# CLIMA 2013

## 11th REHVA World Congress & 8th International Conference on IAQVEC



**June 16–19, 2013**
**Prague Congress Centre, Czech Republic**

**„Energy Efficient, Smart and Healthy Buildings"**

REHVA 50 1963 2013 Federation of European Heating, Ventilation and Air-conditioning Associations

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SPOLEČNOST PRO TECHNIKU PROSTŘEDÍ
SOCIETY OF ENVIRONMENTAL ENGINEERING

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# PROCEEDINGS

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# A Study on the Evaluation of Heating and Cooling Energy Efficiency in Residential Buildings for Climatic Zones of Turkey

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**Abstract**

*The environmental and energy problems that have arisen in Turkey, because of the increase in energy consumption, necessitate efficient use of energy in the residential sector which is the main sector of primary energy consumption. In Turkey, most of the common types projects of mass production residential buildings are being developed and constructed by TOKI (Housing Development Administration of Turkey). These buildings in which energy efficient approach has been disregarded for years, cause to gradually increase on heating and cooling energy consumptions. In regards to national economics, it is essential to evaluate energy efficiency and to develop suggestions to decrease energy consumptions in residential buildings. It is also an up to date topic which should continually be researched and produced solutions on. To achieve appropriate solutions, cost evaluation also becomes necessary. Because the energy consumption of existing residential buildings drains a major part of Turkey's energy resources, as is in other developing countries. It is obvious that the reduction of energy costs in residential buildings will also contribute to cost reduction in other sectors. Therefore, this paper aims to introduce a study which serves the purpose of producing a choice of energy efficient solutions in order to reduce energy consumptions and energy cost. In this study, different heating and cooling energy efficient scenarios have been developed for a selected residential building, constructed by TOKI, for climatic zones of Turkey. For each scenario, energy simulations have been executed by means of the simulation program, DesignBuilder, the user-friendly visual interface of Energy Plus, and cost analysis has been carried out by using the net present value and discounted payback period method. As a result, energy and cost effective solutions have been presented and discussed for different climatic zones.*

***Keywords – building energy performance; energy efficient retrofitting; energy cost; residential buildings***

## 1. Introduction

Buildings sector is among the most energy intensive sector and it is looming large in terms of energy consumption and environmental impacts. It shall be considered as a priority area for all policies dealing with increasing energy efficiency and combating environmental problems. In Turkey, built-up areas, disregarding energy efficient approach for a long time, have been causing the gradually increase on energy consumption. Especially, nationwide investments of mass production residential buildings by the Housing Development Administration of Turkey (TOKI), has been responsible to meet the dwelling demand rapidly since 2003, have the significant role on energy efficiency level of building sector. In terms of national energy economics, evaluating the energy efficiency level of these existing buildings, developing suggestions for the reduction of energy costs, in other words, energy efficient retrofitting is extremely important at the present day.

Depending on rising standards of living and population growth, the energy demand increases in spite of energy resources depletion. A great portion of energy is consumed by existing residential buildings to achieve comfort conditions in Turkey. On the other hand, to alleviate energy import dependency of Turkey and reduce the environmental effects related to energy consumption, efficient use of energy in buildings is necessitated. Efficient use of energy means that minimizes the energy need without compromising the social welfare, comfort conditions, required performance level and quality. In this context, energy efficient retrofitting of existing residential buildings in building sector, has a great importance to achieve the energy efficiency potential of 35 percent, declared by the General Directorate of Electrical Power Resources Survey and Development Administration of Turkey[1].

To appraise this potential and increase energy efficiency in Turkey, energy costs have to be taken into account. In parallel with increasing energy demand, energy cost is also rising. Furthermore, while various scenarios are developing to reduce heating and cooling energy from the existing residential buildings, also cost effectiveness of these scenarios have to be proven. Therefore, to solve energy problems, while realizing the increasingly energy demand and energy cost, energy and cost effective retrofitting of existing residential buildings has gradually more great importance. This paper aims to introduce a study which has been carried out an evaluation on energy and thermal performance for residential envelopes by developed scenarios, ensuring cost effective energy efficiency opportunities, also incorporated into new buildings.

In this paper, the potential improvement of scenarios was assessed in terms of energy savings by using the energy simulation program, as well as the costs of these options, according to net present value and discounted payback period method, for the different climatic zones of Turkey.

## 2. Methodology

In this study, different energy efficient scenarios, based on building envelope, were applied to existing residential building to evaluate heating and cooling energy consumptions and cost of energy consumptions and initial capital investment of these scenarios. The heating and cooling energy consumptions of existing residential building have been calculated for Istanbul, Ankara, Antalya, Diyarbakır and Erzurum which are representative cities of Turkey for temperate humid, temperate dry, hot humid, hot dry and cold climatic zones, respectively. These climatic zones are based on the results of the previous scientific researches which had been carried out in Istanbul Technical University [2]. On the other hand, In Turkish Standard TS 825 "Rules of Heat Insulation in Building", Turkey has divided into four different climatic zones, Istanbul and Diyarbakır are taken into the same climatic zone in spite of different climatic characteristics [3]. Table 1 shows the explanation of different climatic zones of Turkey and representative cities of these climatic zones.

Table 1. As part of study, selected cities according to climatic zones of Turkey

| Climatic zone[2] | City | Climatic zone[3] | Heating-degree days[4] |
|---|---|---|---|
| Temperatehumid | İstanbul | 2. Zone | 1886 |
| Temperate dry | Ankara | 3.Zone | 3307 |
| Hot humid | Antalya | 1. Zone | 972 |
| Hot dry | Diyarbakır | 2.Zone | 2086 |
| Cold | Erzurum | 4.Zone | 4785 |

## 3. Building Model

The selected existing mass housing project was constructed by TOKI in 2008 in Istanbul. This project was designed on 25.312m$^2$ as 7 blocks (A1, A2, A3, B1, B2, C, D), 408 flats (Figure 1).

For this study, A1 Block (mentioned as existing residential building (ERB)) was taken for energy performance calculation. It is 17 storey high (2 basement floor, ground floor, 12 typical floor and 13$^{th}$ floor as dublex). The block was designed as 4 apartments per typical floor, 2 apartments and storages on basement floors, two dublex apartments on 13$^{th}$ floor and entrance hall on ground floor. The building height is 48.28m, floor to floor height is 2.79m and floor area is 573m$^2$. ERB form factor (width/length) is 1.37. A/V (total facade area/building volume) is 0.19. ERB and the other blocks were modeled on site according to project, to take into the shading effects of buildings in energy performance calculations.

For ERB, each apartment area and hall were accepted as a zone, means heated/cooled area. The core units (stairs, elevators, fire stairs) and ventilation plenums were accepted not conditioned areas, as seen Figure 2.

According to construction characteristics of ERB, for external walls, type 1 and type 2 were consisted of 20cm aerated concrete block, 20cm reinforced concrete block, respectively. For flat roofs, the finish layer was distinctive mark for two types. The finish layer for type 1 was ceramic, for type 2 was gravel. Thickness of existing insulation of the wall, ground floor and roof constructions and relevant U values, are given in Table 2.




Fig. 1 General view of existing mass housing project and site plan

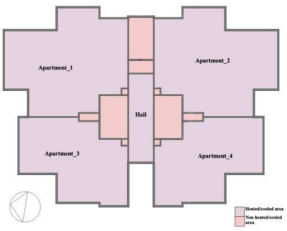



Fig. 2 Schematic plan of ERB

Table 2. Insulation thickness and U value of existing opaque components

| Opaque comp. | Insulation | U Value (W/m$^2$K) |
|---|---|---|
| External wall (type1) | XPS-5cm | $U_{wall1}$=0.371 |
| External wall (type 2) | XPS-5cm | $U_{wall2}$=0.576 |
| Ground floor | XPS-4cm | $U_{floor}$=0.513 |
| Flat roof (type 1) | EPS-5cm | $U_{roof1}$=0.547 |
| Flat roof (type 2) | EPS-5cm | $U_{roof2}$=0.546 |

Window type was double glazed (4mm clear glass+12mm air+4mm clear glass, U:2.725W/m$^2$K) and PVC frame (60mm, U:1.912W/m$^2$K). The transparency ratios as a percentage of the facades were 14, 24, 15, 30 for the north, east, south and west direction, respectively.

## 4. Calculation of Heating and Cooling Energy Consumptions For ERB

In order to evaluate the energy performance of ERB, annual heating and cooling energy consumptions were calculated by using dynamic energy simulation program "Design Builder" that is user-friendly visual interface of Energy Plus [4]. To perform energy simulations, outdoor climate data for five climatic zones of Turkey, were taken from "International Weather for Energy Calculations (IWEC)" files. For the energy consumption calculations, "Typical meteorological Year" file was used. Metabolic rates were set as 110W/person for apartment zones. The thermal resistance of the clothing is measured in units of "clo" and for winter clothing 1 clo, for summer clothing 0.5 clo were used.

According to environmental control, for apartment zones, the comfort value for indoor temperature was assumed to be 21°C for heating period and 25°C for cooling period. For halls, heating set point temperature was accepted 18°C. Natural ventilation was taken into calculations as minimum fresh air(l/s-person) parameter, accepted value was 10 [5]. Hot water radiator central heating system was defined. $COP_{heating}$ was accepted 0.65. Fuel type was defined as natural gas. Cooling system was not designed for the ERB. For this study, characterized cooling system was accepted to evaluate how much energy would be need for cooling of ERB. $COP_{cooling}$ was accepted 4.50. Fuel type was defined as electricity. According to the cooling demand dates, if the indoor air temperature was higher than 23ºC and the outdoor air temperature was less than the indoor air temperature, natural ventilation would be accepted "on" mode.

## 5. Improvement of Scenarios

In order to decrease energy consumption for heating and cooling, different scenarios related to building envelope, were defined in three categories as below:

- Improving the opaque components of building envelope (walls, ground floor, roof) ($Sc_1$, $Sc_2$),
- Improving the transparent components of building envelope (windows) ($Sc_3$, $Sc_4$),
- Combination of previous scenarios ($Sc_1$, $Sc_2$, $Sc_3$, $Sc_4$).

Overview and characteristics of scenarios, mentioned above, are shown in Table 3. Energy simulations for each defined scenarios as above, were carried out for the cities, mentioned in Table 1.

The assumptions for the scenarios of improving the opaque elements, were based on the upper limit U values for walls, ground floor, roof, which were defined in TS 825, shown in Table 4.

According to $Sc_1$, existing opaque elements which were not appropriate to the upper limit U values, defined by TS 825, current insulation thickness were increased to achieve them. As to second scenario ($Sc_2$), extensive green roof application (infill soil thickness 15cm) was used. For different climatic zones, if the calculated U value of green roof was not appropriate to $U_{roof}$ value, defined by TS 825, existing insulation thickness would be increased. For the third scenario ($Sc_3$), glass type was varied according to the conditions of climatic zones. For Istanbul, Ankara, Diyarbakır, heat conservation glasses(low-e coated on second pane), for Erzurum, heat conservation glasses (low-e coated on third pane), for Antalya, solar control and heat conservation glasses (reflective and low-e coated on second pane) were used instead of clear double glazed base type. By the forth scenario ($Sc_4$), aluminum window blinds were used as solar control devices. Solar control devices were located on the west, south and east facades of ERB. Operation schedule of solar control devices were defined as "overheated period of different climatic zones of Turkey"[6], based on the results of the previous scientific researches which had been carried out in Istanbul Technical University. Final scenario ($Sc_5$) was a combination of the previous scenarios.

Table 3. Overview and characteristics of scenarios for ERB

| Scenario | Assumptions |
|---|---|
| $Sc_1$ | Adding insulation layer according to TS 825, |
| $Sc_2$ | Application of green roof on the existing flat roof areas, |
| $Sc_3$ | Changing the existing window type, |
| $Sc_4$ | Adding solar control devices on South, West and East facades, |
| $Sc_5$ | Applying all the previous scenarios together. |

Table 4. The upper limit U values according to TS 825

| City | $U_{wall}$ W/m$^2$K | $U_{floor}$ W/m$^2$K | $U_{roof}$ W/m$^2$K |
|---|---|---|---|
| Istanbul-Diyarbakır | 0.6 | 0.6 | 0.4 |
| Ankara | 0.5 | 0.45 | 0.3 |
| Antalya | 0.7 | 0.7 | 0.45 |
| Erzurum | 0.4 | 0.4 | 0.25 |

Heating, cooling and total energy consumptions (based on primary energy and primary energy factors for electricity and natural gas were taken from CEN standard EN 15603[7]) for all scenarios were compared with the ERB current consumptions according to each climatic zones and calculation results are shown in Figure 3,4,5.

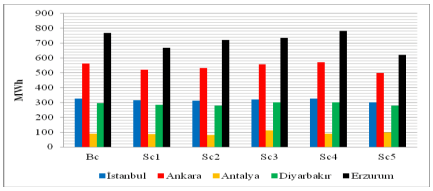



Fig. 3 Heating energy consumptions of scenarios

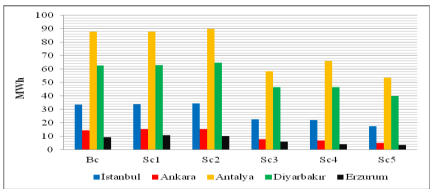



Fig. 4 Cooling energy consumptions of scenarios

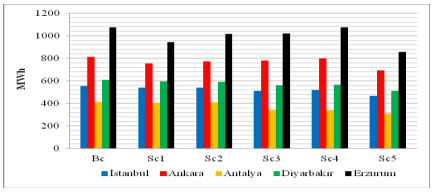



Fig. 5 Total(primary energy) energy consumptions of scenarios

## 6. Cost Analysis

To understand the economic feasibility of energy efficiency scenarios, cost analysis was performed according to net present value (NPV) and discounted payback period (DPP) method.

In this study, square meter unit prices of energy efficient components were obtained from related companies in Turkey. The unit price of electricity and natural gas were taken from Turkish Electricity Transmission Company[8], and Istanbul Gas Distribution Inc.[9], respectively. For this study, a fixed annual percentage interest rate of 10.41%[10] and inflation rate of 8.65% [11] were used. Evaluation period of cost analysis was accepted as 20 years.

Initial capital investment was comprised of insulation (walls, ground floor, roof) and window cost, assumed to be same for each cities. For each scenarios, NPV was calculated according to the sum of initial capital investment and discounted total energy costs for 20 years. Table 5 shows the incremental cost of each scenarios, compared to the base case, the corresponding annual energy savings ($), NPV ($) and DPP (year-month).

Table 5. Cost benefits of scenarios.

| Sc. No | City | Additonal cost ($) | Total annual savings($) | NPV ($) | DPP (y-m) |
|---|---|---|---|---|---|
| | Istanbul | 1383 | 453 | 6204 | 3y 2m |
| | Ankara | 8173 | 1874 | 23199 | 4y 7m |
| $Sc_1$ | Antalya | 922 | 163 | 1798 | 6y |
| | Diyarbakır | 1383 | 485 | 6729 | 2y11m |
| | Erzurum | 18728 | 4450 | 55751 | 4y 5m |
| | Istanbul | 24499 | 440 | -17136 | - |
| | Ankara | 25881 | 1297 | -4172 | - |
| $Sc_2$ | Antalya | 24499 | 23 | -24121 | - |
| | Diyarbakır | 24499 | 450 | -16961 | - |
| | Erzurum | 26803 | 1992 | 6541 | 15y |
| | Istanbul | 6818 | 2001 | 26677 | 3y 7m |
| | Ankara | 6818 | 1379 | 16270 | 5y 3m |
| $Sc_3$ | Antalya | 9221 | 3599 | 51009 | 2y 8m |
| | Diyarbakır | 6818 | 2245 | 30750 | 3y 2m |
| | Erzurum | 6818 | 2071 | 27846 | 3y 5m |
| | Istanbul | 56746 | 1766 | -27197 | - |
| | Ankara | 56746 | 843 | -42641 | - |
| $Sc_4$ | Antalya | 56746 | 3356 | -575 | 20y3m |
| | Diyarbakır | 56746 | 2217 | -19641 | - |
| | Erzurum | 56746 | 177 | -53788 | - |
| | Istanbul | 89446 | 3741 | -26834 | - |
| | Ankara | 97618 | 4459 | -22987 | - |
| $Sc_5$ | Antalya | 91388 | 4955 | -8451 | - |
| | Diyarbakır | 89446 | 4399 | -15829 | - |
| | Erzurum | 109095 | 7739 | 20424 | 16y4m |

## 7. Conclusion

To reduce energy consumption related to heating and cooling in existing buildings by improving the building envelope as energy and cost effective, is

a key area of focus for energy conservation in Turkey. In this study, possible scenarios were suggested to improve the energy efficiency of existing buildings according to different climatic zones and economic feasibility of these scenarios was analyzed.

The evaluation results of heating and cooling energy consumptions of ERB according to different climatic zones, using by Design Builder simulation program, can be summarized as below:

As seen in figure 3, compared to the base case lower heating energy consumption was achieved by $Sc_1$, $Sc_2$, $Sc_3$ and $Sc_5$. On the other hand, using solar control devices on the west, south and west facades only for overheated period of different climatic zones($Sc_4$), didn't have any effect on heating energy consumptions. $Sc_1$, adding insulation layer, provided the lowest heating energy consumption for Ankara and Erzurum, compared to other cities. As to $Sc_1$, energy consumptions for heating were decreased by 8% for Ankara, 13 % for Erzurum, compared to the base case. For İstanbul, Antalya and Diyarbakır, by applying $Sc_2$, green roof application, heating energy consumptions were reduced by 4%, 9%, 6%, respectively. According to $Sc_5$, combination of all scenarios, the heating energy consumptions for Antalya increased more than the base case while decreasing the other cities' heating energy consumptions. By applying $Sc_5$, the reduction ratios of heating energy consumptions, except Antalya, were more than $Sc_1$ and $Sc_2$.

As the figure 4, $Sc_3$, $Sc_4$ and $Sc_5$ reduced the cooling energy consumptions compared to the base case. $Sc_1$, adding insulation layer, and $Sc_2$, green roof application didn't have any effect on decreasing the cooling energy consumptions. By $Sc_3$, and $Sc_4$, the reduction ratios of cooling energy consumptions were 32%, 34% for Istanbul, 46%, 52% for Ankara, 33%, 25% for Antalya, 26%, 26% for Diyarbakir, 37%, 57% for Erzurum respectively. By applying $Sc_5$, cooling energy consumptions were also reduced more than $Sc_3$ and $Sc_4$.

As seen in figure 5, all scenarios provided lower total energy consumptions, based on primary energy, than the base case for all representative cities of climatic zones. But one of these scenarios provided the lowest total primary energy consumptions than the others, compared to the base case. For İstanbul and Diyarbakır, by applying $Sc_3$, total primary energy consumptions were reduced by 8%, 7% respectively. For Ankara and Erzurum, by applying $Sc_1$, total primary energy consumptions were reduced by 7% and 12% respectively. For Antalya, by applying $Sc_4$, total primary energy consumptions were reduced by 17%. As to $Sc_5$, the reduction ratios of total primary energy consumptions, for Istanbul, Ankara, Antalya, Diyarbakır and Erzurum were 16%, 15%, 24%, 16%, 20%, respectively.

The evaluated energy consumption values of each scenario were used to calculate the annual cost savings. To determine the NPV value for each scenario, the sum of energy cost (electricity+natural gas) and initial capital investment of each scenarios were used to calculate the present worth of cumulative cost for the life span of 20 years. DPP was also determined to analyze payback periods of scenarios as year and month. Table 5 shows the cost calculations, performed according to financial data of Turkey. According to the results, among the scenarios, $Sc_1$ and $Sc_3$ could be accepted as cost efficient scenario in terms of higher NPV values and short payback periods compared to the other scenarios. $Sc_3$ was the most efficient scenario than $Sc_1$ in hot climatic zones. In terms of negative NPV values compared to the base case and long payback periods more than 20 years, $Sc_2$ and $Sc_4$ were not economically advantageous for all cities, especially because of incremental cost of these scenarios. In hot climatic zones, despite annual savings for $Sc_4$ was higher than $Sc_1$ and $Sc_3$, applying this scenario could be avoided because of high additional cost. Also for $Sc_5$, the same reasons, mentioned for $Sc_4$ and $Sc_2$, made negative impact on the applicability of this scenario. On the other hand, when energy costs are expected to increase faster than building costs, the cost-effectiveness of the scenarios will be even higher.

In this study, limited cost-optimal energy efficient scenarios related to building envelope were analyzed to reach general results and provide energy and cost efficient scenarios according to different climatic zones of Turkey. According to the results of this study, to implement energy efficiency program for existing residential buildings at modest cost, concentrating on space heating and cooling energy consumptions, regarding to climatic zones, has a great importance for the reduction of energy costs. Increasing awareness to the impact of rising energy prices on heating and cooling energy consumptions costs will provide insight into the energy regulations as how to exploit opportunities to minimize the heating and cooling energy consumptions in accordance with the regional and climatic conditions. For that, this analysis becomes more crucial to make sense of different energy efficient scenarios as economically feasible for retrofitting mass production buildings in Turkey and to create a design guide related to climatic zones.

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