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Residential Window Selection Model for Different Climates of Turkey

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ABSTRACT

This paper gives information on a dynamic model which facilitates the selection of energy and cost efficient windows for residential buildings in Turkey. The model aims to assist the users, designers and contractors for understanding the effects of new window products and their performance implications. A simulation-supported comprehensive parametric study considering many parameters as climate, outdoor obstructions, window to wall ratio (WWR), shading devices, window types and orientation, is performed with EnergyPlus software to understand the impact of each window option with each specific case on the energy use as well as the life-cycle cost issues. The results of the parametric study will be stored through a relational database management system (RDBMS), which stores energy and cost data facilitating the comparison of available window alternatives. By developing a web-based user interface, RDBMS will allow the users to enter the characteristics associated with outdoor and built environment to review and compare the window alternatives.
Keywords: residential buildings, windows, energy and cost efficiency, parametric study, dynamic model

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 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 *et al*, 2000). However, users are often confused about how to decide the most efficient window for their residence since there are many complex issues that are difficult to balance. Knowing the energy and associated cost implications of different windows will help users and builders to make the best decision for their particular application, whether it is a new building or a window replacement. Recently, a research project has been initiated to develop a dynamic model to design and select energy efficient windows for residential buildings. The model aims to assist the users, designers and contractors for understanding the potential and performance implications of the new window products in different climatic regions of Turkey. In this paper, the description of the phases and the functions of the research project have been given briefly by using IDEF0 function modelling method as well as the application of the method. The ultimate objective of the project is to develop a relational database management system (RDBMS), which will indicate the best window alternative for a particular case. Available window alternative performance will be evaluated according to the results of the parametric study and life-cycle cost analysis (LCCA).

2. WINDOW SELECTION MODEL – HIPERWIN

Since the issues affecting the window performance are complicated and include complex relationships, the functions/activities; inputs/outputs; the issues that control them; internal/external mechanisms for implementing the functions and the interrelationships among them are explained by using "IDEF function modelling method" (http://www.idef.com) within the context of the project. The phases describing the preliminary 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 hierarchical series of diagrams which regularly indicate increasing levels of describing functions in detail and their interfaces. In this paper only A0 top-level diagram which comprises the whole approach is given in Figure 1. Each sub-function of the A0 parent diagram is decomposed by the parent boxes. The parent boxes have been detailed by child diagrams at the next lower level until all of the relevant detail of the whole viewpoint can be adequately and explicitly exposed.

2.1. Determining the Outdoor Environment

The impact of windows on building energy use can considerably vary with the location because of the climatic differences. The analysis has been performed for three different climatic regions of Turkey. High degree of mass-housing potential and being the biggest cities with the highest population were 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.

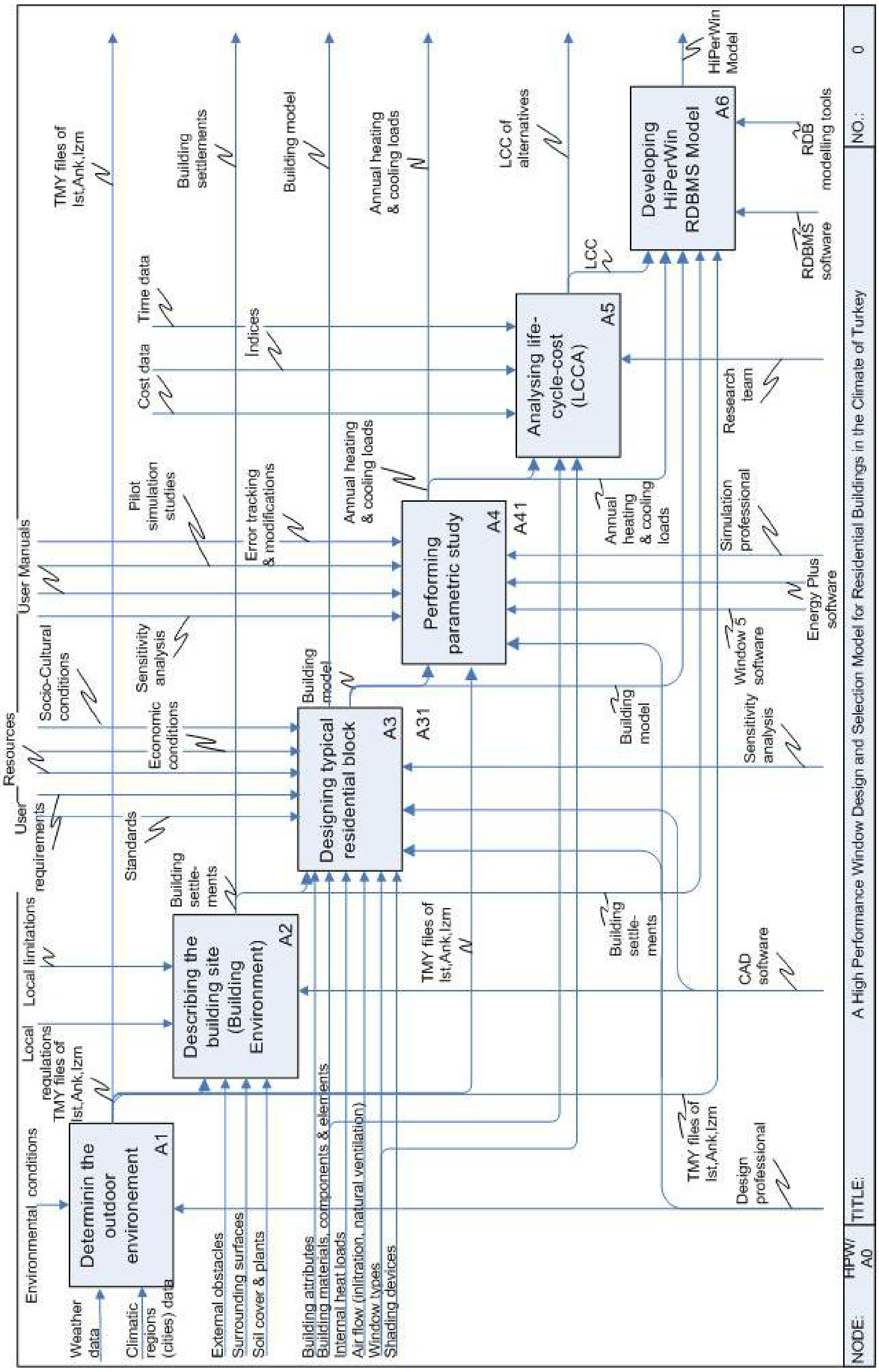


Figure 1 HiPerWin IDEF0 function model top-level diagram.

Table 1. Geographical information and heating/cooling degree days of the analysed cities.

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, DNSol: Direct normal solar radiation, DBT: Dry bulb temperature, WBT: Wet bulb temperature

2.2. Describing the Built Environment

Estimating the energy use of a building with various window alternatives is possible with the determination of an appropriate set of values for the parameters associated with outdoor environment, and built environment. Environment systems represent the main concern of the building design. Therefore at the second stage, properties of the outdoor and indoor environment where all evaluations are performed have been decided. Outdoor environment can be characterized with natural factors such as local climatic factors and the built-environment under different levels such as building settlement, building block, housing unit and building component in the model. The parameters attributed to built-environment were considered on the basis of a building settlement, a single building block, a housing unit as a thermal zone and a functional building element. The parameters that affect the window performance on the building settlement level are as follows (Oral *et al*., 2004):

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

Local regulations, limitations and statistical data related with the cities are the control issues used for modelling the building settlements in the cities for the parametric study. It was declared in the Building Construction Statistics (2005) that 40-45% of the residential building stock has been built individually by the private sector in Turkey and in general, the building sites became urbanized with individual residential blocks, which have been built according to the local regulations. Separately built detached residential blocks were ordered on almost the same sized parcels and the settlements were developed with the repetition of mostly with the same sized buildings. The observations, assumptions and approaches with regard to the built-environment which have been incorporated in the model are as follows:

- Possible building distances from the surrounding buildings, width of the roads and building heights are designated according to the zoning regulations of the cities.
- The building settlement for each residential building block type is modelled with the same sized buildings consistent with the local regulations.

- The buildings are modelled with surrounding same sized blocks with a distance of 15 meters to consider the shading effect of the buildings nearby.
- Slope, orientation, plants and parcel dimensions are considered as the additional input data in characterizing the building site.

2.3. Designing Typical Residential Block

To design the typical buildings representing the residential buildings where the windows are installed depends on the consideration of many issues such as building attributes, building materials, components and elements, internal heat loads, air flow, etc. The main parameters affecting the window performance on building level are as follows:

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

Every building involves a set of unique features and the requiring customized solutions. Therefore, the reference building blocks are designed to represent the scale and occupancy patterns of a Turkish single-family resident in general. According to Building Construction Statistics (2005), 98% of the completed and partially completed residential blocks were constructed as reinforced concrete carcass system. According to Turkey's Statistical Yearbook (2004), 45% of the total building stock were comprised of detached and 3-5 storey height residential building blocks. Hence, the reference buildings were modelled as 5 storeys high, reinforced concrete carcass system. Four residential building block types with different plan shapes were designed and by orienting the buildings different orientations, seven residential building types are generated in order to develop standard representations.

2.3.1. Modelling the Housing Units

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

- Position of the housing unit within the building block
- Dimension of the unit and its shape factor
- Orientation

Each housing unit was modelled as an individual thermal zone. Each zone faces different orientations and has separate heating and cooling system. The basic user requirements, socio-cultural and economical conditions are the main control mechanisms in deciding the size of the housing units. It was declared in Turkish Housing Survey (2004) that on an average of 40% people belongs to an average economical situation has been living in 100 m^2 housing units in big cities. Hence, 100m^2 was accepted as the gross floor area of the base housing unit in the typical buildings and possible building units are designed according to building aspect ratio (BAR), which is the ratio of the housing unit's width to length. Two different BAR's as 0.7 and 1.0 were taken into consideration for determining the building units (Table 2). Standard representation of buildings involve geometrical, constructive and physical properties of the building elements (external wall, floor, roof); window systems and sub-systems (glazing and frame system), interior and exterior shading devices with their control systems; internal heat load effects with schedules (occupancy, lights, equipments); internal mass effects (interior partitions, furniture) and infiltration / natural ventilation effects in detail for accurate and realistic modelling of the building zones.

2.3.2. Developing Window System Alternatives

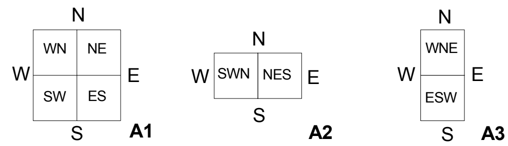
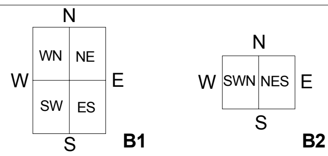
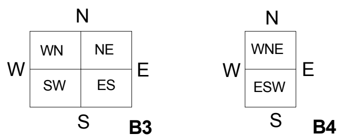
Recent advances in the technology of glazing units offer many alternatives for the energy efficient windows. A meaningful set of glazing unit alternatives were developed by combining the sub-components as glass types and coatings (clear, Low-e, SS-Low-e, etc.), thickness of the gap (12 mm, 16 mm) and infill gas material (air, argon). The energy related properties of the glazing unit alternatives; thermal transmittance (U-value), solar heat gain coefficient (SHGC) and visible transmittance (Tvis) were calculated using Window5 computer program (Mitchell *et al*., 2003). The results have been used as input data to define the window performance values in the whole building energy simulation program. 32 glazing unit alternatives have been developed for the simulations. The window dimensions were defined according 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 was modelled with its detailed dimensional properties (width, outside / inside projection values, inside sill depth, inside reveal depth, etc.) and solar optical properties (solar absorptance, visible absorptance, etc.). Both interior and exterior shading devices were made use of in the window combinations. Tulle curtains are used nearly at all Turkish homes for privacy and are always kept closed during day and night. Therefore all windows were assumed to have tulle curtains. Moreover, exterior moveable window shades are used for solar control in some housing units particularly in summer. Hence two different alternatives of building types with / without the protection of exterior window shades have been taken into account.

2.3.3. 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 housing units having the same building aspect ratio (BAR) can come together within a residential building block according to the local regulations that restrict the building size. Seven different residential building block types have been designed for the simulation-supported parametric study (Table 2). 20

different zones indicating the housing units have been generated in the building blocks. Each zone faces different orientation, have different shape factors and different external wall areas depending on its location in the building block.

Table 2 Housing unit and building block alternatives.

Housing units	Building block alternatives
BAR=1	
BAR=0,7	
BAR=0,7	

2.4. Performing Parametric Study

In accordance with having many parameters such as climate, building type, orientation, window area, shading devices and window alternatives, a comprehensive parametric study is required for developing the energy use and related life-cost data of each case for the model. Simulation assisted model is necessary to predict the future state of each housing unit as a consequence of various parameters. Obtaining the actual energy savings provided with an energy efficient window in a specific climate, for a specific period, for specific environmental conditions and for a specific building and occupants' lifestyle in accordance with control actions is a complex phenomenon. Hence a powerful and comprehensive simulation tool is needed, to develop standard representations of buildings, involving geometrical and semantic properties. The model 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 use depends on building characteristics, occupancy, operational schedules, type of HVAC system, weather and other parameters.

For the parametric study, EnergyPlus simulation software have been used since it has many new capabilities for energy calculations as well as it includes important features associated with modelling of the windows (EnergyPlus Help Manual, 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 modelling of movable interior or exterior shading devices with user-specified controls. EnergyPlus software makes available 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, it imports a window description file from Window5 so that exactly the same window calculated by Window5 can be exported to EnergyPlus for energy analysis (Winkelmann, 2001). Within the context of the parametric study, input macro files have been 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 will be stored in a relational database system as well as their life-cycle cost data.

2.5. Analyzing Life-Cycle Costs (LCC)

The first three stages of cost control process constitute life-cost planning and form the design process as capturing client needs, optimization and documentation. The latter two stages constitute life-cycle cost analysis and are applied to both construction and facility management processes equally. As we deal with only post-construction phases of the buildings in the research project, the life-cost of the window alternatives will be determined in detail (Langston, 2005). For considering the life-cycle cost issues not only the initial or owning costs but also a number of costs including operating, maintaining and finally disposing costs as well as the benefits that occur through the life-cycle of the window alternatives, which are crucial for the performance prediction of windows. Costs incurred at different points in time throughout the life of the window alternatives need to be discounted back to a relevant base date using known cost indices and factors (Fuller and Petersen, 1995). The major cost components that will be considered for life-cost analysis are:

- Investment related costs which occur before a system is put into service, such as planning, design, purchase and construction costs; and residual values (i.e. salvage value) as a future cost at the end of its service life; capital replacement costs which are incurred when replacing major system and paid from capital funds.
- Operation, maintenance and repair costs which occur in its service life and are paid from annual operating budget, such as energy consumption costs, cleaning costs, etc.

Base date (date of study), service date, study (planning & construction) period will be determined for each window alternative; discount rate, local energy unit prices and inflation rates for energy and non-energy prices from TUIK (http://www.tuik.gov.tr) will be used for cost escalation.

2.6. Developing Relational Database Management System (RDBMS)

A dynamic model is needed for record keeping and facilitating the comparison of the available window alternatives by providing self-representation of each case. The model has to dynamically actualize this self-representation via computational applications. For the ultimate objective, a RDBMS will be developed for helping the users to select energy and cost efficient window for a particular defined case. RDBMS will be used to store and retrieve up to date, reliable, timely and the most accurate life-cycle cost and technical information as the results of the all possible cases. In this way, the users will be able to compare the energy saving potentials and life-cycle costs of available window alternatives based on user-defined characteristics of their building system in a particular climate of Turkey. The challenge is to provide the users with up to date, accurate, holistic and detailed technical information on energy and cost efficient window systems. The dynamic feature of RDBMS supports the near future innovations in the window technology.

Various semantic data modelling techniques have been developed to define data from a conceptual view. In order to construct the logical data structure of the HiPerWin RDBMS, IDEF1X technique will be used in defining the meaning of data within the context of its interrelationships with other data. IDEF1X technique can be used to produce a graphical information model representing the structure and semantics of information within energy efficient window selection environment. IDEF1X permits the construction of semantic data models which may serve to support the management of data as a resource, the integration of information systems, and the building of computer databases (IDEF1x Standard, 1993).

The objectives of Phase 0, in other words “project initiation phase” has been defining the project, determining source materials and author conventions. In order to define the concerns of the model i.e. contextual limits, and functional boundaries IDEF0 technique can be employed. Existing IDEF0 models serve as a basis for the problem domain.

Entities (e.g. user, manufacturer, city, building settlement, building, zone, window etc.) which have common attributes and characteristics representing a set of real or abstract thing have been defined in Phase 1, in other words “entity definition phase”. In Phase 2, in other words “relationship definition” phase connection relationships which represent associations between entities will be defined and analysed as identifying, non-identifying, categorization or non-specific relationships. Those are the interrelated components of an IDEF1X view diagram. Each IDEF1X model will be accompanied by a statement of purpose, a statement of scope and a description of any conventions the authors have used during its construction. Then attributes and keys (e.g. “name” and “products” for “manufacturer”) which represent a type of characteristic or property associated with a set of real or abstract thing will be determined for each entity in Phase 3 as “key definitions phase” and Phase 4 as “attribute definitions” phase consecutively.

3. APPLICATION

Basic approaches and other issues in modelling the buildings which affect the heating and cooling energy demand of a building with different window types and the logical data structure are explained within the context of HiPerWin model. The first four phases of the model has been applied to the building type “A3” for Istanbul, Ankara and Izmir. The annual heating and cooling loads were calculated for two housing units – WNE (zone 1) and EWS (zone 2) which lie at the third floor of building A3 by using EnergyPlus software. The aim of the preliminary evaluations and controls is to understand how the window alternatives in housing units of a residential block affect the annual heating/cooling energy loads in three different climates of Turkey. These evaluations are required to adjust the probable inaccurate or incorrect modelling approaches and assumptions before continuing with the comprehensive parametric study.

For this case, window and external wall areas are 10.12 m^2 and 23.63 m^2, respectively since WWR was taken as 30% for all facades facing different orientations. Exterior shading devices was not modelled for sun protection but interior shading devices were modelled on the windows. Exterior walls and roof were thermally insulated with 5 cm extruded polystyrene. The dynamic behaviour of the lights and occupancy in the zones was defined with schedules. The family living in each housing unit was assumed to be four people and the occupancy and user actions were defined according to the observations of traditional Turkish families. In this study three different window types have been considered (Table 3). The heating and cooling systems were assumed as individual systems for each housing unit. For the operational properties of heating and cooling system, the heating system was set as 23°C between 7.00-21.00 and 18°C, between 21.00-7.00 and the cooling system 30°C between 8.00-18.00, 25°C between 18.00-23.00, and 28°C between 23.00-7.00.

Table 3. The Performance Values of Glazing Units

Insulated glazing units (6/12/6 mm)	Window type	U (W/m^2K)	SHGC	Tvis
Clear, air	W1	2.80	0.710	0.779
Clear, Low-e (e3=0.04), argon	W2	1.292	0.566	0.788
Clear, Low-e (e2=0.04), air	W3	1.615	0.413	0.696

U: Center of glass value for ASHRAE winter conditions, SHGC: Centre of glass solar heat gain coefficient at near normal incidence for ASHRAE summer conditions, Tvis: Centre of glass visible transmittance for all glazing layers at normal incidence.

The annual heating and cooling energy loads of the housing units having different window options for three cities are given in Figure 2. The heating loads in Ankara and cooling loads in Izmir are dominant while both heating and cooling requirements have equal significance on energy performance of housing unit having moderate window area (WWR=0.30) in Istanbul. The heating energy of the housing units within the building facing different orientations vary between 9-15% while cooling energy use remains almost the same for the analyzed cases. The results indicate that each window type has different effect in each zone related to heating and cooling energy loads in different climates. General discussions of the results are as follows:

- In the heating dominated climate (mildly hot and dry) as Ankara, U-value has more significant impact on diminishing the heating energy demand than cooling energy. Adding low-e coatings provides further improvements with their low U-value.
- In the cooling dominated climate as Izmir, solar gains yield higher cooling loads and reducing SHGC result in a noticeable decrease in the total cooling loads.
- The heating and cooling loads of the building are close to each other, indicating that the heating and cooling costs must be balanced by detailed analysis for selecting an energy and cost efficient window with LCCA in mixed climates such as Istanbul. Reducing SHGC resulted in a modest increase in total annual energy use, since the benefits in the cooling season are more than offset by the lost solar gain in the heating season.

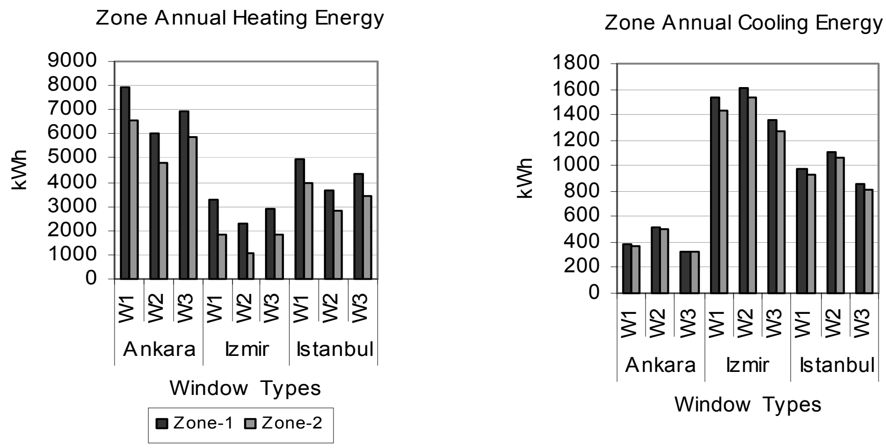


Figure 2 Annual heating and cooling loads of the zones with different window alternatives in Ankara, Istanbul and Izmir.

4. CONCLUSION

In the context of the study, the conceptual HiPerWin model has been explained by using IDEF0 function model with top level diagram indicating the stages of the whole research project. 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 as well as an application study for adjusting the probable inaccurate or incorrect modelling approaches and assumptions before continuing the further stages of the project. It is thought that at the end of the project the proposed model will be used:

- as an energy rating tool for residential windows;
- as a window selection tool in existing residential buildings where a renewal of windows is about to be performed;
- as an assistance for the choice of windows in new residential buildings;

This particular comparative study demonstrates the significance of energy efficient window system design and selection. In this paper although, only limited issues affecting the window performance are taken into consideration, other factors will be analysed throughout the whole project context. Improvements in energy performance must be weighed against both initial and lifecycle costs. Therefore a comprehensive cost analysis will be performed throughout the research project to understand the benefits. However window selection must be tied to overall performance.

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