Performance Based Window Selection Model for Residential Buildings

Aslihan Tavil, Hakan Yaman and Ikbal Cetiner

Faculty of Architecture, Istanbul Technical University, Taskisla, Istanbul, 34437 Turkey

ABSTRACT: In this paper a research project, which aims to develop a model for window selection of residential buildings to assist consumers, designers and contractors for their understanding the effects of new window products and their performance implications, was introduced. The objective of the project was to facilitate the selection of the appropriate window system, which enables energy and cost benefits while providing user comfort conditions of residential buildings in different climates of Turkey. IDEF0 function modeling method was used to describe the phases and functions of the research project. IDEF0 helps to demonstrate the inputs, outputs, controls and mechanisms affecting the formulated functions or activities and the interrelations among them. The final step will be to develop a relational database management system (RDBMS), which provides the indication of the best window option for a particular case.

Keywords: residential buildings, windows, energy and cost efficiency, dynamic model, functional modeling

1. INTRODUCTION

Windows are possibly the most complex and interesting elements in residential design. Today's energy efficient windows can dramatically decrease the heating and cooling costs while increasing the occupant comfort and minimizing window surface condensation problems. In recent years the advances in window technology offer new alternatives for the design of the windows of both new construction and retrofits. High performance window systems may be considered as one of the key factors for reaching sustainable building design challenge by decreasing heating, cooling energy use and they also contribute to national and global efforts to reduce the environmental impacts of non-renewable energy use.

There are many complex issues that are difficult to balance in selecting the best window for sustainable practices and therefore it is not very easy to reach the best window option that provides the maximum energy and cost efficiency while achieving visual and thermal comfort. The energy saving potential of a window is strongly dependent on a large number of variables for instance climate, thermal and geometrical characteristics of the building in which the window is installed [1].

This complexity is such that the actual energy savings obtained with an energy efficient window in a specific climate, for a specific period, for specific environmental conditions and for a specific house and homeowner's lifestyle, can most probably not be known accurately, except by performing highly detailed analysis with a whole building simulation program using proper simplifying assumptions. In accordance with having many parameters such as climate, outdoor obstructions, building type, window area, orientation, shading devices and window alternatives a comprehensive parametric study is required to comprehend the impact of each window option with a particular case on the energy performance of a building in conjunction with cost issues. For considering the cost issues not only the initial costs but also a number of costs including maintenance and operating costs as well as the benefits that occur through the life-cycle of the window is crucial for the performance evaluation of windows.

Recently, a research project was set to develop a dynamic model to design and select energy efficient windows for residential buildings. This model aims to assist the consumers, designers and contractors for understanding the potential and performance implications of the new window products in different climatic regions of Turkey. In this paper, we used IDEF0 function modeling method to describe the phases and functions of the research project [2]. IDEF0 is an effective way to demonstrate the inputs, outputs, controls and mechanisms affecting the formulated functions within the context of the project and the interrelations among them.

The final step will be to develop a relational database management system (RDBMS), which provides the indication of the best window option for a particular case. The results of the parametric study and life-cycle cost data-base developed will be used for window performance evaluation. A web-based interface of the RDBMS will enable the users to enter the environmental conditions and the characteristics of their buildings to review the performance data of the windows. The users will be able to compare the energy saving potentials and life-cycle costs of the alternative windows based on user-defined characteristics of their building system in a particular climate of Turkey.

2. AN ENERGY EFFICIENT WINDOW SELECTION MODEL - HiPerWin

Since the issues affecting the window performance are complicated and include complex relationships, we used IDEF0 function modeling method to explain the functions and activities; inputs; outputs; the issues that control them; and mechanisms used to implement the functions within the context of high performance window selection model (HiPerWin). IDEF0 can provide a procedure for completely and consistently modeling functions required for window selection process. It helps to demonstrate the functional relationships and information that support their integration. The phases describing the preliminary conceptual model were illustrated with a graphical representation of a set of components. Consequently, the components constituting the inputs; functions; the outputs and internal/external mechanisms affecting the functions as well as the interrelationships were presented with hierarchical parent – child diagrams.

HiPerWin IDEF0 model has been developed for performing systems analysis at all levels of the window selection process and for designing a relational database management system (RDBMS) together with a data modeling technique IDEF1x. HiPerWin model was composed of interdependent components (people, software, information, processes etc.) that work together to perform the functions for window selection. The model describes what a window selection process looks like, what controls the process, which processes it works on, which mechanisms it uses to perform its functions, and what it produces.

HiPerWin IDEF0 model was composed of a hierarchical series of diagrams that regularly indicate increasing levels of describing functions in detail and their interfaces within the context of the model. The paper introduces A0 top-level diagram, and A3 and A4 hierarchical parent diagrams, which are the decomposed parts of the model. Each sub-function of the A0 parent diagram was decomposed by the parent boxes. The parent boxes were detailed by child diagrams at the next lower level until all of the relevant detail of the whole viewpoint was adequately exposed.

Estimating the energy use and thermal comfort of a building with various window options is possible with the determination of an appropriate set of values for the parameters. Window design and selection parameters can be separated into the parameters related with outdoor environment and the build environment. The aim is to characterize the outdoor environment with natural factors such as local climatic factors and the build-environment under different criteria of scale such as building settlement, building block, housing unit and building component in the definition model.

Each box in A0 top-level diagram, and A3, A4 parent diagrams were explained in detail in the following paragraphs. All functions and related inputs, outputs, controls and mechanisms in the context of HiPerWin model were represented with a parent diagram given in Figure 1.

2.1 Characterizing the outdoor environment

Comparing windows based on energy performance is often a confusing and difficult process. Outdoor environmental conditions can be of paramount importance in evaluating the energy performance. This aspect is primarily taken into consideration in the model. The impact of windows on building energy use can vary considerably with the location because of the climatic differences. Both heat and moisture flows through the external envelope are affected by outdoor local climatic conditions. Besides, the construction type, the materials of the external envelope and the properties of the building itself, which may differ from region to region, affect the heat and moisture flow. For window performance appraisal, local environmental data for the selected cities: namely climatic data, typical buildings and construction data have to be collected and converted into input data for the analysis.

2.2 Characterizing the built-environment

The parameters attributed to built-environment can be considered on the basis of a building settlement, a single building block, room in a housing unit and a functional building element. The parameters that influence the window performance on the building settlement scale are as follows [3]:

- Dimensions and orientation of external obstacles
- Physical properties of surrounding surfaces (solar reflectivity etc.)
- Soil cover and nature of the ground (plant cover and groups of trees)

According to the statistical data, 40-45% of the residential building stock was produced individually by the private sector in Turkey [4]. In general, the building sites in the cities became urbanized with individual residential apartment blocks, which were constructed according to the local regulations. Separately built detached residential apartment blocks were ordered on almost the same sized parcels in the cities and these settlements were developed with the repetition of mostly the same sized buildings.

In the context of the research project, the residential building settlements in three biggest cities (Istanbul, Ankara, Izmir) in Turkey were taken into consideration and local regulations of these cities were analyzed for rational assumptions in modeling the representative building settlement for the computer simulations. Possible building distances from the surrounding buildings, width of the roads and building heights were characterized according to the zoning regulations of the cities [5].

The dimensions of the parcels in which the blocks settled were determined according to the building height. In the simulation model the building types were accepted to be modeled with surrounding same sized blocks with a distance of 12 meters.

98% of the completed and partially completed residential blocks in the cities were constructed as reinforced concrete skeleton system [4].

Slope, orientation, vegetation and parcel dimensions were considered as the additional input data in characterizing the building site.

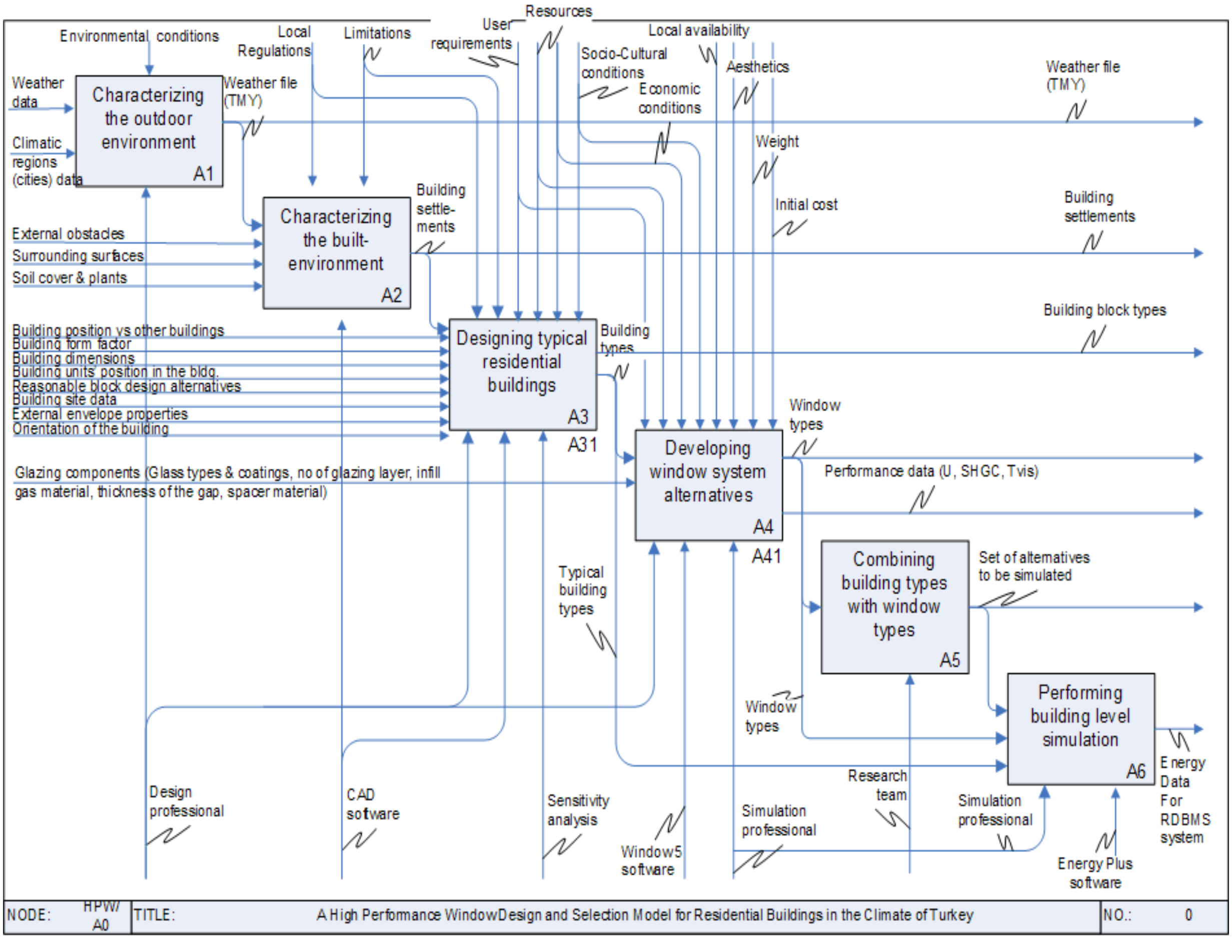


Figure 1: HiPerWin IDEF0 function model top-level diagram.

2.3 Designing Typical Residential Buildings

The main parameters affecting the window performance on the building scale are as follows:

- Orientation of the building
- Position of the building among other buildings
- Building shape factor
- Dimension

The physical and operational characteristics of the buildings are important issues in developing the reference building blocks for the simulation model. The reference building blocks should represent the scale and occupancy patterns of a single-family housing unit of a residential building. Common characteristics were taken into consideration in representing the residential building pattern in Turkey. Detached and 3-5 storey height residential building blocks are 45% of the total building stock [6]. Therefore the typical buildings were accepted as 5 storey height. In designing the reference building types, the position of housing units within the building block were taken into consideration to attain possible options. The inputs, outputs, controls and mechanisms of the function in designing the typical residential building blocks are given in Figure 2.

Determining housing unit types:

The main parameters affecting the window performance on the housing unit scale are as follows:

- Position of the unit or room within the building
- Dimension of the unit and its shape factor
- Orientation

In designing the typical buildings the basic users' requirements, socio-cultural and economical conditions are the main control mechanisms in deciding the size of the housing units. Majority of the traditional Turkish families having an average economical situation are satisfied living in a 100 m^2 housing unit, which mostly fulfills their basic requirements. The ratio of people living in 100 m^2 housing unit in the three cities is 40% in average [7]. Therefore, 100m^2 floor area was accepted as the base housing unit area in the typical buildings and possible building units were designed by taking into account of the shape factor - building aspect ratio (BAR), which is the ratio of the width to the length of the housing unit. Two different BAR's as 0.7 and 1.0 were accepted in determining the building units.

Determining building block types:

The position of the housing unit within the building block is an important factor in determining the building block types. Two or four same sized housing units can come together within a residential building according to the local regulations that restrict the building sizes.

Basically, seven different types of building blocks can be determined by rotating the buildings to take the orientation effect into account (Table 1).

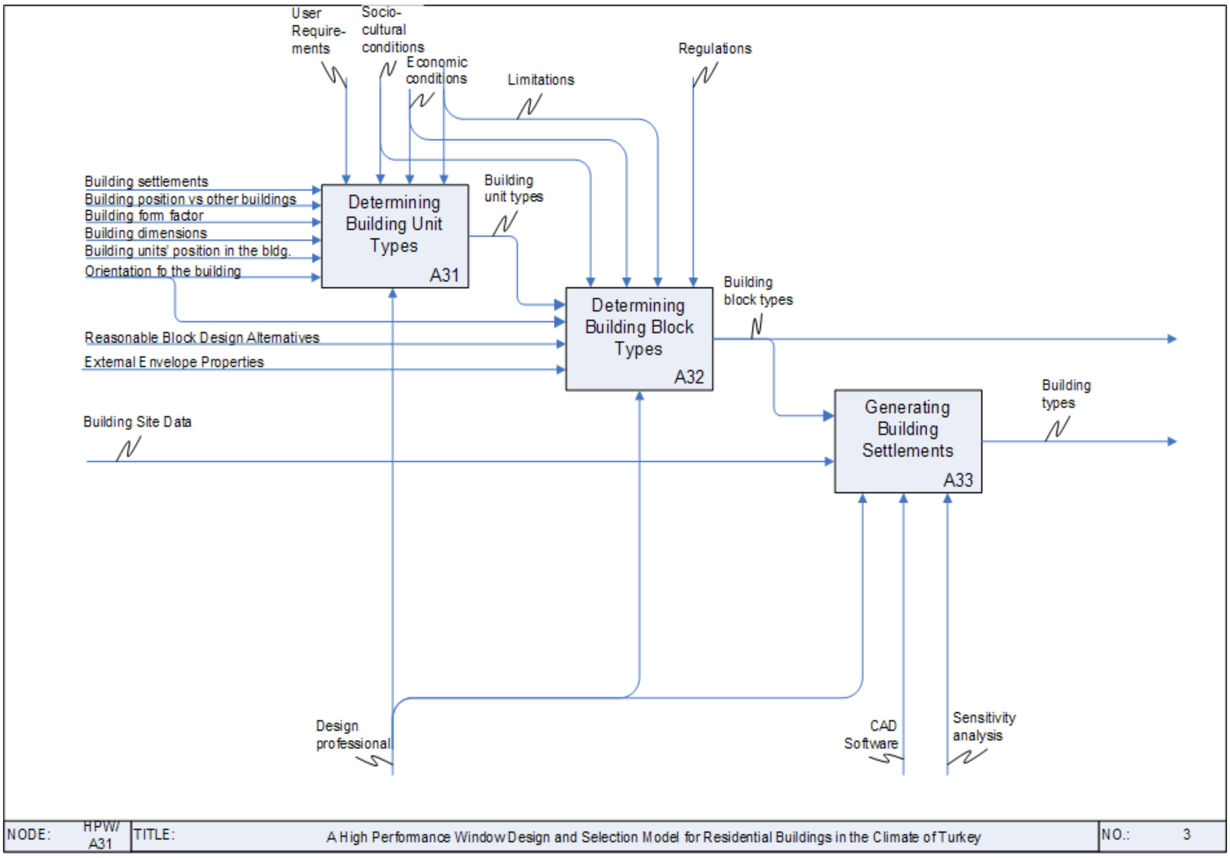
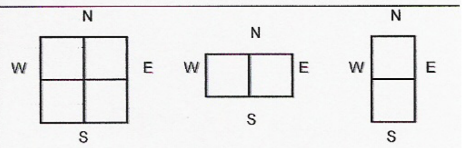
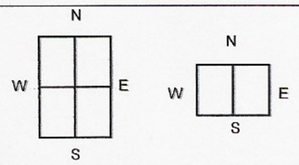
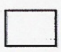
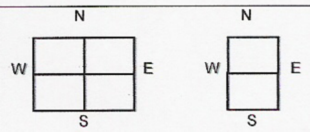


Figure 2: The inputs, outputs, controls and mechanisms of designing the typical residential buildings

Table 1: Housing unit and building block alternatives

Housing units	Building block alternatives
 BAR=1	
 BAR=0.7	
 BAR=0.7	

Many combinations of building blocks can be developed in conjunction with various window options. Reasonable or applicable building block alternatives were determined with a sensitivity analysis in which the annual energy use of the building block combinations was calculated with a whole building simulation program. In the analysis the orientation and different window sizes were considered and the building block types having similar results were eliminated.

Generating building settlements

The building settlement for each residential building block type was arranged with the same sized buildings by considering the local regulations of the three cities. The buildings were assumed to be located with a distance of 12 meters from each other to simplify modeling of the building settlements.

2.4 Developing Window System Alternatives

The main parameters affecting the window performance on transparent component scale are as follows:

- Dimensions of the windows
- Glazing components
- Window performance parameters – U_value, SHGC, Tvis
- Frame type
- Shading devices

The inputs, outputs, controls and mechanisms of the function in developing window system alternatives are given in Figure 3. The determination of window system alternatives to be analyzed was another component of the model. A meaningful set has to be generated among the infinite alternatives, by using an appropriate criterion or criteria. This can easily be done by a design/selection method based on the experience, knowledge and judgment of the design professionals. In the case of the design and selection of energy efficient retrofitting systems, the criterion; "applicability" in terms of local available materials and systems as well as expert workmanship and ease of application, were employed.

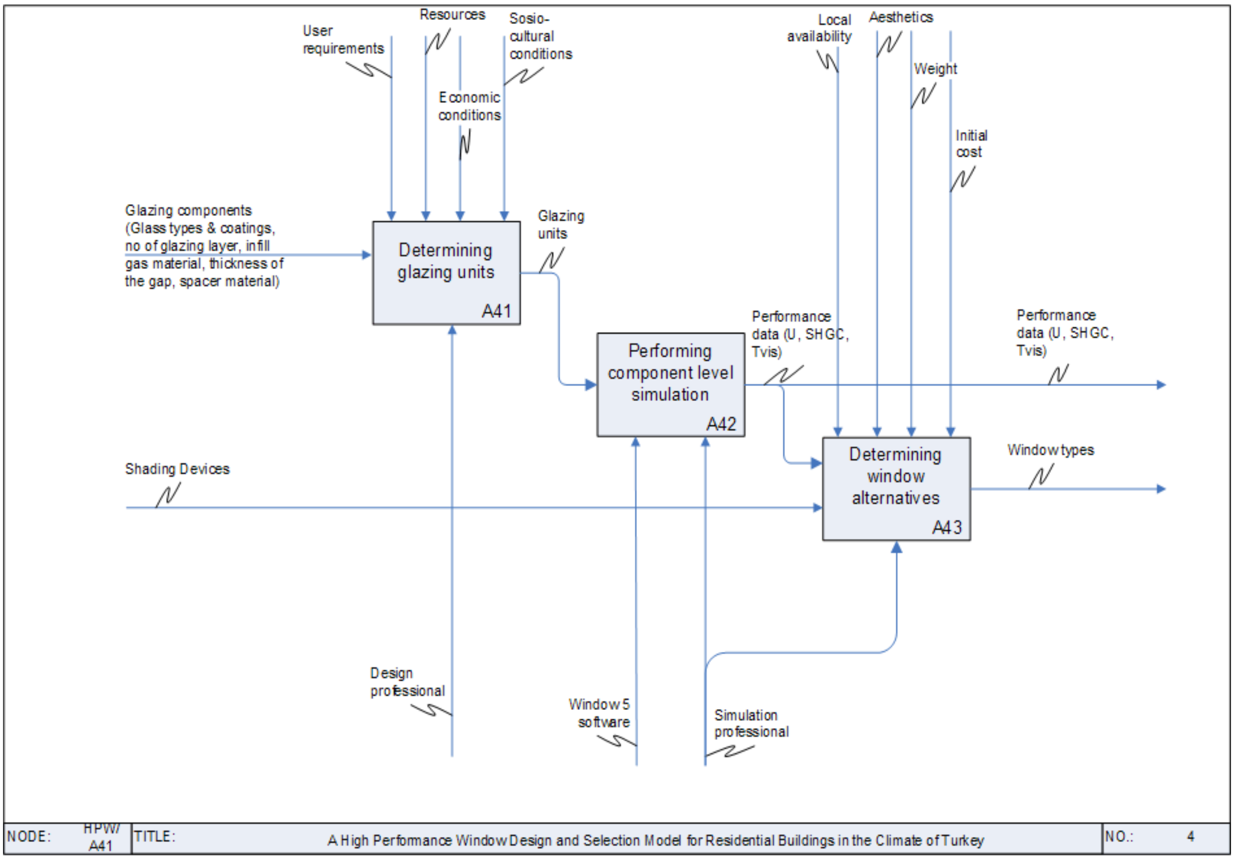


Figure 3: The inputs, outputs, controls and mechanisms of developing window system alternatives

In the model the dimensions of the windows were applied as 45%, 30% and 15% window to wall ratio (WWR) for large, moderate and small windows, respectively. PVC and timber frame types will be considered since they are mostly used in Turkey.

Both interior and exterior shading devices were employed in the combinations for considering the effect of the shading devices. Tulle curtains are used nearly at all Turkish homes for privacy and they are always kept closed during day and night. Moreover, exterior moveable window shades were used for solar control in some housing units particularly in summer. Hence two different alternatives of buildings with and without exterior window shades will be evaluated.

Determining glazing units

Sub-components of a window influence the energy performance of a total window system. Recent advances in their technology offer many alternatives for the energy efficient windows:

- Glass types and coatings
- Number of glazing layers
- Thickness of the gap
- Infill gas material
- Spacer material

Meaningful set of window system alternatives were developed by considering the products and possibilities of the local glass company.

Performing component level simulation

The energy related properties of the window system alternatives were determined by using Window5 computer program [8]. At this stage, thermal transmittance (U-value), solar heat gain coefficient (SHGC) and visible transmittance (Tvis) properties of the window systems, which can be used as the basis for quantifying energy performance and allow accurate comparison at component level were calculated. The window design and selection issues associated with these window performance values can be overwhelming for making a design decision if there were a simple sequence of steps. But sometimes it is not easy to reach right solution based on the defined performance criteria since the energy performance of a window is strongly dependent on a large number of variables. Therefore these data were utilized as inputs to define the window performance values in the whole building energy simulation program. Window properties can be specified in detail with these data.

Developing window alternatives

Appropriate glass types and their combinations were determined with the main requirements like local availability, initial cost, system weight, aesthetics and durability after an elimination process. The products of the local glass company, which is one of the worldwide leading companies were employed in the project and applicable glazing units were defined.

2.5 Combining the Building Types With Window Alternatives

As a result of the combination between the building types and window alternatives many alternatives can be derived. The important point here was to select applicable, appropriate cases to be simulated for developing the RDBMS system, which will contain the possible alternatives. The database must cover the most possible cases that a user may define.

2.6 Performing Building Level Simulation

Within the framework of the study, seven different residential building types were developed for the simulation purposes. The typical buildings used in the simulation studies serve as the base cases for the comparisons and evaluations.

The performance of the buildings with various window types can be represented by using a whole building simulation program. Comparisons of energy use and comfort conditions can be made on longer time periods as annual basis which results in greater accuracy of the prediction and on shorter time scales as daily or hourly basis which can give more information that may be useful in diagnosing the nature of the problems. In order to estimate the performance of a particular building, as opposed to estimating design options, there is a need for a powerful and comprehensive simulation tool, by which all required outdoor and building environment information can be modeled. The application of model-based performance assessment at the whole building level requires detailed definition of outdoor environment, properties of building settlements, building blocks, and housing units with their sub-components as well as operational features of the buildings since heating and cooling energy consumption depends on building characteristics, occupancy, operational schedules, type of HVAC system, weather and other parameters.

In this project EnergyPlus simulation program that combines the best features of BLAST and DOE-2 programs along with many new capabilities will be used for energy calculations [9]. One other reason to select EnergyPlus for simulations was that the program includes important features associated with the modeling of windows. Those features are layer-by-layer input custom glazing, ability to accept spectral optical properties, incidence angle-dependent solar and visible transmission and reflection, iterative heat balance solution to determine glass surface temperatures, calculation of frame and divider heat transfer, and modeling of movable interior or exterior shading devices with user-specified controls. EnergyPlus makes available to analyst calculation capabilities that accurately determine – in a whole building context – the performance of a wide range of window configurations for different climates and building types. Moreover, EnergyPlus accepts a window description file from Window5 so that exactly the same window calculated by Window5 can be exported to EnergyPlus for energy analysis [10].

3. CONCLUSION

In this study, the phases and functions within the context of the research project, which aims to develop a model for energy and cost efficient window selection of residential buildings were introduced by IDEF0 function modeling method. The approach and related complex issues that influence the window performance could be explained to arrange and sustain further steps of the whole project with IDEF0 method. In fact, this paper is an introduction of the HiPerWin model in conjunction with the research project for introducing the foresights to be associated with the whole concept.

It is thought that at the end of the project the proposed model will be used:

- as an energy rating tool for residential windows in Turkey;
- as a window selection tool in existing residential buildings where a change of windows is about to be performed in Turkey;
- to assist in the choice of windows in new residential buildings in Turkey;
- to make comparisons of the energy and cost efficiency of advanced windows in different climates, orientations, and types of buildings with particular features.

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