Evaluation of the Heating & Cooling Energy Demand of a Case Residential Building by Comparing The National Calculation Methodology of Turkey and EnergyPlus through Thermal Capacity Calculations

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ABSTRACT

In all around the world, because of the rapid population growth and exhausting energy sources over time, energy efficiency and energy conservation gradually come into prominence. Hence, in 2002, a directive (EPBD) which obligates reducing energy usage and energy performance in buildings was published by European Union. In this scope, Turkey has developed a National Building Energy Performance Calculation Methodology, BepTr, which is based on simple hourly method in ISO EN 13790 Umbrella Document to determine the energy performance of buildings.

The aim of the paper is to display the energy demand differences resultant from only the envelope's thermal capacity between simplified method which is projected in ISO EN 13790 Umbrella Document and EnergyPlus which is based on full dynamic simulation method.

INTRODUCTION

In all around the world, because of the rapid population growth and exhausting energy sources over time, energy efficiency and energy conservation gradually come into prominence. Hence, a directive which obligates reducing energy usage in buildings improving building energy performance (2002) was published by European countries as a frame work of EPBD. As an emerging country, in Turkey the energy demand is also rapidly rising. The Energy Density is an indicator that is used by all around the world, and it represents primary energy amount which is consumed per gross national product. In Turkey, energy consumption per person is around one fifth of OECD average (2009) and the Energy Density rate is more than twice of European Union Countries (TUIK, 2009).

In the view of such information, in our country that cannot use energy efficiently in production and consumption, and its energy demand rapidly rising for reduction of the energy density, in addition to Building Energy Performance Regulation and Thermal Insulation Regulation in Buildings, as a requirement of the EU accession period Energy Efficiency Act (2007), Enhancing The Efficiency of Usage of Energy Sources and Energy regulation are also came into force.

In Turkey, % 40 of the produced energy is consumed in buildings. As from now on, Turkey has the potential of energy saving to minimize the energy consumption without conceding life comfort by providing efficient usage of the energy. According to the Ministry of Energy (2010), the ratio of energy saving potential is %30 in building sector, %20 in industry sector, and %15 in transportation sector.

Within the scope of this paper, there are two different calculation methodologies for determination of the energy class of buildings by primary energy consumption, has been tested for residential building typologies, such as a single family house as a case study. Calculation of heating and cooling energy demand in ISO EN 13790 umbrella document is based on simple hourly method. The comparison methodologies are simple hourly method and "EnergyPlus" which is a well known dynamic calculation methodology basing on simultaneous multi-zone calculation.

METHODOLOGY

According to EPBD, Building Energy Performance is an amount of the energy which is used in buildings to supply typical requirements of a building such as heating, cooling, ventilation and lighting depending on building typology. All parameters which affect Building Energy Performance are needed to be handled as an integrated system.

The energy balance which is the basic principle of the calculation procedure at the building zone level includes:

- transmission heat transfer between the conditioned space and the external environment, governed by the difference between the temperature of the conditioned zone and the external temperature;
- ventilation heat transfer (by natural ventilation or by a mechanical ventilation system), governed by the difference between the temperature of the conditioned zone and the supply air temperature;
- transmission and ventilation heat transfer between adjacent zones, governed by the difference between the temperature of the conditioned zone and the internal temperature in the adjacent space;
- internal heat gains (including negative gains from heat sinks), for instance from persons, appliances, lighting and heat dissipated in, or absorbed by, heating, cooling, hot water or ventilation systems;
- solar heat gains (which can be direct, e.g. through windows, or indirect, e.g. via absorption in opaque building elements);
- storage of heat in, or release of stored heat from, the mass of the building;
- energy need for heating: if the zone is heated, a heating system supplies heat in order to raise the internal temperature to the required minimum level (the set-point for heating);
- energy need for cooling: if the zone is cooled, a cooling system extracts heat in order to lower the internal temperature to the required maximum level (the set-point for cooling).

Different Calculation Methods

In basic, there are two types of calculation methods:

- quasi-steady-state methods, calculating the heat balance over a sufficiently long time (typically one month or a whole season), which enables one to take dynamic effects into account by an empirically determined gain and/or loss utilization factor;
- dynamic methods, calculating the heat balance with short times steps (typically one hour) taking into account the heat stored in, and released from, the mass of the building.

"Energy performance of buildings – Calculation of energy use for space heating and cooling" EN ISO 13790:2008 International Standard covers three different types of method:

- a fully prescribed monthly quasi-steady-state calculation method (plus, as a special option, a seasonal method);
- a fully prescribed simple hourly dynamic calculation method;
- calculation procedures for detailed (e.g. hourly) dynamic simulation methods.

The alternative simple method for hourly calculations has been added to facilitate the calculation using hourly user schedules (such as temperature set-points, ventilation modes, operation schedule of movable solar shading and/or hourly control options based on outdoor or indoor climatic conditions).

The procedures for the use of more detailed simulation methods ensure compatibility and consistency between the applications of different types of method.

At national level, it may be decided which of these three types of method are mandatory or are allowed to be used, depending on the application (purpose of the calculation) and building type. This choice typically depends on the use of the building (residential, office, etc.), the complexity of the building and/or systems, the application (energy performance requirement, energy performance certificate or recommended energy performance measures, other).

Dynamic methods

In the dynamic methods, an instantaneous surplus of heat during the heating period has the effect that the internal temperature rises above the set-point, thus removing the surplus heat by extra transmission, ventilation and accumulation, if not mechanically cooled. Also, a thermostat set-back or switch-off might not lead directly to a drop in the internal temperature, due to the inertia of the building (heat released from the building mass). A similar situation applies to cooling.

A dynamic method models thermal transmission, heat flow by ventilation, thermal storage and internal and solar heat gains in the building zone. The heat capacity calculation is defined in ISO EN 13786 "Thermal Performance of Building Components – Dynamic Thermal Characteristics – Calculation Methods :2007".

Quasi-steady-state methods

In the quasi-steady-state methods, the dynamic effects are taken into account by introducing correlation factors.

For heating, a utilization factor for the internal and solar heat gains takes account of the fact that only part of the internal and solar heat gains is utilized to decrease the energy need for heating, the rest leading to an undesired increase of the internal temperature above the set-point.

For cooling, there are two different ways to represent the same method:

a) utilization factor for losses (mirror image of the approach for heating)
b) utilization factor for gains (similar as for heating)

Simple hourly method coupling the thermal mass

Heat transfer by transmission is split into the window part, H_{tr},w, taken as having zero thermal mass, and the remainder, Htr,op, containing the thermal mass which in turn is split into two parts: Htr,em and Htr,ms. The thermal mass is represented by a single thermal capacity, Cm, located between Htr,ms and Htr,em. A coupling conductance is defined between the internal air node and the central node.

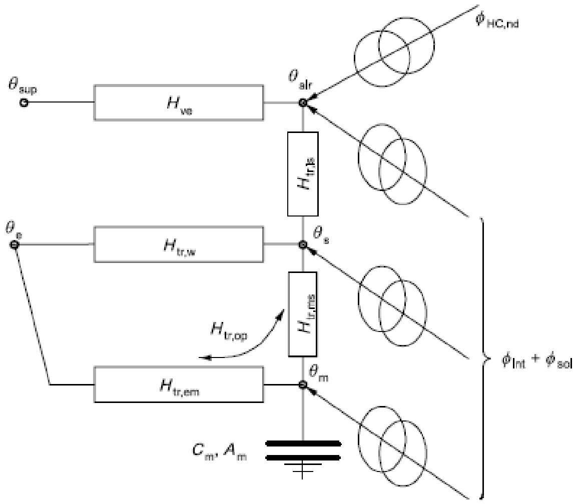


Figure 1 Five resistances, one capacitance (5R1C) model

$$H_{em} = 1/(1/H_{op} - 1/H_{ms}) \quad (1)$$
$$H_{ms} = h_{ms}A_m \quad (2)$$

H_{ms} is the coupling conductance between nodes m and s, expressed in watts per kelvin;
h_{ms} is the heat transfer coefficient between nodes m and s, with fixed value hms = 9,1, expressed in watts per square metres kelvin;
A_m is the effective mass area, expressed in square metres.

$$A_m = C_{m^2} / (\sum x A_j \ x \ \kappa_j) \quad (3)$$

Cm is the internal heat capacity, determined in accordance with 12.3.1, expressed in joules per kelvin;
Aj is the area of the element j, expressed in square metres;
κj is the internal heat capacity per area of the building element j, expressed in joules per square metres kelvin.

Simple hourly method internal heat capacity of the building

For the simple hourly method, the internal heat capacity of the building zone, Cm, expressed in joules per Kelvin, is calculated by summing the heat capacities of all the building elements in direct thermal contact with the internal air of the zone under consideration, also by using Equation (4).

$$C_m = \sum x A_j \ x \ \kappa j \quad (4)$$

Table 1 - Maximum thickness to be considered for internal heat capacity.

Application	Maximum thickness m
Determination of the gain or loss utilization factor (period of variations: 1d)	0,10

Alternatively, it may be decided nationally, for specific applications and building types, to use default values as a function of the type of construction. In the absence of national values, the values from Table 2 may be used.

Table 2 - Default values for dynamic parameters.

Class[a]	Monthly and seasonal method	Simple hourly method	
	C_m J/K[b]	A_m m^2	C_m J/K
Very light	80 000 × A_f	2,5 × A_f	80 000 × A_f
Light	110 000 × A_f	2,5 × A_f	110 000 × A_f
Medium	165 000 × A_f	2,5 × A_f	165 000 × A_f
Heavy	260 000 × A_f	3,0 × A_f	260 000 × A_f
Very heavy	370 000 × A_f	3,5 × A_f	370 000 × A_f

THE CASE BUILDING

The case study presented and evaluated is a residential building, located in Istanbul city, TURKEY. Case building is a floor which is located in between two other conditioned floors in a multistory apartment block. The floor area is 65,3 m^2 consisting living and cooking areas. Three occupants accommodate in the house. The transparency is only on the south façade of the building while other facades are totally opaque. The boundary conditions of the facades are determined as adiabatic for north and east exterior (adjacent to other residential units) walls.

The case building is located in the low density city and it is open to environmental effects. Air tightness level is high depending on air change value (n50). By this way, obtained air change rate per hour is shown in the Table 3. The selected materials which are given in Table 4 are same for both simple hourly and dynamic method. The transparency ratio of the south surface is selected %20 to show the effect of the thermal mass from the opaque parts (Figure 2). The heating set point is 19°C and the cooling is 26°C.

Five different construction and material types are selected for the external walls as shown in Table 4. Basically all the construction layers are the same except the core materials as air gap, brick, aerated concrete, concrete and stone.

Table 3. Air change rate per hour.

Shielding class	Air change value 1/h (n50)	Tightness	Air change per hour (n)
Open	2	High	0,5

Table4. Material list

STEEL CONSTRUCTION					Only BepTr		Only EnergyPlus	
Name of the Material	Thickness	Thermal conductivity	Density	Emissivity	Cm	Am	Roughness	Cp
	(d)	(λ) W/(m2K)	ρ (kg/m3)	ε	(ISO EN 13790)			J/kgK
	m							EN10456
Cement mortar	0,03	1,6	1400	0,9	2,5	165000	Medium	1000
EPS	0,04	0,04	30	-	2,5	110000	Medium	920
Fibercement Panel	0,01	0,37	1000	-	2,5	165000	Medium	1250
Air Gap (Steel Stud)	**0,15**	**0,16(R)**		**-**			**Smooth**	
Gypsum Board	0,025	0,25	800	-	2,5	165000	Medium	1090

BRICK CONSTRUCTION					Only BepTr		Only EnergyPlus	
Name of the Material	Thickness	Thermal conductivity	Density	Emissivity	Cm	Am	Roughness	Cp
	(d)	(λ) W/(m2K)	ρ (kg/m3)	ε	(ISO EN 13790)			J/kgK
	m							EN10456
Cement mortar	0,03	1,6	1400	0,9	2,5	165000	Medium	1000
EPS	0,04	0,04	30	-	2,5	110000	Medium	920
Fibercement Panel	0,01	0,37	1000	-	2,5	165000	Medium	1250
Brick	**0,15**	**0,35**	**650**	**-**	**2,5**	**110000**	**Medium**	**1000**
Gypsum Board	0,025	0,25	800	-	2,5	165000	Medium	1090

AERATED CONCRETE CONSTRUCTION					Only BepTr		Only EnergyPlus	
Name of the Material	Thickness	Thermal conductivity	Density	Emissivity	Cm	Am	Roughness	Cp
	(d)	(λ) W/(m2K)	ρ (kg/m3)	ε	(ISO EN 13790)			J/kgK
	m							EN10456
Cement mortar	0,03	1,6	1400	0,9	2,5	165000	Medium	1000
EPS	0,04	0,04	30	-	2,5	110000	Medium	920

Fibrocement Panel	0,01	0,37	1000	-	2,5	165000	Medium	1250
Aerated Concrete	**0,15**	**0,14**	**400**	**-**	**2,5**	**110000**	**High**	**1000**
Gypsum Board	0,025	0,25	800	-	2,5	165000	Medium	1090

CONCRETE CONSTRUCTION					Only BepTr		Only EnergyPlus	
Name of the Material	Thickness	Thermal conductivity	Density	Emissivity	Cm	Am	Roughness	Cp
	(d)	(λ) W/(m2K)	ρ (kg/m3)	ε	(ISO EN 13790)			J/kgK
	m							EN10456
Cement mortar	0,03	1,6	1400	0,9	2,5	165000	Medium	1000
EPS	0,04	0,04	30	-	2,5	110000	Medium	920
Fibrocement Panel	0,01	0,37	1000	-	2,5	165000	Medium	1250
Concrete	**0,15**	**2,1**	**2400**	**-**	**3**	**260000**	**Medium**	**840**
Gypsum Board	0,025	0,25	800	-	2,5	165000	Medium	1090

MASONRY CONSTRUCTION					Only BepTr		Only EnergyPlus	
Name of the Material	Thickness	Thermal conductivity	Density	Emissivity	Cm	Am	Roughness	Cp
	(d)	(λ) W/(m2K)	ρ (kg/m3)	ε	(ISO EN 13790)			J/kgK
	m							EN10456
Cement mortar	0,03	1,6	1400	0,9	2,5	165000	Medium	1000
EPS	0,04	0,04	30	-	2,5	110000	Medium	920
Fibrocement Panel	0,01	0,37	1000	-	2,5	165000	Medium	1250
Concrete	**0,15**	**2,1**	**2400**	**-**	**3**	**260000**	**Medium**	**840**
Stone Wall	**0,15**	**0,41**	**800**	**-**	**3**	**260000**	**Medium**	**1000**
Gypsum Board	0,025	0,25	800	-	2,5	165000	Medium	1090

Table 5 - U values of the five different exterior walls.

Construction names	U Values W/m²K
Steel Construction	0,687
Brick Construction	0,587
Aerated Concrete Construction	0,422
Concrete Construction	0,732
Masonry Construction	0,602

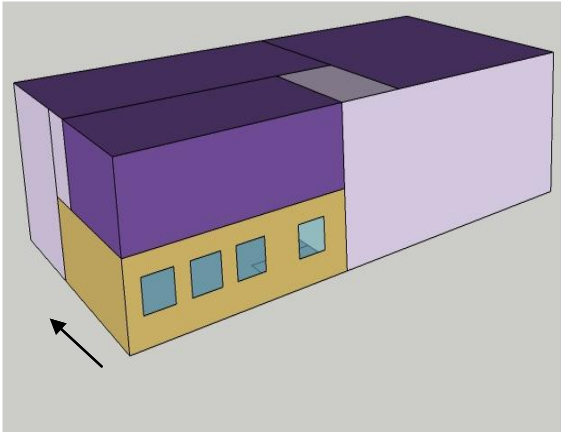


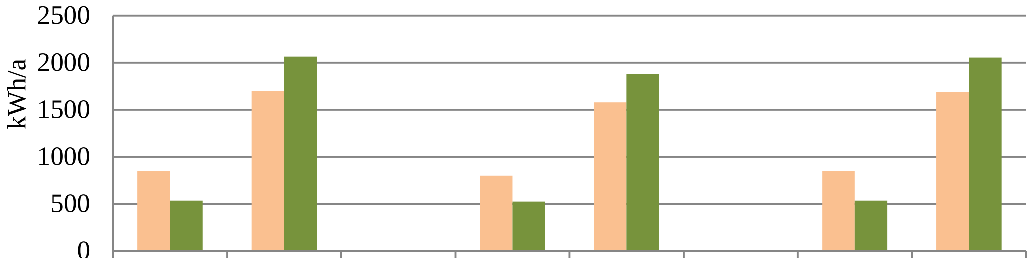
Figure 2 - Case Building

Table 6 - Lighting, occupant and electric equipment schedules.

Occupancy Schedule	Lighting Schedule	Equipment Schedule
00:00 - 06:59 0	00:00 - 16:59 1,3 W	00:00 - 06:59 0,65 W
07:00 - 24:00 0,5	17:00 - 22:59 117,6 W	07:00 - 16:59 32,7 W
	23:00 - 24:00 65,3 W	17:00 - 24:00 65,3 W

RESULTS

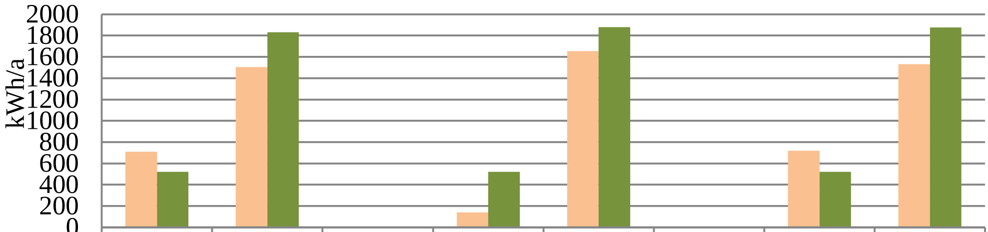
Results for Steel Wall



	4cm EPS, 15cm construction U Value:0,687		changing insulation thickness U Value:0,602 (4,82cm EPS)		changing construction thickness U Value:0,687	
	Cooling	Heating	Cooling	Heating	Cooling	Heating
ENERGY PLUS Steel Wall	844,32	1699,4	797,67	1576,75	844,32	1688,4
SIMPLE HOURLY METHOD Steel Wall	532,28	2062,97	522,41	1879,95	532,28	2052,97

Figure 3 - Annual heating and cooling demand analysis results for thickness of the materials on steel construction.

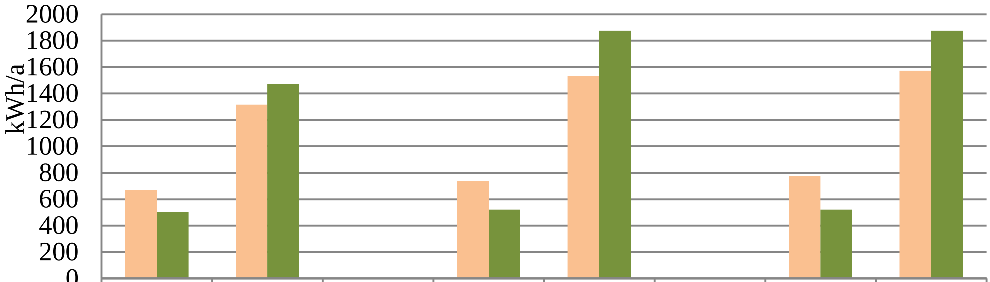
Results for Brick Wall



	4cm EPS, 15cm construction U Value:0,587			changing insulation thickness U Value:0,602 (3,75cm EPS)			changing construction thickness U Value:0,60 (13cm Brick)	
	Cooling	Heating		Cooling	Heating		Cooling	Heating
ENERGY PLUS Brick Wall	710,17	1504,71		140,46	1653,88		719,5	1531,83
SIMPLE HOURLY METHOD Brick Wall	519,99	1832,01		522,42	1880,12		522,21	1875,87

Figure 4 - Annual heating and cooling demand analysis results for thickness of the materials on brick construction.

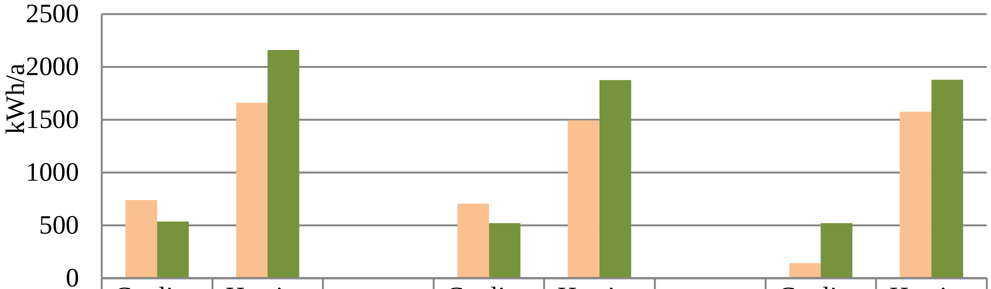
Results for Aerated Concrete Wall



	4cm EPS, 15cm construction U Value:0,422			changing insulation thickness U Value:0,6 (1,2cm EPS)			changing construction thickness U Value:0,6 (5,2cm ytong)	
	Cooling	Heating		Cooling	Heating		Cooling	Heating
ENERGY PLUS Ytong Wall	670,18	1316,95		735,95	1533,00		775,69	1572,81
SIMPLE HOURLY METHOD Ytong Wall	504,7	1471,98		522,21	1875,87		522,21	1875,87

Figure 5 - Annual heating and cooling demand analysis results for thickness of the materials on aerated concrete construction.

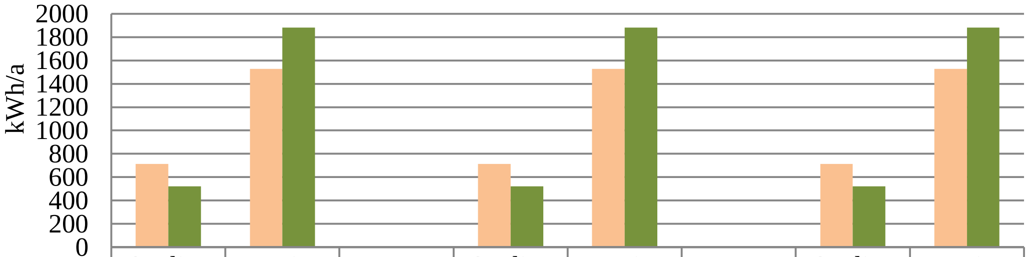
Results for Concrete Wall



	4cm EPS, 15cm construction U Value:0,732			changing insulation thickness U Value:0,6 (5,2cm EPS)			changing construction thickness U Value:0,602 (77cm Concrete)	
	Cooling	Heating		Cooling	Heating		Cooling	Heating
ENERGY PLUS Concrete Wall	738,08	1659,45		707,33	1493,26		141,84	1574,54
SIMPLE HOURLY METHOD Concrete Wall	537,6	2158,46		522,21	1875,87		522,4	1879,65

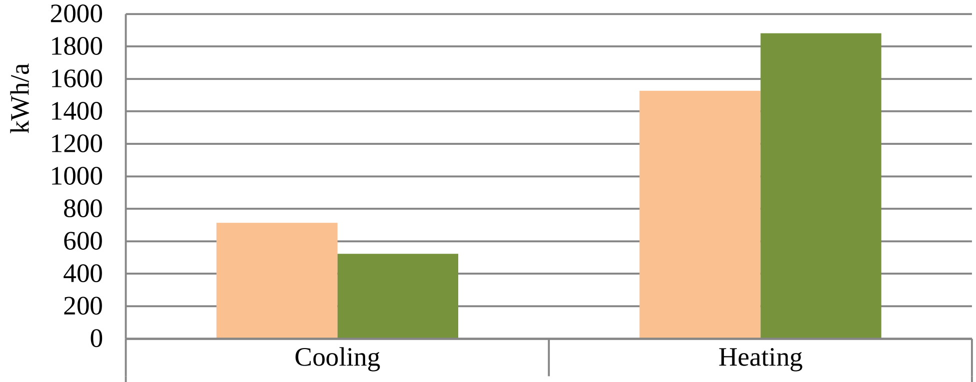
Figure 6 - Annual heating and cooling demand analysis results for thickness of the materials on concrete construction.

Results for Stone Wall



	4cm EPS, 15cm construction U Value:0,602			changing insulation thickness U Value:0,602 (4 cm EPS)			changing construction thickness U Value:0,602 (15cm StoneWall)	
	Cooling	Heating		Cooling	Heating		Cooling	Heating
ENERGY PLUS Stone Wall	713,38	1527,2		713,38	1527,2		713,38	1527,2
SIMPLE HOURLY METHOD Stone Wall	522,43	1880,29		522,43	1880,29		522,43	1880,29

Figure 7 - Annual heating and cooling demand analysis results for thickness of the materials on stone construction.



	Cooling	Heating
	4cm EPS, 15cm construction U Value:0,602	
ENERGY PLUS Stone Wall	713,38	1527,2
SIMPLE HOURLY METHOD Stone Wall	522,43	1880,29

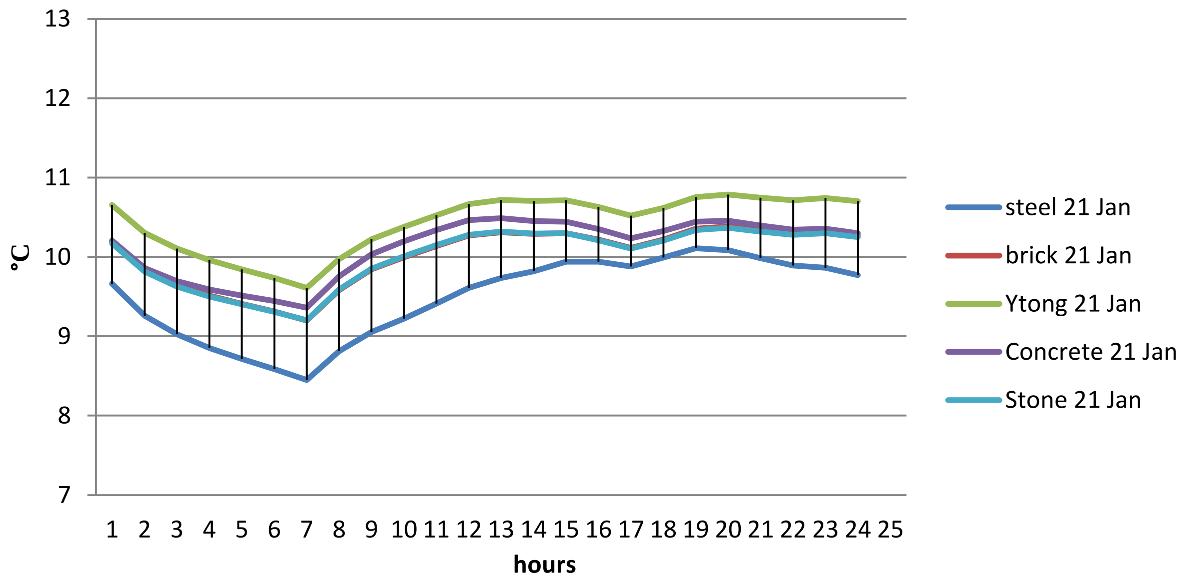


Figure 8 - Daily temperature differences in 21 January for each construction type.

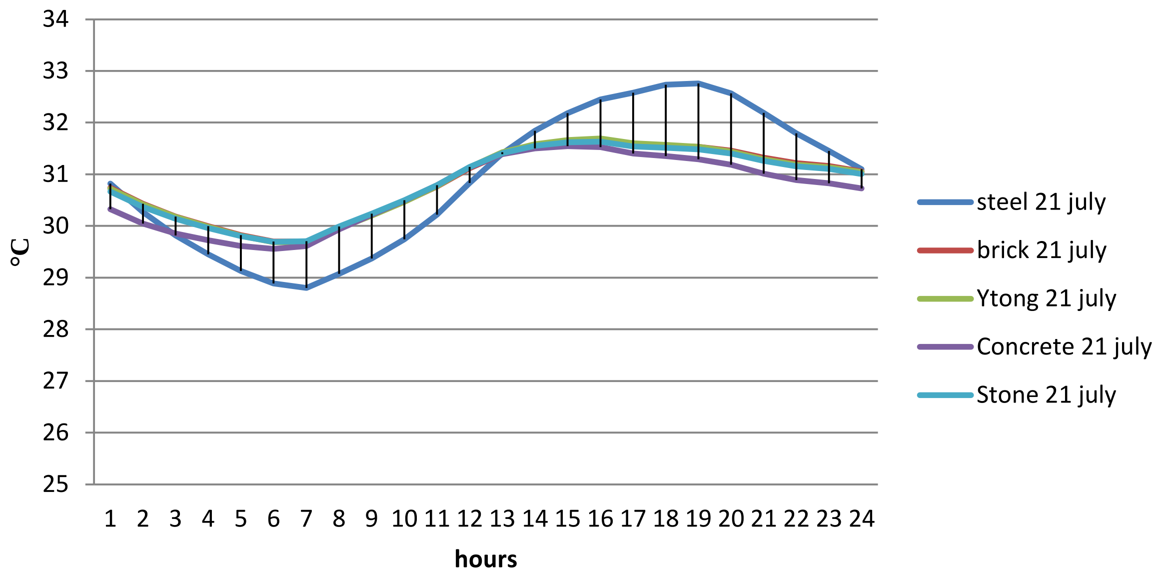


Figure 9 - Daily temperature differences in 21 July for each construction type.

According to the results of Simple Hourly Method and Dynamic Simulation the Building Energy Performances of a simple residential unit are changing similarly for each construction type. The results showed that Simple Hourly Method's Thermal mass calculations may be reliable in non-complex building types.

According to the results obtained from both calculation methodology showed that although the concrete is the material which has the highest thermal storage capacity, it should be used in very thick constructions. However the best building energy performances are obtained by aerated concrete constructions.

CONCLUSION

In conclusion, for the non-complex building types the simplified calculation method of thermal mass in the building energy performance calculations gives results parallel to dynamic calculations. The studies should be extended for the complex building definitions to evaluate and compare the both simple hourly and dynamic building energy performance calculation methodologies. However the limits of building description in the simplified methodology may interfere to compare the mass storage capacities of building materials precisely.

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