Design and Development of an Intelligent Energy Controller for Home Energy Saving in Heating/Cooling System

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Abstract

Energy is consumed every day at home as we perform simple tasks, such as watching television, washing dishes and heating/cooling home spaces during season of extreme weather conditions, using appliances, or turning on lights. Most often, the energy resources used in residential systems are obtained from natural gas, coal and oil. Moreover, climate change has increased awareness of a need for expendable, energy recourses. As a result, carbon dioxide emissions are increasing and creating a negative effect on our environment and on our health. In fact, growing energy demands and limited natural resource might have negative impacts on our future. Therefore, saving energy is becoming an important issue in our society and it is receiving more attention from the research community.

This thesis introduces a intelligent energy controller algorithm based on software agent approach that reduce the energy consumption at home for both heating and cooling spaces by considering the user's occupancy, outdoor temperature and user's preferences as input to the system. Thus the proposed approach takes into consideration the occupant's preferred temperature, the occupied and unoccupied spaces, as well as the time spent in each area of the home.

A Java based simulator has been implemented to simulate the algorithm for saving energy in heating and cooling systems. The results from the simulator are compared to the results of using HOT2000, which is Canada's leading residential energy analysis and rating software developed by CanmetENERGY's Housing, Buildings, Communities and Simulation (HBCS) group. We have calculated how much energy a home modelled will use under emulated conditions. The results showed that the implementation of the proposed energy controller algorithm can save up to 50% in energy consumption in homes dedicated to heating and cooling systems compared to the results obtained by using HOT2000.

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List of Acronyms

Acronym	Definition
AC	Air Conditioner
AIM	A novel architecture for the modeling and managing energy consumption of household appliances
DWH	Domestic Water Heating
GPS	Global Positioning System
GUI	Graphical user Interface
HAVC	Heating, Ventilation, and Air Conditioning
IR	Infrared
NRCan	Natural Resources Canada
PDA	Personal Digital Assistant
RF	Radio Frequency
RFID	Radio-frequency identification
SAPT	Space Activity Percentage Threshold
W3C	World Wide Web Consortium
WSN	Wireless Sensors Network

List of units

KWH = Kilowatt hour
M = meter
MJ = Mega Joule
WH = Watts hour

MJ = a unit of work or energy, equal to one million joules.

KWH = measures a unit of energy, equal to 3,600,000 joules (3.6 MJ). It can also be described as the amount of energy that would be transferred at a constant rate of one kilowatt for one hour.

Watts= an amount of power, especially electric power, expressed in watts or kilowatts.

The following equations will be used in Chapter 4 Simulation, Result, and Evaluation:

Convert MJ to KWH = 1 MJ = 0.27777777777778 kWh (1)

Convert KWH to MJ = 1 kWh = 3.6 MJ (2)

Convert KW to WH= 1 kilowatt = 1000 WH (3)

Chapter 1: Introduction

Information technology is developing so quickly that present and future homes can run with greater efficiency due to a wide spectrum of devices that function to make our lives more comfortable, such as programmable thermostats and dimmers for light systems. These devices provide us with the ability to save energy in our homes; however, most home devices for controlling heating/cooling systems lack of intelligence to perform tasks that allow saving energy in more efficient way. In addition, these devices do not tell us where and when to focus on saving energy. A recent study done by the United States Environmental Protection Agency found that households with programmable thermostats maintain a higher rate of energy consumption on average than those with manual controls due to incorrect programming or the disabling of them [1]. The same study found that programming thermostats can be challenging if the exact occupancy patterns of the home is unknown, especially with multiple occupants who come and go at different times [2]. A survey done at the University of Alberta found that energy conservation resulting from programmable thermostats in residential homes is much less than expected to save [3]. It is therefore evident that a balance needs to be created between occupants 'comfort and environmental safety.

A vast amount of research has been done with regard to energy management, but there have been limitations on hardware and software technologies that restrict the application of new ideas proposed in order to save energy in homes' systems (e.g. HVAC, Lighting, Appliances, etc). Significant of research has been dedicated to the building of monitoring systems that allow home owners to track energy usage, encouraging a reduction in expenditure. An application called WattBo[4] designed by researchers in Indiana University Bloomington – in the United Sate- for Apple Iphone and Ipad that communicate with home electrical systems and permits the user to view readings in real-time as well as to analyze the energy consumption for each appliance in the long term. Another application, developed by the Georgia Institute of Technology, consists of an energy consumption display (ECD) that presents real-time energy consumption as a simple bar graph on a portable or stationary display screen aiding homeowners reduce energy usage [5]. Similarly, researchers at

Pervasive Computing lab in Swiss Federal Institute of Technology University in Zurich / Switzerland proposed an interactive system that provides the user with real-time energy consumption information by connecting the smart home meter to the user's mobile phone. The motivation behind their system is to educate those who are willing to save energy at home but lack key information regarding energy consumption. It is generally expected that providing real-time energy consumption data can reduce residential energy waste from five to fifteen per cent [6]. In fact, [1] mentioned that homeowners do not know how much money they spend on energy usage in their homes, and this is an obstacle as they attempt to save energy and money. Consider the following: when occupants leave home without turning off their HVAC system (that cools or heats the home). If intelligent agents were used to control the home HVAC system and to manage the temperature on behalf of the homeowner, money and energy can be saved thereby improving financial and environmental situations. According to a 2007 report by Natural Resources Canada [7], Canadians spent about $166 billion on energy to heat and cool their homes and offices, as well as to operate appliances, cars and industrial processes. Moreover, the residential sector used 63% of energy for space heating. The percentage of floor space coolers rose from 23 % in 1990 to 43 % in 2007. As a result, the energy required to cool Canadian homes rose by 167%. A study done by The United State Energy Information Administration in 2010[1] showed that 20-30% of HVAC energy consumption could be saved by turning off the HAVC system when occupants are sleeping or out of the house, and could prevent 1.12 billion tons of pollutants from being released into the air each year . A study done at the University of Kuala Lumpur [8] mentioned the three dimensions of energy efficiency: energy saving, customer satisfaction, and customer awareness. Energy saving can be realized by initiating an intelligent system that can detect occupant presence or absence, and adjust the environment accordingly. For example, automatic light switching on or off when a person enters leaves a room. Customer satisfaction can be achieved by determining the occupant's comfort level, while customer awareness can be accomplished by real-time monitoring that allows users to see the level and cost of energy they consume on a daily basis.

As [8] mentioned, "Energy efficiency can be defined as the use of less energy to provide the same level of energy service to the user." The concept of energy management is to create means of lowering energy use that satisfies user preferences while reaching an energy-saving target. Moreover, as [9] suggested, energy efficient residential homes are beneficial for two reasons: they protect our environment and reduce the cost of the whole building lifecycle.

1.2. Motivation

In Canada, the residential sector is an important area with regard to energy consumption as it accounts for 22 % of global energy consumption [10]. According to [11] it is approximated that HVAC systems consume about 50% of the total energy used in buildings. Between 1990 and 2005, energy use in Canada increased by nearly 22% and, as a result, Canada's total greenhouse gas (GHG) emissions increased by approximately the same amount [12].

In terms of economics, a report released by Global Economic Research in June 2011[13] state that energy costs were significantly high, led by an approximate 40% increase in gasoline and heating fuel prices over the past two years. . Household expenditures on energy use were roughly $60 billion in 2010, or approximately $4,500 per household. It is estimated that increasing energy costs will add about $6 billion to the country's energy bill in 2011.

In the UK buildings are responsible for about 50% of energy consumption and are responsible for a similar proportion of Co2 emissions[14]. Daily activities such as running heaters or air conditioners are contributing to rapid changes in the global temperature. According to a report released in April 2007 by the United Nations-sponsored Intergovernmental Panel on Climate Change [15], the effects of energy use over the next century will be widespread and severe.

From a health perspective, the average home emission of carbon dioxide is more than twice as common as similar illness from the average car is emission [16]. As mentioned by the World Health Organization [17], air pollution is a major environmental and health risk, and is estimated to cause approximately 2 million unexpected deaths worldwide per year.

As a result, there is an urgent need to assist people in the improvement of life quality, financial saving, and to protect our environment. Therefore, there is pressure on researchers to build and develop systems that can save energy in homes while maintaining the comfort of those who reside in them.

1.3. Problem Statement

Advances in home technology, software agent methodologies, and in communication between automation software and electrical devices in the home have broken the barriers that have faced researchers seeking to develop software agents that can enable energy saving. As a result, autonomous methods of triggering energy use can be developed to function only when necessary. Fortunately, according to a new research report by Berg Insight [18], the number of new, smart, home installations worldwide was 0.44 million in 2010. This number is expected to reach 5.38 million by 2015.

The objective of this thesis is to design an intelligent software agent that saves energy at home when using heating and cooling systems. This software takes into consideration both the occupant's preferred temperature as well as the activity percentage of the time spent in each area of the home. The activity percentage in each space will be calculated by the behavioural activity agent, determining the occupied / unoccupied time of each space. Each space agent will monitor the presence of the occupant(s) through a door sensor. Moreover, the algorithm will derive the user preferred indoor temperature from the information stored in the data base. The user enters this information during the house set-up stage.

1.4. Thesis Contribution

In brief, the main contributions of this thesis are design and development of an intelligent algorithm that efficiently manages the energy consumption in home cooling and heating systems. The algorithm considers the occupants' preferred temperature, vacation plans, occupied and unoccupied spaces, and the percentage of time spent in each area of the home.

In addition, an energy management questionnaire is provided for each household. The main goal of the survey is to capture information about user knowledge of intelligent software agents and their willingness to adapt the intelligent system in their homes [Appendix B].

1.5. Thesis outline

This thesis is organized as follow: Chapter 2 describes the background information and related work. Chapter 3 describes the proposed architecture of the system, its components, and the relationship between those components. Chapter 4 describes the system user interface as well as the simulation results and evaluations. Finally, Chapter 5 concludes the thesis with future vision.

Chapter 2 Background Information and Related Work

2.1. Background Information

Our proposed energy controller algorithm is based on smart homes and multi-agent systems to save energy in homes heating/cooling system. In this section an explanation about smart homes and multi-agent systems concepts are provided.

2.1.1. Smart Home

The first background topic to be discussed is in the area of smart homes. Smart home, or intelligent home, or home networking are the main terms to refer and can be defined as an electronic networking technology that integrates appliances and other devices such as light switches, thermostats, video cameras, etc. so the home can be monitored and controlled as a single machine[19] .A smart home is a living environment that consists of sensors, actuators, networks and middleware that collect information about the home to provide comfortable living for the occupants [19]. A smart home has the technological capability to adjust itself in certain circumstances to make the home more comfortable for its occupants while sharing a common interface that links it to systems and services outside the home [20]. Moreover, smart homes aid occupants in rearranging the day-to-day schedule, securing a high quality of living conditions and allowing residents to reduce their energy consumption costs [21]. Smart homes have many applications that can facilitate our lives in different ways, e.g., a smart home can help elderly people to live more comfortably, notifying them about abnormal situations in the home. Furthermore, it can assist home owners in their daily activities, such as plant watering and pet feeding.

In a smart home domain [22], the following technological elements must be present: intelligent control, home automation and an internal network.

The intelligent control is provided by a control system that is comprised of two types of elements: sensors, which will monitor, control and report the status of the home environment; and a control agent (human or software based) that acts on the information provided by the sensors. In the case of software, the control system runs on a home computer or embedded in an electronic device to control a subset of the home appliances.

The home automation function is fulfilled by electronic-mechanical devices called actuators that interact and modify the environment by accomplishing specialized tasks. For example, actuators can change the status of home devices such as switching lights on and off [23].

The main goal of a home network is simply to ensure that all of the components that integrate the system can receive and send instructions to each other. Smart home network technology can be subdivided into three main areas: Powerline, Busline and Wireless.

Powerline systems are made of devices that can be connected directly to the main power network installation. These devices use electrical conventional wiring to send data to the devices that will activate or deactivate them.

Busline smart homes use a separate cable (twisted pair) to transmit data to devices and actuators, while Wireless systems do not require any wires to operate. This technology can be further subdivided into RF and IR [23] [24].

As mentioned in [25], home automation has been developed in three primary areas:

1. HVAC (heating, ventilation, air conditioner).
2. Security, such as fire alarm and detection system.
3. Lighting control, automation for electricity and water metering.

Thus our approach deals with improving the design of energy home controller with the capacity to be programmed automatically by the user's occupancy patterns as main input.

2.1.1. 1.Smart home and energy consumption monitoring

Golzar and Tajozzakerin [26] presented an internet-based, smart remote control system for home automation, which is connected to a home web-server. The system adapts power consumption to available power resources that meet the user comfort and cost criteria. All home appliances are connected to the remote control system. As a result, home owners can control and monitor all appliances remotely via the internet, and are thus able to turn an appliance on or off.

Marco Jahn and Marc Jentsch [27] introduced a smart meter integrated with the smart home environment. Occupants can interact with the system both stationary and through mobile interfaces. For each device the system displays the current consumption in watts, cost per hour, and cost projected over one year using an adjustable average per-day usage time.

2.1.2. Agent system

An agent can be defined as the following: "...a computer system that is situated in some environment, that is capable of autonomous action within that environment in order to meet its design objectives"[28].An autonomous software agent is, as defined by Stan Franklin and Art Graesser [29], "...a system situated within an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to affect what it senses in the future".

Wooldridge [30] mentioned three behaviours of intelligent agents: reactive, pro-active and social. Reactive behaviour implies an ongoing communication with its environment, and a response to changes that occur in it. Pro-active behaviour signifies that the agent works toward achieving its goal, while social behaviour implies an ability to interact with other agents (and possibly humans) via cooperation, coordination and negotiation. The multi-agent systems with social behaviour work in two ways: achieve its goal, and response to the changes that happen in the environment. Therefore, our proposed system is based on multi-agent with the social behaviour. The agents in the multi-agent system work to achieve energy saving, and in the same time consider the occupants appearance in the home and their preferences regarding the indoor temperature.

Multi-agent systems (MASs) are characterized by the interaction of two or more agents trying to solve problems in cooperation [31]. The characteristics of MASs are as follow: each agent has incomplete information or capabilities for solving the problem and, thus, has a limited viewpoint; there is no global system control; and the data are decentralized and distributed among the agents [32]. Agents in multi-agent systems have the capability to negotiate to solve or handle a task. The negation can be dived into two main groups: competitive and cooperative. Competitive negation means each agent tries to achieve its own goal and to maximize its local utility. Cooperative negotiation means that all agents try to maximize the global utility [33]. Researchers from Shandong Jianzhu University [34] mentioned the strong points of multi-agent system. Firstly, they allow for the development of a simple and lightweight agent that achieves goals by working with other agents. Secondly, the complex problem can be divided into simpler sub-problems that can be solved by the multi-agent system. Researchers from the University of Karlskrona [35] have pointed out that further advantages of a multi-agent system are scalability and re-configurability. New agents can easily join the system and old agents can be easily customized by adding new rules or updating old rules. Therefore we have considered these advantages in order to proposed an algorithm based on multi_agent to handle different tasks to efficiently handles the performance of home systems such Heating Ventilation and Air Conditioning (HVAC).

2.1.2. 1. Agent technology used in home automation

The intelligent home project (IHome) at the University Of Massachusetts Amherst (UMASS) is an application of multi-agent system technology. The IHome population set includes agents like an intelligent Water Heater, Coffeemaker, Heater, A/C, Dishwasher, and a robot for fetching items and moving physical goods from one location to another. The home agents analyze their assigned tasks and select appropriate actions based on the occupant's preferences and the accessible resources. For instance, the Dishwasher agent may decide to run a cold cycle or wait until hot water becomes available. Moreover, the A/C agent objective is to monitor the preferred temperature [36] [37].

Researchers at the University of Texas in Arlington built a smart home system in their project MavHome (Managing an Intelligent Versatile Home). The project goal was to create a home that acted as an intelligent agent that perceived the home state through sensors and acted in the environment through device controllers to maximize occupant comfort and to minimize operation cost. The project has a hierarchical architecture. The top component is the decision layer that selects the appropriate action, then the information layer that gathers and stores information for the decision layer. Next, the communication layer facilitates communication among the agents and the physical layer that contains the devices in the home [38].

Researchers at the University of Valladolid represented a multi-agent system in a smart home that enabled interoperability between occupants and home devices. Some of the agents that are included in the system are: a personal agent that keeps a user's personal rules and can modify and update them; a weather agent that downloads weather forecast changes and reports them; and a location agent that identifies user location by RFID receiver and tags. One of the scenarios of this project is when a user creates a personal rule in the personal agent that triggers a voice alarm in his PDA when he leaves home without his umbrella and the weather forecast is rainy [39].

Researchers at Tatung University [40] proposed a home automation system based on a multi-agent system. The system consists of three layers: a network layer that allows the connection between home devices and the intelligent system, the service layer that contains the multi-agent system, and the communication interface layer that contains different channels to communicate outside the home. The service layer informs and warns the user about the environmental situation. The system contains different types of agents, such as: a facilitator agent that coordinates communication between the agents, an appliance agent that monitors appliances, and a communication agent that notifies the home owner about the state of the home.

Researchers at the University of Reading [41] presented a Multi-Agent System for Building Control (MASBO) .The multi-agent system works as middleware between the input from the wireless sensor network and policy management and the building management system that act on the environment. The system is composed of three types of agents. The first type is the personal agent that tracks an individual's location and learns his/her preferences within the environment. The second type is the local agent that is responsible for a particular zone in the home. The third agent is the central agent that is responsible for decision making and interface with external and internal services.

2.2. Literature Review

There are several commercial products that permit the energy reduction in homes systems: such as programmable thermostats for HVACs, light dimmers and controllers for lighting, thus some act based on how they are programmed and others have a degree of intelligence - they act on behalf of the user. Programmable thermostats are a one way to achieve energy saving. Recent studies [1] found that households with programmable thermostats have higher energy consumption on average than those with manual control because users program them incorrectly. Moreover, programmable thermostats cannot determine if there is a need to heat/cool a space based on occupancy, therefore there is waste energy since in this situation the thermostat triggers the command to start heating/cooling a space based on the schedule without considering if there is a real need. These devices are not truly intelligent, and use a static schedule that scarifies either the occupant's comfort or the energy usage.

It will be great if some sort of intelligence can be embed in this type of devices in order to act on users' behalf to heat/cool a space and reduce the demand of energy for spaces that do not require such resources at any moment of time. Moreover, users need a system that functions with the changing patterns in daily life. In fact, the development of agent technology and home automation systems allows researchers to design an automated system that acts on behalf of home occupants.

In this section we will review some of the studies that proposed systems to save energy in homes for different appliances such as TV or computers. A study based in Doshisha University [42] proposed an energy saving television system that can recognize when a user is watching a TV or not; based on that the system can change the TV brightness level automatically. They embedded a camera in the TV that can detect the face of the user as they watch TV. When the camera does not detect a face for some time, the TV brightness is reduced. When the camera detects a face while the TV brightness is lowered, the TV changes the brightness to its default level. They tested their system by arranging a TV, 2 chairs and a table in a room that was two by two meters. They let the users mimic different situations such as watching TV and performing other activities while watching TV such as reading a book or watching TV and playing a game on their laptop. As a result, their system could produce a 30% reduction of TV energy usage.

An energy management and control system of a building is proposed by Sains Malaysia University [43] that reduces energy waste that is caused by human carelessness. The system contains a PC to monitor the electrical appliances and switch them on/off. Additionally, the system contains sensors placed at the entrance of each room to monitor the number of persons entering or leaving the room. A photo sensor is placed outside the building to detect whether it is day or night. A scenario of the system is as follow: when a person enters a room the system will turn on, for example, the light and start counting the number of persons entering and leaving the room. When the number of persons who entered the room is equal to the number of persons leaving the room, then system will turn off all electrical devices in the room. When the number of persons leaving the building is equal to number of persons entering the building, the system will turn off all devices in the building.

Another energy management approach is presented by Fukuoka University [44] that allows the system to monitor the house and make a decision to meet the user's needs and save energy. The system has been applied to many applications in the home: personal computer, television, and home energy management. For the personal computer and television, the devices are equipped with a camera that monitors the direction that the user faces. When the camera does not recognize a user's face, then the TV or PC will be put in sleep mode or screen brightness will be lowered. Additionally, home energy management is another application of the system. The home has a network of sensors such as motion, camera, and vision sensors as well as RFID. These sensors learn the user's behaviour pattern, detect the person's appearance in the home, and detect their location. Based on user behaviour and location, the system can estimate his/her needs. As a result, the system can switch off the appliances that are active but not in use and turn on the appliances that the person is about to use.

In this section we will review the literature associated with home energy saving that use software agent for controlling smart environments.

The goal of the ISES project (Information / Society / Energy / System) at the University of Karlskrona/Ronneby in Sweden [35] is energy saving and increasing occupants' satisfaction. The system consists of a set of software agents that monitor a small building. The system uses the existing power lines for communication between the agents and the electrical devices (sensors, actuators); different agents monitor and control different parts. The system has four main types of agents: personal comfort agents, room agents, environmental parameter agents, and badge system agents. The agents are given a number of rules to deal with different conditions to apply energy saving and take into consideration user(s) preferences. The personal comfort agent contains personal preferences and tries to maximize the individual's satisfaction. Indeed, this agent acts on behalf of the person. The room agent controls and monitors a particular room with the goal of saving energy as much as possible. The environmental parameter agent monitors and controls a particular parameter in a particular room, such as temperature. A badge system agent keeps track of the person's movement in the building.

The scenario of the system is as follow: when a person moves in the building his/her badge system informs his/her personal comfort agent that will then inform and provide the appropriate room with the person's preferences. The room agent will make a decision based on those preferences and energy saving considerations, and then inform the environmental parameter agents to apply the changes in the room. Their simulations show that their multi-agent system controller reduces energy consumption by 40%. The customer satisfaction measurement is calculated using a simple linear model, where 16 degrees C corresponds to 0% satisfaction, and 22 degrees C corresponds to 100%. Their calculation shows that the multi-agent system is able to correctly meet the user's comfort settings. Moreover, they compared their approach with others, which are: Thermostat approach, and timer approach. The timer approach has a timer that starts increasing the temperature before users enter the building and decreases the temperature when people leave the building. The result [35] was: they save 40% compared to the thermostat approach, and 12% compare to the timer-based approach.

The researchers in the ISES project [35] used personal agent that corresponds to each person and a badge system that tracks the person's movements. However, in the proposed system there is consideration for indoor temperature that is comfortable for the home occupants that omit the need for a personal agent for each one in the home. This makes the system less complex, but at the same time effective and meets the occupants' comfort level. Moreover, the proposed system considers the presence of a person in the home, but not a particular person.

Shandong Jianzhu University [34] proposed multi-agent system architecture for energy saving in a building by taking into consideration the presence of the people in the building. The architecture of the system includes a wireless network, Ethernet network, and different types of agents. The system has four main types of agents: personal agents, environment agents, room agents, and management agents. The system also contains an intelligent building management system that acts on the environment and applies the changes. Each personal agent is stored within portable equipment attached to the occupants that communicates and broadcasts preferences by sending messages to the environment agents through the wireless network. The environment agents act as information providers that monitor the room's parameters, such as light, temperature, and detection of human presence by use of infrared sensors. Information is sent to the room agent via wireless network. Room agents control a particular room; it receives the information from the environment agent and sends a message to the management agent through the Ethernet network. As a result, the management agent acts as the information manager and determines the energy optimization for the whole building. The following describes the sequence of events within the system: the environment agent collects information from the sensors about the room and sends it to the room agent through the wireless network. Then, all of the room agents send the information via a message to the management agent through the Ethernet network. The management agent analyzes the information and when it confirms that nobody is in the building, it sends a command through the Ethernet network to the intelligent building management system to apply power saving mode in the building devices. Indeed, the management agent confirms that there is nobody in the building depending on the following factors: no environment agents receive personal preference information; no infrared sensors detect anyone's presence in the building, and when the special room agent, which is placed at the entrance of the building, counts the number of people having exited the building as equal to the number of people having entered the building. Another scenario that illustrates the advantages of a multi-agent system with a wireless network is the following: when the environment agent detects that a person has left the room, it will seek information about that person from the next nearest room. If the nearby room responds by providing information about the person, then the environment agent will not change the room settings. Alternatively, if the management agent indicates that the person is not in the building, the room agent will set the devices to save power.

In the Shandong Jianzhu University [34] approach, RFID technology was used to track people presence in the home. Additionally, individual preferences of temperature levels are stored in portable equipment attached to each person. This being said, the goal of the proposed system is to make the system more user-friendly for the occupant in the sense that users do not need to think about wearing tracking devices. Additionally, the proposed system stored occupant preferences in a home computer which makes the system faster in the sense that the system does not need to broadcast each user preference.

Politecnico di Milano University [45] presented a home energy management system that is under development within the European project (AIM) to save energy at home by implementing a hierarchical hybrid network architecture called MobilWSN to monitor user presence, temperature, and light in the home environment. In their design, they used a wireless sensor network to monitor psychical parameters such as light and temperature, as well as the presence of users in the home by using infrared sensors in each room. From the gathered data, the system can create profiles of the occupants' various behaviours and the way they interact with the home environment and appliances. Moreover, the system contains temperature and light profiles. Indeed, the system contains an algorithm that keeps track of changes in the environment that are detected by the sensor network and updates the profiles accordingly. The intelligent algorithm can use these profiles to optimize energy consumption and apply the most appropriate user requirements when that user is at home. Hence, the goal of the AIM project is to enable the system to predict actual user preferences on the basis of previous observed behaviour. The system starts with a monitoring period (i.e. one week or one month) that gathers information about each profile. At the end of the period, a calculation is done to cluster similar daily profiles. During the monitoring period the user can change the environmental parameters manually. Their simulations testes are based on a five room house for 300 days to create the profiles and test the predictive algorithm. One of the tests on the cooling system of the house showed that AIM's algorithm reduced the functioning time of the cooling system by 28%.

In the AIM scientists' approach, they monitored and recorded user preference temperatures. However, the proposed system minimizes user action in temperature change. At the start of the system, the user will enter the maximum and minimum preferred temperature, and the maximum and minimum comfort temperature. After that, the system will use these settings to provide user comfort levels. In other words, the system will not exceed the user maximum temperature or go below the minimum temperature preferred by the user. Additionally, the proposed system used the activity percentage of time spent in each space in a more advanced way that saves more energy and maximizes the lifetime of the heating/cooling system. The proposed system used the activity percentage to differentiate between appropriate temperatures in empty and occupied space, and to determine the suitable temperature for when a user departs the space and when the spaces need to be cooled or warmed in the morning time. However, their system used the activity percentages to predict user presence in a space.

The similarity between our presented system and Politecnico di Milano University system [45] is the distributed thermostat that applies different temperatures in occupied and unoccupied spaces, respectively. The AIM study mentioned an example about instances of hot weather, when the air conditioner will be turned off in unused spaces. However, they did not mention how they used the recorded temperature to determine the appropriate setting for unoccupied spaces during cold weather.

A proposed system from the University of Virginia [1], called 'smart thermostat,' uses occupancy sensors to automatically turn off the HVAC when the occupants are sleeping or away. Their approach contains wireless motion and door sensors to gather information about the occupants of the home. The system employs three energy-saving techniques: turning the HVAC off, turning the HVAC on, and deep setback. The researchers used the Hidden Markov Model to estimate the probability of the home being in each of the three states:

away, when no one at home; active, when at least one user is awake; and sleep, when all users at home are sleeping.

For turning on the HVAC, they chose an optimal preheat time that minimizes energy consumption. The preheat time is based on efficiency and historical occupancy patterns at home. Moreover, the historical occupancy pattern at home allows the system to decide when to go into deep setback point because it will determine that the house is unoccupied and highly unlikely to be reoccupied.

In the University of Virginia's experimental system [1], an Energy Plus Simulator was used, which is a model described as integrating the physical description of a building (including walls, floors and doors) with the description of mechanical equipment (heating and cooling), occupancy schedule, and other household equipment. This model was provided by the U.S. department of energy.

Empirical tests were performed within eight homes, followed by simulation tests using Energy Plus Simulator. Scientists compared the empirical and simulation test results for energy consumption, and found that they match. Their approach achieved a 28% reduction of energy use. They compared their approach with a commercially available system that uses similar sensors and found that the latter only saved 6.8% of energy on average.

In the smart thermostat approach mentioned above, they use door and motion sensors to determine if the occupants are awake, asleep or away, in order to apply the appropriate temperature in the house. For example, in their system, to apply a 'sleep' temperature, all occupants should be asleep. Unfortunately, in real life, we cannot guarantee that all occupants be awake, asleep or away at the same time. Since they apply the same temperature throughout the house, energy will be wasted. However, in a distributed thermostat system, sleep temperatures can be applied in spaces where the occupants are sleeping, while different temperatures can be applied in spaces where occupants are awake.

In Table 1, we show the main features of the previously listed energy saving. In this table, we arranged the columns to have an alphabetical shortcut of the studied systems. The evaluated systems are listed as following:

A. The ISES project (Information / Society / Energy / System) at the University of Karlskrona/Ronneby in Sweden [35].
B. Shandong Jianzhu University system [34].
C. Politecnico di Milano University system [45].
D. University of Virginia system [1].

We divided each evaluated criteria into two levels, depending on the satisfaction level of the listed requirement. The two levels are: satisfied(S), and not satisfied (N).

S: ✓ .

N: - .

		Home Energy Saving System			
	Features	A	B	C	D
1	Track each person in the house by using tracking location system	✓	✓	-	-
2	Give decision for each space in the house separately	-	-	✓	-
3	Consider space activity percentage	-	-	✓	✓
4	Use multi-agent system	✓	✓	-	-
5	Use personal agent (each person in the house)	✓	✓	-	-
6	Use space agent	✓	✓	-	-
7	Use house global agent	-	✓	-	-
8	Includes occupant(s) indoor preferred temperature	✓	-	✓	✓
9	Apply energy saving indoor temperature when the house is empty	-	✓	-	✓
10	Use GPS to locate occupant(s) around the house (in North America)	-	-	-	-

Table 1: Features comparison for some related home energy saving systems

2.3. Conclusion:

Based on the review results presented in table1, we conclude that there is a need for a system that fulfills most of the requirements and features. This system will be discussed in the next chapter and we will highlight the features that the system meets; which previously mentioned in table1.

Chapter3: The Proposed Intelligent Energy Controller

This chapter discusses the architecture and components of the intelligent energy controller. These components work together in order to save energy for heating/cooling systems and take into consideration occupant(s) comfort levels as well as the time spent in each area of the home. We propose a multi-agent system (feature4) which components cooperate in order to achieve the energy efficiency goal without sacrificing the occupant(s) comfort level. To simulate the proposed algorithm we emulate doorway sensors, indoor temperature sensors and an actuator(s) in each space (feature 6), as well as outdoor temperature sensor(s). Figure 1 shows the high level design of the proposed system.

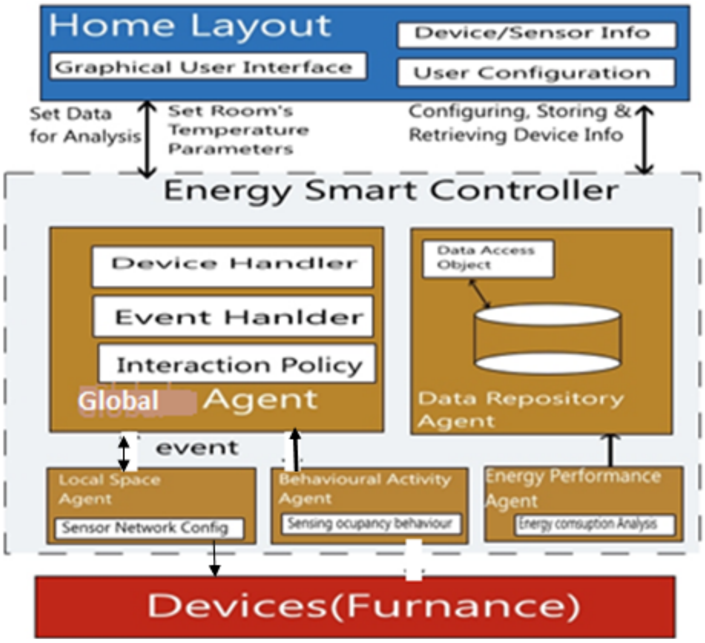


Figure 1: high-level design of the proposed system

In the home layout, the user enters his/her personal information such as indoor temperature preferences and vacation plans (feature 8). After that, the system stores the personal information in the data base to be used by the global agent, and to prevent prompting the user for said information again in case the system shuts down. Moreover, the system creates a map for the spaces, devices (HVAC) and sensors in the home to allow the global agent to make the appropriate decision for each space that saves energy and meets the user comfort level. In the global agent, there is a device handler component that receives input regarding the status of each HVAC in each space. The event handler receives the input regarding the occupancy status in each space. Finally, the interaction policy contains the rules that deal with the dynamic status in each space in the home; this meets user preferences and simultaneously achieves energy saving. All of the global agent components cooperate to determine the appropriate decision regarding the indoor temperature for the current event in each space.

We propose an algorithm that has one global agent (feature 7) and more than one local space agent, the distribution of which depends on the number of determined spaces within the house. Each space agent communicates with the global agent, sending information about the indoor temperature and the status of the door sensor. The global agent sends a decision to each local space agent based on the current indoor temperature and door sensor status. Additionally, the global agent takes into consideration the activity percentage (feature 3) of time spent in each area of the home in order to make the appropriate decision for the heating/cooling system in each space (feature 2). This feature –feature 2: Give decision for each space in the house separately- is the main difference between our proposed system and the University of Virginia’s system [1]. Our presented system used a distributed thermostat to apply different indoor temperatures based on occupied and unoccupied spaces. However, their system applies the same temperature throughout the entire house.

The local space agent monitors the space via door sensor and indoor temperature sensor. Each local space agent sends the information to the global agent. As a result, the global agent considers the information from the behavioural activity Agent and the local agent to make a decision for each space in the house. Moreover, the global agent considers the user’s personal information from the data base, as well as the GPS statuses (feature 10) when the house is empty, meaning all of the occupants are away from the house. Figure 2 shows the use case diagram for the propose system. Figure 3 shows the package diagram of the system.

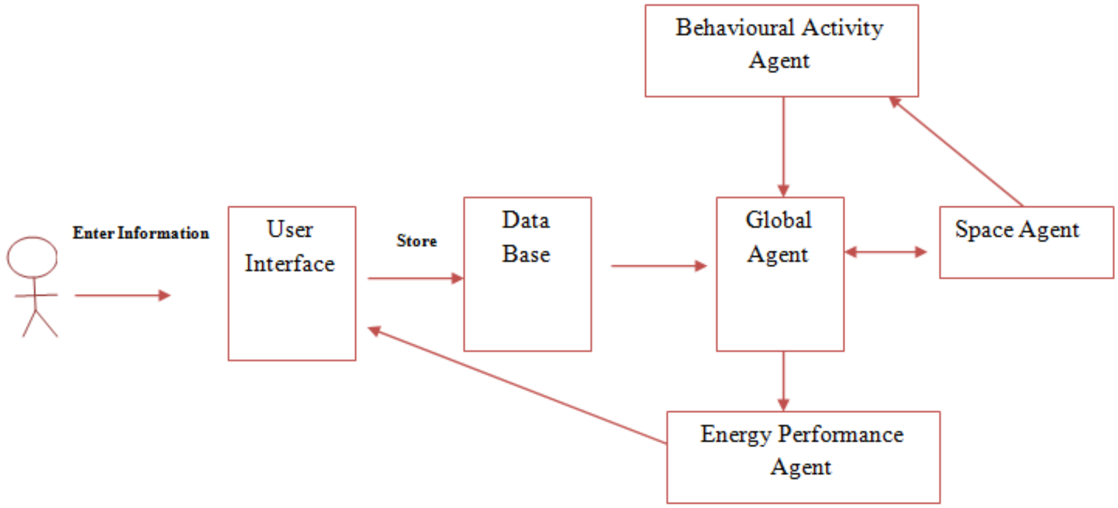


Figure 2: Use case diagram of the proposed systems

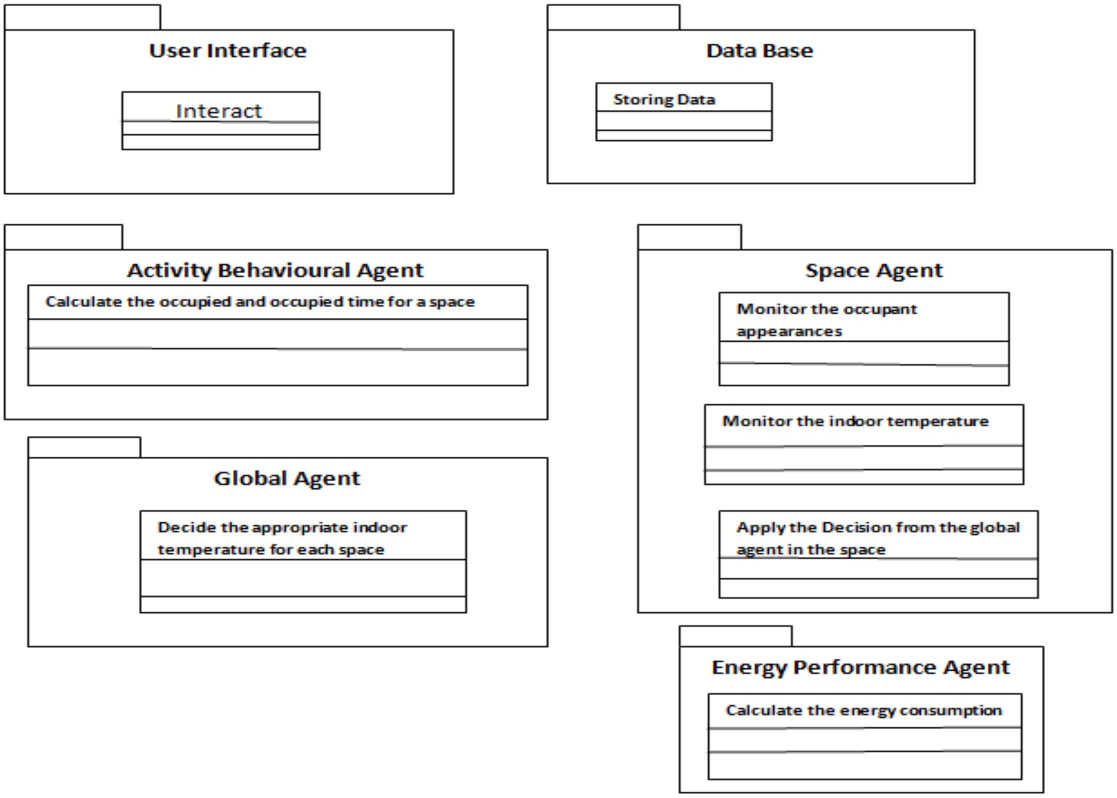


Figure 3: Package diagram of the proposed systems

Figure 4 shows the class diagram of the system in the house setup stage where the user enters his/her vacation plan and other information that will be mentioned in chapter 4(section 4.2.1.) . The system also has a record of city public holidays. Each local space agent monitors the space with door sensors and indoor temperature sensors. Each local space agent receives a decision from the global agent. Next, the local space agent sends a command to the actuator that controls the HVAC. The behavioural activity calculation class calculates for each space the occupied and unoccupied time that is taken into consideration by the global agent to determine the appropriate indoor temperature for each space in the house.

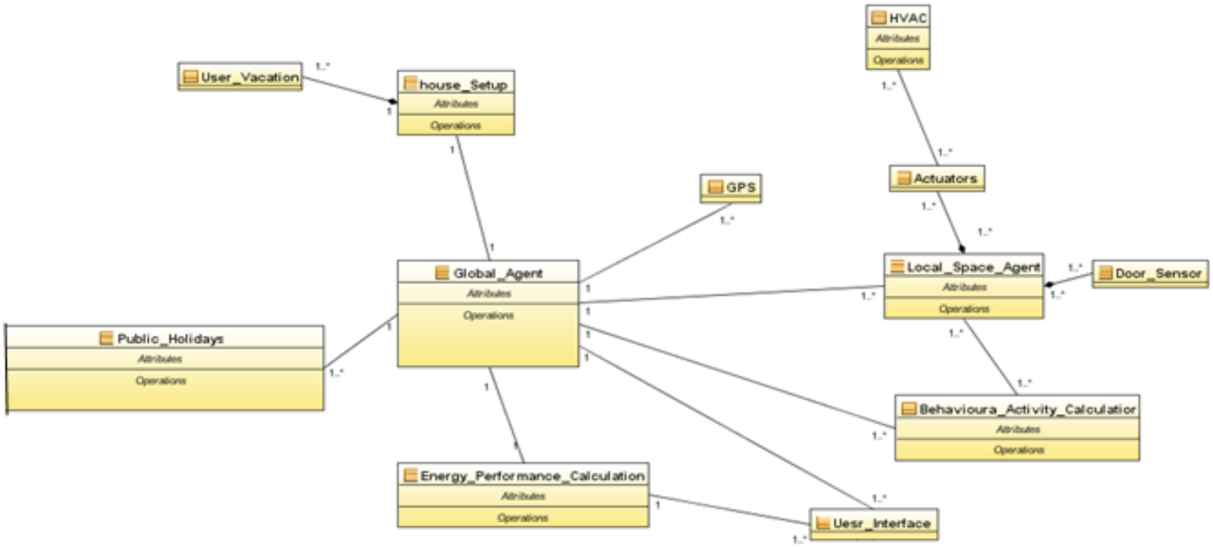


Figure 4: class diagram of the proposed system

Overview

In the following sections there are details about each component in figures 2. In the global agent section, there are details about how the global agent works, which is as follow: Section 3.3.1 shows how the global agent determines the current season in order to decide whether the house needs to be warmed or cooled. In other words, the global agent considers some input parameters to decide if the heater or air conditioner needs to be turned on. Section 3.3.2 shows when the global agent decides to apply the energy saving temperature in the house. Section 3.3.3 describes the system's modes and the global agent process and actions taken when the weather is cold (cold weather process decisions) or hot (hot weather process decisions). Moreover, in this section are explanations of the system's vacation mode. Section 3.3.4 shows how the global agent determines the lowest and highest limit for indoor temperature. Finally, section 3.3.5 explains the global agent's decision to turn the HVAC on or off in each space of the house.

3.1. User Interface

This component is connected to energy consumption and the global agent. The user can see the energy consumption through his/her user interface such as a mobile phone, laptop, etc. Moreover, the user can also see the status of the house sensors, current temperature, etc. The user interface is also used to interact with the house setup component.

3.2. House Setup component

This is the first component that starts the system. In this stage, the user enters through the user interface information relating to his/her daily life, such as his /her preferred indoor temperature, wake up time, vacation plan(s), etc. Regarding the user preferred and comfort temperature; the user will enter the following:

- Maximum user preferred temperature: the global agent will apply this temperature in cold weather when the space's door sensor status is on.
- Minimum user preferred temperature: the global agent will apply this temperature in hot weather when the space's door sensor status is on.
- Maximum user comfort temperature: the global agent will apply this temperature in hot weather when the space's door sensor status is off, but the house isn't empty.
- Minimum user comfort temperature: the global agent will apply this temperature in cold weather when the space's door sensor status is off, but the house isn't empty.

There will be more details in Chapter 4 regarding the user input through the user interface. The system stores this information in a database to be used by the intelligent energy controller algorithm. The advantage of storing user information in the database is to avoid requiring repeated user input in the case of a system shut down or restart.

3.3. Global agent module

The global agent is the main brain of this approach. The most important step in development of this component is the home target settings. The model used to define the target setting is control, memory, learning, feedback, dynamic response and adaptability. We follow the human intelligence approach to define the characteristics of this agent. It is very well-know that learning and memory capabilities of human being are fundamental elements of intelligence. It makes decisions based on different scenarios decides the appropriate indoor temperature for each space based on the current indoor temperature, the status of the door senor, the user preferred indoor temperature which the user will enter his / her maximum and minimum preferred temperature in the house setup stage , and the activity percentage for the space.

There is an agent for each space in the house. For example, Figure 5 has five spaces; therefore, there are five local space agents and one global agent. The global agent will apply user comfort temperature in the shared zone like the corridor. In this way the system meets the user comfort level, and achieves the energy saving concept. Each local space agent monitors the indoor temperature and the status of the door sensor which indicates if there is a user(s) within the space. The local space agent sends this information to the global agent. As a result, the global agent sends to each space agent the decision regarding the appropriate indoor temperature. The space agent applies this temperature through the actuator(s). In addition, each local space agent sends the status of the door sensor to the behavioural activity agent to calculate the percentage of occupied time within the space.

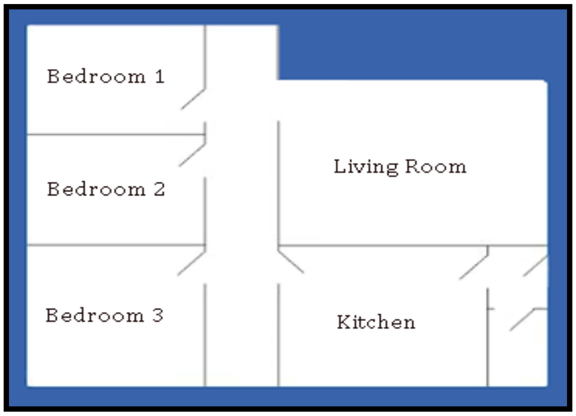


Figure 5 : a sample consists of five different spaces; each space has a dedicated local agent

The global Agent functionality can be described as follow:

Let’s consider the following variables:

X1= Current Space Indoor Temperature.

X2= Space Activity Percentage.

X3= Space door Sensor.

Z= all the spaces’ door sensors in the house.

G= GPS.

SAPT = Space Activity Percentage threshold= 50

Y1= User preferred indoor temperature.

Y2= user comfort indoor temperature.

Y3= energy saving indoor temperature

Given a set of observations (x1, x2, x3, Z, G), where each space in the house has its own copy of the following variables: x1, x2, x3.

$$F(y) = \begin{cases} \text{If ((x3) \&\& (Z) then y1} \\ \text{If ((! (x3))\&\&Z) then y2} \\ \text{If (! (Z)) then y3 (feature 9)} \\ \text{If ((! Z) \&\& G) then} \\ \text{If (x2 >= SAPT) then y1} \\ \quad \text{Else if (x2< SAPT) then y2} \\ \qquad \text{If ((x3) \&\& (x1! = y1)) then y1} \end{cases}$$

3.3.1. Determine Season method

The global agent requires the outdoor temperature in order to compare it with the user minimum preferred temperature and user maximum preferred temperature to determine whether the house needs to be heated or cooled.

This method has the following input: (User minimum preferred temperature, User maximum preferred temperature, Outdoor temperature). The output will be one of the following: (turn the heater on, or turn the air conditioner on or no need to heat or cool the house).

As shown in figure 6, the global agent will consider outdoor temperature, user maximum preferred temperature, and user minimum preferred temperature to determine the season as following:

IF (the outdoor temperature > the user minimum preferred temperature && < user maximum preferred temperature) then the season will be spring when user does not need to heat or cool the house.

IF (the outdoor temperature > user maximum preferred temperature), then the weather is hot and the global agent will turn on the air conditioner to cool the house.

IF (the outdoor temperature < user minimum preferred temperature), then the weather is cold and the global agent will turn on the heater to warm the house.

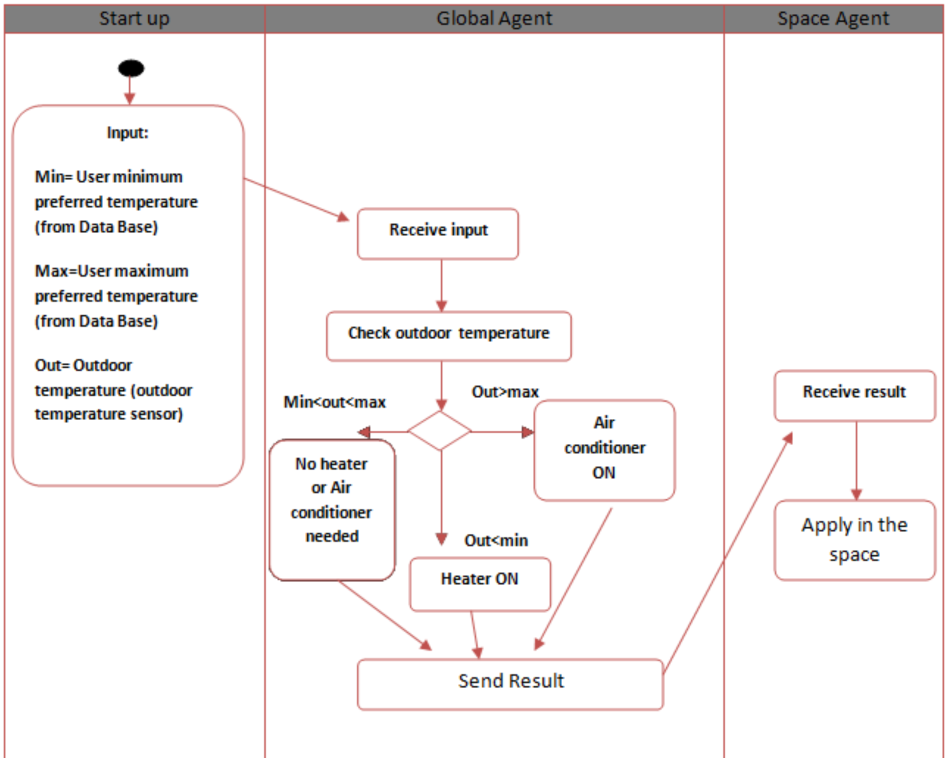


Figure 6 : Activity diagram for Determine Season method

3.3.2. Save Energy Temperature method

This method input will be the status for all the spaces' door sensor. If all the spaces' door senors are off, then this method will be activated.

The global agent will decide to apply 'save energy temperature' when the house is empty. This means that the status of the door sensor in each space is off; therefore, the global agent concludes that there is no occupant(s) in the house.

In cold weather, the global agent keeps the temperature between 10°C and 12°C. According to [1] this range of temperature is considered safe enough to keep the house's pipes from freezing. In hot weather, the global agent will shut down the air conditioner.

The following pseudo-code shows the global agent's decision to keep the indoor temperature of the space between 10°C and 12°C:

```
If (space indoor temperature <= 10)
        Then
            Turn on the heater to warm the space
        Else
    If (space indoor temperature > 12)
  Then
Turn off the heater in the space
```

3.3.3. Space Decision Module

In the system there are two modes:

Normal mode: the house is not empty. In other words, all or some spaces contain occupants.

Vacation mode: the house is empty for the following reasons:

- The occupant(s) is on vacation, either during a public holiday or a personal vacation plan.
- The occupant is at work or not in the house for period of time during the day.

The following are the descriptions of the modes

Normal mode

The global agent needs to consider many parameters to calculate the time needed to warm a space in order to reach the maximum user preferred temperature within a specific time. Some of these parameters are: space size, space insulation, outdoor temperature, current indoor temperature, and the desired indoor temperature. The global agent works under the following assumptions: the wake up period indoor temperature will last for two hours, and after that the temperature will decrease but remain at the user preferred indoor temperature. The reason for this is that during cold weather, the user needs the house to be warmed once he/she wakes up after the sleep time where the indoor temperature would be considered uncomfortable for the wake up time. After that, the house will be warmed based on the user's movement, as the user will be getting dressed for cold weather. As a result, the user can save energy in their heating system and still enjoy his/her acceptable indoor temperature. Another assumption is when the space suddenly becomes empty, the global agent will wait for a given period of time; i.e. Two minutes before making the decision to change or maintain the current indoor temperature. The reason for the waiting period is to make sure that the global agent will make the right decision and is not sacrificing the user's comfort level. The global agent will wait 20 minutes to monitor the house when it is empty, which means all door sensors in each space are off, before applying the energy saving temperature to the house. The final assumption is in the space activity percentage, which is as follow: the space considers having a high activity percentage when its calculation result is larger than or equal to 50. The space considers having a low activity percentage when its calculation result is less than 50. As a result, the space activity percentage threshold (SAPT) is equal to 50.

In normal mode, the global agent will decide to warm the house's spaces during cold weather, and cool the house's spaces during hot weather.

Cold Weather process Decisions

Wake up period: For the morning period preparation the global agent will activate the Wake up Period method. This method takes input: (space door sensor, space activity percentage) for each space in the house and the output will be (the appropriate indoor temperature for each space in the house). In this method, the global agent starts preparation for this period before the occupant(s) wake up in order to reach the maximum user preferred temperature once the occupant(s) wakeup time is reached. The global agent will calculate the difference between the current time and the wake up time. As a result, if the difference equals the preparation time for the morning period, then the global agent will start to warm the house's spaces. For example, if the user wakes up at 6:00a.m. and the spaces that need to be warmed take 15 minutes to reach the maximum user preferred temperature, and then the global agent will start warming the spaces at 5:45 a.m. in order to reach the maximum user preferred temperature by 6:00 a.m. The global agent will start warm the space(s) with door senor status=ON and spaces with high activity percentage even if the door Sensor status= OFF because this means the space is likely to be used in the morning. The maximum user preferred temperature will last for two hours unless the house is empty, Figure 7 shows the Activity diagram for Wake up Period method as following:

The global agent will consider the door sensor status and space activity percentage for each space to determine the appropriate indoor temperature for each space in the wakeup period as follow:

IF (the space door senor = on) which indicate there is somebody in the space, then the global agent will apply maximum user preferred temperature.

IF (the space door senor = off) which indicate there is nobody in the space, then the global agent will check the space activity percentage to do the following:

> IF (the space activity percentage >= SAPT), then the global agent will apply maximum user preferred temperature.
>
> IF (the space activity percentage < SAPT), then the global agent will apply maximum user comfort temperature.

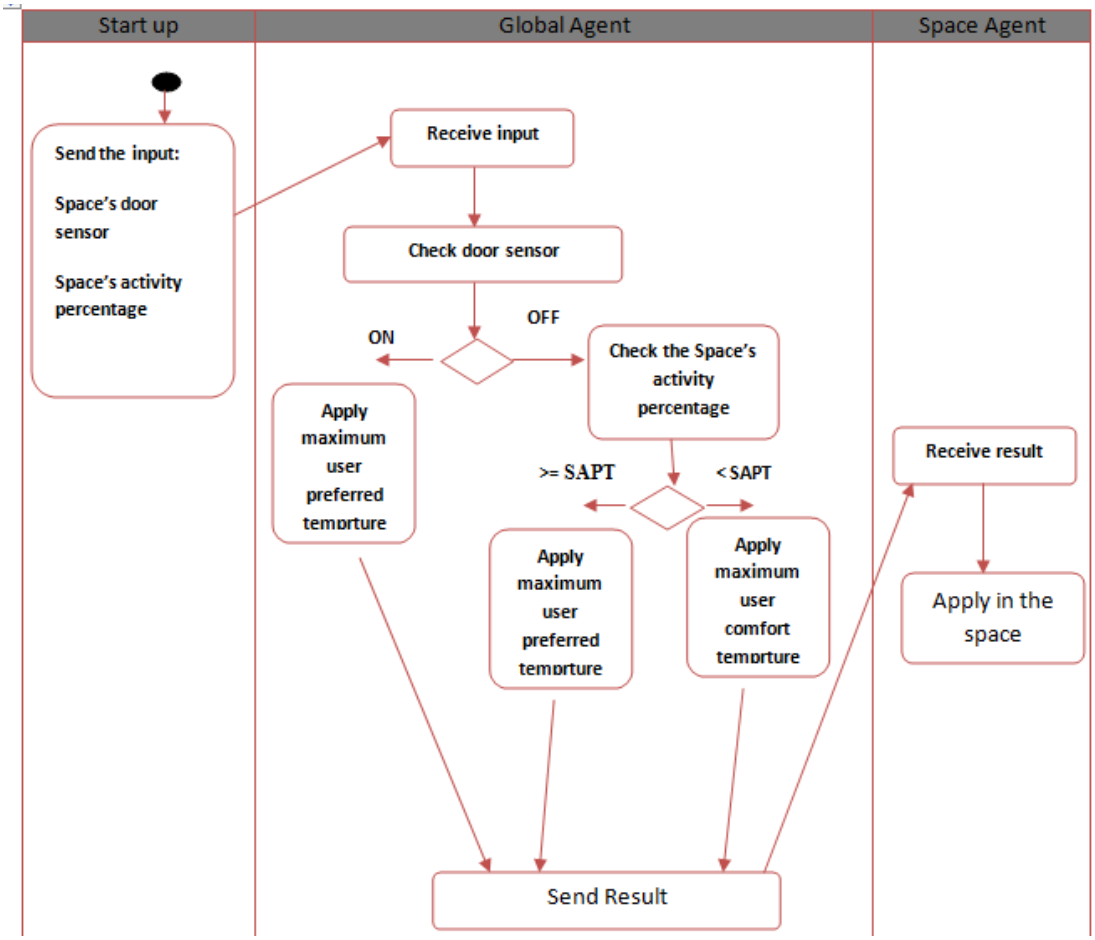


Figure 7: Activity diagram for Wake up Period method

After two hours, the global agent will do the following:

IF (space's door sensor= on) then apply (maximum user preferred temperature –n) (the value of n will be describe in section 3.3.4)

Else IF (space's door sensor= off) then apply maximum user comfort temperature

When a space suddenly becomes empty then the global agent will activate Determine Space Appropriate Temperature Cold Weather method: the method input is: (space activity percentage, the space door sensor), and the output is (the appropriate temperature for the space)

The method works as follow:

```
IF (space’s door sensor=OFF) // the house is not empty, but suddenly a space becomes empty.
Then
IF (space’s activity percentage) < SAPT Then applies maximum user comfort temperature
Else
IF (space’s activity percentage) >=50 Then monitor the space for 2 minutes and do not change the current indoor temperature //
IF (during 2 minutes the space’s door senor = on) which means that someone is in the space: Then no changing in the current indoor temperature
After 2 minutes:
  IF (space’s door sensor=OFF) Then apply   maximum user comfort temperature
   Else IF (space’s door sensor=On) Then no changing in the current indoor temperature
```

Since the global agent doesn’t change the current indoor temperature once the space is empty, a user satisfaction level can be reached. Moreover, we can save the heating system lifetime period rather than continuously changing the temperature or turning the system on and off. Figure 8 demonstrates Determine Space Appropriate Temperature Cold Weather method.

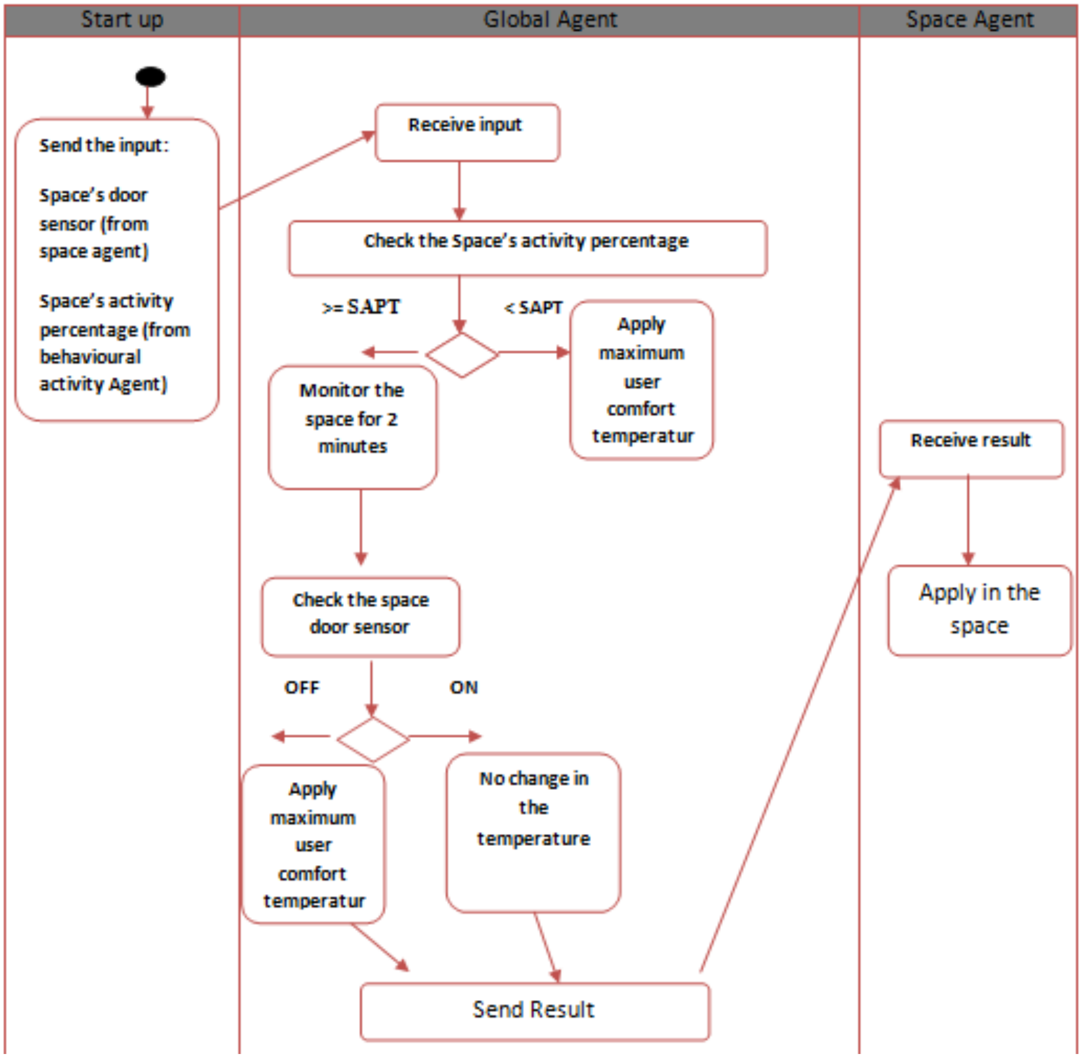


Figure 8: Activity diagram for Determine Space Appropriate Temperature Cold Weather method

When the house becomes empty for 20 minutes (the day is not a user vacation plan or a holiday), then the global agent will activate Cold Weather save Energy Temperature method (3.3.2) as follow:

IF (the house is empty for 20 minutes) // all the space's door sensor status = off

Then

Apply energy saving temperature to the entire house // keep indoor temperature between 10°C and 12°C

The following figure (figure 9) shows Cold Weather Save Energy Temperature method.

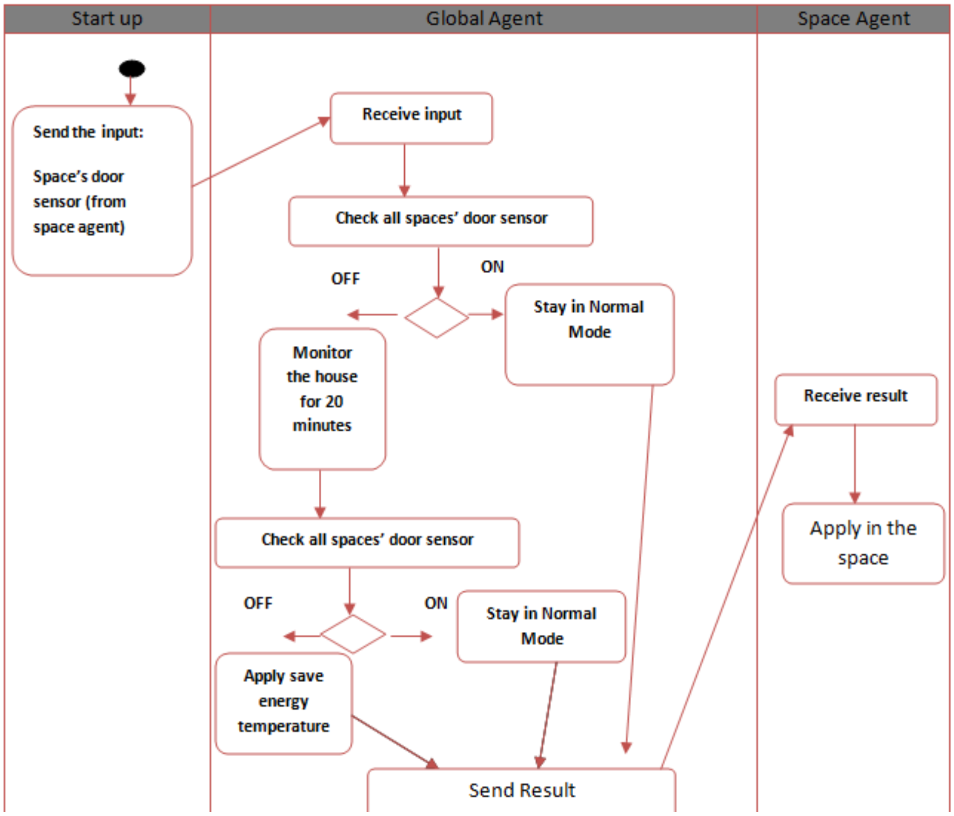


Figure 9 : Activity diagram for Cold Weather Save Energy Temperature method

When GPS recognize user(s) around the home, the global agent will activate the GPS Cold Weather method as in figure 10. This method input (space activity percentage for each space), and the output will be (the appropriate temperature for each space). In this method the global agent sends order for each local space agent as following:

IF (GPS) = true

Then

IF (space activity percentage>=SAPT) Then apply maximum user preferred temperature

Else if (space activity percentage < SAPT) Then apply maximum user comfort temperature

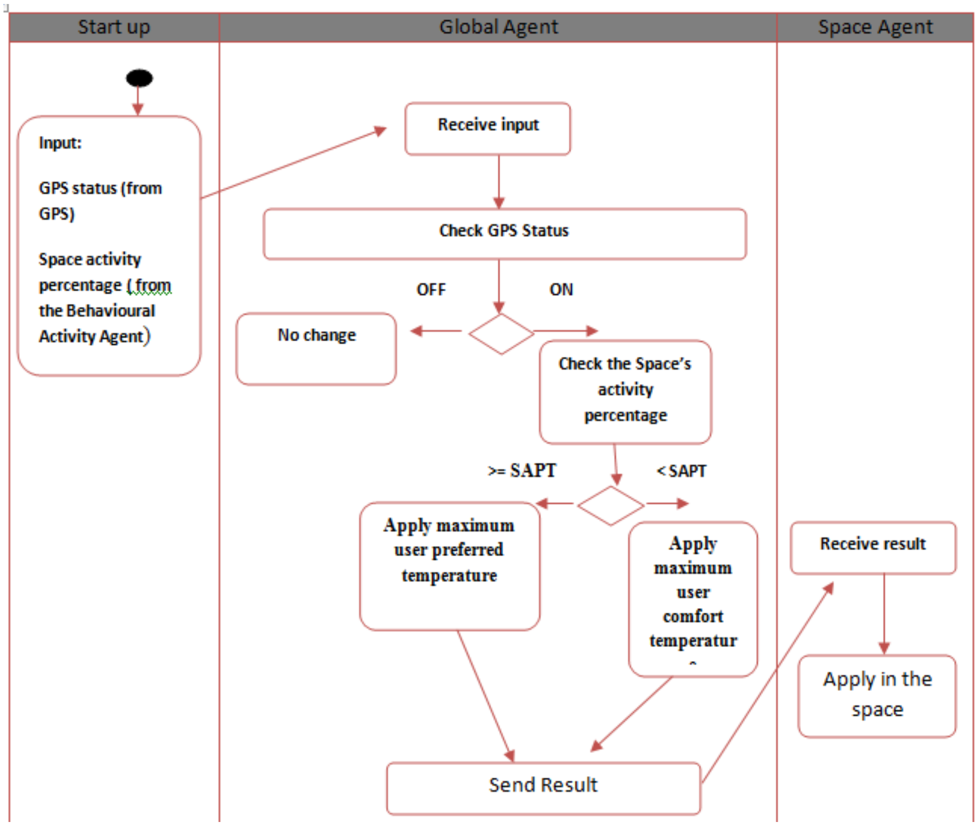


Figure 10: Activity diagram for GPS Cold Weather method

When a space with maximum user comfort temperature recognizes a user as having entered, the global agent will apply the maximum user preferred temperature in the space.

Hot Weather process Decisions

When the house is not empty then the global agent will activate Hot Weather Indoor Temperature method. This method input is (space door sensor) for each space, and the output is (the appropriate indoor temperature) in each space. In this method, the global agent applies the indoor temperature in each space as follow:

IF (house not empty) // some or all of the space's door sensor status = on

Then

IF (space's door sensor=on) then apply minimum user preferred temperature +n) // (the value of n will be described in section 3.3.4).

Else if (space's door sensor=off) then apply minimum user comfort temperature. Figure 11 shows the Activity diagram for Hot Weather Indoor Temperature method.

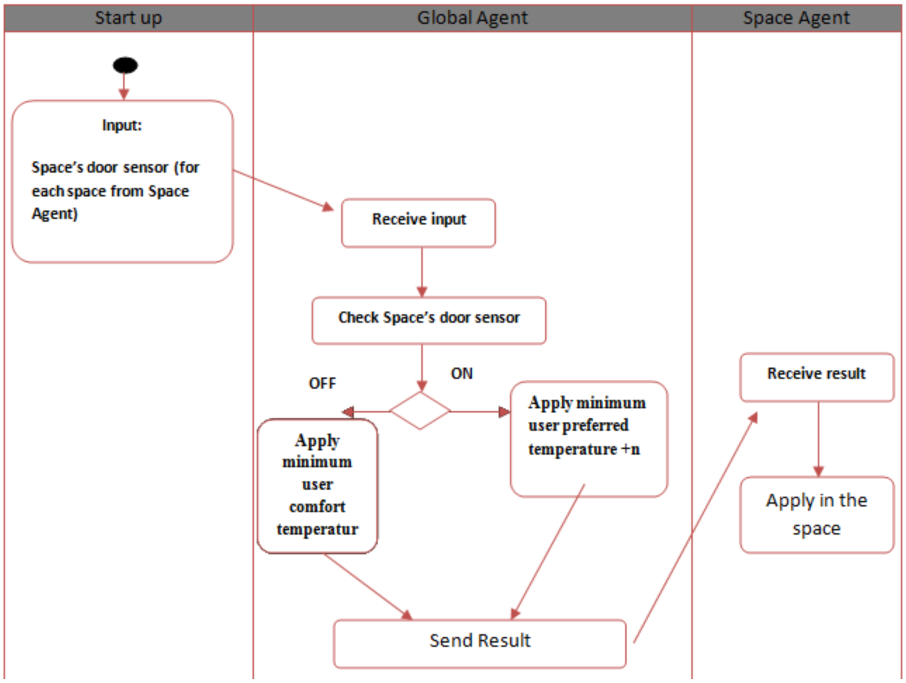


Figure 11: Activity diagram for Hot Weather Indoor Temperature method

When the house becomes empty for 20 minutes, then the global agent will activate Hot Weather save Energy Temperature method (3.3.2) as follow:

IF (house is empty for 20 minutes) // all the space's door sensor status = off

Then

Apply energy saving temperature in the entire house // turns off the air conditioner. Figure 12 shows the Activity diagram for Hot Weather save Energy Temperature method.

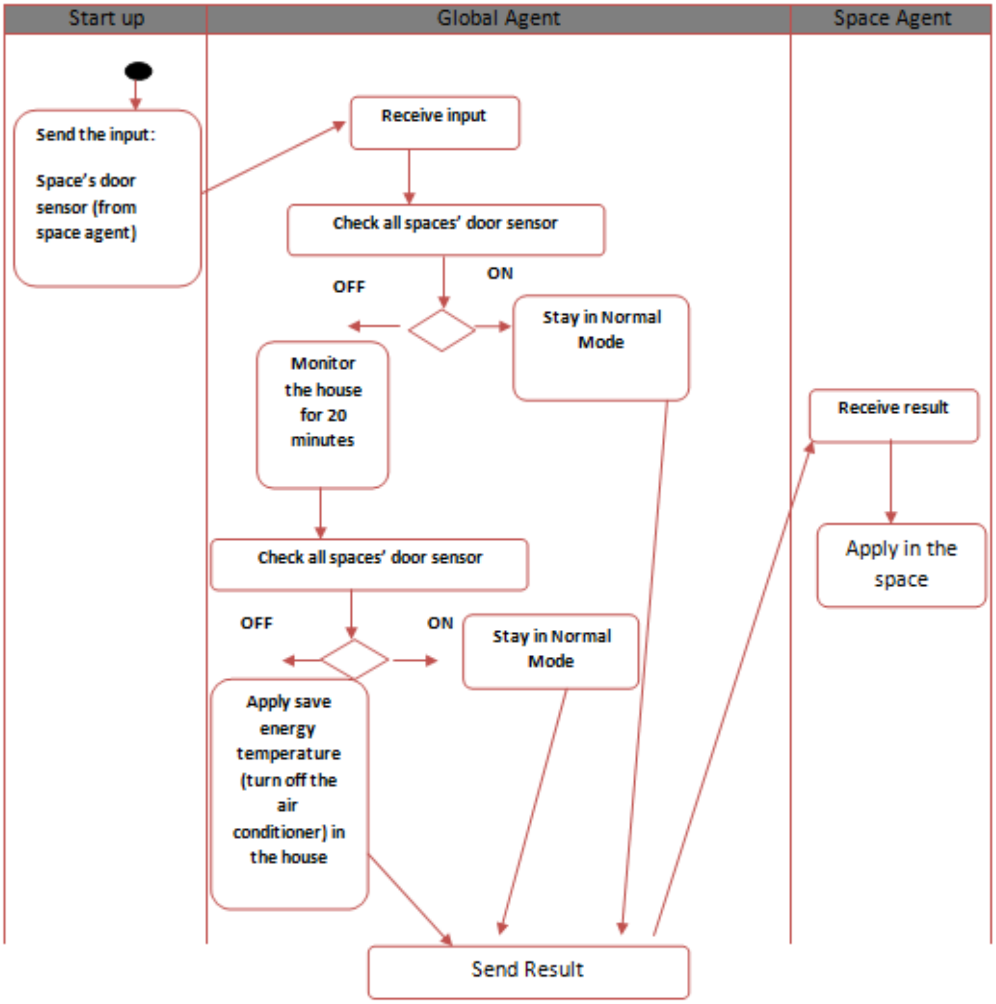


Figure 12: Activity diagram for Hot Weather save Energy Temperature method

When a space suddenly becomes empty then the global agent will activate Determine Space Appropriate Temperature Hot Weather method: the method input: (space activity percentage, the space door sensor), and the output is (the appropriate temperature for the space)

The method works as follow:

IF (space's door sensor=OFF) // the house is not empty, but suddenly a space becomes empty.

Then

IF (space's activity percentage) < SAPT Then apply minimum user comfort temperature

Else

IF (space's activity percentage) >=SAPT Then monitor the space for 2 minutes and do not change the current indoor temperature //

IF (during 2 minutes the space's door sensor = on) which means that someone in the space: then no changing in the current indoor temperature

After 2 minutes:

IF (space's door sensor=OFF) Then apply minimum user comfort temperature

Else IF (space's door sensor=On) Then no changing the current indoor temperature.

Figure 13 shows the activity diagram for Determine Space Appropriate Temperature Hot Weather method.

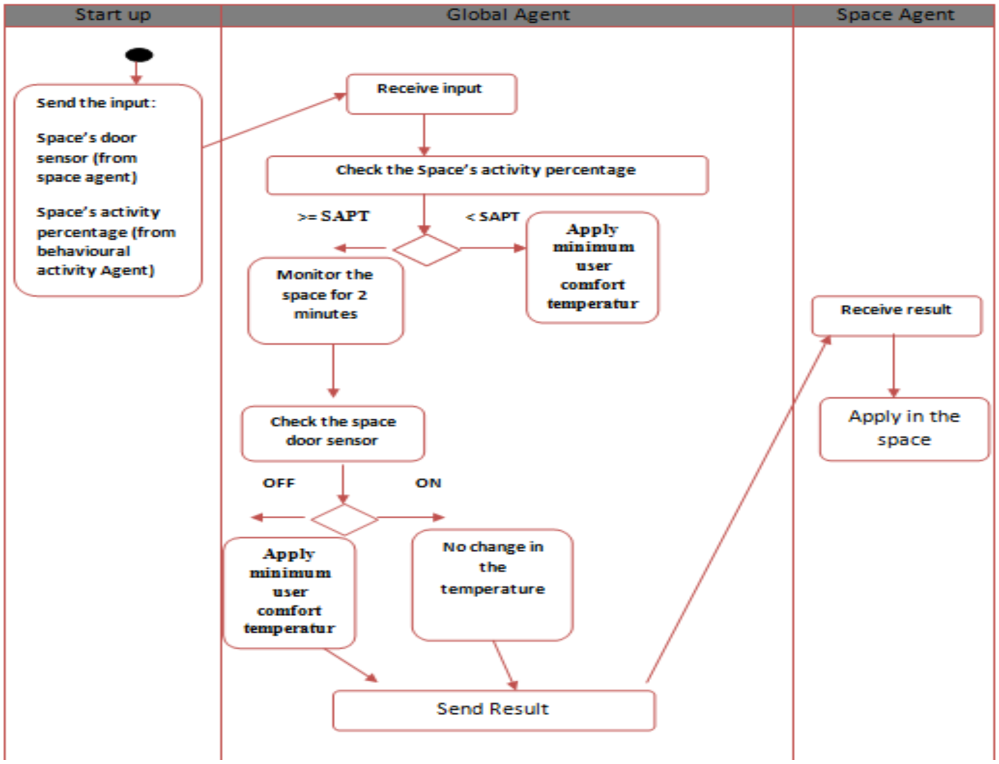


Figure 13: activity diagram for Determine Space Appropriate Temperature Hot Weather method

When GPS recognize user(s) around the home, the global agent will activate the GPS Hot Weather method. This method input (space activity percentage for each space), and the output will be (the appropriate temperature for each space). In this method the global agent sends order for each local space agent as following:

IF (GPS) = true

Then

IF (space activity percentage>=SAPT) then apply minimum user preferred temperature

Else if (space activity percentage <SAPT) then apply minimum user comfort temperature

Vacation Mode

As mentioned in section (3.3.3), vacation mode can be a period where the occupant(s) is outside the house either for vacation, work, or other reasons. The global agent will first check that all space door sensors = OFF in order to apply vacation mode in case the occupant(s) does not go on vacation or if one occupant is still in the house.

When the user(s) is on vacation, the global agent will apply 'save energy temperature' to the whole house.

In this mode the global agent will activate the Vacation Method. This method inputs are: (door sensor status, indoor temperature, and the current date), and the output is :(appropriate indoor temperature). Figure14 shows the use case diagram of the Vacation Method which is as follow:

IF (current date== the end of the current vacation period) then the global agent will enable vacation end method (B1)

Else IF (GPS = true) Then the global agent will enable vacation cancellation method (B2).

Else the global agent keeps the house in energy saving temperature.

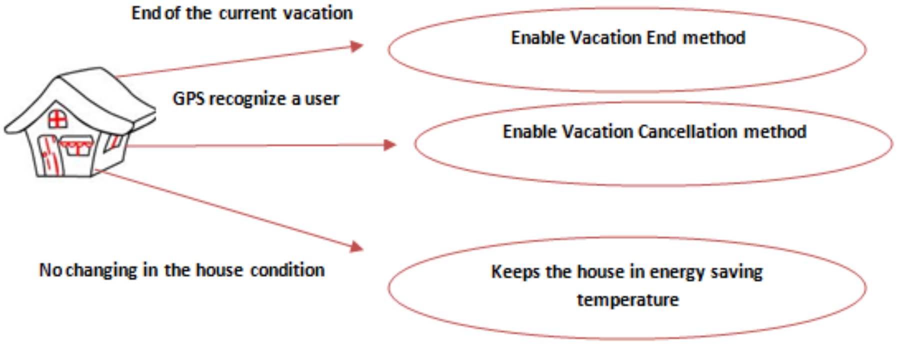


Figure 14: Use case diagram of the Vacation Method

In the vacation mode there exist two situations:

B1. When the vacation end date is reached, it cannot be guaranteed that the occupant(s) will return home. For example, they may choose to remain out of the house longer to prolong their vacation.

B2. Vacation cancellation: when the vacation date end has not been reached but the GPS recognizes that the occupant(s) has returned to the house. In this way, it can be guaranteed that at least one occupant will be at home.

B1. Vacation End Method

This method takes input :(space door senors, current time), and the output :(appropriate indoor temperature for each space). In this method, when the vacation finishes, the global agent will apply user comfort temperature to the whole house.

IF (a space door sensor = ON) // that means that occupant(s) are in the home:

Then the global agent will apply (user preferred temperature in space(s) with door sensor status =on) && (user comfort temperature with door sensor status =off).

Figure 15 shows the global agent decision in the Vacation End method for cold weather: when the weather is cold the global agent will consider spaces' door sensor status and the current time to determine the appropriate temperature in case the user's vacation period is finished. The global agent will apply the user's maximum comfort temperature to the entire house. If any of the door sensors turn on, indicating that someone has entered the space, the global agent will check the current time to apply the appropriate temperature in the space. This is accomplished as follow:

- IF (the current time is within the wake-up period), then the global agent will apply user maximum preferred temperature.
- IF (the current time is not within the wake-up period), then the global agent will apply (Maximum user preferred temperature -n.)

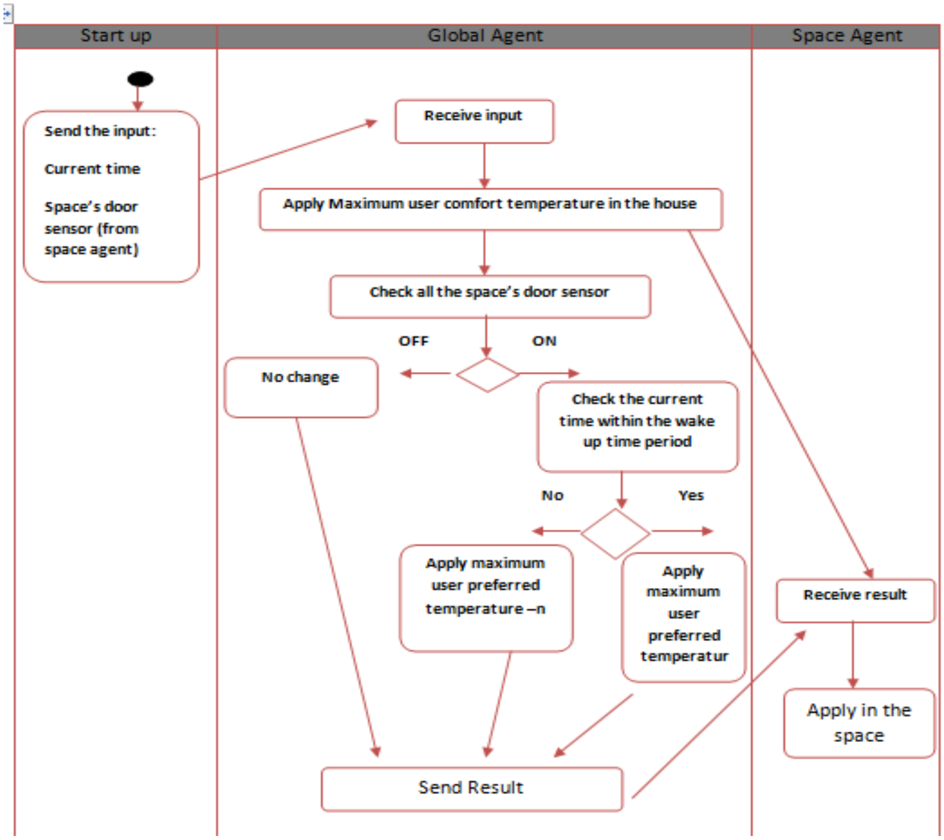


Figure 15 : activity diagram for Vacation End method

B2.Vacation Cancellation Method

This method takes input :(space activity percentage, current time), and the output: (appropriate indoor temperature for each space). In this method, when the GPS recognizes that users are present in the home, spaces with a high activity percentage will be set to the user preferred temperature, while spaces with a low activity percentage will be set to the user comfort temperature.

As shown in figure 16 , the global agent will be consider space activity percentage to determine how often the space is used, as well as the current time to determine the appropriate temperature in case the user cancels his/her vacation before its end date. This is accomplished as follow:

IF (the space activity percentage <SAPT), then the global agent will apply maximum user comfort temperature.
Else the global agent will check the current time as following:

- If the current time is in the wake up period, then the global agent will apply user maximum preferred temperature.
- If the current time is not in the wake up period, then the global agent will apply (Maximum user preferred temperature –n).

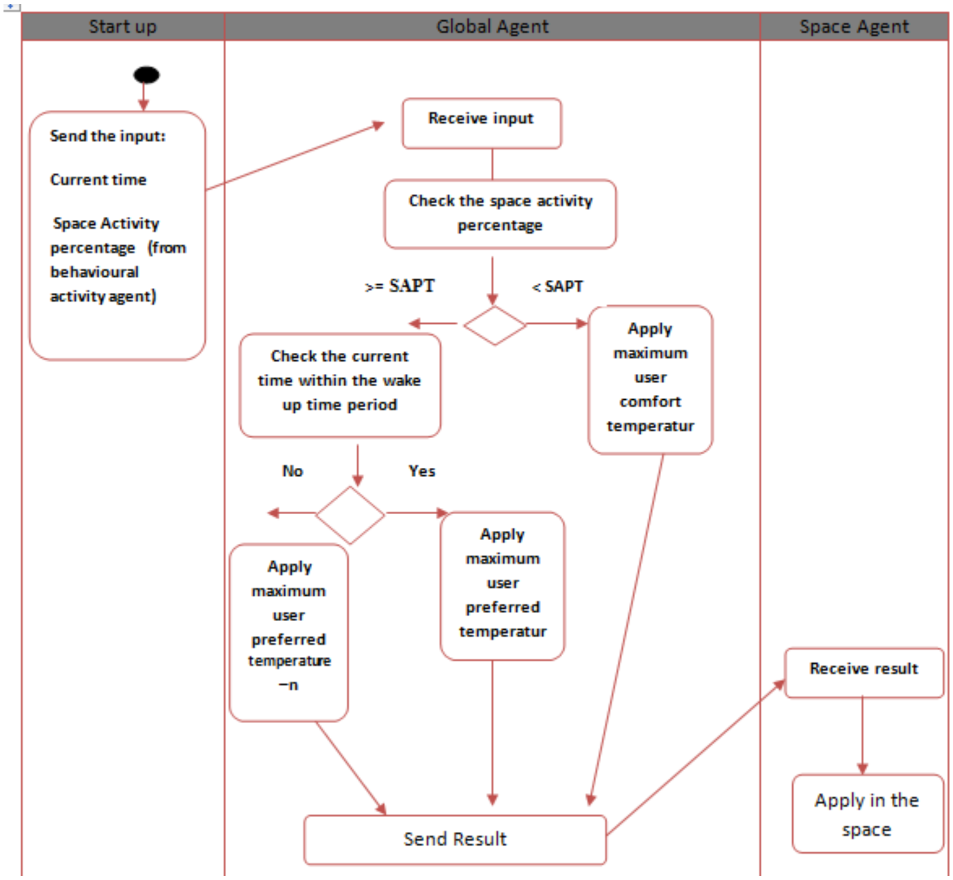


Figure 16 : activity diagram for Vacation Cancellation Method

3.3.4. Determining the low and high limit for indoor temperature

In the house setup stage, the first question will ask the user if he\she has an air conditioned home. If the answer is yes, then the user will enter the four values of indoor temperature as mentioned in section 3.2. If the answer is no, the user will enter three values: maximum preferred temperature, minimum preferred temperature, and minimum comfort temperature. Figure 17 describes how the global agent determines the required temperature values from the user. The global agent will use, in both cases, the difference between the maximum preferred temperature and the minimum preferred temperature to determine the n value that will be considered after the ‘wake up’ period during cold and hot weather. For example, if the user’s maximum preferred temperature is 24 and the user’s minimum preferred temperature is 20 then n= 2. Alternatively, if the user’s maximum preferred temperature is 24 and the minimum preferred temperature is 23, then n=1. Figure 18 describes how the global agent calculates value n. The calculation can be accomplished as follow:

The algorithm considers user maximum and minimum preferred temperature. It will then calculate the difference between the two values.

IF (user maximum preferred temperature - user minimum preferred temperature> = 3) then n =2.

Else (n = maximum preferred temperature - user minimum preferred temperature).

This way the global agent will not go below the user's minimum preferred temperature.

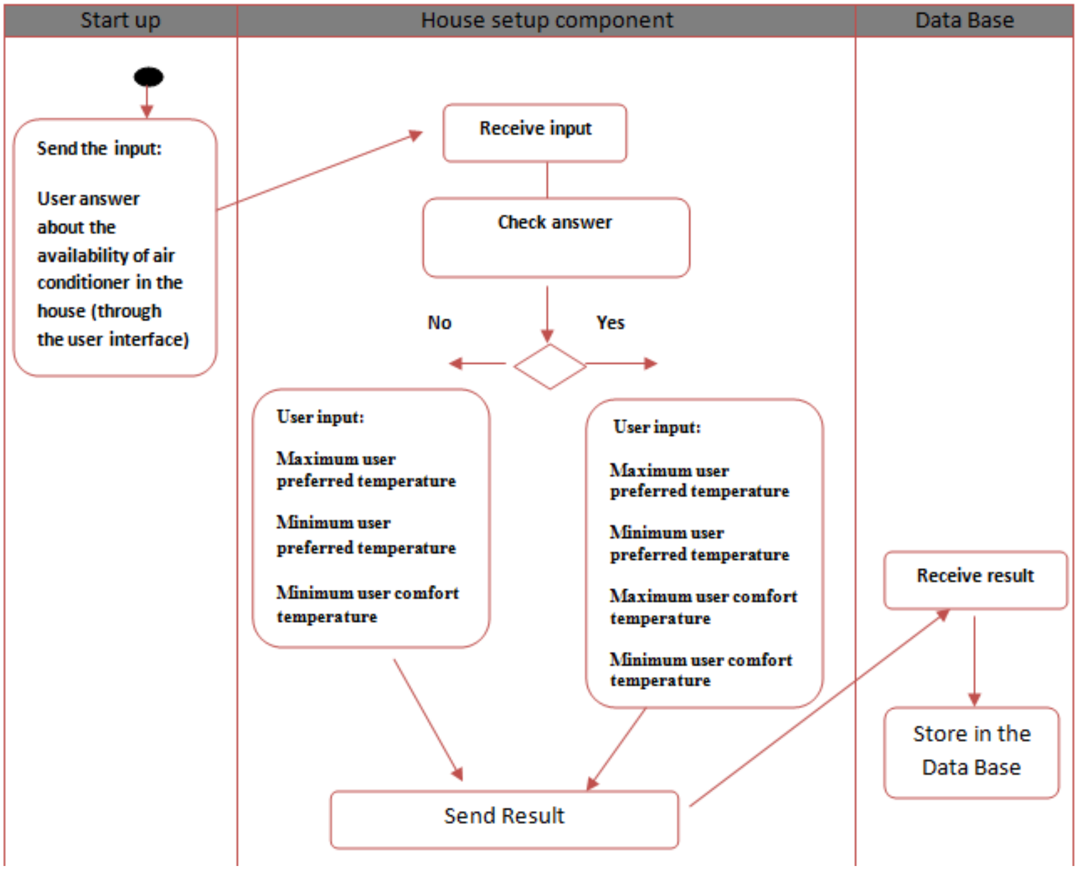


Figure 17 : Activity diagram for the House Setup Stage for user input for preferred indoor temperature

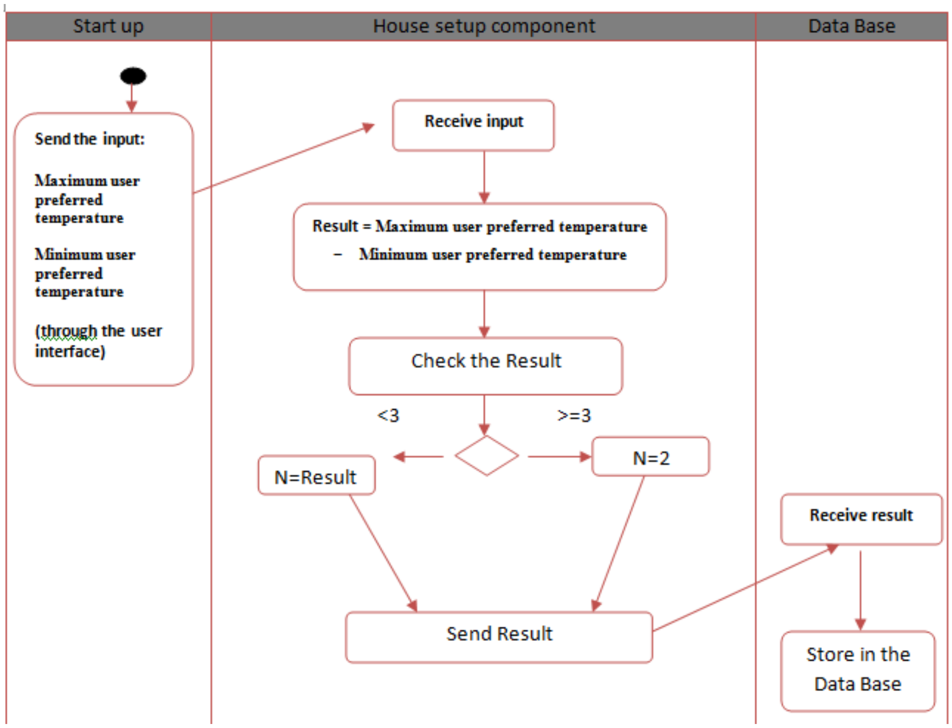


Figure 18: Activity diagram for the calculation of the minimum limit for the indoor temperature

3.3.5. Turning on/off the heater and air conditioner

During cold weather, when the heater achieves the desired indoor temperature it will be turned off. Similarly, when the air conditioner reaches the desired indoor temperature during hot weather, it will be turned off. In our system, when the indoor temperature falls to two degrees below the desired temperature, the heater will be turned on. In hot weather, when the indoor temperature increases by two degrees above the desired temperature, the air conditioner will be turned on. The following is the pseudocode that demonstrates the previous explanation.

```
If (air conditioner) {// air conditioner is on

If (space indoor temperature > user minimum temperature + 2) // hot weather
```

```
        {
 ACPowered[i] =true; //the result turn on the air conditioner. The letter (i) mean the different spaces in the house since the global agent deal with each space separately.
           ……          }
Else {// heather is on
If (space indoor temperature < user maximum temperature -2) // cold weather
       {
         HeaterPowered[i] =true; \\ result turn on the heater
         …… }}
```

3.4. Energy Performance Agent

This agent calculates the energy consumption of the heating/cooling system when it is turned on. Moreover, this agent receives the status of HVAC from the global agent that obtains information from each local space agent in the house. The calculation is accomplished as follow:

Space [i] size= space width * space length; // entered the values as input, space[i] because the calculation will be for each space in the house

Space[i] Energy consumption = (watts * used) * space[i] size; // watts required for HVAC system which is value as input, Used= the time where the HVAC is on.

House energy consumption = House energy consumption + Space[i] Energy consumption;

3.5. Behavioural Activity Agent

This agent receives the status of each space as either occupied or unoccupied from each local space agent. The space will be occupied when the door sensor status =ON, and the space will be unoccupied when the door sensor status =OFF. The behavioural activity agent calculates the percentage of each space whether it is occupied or unoccupied. This component will calculate the percentage for each space in normal mode. However, the behavioural activity agent will stop calculating the percentage for each space during vacation mode unless there is a reading from the sensor(s) which indicating that there is an occupant(s) in the house. The space considers having a high activity percentage if its parentage is higher than or equal to SAPT. The space considers having a low activity percentage if its percentage is lower than SAPT.

The calculation for a space activity percentage is done as follow: The space activity percentage= (Time Space door status ON / (time space door status ON + time space door status OFF))*100.

The global agent will use the percentage of each space in the following cases:

1- When a space is empty, the global agent will apply the user comfort temperature if the activity percentage of the space is low. On the other hand, if the activity percentage of the space is high, then the global agent will wait for two minutes before deciding to whether to apply the user comfort temperature or to maintain the user's preferred temperature. As a result, the global agent can increase the lifetime of the heater or air conditioner instead of turning it on and off. As shown in figures (8, 13).
2- In the morning period, the space(s) with a high activity percentage will have user preferred temperature, but the space(s) with a low activity percentage will have user comfort temperature. As shown in figure (7).
3- When the GPS recognizes a user(s) in normal mode or during vacation cancellation, the space(s) with a high activity percentage will have user preferred temperature, while the space(s) with a low activity percentage will have user comfort temperature. As shown in figure (10).

3.6. Global Positioning System (GPS)

This component recognizes if an occupant is present in the home. This part of the system is useful when the house is empty, as the GPS can inform the global agent that a user(s) is around the house. As a result, the global agent will apply the suitable temperature for either the warm or cool season based on the activity percentage in each space.

Chapter 4: Simulation, Result and Evaluation

This chapter discusses the simulation and evaluation of the proposed algorithm. The algorithm analyzed by simulation many situations such as: an empty house; some spaces empty while others have occupants; occupants returning to the house; cold weather; and hot weather. For simulation purposes for our algorithm, we selected January and February to represent the cold weather season and July to represent the hot weather season. The results are evaluated and compared based on well-known energy home simulation software HOT2000.

4.1. HOT2000

HOT2000 is energy simulation modeling software developed and maintained by Natural Resources Canada (NRCan). It is primarily used to estimate annual energy consumption and calculates the heat loss and gain of a house. HOT2000 conducts a month-by-month energy analysis based on house-specific information and local weather data [48]. HOT2000 models various types of houses: detached, semi-detached left unit, semi-detached right unit, and semi-detached middle unit. A detached house is a free-standing, single-family dwelling unit that does not share a common wall with any other structure. Semi-detached is a house that is attached to another house on one or two sides. For space heating, HOT2000 calculates both monthly and seasonal efficiencies for many space heating system types, and it also calculate the heat loss for the heating system based on house location, orientation, and solar gain, doors and windows components. Moreover for the space cooling, HOT2000 model many types of cooling system and determine the correct cooling system size for a house.

The inputs of HOT2000 software are: building geometry, construction characteristics, and geographical location of the house. The data is entered through a graphical user interface. Many defaults values are provided if the user is not sure of certain values, such as wall measurement and wall type. The output of the system is a report on the house analysis; HOT2000 includes: a weather file, economic and financial conditions, and fuel costs. The house analysis includes detailed monthly tables; annual heat loss and HVAC load results. Appendix C contains some screenshots of HOT2000 software.

4.2. Description for the proposed system

4.2.1. House set-up component

The first step in the system is asking the user questions regarding his/her comfort level. The questions are as follow:

- Ask if the user has air conditioner
- Maximum user preferred temperature
- Minimum user preferred temperature
- Maximum user comfort temperature
- Minimum user comfort temperature
- User vacation plan(s)
- Wake up time on weekdays
- Wake up time on Saturday
- Wake up time on Sunday
- Amount of time needed to warm the house before wake-up time. (This is for simulation purposes, but in reality, the global agent should calculate the time needed to warm or cool each space in the house to reach the user preferred temperature based on many considerations such as the space size, indoor and outdoor temperature for the space, insulation level, number of people within the space, and the space position as shady or sunny.)
- House size (width, depth)
- Space number (for simulation purposes, but in reality the system can automatically recognize the number of identified spaces in the house via the door sensors in each space. Moreover, the user will enter the name and the size (width, depth) for each space.)
- Heat loss/gain rate (for simulation purposes, but in reality the global agent should calculate the time needed to warm or cool each space in the house in order to reach the user preferred temperature. This is based on many considerations, such as the

space size, indoor and outdoor temperature of the space, insulation level, number of people within the space, and whether the space is shady or sunny.)

- Outdoor temperature (for simulation purposes, but in reality the system will take the outdoor temperature from outdoor sensors or a weather web site.)
- Watt consumption calculated from HOT2000.

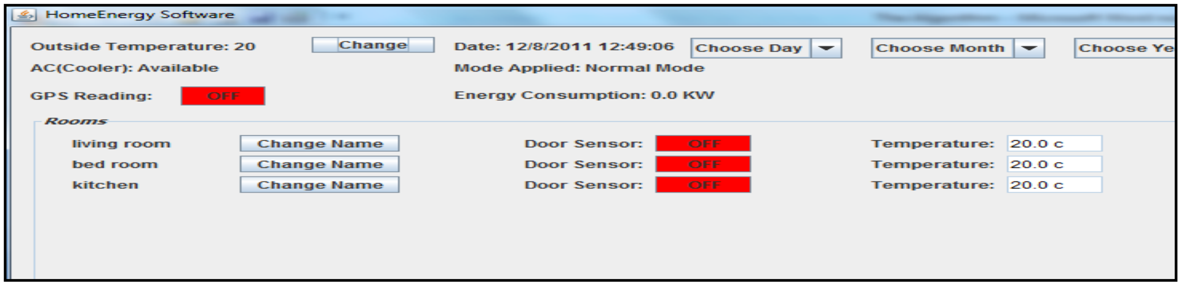
In Appendix A there are several screenshots of the GUI for the program that display some of the user's questions.

4.2.2 The GUI for the proposed system

A java-based simulator is designed to simulate the algorithm for saving energy in the house heating and cooling system. The program is used to simulate hot and cold weather, while the input for the average monthly temperature is taken from HOT2000.Morover, the watts consumption value is calculated based on the HOT2000 simulation program. The algorithm takes into consideration the assumption by HOT2000 that the house holds two adults for 50% of the time, and two children for 50.0% of the time. In other words, occupants spend 50% of their time in the house. At the end of the simulation there was comparison and evaluation of energy consumption and the cost with the result in HOT2000.

The system used Derby that is a 100% Java technology database. It is fully transactional, secure, and easy to use. There are two tables in the data base: one to store the responses to questions in the house setup stage, and the other to store the space-related information, such as space name, ID, period of time door sensor=ON, period of time door sensor=OFF, and space indoor temperature.

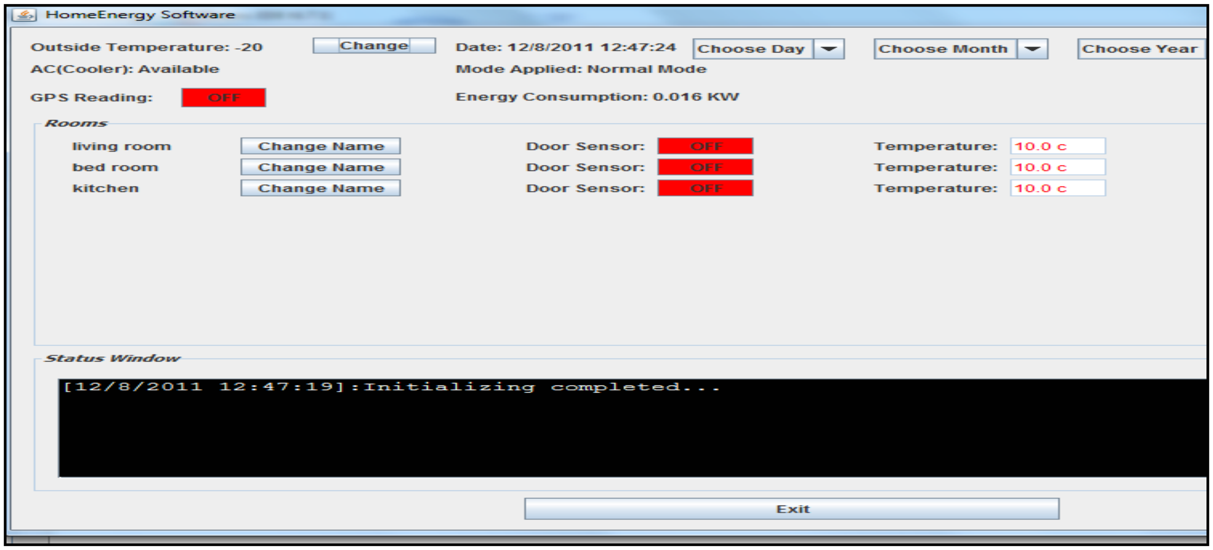
In the proposed algorithm, there is some assumption: at the start of the program, the indoor temperature for each space will depend on the outdoor temperature. This means that if the outdoor temperature is equal to 10°C or below, the indoor temperature will equal 10°C. Alternatively, if the outdoor temperature is greater than 10°C then the indoor temperature will equal the outdoor temperature. Following that, the indoor temperature will increase or decrease toward the user preferred temperature based on the day, time, occupied and unoccupied space, and occupied or unoccupied house. In figure 19 the outdoor temperature is equal 20 °C which is larger than 10°C. As a result the space indoor temperature will be equal to the outdoor temperature. In figure 20 the outdoor temperature is equal - 20 °C which is below 10°C. As a result the space indoor temperature will be equal 10°C.



Outside Temperature: 20
AC(Cooler): Available
GPS Reading: OFF
Date: 12/8/2011 12:49:06
Mode Applied: Normal Mode
Energy Consumption: 0.0 KW

living room Door Sensor: OFF Temperature: 20.0 c
bed room Door Sensor: OFF Temperature: 20.0 c
kitchen Door Sensor: OFF Temperature: 20.0 c

Figure 19: GUI screenshot demonstrates the relationship between indoor and outdoor temperature when outdoor temperature is above 10°C



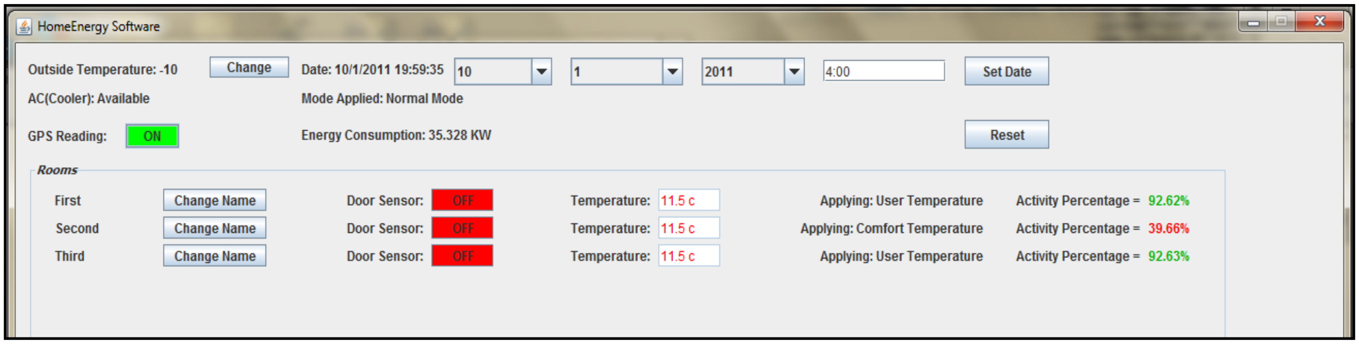
Outside Temperature: -20
AC(Cooler): Available
GPS Reading: OFF
Date: 12/8/2011 12:47:24
Mode Applied: Normal Mode
Energy Consumption: 0.016 KW

living room Door Sensor: OFF Temperature: 10.0 c
bed room Door Sensor: OFF Temperature: 10.0 c
kitchen Door Sensor: OFF Temperature: 10.0 c

```
[12/8/2011 12:47:19]:Initializing completed...
```

Figure 20: GUI Screenshot demonstrates the relationship between indoor and outdoor temperature when the outdoor temperature below 10°C

The program simulates different months, days and times. This occurs by changing some information in the GUI such as changing the time, date, and door sensor for one or more spaces, outdoor temperature, and GPS status as shown in figure 21. For the space indoor temperature, the door sensor label with a red color value represents that the heater is on as shown in figure 21, while the door sensor label with blue color value represents that the AC is on as shown in figure 22, and the door sensor label with black color value represents that neither heater nor AC is on as shown in figure 30. For the space activity percentage value, the activity percentage label with green color value means that the space is occupied for 50% of time or more, while the activity percentage label with red color value means that the space is occupied for less than 50% of time as shown in figure 22.

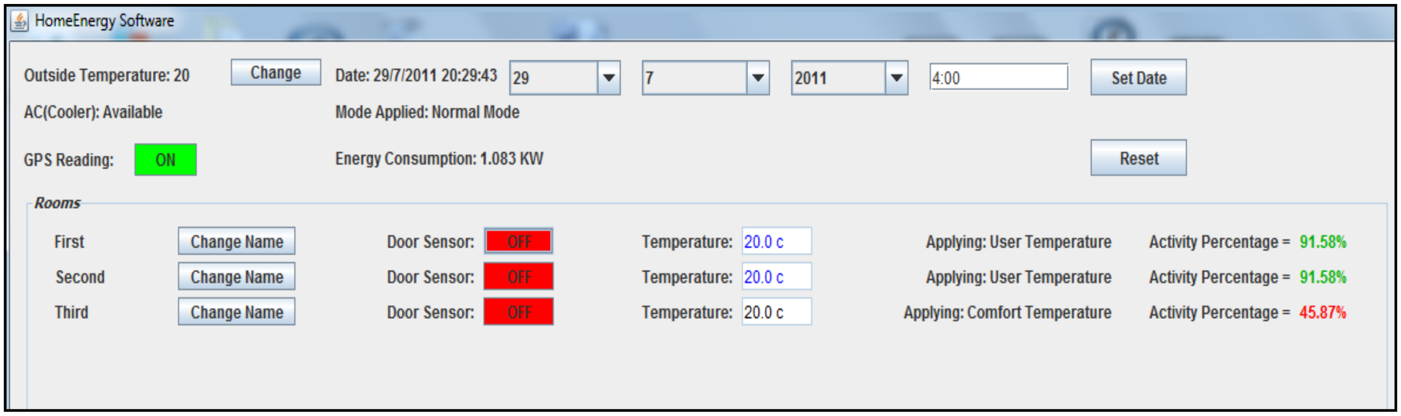


Outside Temperature: -10
Date: 10/1/2011 19:59:35
10 | 1 | 2011 | 4:00
AC(Cooler): Available
Mode Applied: Normal Mode
GPS Reading: ON
Energy Consumption: 35.328 KW

Rooms

	Door Sensor:	Temperature:	Applying:	Activity Percentage =
First	OFF	11.5 c	User Temperature	92.62%
Second	OFF	11.5 c	Comfort Temperature	39.66%
Third	OFF	11.5 c	User Temperature	92.63%

Figure 21: GUI Snapshot demonstrate the way to change the date



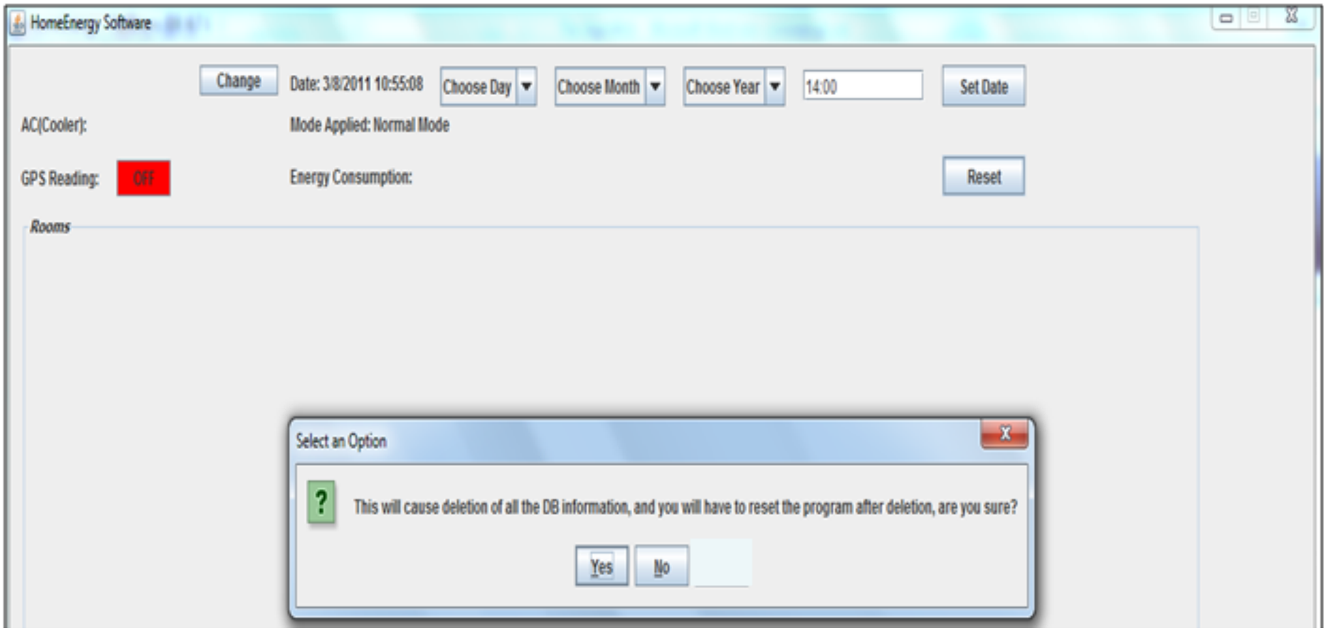
Outside Temperature: 20
Date: 29/7/2011 20:29:43
29 | 7 | 2011 | 4:00
AC(Cooler): Available
Mode Applied: Normal Mode
GPS Reading: ON
Energy Consumption: 1.083 KW

Rooms

	Door Sensor:	Temperature:	Applying:	Activity Percentage =
First	OFF	20.0 c	User Temperature	91.58%
Second	OFF	20.0 c	User Temperature	91.58%
Third	OFF	20.0 c	Comfort Temperature	45.87%

Figure 22: GUI Screenshot demonstrate the AC is turned ON

In the GUI, the Mode Applied label shows the current mode; which either normal mode or vacation mode. In figure 20 the mode applied is normal mode. The system provides the flexibility to set the GPS and door sensor for each space button on or off, and to observe the heating / cooling energy consumption value. There is a reset button that allows for the deletion of all data within the data base as shown in Figure 23, as well as an Exit button to close the GUI while saving the current data and values such as space door sensor status and energy consumption value.



Date: 3/8/2011 10:55:08

14:00

AC(Cooler):

Mode Applied: Normal Mode

GPS Reading: OFF

Energy Consumption:

This will cause deletion of all the DB information, and you will have to reset the program after deletion, are you sure?

Figure 23: GUI shows the action when press the reset button.

4.3. Result for the proposed system simulation and comparison with HOT2000

4.3.1. Energy Consumption calculation

Since the result from our proposed algorithm simulation compared to HOT2000, the input parameters should be the same in order to have correct comparison and evaluation. HOT2000 conducts a monthly energy balance on a house design to determine potential energy (space heating, space cooling) requirements [46]. Therefore, one of these parameters is the energy consumption for the house's heating/cooling system. This parameter is obtained from HOT2000 and uses it as input for our proposed algorithm. The following flowchart (figure 24) shows the steps taken to calculate the energy consumption for a period of one month. The other parameters for our proposed algorithm will be mentioned in section 5.4.

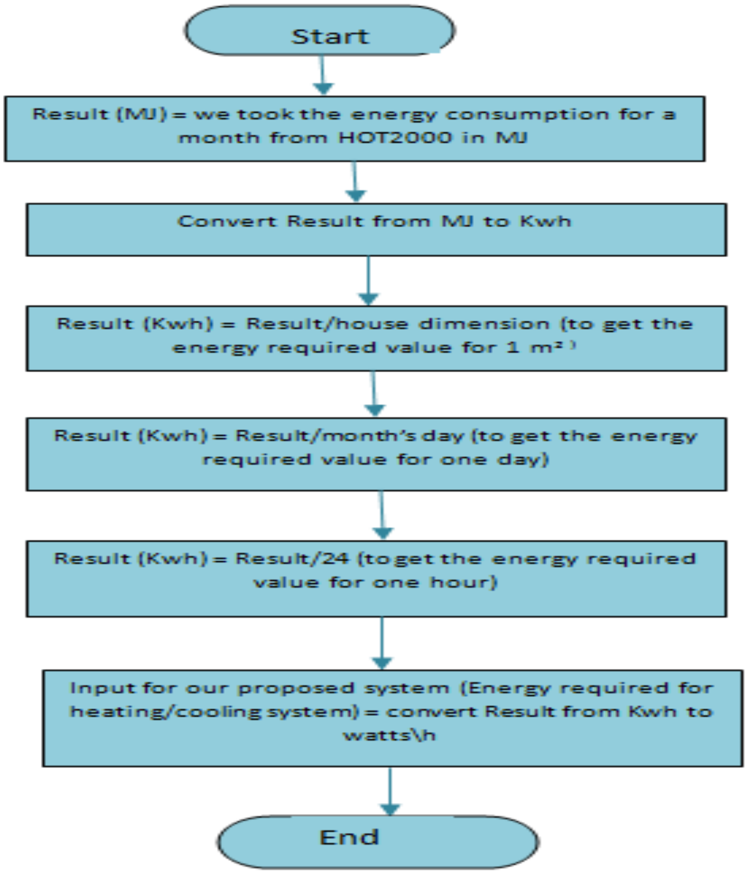


Figure 24: Energy consumption calculation flowchart

4.3.2. Result comparison

The following flowchart (figure 25) shows the steps to compare the energy consumption from the proposed algorithm with the energy consumption form HOT2000.

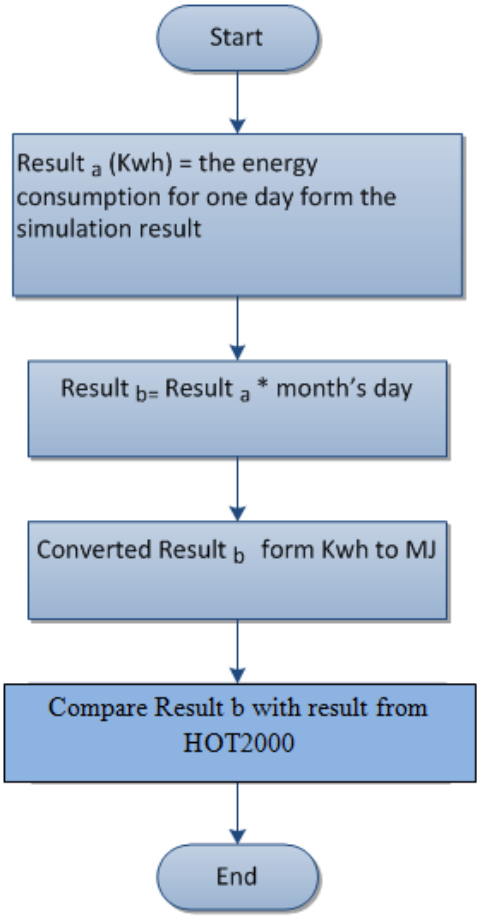


Figure 25: Energy consumption result comparison flowchart

4.3.3. House Space's number and size as input

The system asks the user to enter the space number and size in order to divide the house's dimension into spaces. In other words, HOT2000 does not divide the house dimensions into different space, but the proposed algorithm takes into consideration the various spaces individually. Because the results of the simulation will be compared with HOT2000, the input of house size will be the same as the case study that will be compared with HOT2000. To calculate the energy consumption for each space, our system multiplies the space size by the time that the heater/AC is turned on.

4.4. Simulation1 for January month to calculate and compare energy consumption and cost with HOT2000

Input parameters

In order to compare the result of the proposed algorithm with HOT2000 some of the input parameters should be the same and they are: the simulated month, house type, house story number, the house dimension, number of occupants in the house, occupied and unoccupied time, and watts consumption (energy consumption for heating/cooling system). All these parameters are taken from the use of HOT2000 to calculate how much energy a house will use.

Case Study 1: January month

4.4.1. House characteristic (HOT2000)

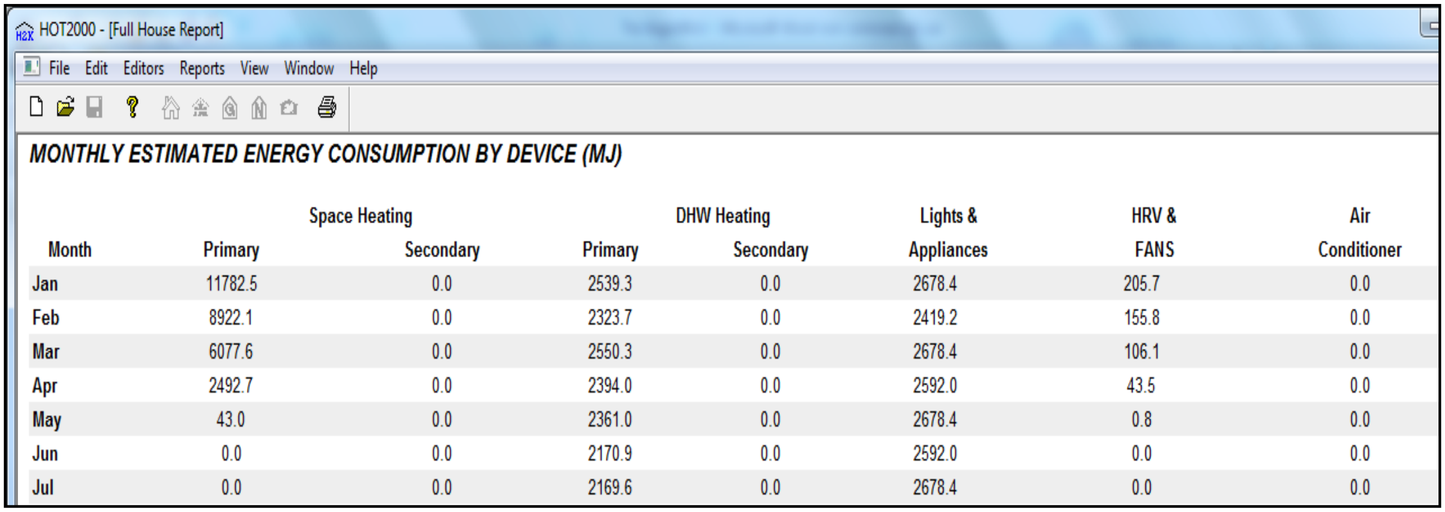
- House type: Row, middle unit
- Number of storeys: 2
- House dimensions (width, depth) = 10 m*10 m

Occupants:

- 2 Adults for 50.0% of the time
- 2 Children for 50.0% of the time

Calculation for watts consumption

Monthly estimated energy consumption for January (HOT2000) = 11782.5 MJ. Figure 26 shows the monthly estimated energy consumption for January.

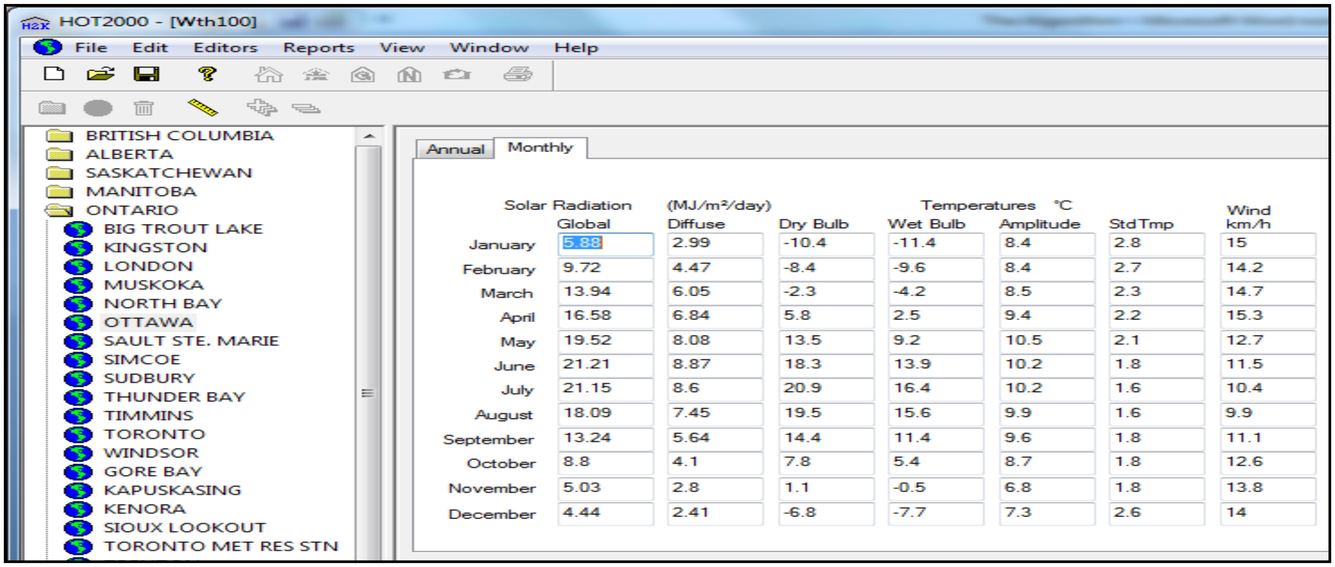


MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		DHW Heating		Lights &	HRV &	Air
Month	Primary	Secondary	Primary	Secondary	Appliances	FANS	Conditioner
Jan	11782.5	0.0	2539.3	0.0	2678.4	205.7	0.0
Feb	8922.1	0.0	2323.7	0.0	2419.2	155.8	0.0
Mar	6077.6	0.0	2550.3	0.0	2678.4	106.1	0.0
Apr	2492.7	0.0	2394.0	0.0	2592.0	43.5	0.0
May	43.0	0.0	2361.0	0.0	2678.4	0.8	0.0
Jun	0.0	0.0	2170.9	0.0	2592.0	0.0	0.0
Jul	0.0	0.0	2169.6	0.0	2678.4	0.0	0.0

Figure 26: Snapshot form HOT2000 shows January monthly estimated energy consumption

- Convert HOT2000 monthly estimated energy consumption to Kwh = 11782.5 * 0.278 = 3272.92 KWh (according to equation (1)).
- Calculate the energy consumption (Kwh) for 1 m^2 (/100) = 3272.92 /100= 32.73 Kwh (divided by 100 because the house dimension is 10 m * 10m. So we can get the energy required for 1m^2).
- Calculate the energy consumption (Kwh) for one day (/31) = 32.73 /31= 1.06 Kwh (since January has 31 days, so we dived the result by 31 to get the energy required for one day).
- Calculate the energy consumption (Kwh) for one hour (/24) = 1.06 /24= 0.044 Kwh (since the day is 24 hour, so we dived the result by 24 to get the energy required for one hour).
- Convert the energy consumption (Kwh) to WH = 0.044 *1000= 44 WH (according to equation (3)).
- As a result the energy required for the heating system = 44 WH.



	Solar Radiation (MJ/m²/day)		Temperatures °C				Wind
	Global	Diffuse	Dry Bulb	Wet Bulb	Amplitude	StdTmp	km/h
January	5.88	2.99	-10.4	-11.4	8.4	2.8	15
February	9.72	4.47	-8.4	-9.6	8.4	2.7	14.2
March	13.94	6.05	-2.3	-4.2	8.5	2.3	14.7
April	16.58	6.84	5.8	2.5	9.4	2.2	15.3
May	19.52	8.08	13.5	9.2	10.5	2.1	12.7
June	21.21	8.87	18.3	13.9	10.2	1.8	11.5
July	21.15	8.6	20.9	16.4	10.2	1.6	10.4
August	18.09	7.45	19.5	15.6	9.9	1.6	9.9
September	13.24	5.64	14.4	11.4	9.6	1.8	11.1
October	8.8	4.1	7.8	5.4	8.7	1.8	12.6
November	5.03	2.8	1.1	-0.5	6.8	1.8	13.8
December	4.44	2.41	-6.8	-7.7	7.3	2.6	14

Figure 27: HOT2000 screenshot for monthly outdoor temperature

4.4.2. Input to the program

Maximum preferred temperature	24 °C
Minimum preferred temperature	23 °C
Maximum comfort temperature	35 °C
Minimum comfort temperature	15 °C
Wake-up time during weekdays	6:00 a.m.
Wake-up time on Saturday	8:00 a.m.
Wake-up time on Sunday	9:00 a.m.
Outdoor temp:	-10 °C (as shown in Figure 27)
Degree up/down	0.5
Energy consumption watts	44 WH
House depth, width	10 m *10 m
Space number	3
Space 1 size	5 m * 5m
Space 2 size	5 m *5m
Space 3 size	5m *10m
Time to prepare(warm the house) in the morning	10 minutes
User vacation	17/1-20/1
Day to simulate	10/1/2011

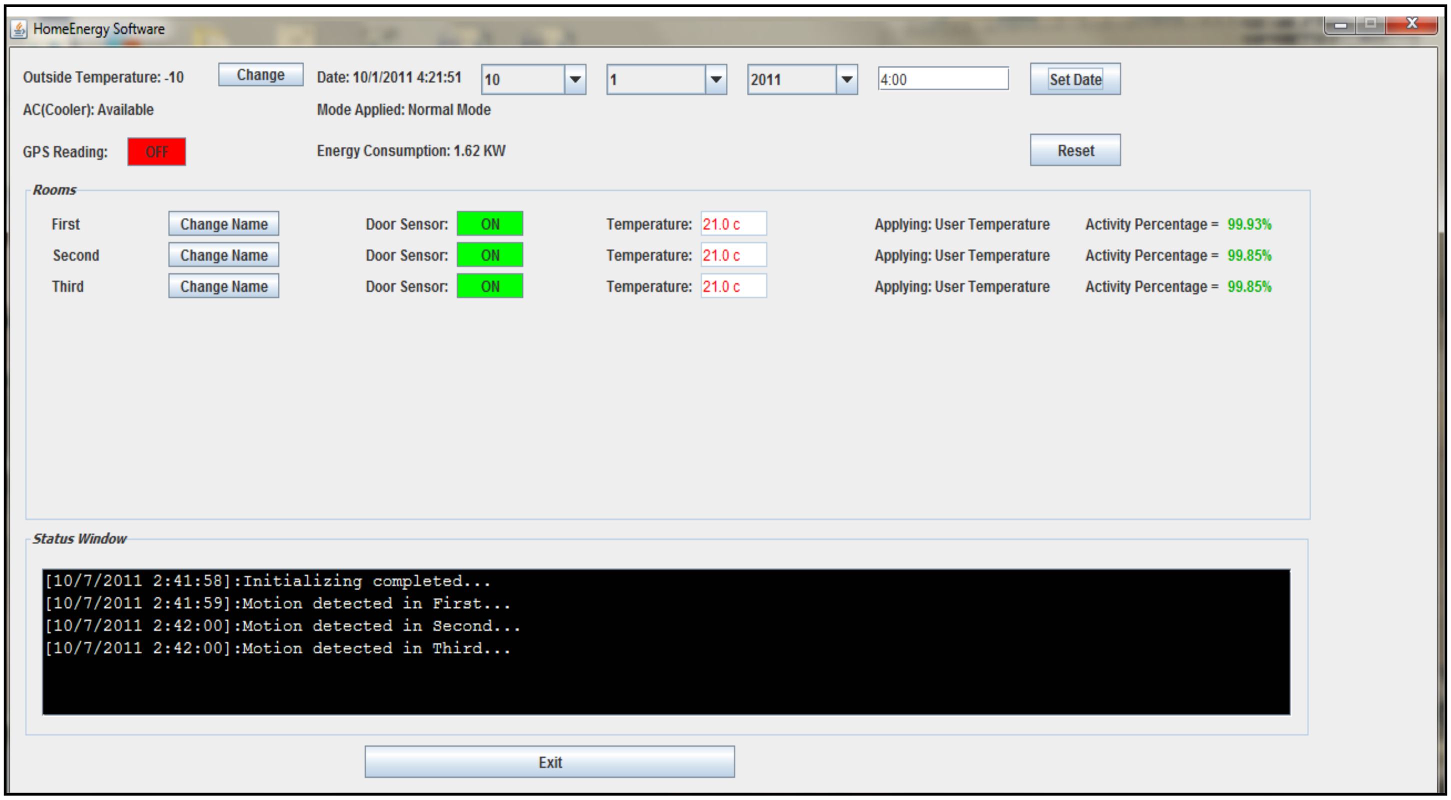
Table 2: input parameters values to case study 1 – January month-

4.4.3. Scenario of the simulation

In the simulation the house is divided into spaces to cover the house's dimensions. In this simulation the house is divided into three spaces. The simulation lasts for 24 hours (one day).

- From 4 a.m. to 6:00 a.m. all spaces door sensors ON
- At 6 a.m. space number 2 door sensor is OFF
- From 8 a.m. to 8 p.m. house empty (all door sensors is OFF)
- From 8 p.m. to 11 pm all spaces door sensors ON
- From 11 a.m. to 4 a.m. space number 2 door sensor is OFF

The following figures demonstrate the simulation of case study 1 for January. Figure 28 shows how the motion is detected in the status window when the door sensor button is pressed. This provides flexibility to simulate the situation when the space door sensor is on (occupied) or off (unoccupied). As a result, this will lead to different decisions from the global agent for each space reading the appropriate indoor temperature. Figures 29-30 show the action when a space has become empty and when a space has a high or low activity percentage. These figures show the decision of the global agent when a space has a high activity percentage, meaning that the space is used often by the occupants. As a result, the global agent will wait- before changing the current temperature- a user returns. Otherwise, the comfort temperature will be applied to the space to save energy. Figure 31 shows the action taken when the house becomes empty. If all of the door sensor statuses are off, the global agent will wait for some time to check that the house is empty and then apply 'save energy temperature' in the house. Finally, figures 32-33 show the action taken when GPS is on. When the house is empty and GPS status switches on, it signifies that at least one user is home. As a result, the global agent will apply normal mode in the house and the following decision will be made: the space(s) with a high activity percentage will trigger user preferred temperature, and the space(s) with a low activity percentage will trigger user comfort temperature.

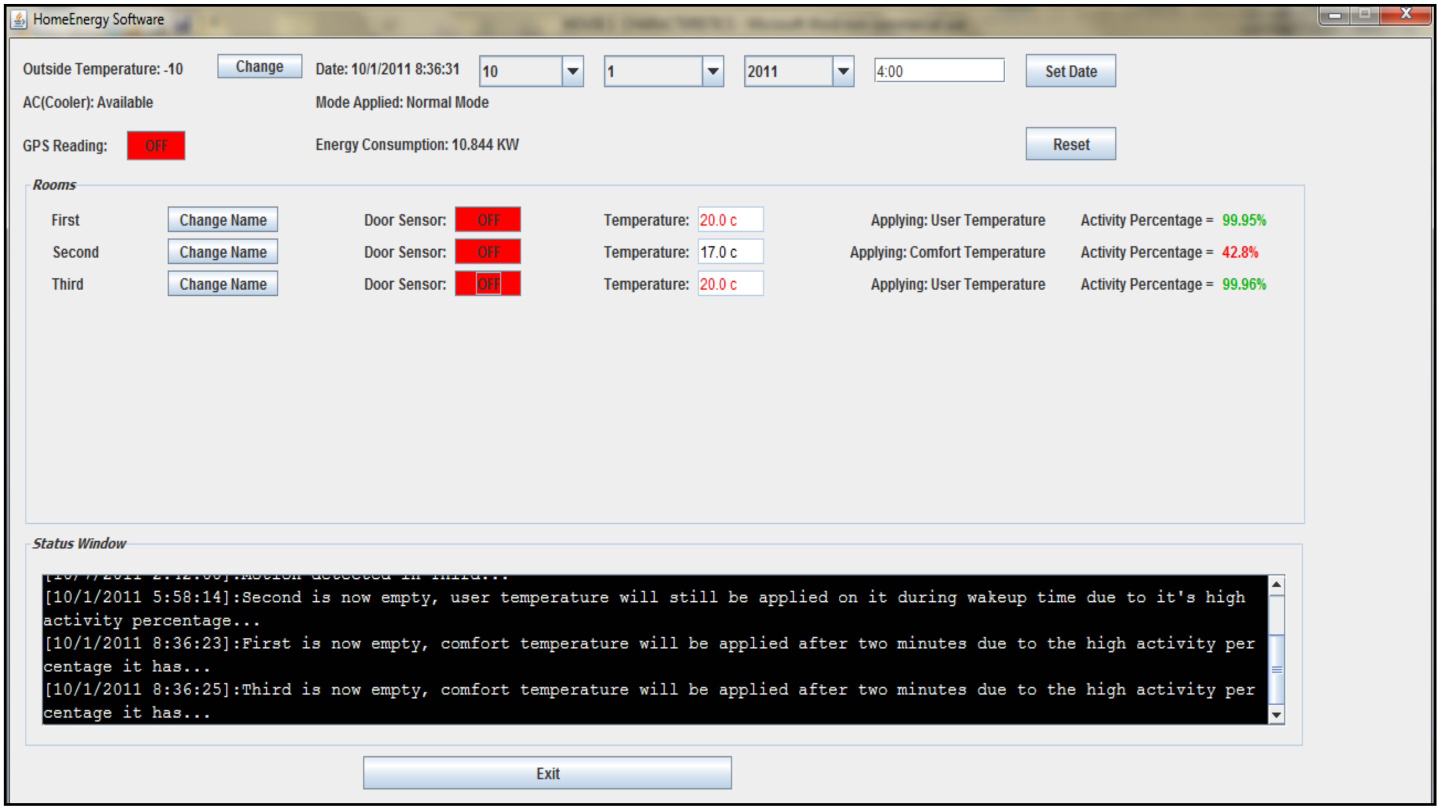


Outside Temperature: -10
Date: 10/1/2011 4:21:51
10 | 1 | 2011 | 4:00
AC(Cooler): Available
Mode Applied: Normal Mode
GPS Reading: OFF
Energy Consumption: 1.62 KW

First	Door Sensor: ON	Temperature: 21.0 c	Applying: User Temperature	Activity Percentage = 99.93%
Second	Door Sensor: ON	Temperature: 21.0 c	Applying: User Temperature	Activity Percentage = 99.85%
Third	Door Sensor: ON	Temperature: 21.0 c	Applying: User Temperature	Activity Percentage = 99.85%

```
[10/7/2011 2:41:58]:Initializing completed...
[10/7/2011 2:41:59]:Motion detected in First...
[10/7/2011 2:42:00]:Motion detected in Second...
[10/7/2011 2:42:00]:Motion detected in Third...
```

Figure 28: screenshot for case 1 simulation (January month simulation) -1- motion detection

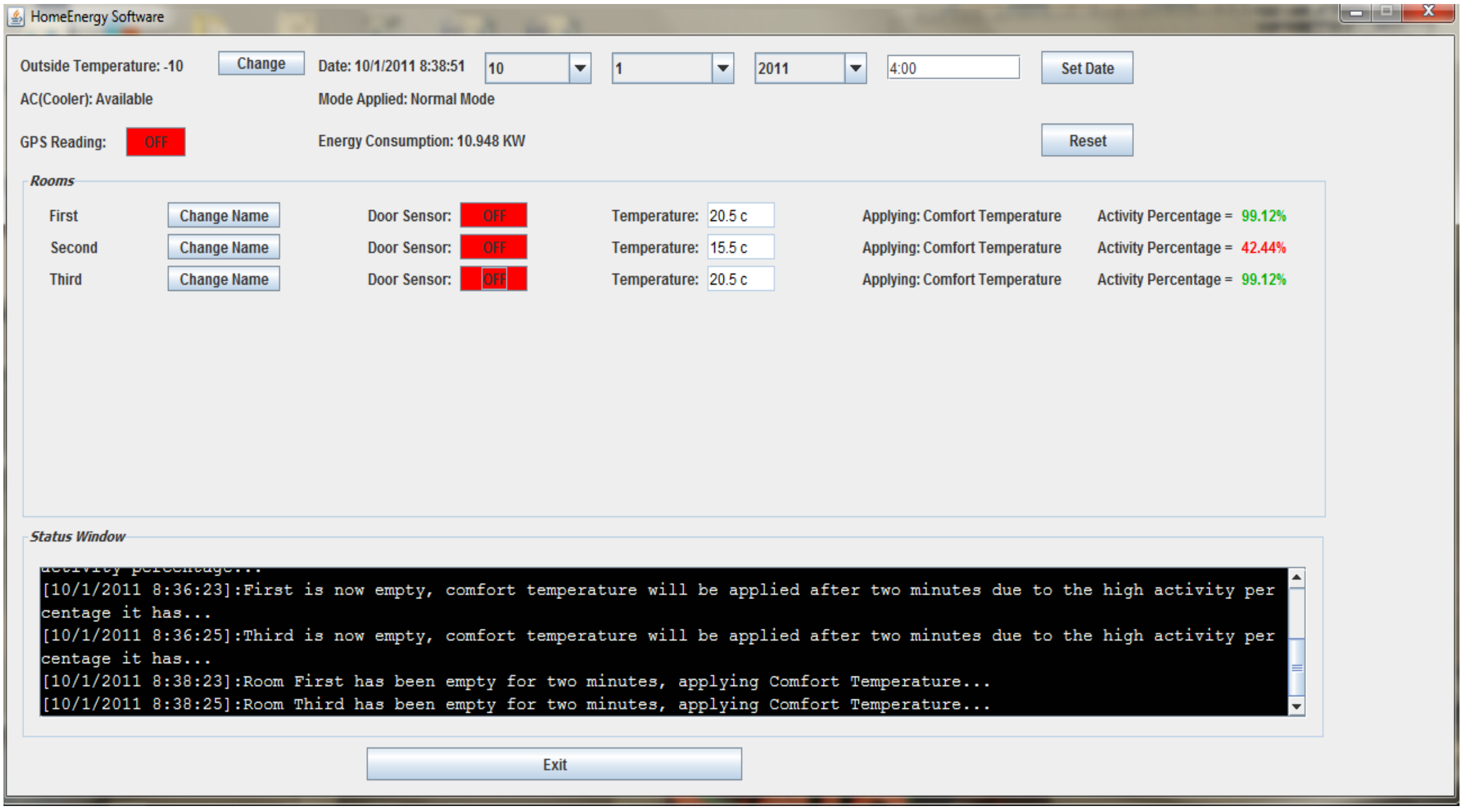


Outside Temperature: -10
Date: 10/1/2011 8:36:31
10 | 1 | 2011 | 4:00
AC(Cooler): Available
Mode Applied: Normal Mode
GPS Reading: OFF
Energy Consumption: 10.844 KW

First	Door Sensor: OFF	Temperature: 20.0 c	Applying: User Temperature	Activity Percentage = 99.95%
Second	Door Sensor: OFF	Temperature: 17.0 c	Applying: Comfort Temperature	Activity Percentage = 42.8%
Third	Door Sensor: OFF	Temperature: 20.0 c	Applying: User Temperature	Activity Percentage = 99.96%

```
[10/1/2011 5:58:14]:Second is now empty, user temperature will still be applied on it during wakeup time due to it's high
activity percentage...
[10/1/2011 8:36:23]:First is now empty, comfort temperature will be applied after two minutes due to the high activity per
centage it has...
[10/1/2011 8:36:25]:Third is now empty, comfort temperature will be applied after two minutes due to the high activity per
centage it has...
```

Figure 29: screenshot of case 1 simulation -2- (January month simulation) a space become empty

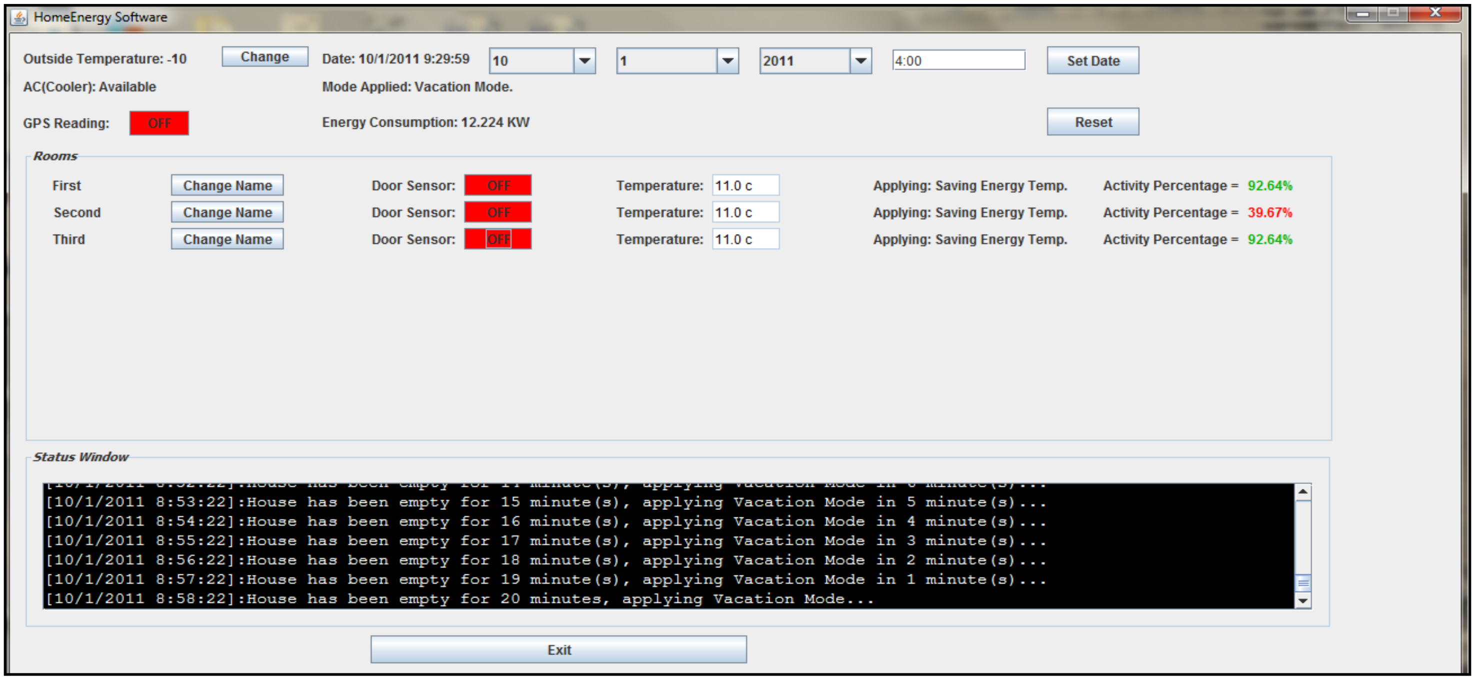


Outside Temperature: -10
Date: 10/1/2011 8:38:51
10
1
2011
4:00
AC(Cooler): Available
Mode Applied: Normal Mode
GPS Reading: OFF
Energy Consumption: 10.948 KW

First	Door Sensor: OFF	Temperature: 20.5 c	Applying: Comfort Temperature	Activity Percentage = 99.12%
Second	Door Sensor: OFF	Temperature: 15.5 c	Applying: Comfort Temperature	Activity Percentage = 42.44%
Third	Door Sensor: OFF	Temperature: 20.5 c	Applying: Comfort Temperature	Activity Percentage = 99.12%

```
[10/1/2011 8:36:23]:First is now empty, comfort temperature will be applied after two minutes due to the high activity per
centage it has...
[10/1/2011 8:36:25]:Third is now empty, comfort temperature will be applied after two minutes due to the high activity per
centage it has...
[10/1/2011 8:38:23]:Room First has been empty for two minutes, applying Comfort Temperature...
[10/1/2011 8:38:25]:Room Third has been empty for two minutes, applying Comfort Temperature...
```

Figure 30: screenshot of case 1 simulation -3- (January month simulation) a space become empty

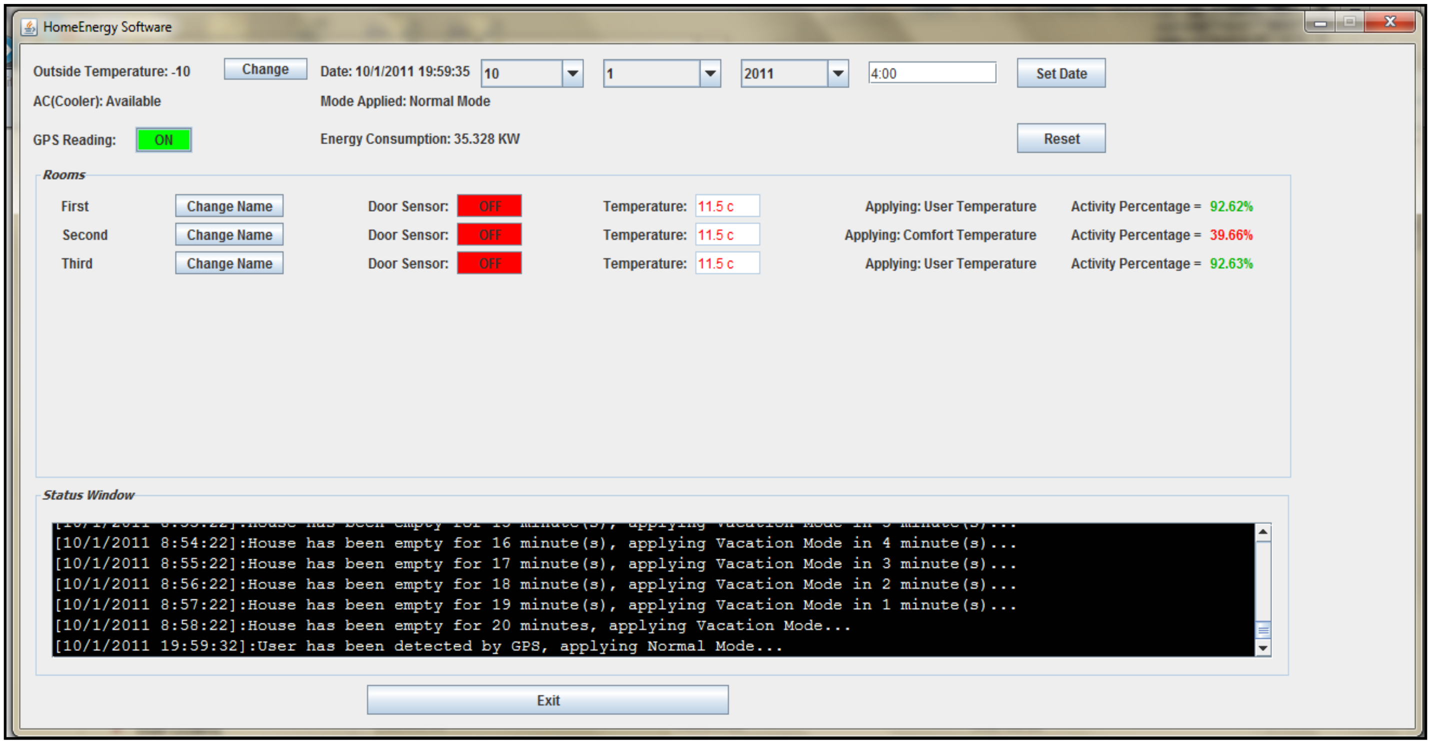


Outside Temperature: -10
Date: 10/1/2011 9:29:59
10
1
2011
4:00
AC(Cooler): Available
Mode Applied: Vacation Mode.
GPS Reading: OFF
Energy Consumption: 12.224 KW

First	Door Sensor: OFF	Temperature: 11.0 c	Applying: Saving Energy Temp.	Activity Percentage = 92.64%
Second	Door Sensor: OFF	Temperature: 11.0 c	Applying: Saving Energy Temp.	Activity Percentage = 39.67%
Third	Door Sensor: OFF	Temperature: 11.0 c	Applying: Saving Energy Temp.	Activity Percentage = 92.64%

```
[10/1/2011 8:53:22]:House has been empty for 15 minute(s), applying Vacation Mode in 5 minute(s)...
[10/1/2011 8:54:22]:House has been empty for 16 minute(s), applying Vacation Mode in 4 minute(s)...
[10/1/2011 8:55:22]:House has been empty for 17 minute(s), applying Vacation Mode in 3 minute(s)...
[10/1/2011 8:56:22]:House has been empty for 18 minute(s), applying Vacation Mode in 2 minute(s)...
[10/1/2011 8:57:22]:House has been empty for 19 minute(s), applying Vacation Mode in 1 minute(s)...
[10/1/2011 8:58:22]:House has been empty for 20 minutes, applying Vacation Mode...
```

Figure 31: screenshot shot of case 1 simulation -4-(January month simulation) the house become empty



Outside Temperature: -10

Date: 10/1/2011 19:59:35 | 10 | 1 | 2011 | 4:00

AC(Cooler): Available

Mode Applied: Normal Mode

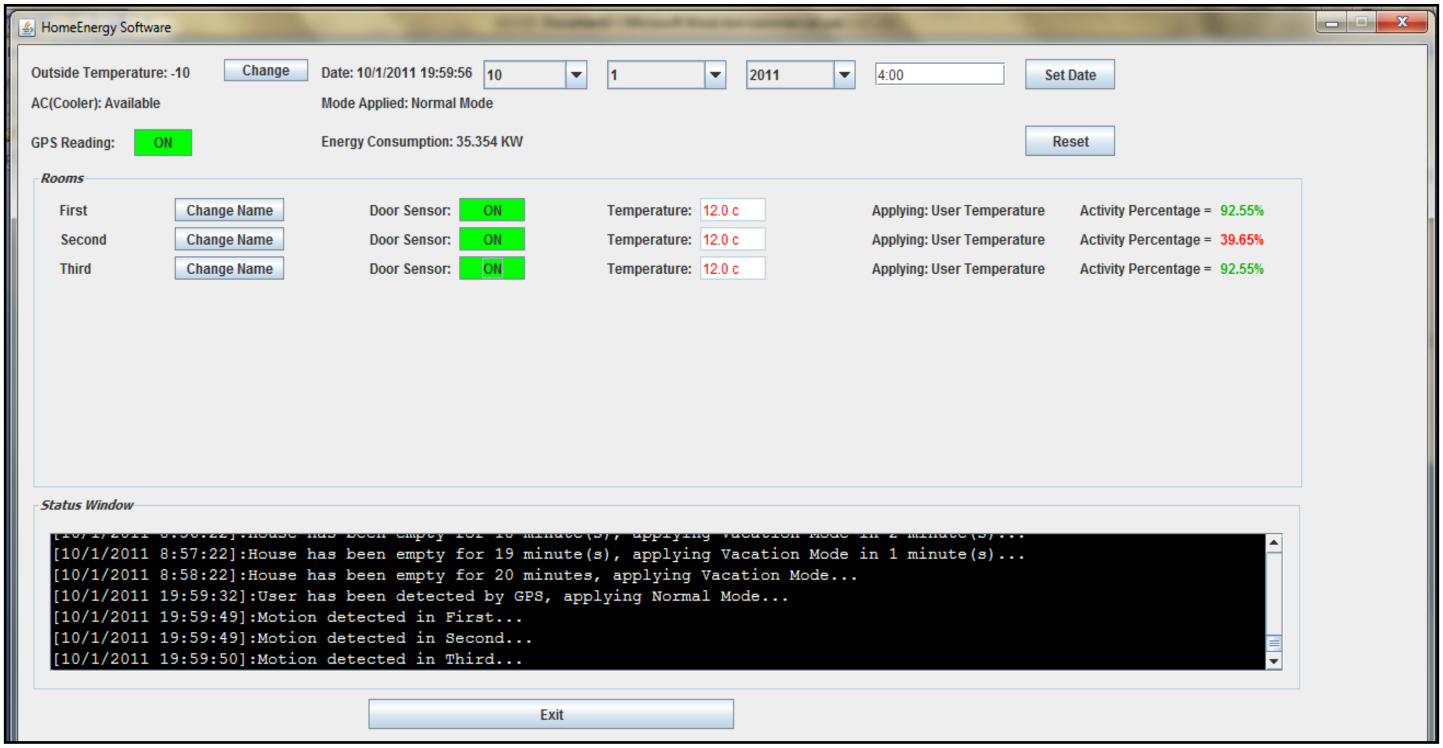
GPS Reading: ON

Energy Consumption: 35.328 KW

First	Door Sensor: OFF	Temperature: 11.5 c	Applying: User Temperature	Activity Percentage = 92.62%
Second	Door Sensor: OFF	Temperature: 11.5 c	Applying: Comfort Temperature	Activity Percentage = 39.66%
Third	Door Sensor: OFF	Temperature: 11.5 c	Applying: User Temperature	Activity Percentage = 92.63%

```
[10/1/2011 8:54:22]:House has been empty for 16 minute(s), applying Vacation Mode in 4 minute(s)...
[10/1/2011 8:55:22]:House has been empty for 17 minute(s), applying Vacation Mode in 3 minute(s)...
[10/1/2011 8:56:22]:House has been empty for 18 minute(s), applying Vacation Mode in 2 minute(s)...
[10/1/2011 8:57:22]:House has been empty for 19 minute(s), applying Vacation Mode in 1 minute(s)...
[10/1/2011 8:58:22]:House has been empty for 20 minutes, applying Vacation Mode...
[10/1/2011 19:59:32]:User has been detected by GPS, applying Normal Mode...
```

Figure 32: screenshot shot of case 1 simulation -5-(January month simulation) GPS detection



Outside Temperature: -10

Date: 10/1/2011 19:59:56 | 10 | 1 | 2011 | 4:00

AC(Cooler): Available

Mode Applied: Normal Mode

GPS Reading: ON

Energy Consumption: 35.354 KW

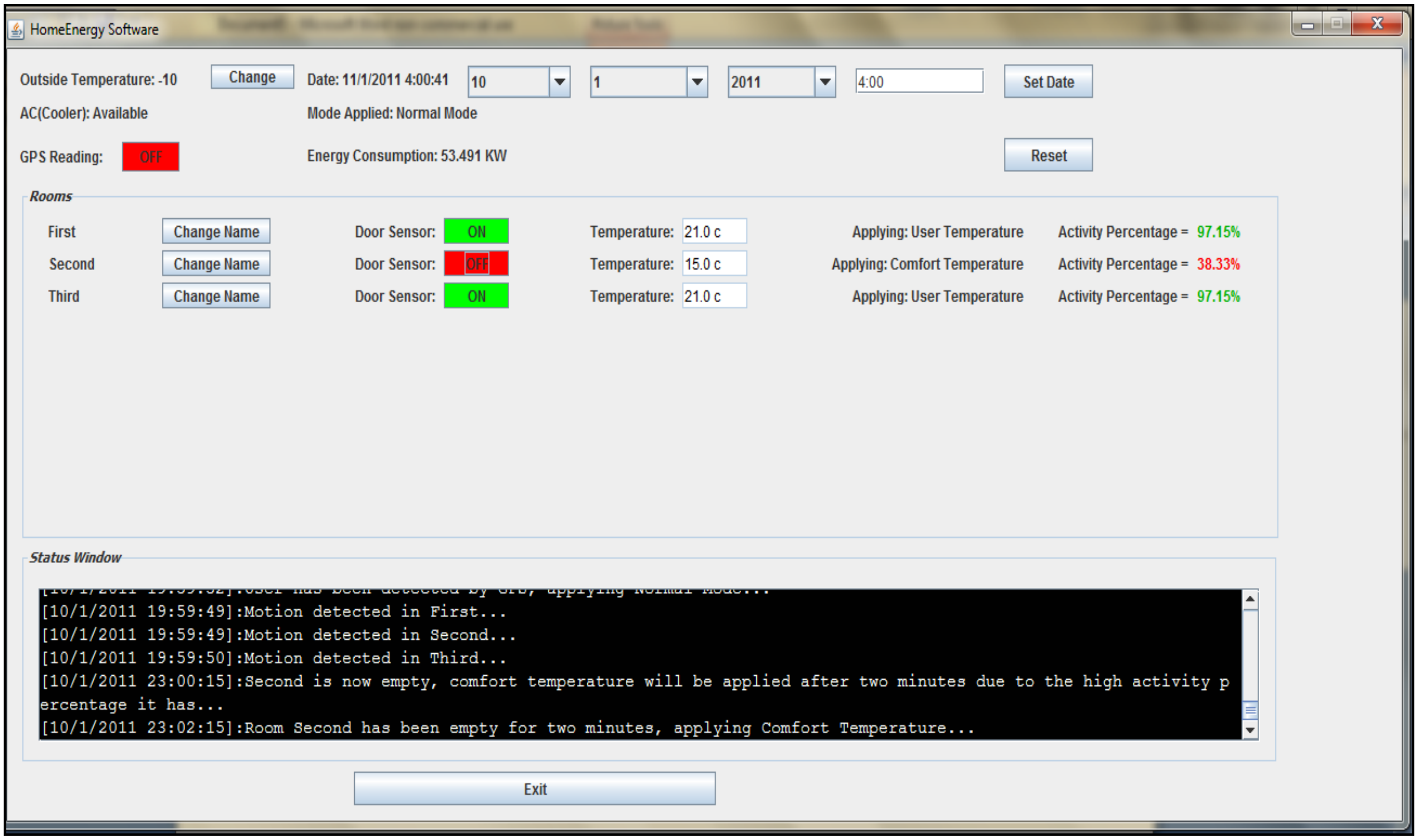
First	Door Sensor: ON	Temperature: 12.0 c	Applying: User Temperature	Activity Percentage = 92.55%
Second	Door Sensor: ON	Temperature: 12.0 c	Applying: User Temperature	Activity Percentage = 39.65%
Third	Door Sensor: ON	Temperature: 12.0 c	Applying: User Temperature	Activity Percentage = 92.55%

```
[10/1/2011 8:57:22]:House has been empty for 19 minute(s), applying Vacation Mode in 1 minute(s)...
[10/1/2011 8:58:22]:House has been empty for 20 minutes, applying Vacation Mode...
[10/1/2011 19:59:32]:User has been detected by GPS, applying Normal Mode...
[10/1/2011 19:59:49]:Motion detected in First...
[10/1/2011 19:59:49]:Motion detected in Second...
[10/1/2011 19:59:50]:Motion detected in Third...
```

Figure 33: screenshot shot of case 1 simulation -6-(January month simulation) GPS detection

4.4.4. Result and Evaluation

After 24 hours of simulation the energy consumption = 54 Kwh/ day as shown in figure 34.



Outside Temperature: -10

AC(Cooler): Available

GPS Reading: OFF

Date: 11/1/2011 4:00:41 | 10 | 1 | 2011 | 4:00

Mode Applied: Normal Mode

Energy Consumption: 53.491 KW

First — Door Sensor: ON — Temperature: 21.0 c — Applying: User Temperature — Activity Percentage = 97.15%

Second — Door Sensor: OFF — Temperature: 15.0 c — Applying: Comfort Temperature — Activity Percentage = 38.33%

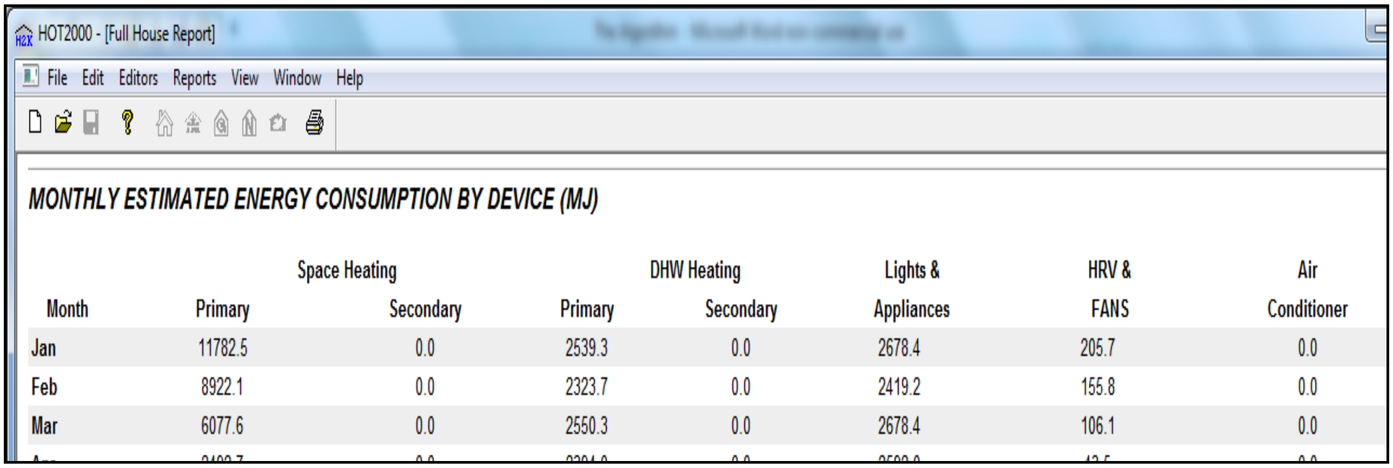
Third — Door Sensor: ON — Temperature: 21.0 c — Applying: User Temperature — Activity Percentage = 97.15%

```
[10/1/2011 19:59:49]:Motion detected in First...
[10/1/2011 19:59:49]:Motion detected in Second...
[10/1/2011 19:59:50]:Motion detected in Third...
[10/1/2011 23:00:15]:Second is now empty, comfort temperature will be applied after two minutes due to the high activity p
ercentage it has...
[10/1/2011 23:02:15]:Room Second has been empty for two minutes, applying Comfort Temperature...
```

Figure 34: screenshot shot result case study 1 (January month simulation)

- The energy consumption for a month = energy consumption for a day * month's day= 54*31= 1647 Kwh
- Converter The energy consumption for a month to (MJ) = 1647* 3.6= 6026.4 MJ (according to equation (2))

To calculate January energy cost for our proposed algorithm, the following steps and considerations were taken: in HOT2000 the designers considered natural gas to heat the house and for DWH (Domestic Water Heating). Therefore, according to HOT2000, the equation to calculate the cost is: energy cost (4) =((□□□□□□ □□□□□□□□□□+□□□)/38)*0.5338 . Figure 35 shows the value for DWH for January from HOT2000.



MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

Month	Space Heating Primary	Space Heating Secondary	DHW Heating Primary	DHW Heating Secondary	Lights & Appliances	HRV & FANS	Air Conditioner
Jan	11782.5	0.0	2539.3	0.0	2678.4	205.7	0.0
Feb	8922.1	0.0	2323.7	0.0	2419.2	155.8	0.0
Mar	6077.6	0.0	2550.3	0.0	2678.4	106.1	0.0

Figure 35: screenshot shot from HOT2000 for monthly energy consumption for case study 1

Proposed Algorithm energy cost

- Energy cost for January = according to energy Cost equation :

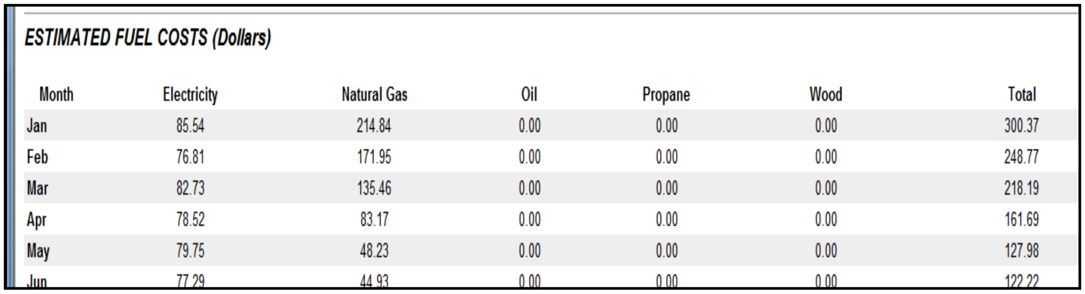
=((□□□□□□ □□□□□□□□□□□+□□□)/38)*0.5338

6026.4 + 2539.3= 8565.7/ 38= 225.4 MJ

225.4* 0.5338 =$ 120.3

HOT2000 energy Cost

- Energy consumption for January = 11782.5 MJ as shown in figure 26.
- Energy cost according to equation number (4) = ((11782.5 + 2539.3 /38) * 0.5338= $201. Figure 36 shows the estimated fuel cost in January for HOT2000.



ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	85.54	214.84	0.00	0.00	0.00	300.37
Feb	76.81	171.95	0.00	0.00	0.00	248.77
Mar	82.73	135.46	0.00	0.00	0.00	218.19
Apr	78.52	83.17	0.00	0.00	0.00	161.69
May	79.75	48.23	0.00	0.00	0.00	127.98
Jun	77.29	44.93	0.00	0.00	0.00	122.22

Figure 36: screenshot shot of HOT2000 for fuel cost for case study 1- January month-

Calculation for energy saving for our proposed system compared to HOT2000

Energy saving $^{(5)}$ = (HOT2000 energy consumption – our proposed system energy consumption) / HOT2000 energy consumption) * 100

Energy saving = ((11782.5 - 6026.4) / 11782.5) * 100 = 50 %

We compared the simulation results obtained from our implementation to the one obtained through the use of HOT2000 as can be seen in Figures 37 and 38. The following charts compare the energy consumption and energy cost for January between the proposed system and HOT2000. Figure 37 shows the energy consumption for January: the proposed system energy consumption is around 6026.4 MJ, and HOT2000 energy consumption is 11783.5 MJ. This means that the proposed system saved 50% of energy consumption in January. Figure 38 shows the January cost for heating the house: the proposed system energy cost totalled $120, versus HOT2000 at $201. This means the proposed system decreases the cost by 40% ($ 81) compared to HOT2000.

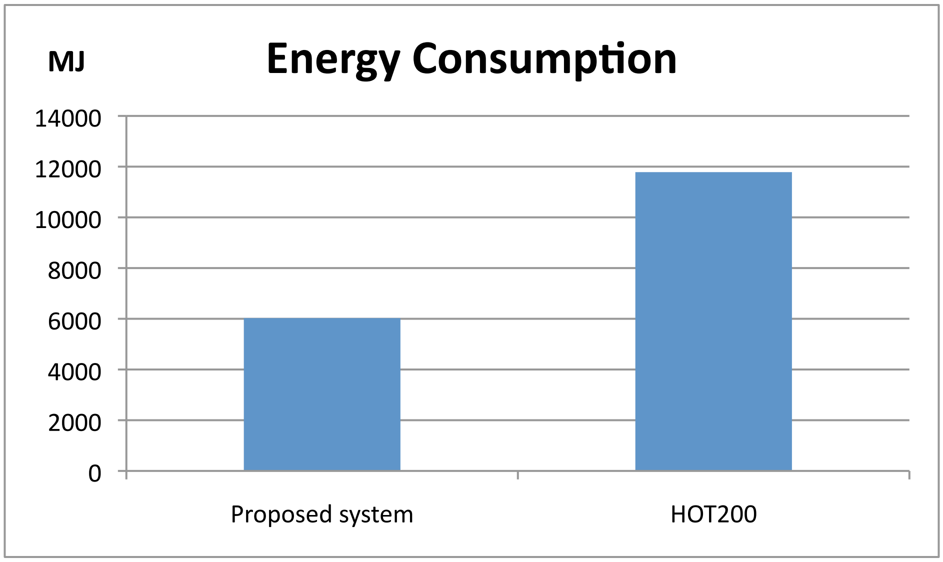


Figure 37: energy consumption comparison case study 1- January month-

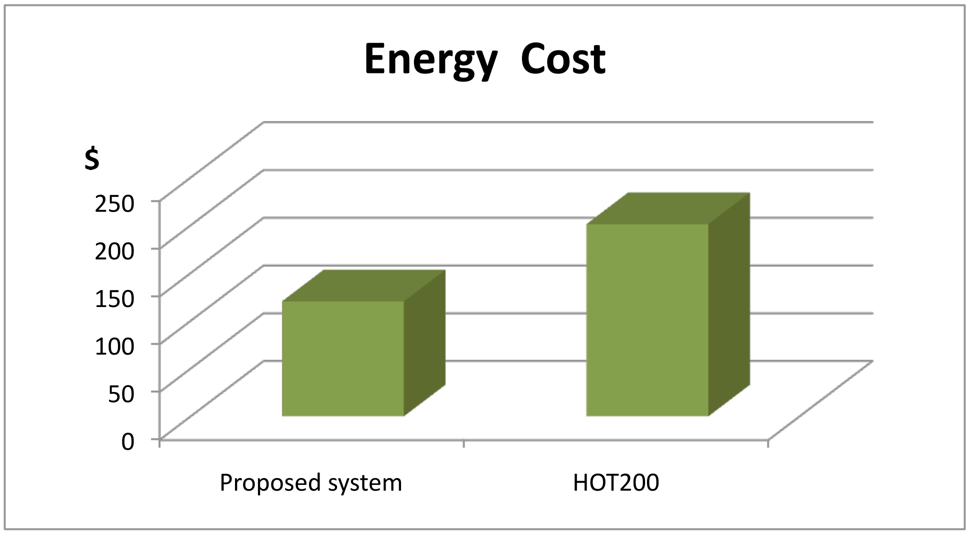


Figure 38: Energy cost comparison case study 1 - January month-

4.5. Simulation2 for February month to calculate and compare energy consumption and cost with HOT2000

Case Study 2: February month

4.5.1. House characteristic (HOT2000)

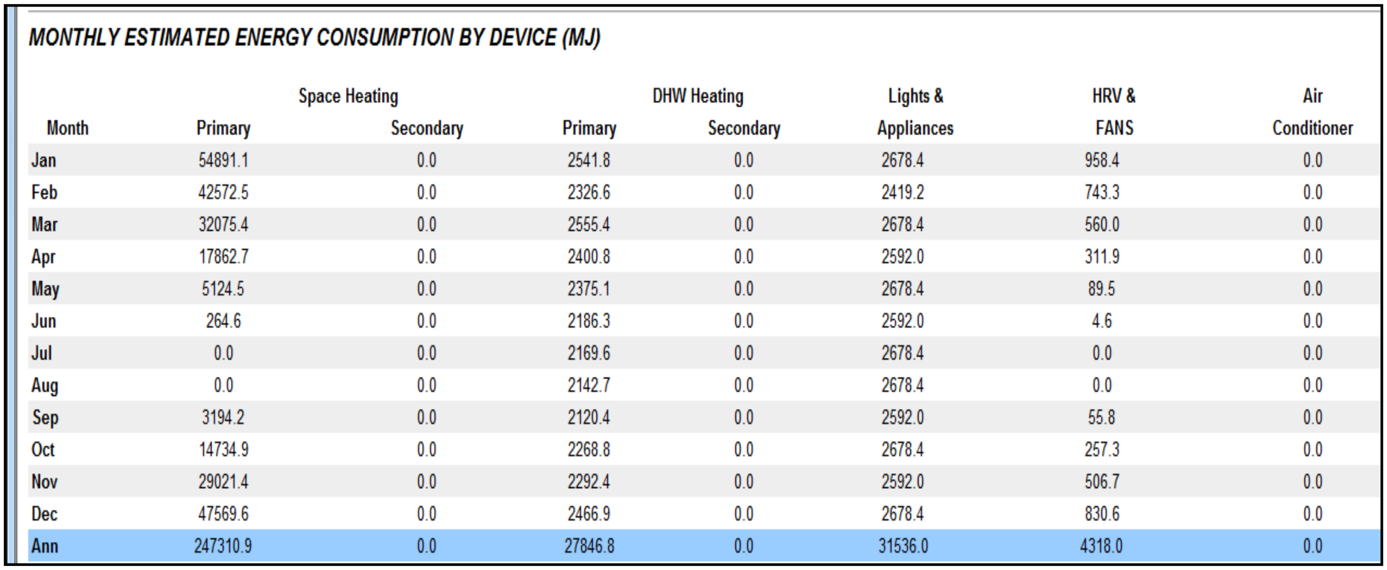
- House type: Single Detached
- Number of storeys: 2
- House dimensions (width, depth) = 20 m*20 m

Occupants

- 2 Adults for 50.0% of the time
- 2 Children for 50.0% of the time

Calculation for watts consumption

HOT2000 monthly estimated energy consumption for February = 42572.5 MJ Figure 39 shows the monthly estimated energy consumption for February.



MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

Month	Space Heating		DHW Heating		Lights & Appliances	HRV & FANS	Air Conditioner
	Primary	Secondary	Primary	Secondary			
Jan	54891.1	0.0	2541.8	0.0	2678.4	958.4	0.0
Feb	42572.5	0.0	2326.6	0.0	2419.2	743.3	0.0
Mar	32075.4	0.0	2555.4	0.0	2678.4	560.0	0.0
Apr	17862.7	0.0	2400.8	0.0	2592.0	311.9	0.0
May	5124.5	0.0	2375.1	0.0	2678.4	89.5	0.0
Jun	264.6	0.0	2186.3	0.0	2592.0	4.6	0.0
Jul	0.0	0.0	2169.6	0.0	2678.4	0.0	0.0
Aug	0.0	0.0	2142.7	0.0	2678.4	0.0	0.0
Sep	3194.2	0.0	2120.4	0.0	2592.0	55.8	0.0
Oct	14734.9	0.0	2268.8	0.0	2678.4	257.3	0.0
Nov	29021.4	0.0	2292.4	0.0	2592.0	506.7	0.0
Dec	47569.6	0.0	2466.9	0.0	2678.4	830.6	0.0
Ann	247310.9	0.0	27846.8	0.0	31536.0	4318.0	0.0

Figure 39: Screenshot shot from HOT2000 shows February monthly estimated energy consumption

- Convert HOT2000 monthly estimated energy consumption to Kwh = 42572.5 * 0.278 = 11825.69 KWh (according to equation (1)).
- Calculate the energy consumption (Kwh) for 1 m^2 (/400) = 11825.69 /400= 29.56 Kwh. (divided by 400 because the house dimension is 20 m * 20 m. So we can get the energy required for $1m^2$).
- Calculate the energy consumption (Kwh) for one day (/28) = 29.56 /28= 1.055865575396786 Kwh. (since February has 28 days, so we dived the result by 28 to get the energy required for one day).
- Calculate the energy consumption (Kwh) for one hour (/24) = 1.056/24= 0.044 Kwh. (since the day is 24 hour, so we dived the result by 24 to get the energy required for one hour)
- Convert the energy consumption (Kwh) to WH= 0.044*100= 44 WH.
  (According to equation (3))
- As a result the energy required for the heating system = 44 WH.

4.5.2. Input to the program

Maximum preferred temperature	24 °C
Minimum preferred temperature	23 °C
Maximum comfort temperature	35 °C
Minimum comfort temperature	15 °C
Wake up time during the weekday	6:00 a.m.
Wake up time on Saturday	8:00 a.m.
Wake up time on Sunday	9:00 a.m.
Outdoor temp	-8 °C
Degree up/down	0.5
energy consumption watts	44 WH
House depth, width	20 m *20 m
Space number	4
Space 1 size	10 m *10 m
Space 2 size	10 m *10 m
Space 3 size	10 m *10 m
Space 4 size	10 m *10m
Time to prepare(warm the house) in the morning	10 minutes
User vacation	26/2-28/2
Day to simulate	14/2/2011

Table 3: input values for case study 2- February month-

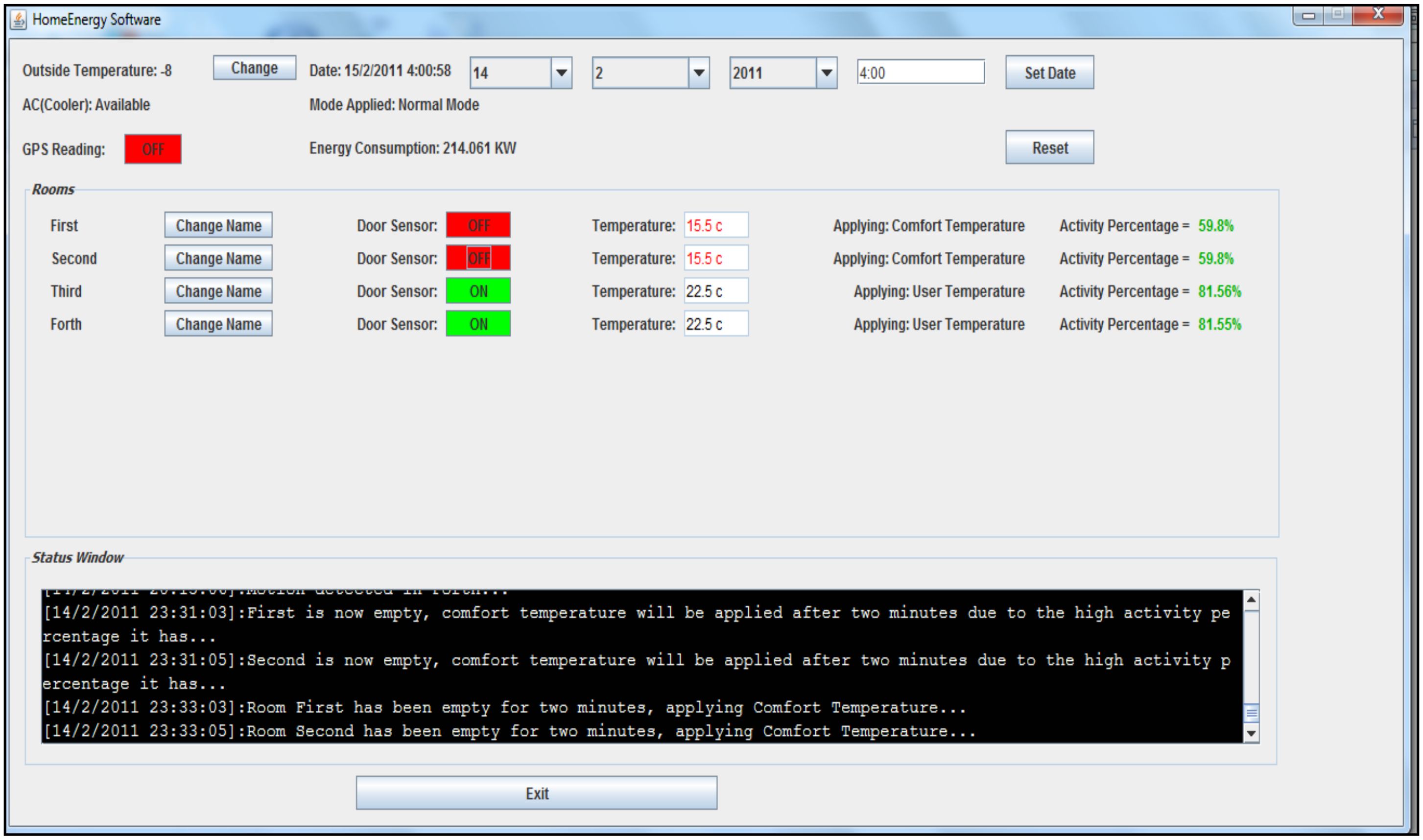
4.5.3. Scenario of the simulation

In the simulation, the house is divided into spaces to cover all dimensions of the home. In this simulation, the house was divided into four spaces. The simulation lasted for 24 hours (one day).

- From 4a.m. to 6:00 a.m. all space door sensors ON
  - At 6 a.m. space number (3,4) door sensor is OFF
  - From 8 a.m. to 8 p.m. house empty (all door sensors is OFF)
  - From 8 p.m. to 11 pm all spaces door sensors ON
  - From 11 a.m. to 4 a.m. space (1,2) door sensor is OFF

4.5.4. Result and Evaluation

After 24 hours of simulation the energy consumption = 214.061 Kwh/ day as shown in figure 40.



Outside Temperature: -8

Date: 15/2/2011 4:00:58 | 14 | 2 | 2011 | 4:00

AC(Cooler): Available

Mode Applied: Normal Mode

GPS Reading: OFF

Energy Consumption: 214.061 KW

First — Door Sensor: OFF — Temperature: 15.5 c — Applying: Comfort Temperature — Activity Percentage = 59.8%

Second — Door Sensor: OFF — Temperature: 15.5 c — Applying: Comfort Temperature — Activity Percentage = 59.8%

Third — Door Sensor: ON — Temperature: 22.5 c — Applying: User Temperature — Activity Percentage = 81.56%

Forth — Door Sensor: ON — Temperature: 22.5 c — Applying: User Temperature — Activity Percentage = 81.55%

```
[14/2/2011 23:31:03]:First is now empty, comfort temperature will be applied after two minutes due to the high activity pe
rcentage it has...
[14/2/2011 23:31:05]:Second is now empty, comfort temperature will be applied after two minutes due to the high activity p
ercentage it has...
[14/2/2011 23:33:03]:Room First has been empty for two minutes, applying Comfort Temperature...
[14/2/2011 23:33:05]:Room Second has been empty for two minutes, applying Comfort Temperature...
```

Figure 40: Case study 2 result – February month-

- The energy consumption for a Month = energy consumption for a day * month's day=214.061 *28 = 5993.71 KWh
- Converter the energy consumption for a month to (MJ) = 5993.71 *3.6= 21577.35 MJ. (according to equation (2))

To calculate February energy cost for our proposed algorithm, the following steps and considerations were taken: in HOT2000 the designers considered natural gas to heat the house and for DWH (Domestic Water Heating). Therefore, according to HOT2000, the equation to calculate the cost is: Energy cost $^{(4)}$ =((□□□□□□ □□□□□□□□□□□□+□□□)/38)*0.5338 . Figure 40 shows the value for DWH for February.

Proposed Algorithm energy cost

Energy cost for February = according to energy cost equation (4):

*=((⍰⍰⍰⍰⍰⍰ ⍰⍰⍰⍰⍰⍰⍰⍰⍰⍰⍰+⍰⍰⍰)/38)*0.5338*

= (21577.3488 + 2326.6) /38)*0.5338=$ 335.8

HOT2000 energy Cost

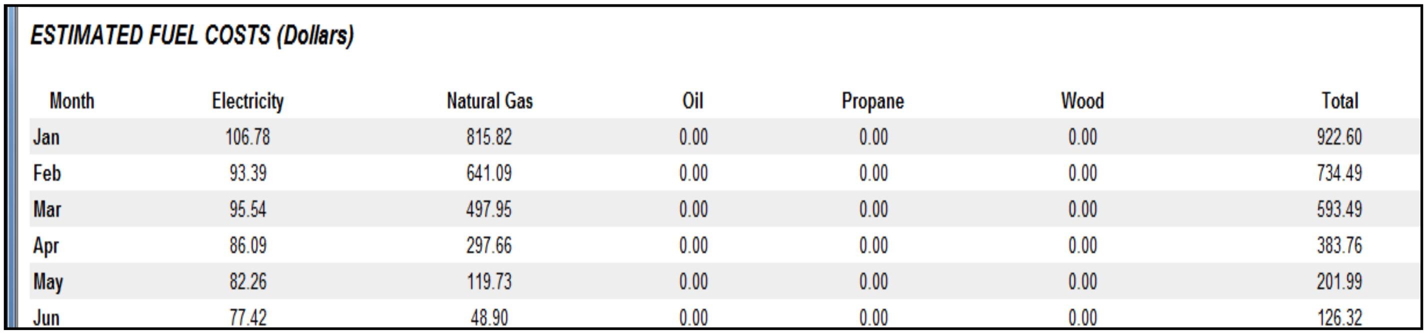
- Energy consumption for February = 42572.5 MJ

Energy Cost according to equation number (4) = ((42572.5 + 2326.6 / 38))* 0.5338 = $630.7. Figure 41 shows the estimated natural gas cost in February.

Calculation for energy saving for our proposed system compared to HOT2000

Energy saving (5) = (HOT2000 energy consumption – our proposed system energy consumption) / HOT2000 energy consumption) * 100

Energy saving = ((42572.5 - 21577.3488) / 42572.5)*100 = 49.32 %



ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	106.78	815.82	0.00	0.00	0.00	922.60
Feb	93.39	641.09	0.00	0.00	0.00	734.49
Mar	95.54	497.95	0.00	0.00	0.00	593.49
Apr	86.09	297.66	0.00	0.00	0.00	383.76
May	82.26	119.73	0.00	0.00	0.00	201.99
Jun	77.42	48.90	0.00	0.00	0.00	126.32

Figure 41: Estimated fuel cost from HOT2000 for case study 2 – February month-

We compared the simulation results obtained from our implementation to the one obtained through the use of HOT2000, as can be seen in Figures 42 and 43 .The following charts compare the energy consumption and energy cost for February between the proposed system and HOT2000. Figure 42 shows the energy consumption for February: the proposed system energy consumption is approximately 21577MJ, and HOT2000 is 42572.5 MJ. This means that the proposed system saved 49% of energy consumption in February. Figure 43 shows February's cost of heating the house: the proposed system was $336, and HOT2000 was

$631. This means that the proposed system decreased the cost by 47% ($ 295) compared to HOT2000.

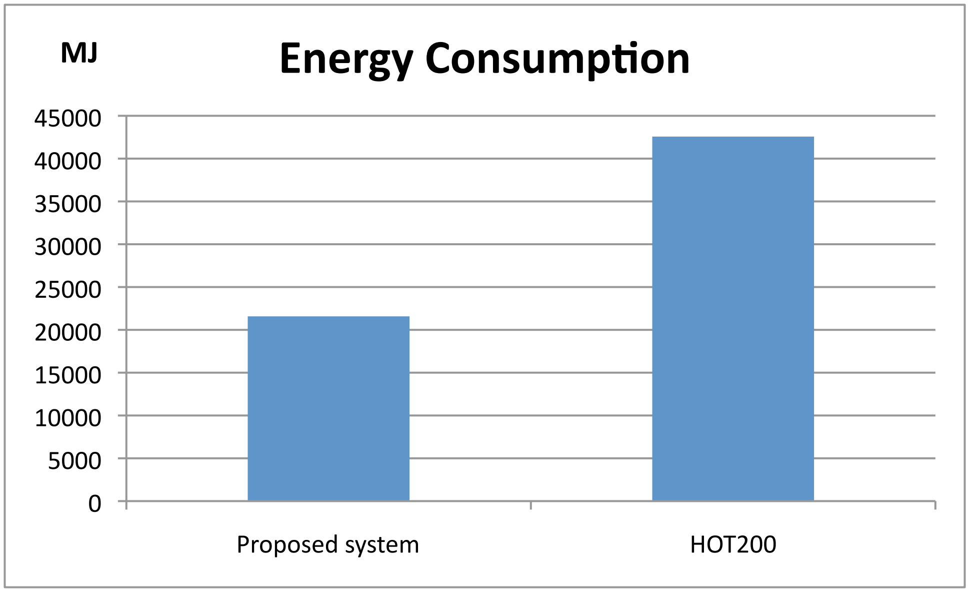


Figure 42: energy consumption comparison for case study 2 – February month-

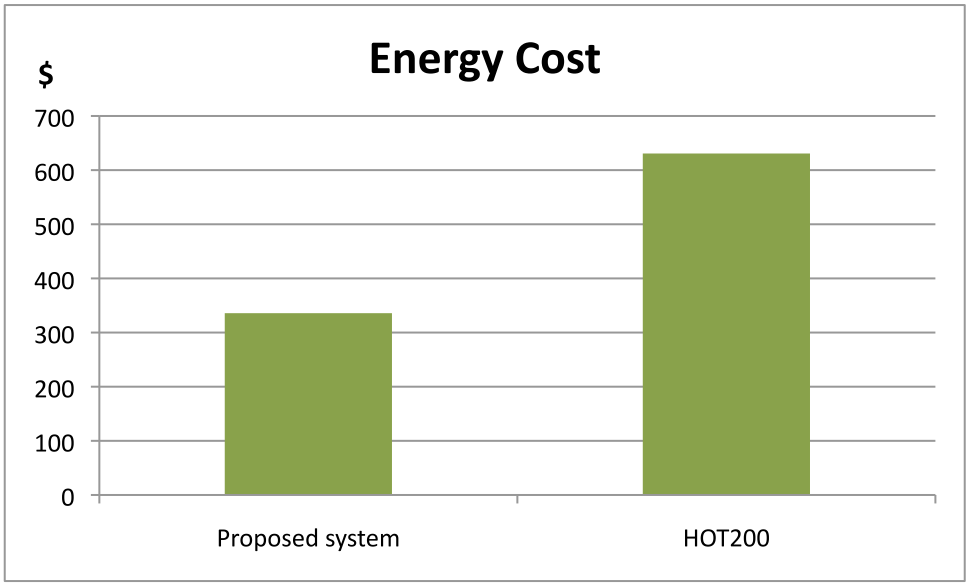


Figure 43: Energy cost comparison for case study 2 – February month-

4.6. Simulation3 for July month to calculate and compare energy consumption and cost with HOT2000

Case Study3: July month

4.6.1. House characteristic (HOT2000)

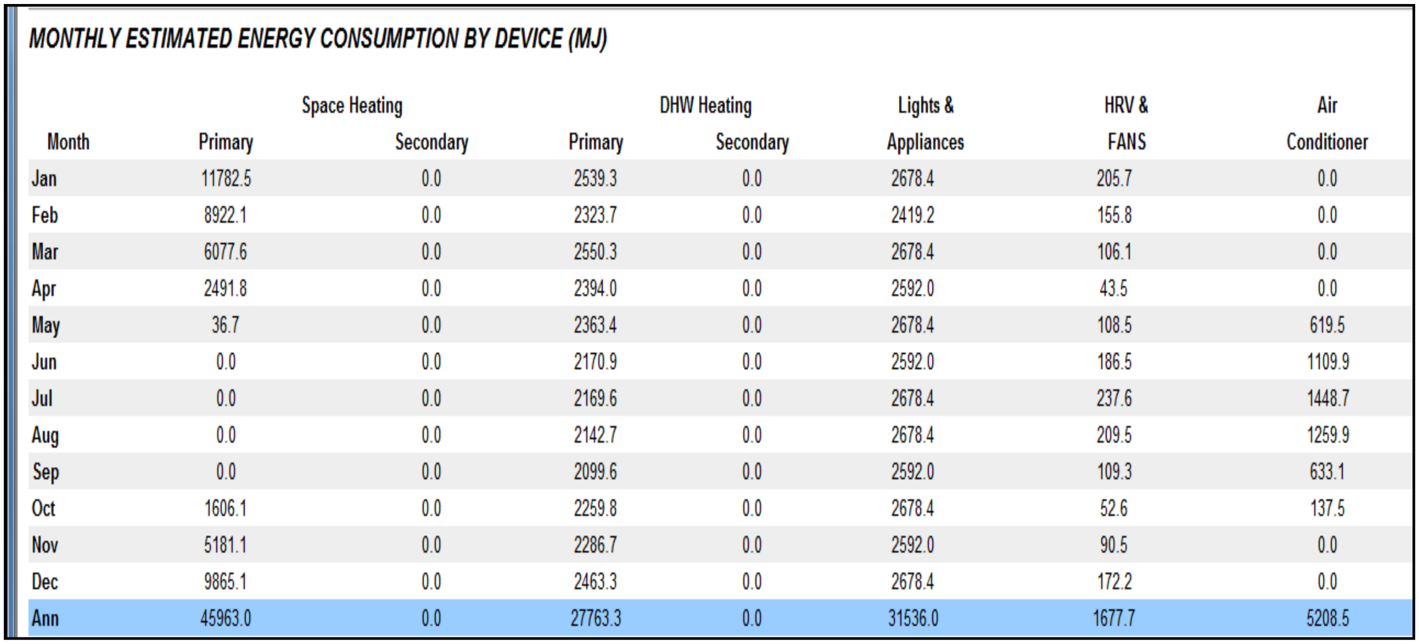
- House type: Row, middle unit
- Number of storeys: 2
- House dimensions (width, depth) = 10*10

Occupants:

- 2 Adults for 50.0% of the time
- 2 Children for 50.0% of the time

Calculation for watts consumption

Monthly estimated energy consumption (MJ) for July (HOT2000) = 1448.7 MJ. Figure 44 shows the monthly estimated energy consumption for July.



MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

	Space Heating		DHW Heating		Lights &	HRV &	Air
Month	Primary	Secondary	Primary	Secondary	Appliances	FANS	Conditioner
Jan	11782.5	0.0	2539.3	0.0	2678.4	205.7	0.0
Feb	8922.1	0.0	2323.7	0.0	2419.2	155.8	0.0
Mar	6077.6	0.0	2550.3	0.0	2678.4	106.1	0.0
Apr	2491.8	0.0	2394.0	0.0	2592.0	43.5	0.0
May	36.7	0.0	2363.4	0.0	2678.4	108.5	619.5
Jun	0.0	0.0	2170.9	0.0	2592.0	186.5	1109.9
Jul	0.0	0.0	2169.6	0.0	2678.4	237.6	1448.7
Aug	0.0	0.0	2142.7	0.0	2678.4	209.5	1259.9
Sep	0.0	0.0	2099.6	0.0	2592.0	109.3	633.1
Oct	1606.1	0.0	2259.8	0.0	2678.4	52.6	137.5
Nov	5181.1	0.0	2286.7	0.0	2592.0	90.5	0.0
Dec	9865.1	0.0	2463.3	0.0	2678.4	172.2	0.0
Ann	45963.0	0.0	27763.3	0.0	31536.0	1677.7	5208.5

Figure 44: Monthly Estimated energy consumption for case study 3 from HOT2000

- Convert HOT2000 monthly estimated energy consumption to Kwh = 1448.7 * 0.278 = 402.42 KWh (according to equation (1)).
- Calculate the energy consumption (Kwh) for 1 m^2 (/100) = 402.42 /100= 4.02Kwh. (Divided by 100 because the house dimension is 10m * 10m m. So we can get the energy required for $1m^2$).
- Calculate the energy consumption (Kwh) for one day (/31) = 4.02/31= 0.129 Kwh. (since July has 31 days, so we dived the result by 31 to get the energy required for one day).
- Calculate the energy consumption (Kwh) for one hour (/24) = 0.129 /24= 0.0054 Kwh since the day is 24 hour, so we dived the result by 24 to get the energy required for one hour)

  Convert the energy consumption (Kwh) to WH= 0.0054*100= 5.4 WH (according to equation (3))
  - As a result the energy required for the cooling system = 5.4 WH

4.6.2. Input to the program

Maximum preferred temperature	19 °C
Minimum preferred temperature	16 °C
Maximum comfort temperature	35 °C
Minimum comfort temperature	15 °C
Wake up time during the weekday	6:00 a.m.
Wake up time on Saturday	8:00 a.m.
Wake up time on Sunday	9:00 a.m.
Outdoor temp	20 °C
Degree up/down	0.5
Energy consumption watts	5.4 WH
House depth, width	10 m *10 m
Space number	3
Space 1 size	5 m *5 m
Space 2 size	5 m *5 m
Space 3 size	5 m *10 m
Time to prepare user temperature in the morning	10 minutes

Day to simulate	28/7/2011

Table 4: input values for case study 3 – July month-

4.6.3. Scenario of the simulation

In the simulation, the house was divided into spaces to cover the house's dimensions. In this simulation the house was divided into three spaces. The simulation lasted for 24 hours (one day).

- From 4 a.m. to 6 a.m. all space door sensors ON
- At 6 a.m. space number(3)door sensor is OFF
- From 8 a.m. to 8 p.m. house empty (all door sensors OFF)
- From 8 p.m. to 11 p.m. all space door sensors ON
- From 11 a.m. to 4 a.m. space (1) door sensor is OFF

4.6.4. Result and Evaluation

- After 24 hours of simulation the energy consumption = 2.9 KWh/day
- The energy consumption for a month = energy consumption for a day * month's day= 2.9* 31 = 89.9 KWh
- Converter The energy consumption for a month to (MJ) = 89.9* 3.6= 323.64 MJ/month (according to equation (2))
- HOT2000 energy consumption in July = 1448.7 MJ

Calculation for energy saving comparing to HOT2000

Energy saving (5) = (HOT2000 energy consumption – our proposed system energy consumption) / HOT2000 energy consumption) * 100

Energy saving = ((1448.7 - 323.64)/ 1448.7) * 100 = 77%

To calculate the energy consumption cost, HOT2000 used electricity for air conditioner, lighting, appliances, and fans. Therefore, the energy cost calculation: Energy cost (6) = (((appliance energy consumption+ fan energy consumption+ air conditioner energy consumption) * 0.278))* 0.0999)))// 0.278 to convert the sum of the energy consumptions from MJ to Kwh according to equation (1). Figure 44 shows the energy consumption for light, appliances and fans from HOT2000.

Energy Cost calculation

Energy cost (6) = (((appliance energy consumption+ fan energy consumption+ air conditioner energy consumption) * 0.278))* 0.0999)))

Proposed algorithm energy cost == (((2678.4 + 237.6+ 323.64) *0.278)) 0.0999))) = $ 89.9

HOT2000 energy cost = (((2678.4 + 237.6+ 1448.7) *0.278))*0.0999 $ 121.1.

We compared the simulation results obtained from our implementation to the one obtained through the use of HOT2000, as can be seen in Figures 45 and 46. The following charts compare the energy consumption and cost for July between the proposed system and HOT2000. Figure 45 shows the energy consumption for July: the proposed system energy consumption is around 323.64 MJ, and HOT2000 is 1448.7 MJ. This means that the proposed system saved 77% energy consumption in July. Figure 46 shows July's energy cost of cooling the house: the proposed system energy cost totalled $90, and HOT2000 totalled $121. This means the proposed system decreased the cost by 26% ($ 31) compared to HOT2000.

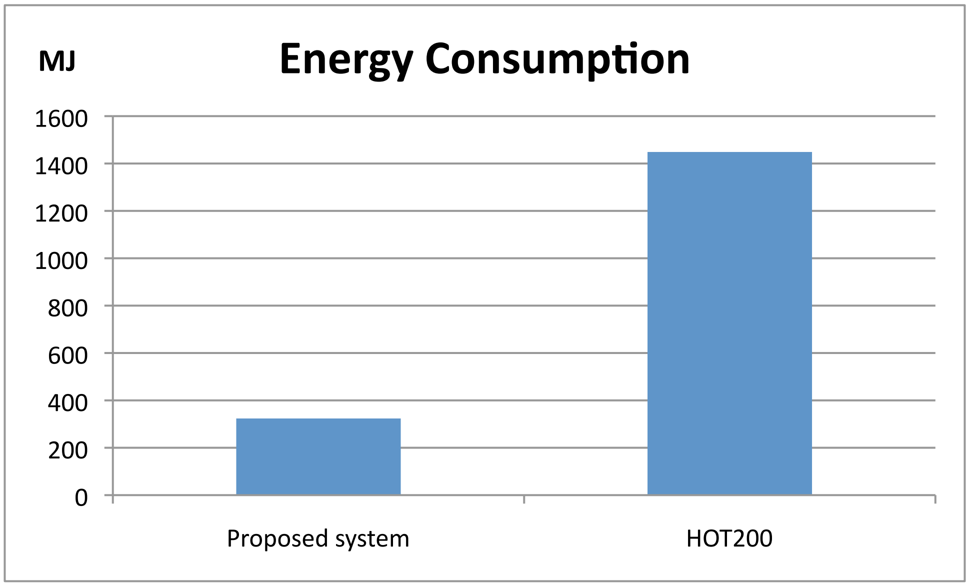


Figure 45: Energy consumption comparison for case study 3 – July month-

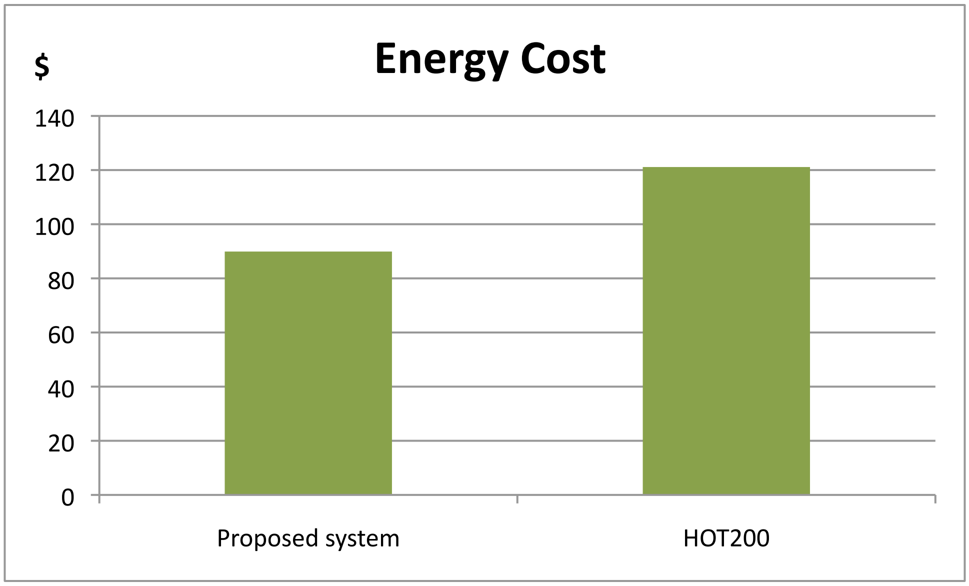


Figure 46: Energy cost comparison for case study 3 – July month-

4.7: Simulation 4 for a year to calculate and compare energy consumption and cost with HOT2000

Case Study4: comparison between the proposed algorithm and HOT2000 for one year

We modeled a two- story single unit house, 10*10 dimensions. Moreover, the house equipped with furnace and air conditioning. HOT200 heat or cool the house as one unit, but our system deal with each space separately and assign different indoor temperature in each space. Therefore in the simulation program, the house is divided into three spaces, the house contains door sensors to monitor the occupants, and the house contains indoor temperature sensors to monitor the house indoor temperature. The following figure 46 shows the comparison between our proposed system and HOT2000 regarding the energy consumption for a whole year. According to HOT200 weather file, the hot weather months are: from May to September. In addition, the other months represent the cold weather season. As shown in figure 47 our proposed system reduces the energy consumption by 57% for heating system compared to HOT2000. Moreover, the proposed system reduces energy consumption by 70% for cooling system compared to HOT2000. As a result, our proposed system can reduce the home energy consumption by 62% compared to HOT2000.

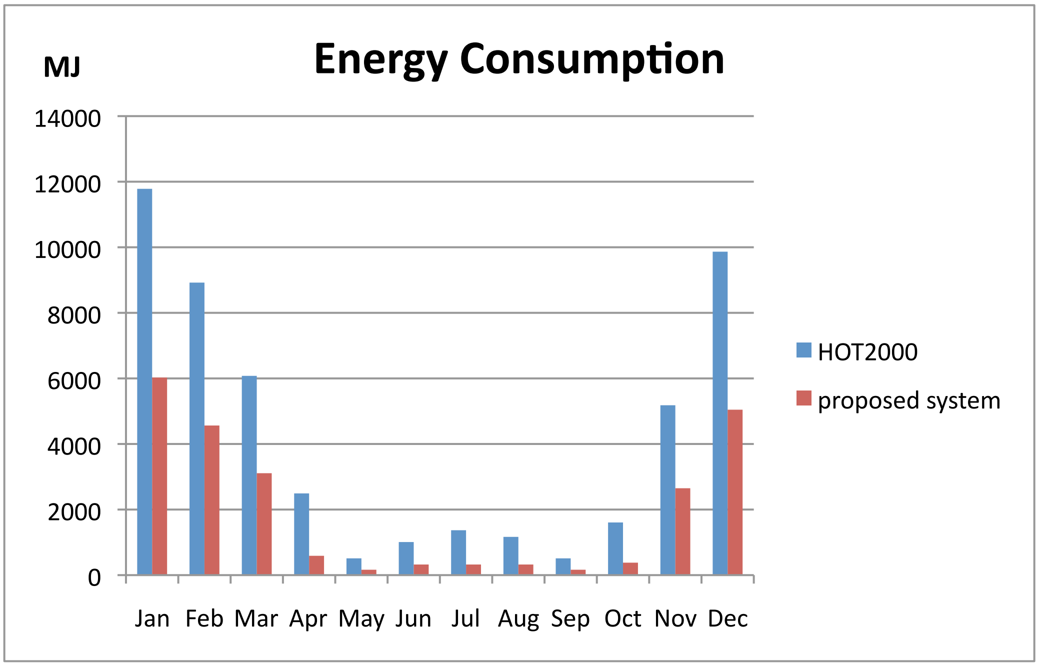


Figure 47: Comparison of energy consumption between our propped system and HOT2000 for a year

Chapter 5: Conclusion and Future Work

With the huge demand and limitation on energy resources and the negative impact of air pollution in our environment and our health, the need for a smart system to control the use of energy in our homes has increased. In this thesis, an intelligent energy controller algorithm is proposed in order to decrease energy use in the heating and cooling system within the home by taking into consideration occupant preferences, the activity patterns in the home, and occupied and unoccupied spaces. The system displays the benefits of smart homes and intelligent multi-agent technologies.

The system can recognize user(s) presence in each space and in the whole house by using online monitoring from the door sensors in each space. Moreover, the proposed algorithm used the information from each space agent and the behavioural activity agent in order to apply the appropriate temperature. It also used the activity percentage for each space to achieve user comfort level, save energy and maintain heating/cooling system life. In addition, the proposed algorithm can save energy during vacation mode and still keep the house in safe condition to prevent pipes from freezing in the winter.

In order to evaluate our system's performance, the system is simulated by a java program and the results are compared to HOT2000. During the simulation the system was tested for many situations, including simulations of winter and summer months. As a result, the system saved 50% of energy consumption compared to HOT2000. The energy consumption and cost for the specific months that were simulated were compared with results derived from HOT2000. The simulation was done as follow: select a month, calculate the energy consumption from HOT 2000, enter the input values such as user preferred temperature, wake-up time, etc. Simulate for one day and then multiply with the month's day number. Finally, compare the result with the month's result in HOT2000.

This study opens the door for some interesting future work. Adding a motion sensor along with door sensors in each space would allow the system to differentiate between the indoor spaces temperatures when the user(s) is awake and asleep. This can be done as follow: if the door and motion senors are on then the user is awake; if the door senor is on and the motion senor is off then the user is asleep. As a result, this will save more energy as people like to make their houses colder in the winter and hotter in the summer while they sleep. Moreover, the activity percentage calculation could be separated for each period of time to make the prediction of user(s) presence more accurate. For example, to warm a space in the morning, the global agent will look at the wake-up period time to see if the space is likely to be used in the morning. In other words, if the user wakes up at 6:00 a.m., the proposed algorithm will check the activity percentage between 6:00 and 7:00 a.m. and determine the indoor temperature. Connecting the system with a user's device, such as a smart phone, to update his/her vacation plan would also be beneficial. This will force the system to update in order to match the user's vacation plan and therefore minimize the input needed from the user so as to allow them to enjoy their vacation.

An interesting extension would be to test the system in reality and to examine how quickly GPS technology will help to meet the user's preferences before he/she arrive at home.

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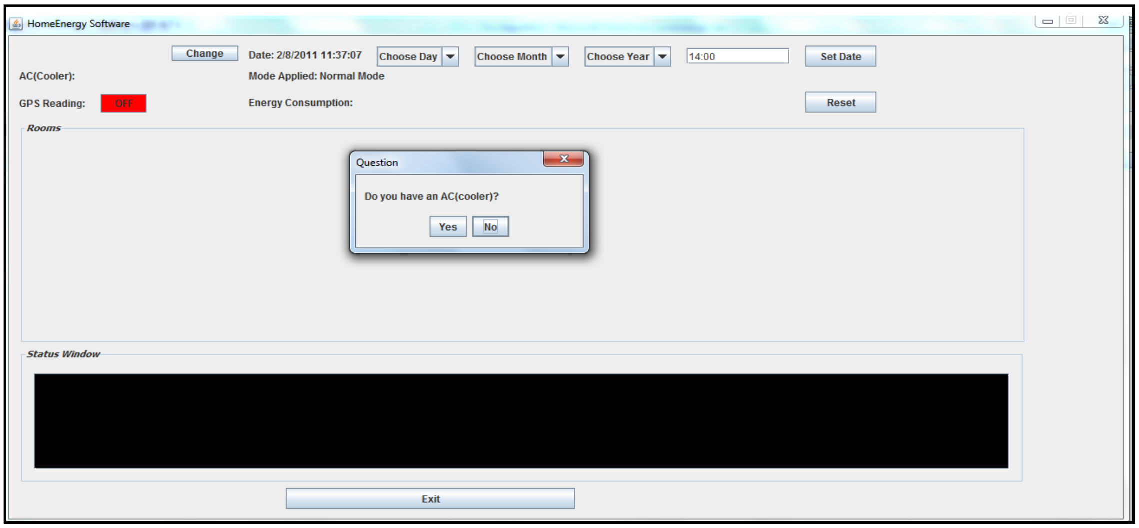
Appendix A: Software Screen Shots



Date: 2/8/2011 11:37:07

14:00

AC(Cooler):

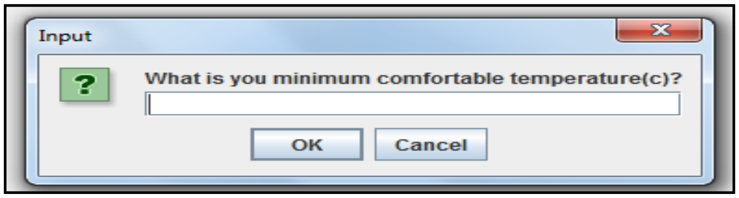
Mode Applied: Normal Mode

GPS Reading: OFF

Energy Consumption:

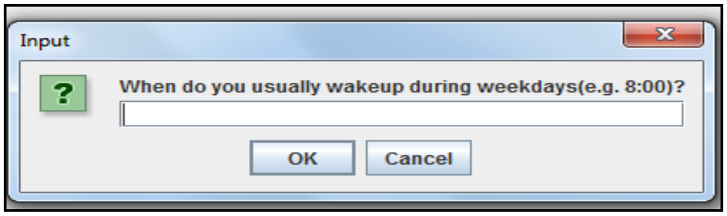
Do you have an AC(cooler)?

Figure A.1: Screenshot -1-



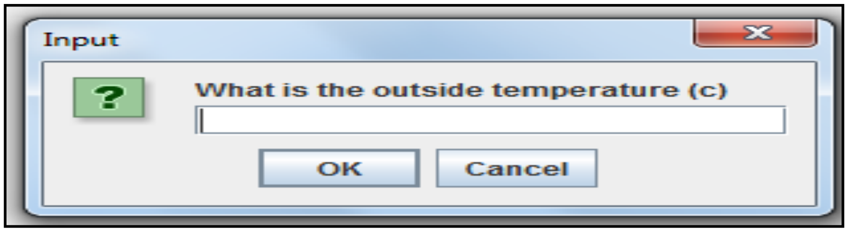
What is you minimum comfortable temperature(c)?

Figure A.2: Screenshot -2-



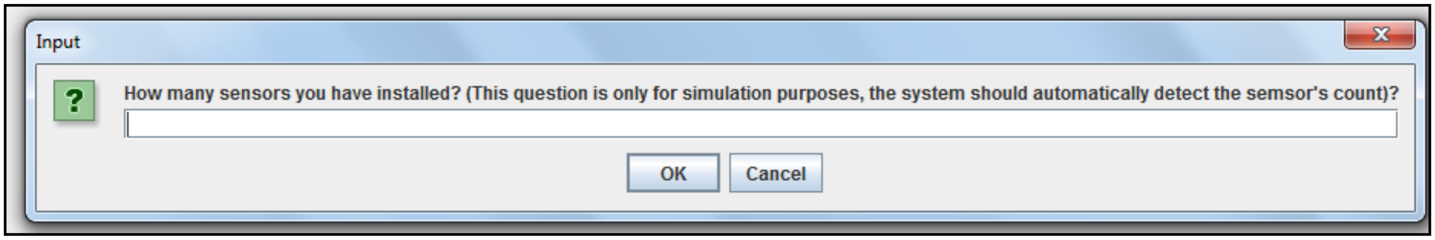
When do you usually wakeup during weekdays(e.g. 8:00)?

Figure A.3: Screenshot -3-



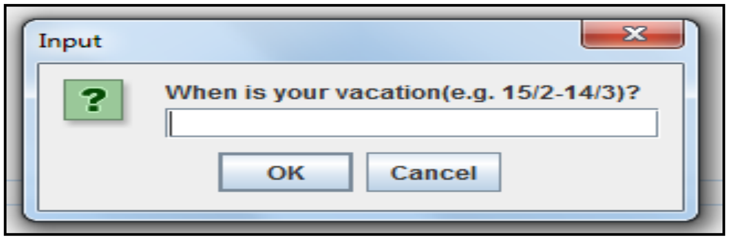
What is the outside temperature (c)

Figure A.4: Screenshot -4-



How many sensors you have installed? (This question is only for simulation purposes, the system should automatically detect the semsor's count)?

Figure A.5: Screenshot -5-

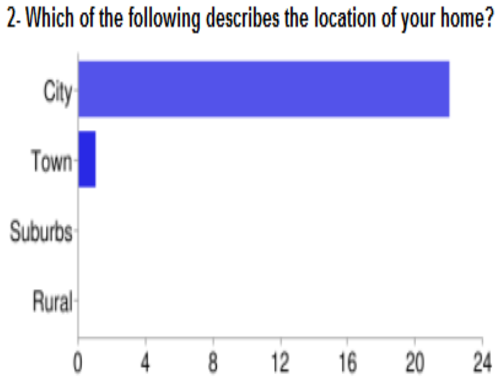


When is your vacation(e.g. 15/2-14/3)?

Figure A.6: Screen Shot -6-

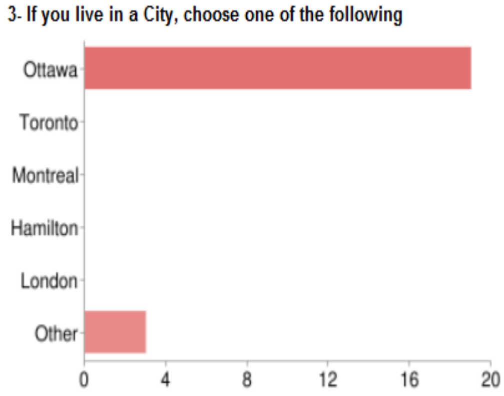
Appendix B: Energy Management Questionnaire

An energy management questionnaire was conducted for each household. The purpose of this study was to gather information about the home type, heating/cooling system and also to learn more about the idea of intelligent systems for saving energy and controlling heating/cooling systems in the home. There were three sections in the survey: location and home type, heating\cooling system, and intelligent system for heating\cooling. There were 23 participants in the survey; 96% of those live in the city and 4% live in town (Figure B.1). 86% of participants live in Ottawa (Figure B.2).



City	22	96%
Town	1	4%
Suburbs	0	0%
Rural	0	0%

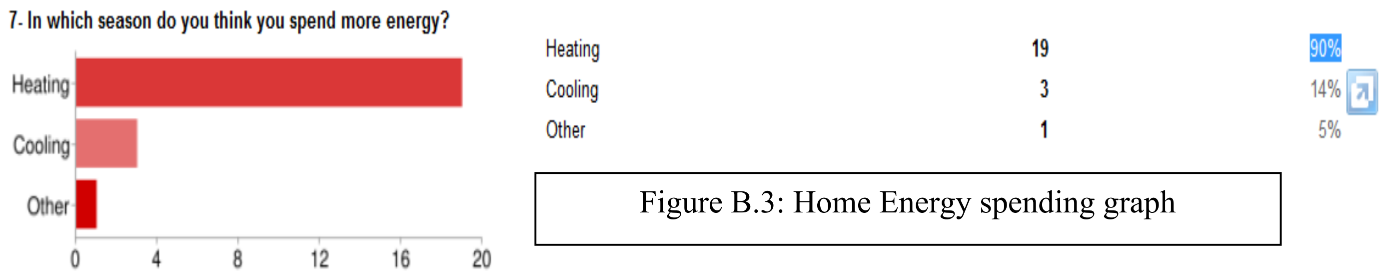
Figure B.1: Home Type graph



Ottawa	19	86%
Toronto	0	0%
Montreal	0	0%
Hamilton	0	0%
London	0	0%
Other	3	14%

Figure B.2: City location graph

In the heating/cooling system section, one of the questions asked which season the user spent more energy on. 90% used more energy during the heating season. The answer was as follow (Figure B.3):



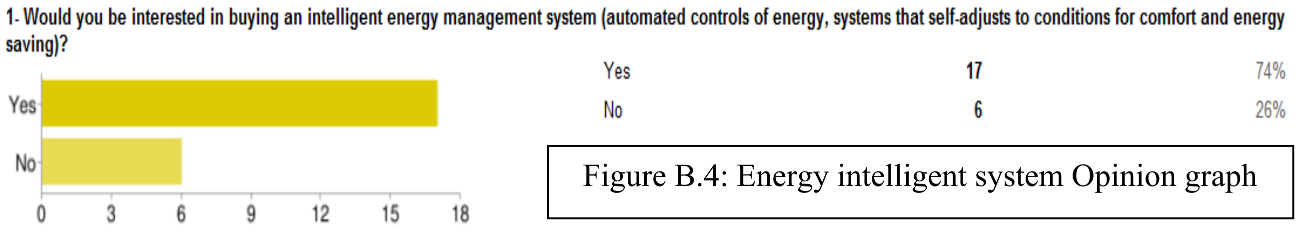
7- In which season do you think you spend more energy?

Heating	19	90%
Cooling	3	14%
Other	1	5%

Figure B.3: Home Energy spending graph

In the intelligent heating/cooling system section, the questions were in regard to an intelligent system that controls heating/cooling in the home and the amount of knowledge the participants had about this kind of system, and how willing they were to have this system in their home. The results of this section were interesting and give researchers and the academic sector information on how to educate people about these kinds of systems, and what people expected from them.

The results of this section are: 74% (Figure B.4) would be interested in buying an intelligent energy management system.



1- Would you be interested in buying an intelligent energy management system (automated controls of energy, systems that self-adjusts to conditions for comfort and energy saving)?

Yes	17	74%
No	6	26%

Figure B.4: Energy intelligent system Opinion graph

The next question was used to determine how individuals rank the characteristics of the system. The ranking system was from 1 to 5 where 1 is the highest priority and 5 is the lowest. Characteristics were: price, user friendliness, high quality, good capabilities, and customizable. The first characteristic is price and the majority of the participants ranked it as number two, with a percentage of 22%. The second characteristic is user friendliness (easy to manage) and the majority of the participants rank it as number one with a percentage of 43% (Figure B.5).


Price

1	**4**	17%
2	**5**	22%
3	**3**	13%
4	**2**	9%
5	**3**	13%

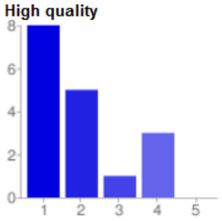
Figure B.5: Energy intelligent system characteristics priority


User friendly (easy to manage)

1	**10**	43%
2	**2**	9%
3	**1**	4%
4	**2**	9%
5	**2**	9%

The third characteristic is good capability in terms of energy saving features, broader control capabilities and 39% of the participants rank it as number one (Figure B. 6).

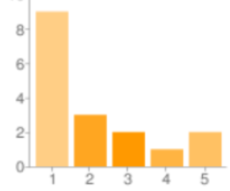
Finally, the fourth characteristic is customizable and 30% of the participants rank it as number one. The results are depicted in the graphs (Figure B.7):


High quality

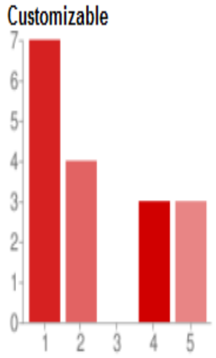
1	**8**	35%
2	**5**	22%
3	**1**	4%
4	**3**	13%
5	**0**	0%

Figure B.6: Energy intelligent system characteristics priority

Good capabilities as energy saving features, broader control capabilities



1	**9**	39%
2	**3**	13%
3	**2**	9%
4	**1**	4%
5	**2**	9%



1	7	30%
2	4	17%
3	0	0%
4	3	13%
5	3	13%

Figure B.7: Energy intelligent system characteristics priority

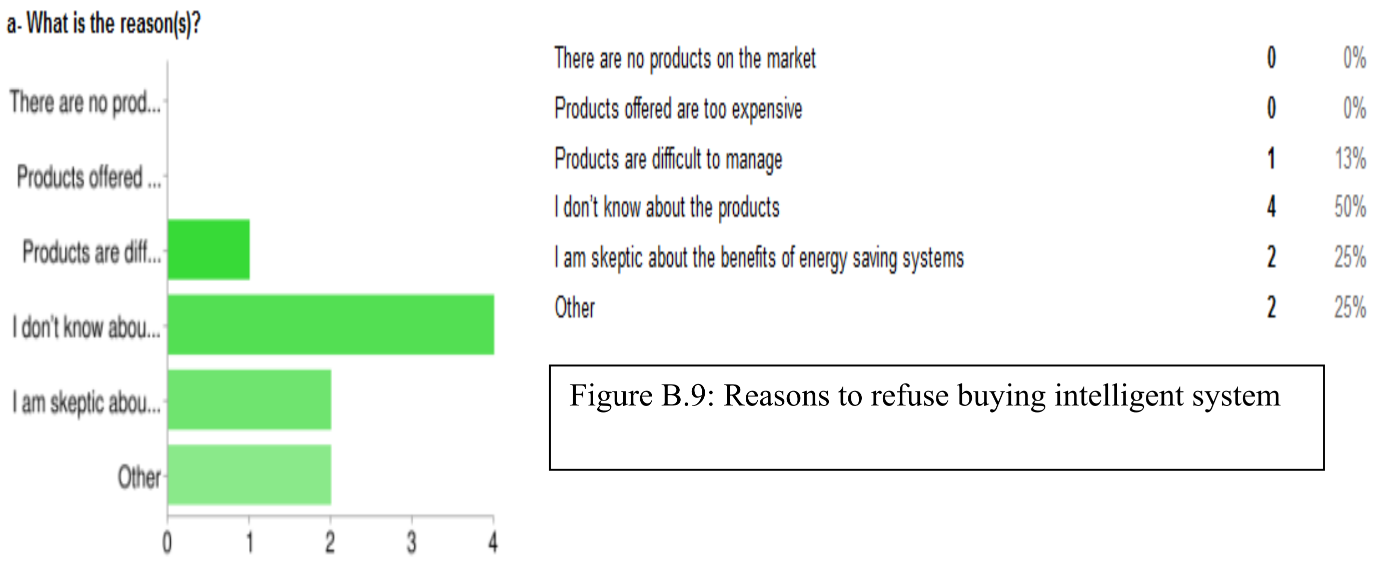
This survey can give the commercial and business sector ideas about the price that people are willing to pay. In the survey, 94 % (Figure B.8) of the participants are willing to pay a price between $ 1000 and $2000.

2b - How much would you pay for a new system that would allow you to save more energy by controlling heating/cooling in your home?

$0	0	0%
$1-$2,000	16	94%
$2,000-$4,000	1	6%
More than $4,000	0	0%

Figure B.8: The average price to buy intelligent system

The survey showed that people require greater education and knowledge about the benefits of this kind of system for their environment, budget, and even their health. 50 % of the participants were not interested in having an intelligent system in their home (Figure B.9) because they aren't aware of the products available in the market, and 25 % were skeptical about the benefits of energy saving systems. The result is depicted in the following graph.

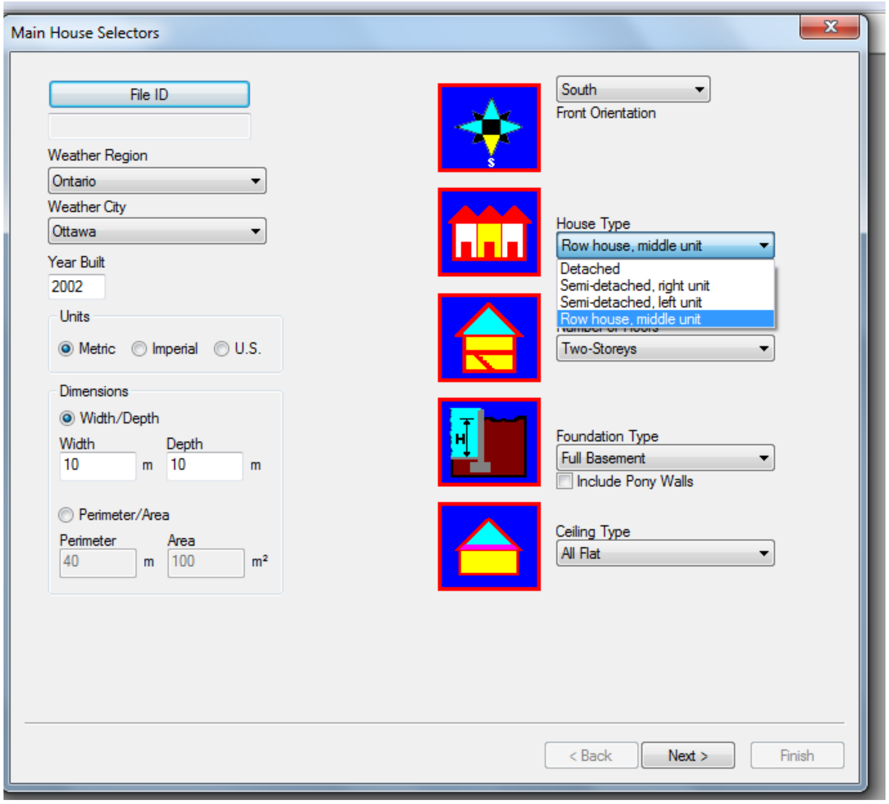


a- What is the reason(s)?

There are no products on the market	0	0%
Products offered are too expensive	0	0%
Products are difficult to manage	1	13%
I don't know about the products	4	50%
I am skeptic about the benefits of energy saving systems	2	25%
Other	2	25%

Figure B.9: Reasons to refuse buying intelligent system

Appendix C: HOT2000 Screenshot



Weather Region: Ontario

Weather City: Ottawa

Year Built: 2002

Units: ● Metric ○ Imperial ○ U.S.

Dimensions

● Width/Depth

Width 10 m Depth 10 m

○ Perimeter/Area

Perimeter 40 m Area 100 m²

South

Front Orientation

House Type: Row house, middle unit

Detached
Semi-detached, right unit
Semi-detached, left unit
Row house, middle unit

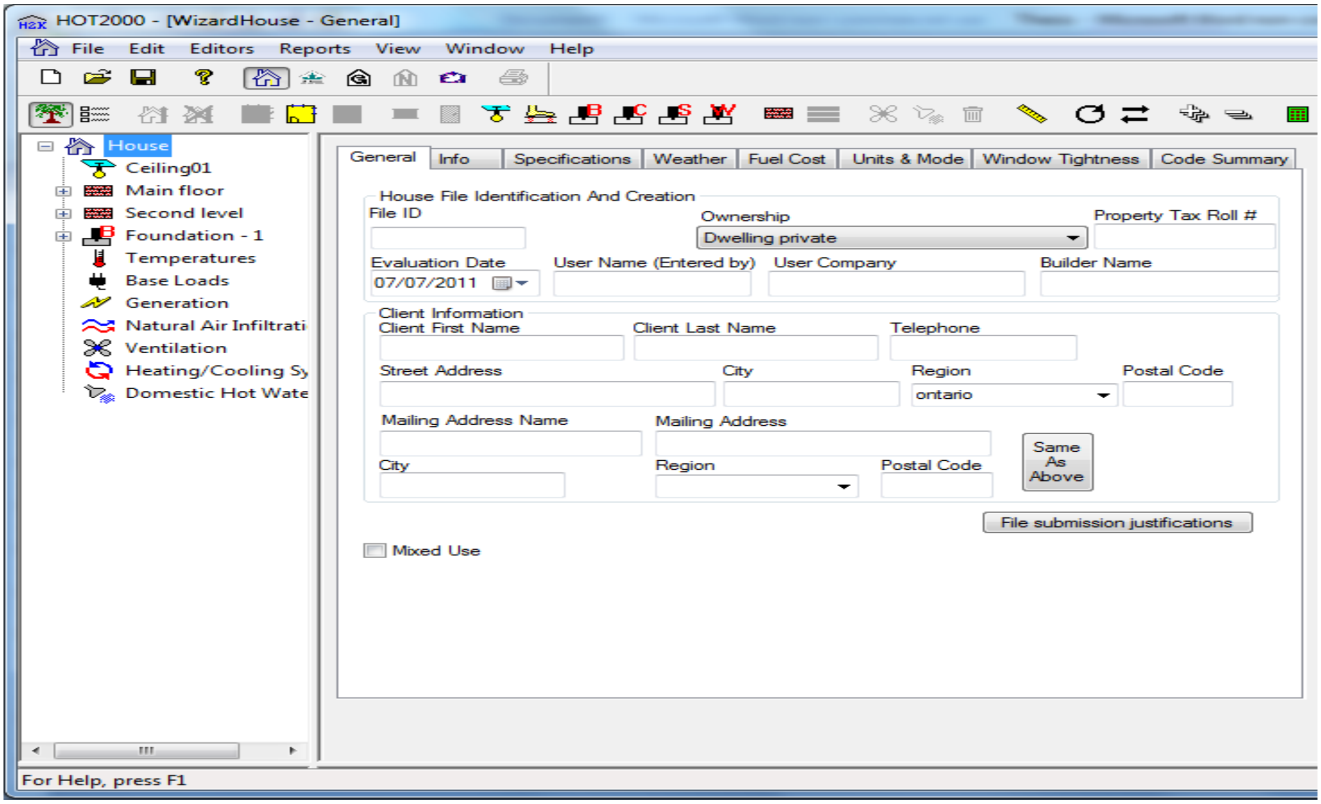
Two-Storeys

Foundation Type: Full Basement

☐ Include Pony Walls

Ceiling Type: All Flat

Figure C.1: Main screen of HOT2000



House File Identification And Creation

File ID:
Ownership: Dwelling private
Property Tax Roll #:
Evaluation Date: 07/07/2011
User Name (Entered by):
User Company:
Builder Name:

Client Information

Client First Name:
Client Last Name:
Telephone:
Street Address:
City:
Region: ontario
Postal Code:
Mailing Address Name:
Mailing Address:
City:
Region:
Postal Code:

☐ Mixed Use

Figure C.2: Wizard House Selections