Thermal Model of a House using Electric Circuits Analogy

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Abstract: The aim of this paper is to produce a thermal model of a house using electrical circuit analogy which gives information about indoor temperatures and power consumption of electrical heater in each room of the house. The information obtained from the power consumption of each electrical heater serves to estimate the peak consumption which gives problems in the grid. The house under survey has 5 rooms: a bedroom, a bathroom, a kitchen, a living-room, and an anteroom. The layers of internal and external walls, windows, roofs and floors are thermal modeling into electrical components from which a circuit is assembled. Using node voltage method in each circuit a state space equations are obtained, each of this equations are simulated in MATLAB environment considering electrical heater time of use based on occupant behavior. Having this model allows us to simulate the change of temperature of each room, design efficiency the controls algorithm and estimates peak consumption for improving its reduction.

1 INTRODUCTION

A recent report from the International Energy Agency (IEA, 2018) shows that energy consumption has increased, especially in the residential and commercial buildings sector. Excessive energy consumption nowadays has caused problems for the environment due to the increase in carbon emissions and therefore the reduction of energy consumption especially in buildings is a trend in the world today. Statistics (ERE, 2017) show that in Albania only 49 of total energy goes to residential users. Seeing these problems we decided that the main contribution in this paper is to use analogies between thermal and electrical models and methods in order to obtain a better durability in terms of increasing energy efficiency in buildings. This analogy is the most important objective for smart grid technologies. Reduction of energy consumption can be done by choosing materials that are good thermal insulators or with efficient management of heating or cooling. An energy efficient building has many advantages including reduction of the greenhouse effect, environment degradation, consumption of natural resources, energy dependence on the outside and environmental damage and pollution. It decrease costs in energy from houses and businesses, increase the security of the energy supply and decrease production costs.In this article the thermal model of a house is created using electric circuit analogy (Parnis, 2012),(Vasak et al., 2011), (Ivan et al., 2017). The house is composed of 5 rooms where each of them has an RC circuit model where R and C represent respectively the resistance and thermal capacity of the material of the layer of walls, ceiling, foundation, windows and doors presented in section 2. The current in the circuit represents the heat flux and the electric potential at the point represents the temperature of that point. A model of state space was obtained in each of the circuits. In section 3 we present the temperatures and power consumed by the heaters in each room. The results are obtained by simulating the state space model in the MATLAB environment (Behravan et al., 2017)for 168 hours. We are considering outdoor temperature variation for typical winter day in Tirana Albania (Lee et al., 2016). The model in MATLAB also includes a program that determines the working time of heaters. Knowing that during working days in Albania normal working time is 08:00-16:00. The total power consumed by heaters over a week is shown in section 4 including peak power consumption occurrence and its value.

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2 THERMAL MODEL OF HOUSE

Consider a storey house (Skruch, 2014) containing five rooms: a living-room, a bedroom, an anteroom, a kitchen and a bathroom (Figure 1) (Shi et al., 2018). The external walls of all rooms are made of four layers (the total thickness of the walls is 47 cm) including mineral wool as an insulating material (15 cm), internal (1 cm) and external (1 cm) cement-lime plasters, structural clay tile (30 cm). The internal walls are made of three layers (the thickness of the walls is 12 cm) including brick (10cm) and cement-lime plaster on both sides (1 cm). The roof is flat made of four layers (24.29 cm thick) including mineral wool (20 cm), EPDM (ethylene propylene diene monomer) rubber (4.5 mm), timber wood (2.54 cm) and plaster ceiling tiles (1.3 cm). The foundation is made of five layers (61 cm thick) including gravel (15 cm), aerated concrete slab (20 mm), polystyrene as an insulating material (20 cm), screed (5 cm) and wood (1cm). All exterior and internal doors are made of wood. All windows are double glazed.

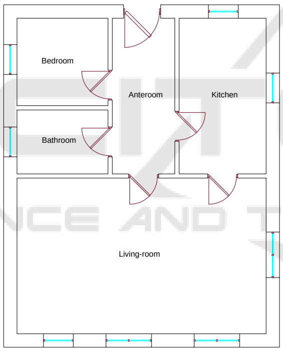

Figure 1: Floor plan of the house.

The surfaces of the internal and external walls, floors, and ceilings $A_{ij}(m^2)$ are summarized in the Table 2. In the Table 1 is shown list of the rooms. In this table are considered as rooms the earth and outer space with index -1 and 0, respectively.

Table 1: List of rooms with associated indexes.

Room name	Index i
Earth	-1
Outer space	0
Bedroom	1
Bathroom	2
Living-room	3
Kitchen	4
Anteroom	5

Table 2: Areas of the surfaces between separated zones.

A_{ij} (m^2)	-1	0	1	2	3	4	5
1	7.51	21.18	0	6.9	0	0	6.77
2	5.31	10.11	6.9	0	6.9	0	4.8
3	36.43	79.36	0	6.9	0	6.87	4.75
4	13.02	31.07	0	0	6.87	0	11.8
5	9.39	14.14	6.77	4.8	4.75	11.8	0

To obtain the thermal models of each room we will first start with the dimensions of the foundation, ceiling, walls, windows and doors. Each of them is made up of several layers of different thicknesses and materials that influence the room's interior temperature. A wall can be represented by an RC electrical circuit where the active electrical resistance R represents the thermal resistance of the layer, the capacitance C represents the thermal capacity of the layer. The same procedure is performed for foundation, ceiling, door and window of the room. Knowing the surface, the thickness and the type of material of each layer, we first calculate the resistance and thermal capacity of the layers then obtaining the whole thermal model of the room based on electrical circuit analogy.

For example, the value of a resistor used to model the thermal resistance of a layer of area A (m^2), thickness x (m) and thermal conductivity k (W/mK) is given by equation 1:

$$R = \frac{x}{A \cdot k} \tag{1}$$

The electrical capacitance used to model the thermal capacitance of a wall layer of area A (m^2), thickness x (m) and made of material with density ρ (kg/m^3) and specific heat c_p ($J/kg \cdot C$) is given by equation 2:

$$C = \frac{x \cdot A \cdot \rho \cdot c_p}{3600} \tag{2}$$

2.1 Bedroom Modeling

The bedroom except the floor, ceiling and walls contain a window which is in contact with the outer space and a door which is in contact with the anteroom. After calculating the resistances and capacities of each layer we create the whole thermal model of the room (Bastida et al., 2019). The exterior walls, foundation and ceiling have the same model for each of the rooms. For this reason, it is not necessary to repeat these equations many times. The equation are written in this section.

State Space equations which determine the temperature of each layer of external wall of Bedroom:

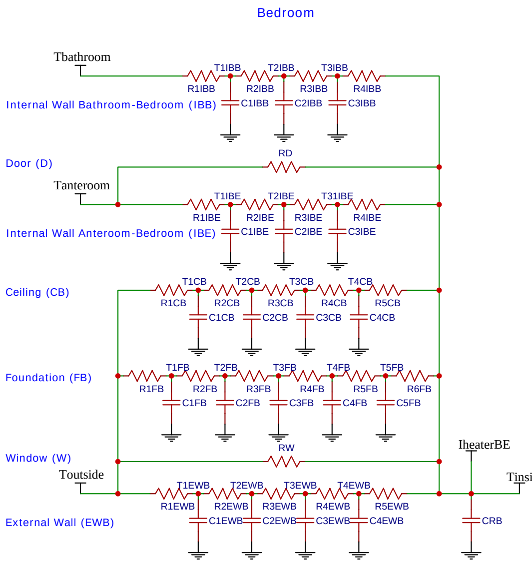

Figure 2: Thermal Circuit Model of Bedroom.

$$\begin{cases} C_{1ewb}\cdot\frac{dT_{1ewb}}{dt}=\frac{T_{outside}-T_{1ewb}}{R_{1ewb}}+\frac{T_{2ewb}-T_{1ewb}}{R_{2ewb}}\\ C_{2ewb}\cdot\frac{dT_{2ewb}}{dt}=\frac{T_{1ewb}-T_{2ewb}}{R_{2ewb}}+\frac{T3ewb-T2ewb}{R3ewb}\\ C_{3ewb}\cdot\frac{dT_{3ewb}}{dt}=\frac{T_{2ewb}-T_{3ewb}}{R_{3ewb}}+\frac{T_{4ewb}-T_{3ewb}}{R_{4ewb}}\\ C_{4ewb}\cdot\frac{dT_{4ewb}}{dt}=\frac{T_{3ewb}-T_{4ewb}}{R_{4ewb}}+\frac{T_{5ewb}-T_{4ewb}}{R_{5ewb}} \end{cases} \quad (3)$$

where, C_{1ewb}, C_{2ewb}, C_{3ewb} and C_{4ewb} - thermal capacities of each layer of external wall (J/C), T_{1ewb}, T_{2ewb}, T_{3ewb}, T_{4ewb} and T_{5ewb} - Temperature of each layer of external wall (C), $T_{outside}$, - outside temperature (C), R_{1ewb}, R_{2ewb}, R_{3ewb}, R_{4ewb} and R_{5ewb} - thermal resistance of each layer of external wall (C/W).

State Space equations which determine the temperature of each layer of foundation of Bedroom:

$$\begin{cases} C_{1fb}\cdot\frac{dT_{1fb}}{dt}=\frac{T_{outside}-T_{1fb}}{R_{1fb}}+\frac{T_{2fb}-T_{1fb}}{R_{2fb}}\\ C_{2fb}\cdot\frac{dT_{2fb}}{dt}=\frac{T_{1fb}-T_{2fb}}{R_{2fb}}+\frac{T_{3fb}-T_{2fb}}{R_{3fb}}\\ C_{3fb}\cdot\frac{dT_{3fb}}{dt}=\frac{T_{3fb}-T_{2fb}}{R_{3fb}}+\frac{T_{4fb}-T_{3fb}}{R_{4fb}}\\ C_{4fb}\cdot\frac{dT_{4fb}}{dt}=\frac{T_{3fb}-T_{4fb}}{R_{4fb}}+\frac{T_{5fb}-T_{4fb}}{R_{5fb}}\\ C_{5fb}\cdot\frac{dT_{5fb}}{dt}=\frac{T_{4fb}-T_{5fb}}{R_{5fb}}+\frac{T_{6fb}-T_{5fb}}{R_{6fb}} \end{cases} \quad (4)$$

where, C_{1fb}, C_{2fb}, C_{3fb}, C_{4fb} and C_{5fb} - thermal capacities of each layer of foundation (J/C), T_{1fb}, T_{2fb}, T_{3fb}, T_{4fb}, T_{5fb} and T_{6fb}, - temperature of each layer of foundation (C), R_{1fb}, R_{2fb}, R_{3fb}, R_{4fb}, R_{5fb} and R_{6fb}- thermal resistance of each layer of foundation (C/W).

State Space equations which determine the temperature of each layer of ceiling of Bedroom:

$$\begin{cases} C_{1cb}\cdot\frac{dT_{1cb}}{dt}=\frac{T_{outside}-T_{1cb}}{R_{1cb}}+\frac{T_{2cb}-T_{1cb}}{R_{2cb}}\\ C_{2cb}\cdot\frac{dT_{2cb}}{dt}=\frac{T_{1cb}-T_{2cb}}{R_{2cb}}+\frac{T_{3cb}-T_{2cb}}{R_{3cb}}\\ C_{3cb}\cdot\frac{dT_{3cb}}{dt}=\frac{T_{2cb}-T_{3cb}}{R_{3cb}}+\frac{T_{4cb}-T_{3cb}}{R_{4cb}}\\ C_{4cb}\cdot\frac{dT_{4cb}}{dt}=\frac{T_{3cb}-T_{4cb}}{R_{4cb}}+\frac{T_{5cb}-T_{4cb}}{R_{5cb}} \end{cases} \quad (5)$$

where, C_{1cb}, C_{2cb}, C_{3cb} and C_{4cb} - thermal capacities of each layer of ceiling (J/C), T_{1cb}, T_{2cb}, T_{3cb}, T_{4cb} and T_{5cb} - Temperature of each layer of external ceiling (C), R_{1cb}, R_{2cb}, R_{3cb}, R_{4cb} and R_{5cb} - thermal resistance of each layer of external ceiling (C/W).

State Space equations which determine the temperature of each layer of internal wall between anteroom and bedroom:

$$\begin{cases} C_{1be}\cdot\frac{dT_{1be}}{dt}=\frac{T_{anteroom}-T_{1be}}{R_{1be}}+\frac{T_{2be}-T_{1be}}{R_{2be}}\\ C_{2be}\cdot\frac{dT_{2be}}{dt}=\frac{T_{1be}-T_{2be}}{R_{2be}}+\frac{T_{3be}-T_{2be}}{R_{3be}}\\ C_{3be}\cdot\frac{dT_{3be}}{dt}=\frac{T_{2be}-T_{3be}}{R_{3be}}+\frac{T_{4be}-T_{3be}}{R_{4be}} \end{cases} \quad (6)$$

where, C_{1be}, C_{2be} and C_{3be} - thermal capacities of each layer of internal wall between anteroom and bedroom (J/C), T_{1be}, T_{2be}, T_{3be} and T_{4be} - temperature of each layer of internal wall between anteroom and bedroom (C), $T_{anteroom}$, - anteroom temperature (C), R_{1be}, R_{2be}, R_{3be} and R_{4be} - thermal resistance of each layer of internal wall between anteroom and bedroom (C/W).

State Space equations which determine the temperature of each layer of internal wall between bathroom and bedroom:

$$\begin{cases} C_{1ibb}\cdot\frac{dT_{1ibb}}{dt}=\frac{T_{bathroom}-T_{1ibb}}{R_{1ibb}}+\frac{T_{2ibb}-T_{1ibb}}{R_{2ibb}}\\ C_{2ibb}\cdot\frac{dT_{2ibb}}{dt}=\frac{T_{1ibb}-T_{2ibb}}{R_{2ibb}}+\frac{T_{3ibb}-T_{2ibb}}{R_{3ibb}}\\ C_{3ibb}\cdot\frac{dT_{3ibb}}{dt}=\frac{T_{2ibb}-T_{3ibb}}{R_{3ibb}}+\frac{T_{4ibb}-T_{3ibb}}{R_{4ibb}} \end{cases} \quad (7)$$

where, C_{1bb}, C_{2bb} and C_{3bb} - thermal capacities of each layer of internal wall between bathroom and bedroom (J/C), T_{1bb}, T_{2bb}, T_{3bb} and T_{4bb} - temperature of each layer of internal wall between bathroom and bedroom (C),$T_{bathroom}$, - bathroom temperature (C), R_{1bb}, R_{2bb}, R_{3bb} and R_{4bb} - thermal resistance of each layer of internal wall between bathroom and bedroom (C/W).

Differential equation which determine the temperature of bedroom:

$$\begin{cases} C_{rb}\cdot\frac{dT_{inside}}{dt}=\frac{T_{4ewb}-T_{inside}}{R_{5ewb}}+\frac{T_{outside}-T_{inside}}{R_{w}}\\ +\frac{T_{5fb}-T_{inside}}{R_{6fb}}+\frac{T_{4cb}-T_{inside}}{R_{5cb}}+\frac{T_{3be}-T_{inside}}{R_{4be}}\\ +\frac{T_{anteroom}-T_{inside}}{R_{d}}+\frac{T_{3ibb}-T_{inside}}{R_{3ibb}}+I_{heatrerBE} \end{cases} \quad (8)$$

where, C_{rb} - thermal capacities of bedroom (J/C), T_{inside}, - bedroom temperature (C), R_w - thermal resistance of the window of room (C/W), R_d - thermal resistance of the door of room (C/W), $I_{heatrerBE}$- heat flux of heater in bedroom.

2.2 Bathroom Modeling

The bathroom except the floor, ceiling and walls contain a window which is in contact with the outer space and a door which is in contact with the anteroom. After calculating the resistances and capacities of each layer we create the whole thermal model of the room.

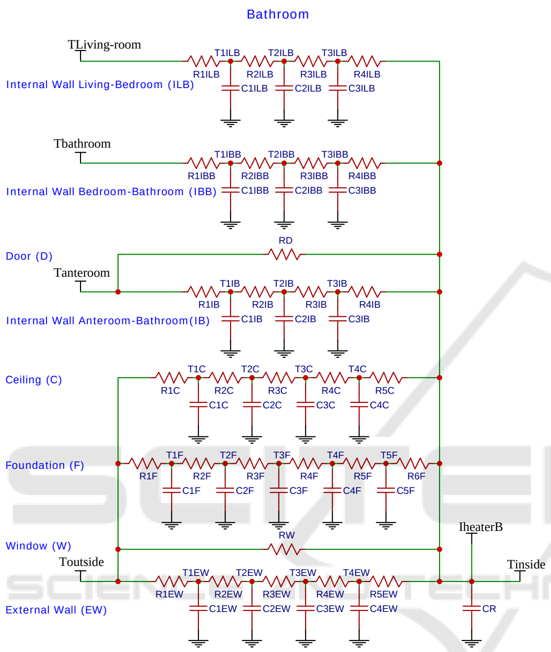

Figure 3: Thermal Circuit Model of Bathroom.

State Space equations which determine the temperature of each layer of internal wall between anteroom and bathroom:

$$\left\{\begin{aligned} C_{1ib}\cdot\frac{dT_{1ib}}{dt} &= \frac{T_{anteroom}-T_{1ib}}{R_{1ib}}+\frac{T_{2ib}-T_{1ib}}{R_{2ib}} \\ C_{2ib}\cdot\frac{dT_{2ib}}{dt} &= \frac{T_{1ib}-T_{2ib}}{R_{2ib}}+\frac{T_{3ib}-T_{2ib}}{R_{3ib}} \\ C_{3ib}\cdot\frac{dT_{3ib}}{dt} &= \frac{T_{2ib}-T_{3ib}}{R_{3ib}}+\frac{T_{4ib}-T_{3ib}}{R_{4ib}} \end{aligned}\right\} \quad (9)$$

where, C_{1ib}, C_{2ib} and C_{3ib}- thermal capacities of each layer of internal wall between anteroom and bathroom (J/C), T_{1ib}, T_{2ib}, T_{3ib} and T_{4ib} - temperature of each layer of internal wall between anteroom and bathroom (C), Tanteroom, - anteroom temperature (C) R_{1ib}, R_{2ib}, R_{3ib} and R_{4ib} - thermal resistance of each layer of internal wall between anteroom and bathroom (C/W)

State Space equations which determine the temperature of each layer of internal wall between bedroom and bathroom are the same as (7).

System of differential equations which determine the temperature of each layer of internal wall between bathroom and living-room:

$$\left\{\begin{aligned} C_{1ilb}\cdot\frac{dT_{1ilb}}{dt} &= \frac{T_{Living}-T_{1ilb}}{R_{1ilb}}+\frac{T_{2ilb}-T_{1ilb}}{R_{2ilb}} \\ C_{2ilb}\cdot\frac{dT_{2ilb}}{dt} &= \frac{T_{1ilb}-T_{2ilb}}{R_{2ilb}}+\frac{T_{3ilb}-T_{2ilb}}{R_{3ilb}} \\ C_{3ilb}\cdot\frac{dT_{3ilb}}{dt} &= \frac{T_{2ilb}-T_{3ilb}}{R_{3ilb}}+\frac{T_{4ilb}-T_{3ilb}}{R_{4ilb}} \end{aligned}\right\} \quad (10)$$

where, C_{1lb}, C_{2lb} and C_{3lb} - thermal capacities of each layer of internal wall between living-room and bathroom (J/C), T_{1lb}, T_{2lb}, T_{3lb} and T_{4lb} - temperature of each layer of internal wall between living-room and bathroom (C), TLiving-room, - Living-room temperature (C) R_{1lb}, R_{2lb}, R_{3lb} and R_{4lb} - thermal resistance of each layer of internal wall between anteroom and bathroom (C/W)

Differential equations which determine the temperature of bedroom:

$$\left\{\begin{aligned} & C_r\cdot\frac{dT_{inside}}{dt} = \frac{T_{4ew}-T_{inside}}{R5ew}+\frac{T_{outside}-Tinsde}{R_w} \\ & +\frac{T_{5f}-T_{inside}}{R_{6f}}+\frac{T_{4c}-T_{inside}}{R_{5c}}+\frac{T_{5ib}-Tinsde}{R_{4ib}} \\ & +\frac{T_{anteroom}-T_{inside}}{R_d}+\frac{T_{3ibb}-T_{inside}}{R_{4ibb}} \\ & +\frac{T3ilb-Tinsde}{R4ilb}+I_{heatrerB} \end{aligned}\right\} \quad (11)$$

where, C_r - thermal capacities of bathroom (J/C), T_{inside}, - bathroom temperature (C), R_w - thermal resistance of the window (C/W), R_d - thermal resistance of the door (C/W), $I_{heatrerB}$- heat flux of heater in bathroom.

2.3 Living-room Modeling

The Living-room except the floor, ceiling and walls contain four windows which are in contact with the outer space and two doors which are in contact respectively with anteroom and kitchen. After calculating the resistances and capacities of each layer we create the whole thermal model of the room.

State Space equations which determine the temperature of each layer of internal wall between living-room and anteroom:

$$\left\{\begin{aligned} C_{1ik}\cdot\frac{dT_{1ik}}{dt} &= \frac{T_{anteroom}-T_{1ik}}{R_{1ik}}+\frac{T_{2ik}-T_{1ik}}{R_{2ik}} \\ C_{2ik}\cdot\frac{dT_{2ik}}{dt} &= \frac{T_{1ik}-T_{2ik}}{R_{2ik}}+\frac{T_{3ik}-T_{2ik}}{R_{3ik}} \\ C_{3ik}\cdot\frac{dT_{3ik}}{dt} &= \frac{T_{2ik}-T_{3ik}}{R_{3ik}}+\frac{T_{4ik}-T_{3ik}}{R_{4ik}} \end{aligned}\right\} \quad (12)$$

where, C_{1ik}, C_{2ik} and C_{3lik} - thermal capacities of each layer of internal wall between anteroom and living-room (J/C), T_{1ik}, T_{2ik}, T_{3ik} and T_{4ik} - temperature of each layer of internal wall between anteroom and living-room (C), $T_{anteroom}$, - anteroom temperature (C) R_{1ik}, R_{2ik}, R_{3ik} and R_{4ik} - thermal resistance of each

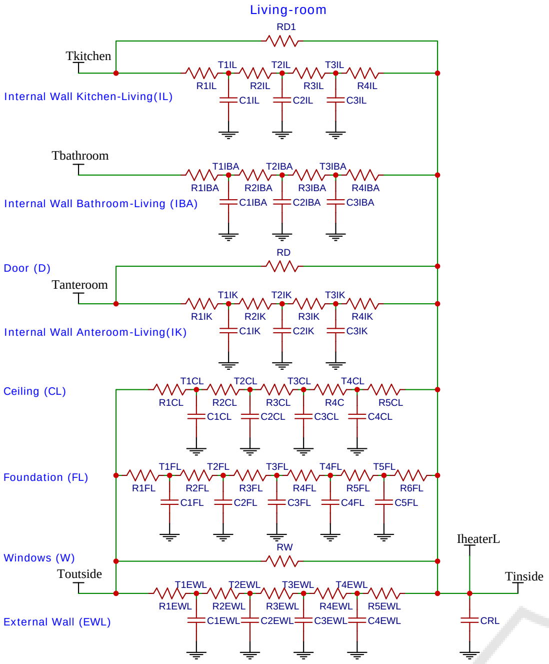

Figure 4: Thermal Circuit Model of Living-room.

layer of internal wall between anteroom and living-room (C/W).

State Space equations which determine the temperature of each layer of internal wall between living-room and bathroom are the same as (10).

State Space equations which determine the temperature of each layer of internal wall between kitchen and living-room:

$$\left\{\begin{aligned} C_{1il}\cdot\frac{dT_{1il}}{dt} &= \frac{T_{kitchen}-T_{1il}}{R_{1il}}+\frac{T_{2il}-T_{1il}}{R_{2il}}\\ C_{2il}\cdot\frac{dT_{2il}}{dt} &= \frac{T_{1il}-T_{2il}}{R_{2il}}+\frac{T_{3il}-T_{2il}}{R_{3il}}\\ C_{3il}\cdot\frac{dT_{3il}}{dt} &= \frac{T_{2il}-T_{3il}}{R_{3il}}+\frac{T_{4il}-T_{3il}}{R_{4il}} \end{aligned}\right\} \tag{13}$$

where, C_{1il}, C_{2il} and C_{3lil} - thermal capacities of each layer of internal wall between living-room and kitchen (J/C), T_{1il}, T_{2il}, T_{3il} and T_{4il} - temperature of each layer of internal wall between living-room and kitchen (C), $T_{kitchen}$, - kitchen temperature (C) R_{1il}, R_{2il}, R_{3il} and R_{4il} - thermal resistance of each layer of internal wall between living-room and kitchen (C/W)

Differential equations which determine the temperature of living-room:

$$\left\{\begin{aligned} & C_{rl}\cdot\frac{dT_{inside}}{dt} = \frac{T_{4ewl}-T_{inside}}{R_{5ewl}}+\frac{T_{outside}-T_{inside}}{R_{w}}\\ & +\frac{T_{5fl}-T_{inside}}{R_{6fl}}+\frac{T_{4cl}-T_{inside}}{R_{5cl}}+\frac{T_{3ik}-T_{inside}}{R_{4ik}}\\ & +\frac{T_{anteroom}-T_{inside}}{R_{d}}+\frac{T_{3iba}-T_{inside}}{R_{4iba}}\\ & +\frac{T_{3il}-T_{inside}}{R_{4il}}+I_{heaterL} \end{aligned}\right\} \tag{14}$$

where, C_{rl} - thermal capacities of living-room (J/C), T_{inside}, - living-room temperature (C), R_w - thermal resistance of the window (C/W), R_d - thermal resistance of the door (C/W), $I_{heatrerL}$- heat flux of heater in living-room.

2.4 Kitchen Modeling

The Kitchen except the floor, ceiling and walls contain two windows which are in contact with the outer space and two doors which are in contact respectively with anteroom and living-room. After calculating the resistances and capacities of each layer we create the whole thermal model of the room.

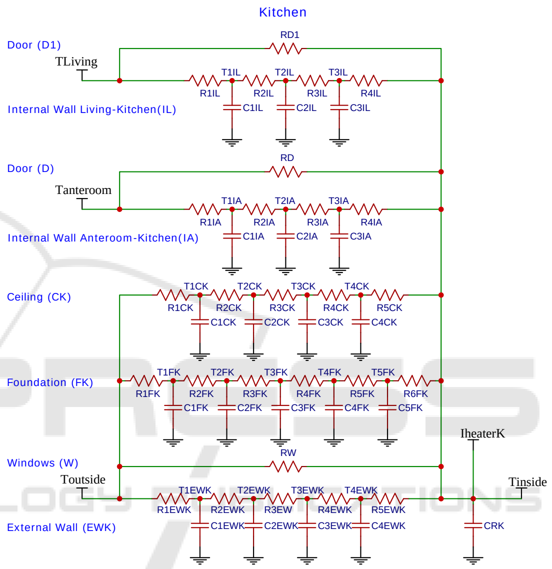

Figure 5: Thermal Circuit Model of Kitchen.

State Space equations which determine the temperature of each layer of internal wall between kitchen and anteroom:

$$\left\{\begin{aligned} C_{1ia}\cdot\frac{dT_{1ia}}{dt} &= \frac{T_{anteroom}-T_{1ia}}{R_{1ia}}+\frac{T_{2ia}-T_{1ia}}{R_{2ia}}\\ C_{2ia}\cdot\frac{dT_{2ia}}{dt} &= \frac{T_{1ia}-T_{2ia}}{R_{2ia}}+\frac{T_{3ia}-T_{2ia}}{R_{3ia}}\\ C_{3ia}\cdot\frac{dT_{3ia}}{dt} &= \frac{T_{2ia}-T_{3ia}}{R_{2ia}}+\frac{T_{4ia}-T_{3ia}}{R_{4ia}} \end{aligned}\right\} \tag{15}$$

where, C_{1ia}, C_{2ia} and C_{3lia} - thermal capacities of each layer of internal wall between anteroom and kitchen (J/C), T_{1ia}, T_{2ia}, T_{3ia} and T_{4ia} - temperature of each layer of internal wall between between anteroom and kitchen (C), $T_{anteroom}$, - anteroom temperature (C) R_{1ia}, R_{2ia}, R_{3ia} and R_{4ia} - thermal resistance of each layer of internal wall between anteroom and kitchen (C/W)

State Space equations which determine the temperature of each layer of internal wall between living-room and kitchen are the same as (13). Differential equations which determine the temperature of kitchen:

$$\begin{cases} C_{rk} \cdot \frac{dT_{inside}}{dt} = \frac{T_{4ewk}-T_{inside}}{R_{5ewk}} \\ + \frac{T_{5fk}-T_{inside}}{R_{6fk}} + \frac{T_{4ck}-T_{inside}}{R_{5ck}} + \frac{T_{living}-T_{inside}}{R_{d1}} \\ + \frac{T_{anteroom}-T_{inside}}{Rd} + \frac{T_{3il}-T_{inside}}{R_{4il}} \\ + \frac{T_{3ia}-T_{inside}}{R_{4ia}} + \frac{T_{outside}-T_{inside}}{R_w} + I_{heatrerK} \end{cases} \quad (16)$$

where, C_{rk} - thermal capacities of living-room (J/C), T_{inside}, - living-room temperature (C), R_w - thermal resistance of the window (C/W), R_d - thermal resistance of the door (C/W), $I_{heatrerK}$- heat flux of heater in kitchen.

2.5 Anteroom Modeling

The anteroom except the floor, ceiling and walls contain five doors which are in contact respectively with outer space, bedroom, bathroom, living-room and kitchen. After calculating the resistances and capacities of each layer we create the whole thermal model of the room.

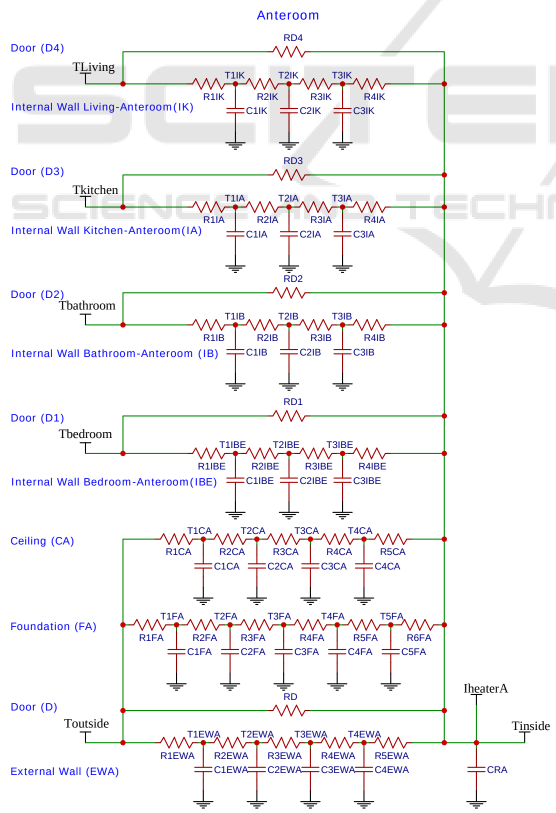

Figure 6: Thermal Circuit Model of Anteroom.

State Space equations which determine the temperature of each layer of internal wall between kitchen and anteroom:

$$\begin{cases} C_{1ia} \cdot \frac{dT_{1ia}}{dt} = \frac{T_{anteroom}-T_{1ia}}{R_{1ia}} + \frac{T_{2ia}-T_{1ia}}{R_{2ia}} \\ C_{2ia} \cdot \frac{dT_{2ia}}{dt} = \frac{T_{1ia}-T_{2ia}}{R_{2ia}} + \frac{T_{3ia}-T_{2ia}}{R_{3ia}} \\ C_{3ia} \cdot \frac{dT_{3ia}}{dt} = \frac{T_{2ia}-T_{3ia}}{R_{3ia}} + \frac{T_{4ia}-T_{3ia}}{R_{4ia}} \end{cases} \quad (17)$$

where, C_{1ia}, C_{2ia} and C_{3lia} - thermal capacities of each layer of internal wall between anteroom and kitchen (J/C), T_{1ia}, T_{2ia}, T_{3ia} and T_{4ia} - temperature of each layer of internal wall between between anteroom and kitchen (C), $T_{anteroom}$, - anteroom temperature (C) R_{1ia}, R_{2ia}, R_{3ia} and R_{4ia} - thermal resistance of each layer of internal wall between anteroom and kitchen (C/W).

System of differential equations which determine the temperature of each layer of internal wall between bedroom and anteroom, bathroom and anteroom, living-room and anteroom, kitchen and anteroom are respectively the same as (6), (9), (12) and (15).

Differential equations which determine the temperature of anteroom:

$$\begin{cases} C_{ra} \cdot \frac{dT_{inside}}{dt} = \frac{T_{4ewa}-T_{inside}}{R_{5ewa}} \\ + \frac{T_{5fa}-T_{inside}}{R_{6fa}} + \frac{T_{4ca}-T_{inside}}{R_{5ca}} + \frac{T_{3ibe}-T_{inside}}{R_{4ibe}} \\ + \frac{T_{bedroom}-T_{inside}}{R_{d1}} + \frac{T_{3ib}-T_{inside}}{R_{4ib}} \\ + \frac{T_{bathroom}-T_{inside}}{R_{d2}} + \frac{T_{kitchen}-T_{inside}}{R_{d3}} \\ + \frac{T_{living}-T_{inside}}{R_{d4}} + \frac{T_{3ik}-T_{inside}}{R_{4ik}} \\ + \frac{T_{3ia}-T_{inside}}{R_{4ia}} + \frac{T_{outside}-T_{inside}}{R_d} + I_{heaterA} \end{cases} \quad (18)$$

where, C_{ra} - thermal capacities of anteroom (J/C), T_{inside}, - anteroom temperature (C),(C/W), R_d, R_{d1},R_{d2},R_{d3},R_{d4} - thermal resistance of doors (C/W), $I_{heatrerA}$- heat flux of heater in anteroom.

3 SIMULATION RESULT

Based on the State Space equations obtained from the models of thermal circuits of each room we create models of each room in the Simulink MATLAB environment. Knowing the dimensions of each layer given in the first section and the values of the thermal parameters of each layer Table 4 are calculated the thermal capacity and resistance of each layer based on equations (1) and (2).

The model in this environment has been simulated for 168 hours where the outside temperatures are taken over a week in the city of Tirana, Albania shown graphically in Figure 7. Knowing that people in Albania normally work from Monday to Friday

Table 3: Time of use of heater in each room.

Room	Day	Operating hours	Run-Time (hours)
Living room	Monday	17:00-23:00	6
	Tuesday	17:00-22:00	5
	Wednesday	18:00-23:00	5
	Thursday	17:00-23:00	6
	Friday	16:00-24:00	8
	Saturday	8:00-10:00	2
		16:00-23:00	7
	Saturday	8:00-10:00	2
		16:00-23:00	7
Bedroom	Monday	21:00-23:30	2.5
	Tuesday	20:00-23:00	3
	Wednesday	22:00-24:00	2
	Thursday	21:00-23:30	2.5
	Friday	21:00-24:00	3
	Saturday	20:00-23:00	3
	Saturday	21:00-24:00	3
Kitchen	Monday	18:00-21:30	3
	Tuesday	17:00-19:00	2
	Wednesday	17:30-20:00	2.5
	Thursday	18:00-21:00	3
	Friday	19:00-22:00	3
	Saturday	10:00-13:00	3
		19:00-21:30	2.5
	Saturday	11:00-13:00	2
		18:00-21:00	3
Anteroom	Monday	17:00-23:00	6
	Tuesday	17:00-22:00	5
	Wednesday	18:00-23:00	5
	Thursday	17:00-23:00	6
	Friday	16:00-24:00	8
	Saturday	08:00-12:00	4
		16:00-23:00	7
	Saturday	08:00-13:00	5
		16:00-23:00	7
Bathroom	Monday	22:00-23:00	1
	Tuesday	21:00-23:00	2
	Wednesday	22:00-23:00	1
	Thursday	21:00-23:00	2
	Friday	22:00-23:00	1
	Saturday	08:00-09:00	1
	Saturday	21:00-23:00	2

between 8:00 and 16:00, we decide the time of operation of the heaters in each room. The temperature is controlled with the two-position ON-OFF regulator.

After simulating the thermal model of Living-room, bedroom, kitchen, anteroom and bathroom where was implemented also a program which control the time of use of heater in each room based in table 3, the simulation results are obtained and shown graphically in Figures 8-12.

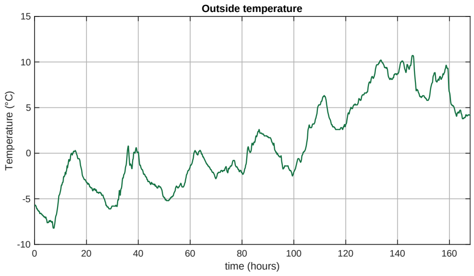

Figure 7: Outside temperature.

Table 4: Time of use of heater.

Material Description	k $(W/m \cdot K)$	c_p $(J/kg \cdot C)$	ρ $(W/m \cdot K)$
Gravel	0.360	840	1840
Aerated Concrete slab	0.160	840	500
Polystyrene	0.030	1380	25
Screed	0.410	840	1200
Wood	0.22	1360	550
Cement Plaster	0.720	800	1860
Brick	0.840	800	1700
Mosque	0.024		
Mineral Wool	0.046	837	10
Clay Tile	0.840	800	1900
Air	10	1005	1.205
EPDM	0.17	2000	110
Timber Wood	0.121	837	593
Plaster Ceiling Tiles	0.380	840	1120

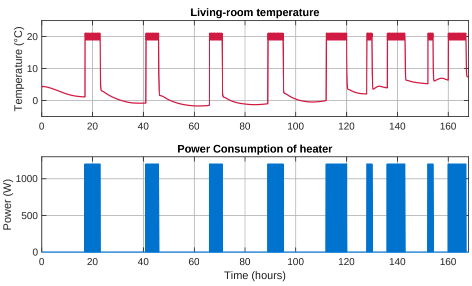

Figure 8: Living-room temperature and power consumption.

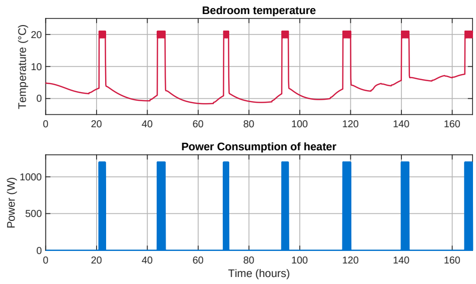

Figure 9: Bedroom temperature and power consumption.

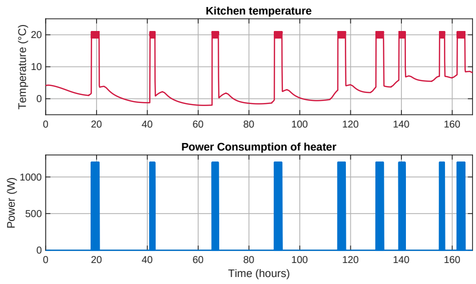

Figure 10: Kitchen temperature and power consumption.

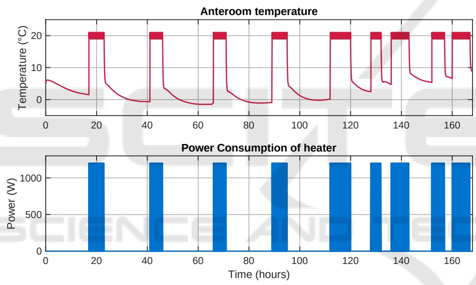

Figure 11: Anteroom temperature and power consumption.

4 CONCLUSION

The purposes of this paper has been to develop thermal model of a house using electrical RC circuit analogy to analyze the temperatures and power consumption of heaters in each room. This analogy makes it possible to develop directly accurate models insofar as the temperatures within the walls are not required. This model is described using state space equations for temperature response of each room because it is an efficient and practical method to reduce energy consumption and to improve thermal comfort. We simulated the model in order to take the temperature of each room in Matlab, Simulink environment. Dynamics in temperature are controlled using two positional regulator in specified hours. Total power consumption of all heaters, which is shown in Figure 13 indicates the peak demand occurs between 19:00-20:00 in Tuesday and 08:00- 09:00 in Saturday. Because

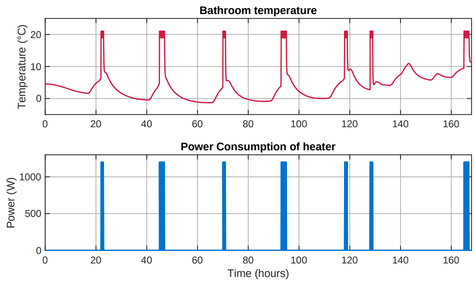

Figure 12: Bathroom temperature and power consumption.

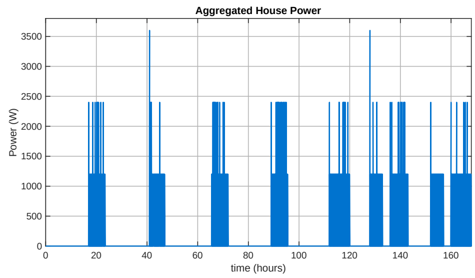

Figure 13: Total power consumption.

of negative effect of peak demand (the cost of energy production is high due to the use of peaking power plants) in the future our focus will be reducing energy for heating using Model Predictive Control (MPC).

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