., T8 lamp Electronic Ballast	84	34	0.91
	Classroom	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	871	64	0.94
	Classroom	None	Fluorescent	(4) 48 in., T8 lamp Electronic Ballast	62	128	0.94
	Classroom	None	Metal Halide with High Inten	150W lamp (MH)	12	150	1.27
	Classroom	None	Metal Halide with High Inten	400W lamp (MH)	8	400	1.15
	Storage/Other	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	20	64	0.94
	Storage/Other	None	Compact Fluorescent	Twin, (1) 9W lamp - Electromagnetic Standard Ballast	2	9	1.22
	Exterior	None	Metal Halide with High Inten	150W lamp (MH)	5	150	1.27
	Exterior	None	Metal Halide with High Inten	70W lamp (MH)	36	70	1.36
	Bathroom	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	93	64	0.94
	Gymnasium	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	39	64	0.94
	Gymnasium	None	Metal Halide with High Inten	400W lamp (MH)	38	400	1.15
	Hallway	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	155	64	0.94
	Hallway	None	Fluorescent	(2) 24 in., T8 lamp Electronic Ballast	31	34	0.91
	Hallway	None	Fluorescent	(1) 48 in., T8 lamp Electronic Ballast	166	32	1
	Hallway	None	Compact Fluorescent	Twin, (2) 40W lamp - Electromagnetic Standard Ballast	12	80	1.06
	Cafeteria	None	Fluorescent	(2) 48 in., T8 lamp Electronic Ballast	20	64	0.94
	Cafeteria	None	Fluorescent		8	34	0.91
	Office	None	Fluorescent		140	64	0.94
	Office	None	Fluorescent		16	34	0.91
	Hallway	None	Fluorescent		76	64	0.94
	Auditorium	None	Metal Halide with High Inten		10	400	1.15

(2) 48 in., T8 lamp Electronic Ballast
(3) 48 in., T8 lamp Electronic Ballast
(4) 48 in., T8 lamp Electronic Ballast
(1) 60 in., T12 lamp Mag-Std Ballast
(2) 60 in., T12 lamp Mag-Std Ballast
(1) 60 in., T12 HO lamp Mag-Std Ballast
(2) 60 in., T12 HO lamp Mag-Std Ballast
(1) 60 in., T12 ES VHO lamp Mag-Std Ballast

User Habits

Is there a tendency to override timers or occupancy sensors?	Never
Is there a tendency to override lighting controls?	Never
If there are no lighting controls, are users likely to leave lights on?	Occasionally
Are classroom lights turned off by janitorial staff at end of day?	Yes

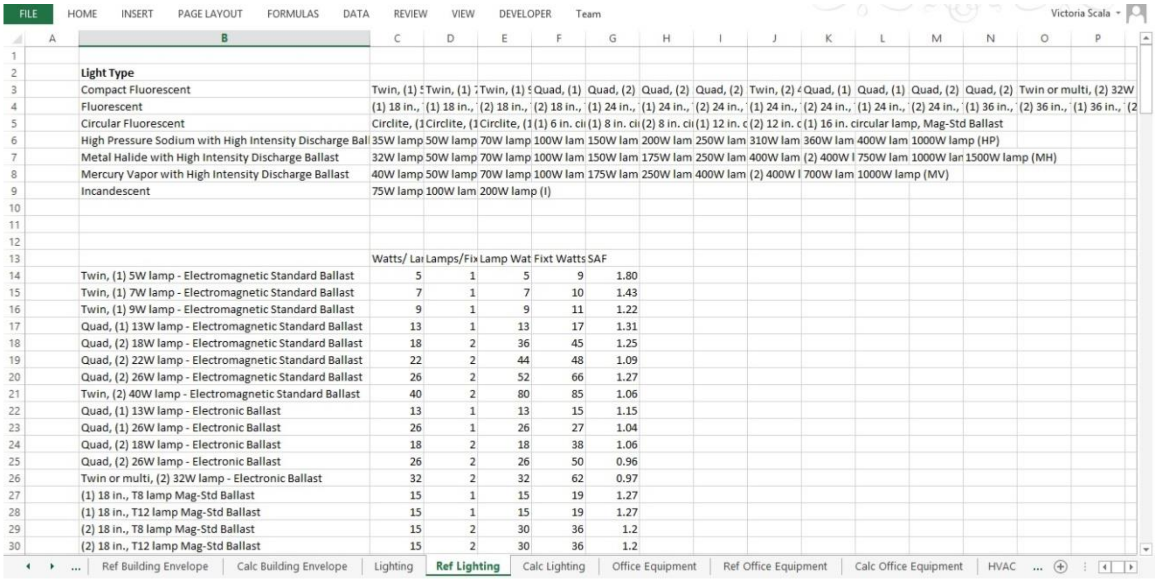
Security and Emergency Lighting

Are the lights in hallways and stairs on 24 hours 7 days a week?	Yes
Do these lights have a reduced after hours setting?	No
Are hallways equipped with emergency lighting?	No
Is there a generator for lighting, fire safety, and building systems?	No

Quantity of Exit Signs: 31 Number that are LED: 0

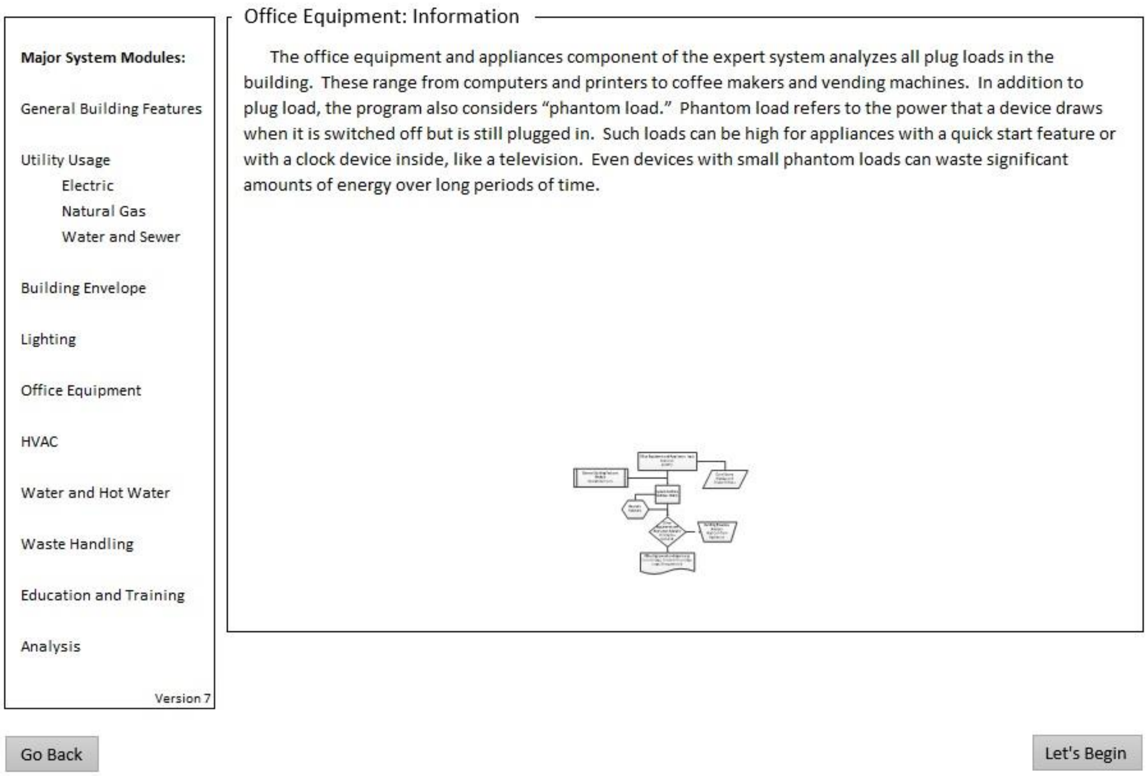
Other Observations/Comments

Figure B.17 Input for the lighting module of the expert system.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1																
2		**Light Type**														
3		Compact Fluorescent	Twin, (1) 5	Twin, (1) 7	Twin, (1) 9	Quad, (1)	Quad, (2)	Quad, (2)	Quad, (2)	Twin, (2) 4	Quad, (1)	Quad, (1)	Quad, (2)	Quad, (2)	Twin or multi, (2) 32W	
4		Fluorescent	(1) 18 in.,	(1) 18 in.,	(2) 18 in.,	(2) 18 in.,	(1) 24 in.,	(1) 24 in.,	(2) 24 in.,	(1) 24 in.,	(2) 24 in.,	(1) 24 in.,	(2) 24 in.,	(1) 36 in.,	(2) 36 in.,	(1) 36 in.,
5		Circular Fluorescent	Circlite, (1	Circlite, (1	Circlite, (1	(1) 6 in. ci	(1) 8 in. ci	(2) 8 in. ci	(1) 12 in. c	(2) 12 in. c	(1) 16 in. circular lamp, Mag-Std Ballast					
6		High Pressure Sodium with High Intensity Discharge Ball	35W lamp	50W lamp	70W lamp	100W lam	150W lam	200W lam	250W lam	310W lam	360W lam	400W lam	1000W lamp (HP)			
7		Metal Halide with High Intensity Discharge Ballast	32W lamp	50W lamp	70W lamp	100W lam	150W lam	175W lam	250W lam	400W lam	(2) 400W l	750W lam	1000W lar	1500W lamp (MH)		
8		Mercury Vapor with High Intensity Discharge Ballast	40W lamp	50W lamp	70W lamp	100W lam	175W lam	250W lam	400W lam	(2) 400W l	700W lam	1000W lamp (MV)				
9		Incandescent	75W lamp	100W lam	200W lamp (I)											
10																
11																
12																
13			Watts/ La	Lamps/Fix	Lamp Wat	Fixt Watts	SAF									
14		Twin, (1) 5W lamp - Electromagnetic Standard Ballast	5	1	5	9	1.80									
15		Twin, (1) 7W lamp - Electromagnetic Standard Ballast	7	1	7	10	1.43									
16		Twin, (1) 9W lamp - Electromagnetic Standard Ballast	9	1	9	11	1.22									
17		Quad, (1) 13W lamp - Electromagnetic Standard Ballast	13	1	13	17	1.31									
18		Quad, (2) 18W lamp - Electromagnetic Standard Ballast	18	2	36	45	1.25									
19		Quad, (2) 22W lamp - Electromagnetic Standard Ballast	22	2	44	48	1.09									
20		Quad, (2) 26W lamp - Electromagnetic Standard Ballast	26	2	52	66	1.27									
21		Twin, (2) 40W lamp - Electromagnetic Standard Ballast	40	2	80	85	1.06									
22		Quad, (1) 13W lamp - Electronic Ballast	13	1	13	15	1.15									
23		Quad, (1) 26W lamp - Electronic Ballast	26	1	26	27	1.04									
24		Quad, (2) 18W lamp - Electronic Ballast	18	2	18	38	1.06									
25		Quad, (2) 26W lamp - Electronic Ballast	26	2	26	50	0.96									
26		Twin or multi, (2) 32W lamp - Electronic Ballast	32	2	32	62	0.97									
27		(1) 18 in., T8 lamp Mag-Std Ballast	15	1	15	19	1.27									
28		(1) 18 in., T12 lamp Mag-Std Ballast	15	1	15	19	1.27									
29		(2) 18 in., T8 lamp Mag-Std Ballast	15	2	30	36	1.2									
30		(2) 18 in., T12 lamp Mag-Std Ballast	15	2	30	36	1.2									

Figure B.18 Lighting reference, or data library, screen for drop down menus within the lighting input screen in Figure B.17. This particular worksheet has over two hundred lines of data, only a portion is shown above.



The office equipment and appliances component of the expert system analyzes all plug loads in the building. These range from computers and printers to coffee makers and vending machines. In addition to plug load, the program also considers “phantom load.” Phantom load refers to the power that a device draws when it is switched off but is still plugged in. Such loads can be high for appliances with a quick start feature or with a clock device inside, like a television. Even devices with small phantom loads can waste significant amounts of energy over long periods of time.

Figure B.19 Information on the office equipment module.

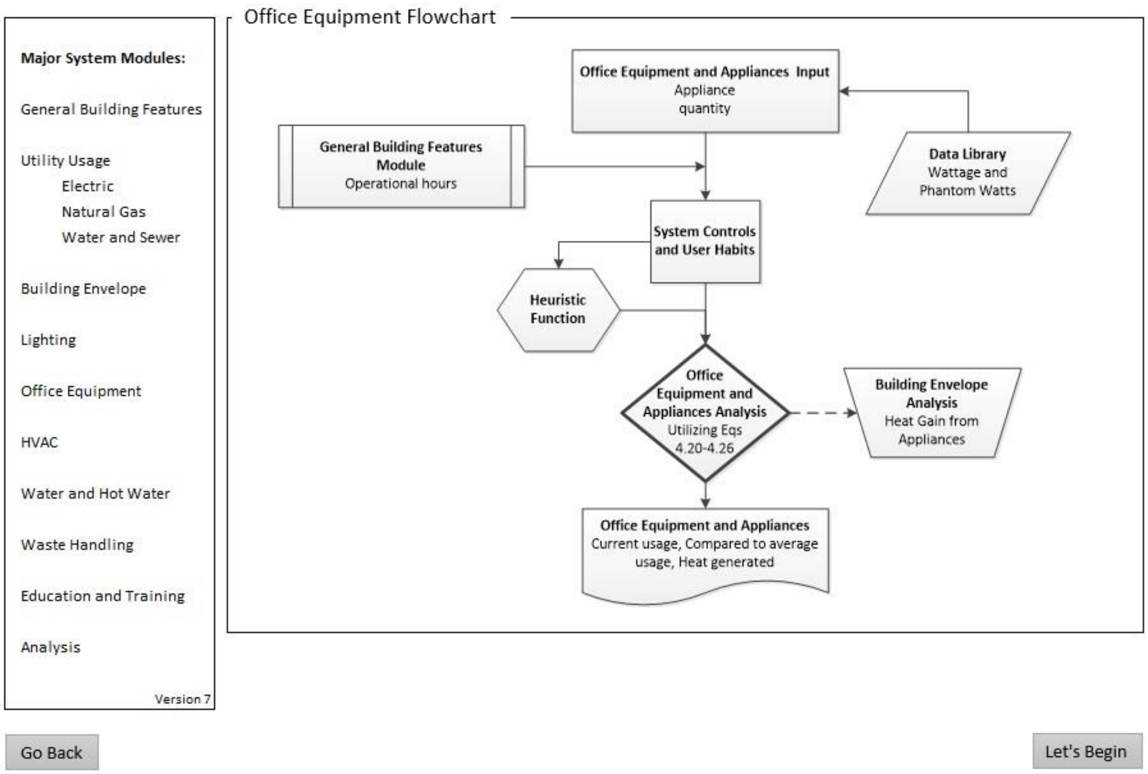
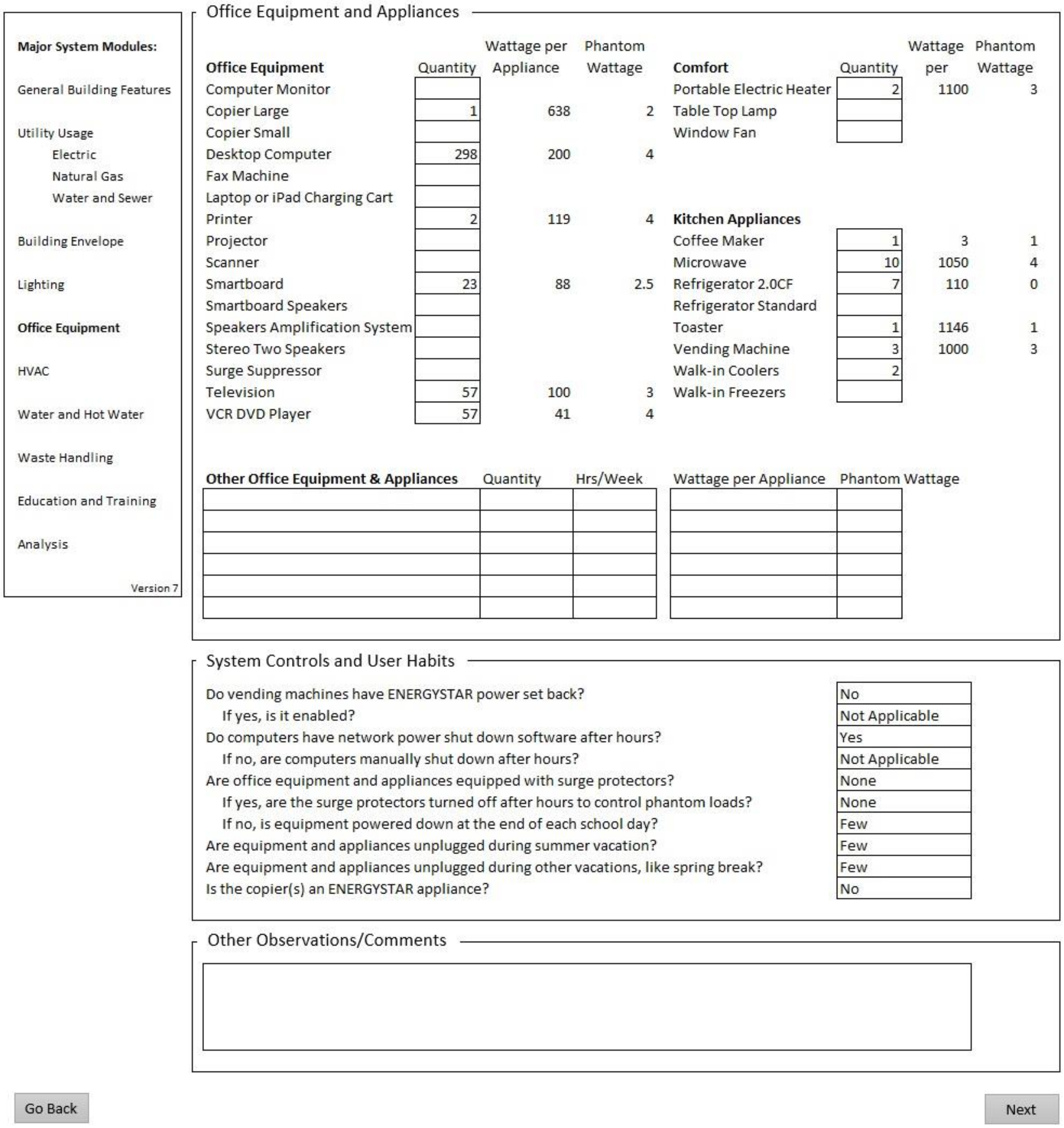


Figure B.20 Flowchart of the office equipment module.



Office Equipment and Appliances

Office Equipment	Quantity	Wattage per Appliance	Phantom Wattage
Computer Monitor			
Copier Large	1	638	2
Copier Small			
Desktop Computer	298	200	4
Fax Machine			
Laptop or iPad Charging Cart			
Printer	2	119	4
Projector			
Scanner			
Smartboard	23	88	2.5
Smartboard Speakers			
Speakers Amplification System			
Stereo Two Speakers			
Surge Suppressor			
Television	57	100	3
VCR DVD Player	57	41	4

Comfort	Quantity	Wattage per	Phantom Wattage
Portable Electric Heater	2	1100	3
Table Top Lamp			
Window Fan			

Kitchen Appliances			
Coffee Maker	1	3	1
Microwave	10	1050	4
Refrigerator 2.0CF	7	110	0
Refrigerator Standard			
Toaster	1	1146	1
Vending Machine	3	1000	3
Walk-in Coolers	2		
Walk-in Freezers			

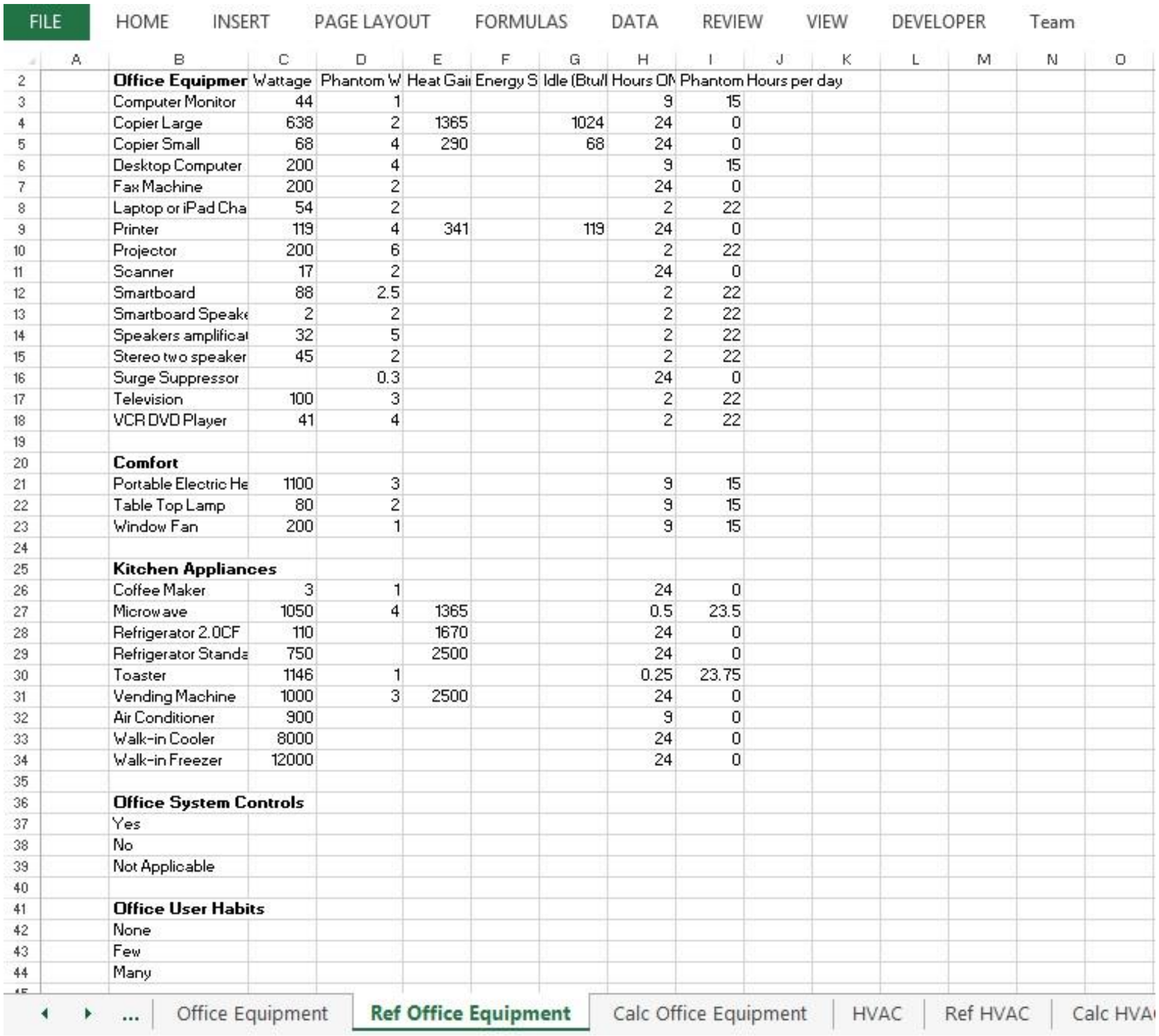
Other Office Equipment & Appliances	Quantity	Hrs/Week	Wattage per Appliance	Phantom Wattage

System Controls and User Habits

Do vending machines have ENERGYSTAR power set back?	No
If yes, is it enabled?	Not Applicable
Do computers have network power shut down software after hours?	Yes
If no, are computers manually shut down after hours?	Not Applicable
Are office equipment and appliances equipped with surge protectors?	None
If yes, are the surge protectors turned off after hours to control phantom loads?	None
If no, is equipment powered down at the end of each school day?	Few
Are equipment and appliances unplugged during summer vacation?	Few
Are equipment and appliances unplugged during other vacations, like spring break?	Few
Is the copier(s) an ENERGYSTAR appliance?	No

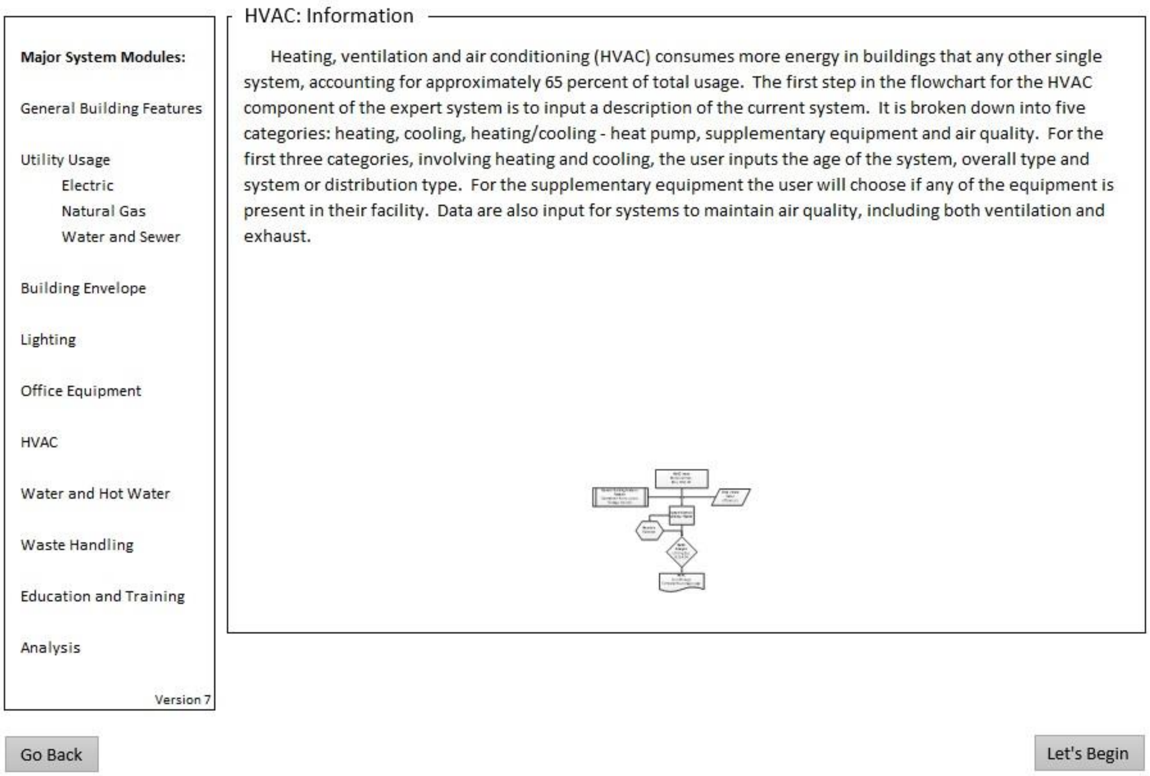
Other Observations/Comments

Figure B.21 Office equipment and appliances module input screen.



	B	C	D	E	F	G	H	I
2	**Office Equipmer**	Wattage	Phantom W	Heat Gai	Energy S	Idle (Btu/l	Hours ON	Phantom Hours per day
3	Computer Monitor	44	1				9	15
4	Copier Large	638	2	1365		1024	24	0
5	Copier Small	68	4	290		68	24	0
6	Desktop Computer	200	4				9	15
7	Fax Machine	200	2				24	0
8	Laptop or iPad Cha	54	2				2	22
9	Printer	119	4	341		119	24	0
10	Projector	200	6				2	22
11	Scanner	17	2				24	0
12	Smartboard	88	2.5				2	22
13	Smartboard Speake	2	2				2	22
14	Speakers amplificat	32	5				2	22
15	Stereo two speaker	45	2				2	22
16	Surge Suppressor		0.3				24	0
17	Television	100	3				2	22
18	VCR DVD Player	41	4				2	22
19								
20	**Comfort**							
21	Portable Electric He	1100	3				9	15
22	Table Top Lamp	80	2				9	15
23	Window Fan	200	1				9	15
24								
25	**Kitchen Appliances**							
26	Coffee Maker	3	1				24	0
27	Microwave	1050	4	1365			0.5	23.5
28	Refrigerator 2.0CF	110		1670			24	0
29	Refrigerator Standa	750		2500			24	0
30	Toaster	1146	1				0.25	23.75
31	Vending Machine	1000	3	2500			24	0
32	Air Conditioner	900					9	0
33	Walk-in Cooler	8000					24	0
34	Walk-in Freezer	12000					24	0
35								
36	**Office System Controls**							
37	Yes							
38	No							
39	Not Applicable							
40								
41	**Office User Habits**							
42	None							
43	Few							
44	Many							

Figure B.22 Office equipment reference, or data library, screen for drop down menus within the office equipment input screen in Figure B.21.



Heating, ventilation and air conditioning (HVAC) consumes more energy in buildings that any other single system, accounting for approximately 65 percent of total usage. The first step in the flowchart for the HVAC component of the expert system is to input a description of the current system. It is broken down into five categories: heating, cooling, heating/cooling - heat pump, supplementary equipment and air quality. For the first three categories, involving heating and cooling, the user inputs the age of the system, overall type and system or distribution type. For the supplementary equipment the user will choose if any of the equipment is present in their facility. Data are also input for systems to maintain air quality, including both ventilation and exhaust.

Figure B.23 Background information and interaction on the HVAC module.

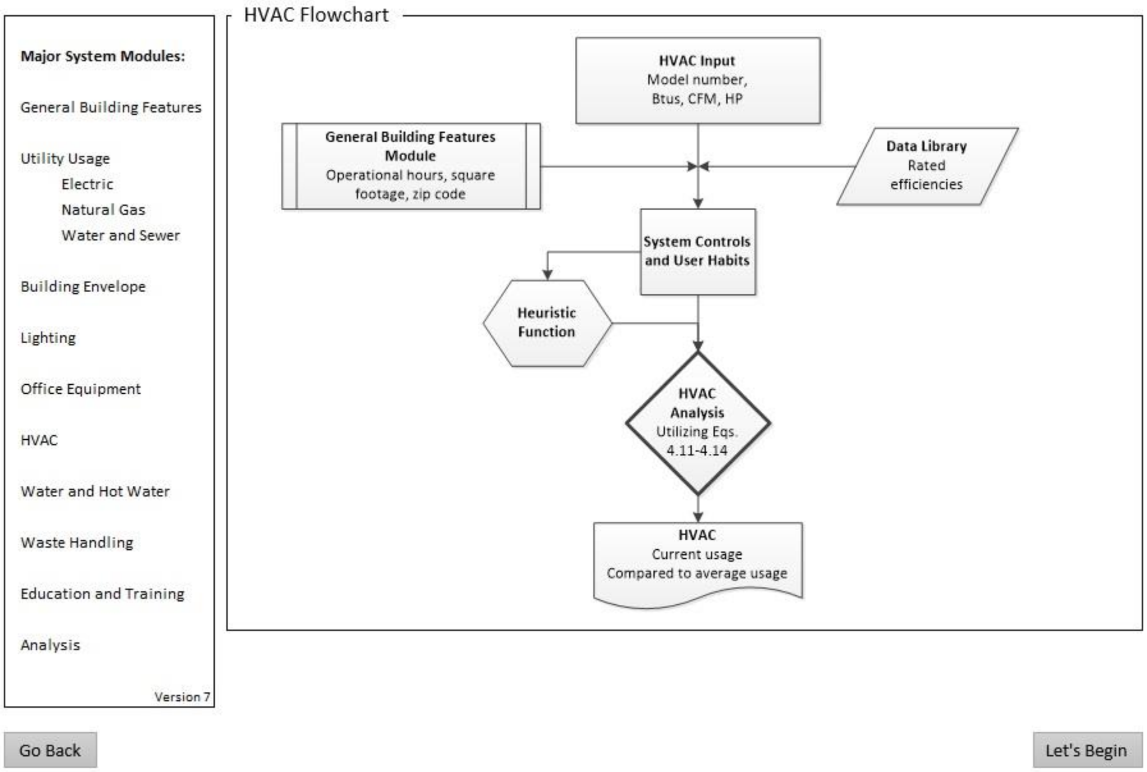
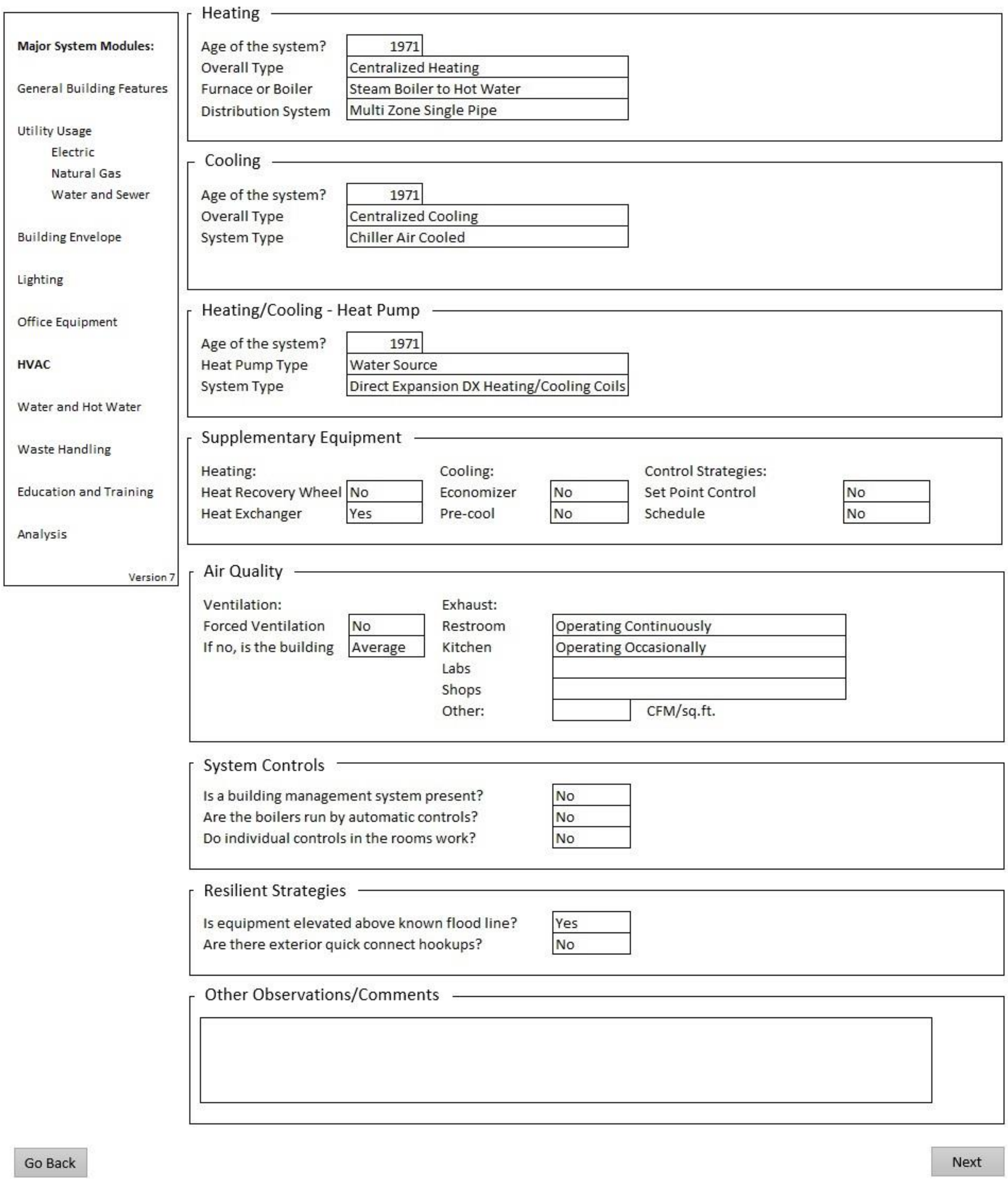


Figure B.24 Flowchart showing interaction of the HVAC module.



Heating

Age of the system?	1971
Overall Type	Centralized Heating
Furnace or Boiler	Steam Boiler to Hot Water
Distribution System	Multi Zone Single Pipe

Cooling

Age of the system?	1971
Overall Type	Centralized Cooling
System Type	Chiller Air Cooled

Heating/Cooling - Heat Pump

Age of the system?	1971
Heat Pump Type	Water Source
System Type	Direct Expansion DX Heating/Cooling Coils

Supplementary Equipment

Heating:		Cooling:		Control Strategies:	
Heat Recovery Wheel	No	Economizer	No	Set Point Control	No
Heat Exchanger	Yes	Pre-cool	No	Schedule	No

Air Quality

Ventilation:		Exhaust:	
Forced Ventilation	No	Restroom	Operating Continuously
If no, is the building	Average	Kitchen	Operating Occasionally
		Labs	
		Shops	
		Other:	CFM/sq.ft.

System Controls

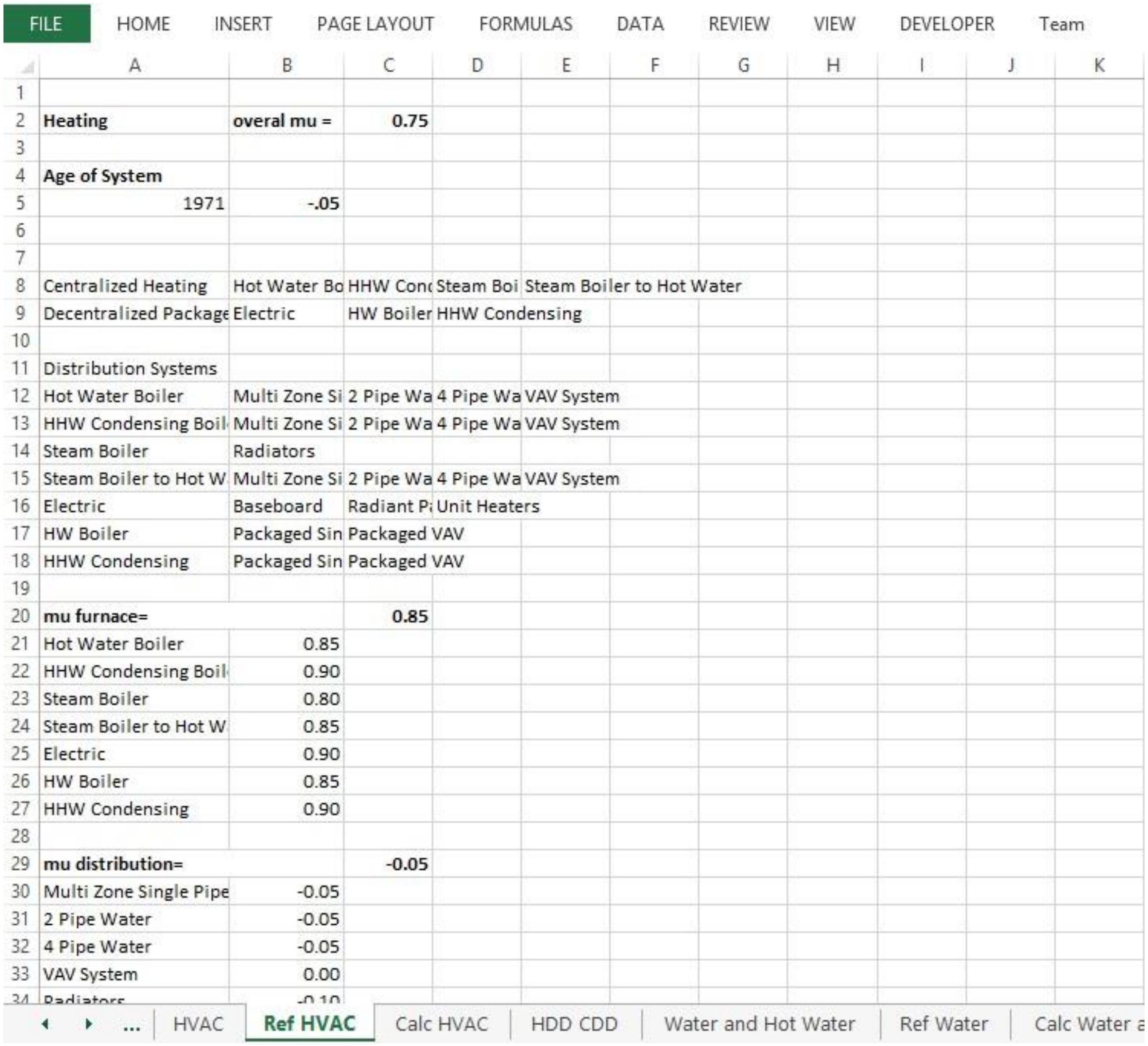
Is a building management system present?	No
Are the boilers run by automatic controls?	No
Do individual controls in the rooms work?	No

Resilient Strategies

Is equipment elevated above known flood line?	Yes
Are there exterior quick connect hookups?	No

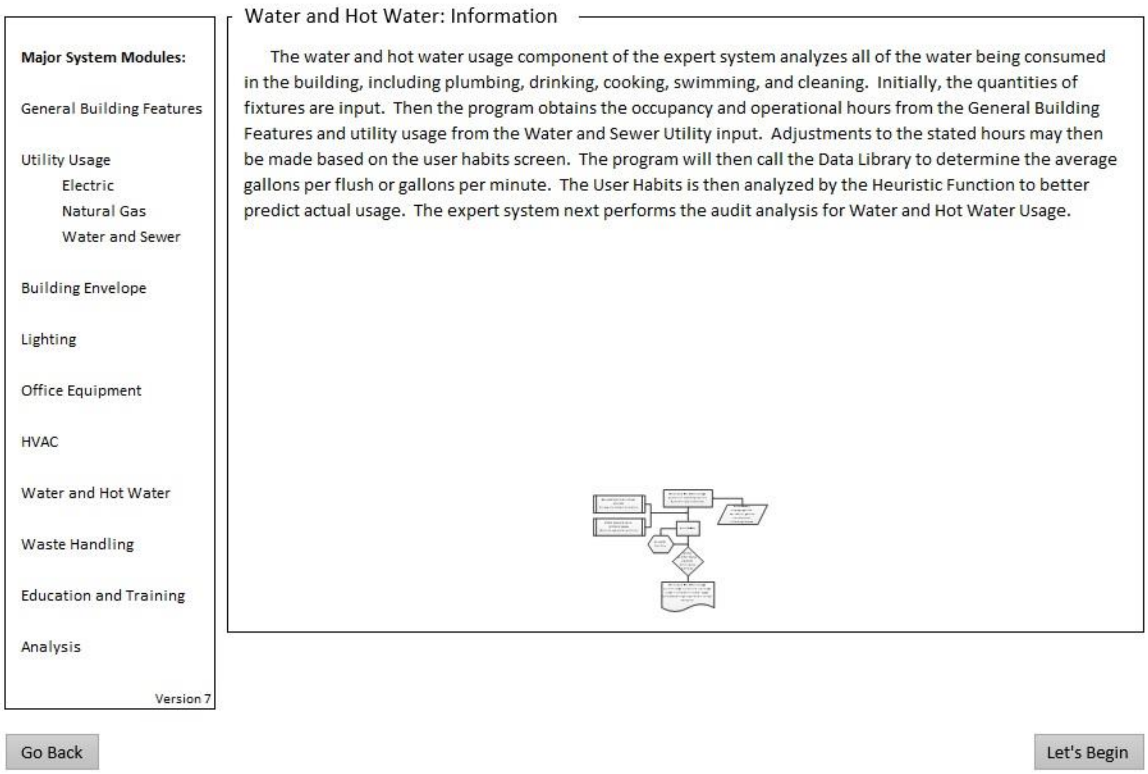
Other Observations/Comments

Figure B.25 Screenshot of the HVAC module input screen.



	A	B	C	D	E	F	G	H	I	J	K
1											
2	**Heating**	**overal mu =**	**0.75**								
3											
4	**Age of System**										
5	1971	**-.05**									
6											
7											
8	Centralized Heating	Hot Water Bo	HHW Conc	Steam Boi	Steam Boiler to Hot Water						
9	Decentralized Package	Electric	HW Boiler	HHW Condensing							
10											
11	Distribution Systems										
12	Hot Water Boiler	Multi Zone Si	2 Pipe Wa	4 Pipe Wa	VAV System						
13	HHW Condensing Boil	Multi Zone Si	2 Pipe Wa	4 Pipe Wa	VAV System						
14	Steam Boiler	Radiators									
15	Steam Boiler to Hot W	Multi Zone Si	2 Pipe Wa	4 Pipe Wa	VAV System						
16	Electric	Baseboard	Radiant P	Unit Heaters							
17	HW Boiler	Packaged Sin	Packaged VAV								
18	HHW Condensing	Packaged Sin	Packaged VAV								
19											
20	**mu furnace=**		**0.85**								
21	Hot Water Boiler	0.85									
22	HHW Condensing Boil	0.90									
23	Steam Boiler	0.80									
24	Steam Boiler to Hot W	0.85									
25	Electric	0.90									
26	HW Boiler	0.85									
27	HHW Condensing	0.90									
28											
29	**mu distribution=**		**-0.05**								
30	Multi Zone Single Pipe	-0.05									
31	2 Pipe Water	-0.05									
32	4 Pipe Water	-0.05									
33	VAV System	0.00									
34	Radiators	-0.10									

Figure B.26 HVAC reference, or data library, screen for drop down menus within the HVAC input screen in Figure B.25. This worksheet has over 100 lines of data and only a portion was shown.



The water and hot water usage component of the expert system analyzes all of the water being consumed in the building, including plumbing, drinking, cooking, swimming, and cleaning. Initially, the quantities of fixtures are input. Then the program obtains the occupancy and operational hours from the General Building Features and utility usage from the Water and Sewer Utility input. Adjustments to the stated hours may then be made based on the user habits screen. The program will then call the Data Library to determine the average gallons per flush or gallons per minute. The User Habits is then analyzed by the Heuristic Function to better predict actual usage. The expert system next performs the audit analysis for Water and Hot Water Usage.

Figure B.27 Information on the water and hot water module.

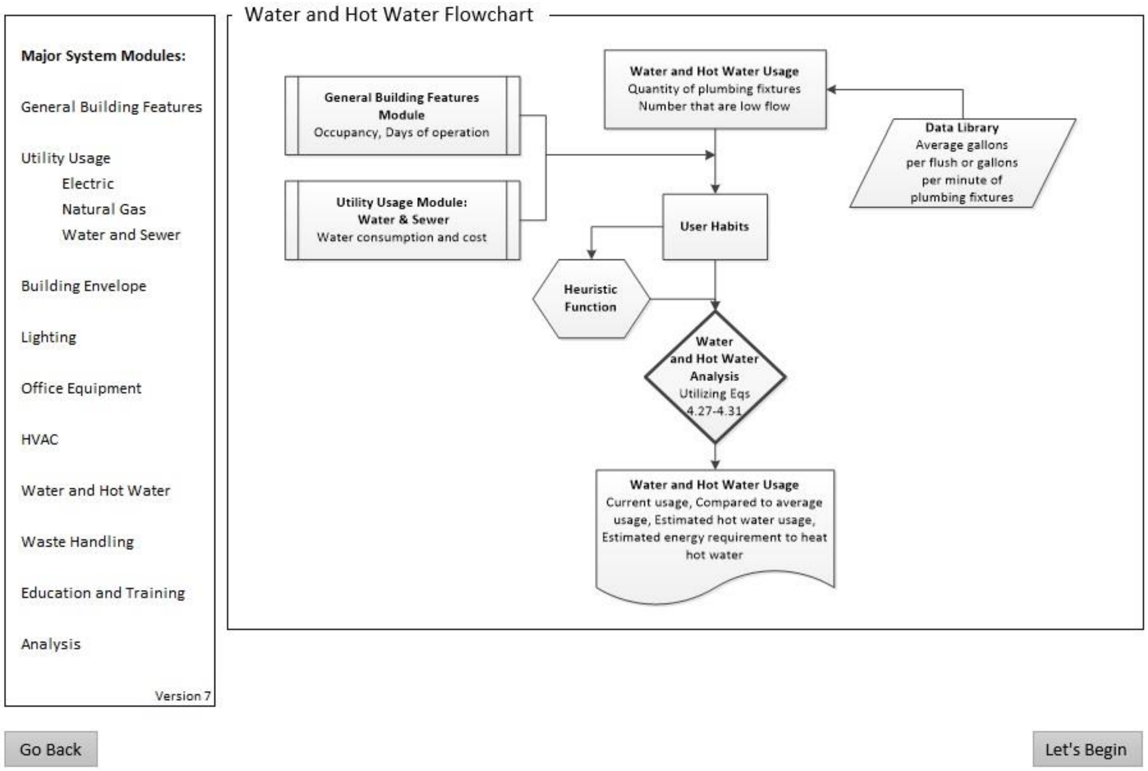
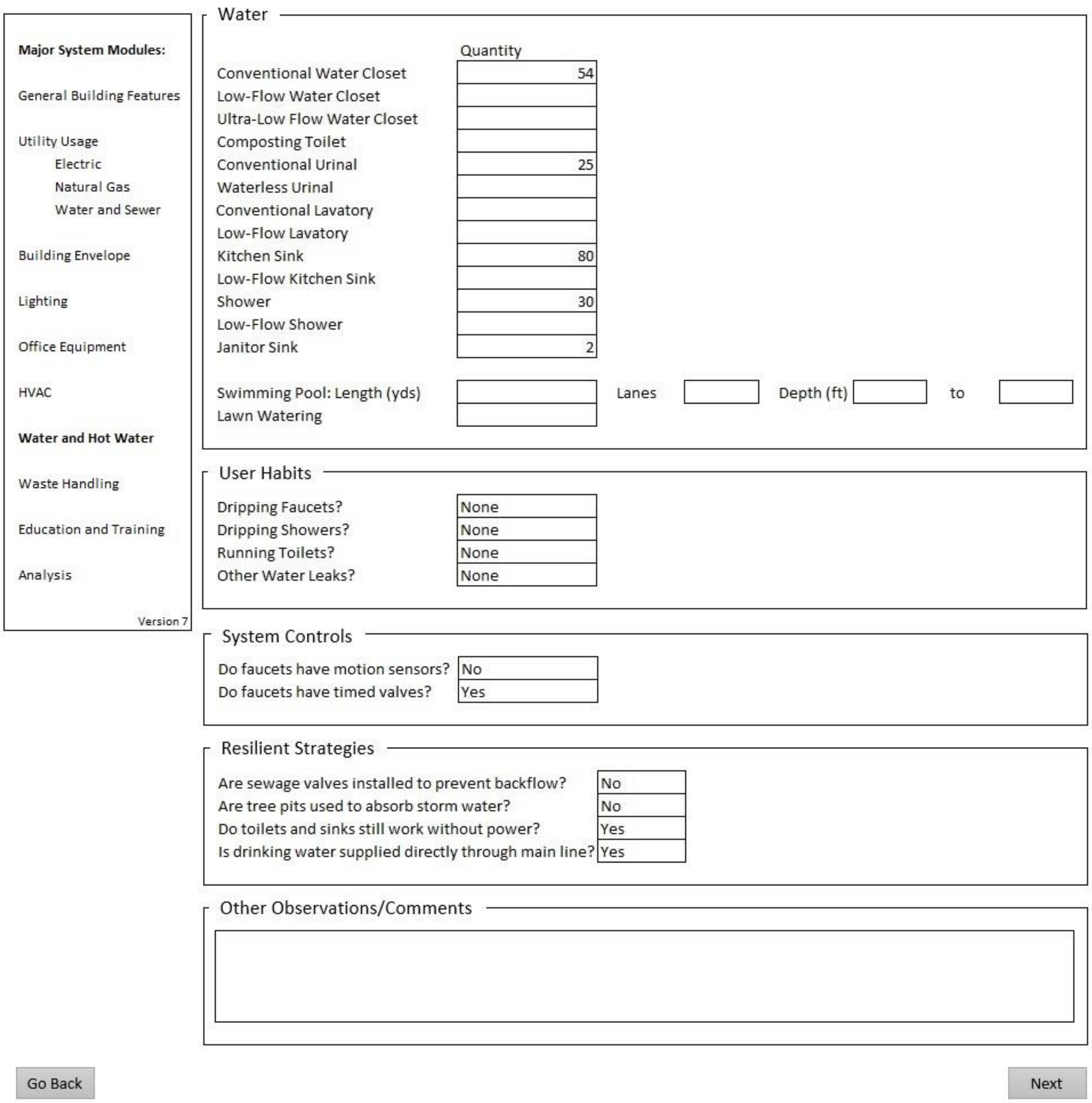


Figure B.28 Flowchart of the water and hot water module.



Water

	Quantity
Conventional Water Closet	54
Low-Flow Water Closet	
Ultra-Low Flow Water Closet	
Composting Toilet	
Conventional Urinal	25
Waterless Urinal	
Conventional Lavatory	
Low-Flow Lavatory	
Kitchen Sink	80
Low-Flow Kitchen Sink	
Shower	30
Low-Flow Shower	
Janitor Sink	2

Swimming Pool: Length (yds) Lanes Depth (ft) to

Lawn Watering

User Habits

Dripping Faucets?	None
Dripping Showers?	None
Running Toilets?	None
Other Water Leaks?	None

System Controls

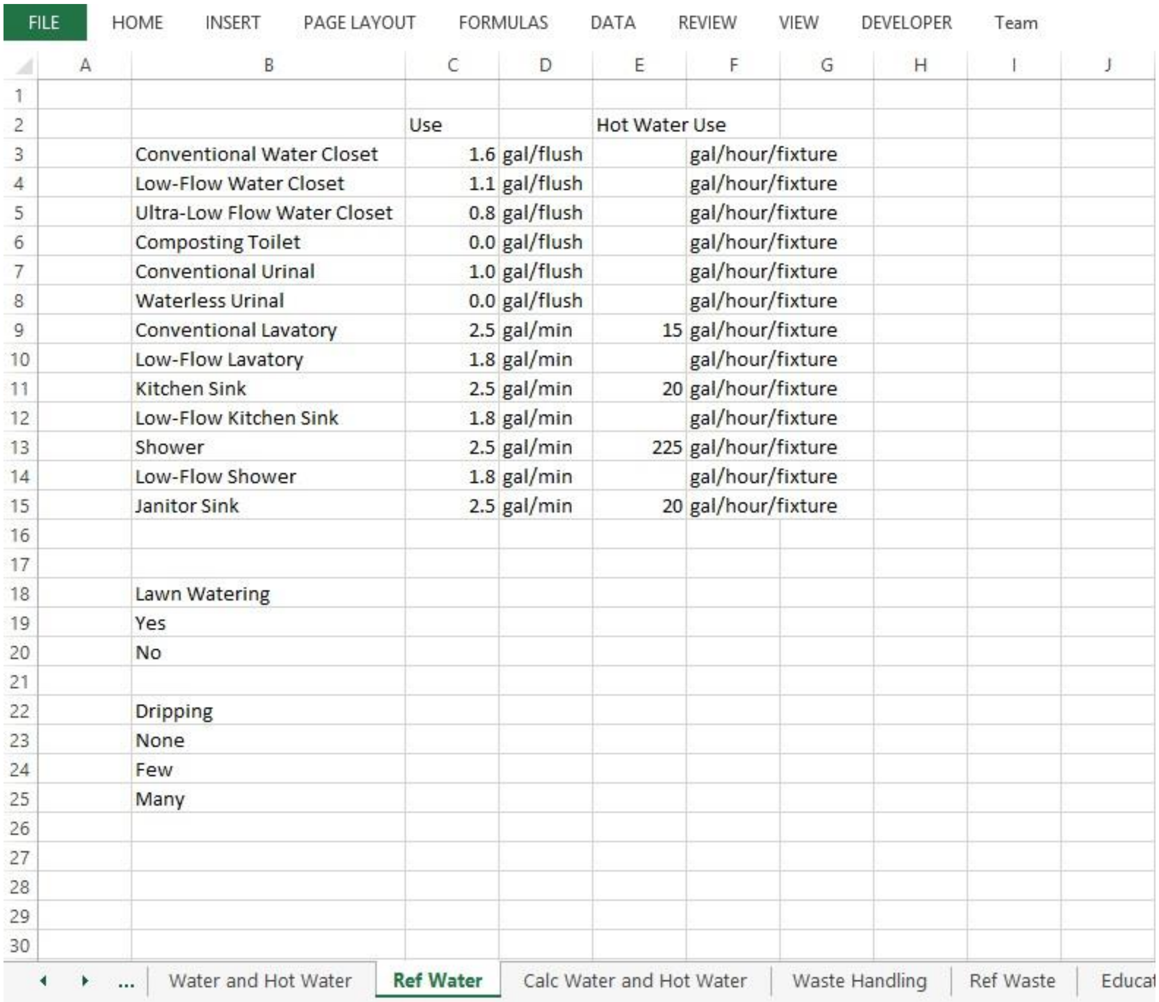
Do faucets have motion sensors?	No
Do faucets have timed valves?	Yes

Resilient Strategies

Are sewage valves installed to prevent backflow?	No
Are tree pits used to absorb storm water?	No
Do toilets and sinks still work without power?	Yes
Is drinking water supplied directly through main line?	Yes

Other Observations/Comments

Figure B.29 Screenshot of the water and hot water module input screen.

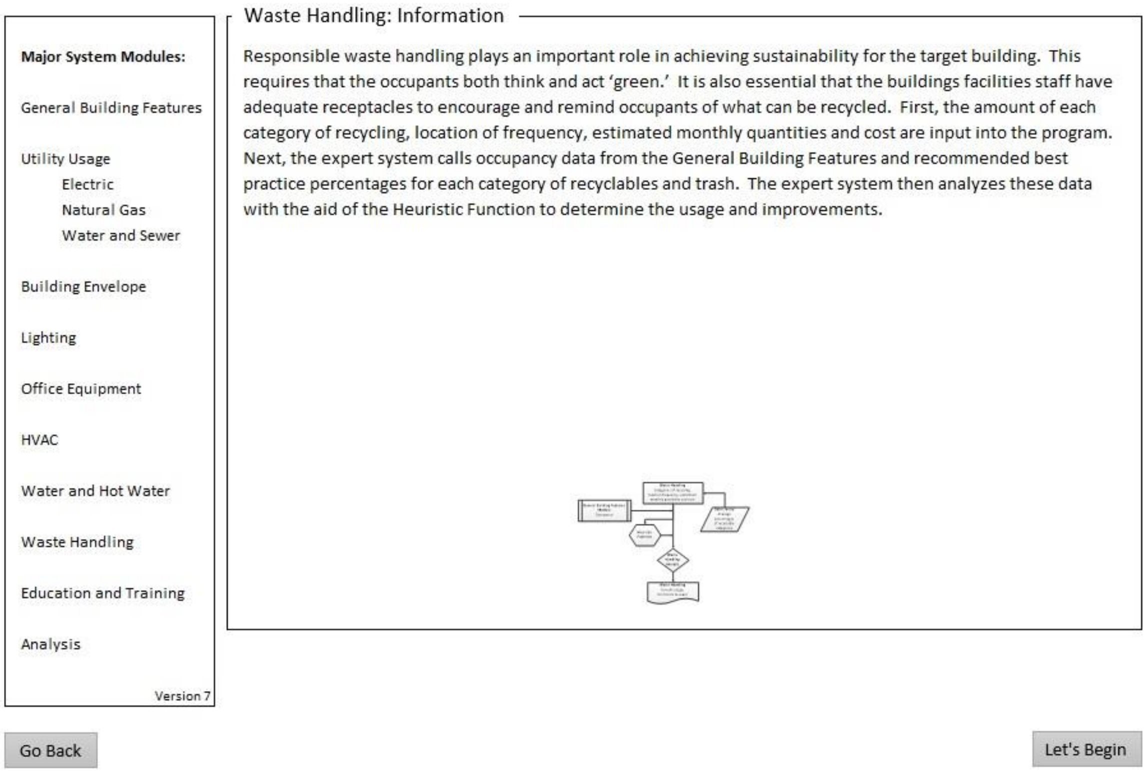


	Use		Hot Water Use	
Conventional Water Closet	1.6	gal/flush		gal/hour/fixture
Low-Flow Water Closet	1.1	gal/flush		gal/hour/fixture
Ultra-Low Flow Water Closet	0.8	gal/flush		gal/hour/fixture
Composting Toilet	0.0	gal/flush		gal/hour/fixture
Conventional Urinal	1.0	gal/flush		gal/hour/fixture
Waterless Urinal	0.0	gal/flush		gal/hour/fixture
Conventional Lavatory	2.5	gal/min	15	gal/hour/fixture
Low-Flow Lavatory	1.8	gal/min		gal/hour/fixture
Kitchen Sink	2.5	gal/min	20	gal/hour/fixture
Low-Flow Kitchen Sink	1.8	gal/min		gal/hour/fixture
Shower	2.5	gal/min	225	gal/hour/fixture
Low-Flow Shower	1.8	gal/min		gal/hour/fixture
Janitor Sink	2.5	gal/min	20	gal/hour/fixture

Lawn Watering
Yes
No

Dripping
None
Few
Many

Figure B.30 Screenshot of the water and hot water data library for water input screen.



Responsible waste handling plays an important role in achieving sustainability for the target building. This requires that the occupants both think and act 'green.' It is also essential that the buildings facilities staff have adequate receptacles to encourage and remind occupants of what can be recycled. First, the amount of each category of recycling, location of frequency, estimated monthly quantities and cost are input into the program. Next, the expert system calls occupancy data from the General Building Features and recommended best practice percentages for each category of recyclables and trash. The expert system then analyzes these data with the aid of the Heuristic Function to determine the usage and improvements.

Figure B.31 Information on the waste handling module.

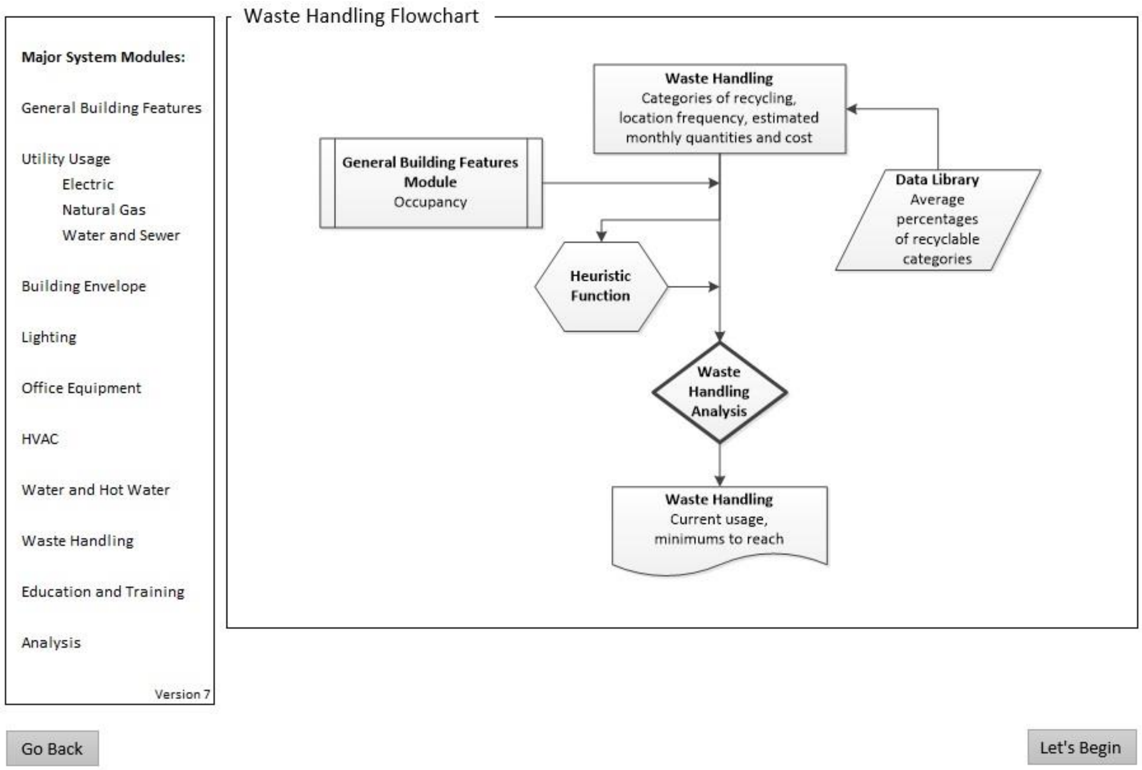
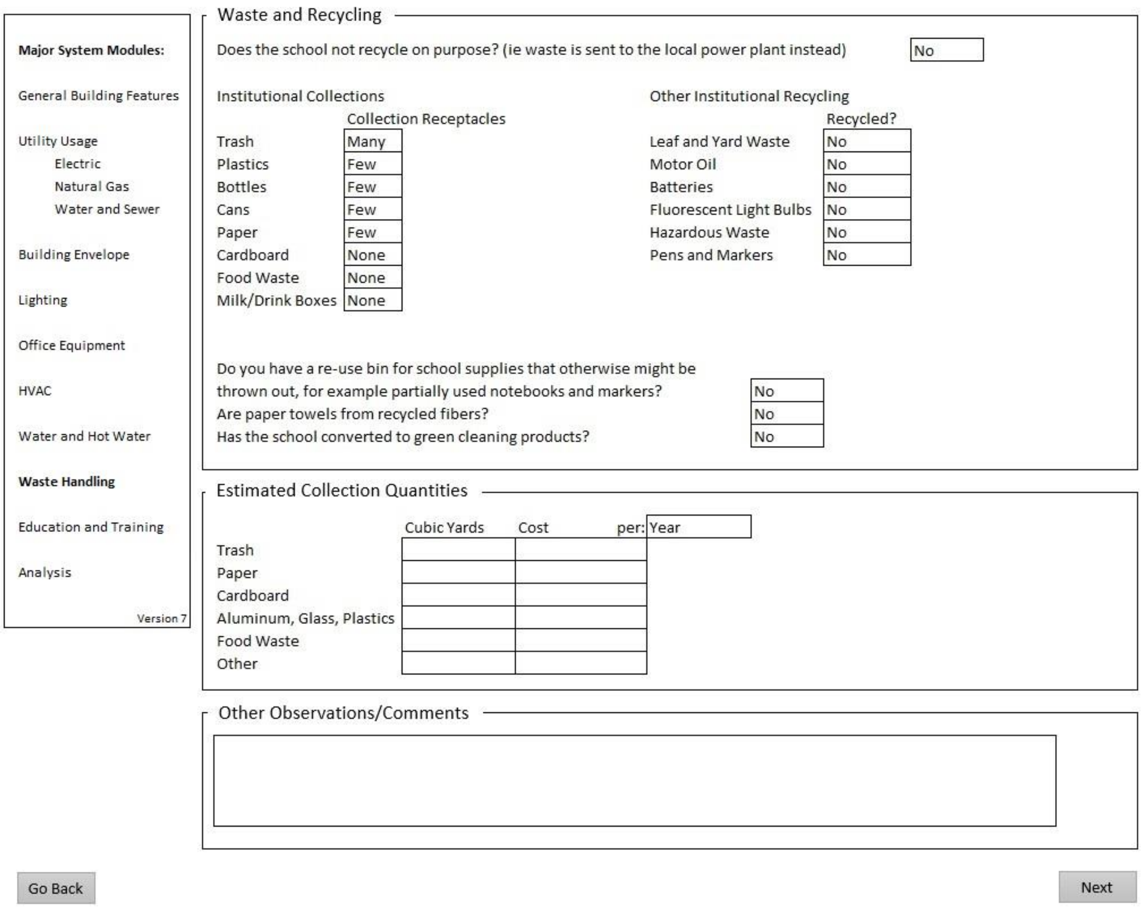


Figure B.32 Flowchart of the waste handling module.



Waste and Recycling

Does the school not recycle on purpose? (ie waste is sent to the local power plant instead) No

Institutional Collections

	Collection Receptacles
Trash	Many
Plastics	Few
Bottles	Few
Cans	Few
Paper	Few
Cardboard	None
Food Waste	None
Milk/Drink Boxes	None

Other Institutional Recycling

	Recycled?
Leaf and Yard Waste	No
Motor Oil	No
Batteries	No
Fluorescent Light Bulbs	No
Hazardous Waste	No
Pens and Markers	No

Do you have a re-use bin for school supplies that otherwise might be thrown out, for example partially used notebooks and markers? No

Are paper towels from recycled fibers? No

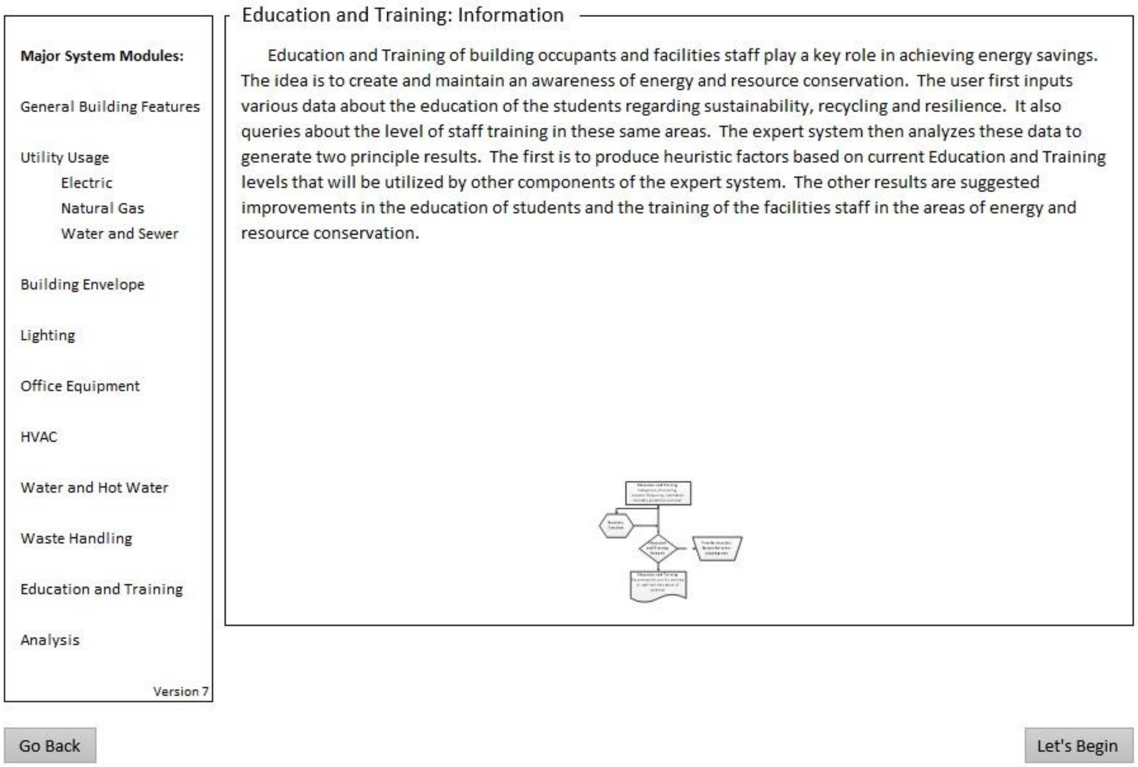
Has the school converted to green cleaning products? No

Estimated Collection Quantities

	Cubic Yards	Cost	per: Year
Trash			
Paper			
Cardboard			
Aluminum, Glass, Plastics			
Food Waste			
Other			

Other Observations/Comments

Figure B.33 Input screen of the waste handling module.



Education and Training of building occupants and facilities staff play a key role in achieving energy savings. The idea is to create and maintain an awareness of energy and resource conservation. The user first inputs various data about the education of the students regarding sustainability, recycling and resilience. It also queries about the level of staff training in these same areas. The expert system then analyzes these data to generate two principle results. The first is to produce heuristic factors based on current Education and Training levels that will be utilized by other components of the expert system. The other results are suggested improvements in the education of students and the training of the facilities staff in the areas of energy and resource conservation.

Figure B.34 Information on the education and training module.

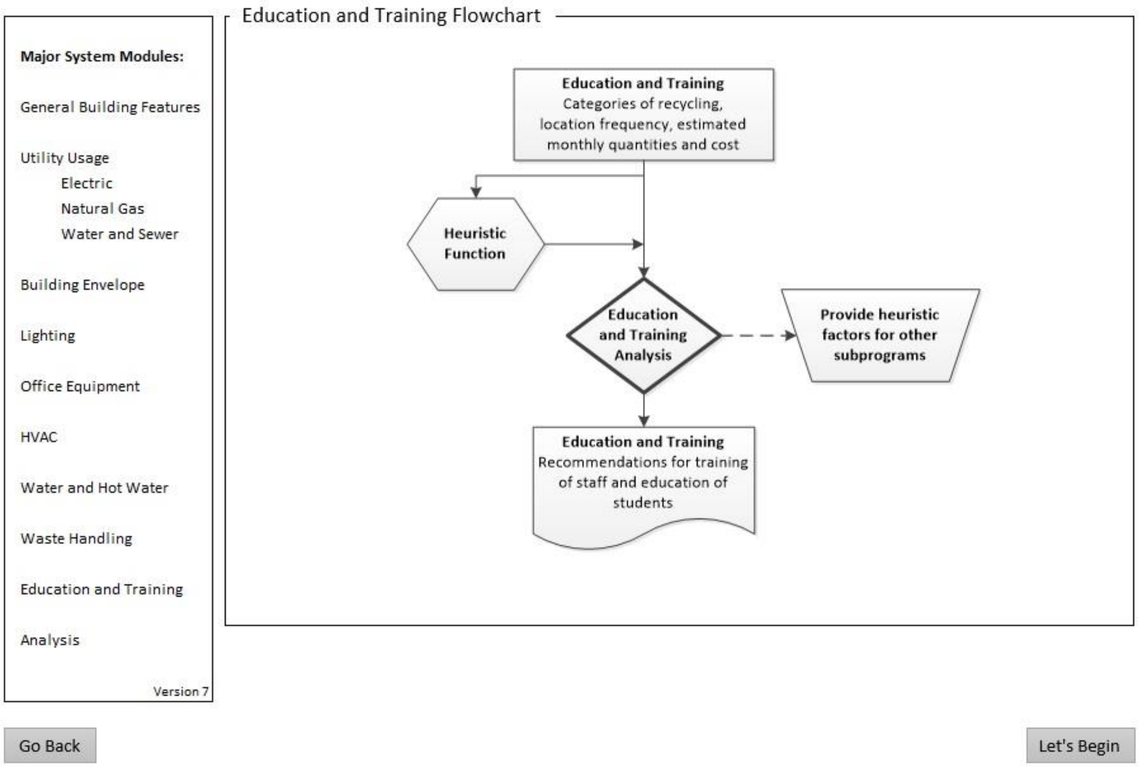
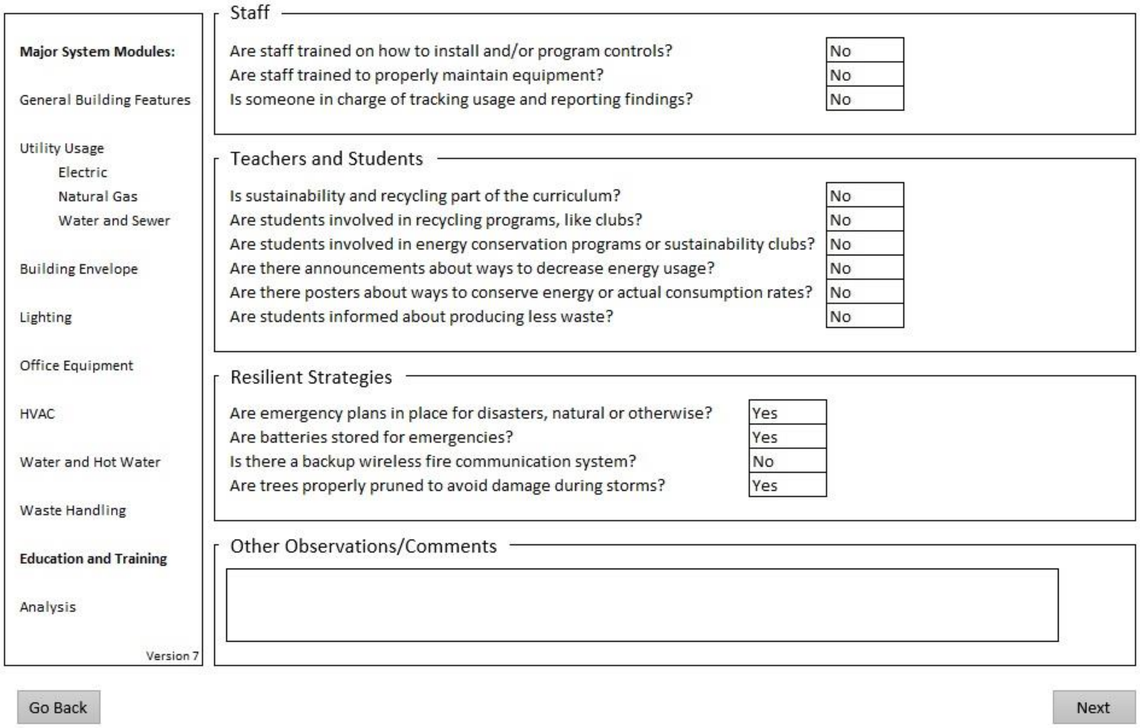


Figure B.35 Flowchart of the education and training module.



Staff

Are staff trained on how to install and/or program controls?	No
Are staff trained to properly maintain equipment?	No
Is someone in charge of tracking usage and reporting findings?	No

Teachers and Students

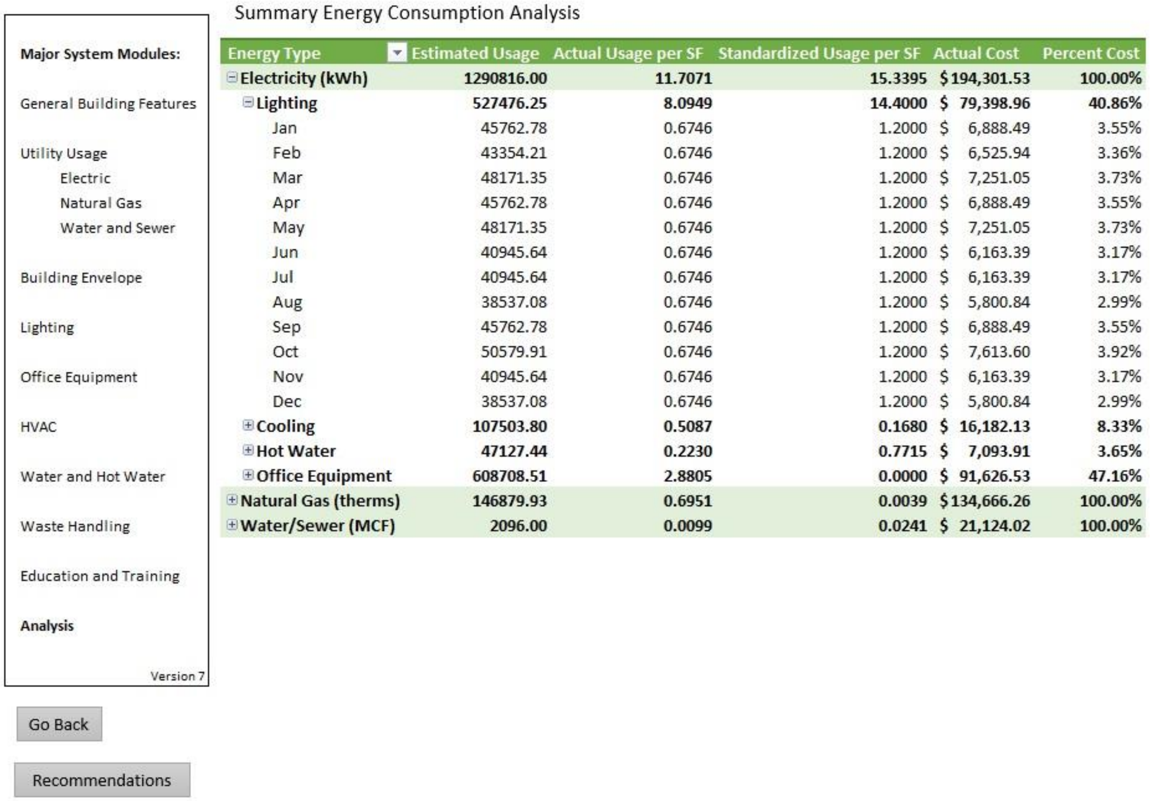
Is sustainability and recycling part of the curriculum?	No
Are students involved in recycling programs, like clubs?	No
Are students involved in energy conservation programs or sustainability clubs?	No
Are there announcements about ways to decrease energy usage?	No
Are there posters about ways to conserve energy or actual consumption rates?	No
Are students informed about producing less waste?	No

Resilient Strategies

Are emergency plans in place for disasters, natural or otherwise?	Yes
Are batteries stored for emergencies?	Yes
Is there a backup wireless fire communication system?	No
Are trees properly pruned to avoid damage during storms?	Yes

Other Observations/Comments

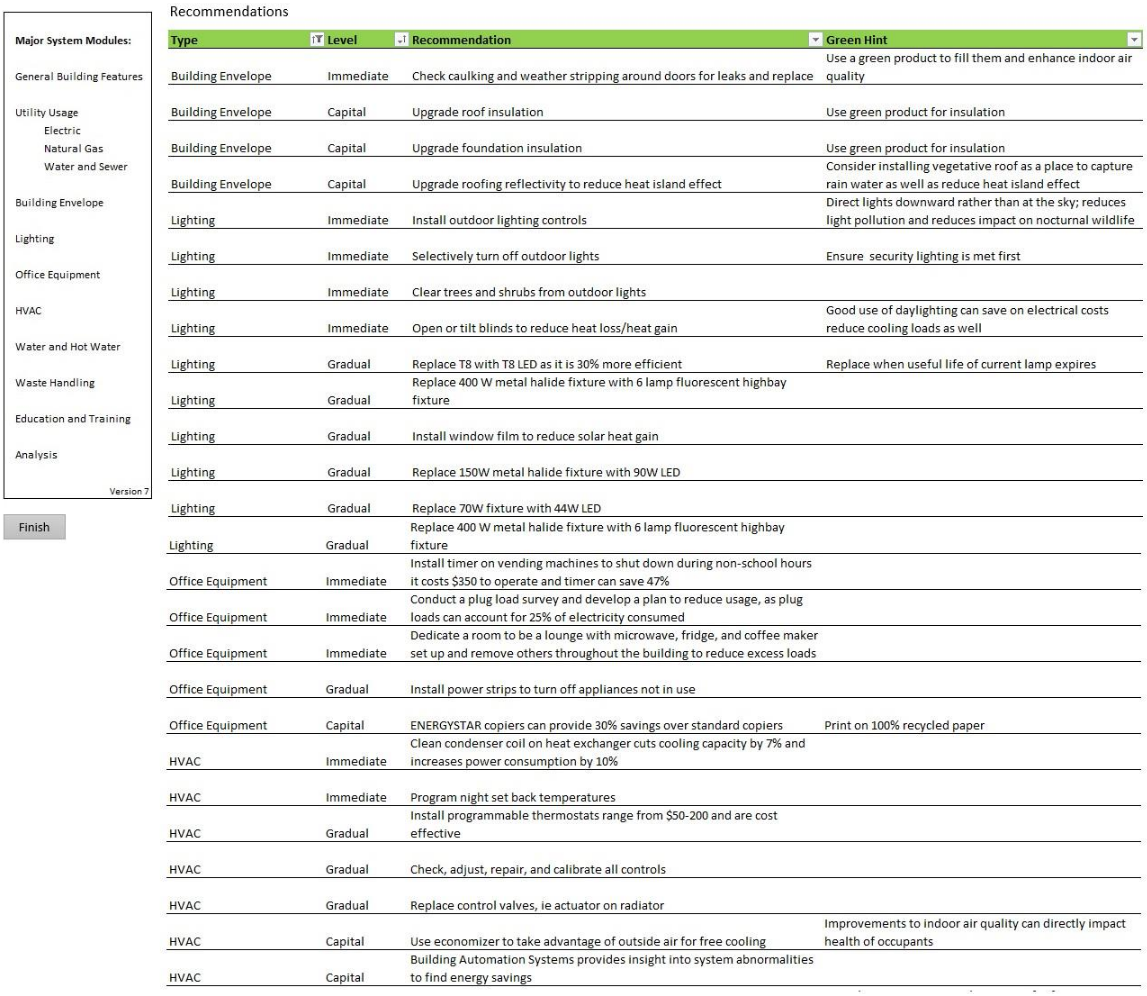
Figure B.36 Input screen of the education and training module.



Summary Energy Consumption Analysis

Energy Type	Estimated Usage	Actual Usage per SF	Standardized Usage per SF	Actual Cost	Percent Cost
⊟Electricity (kWh)	**1290816.00**	**11.7071**	**15.3395**	**$194,301.53**	**100.00%**
⊟Lighting	**527476.25**	**8.0949**	**14.4000**	**$ 79,398.96**	**40.86%**
Jan	45762.78	0.6746	1.2000	$ 6,888.49	3.55%
Feb	43354.21	0.6746	1.2000	$ 6,525.94	3.36%
Mar	48171.35	0.6746	1.2000	$ 7,251.05	3.73%
Apr	45762.78	0.6746	1.2000	$ 6,888.49	3.55%
May	48171.35	0.6746	1.2000	$ 7,251.05	3.73%
Jun	40945.64	0.6746	1.2000	$ 6,163.39	3.17%
Jul	40945.64	0.6746	1.2000	$ 6,163.39	3.17%
Aug	38537.08	0.6746	1.2000	$ 5,800.84	2.99%
Sep	45762.78	0.6746	1.2000	$ 6,888.49	3.55%
Oct	50579.91	0.6746	1.2000	$ 7,613.60	3.92%
Nov	40945.64	0.6746	1.2000	$ 6,163.39	3.17%
Dec	38537.08	0.6746	1.2000	$ 5,800.84	2.99%
⊞Cooling	**107503.80**	**0.5087**	**0.1680**	**$ 16,182.13**	**8.33%**
⊞Hot Water	**47127.44**	**0.2230**	**0.7715**	**$ 7,093.91**	**3.65%**
⊞Office Equipment	**608708.51**	**2.8805**	**0.0000**	**$ 91,626.53**	**47.16%**
⊞Natural Gas (therms)	**146879.93**	**0.6951**	**0.0039**	**$134,666.26**	**100.00%**
⊞Water/Sewer (MCF)	**2096.00**	**0.0099**	**0.0241**	**$ 21,124.02**	**100.00%**

Figure B.37 Summary energy consumption analysis screen.



Recommendations

Type	Level	Recommendation	Green Hint
Building Envelope	Immediate	Check caulking and weather stripping around doors for leaks and replace	Use a green product to fill them and enhance indoor air quality
Building Envelope	Capital	Upgrade roof insulation	Use green product for insulation
Building Envelope	Capital	Upgrade foundation insulation	Use green product for insulation
Building Envelope	Capital	Upgrade roofing reflectivity to reduce heat island effect	Consider installing vegetative roof as a place to capture rain water as well as reduce heat island effect
Lighting	Immediate	Install outdoor lighting controls	Direct lights downward rather than at the sky; reduces light pollution and reduces impact on nocturnal wildlife
Lighting	Immediate	Selectively turn off outdoor lights	Ensure security lighting is met first
Lighting	Immediate	Clear trees and shrubs from outdoor lights	
Lighting	Immediate	Open or tilt blinds to reduce heat loss/heat gain	Good use of daylighting can save on electrical costs reduce cooling loads as well
Lighting	Gradual	Replace T8 with T8 LED as it is 30% more efficient	Replace when useful life of current lamp expires
Lighting	Gradual	Replace 400 W metal halide fixture with 6 lamp fluorescent highbay fixture	
Lighting	Gradual	Install window film to reduce solar heat gain	
Lighting	Gradual	Replace 150W metal halide fixture with 90W LED	
Lighting	Gradual	Replace 70W fixture with 44W LED	
Lighting	Gradual	Replace 400 W metal halide fixture with 6 lamp fluorescent highbay fixture	
Office Equipment	Immediate	Install timer on vending machines to shut down during non-school hours it costs $350 to operate and timer can save 47%	
Office Equipment	Immediate	Conduct a plug load survey and develop a plan to reduce usage, as plug loads can account for 25% of electricity consumed	
Office Equipment	Immediate	Dedicate a room to be a lounge with microwave, fridge, and coffee maker set up and remove others throughout the building to reduce excess loads	
Office Equipment	Gradual	Install power strips to turn off appliances not in use	
Office Equipment	Capital	ENERGYSTAR copiers can provide 30% savings over standard copiers	Print on 100% recycled paper
HVAC	Immediate	Clean condenser coil on heat exchanger cuts cooling capacity by 7% and increases power consumption by 10%	
HVAC	Immediate	Program night set back temperatures	
HVAC	Gradual	Install programmable thermostats range from $50-200 and are cost effective	
HVAC	Gradual	Check, adjust, repair, and calibrate all controls	
HVAC	Gradual	Replace control valves, ie actuator on radiator	
HVAC	Capital	Use economizer to take advantage of outside air for free cooling	Improvements to indoor air quality can directly impact health of occupants
HVAC	Capital	Building Automation Systems provides insight into system abnormalities to find energy savings	

Figure B.38 Recommendations screen is continued in Figure B.39. Recommendations can be sorted by module and by level of recommendation.

Water and Hot Water	Gradual	Timed shut off valves on faucets	Using less water ensures clean water for future generations
Water and Hot Water	Gradual	Set water heaters on timers priced at $40-50	
Waste Handling	Immediate	Consider recycling motor oil	
Waste Handling	Immediate	Consider a reuse bin partially used supplies that could still be used before being thrown away	
Waste Handling	Immediate	Consider using paper towels that are from recycled fibers	
Waste Handling	Immediate	Convert to green cleaning products	Enhances indoor air quality
Waste Handling	Immediate	Consider composting leaf and yard waste	
Waste Handling	Immediate	Consider recycling batteries	
Waste Handling	Immediate	Consider a bin for used markers and pens and send them to Crayola	
Education and Training	Immediate	Train staff to use and program controls properly	
Education and Training	Immediate	Train staff on proper maintenance and good practice of equipment	
Education and Training	Immediate	Elect someone to be in charge of tracking usage and reporting findings	
Education and Training	Immediate	Incorporate sustainability and recycling into the curriculum	Teaching students to be green to continue green practices for future generations
Education and Training	Immediate	Start a recycling program	Allow students to use the money from recycling to purchase seeds for a community garden
Education and Training	Immediate	Start a energy conservation or sustainability club	Encourage student advocacy. Students place light bulb stickers on light switches.
Education and Training	Immediate	Make announcements on ways to decrease energy use	
Education and Training	Immediate	Display posters on ways to reduce usage and post actual usage to make competitions to reduce	
Education and Training	Immediate	Inform students and staff about producing less waste	
Preventative Maintenance	Immediate	Review cleaning and maintenance activities	Use green cleaning products to reduce harmful chemicals in the building
Preventative Maintenance	Immediate	Provide training for key staff	
Preventative Maintenance	Immediate	Perform energy audits and surveys to monitor usage	
Resilient Strategies		Utility failures often disable the heating and cooling systems, ensure insulation and air seals of walls, windows, door and roof are adequate	
Resilient Strategies		Have a backup wireless fire communication system	
Resilient Strategies		Generators for lighting, fire safety, and building systems	
Resilient Strategies		Use heavy pavers on the roof in place of gravel for wind resistance	
Resilient Strategies		Exterior quick connect hookups allow easy connection to portable generators	
Resilient Strategies		Use tree pits to absorb rain during storms	
Resilient Strategies		Keep hallways lit during blackouts	
Resilient Strategies		Sewage valves prevent sewage backflow into basements during rainstorms and floods	
Resilient Strategies		Use light colored roofing material to reflect heat and light back into the atmosphere, reducing heat island effect	

Figure B.39 Recommendations screen continued from Figure B.38.

APPENDIX C

CALCULATIONS

The following are example calculations that are performed by the expert system. Arts High School was used for the example. Starting with the first module, Building Envelope, the heat loss and gain needs to be calculated by month. Heat gain and loss is due to various components. Heat gain or loss is found from the following components: walls, roof, windows and doors. These are shown in Equations C.1 to C.12. Heat gain from lighting, appliances, people, and the Sun's radiant energy, must also be found and are shown in Equations C.13 to C.22. In order to determine the total heat gain and loss through a building, all of the above equations are combined into Equation C.23. The following equations considers the month of January. Each of the following equations is then repeated for each given month within the model.

Heat loss through the walls is calculated from Equation C.1.

$$Q_{WL} = \tag{C.1}$$

$$(Avg\ Temp - Set\ Point) \times$$

$$\left[(1 - Builing\ addition\ \%)\left(U_{wall\ original} \times Wall\ Area\right) +\right.$$

$$\left.(Building\ addition\ \% \ \times U_{wall\ addition} \times Wall\ Area)\right]$$

$$Q_{WL} = \tag{C.2}$$

$$(36°\mathrm{F} - 72°\mathrm{F}) \times \left[(1 - 0.48)\left(0.124\ \frac{Btu}{hr} ft^2 °\mathrm{F}\ \times 53{,}948.5\ ft^2\right) +\right.$$

$$\left.\left(0.48\ \times 0.118 \frac{Btu}{hr} ft^2 °\mathrm{F} \times 53{,}948.5\ ft^2\right)\right]$$

$$Q_{WL} = -235{,}233\ {}^{Btu}/_{hr} \tag{C.3}$$

Heat loss through the roof is determined from Equation C.4 below.

$$Q_R = (Avg\ Temp - Set\ Point) \times \big[\big(U_{roof\ original} \times Roof\ \ Area\big) + \big(U_{roof\ addition} \times Roof\ \ Area\big) + (U_{other\ material} \times Roof\ \ Area)\big] \tag{C.4}$$

$$Q_R = (36°\text{F} - 72°\text{F}) \times \left[\left(0.08 \frac{Btu}{hr} ft^2 °\text{F} \times 28{,}961\ ft^2\right) + \left(0.045 \frac{Btu}{hr} ft^2 °\text{F} \times 35{,}136 ft^2\right)\right] \tag{C.5}$$

$$Q_R = -83{,}408\ {}^{Btu}/_{hr} \tag{C.6}$$

Heat loss through the windows if found using Equation C.7.

$$Q_{WN} = [U_{standard\ windows}(Height_{standard} \times Width_{standard} \times Quantity_{standard}) \times (Average\ Temp - Set\ Point) \times (IAC \quad \times SHGC)] + [U_{non-\ standard\ windows}(Height_{non-standard} \times Width_{non-standard} \times Quantity_{non-standard}) \times (Average\ Temp - Set\ Point) \times (IAC \quad \times SHGC_{non-standard})] \tag{C.7}$$

$$Q_{WN} = \left[\left(2.27 \frac{Btu}{hr} ft^2 °\text{F}\right)(5ft \times 3ft \times 369) \times (36°\text{F} - 72°\text{F}) \times (0.46 \times 0.76)\right] + \left[\left(0.92 \frac{Btu}{hr} ft^2 °\text{F}\right)(5ft \times 2ft \times 128) \times (36°\text{F} - 72°\text{F}) \times (0.4 \times 0.76)\right] \tag{C.8}$$

$$Q_{WN} = -105{,}421\ {}^{Btu}/_{hr} \tag{C.9}$$

Heat loss through the doors is found using Equation C.10.

$$Q_D = (Average\ Temp - Set\ Point) \times (Door\ Area) \times (Quantity_{North} \times U_{North} + Quantity_{West} \times U_{West} + Quantity_{East} \times U_{East} + Quantity_{South} \times U_{South}) \tag{C.10}$$

$$Q_D = (36°\text{F} - 72°\text{F}) \times (19.5ft^2) \times \left(4 \times 0.35\frac{Btu}{hr}ft^2°\text{F} + 12 \times 0.35\frac{Btu}{hr}ft^2°\text{F} + 9 \times 0.35\frac{Btu}{hr}ft^2°\text{F} + 4 \times 0.35\frac{Btu}{hr}ft^2°\text{F}\right) \quad \text{(C.11)}$$

$$Q_D = -7{,}125\ {Btu}/{hr} \quad \text{(C.12)}$$

Heat gain from lighting is determined using the following equation.

$$Q_L = \sum(3.41 \times Quantity_{each\ fixture\ type} \times Wattage \times SAF) \quad \text{(C.13)}$$

$$Q_L = 480{,}654\ {Btu}/{hr} \quad \text{(C.14)}$$

Heat gain from appliances is found using Equation C.15.

$$Q_A = \sum\left(Quantity_{each\ appliance\ type} \times Heat\ Gain \times Hours\ Appliance\ is\ ON\right) \quad \text{(C.15)}$$

$$Q_A = 655{,}953\ Btu \quad \text{(C.16)}$$

Heat gain from occupants is calculated using Equation C.17.

$$Q_P = (Heat\ gain\ of\ a\ Child \times Enrollment) + (Heat\ gain\ of\ an\ Adult \times Faculty\ \&Staff) \quad \text{(C.17)}$$

$$Q_P = \left(356\ {Btu}/{hr} \times 559\right) + \left(450\ {Btu}/{hr} \times 79\right) \quad \text{(C.18)}$$

$$Q_P = 234{,}694\ {Btu}/{hr} \quad \text{(C.19)}$$

Heat transfer due to Sun’s radiant energy is determined from Equation C.20.

$$Q_S = Total\ Global\ Radiation \times (0.6 \times Surface\ Area\ of\ Building) \times \frac{1\ month}{Number\ of\ days} \times \frac{1\ day}{24\ hours} \quad \text{(C.20)}$$

$$Q_S = 552\frac{\frac{Btu}{ft^2}}{month} \times (0.6 \times 124{,}001ft^2) \times \frac{1\ month}{31\ days} \times \frac{1\ day}{24\ hours} \quad \text{(C.21)}$$

$$Q_S = 55{,}170\ {Btu}/{hr} \quad \text{(C.22)}$$

Total Heat Gain or Loss per month is found using Equation C.23 which incorporates the previous equations.

$$Q_{Total} = \frac{Days}{Month} \times \left(\frac{24\ hrs}{day}(Q_{WL} + Q_R + Q_{WN} + Q_D + Q_S) + Q_A\right) + \tag{C.23}$$

$$\frac{School\ Days}{Month}(Hours\ Building\ is\ Open\ \times Q_L + School\ Hours\ \times Q_P)$$

$$Q_{Total} = \frac{31\ Days}{Month} \times \left(\frac{24\ hrs}{day}\left(-235233\ {}^{Btu}/_{hr} - 83{,}408\ {}^{Btu}/_{hr} - \right.\right. \tag{C.24}$$

$$\left.\left.105{,}421\ {}^{Btu}/_{hr} - 7{,}125\ {}^{Btu}/_{hr} + 55{,}170\ {}^{Btu}/_{hr}\right) + 655{,}953\ Btu\right) +$$

$$\frac{19\ School\ Days}{Month}\left(16\ \times 480{,}654\ {}^{Btu}/_{hr} + 8.75\ \times 234{,}694\ {}^{Btu}/_{hr}\right)$$

$$Q_{Total} = -74{,}284{,}705\ {}^{Btu}/_{month} \tag{C.25}$$

Lighting usage is next calculated for each fixture type. Equation C. 26 is repeated for every type within the model. The annual kWh of lighting is then calculated using Equation C.29.

$$kWh\ per\ fixture = \frac{Wattage}{1000\ W} \times Quantity \times (Hours) \tag{C.26}$$

$$kWh\ per\ fixture = \frac{34}{1000\ W} \times 7 \times (11) \tag{C.27}$$

$$kWh\ per\ fixture = 2.618\ kWh \tag{C.28}$$

$$Annual\ kWh = \sum kWh\ per\ fixture \tag{C.29}$$

If the option is chosen for hallway lighting to be 24 hours a day for security lighting, Equation C.26 is changed to:

$$kWh\ per\ fixture = \frac{Wattage}{1000\ W} \times Quantity \times (24\ Hours) \tag{C.30}$$

Now the energy utilized by the Office Equipment is calculated for each type of appliance. Equation C.31 and C.32 is repeated for each appliance. The monthly kWh is then calculated using Equation C.37.

$$kWh\ per\ appliance = \frac{Wattage}{1000\ W} \times Quantity\ \times Hours\ ON \tag{C.31}$$

$$kWh\ per\ desktop\ computers = \frac{200}{1000\ W} \times 298\ \times 9\ Hours \tag{C.32}$$

$$kWh\ per\ desktop\ computers = 536.4\ kWh \tag{C.33}$$

$$Phantom\ kWh\ per\ appliance = \frac{Phantom\ Wattage}{1000\ W} \times Quantity\ \times$$
$$Hours\ Off\ and\ plugged\ in \tag{C.34}$$

$$Phantom\ kWh\ per\ desktop\ computers = \frac{4}{1000\ W} \times 298\ \times 15\ Hours \tag{C.35}$$

$$Phantom\ kWh\ per\ desktop\ computers = 17.88\ kWh \tag{C.36}$$

$$Monthly\ kWh = \tag{C.37}$$
$$\left(\sum kWh\ per\ appliance + \sum Phantom\ kWh\ per\ appliance\right) \times \frac{days}{month}$$

$$Monthly\ kWh = 37{,}631\ kWh \tag{C.38}$$

The HVAC module has several parts associated with it. The heating load is calculated from Equation C.39 for January. The cooling load is calculated from Equation C.42 and is shown for May since January has no Cooling Degree Days. In the model these are repeated for every month.

$$E_{CH} = 1.77\,\frac{(q_L + Q_{heat\ loss})(DD)}{\eta(HV)\Delta t} \tag{C.39}$$

$$E_{CH} = 1.77\,\frac{\left(3{,}336{,}366{,}827\,{}^{Btu}/_{Month} - 74{,}284{,}705\,{}^{Btu}/_{Month}\right)(912\ days°\mathrm{F})}{75\left(\frac{1\ therm}{1\times10^{-5}\ Btu}\right)(72°\mathrm{F} - 36°\mathrm{F})} \tag{C.40}$$

$$E_{CH} = 19{,}502.90\ Therms \tag{C.41}$$

$$E_{CC} = \frac{q_g(CDD)\frac{1\ month}{days\ in\ month}}{1000(SEER)\Delta t_d} \tag{C.42}$$

$$E_{CC} = \frac{\left(269{,}447{,}005\ {}^{Btu}/_{month}\right)\left(97\ {}^{Btu}/_{month}\right)\frac{1\ month}{31\ days}}{\frac{1000W}{kWh}(14.4)(72°\mathrm{F}-64°\mathrm{F})} \tag{C.43}$$

$$E_{CC} = 7{,}313.77\ kWh \tag{C.44}$$

In order to determine the usage of hot water, Equation C.45 is used. Then from this equation the energy needed to heat the hot water can be determine in Equation C.48. This is repeated within the program for every month.

$$W_{WH} = \left(Factor\ for\ High\ Schools\ \times Enrollment \times \frac{School\ Days}{Month}\right)\left(0.01336\ {}^{CF}/_{gal}\right) \tag{C.45}$$

$$W_{WH} = \left(1.8\ {}^{gal}/_{day} \times 559 \times 19\ {}^{days}/_{month}\right)\left(0.01336\ {}^{CF}/_{gal}\right) \tag{C.46}$$

$$W_{WH} = 2{,}554.14\ {}^{CF}/_{month} \tag{C.47}$$

$$Q = cm\Delta t \tag{C.48}$$

$$Q = \left(1\ {}^{Btu}/_{lb°\mathrm{F}}\right)\left(8.333\ {}^{lbs}/_{gal}\right)\left(19{,}177.80\ {}^{gal}/_{month}\right)(140°\mathrm{F} - 60°\mathrm{F})\left(\frac{1kWh}{3412\ Btu}\right) \tag{C.49}$$

$$Q = 3{,}735.26\ {}^{kWh}/_{month} \tag{C.50}$$

Once the initial audit calculations are completed then the heuristic factors can be determined. The formulas for heuristic factors are shown in more detail in Chapter 5. In the following equations the heuristic factors are solved for using Arts High School.

First, the heuristic factor for building envelope user habits and system controls are found in Equation C.51 and C.54, respectively.

$$H_{BU} = \left[\left(\frac{100-I+(\sum_{n=0}^{a}(N_N\times n) + \sum_{n=0}^{a}(F_W\times n)+ \sum_{n=0}^{a}(M\times n)\ )}{100}\right)\times 0.525\right] + 0.925 \tag{C.51}$$

$$H_{BU} = \left[\left(\frac{100-80+\left(\sum_{n=0}^{a}(0\times 2) + \sum_{n=0}^{a}\left(\left(0.5\times\frac{1}{3}\times 80\right)\times 1\right)+ \sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 80\right)\times 0\right)\ \right)}{100}\right)\times 0.525\right] + 0.925 \tag{C.52}$$

$$H_{BU} = 1.100 \tag{C.53}$$

$$H_{BC} = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(T\times n)- \sum_{n=0}^{a}(N_R\times n)- \sum_{n=0}^{a}(L\times n)]}{100}\right)\times 0.525\right] + 0.925 \tag{C.54}$$

$$H_{BC} = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 20\right)\times 0\right)- \sum_{n=0}^{a}(0\times 2)- \sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 80\right)\times 1\right)\right]}{100}\right)\times 0.525\right] + 0.925 \tag{C.55}$$

$$H_{BC} = 1.170 \tag{C.56}$$

The heuristic factor for lighting user habits and system controls is found next.

$$H_{LU} = \left[\left(\frac{100-I+(\sum_{n=0}^{a}(N_V\times n) + \sum_{n=0}^{a}(O\times n)+ \sum_{n=0}^{a}(A\times n)\ )}{100}\right)\times 0.525\right] + 0.925 \tag{C.57}$$

$$H_{LU} = \left[\left(\frac{100-80+\left(\sum_{n=0}^{a}(0\times 2) + \sum_{n=0}^{a}\left(\left(0.5\times\frac{1}{3}\times 80\right)\times 1\right)+ \sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 80\right)\times 0\right)\right)}{100}\right)\times 0.525\right] + 0.925 \tag{C.58}$$

$$H_{LU} = 1.100 \tag{C.59}$$

$$H_{LC} = \left[\left(\frac{100-\left(I+20\left(\frac{\sum R_C}{R}\right)\right)}{100}\right)\times 0.50\right] + 0.90 \tag{C.60}$$

$$H_{LC} = \left[\left(\frac{100-\left(80+20\left(\frac{0}{27}\right)\right)}{100}\right)\times 0.525\right] + 0.925 \tag{C.61}$$

$$H_{LC} = 1.030 \tag{C.62}$$

The heuristic factor for office equipment user habits and system controls is found using Equation C.63 and C.66, respectively.

$$H_{AC} = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(Y\times n)-\sum_{n=0}^{a}(N_A\times n)-\sum_{n=0}^{a}(N_O\times n)]-[\sum_{n=0}^{a}(N_N\times n)+\sum_{n=0}^{a}(F_W\times n)+\sum_{n=0}^{a}(M\times n)]}{100}\right)0.525\right]+ 0.925 \tag{C.63}$$

$$H_{AC} = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{4}\times 20\right)\times 1\right)-\sum_{n=0}^{a}(0\times 1)-\sum_{n=0}^{a}\left(\left(\frac{1}{4}\times 80\right)\times 1\right)\right]-\left[\sum_{n=0}^{a}(0\times 1)+\sum_{n=0}^{a}\left(.5\left(\frac{1}{4}\times 80\right)\times 0\right)+\sum_{n=0}^{a}\left(\left(\frac{1}{4}\times 80\right)\times 0\right)\right]}{100}\right)0.525\right]+ 0.925 \tag{C.64}$$

$$H_{AC} = 1.109 \tag{C.65}$$

$$H_{AU} = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(Y\times n)-\sum_{n=0}^{a}(N_A\times n)-\sum_{n=0}^{a}(N_O\times n)]-[\sum_{n=0}^{a}(N_{Nu}\times n)+\sum_{n=0}^{a}(F_{Wu}\times n)+\sum_{n=0}^{a}(M_u\times n)]}{100}\right)0.525\right]+ 0.925 \tag{C.66}$$

$$H_{AU} = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{5}\times 20\right)\times 0\right)-\sum_{n=0}^{a}(0\times 1)-\sum_{n=0}^{a}\left(\left(\frac{1}{5}\times 80\right)\times 0\right)\right]-\left[\sum_{n=0}^{a}\left(\left(\frac{1}{5}\times 80\right)\times 1\right)+\sum_{n=0}^{a}\left(.5\left(\frac{1}{5}\times 20\right)\times 3\right)+\sum_{n=0}^{a}\left(\left(\frac{1}{5}\times 20\right)\times 0\right)\right]}{100}\right)0.525\right]+ +0.925 \tag{C.67}$$

$$H_{AU} = 1.146 \tag{C.68}$$

The heuristic factor for HVAC is found using Equation C.69.

$$H_H = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(Y\times n)-\sum_{n=0}^{a}(N_O\times n)]}{100}\right)\times 0.525\right]+0.925 \tag{C.69}$$

$$H_H = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 20\right)\times 0\right)-\sum_{n=0}^{a}\left(\left(\frac{1}{3}\times 80\right)\times 3\right)\right]}{100}\right)\times 0.525\right]+0.925 \tag{C.70}$$

$$H_H = 1.450 \tag{C.71}$$

The heuristic factor for water user habits is found using Equation C.72.

$$H_{WU} = \left[\left(\frac{100-I+(\sum_{n=0}^{a}(N_N\times n)+\sum_{n=0}^{a}(F_W\times n)+\sum_{n=0}^{a}(M\times n))}{100}\right)\times 0.525\right]+0.925 \tag{C.72}$$

$$H_{WU} = \left[\left(\frac{100-80+\left(\sum_{n=0}^{a}(0\times4) + \sum_{n=0}^{a}\left(\left(0.5\times\frac{1}{4}\times80\right)\times0\right)+\sum_{n=0}^{a}\left(\left(\frac{1}{4}\times80\right)\times0\right)\right)}{100}\right)\times 0.525\right] + 0.925 \tag{C.73}$$

$$H_{WU} = 1.030 \tag{C.74}$$

The heuristic factor for waste handling is found using Equation C.75.

$$H_{WH} = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(Y\times n)-\sum_{n=0}^{a}(D\times n)-\sum_{n=0}^{a}(N_O\times n)]}{100}\right)0.525\right] + 0.925 \tag{C.75}$$

$$H_{WH} = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{9}\times20\right)\times0\right)-\sum_{n=0}^{a}(0\times0)-\sum_{n=0}^{a}\left(\left(\frac{1}{9}\times80\right)\times9\right)\right]}{100}\right)0.525\right] + 0.925 \tag{C.76}$$

$$H_{WH} = 1.450 \tag{C.77}$$

The heuristic factor for occupancy information is found using Equation C.78.

$$H_{OI} = \sum_{n=0}^{a}(I_F \times n) + \sum_{n=0}^{a}(O \times n) + \sum_{n=0}^{a}(F_R \times n) \tag{C.78}$$

$$H_{OI} = \sum_{n=0}^{a}(1.1 \times 1) + \sum_{n=0}^{a}(1.2 \times 0) + \sum_{n=0}^{a}(1.3 \times 0) \tag{C.79}$$

$$H_{OI} = 1.100 \tag{C.80}$$

The heuristic factor for education and training is found using Equation C.81.

$$H_{ET} = \left[\left(\frac{100-[I+\sum_{n=0}^{a}(Y\times n)-\sum_{n=0}^{a}(N_O\times n)]}{100}\right)\times 0.525\right] + 0.925 \tag{C.81}$$

$$H_{ET} = \left[\left(\frac{100-\left[80+\sum_{n=0}^{a}\left(\left(\frac{1}{9}\times20\right)\times0\right)-\sum_{n=0}^{a}\left(\left(\frac{1}{9}\times80\right)\times9\right)\right]}{100}\right)\times 0.525\right] + 0.925 \tag{C.82}$$

$$H_{ET} = 1.450 \tag{C.83}$$

The general heuristic factor is found using Equation C.84.

$$H_G = \frac{(H_{WH}+H_{ET}+H_{OI})}{3.0} \tag{C.84}$$

$$H_G = \frac{(1.450+1.450+1.100)}{3.0} \tag{C.85}$$

$$H_G = 1.333 \tag{C.86}$$

The heuristic factors are then applied to the audit calculations to determine the usage accounting for occupant behavior and controls. The synchronization step is then completed to optimize usages. Synchronization is covered in detail in Chapter 6.

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