THE SIMULATIONS OF THE THERMAL PERFORMANCE OF RETROFITTED EXISTING RESIDENTIAL BUILDINGS IN ISTANBUL WITH MICRO-DOE-2.1E COMPUTER PROGRAM

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ABSTRACT

In this study, the thermal performance of the external envelope of existing residential buildings in Istanbul and energy efficient retrofitting of these buildings are being investigated and modelled by MICRO DOE-2.1E. Hour-by-hour weather data for Istanbul and the data to describe each type of the existing residential buildings as well as the data for energy conscious alternative retrofitting systems are prepared. In the simulations, the thermal performance of interior and exterior insulation systems are verified for a selected reinforced concrete residential building block representing the typical characteristics of the residential buildings in Istanbul. The developed alternative solutions for the external envolopes with opaque and transparent components are being simulated. Finally, the alternatives for retrofitting the residential building block is compared and the solutions and the performance of the computer program are discussed.

Keywords: Thermal Analysis, Thermal Performance, Retrofitting, Computer Simulation, External Envelope of Buildings

INTRODUCTION

A research project is set to investigate the thermal performance of the external envelope of existing residential buildings in Istanbul and to develop alternative external envelope systems for energy efficient retrofitting of these buildings. The investigation also covers to understand the effects arising from variation in the residential buildings, elements of external envelope and fenestration properties as types, sizes, orientation, conductance, shading coefficient, infiltration and natural ventilation level. An appropriate range was selected for each variable to insure coverage of the expected variation typical in the residential buildings in Istanbul, Turkey.

A computer program was looked for thermal analysis simulation of the existing residential buildings before and after retrofitting. Computer programs for a simplified energy analysis, based on such as ‘Degree-Day-Method’ or ‘Bin-Method’, were not considered. Building Loads and System Thermodynamics-BLAST and DOE-2 are found comprehensive enough for the energy analysis simulation. They have been used and tested extensively for many years. DOE-2 was selected to analyze the thermal performance of the residential buildings and a PC version of DOE-2.1E, which includes automatic weather processing and batch file creation, was purchased and used for the analysis, [1]. DOE 2.1E is a programme designed to explore the energy behavior of proposed and existing building and their associated HVAC systems. It employs weighting factors for the calculation of thermal loads and room temperatures. With weighting factor method, an hourly thermal load calculation is performed based on a physical description of the building and that hour’s ambient weather conditions. These loads are used, along with the characteristics and availability of heating or cooling systems for the building to calculate air temperatures and heat extraction or heat addition rates, [2].

The early version of the program DOE-2.1A is described in DOE-2 Engineers Manual which describes the each part of the program as main processors and the programs for the simulation and the energy analysis as building description language-(BDL), loads, systems and plant simulators and life-cycle costing-(LCC) methodology, [2]. The program, which is a widely used, provides a rapid and detailed analysis of energy consumption in buildings.

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However, the information flow in the program is difficult to discern and the program is cumbersome to use in a consequence of the structure of the FORTRAN language.

In this study, the possibilities provided by the program are used to analyze the thermal performance of a building block representing the existing typical residential buildings in Istanbul and the energy efficient alternative retrofitting systems. In this context, a level of thermal performance for the energy efficient alternatives and their components are presented which is important for providing heating energy savings and sufficient thermal comfort in residential buildings.

The systems, plant and economic analysis in the program are used to calculate and evaluate HVAC systems and designing energy efficient buildings or building retrofitting that have low life-cycle cost. Energy consumption is affected by the operation of primary and secondary HVAC systems. However, a large part of the program concerning the heating system and the economic analysis could not be used in the analysis as DOE-2.1E does not include the Central-Heating-System with fluid media for heat distribution, which is extensively used to heat the residential buildings in Istanbul, [3].

Basically, three parts of the program as Program Control, Building Description Language-BDL processor and Loads program are used, and the two groups of data files which are the weather data file of Istanbul and the building description input file are prepared for loads simulations. The approaches accepted in preparing these data files affect the efficient use of the program. Consequently, the usability of the program is evaluated with the analysis of the thermal performance of the existing residential buildings in Istanbul.

SETTING UP THE DATA FOR DOE-2.1E

Hourly weather data and the data for the description of each building are required to run Loads Program. Therefore, hour-by-hour weather data for Istanbul, and the data to describe each type of the existing residential buildings as well as the data for energy conscious alternative retrofitting systems are prepared.

The Weather Data Of Istanbul

As the accuracy of weather variables are very important in the calculation of heat transfer through the external envelope of buildings, the information of the weather variables obtained from the meteorological station for the location where the building exists, must be in detail. The subprograms of DOE-2 require hourly weather data to run. Each weather data file contains one year (8760 hours) of data for each weather variables. In DOE-2 library, basically two groups of weather files, Test Reference Year-(TRY) file with (60x8760) characters and Test Meteorological Year-(TMY) file with (132x8760) characters are available for most USA cities but not for Turkey. Both files have different format and variables.

TRY file consists of hourly weather data values for a selected reference year. In this file, the values of the type, amount and layers of cloudiness which are not measured in the meteorological stations in Turkey are required in detail. The TMY files comprise specific calendar months selected from the entire recorded span for a given station as the most representative or typical for that station and month. The selection of the representative months is made according to a method given in ASHRAE Fundamentals, [4].The weather parameters in TMY format which contain the detailed values of radiation was chosen in preparing the ‘Hourly Meteorological Year’ file for Istanbul.

The weather variables available in the TMY files and used by DOE-2 are solar time and local standard time, extraterrestrial and direct-normal radiation, standard year corrected radiation as observed radiation, dry-bulb and dew-point temperatures, atmospheric pressure, wind speed and direction, sky cover and snow cover. The weather variables used in preparing Istanbul weather file were handled in three groups:

- The measured hourly weather data which are used directly in Istanbul TMY file. These variables are, the wind, the dry bulb temperature and the observed radiation.
- The data which are converted to hourly data from the values measured at 7.00, 14.00, 21.00. These are the visibility, the sky cover and the snow cover.
- The data which are calculated from the other measured weather variables. These are, the dew point temperature, the

extraterrestrial radiation and the direct normal radiation.

It has been a hard task to prepare an hour by hour weather data file and to integrate it to TMY file of Istanbul.

The hourly dew point temperature-(Td) is calculated in accordance with DIN 4108 [5], considering the measured relative humidity-(φ) and the water vapor pressure in saturated air-(Ps, N/m^2) associated with the measured dry bulb temperatures. The equation is:

$$Td = \left[\sqrt[n]{Ps \times \varphi / a \times 100} - b\right] \times 100^{o}C$$

Where:

$Ps = a\,(b+T/100)^n$,

T : measured dry-bulb temperature

for 0°C < T < 30°C, a: 288.68 N/m^2, b: 1.098, n : 8.02,
for -20°C < T < 0°C, a: 4.689 N/m^2, b: 1.486, n : 12.30.

In determining the hourly values of the direct normal radiation-(R_{dn} , kJ/m^2), the measured hourly values of the observed solar radiation-(R_S , kJ/m^2) on a horizontal plane are used. The observed radiation has two components, the direct and the diffuse radiation. The direct part of the observed radiation is calculated by considering the sky condition, [6]. Thus, hourly direct normal radiation-(R_{dn}) was calculated as the following:

$$R_{dn} = R_S \times (1/\cos\theta) \times K$$

Where:

θ : incident angle for each hour, [4],

K : ratio between direct radiation and the observed radiation, for which the observed sky cover was considered in the calculation.

The TMY weather file of Istanbul was packed in (ASCII) formats and processed with the Weather Processor provided with the PC version DOE-2.1E program. This process took time much longer than expected, as it is difficult to find the mistakes in the text (ASCII) formatted weather file due to the structure of the FORTRAN language. Since, the weather processor does not give the errors in the weather file.

Building Description Language-(BDL) for Loads

The thermal performance of a building is determined by its shape, the thermal properties of materials, the size and the position of walls, floors, roofs, windows, doors and the transient effects of shading, occupancy patterns, lighting schedules, equipment operation, ambient conditions and temperature and humidity controls.

In order to enter these information for the simulation of the thermal performance of a building, DOE 2.1E uses a computer language, Building Description Language-(BDL). Through the use of BDL, the appropriate physical parameters of the building can be described as instructions for loads input file.

In this study, a five story high, reinforced concrete building block representing the typical residential buildings in Istanbul is chosen as a sample building. The components of this building such as the reinforced concrete structure, the exterior non-load bearing brick walls, the large overhanging exterior floors open to external environment, the single pane windows, the balconies and the tiled pitched-roof reflect the typical properties of building stock in Istanbul.

The properties relating to the sample building, which can be specified and transferred to the computer environment, are the data concerned with:

- the location and the orientation of the building as latitude, longitude, time-zone and azimuth angle,
- the space conditions of the building as temperature, infiltration rate, floor weight, area and volume,
- the physical, dimensional and orientation properties of the building shades such as balconies,
- the physical properties of the materials used in the layers of the components,
- the layer, the construction and the dimensional properties of the opaque components as exterior walls, overhanging floors and pitched-roofs,
- the physical and the dimensional properties of the transparent components as doors and windows.

The internal load components which are due to people, lights and equipment in a space of a building are not taken into consideration in the loads input file as it is difficult to put forward an accurate day or week schedule in a residential building. Therefore, in defining the internal loads in the space, only the conditions refer to the infiltration, the floor weight of the building structure and the temperature of the space are specified.

The definition of some of the building components as data for loads input file, appeared to be very difficult. Therefore, some intricate approaches are made in the description of the exterior building components. These approaches are given below according to the component:

- In specifying the exterior walls, the elements of the reinforced concrete system (columns, beams) and the non-load bearing brick walls are defined separately as different wall systems. The lintels are seem to be a part of an exterior wall, nevertheless it has not been possible to define them in their real positions as the area of them are added to the total wall area. Consequently, the areas of the lintels are taken into account with the areas of the concrete walls
- In specifying the exterior overhanging floor, some problems occurred in defining the corner part of the component in question. Thus, the insulation can not be described properly to avoid the heat bridge in the corner of the overhanging floor . This problem becomes important in providing the continuity of the insulation materials in energy efficient building components such as exterior walls and floors.
- The tilted and triangular surface areas of the roof are described with equivalent rectangular surfaces with their orientation and tilt.
- The transparent components are specified with their dimensional properties besides their glass type and window shade type. The properties of the frame could not be taken into consideration.
- Modeling the section areas where the heat bridges in corners occur is the biggest problem occurred in specifying data. It is not possible to define those places in detail as the program calculates the heat flux in one dimension.

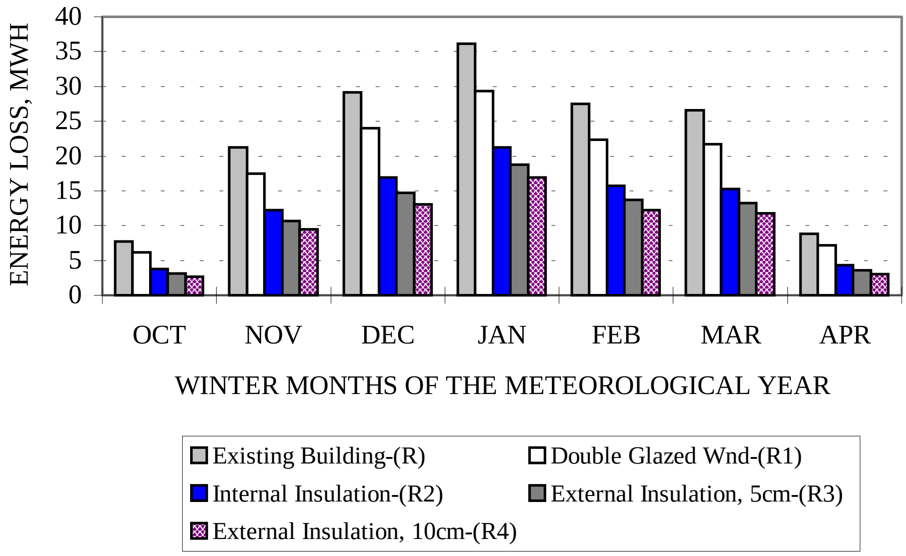
The total floor area and volume of the sample building are 1094 m^2 and 2956 m^3 and the total exterior wall and total window area are calculated as 823 m^2 and 317 m^2, respectively, the transparency ratio is %29. The ratio of the building width to its height is 0.7. The body of the non-bearing walls of the building is formed from hallow bricks with 13.5 cm width. The exterior overhanging floor which is 1.50 m width, surrounds the three elevation of the building. The glass type of the window is 3 mm clear single pane with a U value of 6.31 W/m^2K. The average U value of the windows is calculated as 5.165 W/m^2K.

SIMULATION

In Istanbul, interior and exterior insulation systems are applicable in retrofitting the exterior envelope of the residential buildings. In the simulations, the thermal performance of both alternatives are verified for the sample building. The thermal effects of the building components that are retrofitted with these thermal insulation systems are evaluated. All the components of the sample (existing) building-(R) are thermally uninsulated. In the first alternative insulation system, the clear single pane windows are changed to clear double glazed windows-(R1) with the U value of 2.74 W/m^2K In the second alternative-(R2), the interior surface of the external brick walls and the roof slab are thermally insulated with 5 cm expanded polystyrene or glass wool with thermal conductivity-(k) of 0.04 W/mK. In the last two alternative insulation systems-(R3 and R4), the exterior walls, the exterior overhanging floor and the roof slab are thermally insulated externally with 5 and 10 cm thermal insulation materials respectively. The glass type of the single pane windows are retrofitted with double glazed windows in all insulation systems. The energy losses and savings of the alternative systems are calculated with MICRO-DOE2.1E computer program.

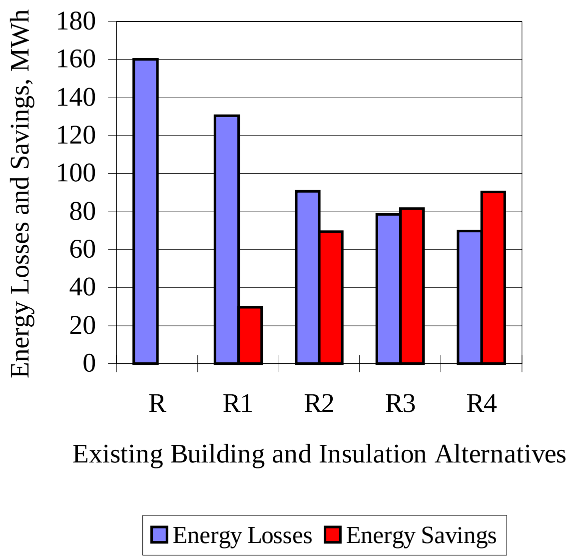
The monthly energy losses of the existing building and the two alternatives occurred during the heating period of Istanbul which is between October to April are given in *Figure 1*. The monthly energy losses shows that the results verify the accepted approaches in preparing the weather file of Istanbul. The energy losses for a year in the existing building-(R) is calculated as 160.17 MWh. The amount of energy saved with the alternative insulation systems (R1 to R4) are 29.69 MWh, 69.57 MWh and 81.71 MWh and 90.44 MWh which are 18.5 %, 43.4 %, 51.0 % and 56.5 % respectively, when compared with energy losses of the existing uninsulated building, (*Figure 2)*.

Figure 1: Energy Losses of the Existing Building and the Buildings with Internal and External Insulation and Double Glazed Windows



The effect of thermal insulation on each building component is evaluated for the second alternative insulation system-(R2) in respect to uninsulated building-(R). By retrofitting of each building component, the thermal performance of the externally insulated wall, the double glazed window and the roof will become 72 %, 60 %, 26 % more efficient, respectively.

Figure 2: Yearly Energy Losses and Savings of the Existing Building -(R), Building with Double Glazed Window -DG-(R1), with Internal Insulation and DG-(R2), with 5 cm External Insulation and DG-(R4)



CONCLUDING REMARKS

By means of the computer program DOE 2.1.E, it is possible to reach rather detailed thermal analysis of buildings. Although, the program is selected on the account of providing a rapid and detailed thermal analysis, some problems occurred in the preparation of TMY weather file and the BDL files for the building description, due to the conditions in Turkey. Therefore, it took time to prepare the program for the simulation and the simulation could not be run for each building component with similar efficiency. The problems are:

- As the system and the plant sections of the program does not include the Central-Heating-System with fluid media for heat distribution, which is extensively used for heating the residential buildings in Istanbul, a large part of the program concerning the heating system and the economic study with life-cycle-costing could not be used together with the thermal analysis.
- Preparing the TMY weather file of Istanbul with specified format took considerable amount of time. Calculations of the direct normal radiation and dew point temperature were required a particular attention. The usage of a program would be more efficient on the international platform if it includes a systematic approach in preparing weather data by using standard measurements.
- The definitions of some building components as the exterior overhanging floor, the triangular tilted roof, window frame etc. in BDL input file appeared to be very difficult. Among all, modeling the section areas of heat bridges in corners occurs the biggest problem in specifying data. Therefore, some intricate, even evasive approaches required to be made in the description of those exterior building components.

In spite of the difficulties occur in using the program, the results obtained from the simulation are found satisfactory. The results confirm the accuracy of the accepted approaches that are used in preparing the weather files and input data for loads program.

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