IMPACT OF ENERGY ORIENTED MEASURES OVER CO_2 EMISSIONS OF A THERMALLY INSULATED LOW-RISE APARTMENT BUILDING IN IZMIR, TURKEY

MÜMİNE GERÇEK[1]
ZEYNEP DURMUŞ ARSAN[2]

ABSTRACT

Climate change has drawn the attention of many researchers and practitioners to focus on the methods to address the challenges in achieving low-carbon buildings and cities and in future developments. Nevertheless, few studies have explored the impacts of thermal mass applications for the lowest carbon emissions of building operational energy consumption. A comparative study of CO_2 emissions due to different wall and floor compositions is presented in accordance with their lifespans for a hot-humid climate site. Aim of this study is to examine the relation between the energy oriented operations and carbon emissions of the building. Firstly, an existing low-rise building in İzmir is selected, then modelled in the dynamic simulation model software DesignBuilder v4 by synchronizing drawings with basic operational principles of the program. Furthermore, various influence factors of building envelope thermal characteristics are selected as follows: type, location, thickness and thermal specifications of materials used by keeping thermal conductivity value constant. Selection of optimal CO_2 emission case would be investigated based on the simulation results. The research would provide further information about variable CO_2 emission levels depending on the changes in building envelope of a thermally insulated building.

Keywords: Housing, CO_2 emission, Thermal mass, Energy efficiency

[1] Mümine GERÇEK, Izmir Institute of Technology, Department of Architecture, İZMİR
[2] Dr. Zeynep DURMUŞ ARSAN, Izmir Institute of Technology, Department of Architecture, İZMİR

1. INTRODUCTION

In many countries, energy consumption of buildings is 25–40% of the total energy consumption, in which most of the energy is used for space heating or cooling (i.e., air-conditioning) of buildings (Zeng et al. 2011). The huge energy consumption for heating or cooling buildings not only demands valuable fossil fuel resources, but also emits a huge amount of CO_2 and other pollutants into the atmosphere. In fact, studies related to energy efficient buildings are of great importance all around the world. For example, Turkey paid \$60.1 billion for energy exports and the dependence on foreign energy sources reached 72% in 2012, based on data from the Ministry of Energy and Natural Resources (MENR) and Turkish Statistical Institute (TUIK). Annual average energy demand saw an increase as 4.6%, while remaining at 1.6% in EU member states after the 1990s (Düzgün and Kömürgöz 2014). This creates the energy oriented approach where minimization of energy consumption is the main target. When the amount of CO_2 released in building is the main indicator for reaching sustainability, the energy measures taken for achieving required heat transmittance coefficient (U) value may contradict with the targets for minimization of CO_2 emissions.
There are different ways to reduce mechanical energy needs of buildings, which are shading, control of daytime ventilation, and use of better thermal mass qualities (CIBSE TM 36 2005). This paper focuses on thermal mass which is related with the heat gain of a building.
Thermal capacitance is the amount of heat required for a unit temperature change in material’s temperature. It is also necessary to examine the time required for materials response to heat gain. Hence, thermal mass is associated with the building time constant $t_c = m \times c / (U \times A)$, which explains the speed of building reaction to incoming heat as well as its thermal capacitance. In other words, transformation of mass into volume and density $(m = \rho \times V)$, time constant formula is defined as:

$$t_c = \frac{\sum_{i=l}^{i=n} \rho_i \times V_i \times c_i}{\sum_{i=l}^{i=n} (U_i \times A_i)} \qquad \text{Eq(1)}$$

So that, increasing density, volume, specific heat, and reducing overall conductance-area product of the building (UA) will also increase time constant and thermal mass. Decisions about placement of thermal mass is also considered in order to increase its exposure to solar heat gains. In this content, primary and secondary thermal mass issues take place where exposure to solar heat input straightforward describes primary, while exposure to internal heat input is observed as well as heat transfer with air conditioning system in secondary thermal mass.
In buildings, thermal mass is typically provided by heavyweight materials such as brick, stone or earth-based materials. Although inclusion of thermal mass in this way has thermal benefits, it is important to compare them in order to investigate better options. For example, the impact of thermal mass on the thermal performance of

several types of Australian residential construction was examined numerically using the AccuRate energy rating tool. The performance of each construction type was evaluated using four different hypothetical building envelopes, referred to here as building modules. It was found that the thermal mass had a dramatic impact on the thermal behaviour of the modules studied, particularly in those where the thermal mass was within a protective envelope of insulation. The RBV and CB constructions were found to be the most effective walling systems in this regard (Gregory et al. 2008). Then, analysis of the effect of several wall and building design features on the energy savings is seen owing to thermal mass in exterior walls of residential buildings. Thermal mass effects on annual heating and cooling loads were analysed in 12 climates for three types of exterior walls including insulation placement and U value variations. The study highlights the heating and cooling load decreases due to various interactions between parameters affecting thermal mass (Byrne and Ritschard 1985). Later on, construction materials studies with regard to life-cycle assessment and CO_2 emissions as energy efficiency criteria are also included into researches. The actual building was being constructed in concrete, and two further versions were designed with steel or timber structures and finishes. Besides, large quantities of finish materials were common to all three buildings. Both energy use and CO_2 emissions have been assessed over three main stages in the life of a building: initial production of the building materials; operation of the building; and the refurbishment and maintenance of the building materials over the building's effective life. DesignBuilder software was used to estimate whole life-cycle energy used and CO_2 emitted in the operation of the buildings over a period of 60 years. The results showed that operating CO_2 emissions were majority of life-cycle CO_2 emissions, instead of total embodied emissions. The findings were of significance, in the assessment and weighting of the embodied energy and embodied CO_2 components of building sustainable rating tools (Fernandez 2008).

However, these kind of researches do not fulfil the need for focusing on the relation between thermal specifications of building and carbon emissions of residential buildings in Turkey. In this context, the specific objective of the present study is to investigate how thermal mass influences building behaviour and CO_2 emissions. Furthermore, this investigation allows determining the effects of low carbon building design on heat absorption capabilities of building envelope.

A flat located in thermally insulated low-rise apartment building in Izmir, created in DesingBuilder v4. is used to investigate how different materials influence building thermal behaviour and environmental performance. Eighteen scenarios are developed over the modifications of thermal mass characteristics through which insulation layer placement, material type, location and thickness are combined for floor, partitions and exterior walls. In order to compare like with like, the overall conductance-area product UA is kept the same for different comparison scenarios. At the end, this paper presents the influence of material types on reducing energy demands and improving energy rating. Besides, it shows the important impact of the lifespans of materials on embodied and operational CO_2 emissions on residential buildings.

2. PHYSICAL IDENTIFICATION

2.1. Weather Data

The study has been carried out in İzmir, west coast of Turkey (38.5°N latitude and 27.02°E longitude). The climate for studied area (İzmir) is hot-humid climate, labelled with Csa (Cs-for dry summer, a- for hot summer) in Köppen climate classification, referring to Mediterranean climate. Thus, the proximity to the Aegean Sea makes summer and winter temperatures relatively temperate, while summers are hot and dry in contrast to mild and rainy winters. July and august are the hottest months of summer, as well as January and february are the coldest of winter. Average maximum temperature is around 38°C during summer period, whereas the average minimum in winter may vary between 0°C and -3°C, which does not last longer than 10 days. Monthly rain level changes between 700-1000 mm depending on the region.

2.2. Location and Description of The House

This study analyses low-rise residential buildings. Thus, an existing low-rise apartment building is selected to represent the general plan schema and architectural features commonly applied in Izmir. Fig. 1,a shows that the case study is a detached apartment, located in Çamdibi region of İzmir with 38.43°N latitude, 27.20°E longitude, and 13 m elevation above sea level, as well as 14° direction to north. In addition, it can be seen from Fig.1,b that close placement of dwellings, and existence of Atatürk Park affects surrounding area texture.

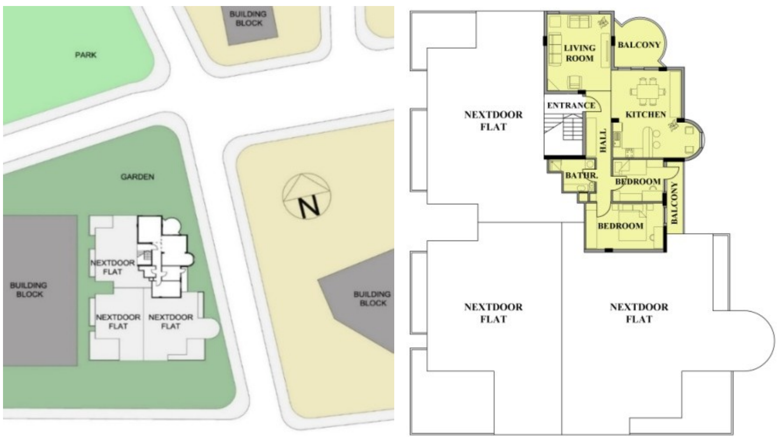

Figure 9 a) Site plan of the building b) Floor plan including selected flat

The selected apartment is a four-storey, multi-family dwelling, consisting of an entrance from north direction. Besides, it is a second floor flat, attached to others on south and west sides. Fig.1, b also presents that the flat has two bedrooms, and a closed balcony facing east, while balcony, kitchen and living room are located towards north-east direction. On the other hand, entrance hole and bathroom are other spaces having blind facades. Balcony is surrounded by living and dining rooms, while large openings are used to take advantage of daylight. Although apertures are wide enough to provide sufficient natural lighting, they increase thermal transmission. In fact, living room and kitchen are the places that cause solar gain most, since glazing units cover larger areas. However, summer is critical because of excessive heat in west coast of Turkey, so curtains are used as a precaution to passive solar gain. In addition, total floor area of the flat is approximately 100 m² with floor-to-ceiling height of 2.80 m.

The thermal properties of the building materials match with the requirements for energy performance rules of TS 825 Energy Standard for low-rise residential buildings. The construction technique of the building is reinforced concrete skeleton system, hollow brick internal partitions, and a composite floor (concrete strengthen with steel framing) covered with parquet, ceramic tile for wet cores. Furthermore, inner partition walls have 0,015 m gypsum plaster, 0,085 m brick, 0,015 m gypsum plaster layers with U value of 2,1 W/ m².K. The flat has floor materials as 0,05 m cement screed, 0,03 m EPS, 0,04 m cement screed, 0,012 m flooring layer; as well as 0,65 W/ m².K U value. Besides, exterior walls have U value of 0,41 W/ m².K with 0,015 m gypsum plaster, 0,03 m EPS, 0,085 m brick, 0,03 m EPS, 0,135 m brick and 0,025 m plastering layers. These existing material conditions of the flat are determined as original scenario for further studies in paper.

Occupancy and lighting patterns of the house are also investigated to analyse further daily energy usage. The house was occupied by a family of two adults and a daughter. The house was in continuous occupancy except working hours in weekdays, so that most of the occupancy occurs between 17:00 and 08:00. Occupancy for the living room was also seen between 19:00 and 23:00.

3. MEASUREMENTS

Test house was equipped with diagnostics equipment for short term external and internal climate monitoring to execute site measurements with collecting data every 10 minutes. Fig.2 indicates installation of a Temp-RH-Light Hobo Data logger (HOBO U12-012) to the balcony to monitor outdoor air temperature and relative humidity. Its resolution is 0.03°C for 25°C temperature, and 0.03% for relative humidity, and its accuracy is ± 0.35°C from 0° to 50°C and ±2.5% from 10% to 90% relative humidity, respectively while another one recording rel. humidity and indoor air temperature was installed to the living room.

Figure 10 Placement of Hobo data loggers in living room and balcony

In addition, environmental data collection in test house started in April 1, 2014 at 00:00 a.m. and it was completed in April 24, 2014 at 11:59 p.m. The windows of the living room had constant conditions such as always closed windows and doors, semi-closed curtains and no mechanical/natural heating or cooling during data collection.

4. SIMULATION

This study used DesignBuilder v4, an energy simulation program developed by DesignBuilder Software Ltd., UK, for building energy modelling and simulation. It offers simple and convenient functions to model building components. Its calculation method is based on EnergyPlus, a building energy simulation program of the United States Department of Energy (USDOE).

The model geometry was created from architectural drawings which were available in DWG format, and converted into DXF format with the right proportions. These scaled drawings were imported into DSM software, and internal spaces were created by tracing the DXF outline of each floor and subdividing the floors with partitions.

Construction types were then created using the specifications obtained from collected data about the building. Input data for living room, kitchen, bedrooms and bathrooms were entered, including its operating occupation, lighting and opening schedules and system description.

In all scenarios, mechanical heating was assumed to be provided by fan-coil unit using coal as heat input. The heating set point was 22◦C in all rooms. The heating system was controlled to keep the set points in all rooms, except for the period of June-September, when the heating was shut down. In addition, mode of operation for mechanical cooling was provided by electricity from grid with cooling set point of 26◦C. It was also shut down for the period of November-February.

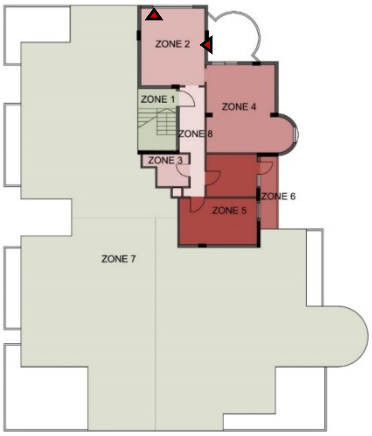

Figure 11 Zonings of the flat including location of indoor & outdoor Hobo data loggers

Fig.3 also points out that the flat has been separated into zones depending on the activities held out. Seven zones are created, while remaining spaces are considered as another zone as well as merging two bedrooms into one. In fact, living room, kitchen and hall form different zones because of having variable activities that would represent reality more accurate which will also reduce errors in the calculation results. On the other hand, open balcony is left aside from these zone categorizations unlike closed balcony. Furthermore, surrounded obstructions such as ground, buildings and trees are also modelled as different components. Green objects are assumed to be solid objects in order to include them into simulation process. Thermal properties of each element has importance for final thermal, energy and carbon emission measurements, so that material properties and surface reflection coefficients are also considered as input data. For example, adiabatic zone and other building materials assigned to be concrete with 0.25 surface reflection coefficient, while trees are accepted as deciduous having 0.3 as well as grass (garden) with 0.2.

4.1. Model Calibration Process

Residential building is used as a base for conducting parametric study. Considering availability of measurement cycle, the calibration with hourly data approach is employed in this paper. Measurements are only made for living room from April 1, 2014 to April 24, 2014, while energy demand and CO_2 emission results are obtained for whole floor during the study. The current hourly thermal performance of the flat is calibrated with measured inner and outer air temperatures. So that, these guidelines define two statistical indices: hourly mean bias error (MBE) and the root mean squared error (RMSE). Lower values of the latter informs us about better prediction by digital model.

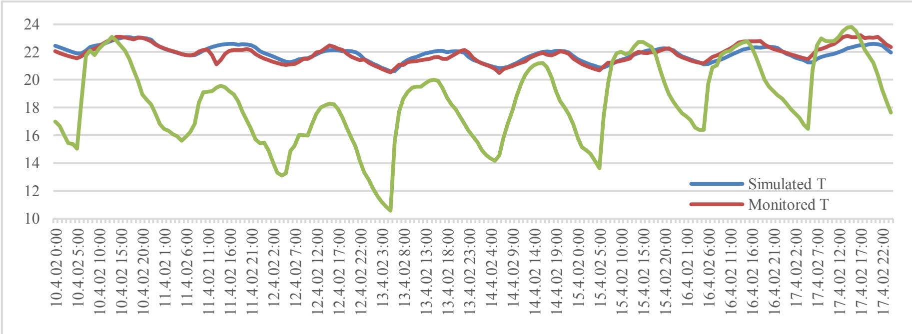

Figure 12 Calibration results of the simulation

Firstly, the calibration in terms of energy consumption is executed in order to decrease heat gains originating from lighting elements. The lighting elements used for living room were selected to be energy efficient in existing conditions. So that, automatically assigned 6 W/m² lighting template for material and energy are arranged to 1 W/m² as well as additional lighting schedule in order to specify differing occupancy ratios. Secondly, 0.4 ac/h air tightness rates of the zones is increased 0.7 ac/h in order to have lower inner temperature than initial conditions. Finally, arrangements about the simulation process options in terms of shading calculations are revised and all buildings are included in shading calculations during the simulation as well as model reflection shading of ground reflected solar. In addition, shadowing interval switched from 20 to 7 days in order to have more accurate results which also contributed closer temperatures to measured ones. In this way the calibration of the model in terms of internal temperature adjustment is completed, and the calibration results can be seen from Fig. 4. Also, the tolerances of hourly calibration indices and the final values of the simulation are specified in Table 1.

STATISTICAL INDICE		ASHRAE 14-2002	IPMVP	MVFEM P	Calibrated Model
hourly	MBE	±10	±20	±10	-1,3
	RMSE	30	20	30	2,81

Table 2 Error ratios for indoor air temperature

4.2. Simulation of Construction Scenarios

A comparative analysis is performed for a wide variety of mass configurations to determine how several complex interactions could change heating, cooling loads and environmental impacts of residential buildings in hot humid climate. Variable parameters are created such as density, thickness, conductivity, and specific heat of the mass layer as well as the location of the insulation layer within the range found in common residential constructions. This set of simulations are investigated in terms of summer and winter temperatures, energy demands, and environmental impacts in accordance with material's lifespans. Four different floors, three internal partitions, ten exterior walls including inner and outer insulation placement configurations are created with regard to previous parameters.

Firstly, initial floor scenario differs from original case by 0,025 m ceramic tile layer on top. Then, ceramic tile is changed with 0,015 m clay tile as second scenario, while turning 0,04 m cement screed into 0,08 m thickness in both, creates another two scenarios.

Secondly, three inner partition wall scenarios are included into experiments. Thus, 0,085 m AAC block between two layers of 0,015 m gypsum plastering creates 1,48 W/ m².K U value of AAC inner partition wall scenario. Besides, 0,09 m glass wool placed between 0,0125 m gypsum board layers and 0,085 m solid brick covered from both sides with 0,015 gypsum plastering having 0,36 W/ m².K and 2,2 W/ m².K U values respectively are two other scenarios.

Thirdly, five exterior wall combinations are produced by changing major wall material as well as keeping 0,08 m EPS, 0,015 m gypsum plastering layers and 0,41 W/ m².K U values constant. Thus, 0,16 m solid brick, 0,06 m AAC block, 0,55 m reinforced concrete, 0,5 m limestone, 0,07 m aerated brick layers are placed towards outermost faces of walls to form exterior wall with inner insulation scenarios. Lastly, these previous five scenarios' layers are mirrored in a way that innermost part of the walls have major construction materials with different thicknesses followed by EPS and gypsum plastering layers as inner to outer arrangement. So that, they provide varieties in exterior wall configurations with outer insulation properties.

5. RESULTS

5.1. Thermal Conditions

The only factor influencing the temperature change is the variations made to specific components of the building like floor, exterior wall or internal partitions according to scenarios. The summer and winter indoor temperature variations for all scenarios are shown in Fig.5 and Fig.6. There is around 1,5 ºC difference between peak temperatures both in winter and summer weeks. In winter time, limestone exterior wall with inner insulation and reinforced concrete wall with outer insulation showed same temperature pattern which is the highest between all scenarios. In addition, same configurations also show the lowest temperature patterns in summer design week. In fact, it can be seen that, they have the maximum time lag in winter and summer design weeks because of having higher thermal mass properties than others. On the other hand, the gypsum board partition wall scenario which has lower thermal mass quality, indicates the lowest temperature for winter time, while limestone exterior wall with outer insulation has the highest temperature for summer time independently from thermal mass properties of materials.

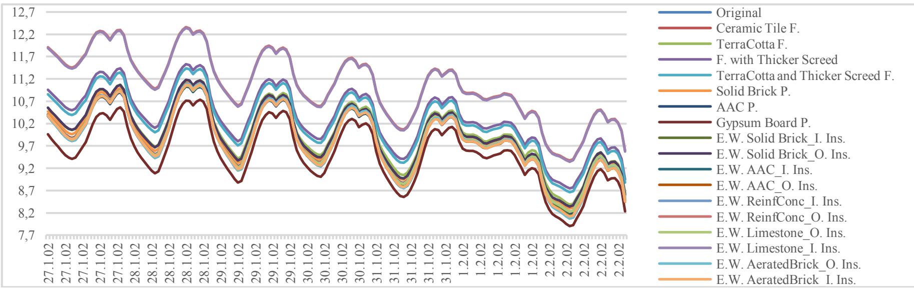

Figure 13 Winter design week indoor air temperatures of scenarios

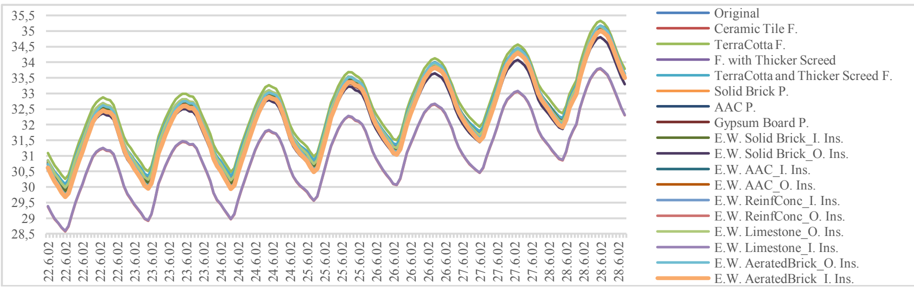

Figure 14 Summer design week indoor air temperatures of scenarios

5.2. Heating and Cooling Loads

Fig.7 shows total mechanical air conditioning energy consumptions of different scenarios for all year. It presents that all scenarios have similar cooling energy demands, while heating creates the difference. In fact, floor scenarios have the biggest impact on reduction of energy loads. The results also present that, combination of thicker screed usage for floor, AAC internal partitions, and reinforced concrete exterior wall with external insulation would establish the lowest energy consuming scenario for the flat. Besides heating and cooling loads are not affected by thermal mass qualities of materials unlike inner temperature values.

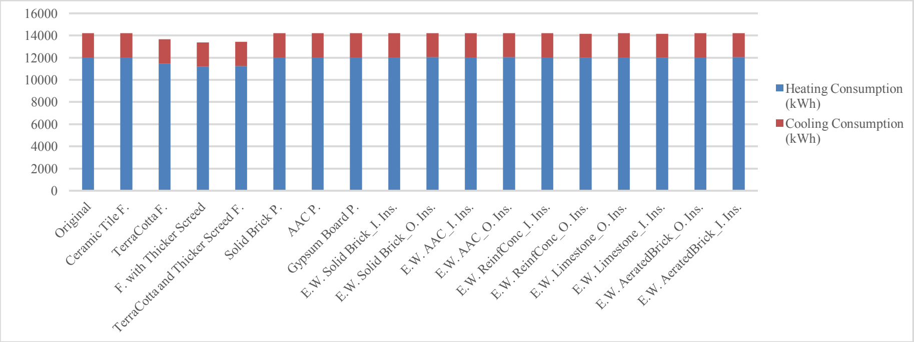

Figure 15 Heating and cooling consumptions of scenarios

5.3. CO_2 Emissions

a. Embodied and Operational CO_2 Emissions

Fig.8 indicates embodied and operational CO_2 emissions released to atmosphere in different scenarios, as a consequence of the energy demands. Operational emissions are almost the same for all of them which is around 8000kg. On the contrary, emissions due to embodied CO_2 makes the difference. AAC partition wall and aerated brick exterior wall options are better than others with 50280kg release regardless thermal mass qualities. Floor with thicker screed has 67650 kg CO_2 emission followed by reinforced concrete exterior walls whereas this type of exterior wall showed the best features for thermal conditions. Consequently, it can be seen that investigations particularly about thermal mass quality is not sufficient in order to decide construction materials of the building. It is also noted that the differences in carbon emissions from one material to another one are not influenced by insulation layer placement.

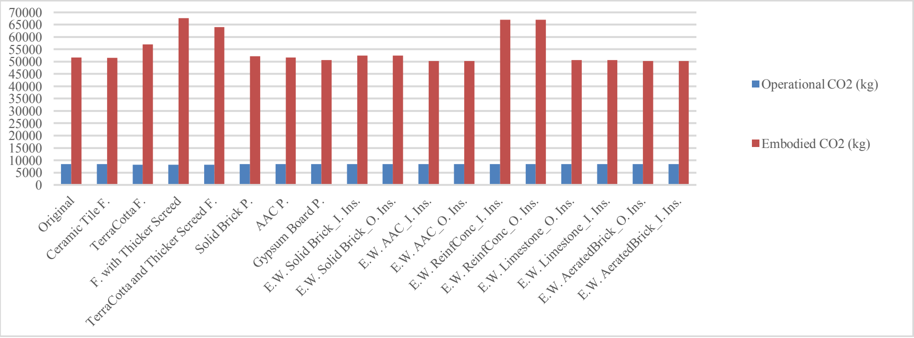

Figure 16 Embodied and operation carbon emissions of scenarios

b. Lifecycle CO_2 Emissions

Lifecycle carbon emissions are studied in accordance with a lifespan of 50 years for three main structure components with different scenarios. Reinforced concrete exterior wall with inner insulation followed by its outer insulation scenario reaches the peak point with around 490.000 kg CO_2 emission, whereas terracotta floor has the least amount as represented in Fig.9. Also, the minimum emission for inner partitions is seen by gypsum board releasing 472.000kg, while solid brick partition reaches the maximum amount. As a result, there are important impacts of lifespans of both the materials and the building itself on CO_2 emissions. Thus, common usage of reinforced concrete is obvious in Turkey, but the sharp difference between other materials in terms of environmental effects cannot be neglected.

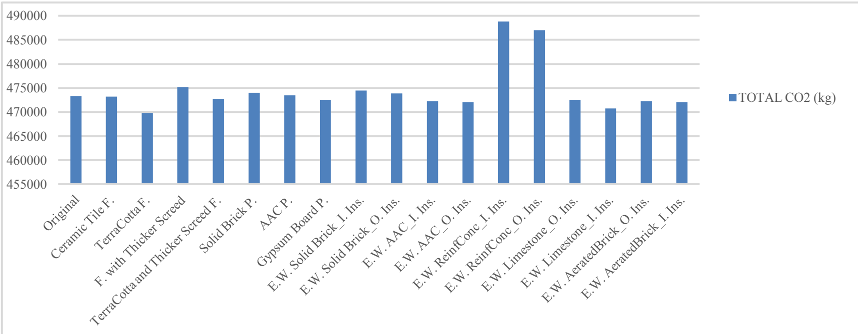

Figure 17 Carbon emissions according to lifespans of scenarios

6. CONCLUSION

The heating and cooling load reduction due to thermal mass are the results of a complex set of interactions between the amount and physical properties of the mass, the location and amount of insulation in the exterior wall, inner partitions and floors that effect solar gain. On the other hand, it is a fact that energy performance assessments do not involve the type of fuel used for mechanic air conditioning. However, one of the major parameters, effecting operational CO_2 emissions of environmental performance is the fuel type (Dombaya, 2012). Besides, not only energy efficiency, but also CO_2 production should also be considered as an evaluation criteria for energy oriented studies in buildings. In this context, this study examined how thermal mass changes building behaviour and CO_2 emissions. Furthermore, this investigation allows determining the effects of low carbon building design on heat absorption capabilities of building envelope.
A thermally insulated low-rise apartment building flat, situated in hot humid climate, is used to analyse how different materials affect building's thermal response and environmental performance. Besides, coal for mechanical heating and electricity for cooling are specified for this study in order to compare energy demands of different materials. There are also eighteen scenarios over the modifications of thermal mass characteristics through which insulation layer placement, material

type, location and thickness are combined for floor, partitions and exterior walls. Comparison is made between same construction element with different configurations by keeping conductance area product constant in order to compare like with like

The result of this study reveals that thermal mass has a noticeable affect on thermal behaviour and CO_2 production considering outer walls, inner partitions and floors together. Besides, it shows the important impact of lifespans of materials on embodied and operational CO_2 emissions on residential buildings.

For further studies, additional mechanical air conditioning or natural ventilation in order to compare inner temperature results and keeping mass layer thickness while varying U values of the construction components are also important points to have more developed results.

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