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High performance window selection model - HiPerWin

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Abstract:
Windows are the most complex elements in residential design, and owners are often confused about how to decide the most efficient window for their residence. A model, namely "A High Performance Window Selection Model – HiPerWin", was developed as a research project for selecting energy and cost efficient residential windows in different climatic regions of Turkey. The challenge was to attain a basic source which supports the user to provide the energy and cost data required for selecting the appropriate window. In this context, the alternatives of the insulated glazing units (IGU) with different properties were generated, and the performance values of the IGU's were calculated. A comprehensive parametric study was conducted for providing the energy use of each case. The present value of both the operational energy consumption and capital costs of window systems was calculated for whole life cost evaluation. A dynamic tool, a relational database management system (RDBMS), was also developed to manage all energy and cost results associated with the building model. By means of the RDBMS the users are able to define their cases and select the most energy and cost efficient window system by using the energy and cost data stored in the database.

Keywords: *Residential buildings, window systems, energy and cost efficiency, parametric study, window selection model, relational database.*

1. Introduction

Windows are possibly the most complex and interesting elements in residential design. At present energy efficient windows can dramatically decrease the heating and cooling costs while increasing the occupants' comfort and minimizing window surface condensation problems. Recently, the advances in window technology offer new alternatives for the design of the windows of both new construction and retrofits (Carmody, 2000*)*. This complexity results in that users are often confused about how to decide the most efficient window for their residence, whether it is a new building or a window replacement. Since energy efficient windows can act to have a positive impact on building energy flows (Arasteh, 1995), and be implemented to reduce the cooling/heating loads and lighting requirements (Lee, 2006), understanding the energy and associated cost implications of different window systems will help users to make the best decision for their particular case.

Models and rating schemes can be utilized for making the best choice by evaluating window performance. These are based either on the selected window properties (U-factor, SHGC, etc.) or the calculated annual heating and cooling loads (Papaefthimiou, 2009). The National Fenestration Rating Council (NFRC) in the USA, for instance, rates the properties of windows, which are thermal transmittance (U-factor), solar heat gain coefficient (SHGC) and air infiltration (NFRC, 2005). Canada's Energy Rating Program (ER) by National Resources Canada (ER, 2009), Window Energy Rating Scheme (WERS, 2010) adopted by Australian Window Council (WERS), and the European Window Energy Rating Systems (EWERS) adopted by British Fenestration Rating Council (BFRC, 2008) are the energy rating systems which rate residential windows for energy performance in the same way as NFRC.

Some countries have already adopted an energy-rating scheme for fenestration to supply an easy instrument for designers, to help their choices considering the climatic zone, the characteristics of the house or building and those of windows. The energy rating system proposed by Maccarini and Zinzi (2001), following the same basic principles, aims to greatly reduce energy end use, as a consequence, also CO_2 emissions. The methodology, implemented for the residential sector, is based on the assessment of thermal performances of three reference buildings as a function of window properties, climatic data and architectural characteristics. Karlsson et al (2001) presented a model to assess energy balance and cost efficiency for several glazing combinations for buildings in a typical mid-Swedish climate. The model renders very simple way to compare existing and non-existing advanced windows in different geographical locations, orientations and buildings. Papaefthimiou et al (2009) proposed a combined methodology for the rating of advanced glazing, which aims to add the economical and the environmental aspect to the existing evaluation systems. Taking into account the special characteristics of the advanced glazing, a life cycle assessment (LCA) study and an eco-efficiency analysis have been combined to provide an alternative rating scheme, which has been applied to an electrochromic window as a case study. Urbikain and Sala (2009) proposed a Window Energy Rating System that would be an indicative of window performance for residential buildings in two climatic zones of Spain, considering the heating loads and energy savings of different types of windows.

There is a lack of a modeling or rating scheme which aids to select the appropriate window type for different climatic regions of Turkey. A model, namely "A High Performance Window Selection Model – HiPerWin" was developed in the context of a research project, which was recently completed, to select energy and cost efficient windows for residential buildings. The challenge was to attain a basic source which supports the user to provide the energy and cost data required for the decision making in the selection of the residential window systems (Tavil et all, 2010).

The ultimate objective of the research project was to develop a relational database management system (RDBMS) which incorporated the whole data and the data to be processed into information regarding the window systems and helped the comparison of the alternatives. Hence query parameters were presented for helping the users to define the built environment and housing unit characteristics of their own case to find out the appropriate window alternatives by comparing the total annual heating/cooling energy consumption and associated capital and ownership costs.

In the context of the research project, the alternatives of the insulated glazing units (IGU) with different optical and physical properties were generated. The performance values which demonstrate the insulation and solar control capabilities of the IGU's were calculated by using Window5 software (LBL, 2009). In accordance with having many parameters such as climate, building type, orientation, window area, shading devices and window components, a comprehensive parametric study was conducted for providing the energy use and associated cost data of each case by using a powerful whole building simulation tool EnergyPlus (LBL, 2010).

Standard representations of buildings (i.e. building model) required for simulations, involving geometrical and semantic properties were stored in the HiPerWin database which was being used during the selection process. The present value (PV) of future cost of window systems was calculated by using the factors and indices, both operational energy costs calculated from the energy simulations and the capital and operating unit costs of window systems. The capital cost includes purchase, installation and finance costs, while operating unit cost includes ownership, maintenance and energy consumption costs.

In this paper, the HiPerWin Process Model is introduced considering the HiPerWin Energy Process Model in particular, and then the HiperWin Model which will help to select energy and cost efficient window systems for residential buildings in different climatic regions of Turkey is explained in detail and is applied for a case.

2. HiPerWin process model

Since the issues affecting the window performance are complicated and include complex relationships, the functions/activities; inputs/outputs; the issues that control the functions; internal/external mechanisms used for implementing the functions and the interrelationships among the functions within the context of the project are explained by using "IDEF0 (Integrated Definition for Function Modelling) method" (see Figure 1) (NIST, 1993). In IDEF0 method the functions describing the conceptual model are illustrated with a graphical representation of a set of components that are presented with hierarchical parent–child diagrams. HiPerWin IDEF0 model is composed of a series of diagrams that hierarchically indicate increasing levels of functions and their interfaces in detail. The top level (A0) diagram of the HiPerWin IDEF0 model consists of six main functions which are briefly described in Figure 2.

2.1. Outdoor environment

The impact of windows on building energy use can considerably vary with the location because of the climatic differences. The analysis is performed for three different climatic regions of Turkey within the context of the project.

High degree of mass-housing potential and being the biggest cities with the highest population are taken as the selection criteria of the cities. Izmir, Istanbul and Ankara represent hot-humid, temperate-humid and temperate-arid climates, respectively. Geographical information and heating and cooling degree-days of the analyzed cities are given in Table 1. "Typical Meteorological Year-TMY" files of the cities are used for the simulations, which are obtained from hourly climatic data in US National Climatic Data Center (Anon, 2001).

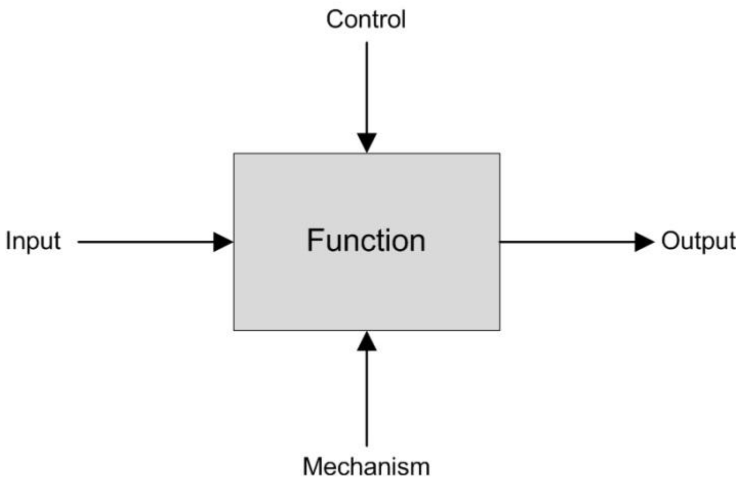


Figure 1. *IDEF0 method arrow positions and roles.*

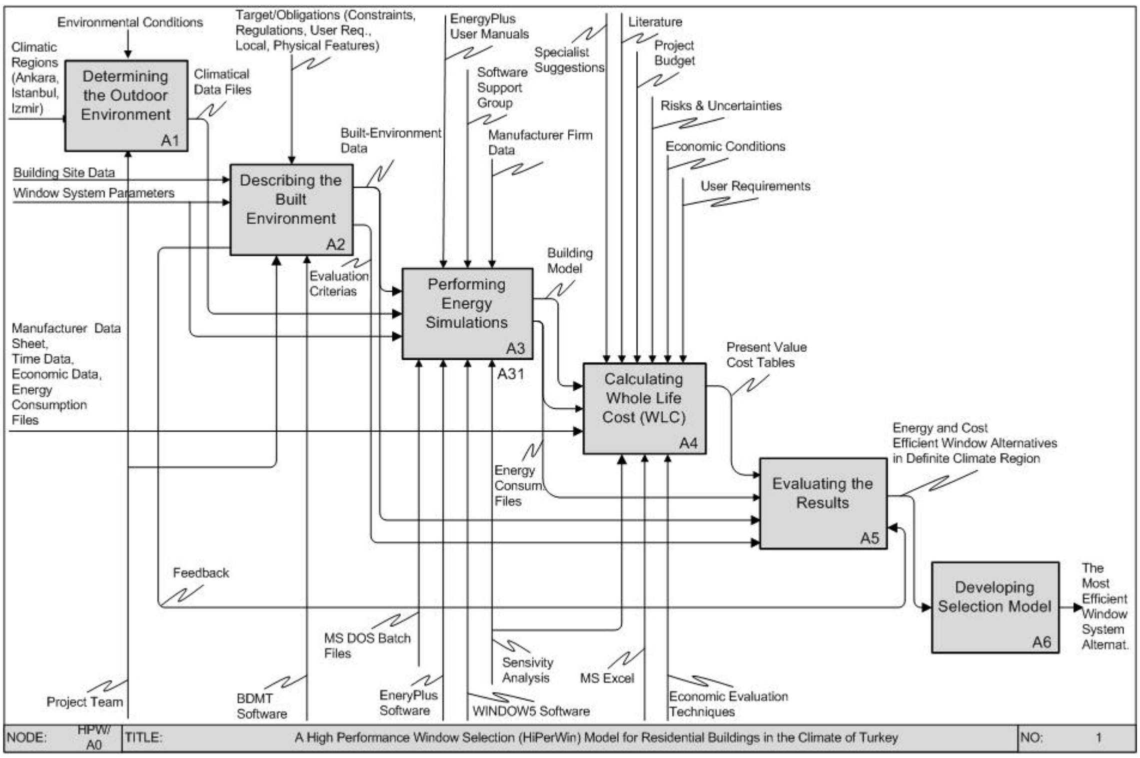


Figure 2. *The development processes of HiPerWin model with HiPerWin IDEF0 A0 diagram.*

Table 1. *Geographical information and climatic data for the cities analysed.*

City	HDD (18 °C)	CDD (18 °C)	Lat.	Long.	DBT (°C)	WBT (°C)	DNSol (W/m^2)
Ankara_C1	6102	360	40.12	-32.98	9.4	5.6	955.2
Istanbul_C2	3505	1054	40.97	-28.82	14.4	11.7	829.3
Izmir_C3	2528	1614	38.5	-27.02	16.7	12.2	1356.2

HDD: Heating degree days, CDD: Cooling degree days, Lat: Latitude,
Long: Longitude, DBT: Dry bulb temperature,
WBT: Wet bulb temperature, DNSol: Direct normal solar radiation.

2.2. Built environment

The built environment is considered on the basis of housing unit, building block and building settlement. This is important in terms of describing a built environment representing factual conditions, such as site data, housing statistics, local regulations, limitations, user requirements, and etc.

The parameters affecting the window performance related with the built environment are grouped as follows (Tavil et all, 2007):

- The parameters related with the housing unit: Unit area, building aspect ratio (BAR), orientation, window to wall ratio (WWR), solar control devices, heating/cooling system, occupation type, and etc.
- The parameters related with the building block: Orientation of the building, building dimensions, number of story, position of the housing unit in the building block, structural system, construction method, and etc.
- The parameters related with the building settlement: Orientations and dimensions of the external obstacles (buildings, trees, etc.), physical properties of surrounding surfaces (solar reflectivity, etc.), soil cover and nature of the ground (plant cover and groups of trees), possible building distances from the surrounding buildings, width of the roads, and etc.

2.3. Energy simulations

In accordance with having many parameters such as climate, building type, orientation, window area, shading devices and window components, a comprehensive parametric study is required for calculating the energy consumption and associated cost data of each case. Obtaining the actual energy consumption in a specific climate, for a specific period, for specific environmental conditions, for a specific orientation and for a specific building and occupants' lifestyle in accordance with control actions is a complex phenomenon in analysing the energy and cost efficiency of a window system. Hence EnergyPlus simulation software is used since it has many new capabilities for energy calculations as well as it includes important features associated with modeling the windows (LBL, 2005). 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 software facilitate to analyse 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 software imports a window description file from Window5 software so that exactly the same window calculated by Window5 can be exported to EnergyPlus for energy analysis (Winkelman, 2001).

Within the context of the parametric study, input macro files (imf) are generated to simulate 10080 options for determining required performance data for the cases which a user may define. At the end of the parametric study annual heating and cooling loads of the possible cases are stored in HiPerWin database as well as whole life cost (WLC) data calculated.

According to the HiPerWin Energy Process Model (see Figure 3), the energy simulations are performed as follows:

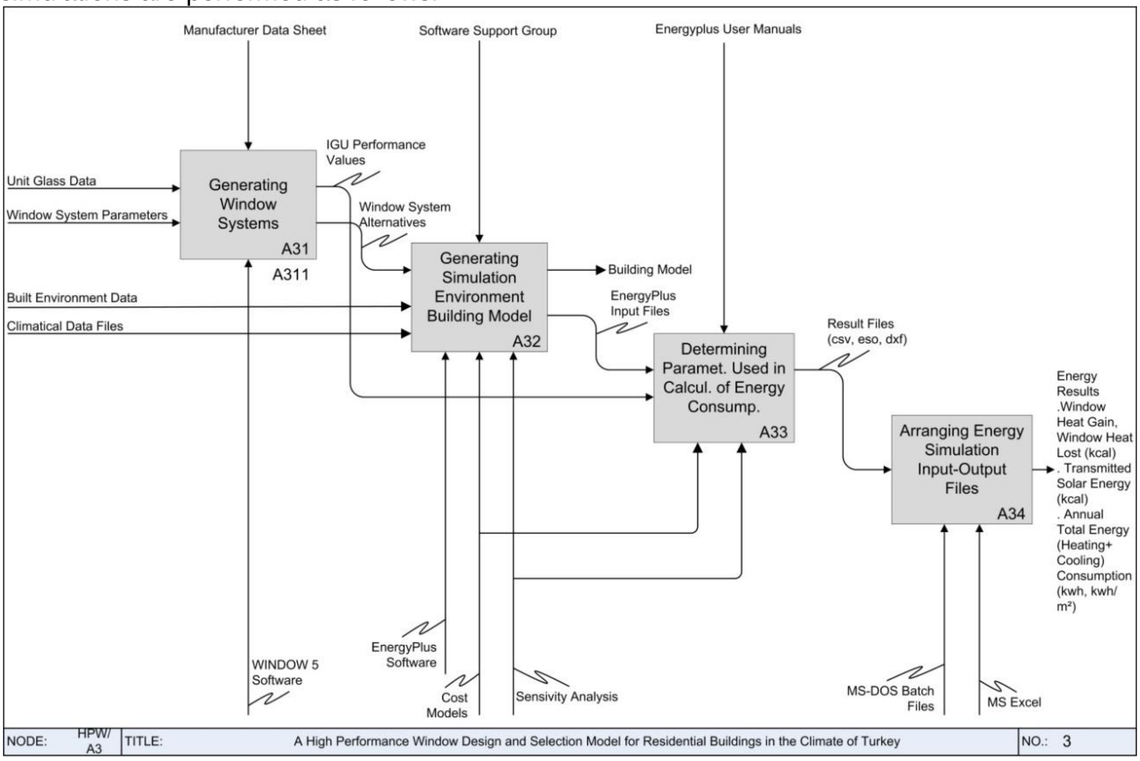


Figure 3. *The processes of energy simulations with HiPerWin IDEF0 A3 Diagram.*

2.3.1. Window systems

Recent advances in the technology of glazing units offer many alternatives for the energy efficient windows. A meaningful set of glazing alternatives can be developed by combining the sub-components as glass types and coatings (clear, Low-e, SS-Low-e, etc.), thickness of the gap (12mm or 16mm) and infill gas material (air or argon).

The window system alternatives are developed in three stages:

- Generating glazing alternatives according to the data related with thickness of the gap and glass from manufacturers
- Calculating the performance values of the generated glazing alternatives
- Developing window system alternatives

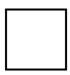
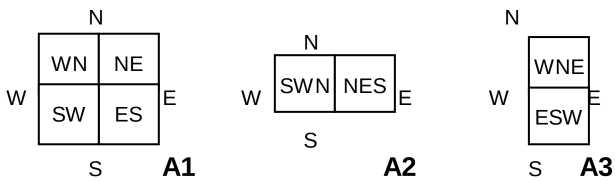
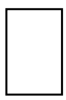
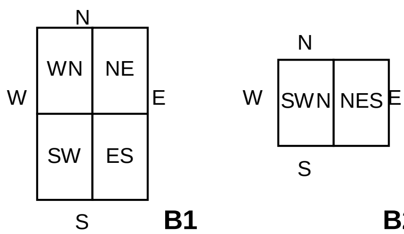
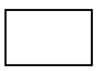
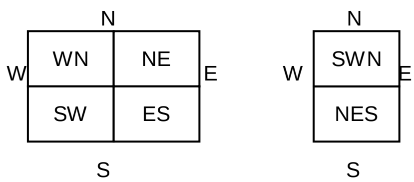
A set of glazing alternatives with various glass types, coatings, thickness of the gap and infill gas are obtained from one of the. The window dimensions are defined leading glass company in Turkey. The energy related properties of the glazing alternatives; thermal transmittance (U-value), solar heat gain coefficient (SHGC) and visible transmittance (Tvis) are calculated using Window5 software. The results are used as inputs to define the window performance values in the EnergyPlus software. Glazing alternatives of 28 in total are developedaccording to window to wall ratio (WWR) of 45%, 30% and 15% representing large, moderate and small area windows, respectively. PVC frame type is widely used for window replacements in Turkey. The PVC frame type having a thermal conductance of 2.46 W/m^2-K is modeled with its detailed dimensional properties (width, outside/inside projection values, inside sill depth, inside reveal depth, etc.) and solar optical properties (solar absorptance, visible absorbtance, etc.). Both interior and exterior shading devices are used in window combinations. Tulle curtains are used nearly at all Turkish homes for privacy and are mostly kept closed during day and night. Exterior moveable window shades are used for solar control in some housing units particularlyin summer. Hence two different alternatives of building types with / without the protection of exterior window shades are analyzed. All cases are assumed to have tulle curtains.

2.3.2. Building model

Making the basic decisions related with the building model and installing them into the simulation environment are necessary. The followings are the issues considered to set up the building model:

- All the constraints such as local regulations, limitations and statistical data related with the cities are taken into account as the control issues used for modeling the building settlements for the parametric study.
- Four basic 5 storey high residential building block types with different plan shapes of 100 m^2 each are designed and seven residential building types are generated for the standard representations by orienting the buildings to different orientations (see Table 2).

Table 2. *Housing unit and building block alternatives.*

Housing Unit	Building Block Alternatives
 BAR=1	 A1 A2 A3
 BAR=0.7	 B1 B2
 BAR=0.7	 B3 B4

2.3.3. Parameters
The parameters affecting on the energy consumption of a window system are determined as:

- glazing unit
- window area
- existence of exterior shading control device

2.3.4. Input-utput files for energy simulation
Arranging the simulation results of all window system alternatives is essential in terms of determining the effects of different climatic regions, building types,window dimensions, glazing units, solar control devices and other building properties on energy and cost performance of window system without causing any complexity and confusion. This is also important in terms of setting up a simulation environment which is consistent with the EnergyPlus software.

2.3.5. Energy use
Annual heating and cooling energy consumption, window heat gain and loss and total direct solar energy values of each housing unit having various properties with the combination of these different window components are calculated with EnergyPlus software. Window alternatives to be evaluated can be increased by adding new window parameters such as advanced glazing types, composite frame types or different shading types, etc.

2.4. Whole life cost (WLC)
Whole Life Cost (WLC) technique is selected to make the comparative cost appraisal of different window systems.This technique helps to find out the most appropriate choices among the proposed window systems which satisfy the performance requirements related with energy and cost efficiency in different climatic regions. Then, realistic evaluation of PV becomes significant by considering multi-criteria which affect window system.

The HiPerWin WLC process model essentially takes into account of design, procurement, construction and post-construction, i.e. operating phase of the building production process (Yaman et all, 2008). The objective is to arrive at an analysis plan and the profiles in the service period of a window component depending on the owners' purchase and replacement decision. The conceptual model of the HiPerWin WLC process consists of the stages of planning WLC analysis, determining WLC analysis requirements, grouping window alternatives and performing WLC analysis.

In the context of the project, the costs of window system alternatives are converted into a common base using a discounted cash flow method which incorporates interest rates and inflation in order to consider different operations taking place during the analysis period. The analysis period, also called service life, is assumed as 25 years, which is adopted from EOTA (the European Organisation for Technical Approvals), regarding working life of construction products (Langton, 2006).

The whole life cost for each window alternative is composed of capital unit cost including purchase, installation and finance costs and operating unit cost including ownership, maintenance and energy consumption costs. In the calculation of the unit capital cost of a window system, all components such as exterior shading devices, window frame, window ledge and hardware (casement, sash, hinges, handle etc.), double glazing, window sill,

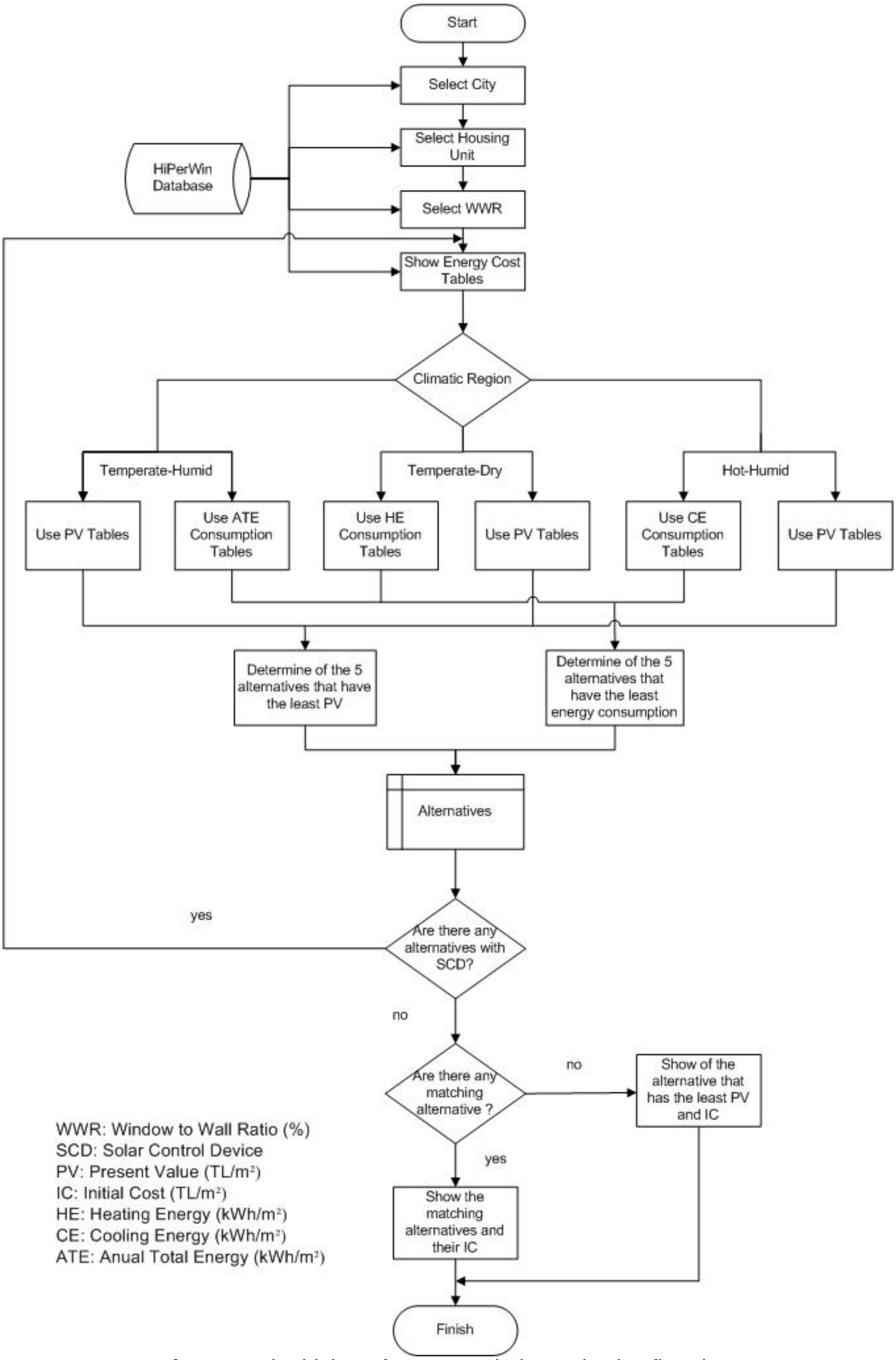


Figure 4. *The high performance window selection flowchart.*

sealant, gaskets and weather strips are taken into account. The unit prices of the materials and the installation are obtained by having an average of the quotations of four Turkish leading vendors. In the calculation of operating costs, the heating and cooling energy loads of housing units with different window systems simulated by EnergyPlus software are considered. Heating systems with natural gas and wall-mounted split air conditioner are assumed to be used in each housing unit. Heating energy costs are determined by multiplying the current natural gas unit price in kWh with annual, monthly or peak day heating energy demands of the housing unit in concern. Additionally, cooling energy costs are determined by multiplying the current electricity unit price in kWh with annual, monthly or peak day cooling energy demands of the housing unit in concern.

2.5. Evaluation process

The energy consumption and cost data of the alternatives are evaluated in order to facilitate the user to select the appropriate window system alternative. Various assessments and outputs can be presented for different users such as designer, owner, contractor, vendor, etc. Energy consumption, cost information and whole life cost of the window alternatives for specific cases can be attained by the guidance of the query parameters. The key items of the built environment and housing unit characteristics which are described at the top level of HiPerWin process model are transformed into query parameters. Query parameters are necessary for helping the users to specify their own case to find out the appropriate window alternatives by comparing their total annual heating/cooling energy consumptions and related initial and operating costs. Those are defined for three climatic regions, twenty housing unit types, three window areas and windows with/without shading strategies. They are presented for guiding the user to retrieve the appropriate alternatives through the database. The results of the appropriate window systems for the particular case will be listed in order. Comments, explanations and suggestions in the context of the whole process will be made and the user will be able to access the technical specifications of the proposed alternatives. If the user does not satisfied with the energy consumption and cost of the options, another case can be specified by changing the query parameters in the design process.

2.6. HiPerWin model

A dynamic tool, relational database management system (RDBMS), is required for keeping records and facilitating the comparison of the available window alternatives by providing self-representation of each case. The tool has to dynamically realize this self-representation via computational applications. The users can select the energy and cost efficient window systems for a particular case by using the RDBMS, which can be used to store and retrieve up-to-date, reliable, timely and the most accurate whole life cost and technical information as the results of all possible cases.

The window system selection stages implemented by using the RDBMS are given in Figure 4. In accordance with the flowchart, the user can firstly select the climatic region (city) and the particular case among the housing typologies. The next stage is to define the window area. The window to wall ratios (WWR) stored in RDBMS are 15%, 30% and 45% representing small, moderate and large area windows, respectively.

Once all selections are made, the energy consumption (heating, cooling and total energy) and cost (initial, heating, cooling and total cost, PV) tables related with the determined case are presented by the RDBMS. If the selected climatic region is a temperate-humid, both the heating/cooling energy use and PV tables are considered. Similarly the heating energy use and PV tables for temperate-dry climatic region, and the cooling energy use and PV tables for hot-humid region are taken into account. Five alternatives with the least energy consumption and PV can be determined by using the tables obtained via RDBMS. At this stage, the alternatives are assumed not to have any solar control device. Therefore, in case of having a case with solar control device, the energy and cost tables associated with that case will be sorted via RDBMS. As a final step, matching values among the five window alternatives with the least energy consumption and PV for the defined case are observed and the alternatives with the least values in terms of energy and cost efficiency are found out. If there are matching alternatives, the window system with the least initial cost is designated as the most efficient window system in terms of energy and cost performance.

3. Application

The HiPerWin selection, in this paper, is modeled for a housing unit in a temperate-humid region like Istanbul. The geographical information and heating-cooling degree days of Istanbul given in Table 2 are used as inputs for EnergyPlus software. The external climatic data obtained from the “Typical Meteorological Year (TMY) file” of Istanbul, which are also necessary for the simulations, are presented in Table 3. The housing unit oriented east, west and south, namely A32 having a BAR of 1 and WWR of 30% is selected for the application. Insulated glass units (IGU’s) are arranged in 5 groups as A, B, C, D and E depending on the glass types. Table 4 illustrates the glass types used in an IGU unit. IGU’s are formed with two glass panes with air gap of 12 and 16mm in between. Either air or argon is used in the gaps of the IGU’s.

Table 3. *Climatic data for Istanbul.*

ISTANBUL	Climatic Data		jan	feb	mar	apr	may	jun	july	aug	sept	oct	nov	dec
	Daily average dry bulb temperature (°C)		5.8	4.9	7.3	12.2	16.8	21.6	24.1	24.2	20.8	16.5	11.4	7.9
	Dew-point temp. (°C)		2.3	-0.6	3.0	5.8	11.4	14.3	17.9	19.2	13.7	10.6	6.9	5.0
	Monthly solar energy statistics (Wh/m²)	direct (avg)	1283	1080	1313	2359	3364	4400	5124	4363	3922	2099	1299	685
		direct (max.)	5193	4829	5548	6798	7954	7731	8100	7599	7102	4813	4197	4785
		day	26	27	26	6	22	14	24	1	18	23	1	14
		diffuse (avg)	1036	1518	2199	2760	3114	3169	2771	2602	2100	1736	1214	985
	Daily average wind speed (m/s)		4.8	5.5	4.1	4.1	4.4	4.0	5.8	5.7	4.9	4.2	4.0	5.6

Table 4. *The glass types used in an insulated glass unit.*

A	B	C	D	E
Clear double glazing	Low-E+ (#3, e=0.04)	Low-E+ (#2, e=0.04)	SSLow-E+ (#2)	SSLow-E+ (#2) and Low-E+ (#3)

The calculated energy and cost results for A32 alternative, which are presented via the RDBMS, are given in Table 5. Since the selected climatic region is a temperature-humid, the RDBMS presents the annual total energy use and PV tables. The alternatives in these tables don't have any solar control device. Therefore, in case of having a case with solar control device, the energy and cost tables associated with that case will be sorted via RDBMS. According to the results:

- While the highest annual total energy consumption is obtained by using air filled clear IGU's (A group), argon filled SSLow-E+Low-E IGU's (E group) considerably reduce the total energy consumption for both of the cases with and without solar control device (SCD).
- SSLow-E+Low-E IGU's (E group) substantially decrease the total energy consumption by decreasing heating energy by Low-E glass and cooling energy by SSLow-E glass.
- SSLow-E+Low-E IGU's (E group) yield the least energy consumption since they reduce heat losses in the heating period and heat gains in the cooling period for the cases with and without SCD.

Table 5. *The energy and cost results of the alternatives for the selected case.*

			Total Energy Consumption (TEC) (kWh/m^2)	Present Value (PV) (TL/m^2)	Initial Cost (IC) (TL/m^2)	Total Energy Consumption (TEC) (kWh/m^2)	Present Value (PV) (TL/m^2)	Initial Cost (IC) (TL/m^2)
Alternatives	Gap	IGU	without SC	without SC	without SC	with SC	with SC	with SC
A32_01	air12	A	59,63	142,34	28,15	49,94	142,25	72,38
A32_02	air16		59,00	142,90	28,50	49,11	142,32	73,08
A32_03	arg12		58,76	143,58	28,88	48,80	142,83	73,84
A32_04	arg16		58,28	144,19	29,23	48,17	143,06	74,54
A32_13	air12	B	51,68	136,44	29,61	42,48	138,11	75,30
A32_14	air16		50,43	137,55	30,00	40,66	137,85	76,08
A32_15	arg12		49,58	137,95	30,34	39,60	137,74	76,76
A32_16	arg16		48,85	138,01	30,00	38,36	136,60	76,08
A32_17	air12	C	51,40	135,25	29,61	42,58	137,94	75,30
A32_18	air16		50,12	136,34	30,00	40,73	137,65	76,08
A32_19	arg12		49,26	136,73	30,34	39,66	137,52	76,76
A32_20	arg16		48,52	136,79	30,00	**38,41**	**136,38**	**76,08**
A32_25	air12	D	49,50	125,05	29,86	44,16	137,05	75,80
A32_26	air16		47,79	124,93	30,19	42,16	136,27	76,46
A32_27	arg12		46,80	125,07	30,59	41,06	136,16	77,26
A32_28	arg16		45,65	125,51	30,92	39,63	135,96	77,92
A32_29	air12	E	48,97	123,82	30,72	44,51	138,27	77,51
A32_30	air16		**47,11**	**123,42**	**31,05**	42,43	137,37	78,17
A32_31	arg12		46,04	123,43	31,45	41,27	137,18	78,97
A32_32	arg16		44,76	123,61	31,78	39,79	136,90	79,63
SC: Solar Control Device Arg: Argon			Total Energy (Heating + Cooling) Consumption –TEC (kWh/m^2) Initial Cost – IC (TL/m^2) Present Value –PV (TL/m^2)					

- Adding SCD to windows in summer period reduces the annual total energy use in all cases depending on the decrease in solar heat gain. The reduction is about 18% for the IGU's in A group, while it changes between 25-36% in other IGU groups.
- The highest energy consumption for both cases with and without SCD is obtained for air filled clear IGU's. However, the lowest energy consumption is achieved with argon filled SSLow-E+Low-E IGU's (E group) for the case without SCD and for argon filled Low-E IGU's (C group) for the case with SCD. According to these results, it is possible to say that the use of SCD on Low-E IGU's is more effective than the use of SCD on SSLow-E IGU's.
- SSLow-E+Low-E IGU's (E group) have the lowest present values (PV) for the cases without SCD, while Low-E IGU's (B and C group) have the lowest PV for the cases with SCD. This is due to the use of SCD with Low-E IGU's which significantly reduces the energy consumption compared to the use of SCD with SSLow-E+Low-E IGU's.
- While the initial costs of clear IGU's are lower than the IGU's developed with other glasses, their PV's are higher due to the increase in their operating costs.
- PV's of the IGU's with Low-E coating (B, C groups) are 0-5% lower than the clear IGU's. Comparatively SSLow-E (D group) and SSLow-E+Low-E (E group) IGU's have PV's which are approximately between 9-15% lower compared with clear IGU's.
- Adding SCD to window systems does not significantly affect the PV's of clear IGU's, however, it brings a considerable increase in the PV's of SSLow-E and SSLow-E+Low-E IGU's and a slightly increase in the PV's of Low-E IGU's. The rate of increase in PV varies between 1-10% depending on the different window sizes and IGU types.

Five alternatives with the least energy consumption and PV for both the cases with and without SCD are presented in Table 5 from the tables obtained via RDBMS. The matching alternatives in terms of energy and cost efficiency are A32_30, A32_31 and A32_32 for the case without SCD and A32_16, A32_20 and A32_28 for the case with SCD. In accordance with the HiPerWin model,

- **A32_30** alternative yields the lowest initial cost for the case without SCD
- **A32_20** alternative yields the lowest initial cost for the case with SCD

Therefore, they are selected as the most efficient window systems in terms of both energy and cost performance in the temperate-humid climate region (Istanbul).

4. Conclusıon

The HiPerWin model is a dynamic model which helps to select the energy and cost efficient window system for residential buildings in different climatic regions of Turkey. It accomplishes the users to select the best window system for their own cases by using the RDBMS, which can be used to store and retrieve up-to-date, reliable, timely, and the most accurate WLC and technical information as the results of all possible cases. Providing the prevalence of the energy and cost efficient window system selection will contribute to national economy and decreasing environmental impacts by enabling the usage of the limited resources which supports the sustainable design on nation-wide. Since there is a lack of source which can be used in WLC calculations of the window systems in Turkey, the implementation of the model will serve as a basic source in further studies. A software tool will be developed using the outcomes of this research for designing the window systems of new residential buildings.

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Yüksek performanslı pencere seçim modeli (HiPerWin)

Günümüzde klasik pencere kavramı pencereden beklenen performans özelliklerinin artmasıyla giderek kaybolmakta; teknolojinin de beraberinde getirdiği çeşitlilik ve gereksinimlerin zaman zaman birbirleriyle çelişen özellikler göstermeleri, pencerelerin tasarım ve seçim sürecini daha karmaşık bir hale getirmektedir. Son yıllarda pencere performansının iyileştirilmesi ile ilgili en önemli gelişmeler; kaplamalı camların ve yalıtımlı cam ünitelerinin üretilmesiyle gerçekleşmiştir. Bir pencerenin enerji performansı; cam ve doğrama özellikleri yanında, iklim, yön, bina tipi, bina kabuğu, tasarım kararları ve bina iç ortamına ilişkin parametrelere bağlı olarak değişmektedir. Pencere tasarım ve seçiminde hedef, kullanıcının pencereden beklentilerinin, bina ve çevresel özellikleri de göz önünde bulunduran teknoloji ve maliyete ilişkin ölçütler ile dengelenerek optimizasyonun sağlanabilmesidir. Farklı pencere seçeneklerinin bina tipine bağlı olarak farklı gereksinmelere cevap vermesi ve ısıtma, soğutma, aydınlatma ile ilgili birbiri ile çelişen ilişkiler kullanıcıların veya tasarımcıların pencere seçiminde doğru karar vermelerini zorlaştırmaktadır. Türkiye'de farklı iklim bölgelerinde enerji ve maliyet ölçütlerine bağlı olarak optimum performans gösteren pencere tiplerinin belirlenmesine olanak sağlayacak bir veri tabanı bulunmamaktadır. Farklı pencere tiplerinin farklı iklim bölgelerinde belirli dış ve iç çevre koşullarına bağlı olarak enerji ve maliyet ilişkilerinin bilinmesi, tasarımcı, yapımcı ve kullanıcıların uygun pencere seçiminde doğru kararı vermelerine yardımcı olacaktır.

Bu çalışmada; Türkiye'de ılımlı-nemli, ılımlı-kuru ve sıcak-nemli üç iklim bölgesinde bulunan farklı konut bina tipleri için, enerji etkin ve uygun maliyetli pencere sistemlerinin seçimine yardımcı olacak dinamik bir modelin alt yapısı anlatılmakta ve modelin işleyişi İstanbul'daki bir konut birimi için açıklanmaktadır.

Pencerenin seçim sürecine ilişkin tüm işlevler/aktiviteler, girdiler/çıktılar, işlevleri kontrol eden iç/dış mekanizmalar, kontrol araçları, ve aralarındaki tüm ilişkiler IDEF0 (Integrated Definition For Function Modeling) metodu kullanılarak açıklanmıştır. IDEF0 modeli ile tanımlanan HiPerWin Süreç Modeli'nde bulunan tüm adımlar, girdiler, çıktılar, ilişkiler, aralarındaki etkileşimler, sınırlayıcılar ve yardımcı unsurlar; kavramsal olarak farklı düzeylerdeki işlevleri ifade eden hiyerarşik kutular şeklinde tanımlanmıştır. En üst düzeydeki kutu, dış çevrenin tanımlanması, yapma çevrenin tanımlanması, enerji benzetimlerinin gerçekleştirilmesi, HiPerWin yaşam dönemi maliyet (LCC) modelinin geliştirilmesi, değerlendirme süreci ve ilişkisel veritabanı yönetim sisteminin kurulması olmak üzere altı alt işlevden oluşmakta ve birbirleriyle ilişkilendirilmektedir.

Dış çevrenin tanımlanması için; Türkiye'nin nüfus ve konut stoku açısından en büyük üç şehri olan Ankara, İstanbul ve İzmir illeri seçilmiştir. Konut stokunun en fazla olduğu şehirler olan İzmir sıcak nemli, İstanbul nemli ve Ankara ise kuru iklim bölgelerini temsil etmektedir. Dış iklimsel faktörlere ilişkin veriler “Enerji Hesapları İçin Uluslararası Hava Verileri (IWEC: International Weather for Energy Calculations)” dosyalarından alınmıştır. Söz konusu veriler U.S. National Climatic Data Center'da arşivlenmiş 18 yıllık DATSAV3 saatlik iklim verilerinden elde edilmiştir.

Yapma çevreye ilişkin parametreler; bina yerleşimi (şehir), konut bloğu (bina), konut birimi (mekan) ve yapı bileşeni ölçeklerinde tanımlanmıştır. Bina yerleşimlerinin modellenmesinde; Ankara, İstanbul ve İzmir şehirlerine ait imar durumları, yönetmelikler, sınırlamalar ve istatistiksel bilgiler kullanılmıştır. Bina ölçeğinde pencere performansını etkileyen temel parametreler; binanın yönü, diğer binalara göre konumu, bina biçim faktörü ve binanın boyutları (eni, boyu, yüksekliği) olarak belirlenmiştir. Konut birimi düzeyinde pencere performansını etkileyen temel parametreler ise; konut biriminin konut bloğu içindeki konumu, konut biriminin boyutları ve biçim faktörü ile yönlendirmedir. Yapı bileşeni ölçeğinde; opak yapı elemanlarının (dış duvar, döşeme, çatı) geometrik, boyutsal, yapısal ve fiziksel özellikleri, pencere sistemleri (cam sistemi, doğrama sistemi), iç ve dış güneş kontrol araçlarının boyutsal ve fiziksel özellikleri ile kontrol şemaları, iç ısı yükü etkileri (kullanıcı, aydınlatmalar, ekipmanlar), iç kütle etkileri (iç bölmeler, mobilyalar) ve ısıl bölgelerdeki hava sızmaları / doğal havalandırma etkileri gerçekçi sonuçlara ulaşabilmek için bilgisayar programında ayrıntılı olarak tanımlanmıştır.

Bu çalışmada kullanılan camlama seçeneklerinin performans değerleri Window5 bilgisayar programı ile hesaplanmakta ve EnergyPlus bilgisayar programında pencere sistemine ilişkin fiziksel özelliklerin tanımlanmasında girdi olarak kullanılmaktadır. Benzetim çalışması kapsamında; 3 iklim bölgesi, 20 farklı konut birimi, 3 farklı pencere alanı, 42 camlama seçeneği ve 2 farklı güneş kontrol stratejisine bağlı olarak 15120 seçenek türetilmiştir. Zaman ve maliyete ilişkin verilerin elde edilmesinde ise; üretici firmalardan, daha önce yapılmış olan çalışmalardan ve ilgili standartlardan yararlanılmaktadır.

Öngörülen bütün parametrelerin kombinasyonu ile oluşturulan seçeneklerin simülasyonlarının gerçekleştirilebilmesi için EnergyPlus programında macro girdi dosyaları hazırlanmış ve tüm seçeneklerin yıllık toplam ısıtma ve soğutma enerjileri ile pencerelerden kaynaklanan yıllık toplam ısıtma ve soğutma yükleri hesaplanmıştır. Maliyet etkin seçenekleri belirlemek için de, her seçeneğe ilişkin toplam yaşam dönemi maliyetleri hesaplanmıştır. Elde edilen ısıtma ve soğutma enerjisi tüketimleri ile toplam yaşam dönemi maliyetleri HiPerWin veritabanına kaydedilmektedir. Bu veriler HiPerWin ilişkisel veri tabanında (HiPerWin_RDB) tanımlanan parametreler ve soru önergeleriyle ilişkilendirilmiştir. Bu şekilde kullanıcı HiPerWin kullanıcı arayüzünde kendisine sorulan soruları cevaplayarak kendi binasının özelliklerine uygun enerji ve maliyet etkin pencereyi seçebilecektir. Sonuç olarak, HiPerWin pencere seçim modeli yardımıyla belirli bir duruma ilişkin iklimsel özellikler, konut birimi, saydamlık oranı, güneş kontrol aracı gibi özellikler tanımlanabilmekte; söz konusu durum için geçerli pencere seçeneklerinin enerji etkinliği ve toplam yaşam dönemi maliyetleri karşılaştırılarak, maliyeti en düşük ve enerji etkinliği en fazla olan pencere seçenekleri belirlenmektedir. Model; kullanıcı, tasarımcı ve yüklenicilerin Türkiye'nin farklı iklim bölgelerindeki konut binaları için yeni pencere ürünlerinin potansiyellerini ve performans etkileşimlerini değerlendirmelerini sağlayacak temel bir kaynak olacaktır.