

## VIRTUAL SIMULATION WITH REAL OCCUPANTS USING SERIOUS GAMES

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### ABSTRACT

Inhabitants play a key role in the global energy consumption of buildings. However, it is difficult to motivate people to be concerned about energy management. Our objective is to make energy consumption visible by simulating the energy impacting behaviours of inhabitants by using Energy Plus and a 3D virtual environment. This will make energy consumption more obvious to people due to the use of a serious game. The nature of this game is exploratory where the player's knowledge about energy consumption is enriched as he plays the game. In this paper a methodology for building a serious game for energy management is proposed. In order to analyse the impact of occupant's behaviour the game is coupled with EnergyPlus. The *Functional Mock-up Interface* (FMI) standard is used for coupling these different tools. Since the occupants experience the impact of their different behaviours on energy consumption, the game creates an awareness about energy management and motivates the occupants to save energy.

### INTRODUCTION

The need to take into account occupants' behaviour in building energy management is becoming increasingly important. There have been several surveys and studies that have demonstrated the strong relation between energy consumption and occupants' behaviour (Raaij and Verhallen 1983, Andersen et al., 2009). Besides these studies, another reason that makes occupants' behaviour one of the most important factors in building energy management is the increasing trend of very low energy consuming buildings or passive buildings. These buildings follow standards proposed by organizations such as EuroACE (Alliance of Companies for Energy efficiency in buildings) and adhere to rules for energy efficiency in buildings (Jensen et al., 2009). The impact of occupants' actions and behaviour is more critical in energy efficient buildings. (Chenailler, 2012) clearly demonstrated this by experiments performed in the PREDIS monitoring and habitat intelligent platform. The monthly thermal energy production in this platform showed that a major portion of the heating power came from the occupants and their usage of certain electrical

appliances. Modelling behaviour in most of the building energy simulations, however, still remains limited to presence/absence profiles. (Kashif et al., 2013b) emphasized that inhabitants' detailed reactive and deliberative behaviours must also be taken into account and proposed a co-simulation methodology to find the impact of certain actions on energy consumption. Similarly, feedback to inhabitants on energy consumption is important in order to reinforce awareness. This includes feedback about different appliances, as well as the power and gas consumption of the whole house (Ueno et al., 2006). The studies have also shown that monetary savings are not necessarily the most prominent factor and can be easily compromised with comfort (McMakin et al., 2002). The objective should be on changing beliefs otherwise all efforts could be useless (Druckman et al., 2011). Learning and particularly active learning is the most effective way to change beliefs. The literature suggests that games accelerate learning, increase motivation and help in the development of cognitive skills (Freitas and Jarvis 2007). Serious games are used in a variety of areas, such as, education, health care and emergency management etc. to serve a purpose other than mere entertainment. The user can learn playfully and significantly since the learning objective is integrated into the game. By just changing a few variables in the game, users can experience many different situations; this would be difficult or impossible to do in reality due to safety, time or cost constraints, etc. (Squire and Jenkins 2003) (Corti, 2006).

There are some existing games intended to reduce energy consumption and change energy related beliefs of users. In EnerCities, the player has to build his own metropolis with the goal to keep the city sustainable. Players have to balance the *People, Planet and Profit* while maintaining electricity supplies, energy conservation and reducing CO<sub>2</sub> (Knol and Vries 2011). 2020Energy is an online serious game about energy efficiency, renewable energy and sustainable development (2020energy). The name 2020Energy is due to the expected energy resource depletion and the possible deadlock in the year 2020. The player has to help people to make better energy choices. Three advisors (economical, environmental and social) are also there to give energy advice to the player. In Energyville the

players are provided with certain options to power the city e.g. geothermal, nuclear, natural gas, coal, etc. The player's scores depend on the selection of certain energy sources, as each power source has its own economic, environmental and social impacts (Energyville). Energy Hog Challenge is another game with the objective of teaching children about energy savings. Energy hogs hide in different places in the house where the energy is wasted, e.g. an old refrigerator, unclean furnace filters, or a cracked or uninsulated attic. The goal is to keep the hogs out of the house by taking certain energy saving measures e.g. caulking leaky windows, replacing incandescent light bulbs with compact fluorescent ones, etc. (EnergyHog).

The work reported in this paper is inspired from the concept of serious games. The objectives are to involve the occupants in energy management and to make energy consumption visible. In this regard, there are certain levels of complexity proposed for the game. In the first step, the game is run as a simulation where the player can drive a virtual character and record the energy consumption and comfort levels. The player can then change some external conditions and replay the game in order to analyse performance. In the next steps, however, the game will be more complex as the player will be given certain missions, and has to drive the virtual character to achieve the goal. A mission could be, for example, cooking or washing while maintaining acceptable levels of cost and comfort. In this step, some computer-driven characters will be introduced. To add more complexity and fun, the player can provide energy advice to the computer-driven characters inside the game and can himself act as a building energy management system. In this paper, however, only the first step is established with a detailed methodology of how to build the serious game for energy management. Thus, by introducing the serious gaming concept into building energy simulations, these simulations would not be specific to only the building experts. Less knowledgeable players will be able to learn the energetic impacts of their activities while having fun with the game. The game is different from the existing ones as all the physical parameters as well as the character's comfort levels are computed at runtime using the building's physical models and inhabitants' thermal comfort models.

## METHODOLOGY

A methodology is proposed to build the serious game for energy management in buildings. It consists of 5 steps: 3D modelling, animation, physical modelling, co-simulation, and game design. Each of these steps is detailed in the sections below.

### 3D Modelling

In order to build the game, 3D models of the character, the building or house, and objects and

appliances are required. The *MakeHuman* software is an open source tool for making 3D models of virtual human characters (MakeHuman). The different characteristics of the character that can be defined inside MakeHuman include, age, gender, height, weight, etc. A skeleton may also be added to the character that can be used later for animations. A virtual female character with a *humanik* skeleton is built for the game as shown in figure 1. This model can then be imported by other 3D computer graphics tools, such as Blender.

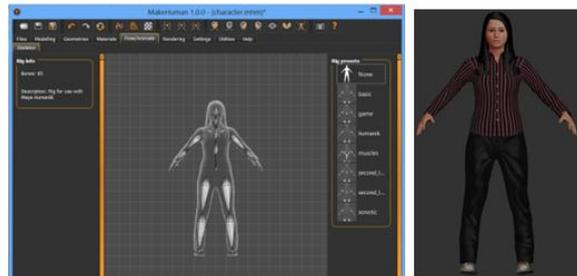


Figure 1: 3D character model

The 3D modelling of the house is done using the SweetHome3D interior design application (SweetHome3D). This allows building a 2D floor plan, arranging furniture in the house, and displaying the results in 3D. The walls, doors and windows can be adjusted to have a certain width, height and thickness. Similarly, the furniture can be selected from already available options, or new furniture can be imported. Once the model is built, it can be exported to the *obj* file format, a universally acceptable format that was first developed by Wavefront Technologies. The exported model can then be imported into other computer graphics applications. Figure 2 shows the model of the house built for the game in SweetHome3d. The upper part of the figure shows the 2D floor plan and the lower shows the 3D view.

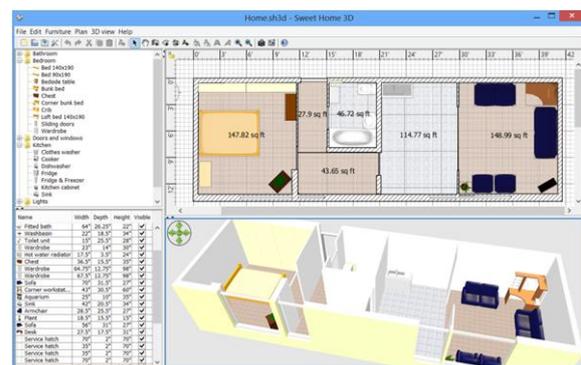


Figure 2: 2D and 3D house model

Once the 3D model of the house is built, it is almost ready to put into the game. There can still be certain object and appliance models that can be developed outside of SweetHome3D and later introduced into the house. For example, complex models such as a fridge where the doors can be opened and closed, or a washing machine that has on/off buttons or rotating knobs to set the temperature, can be built using

Blender. Blender is a computer graphics application for creating 3D visualizations (Blender). Its key features include a fully integrated 3D content creation suite, rigging and skinning animations and rendering etc. Figure 3 shows the 3D model of a fridge where the shelves (imported as separate 3D models) are fitted in at different levels. Some of the models can be obtained from online 3D model repositories and others can be made using a combination of different models. For example, the fridge in figure 3 is made out of a fridge box model with additional material fitted in later.



Figure 3: 3D fridge model in Blender

### Animation

Once the 3D models have built they have to be animated. For the 3D virtual character, the animations could be anything that the game player wants the virtual character to do at home. For example, walking around the house, picking up and putting down things, opening and closing doors, turning on/off buttons on appliances, etc. All these types of animations can be done in a graphics application i.e. Blender in this work. The reason for choosing Blender is its strong capabilities and also because Blender models and animations work perfectly with the selected game engine i.e. JMonkey. Figure 4 shows a screenshot of a character animation in Blender. The circles on different parts of the character's body show the armature bones that can be moved in some particular direction to create different poses. Each bone has its own particular name e.g. LeftForeArm, RightLeg. All of the different poses once added to the timeline are called keyframes. A series of the keyframes makes up an animation, e.g. walk, jump, getFood.

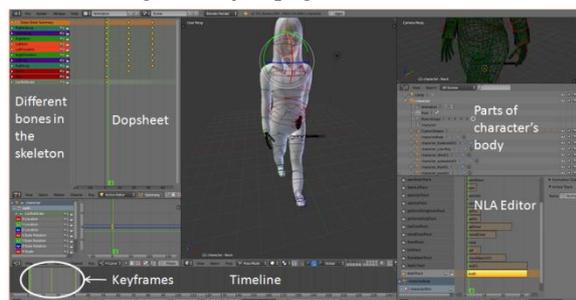


Figure 4: character animation in Blender

JMonkeyEngine, a free, open-source software developed in Java, was used for the game engine (JMonkeyEngine). In JMonkey, transformation i.e. rotation, scaling and movements can be applied to 3D objects. JMonkey also handles projection and rendering. Projection makes an automatic conversion of 3D scene data into a 2D image on the screen. Rendering refers to the shading and lighting of object surfaces. 3D models may also be imported and animations played. The character animation that was built in Blender can be loaded and played in JMonkey. This animation is first registered to the animation controller and then animation channels are attached to each animation sequence. Further, they are triggered by certain events or user inputs. Figure 5 shows the game in JMonkey where the character is walking towards the window.



Figure 5: character walking in the house

The transformations, when applied to 3D objects, give the impression of animation. These type of animations that do not involve armature bones can be created in JMonkey, e.g. opening and closing doors. Thus, the animations on home appliances and objects are created in Jmonkey. Figure 6 shows the door and a pane of the window that are opened by the character. It also shows the heater with a button that changes its colour when turned on or off. In the case of the door and window, rotation is used to create this animation. For the buttons and other parts of the 3D object/appliance models, they can be attached or detached to the scene graph at any event or user input. A scene graph is an optimized data structure used by the game engines to store objects of a 3D scene.

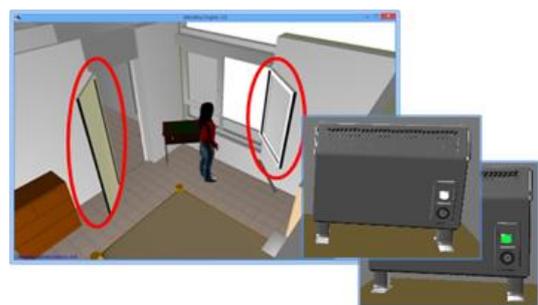


Figure 6: object and appliance animations in JMonkey

## Physical Modelling

In order to analyse the impact of different activities performed by the occupants, thermal and physical models of the building and appliances are required. Once the house is filled with different appliances and the character can perform certain actions on them, physical models may be built. These kind of models have already been developed for co-simulation purposes (Kashif et al., 2012, Kashif et al., 2013a) using Matlab/Simulink. These are quite complex models and require lot of mathematical equations to build them from scratch. However, in this work *EnergyPlus (EP)* (Crawley et al., 2000) is used to cosimulate the physical models. EP is a whole building energy performance simulation program used to model energy and water use in buildings. It reads the input in *idf* format and gives the output as csv, text or html formats. The *idf* file contains the information about the building; that includes, location, construction, exterior and interior environment, envelop, schedules (for internal heat gains), windows, daylighting and HVAC. Certain third-party software products and add-ons, such as OpenStudio application suit, legacy OpenStudio Sketchup (for 3D sketches) are available for advanced functionality. The physical model for the house in the game is built using OpenStudio plug-in for Sketchup to make the sketch of the house. Figure 7 shows the sketch of the house having 4 thermal zones and doors and windows. Certain physical parameters, such as the weather profile, material, occupancy or heating/cooling schedules can further be adjusted in OpenStudio (figure 8). The OpenStudio model can then be exported to *.idf* format to be used with EnergyPlus.

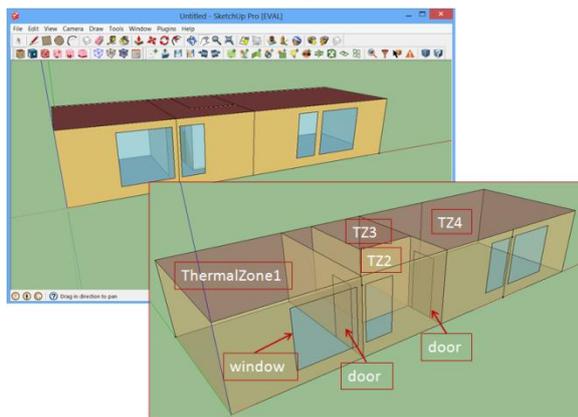


Figure 7: Sketch of the house in Sketchup

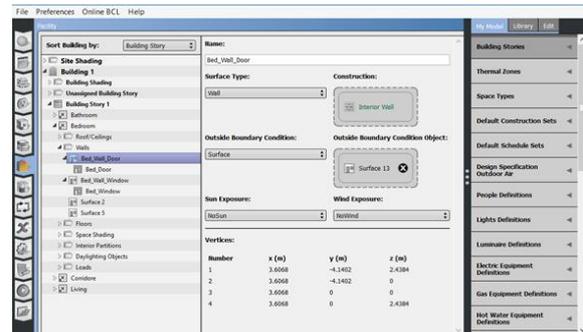


Figure 8: Adjustment of physical parameters in OpenStudio

## Co-Simulation

After building the 3D models, and playing the animations in JMonkey, the physical models are attached to the 3D models and co-simulation is performed. This means that the 3D game needs to be connected to EnergyPlus, and they can exchange signals at run time. In this way the impact of the actions performed by the character in the game on the different physical parameters e.g. temperature, CO<sub>2</sub> levels and energy consumption, are measured. In order to interact with the EnergyPlus model at runtime, it must be exported as a Functional Mock-up Unit (FMU) that is based on the Functional Mock-up Interface (FMI) standard. FMI is a tool-independent standard for the exchange of dynamic models and for co-simulation (Blochwitz et al., 2011). (Plessis et al., 2014) have also used this standard in order to couple an occupants' behaviour simulator with a building energy model in Modelica. The EnergyPlusToFMU software package (Nouidui et al., 2013) is used to export the EnergyPlus model as an FMU. An FMU is composed of the model description file that contains all the input, output variables and a shared library (.dll) that contains the C functions to interface with FMU. However, before exporting the EnergyPlus model as an FMU, the external interfaces must be defined in EnergyPlus. This means that all the input and output variables that will be exchanged between an FMU and the external application must first be defined. Since the JMonkey game engine is in Java, a Java wrapper for the functional mock-up interface called JFMI must be used in order to interact with the FMU. JFMI facilitates the communication between Java programs and the native library. The overall structure of the co-simulation is shown in figure 9.

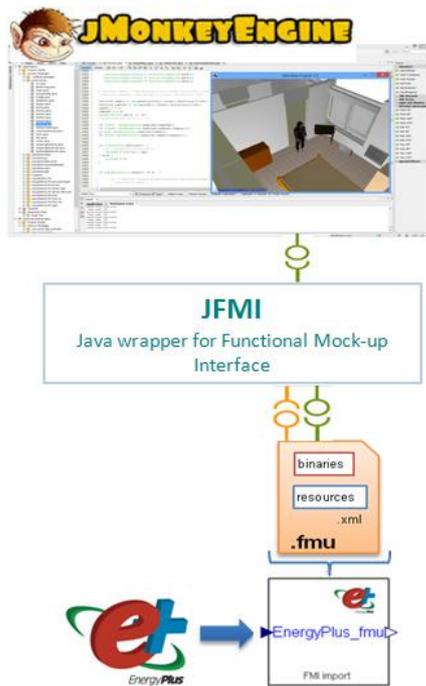


Figure 9: Co-simulation between EnergyPlus and JMonkeyEngine

### Game Design

The last part of the methodology is game design. Game design concerns making the game interesting and in particular ensuring that the player is continually motivated. It is also important to balance the player's ability with game difficulty, which could otherwise reduce his motivation to play. As the player plays the game, he should also be able to learn certain things and increase his skills set, which is the heart of a serious game to learn while having fun with the game. The feedback and rewards will encourage and motivate the player. Game design is important since a game has to be interesting, challenging, informative and above all fun.

In this work the game is designed in JMonkey, and at the moment the game level is kept very simple. Currently, the things that motivate the player are the visualizations of how the different physical parameters change as the game is played. The interest of the player is maintained by the exploration of a 3D house equipped with different appliances and objects. These objects/appliances are not static; rather they change their visual and physical state as some action is performed on them. For example, the player can ask the character to pick the food up from the table and put it in the fridge; the previously empty fridge now appears filled in with the food. The feedback from the different actions, in terms of the total energy consumption of the house, also motivates the player to perform actions that could minimise energy consumption.

### GAME RESULTS

The simulation step size in EnergyPlus is set to 1 minute and in the game it is set to 1 second. This means that each second of real time is equivalent to 1 minute of EnergyPlus simulation time. The serious game starts with a character standing somewhere in the house. This character is, for the moment, totally dependent on the player. The player can drive the character to anywhere in the house using the keyboard. The player can also use the mouse to move the camera without moving the character, or to zoom. The instructions for all the other actions, e.g. to open/close the doors, to put food in the fridge, can also be given to the character using certain keys. However, some additional measures have been taken into account when a key is pressed. For example, when the player presses the 'O' key to open a door or a window, only the door or window that is closest to the character is opened. In order to avoid the case where multiple doors are opened because they are equidistant to the character the concept of *picking* is used to identify the target object. In picking the target is identified by aiming a ray to it and then the specific action is triggered.

As the character moves around the house, heat is emitted from its body causing a small increase in the temperature of the particular zone where the character is located. This physical phenomenon is captured well by EnergyPlus since it receives information about the character's current location at each time step. Upon receiving the information, EnergyPlus recomputes all the different model parameters for all of the zones, e.g. temperature, humidity. EnergyPlus also takes into account the activity level of the characters, which contributes to the heat produced by their bodies. Details of the different activity types and the resulting activity level or equivalent metabolic rate is provided in EnergyPlus, 2014.

Some parameters are chosen to be displayed as the game proceeds. These include the change in the temperature of the rooms, the heater states (fixed or portable), the thermal comfort of the character and the total energy consumption of the house. The thermal comfort of the character is computed using Fanger's thermal comfort model (Fanger, 1973). This computes how comfortable is the character, based on certain parameters including temperature, humidity, metabolic rate, mean radiant temperature and air velocity. A comfort value of 0.0 means that the person is feeling neither hot nor cold but just neutral. Positive and negative values represent degrees of hotness or coldness respectively in a person. Figure 10 shows a screenshot of the game in JMonkey. At the start of the game, the character is located in the bedroom. However, in the figure it can be seen that the player has moved the character from the bedroom to the corridor. The temperature curves for each zone in the upper part of the figure show that initially the

temperature in the bedroom was increasing slowly due to the presence of the character in bedroom. However, after some time the bedroom temperature starts decreasing and the corridor temperature increases. The heating power is initially set to zero as no heating is turned on yet in the game. The thermal comfort of the character also remains constant as the temperature throughout the house is the same due to the absence of a heating system.

Figure 11 shows another screenshot of the game with the fixed heating turned on for each zone. For each room a different set point temperature is set at the start of the game. Thus, the heaters in all the rooms adjust their power so as to maintain the set point temperature with a margin of  $\pm 0.5$ . The fluctuations in temperature shown in the figure are due to this set point being maintained (except for the corridor where there is no heater). Due to this temperature fluctuation, the thermal comfort of the character in the game also fluctuates. Besides the fixed heating in each zone there is also a portable or mobile heater. The player can ask the character to carry the heater from one room to another. In figure 11 the character has put the heater (that was originally in the bedroom in figure 10) in the living room and turned it on. As soon as the character turns on the heater, extra power (red curve) is added to the heater states that is due to the mobile heater. The temperature in the living room starts increasing due to this extra heating and is set to a higher set point temperature. The thermal comfort of the character also changes to the positive side of the comfort scale, which means a bit warm.

As the player advances in the game his knowledge about the building envelop, energy consumption, and thermal comfort enhances. By adjusting the different configurations for the outside environment, the building envelop and appliances, he can analyse the impact in terms of energy consumption, related cost and thermal comfort. This will help the player to explore further and identify the energy efficient behaviours.

## CONCLUSION

In this paper, a serious game is designed for occupants who can analyse the impact of their different activities on energy consumption while having fun with the game. The game is coupled with physical models of the building and appliances using the FMI standard. The contributions in this work include the methodology to build a serious game for energy management, the identification of different tools to build a serious game in the context of energy management, the interconnection between a 3D game and the physical models for energy co-simulation, and building a platform to promote energy efficient behaviours through interactive gaming. In the future we are interested in introducing some intelligent autonomous virtual characters to interact with the characters driven by the player. We would like to build a virtual environment with real actors to

analyse the impact of different energy tariffs. Also we plan to analyse how the advice given to the characters in the game through an energy management system affects their behaviours.

## ACKNOWLEDGEMENT

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Figure 10: Change in temperature of different zones as the character moves around

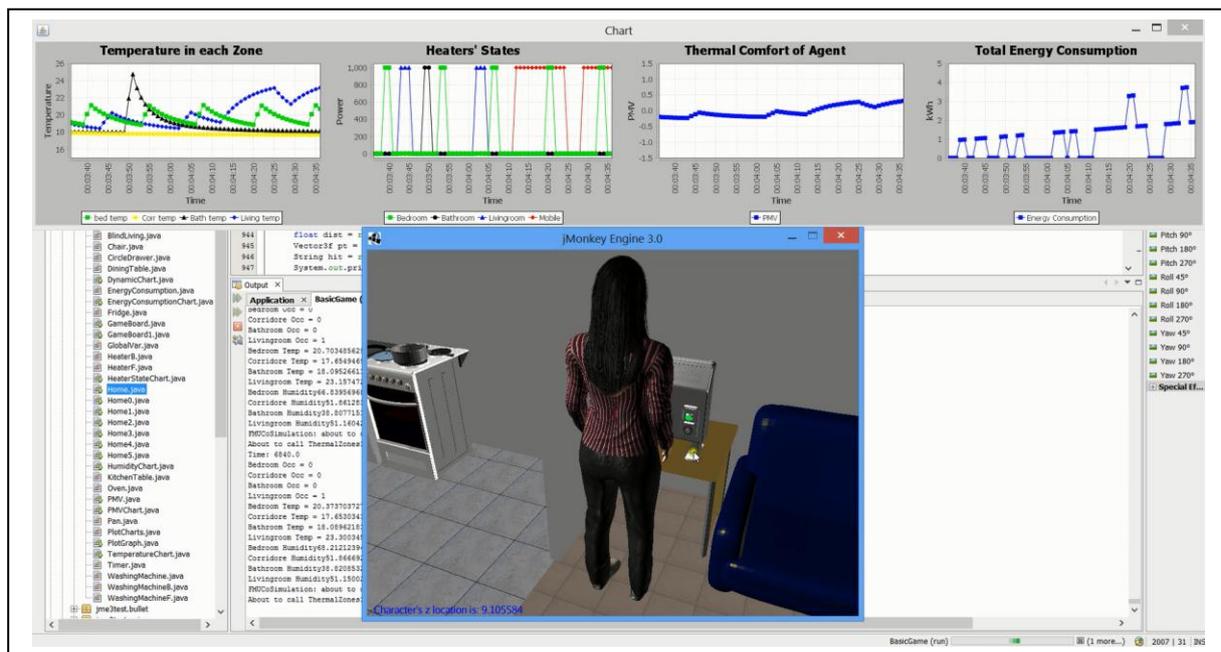


Figure 11: Game run with a heating system turned on in the house