Proceedings of the 2008 World Sustainable Building Conference

Volume 2

ISBN 978-0-646-50372-1

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WORLD SB08 MELBOURNE

World SB08 Melbourne
Melbourne Convention Centre
21–25 September 2008
www.sb08melbourne.com

Editors: Greg Foliente, Thomas Luetzkendorf, Peter Newton and Phillip Paevere

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First published 2008

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ISBN 978-0-646-50372-1

A CONCEPTUAL MODEL FOR ANALYZING LIFE-CYCLE COST OF RESIDENTIAL WINDOWS IN TURKEY

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Keywords: Life-cycle cost analysis, process modeling, residential windows, Turkey

Summary

This paper is the third one reporting an on-going research within an ITU funded research project which aims to develop a dynamic model supporting life-cycle decision-making in the selection of energy and cost efficient window systems for residential buildings in Turkey. HiPerWin life-cycle cost analysis process model which is a sub function of the HiPerWin process model is presented by using IDEF0 function modeling method in detail. 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. Inputs, outputs, controls and mechanisms of each function are expressed. The shortages and difficulties which are faced by the users in life-cycle cost analysis in Turkey are also introduced.

1. Introduction

1. 1. Research Project

Windows are the most complex and interesting elements in residential design and owners 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. This decision is important in terms of creating a more sustainable built environment, which provides a healthy indoor air quality for occupants and increases energy and cost efficiency. Understanding the energy and associated cost implications of different window systems will help the owners or contractors to make the best decision for their particular case, whether it is a new building or a window replacement. Although up-to-date, reliable and accurate, time and cost data can be provided from various sources such as manufactures, contractors, and research institutions, time and cost data regarding the residential window systems are not well-organised in Turkey.

Recently, a research project has been initiated to develop a dynamic model to design and select energy and cost efficient windows for residential buildings, namely “High Performance Window Design and Selection Model for Residential Buildings in Different Climatic Regions of Turkey (HiPerWin)”. The model aims to assist the owners, designers, manufacturers, vendors and contractors to provide their understanding about the potential and performance implications of the new window products in different climatic regions of Turkey. The challenge is to attain a basic source which supports the user to provide the energy and cost data required for the decision making in the design and selection of the residential window systems (Tavil et.al., 2006 and 2007).

The ultimate objective is to develop a relational database (RDB) which comprises the whole data and processes data into information regarding the window systems and helps the comparison of the alternatives. Therefore query parameters are 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 their total annual heating/cooling energy consumption and associated capital and ownership costs at the end of the research project. The HiPerWin model will accomplish the user to select the most energy and cost efficient window system for their own case by considering the issues which have influence on the residential window performance.

In this paper, after discussing the HiPerWin process model briefly, HiPerWin life-cycle cost analysis process model is presented by using IDEF0 function modelling method. The shortages and difficulties which are faced by the users are also introduced.

1.2. Life-Cycle Cost

There have been considerable research and development carried out in the field of life-cycle cost (LCC) in the US, Canada, Australia and EU member countries. The literature on life cycle costing is mostly conceptual in nature, the potential benefits of LCC and the technical issues regarding the application of the approach receive most of the attention in the literature. There is a considerable body of literature relating sustainability assessments on a life cycle basis and, in particular, to one of the main assessment methods – Life Cycle Assessment (Davis Langston, 2007).

The LCC concept was initially applied by the US Department of Defence. Since then a large number of documents, guidelines, standards and reports are available. For instance ISO 15686-5: Building and constructed assets – service life planning (draft), ASTM E917-05 Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, The Norwegian Standard, NS 3454: Life cycle cost for building and civil engineering work – principles and classification, Task Group 4: Life cycle costs in construction, Procurement guide 07: Whole-life costing and cost management, The Green Book by HM Treasury in UK.

ISO 15686-5 draft defines life-cycle cost as the total cost of a building or its components throughout its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value. The National Institute of Standards and Technology (NIST) Handbook defines life-cycle cost as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time (Fuller & Petersen, 1995). Furthermore in ISO 15686-5 draft life-cycle costing is defined as a technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational and asset replacement costs. (Davis Langdon, 2006). This technique is measured over the asset's "effective" life, generally considered as its economic and or operating life (Langston, 2005).

The LCC technique is especially useful when the project alternatives which fulfil the same performance requirements, but differ with respect to the capital and operating costs, have to be compared in order to select the one that maximizes net savings. For example, LCC analysis will help to determine whether the incorporation of a high-performance HVAC or glazing system, which may increase the initial cost but results in dramatically reduced operating and maintenance costs, is cost-effective or not (Fuller, 2007).

Based on these studies, in this paper, LCC technique is selected to make the comparative assessment of different window systems. This technique helps to find out the most appropriate choices among proposed window systems which satisfy the performance requirements related with energy and cost efficiency in different climatic regions. In that point, realistic evaluation of present value becomes significant by considering multi-criteria which affect window system.

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) (web link 1). 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.

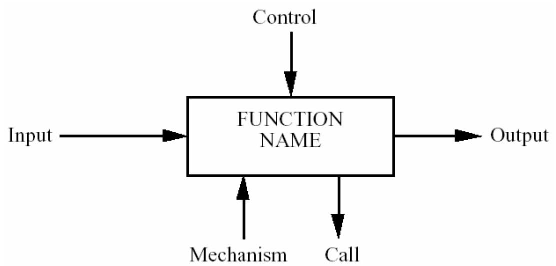

Figure 1 IDEF0 method arrow positions and roles (web link 1).

The top level (A0) diagram of the HiPerWin IDEF0 model consists of six main functions which are briefly described below (see Figure 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.

2. Describing the Built Environment – Estimating the energy consumption 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. The parameters attributed to the built environment are considered on the basis of a building settlement, a single building block, a housing unit as a thermal zone and a functional building element. 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 modelling the building settlements for the parametric study.

3. Designing a Typical Residential Block – Every building involves a set of unique features and 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. Orientation of the building, position of the building among other buildings, building shape factor (rectangular and square plan shape) and building dimension are the built environment parameters used in designing the typical buildings in the project. 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.

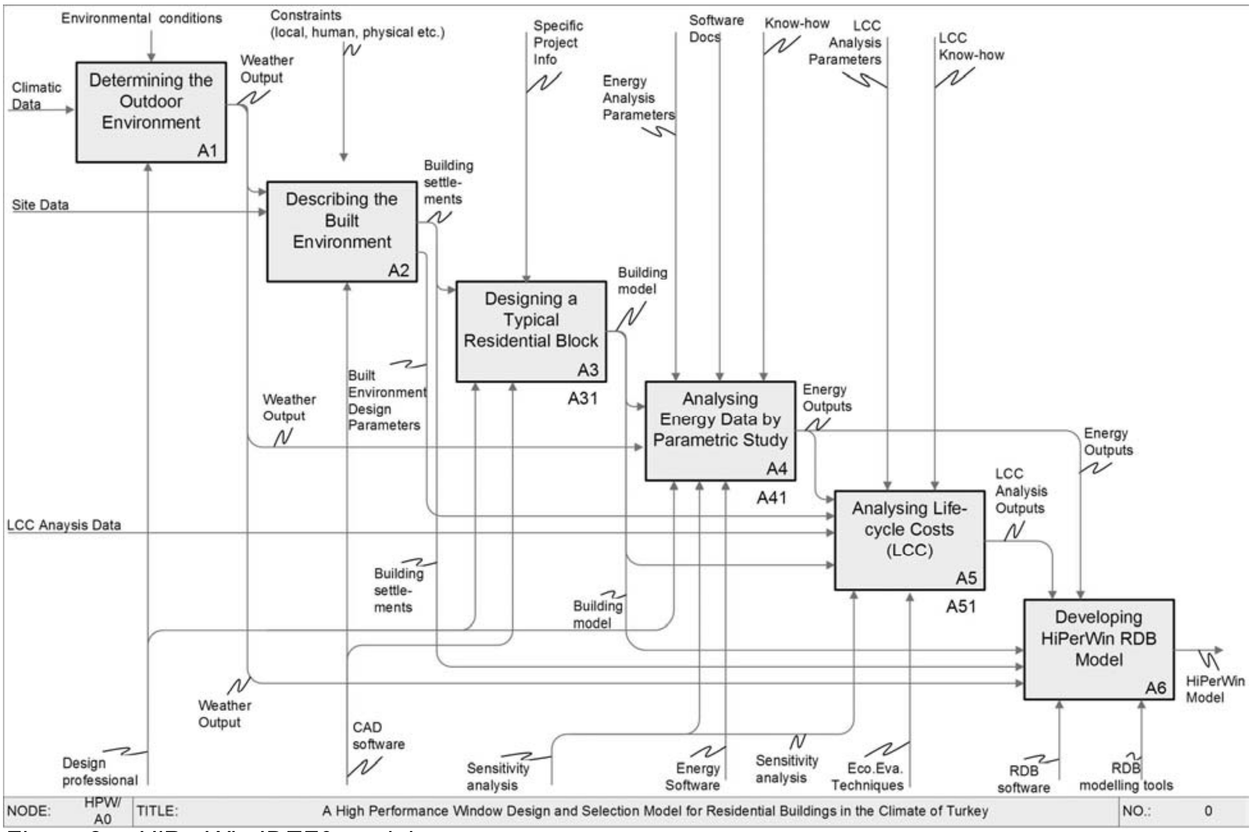

Figure 2 HiPerWin IDEF0 model.

4. Analysing Energy Data by Parametric Study – 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 preparing the energy consumption and associated cost data of each case for the model. Obtaining the actual energy consumption 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 in analysing the energy and cost efficiency of a window system. Hence Energy Plus software, which is a powerful and comprehensive simulation tool, has been used to develop standard representations of buildings (i.e. building model), involving geometrical and semantic properties.

5. Analysing Life-Cycle Costs (LCC) – A5 level diagram which comprises the HiPerWin LCC analysis approach which is the major topic of this paper is given in Figure 3. The parent boxes are detailed with child diagrams at the next lower level until all of the relevant detail of the whole viewpoint can be adequately exposed. A sub-function of the A5 parent diagram is decomposed by the child boxes in A54 diagram.

6. Developing HiPerWin Relational Database (RDB) Model – A dynamic model is required for keeping records and facilitating the comparison of the available window alternatives by providing self-representation of each case. Query parameters related with the characteristics of the built environment and housing unit options are presented in order to specify the particular cases. The model has to dynamically realize this self-representation via computational applications. For reaching the ultimate objective, a RDB is required to be developed for helping the users to select energy and cost efficient window systems for a particular case. RDB 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.

3. HiPerWin Life-Cycle Cost Process Model

LCC methodology is an iterative process in general. From inception to disposal at each stage, decision and procurement processes, the calculation of LCC should be refined to provide increasing certainty of the total LCC of the project. The ultimate goal for carrying out LCC calculations is to aid decision-making in (Davis Langton, 2006):

- assessing and controlling the costs and identifying the cost significant items
- producing the selection of work and expenditure planning profiles.

In this paper, the conceptual model of the HiPerWin LCC analysis process is given in detail by using IDEF0 method. HiPerWin LCC analysis essentially takes into account of post-construction, i.e. operating phase of a building production process. The objective is to arrive at an analysis plan and the profiles in service period of a window component depending on the owners' purchase and replacement decision which can be considered as a key factor in a sustainable building design.

As seen in Figure 3, functions of the HiPerWin LCC analysis process model can be addressed as follows:

1. Planning the HiPerWin LCC analysis,
2. Determining HiPerWin LCC analysis requirements,
3. Grouping window alternatives and
4. Performing HiPerWin LCC analysis.

3.1. Planning the HiPerWin LCC analysis

The first function of the HiPerWin LCC process model is planning the LCC analysis in order to determine the objectives and constraints for developing the plan that will be followed throughout the analysis. A work breakdown structure (WBS) is generated to determine the tasks which have to be performed during LCC analysis and thereafter the WBS is used to classify cost breakdown structure (CBS). Window components (frame types, glazing, thickness of the gap and infill gas material options etc.) to be included in life-cycle costing are also determined. Available resources and the building model are the major inputs of the planning function. The building model consists of built environment data, outdoor environment and climatic data. Planning function is controlled by user requirements and guided by LCC methodologies and know-how. While numerous information technology tools are available on-the-shelf, expertise and advisory are the indispensable mechanisms of the LCC analysis.

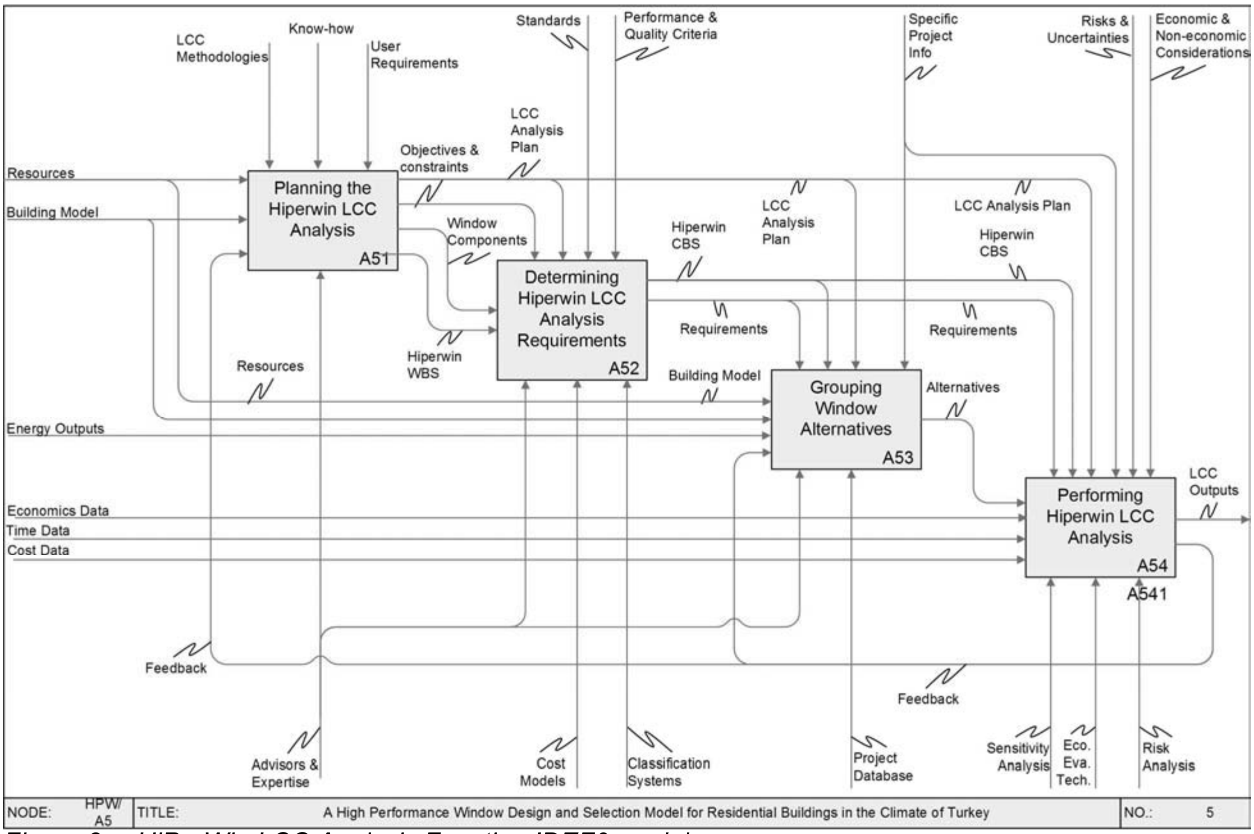

Figure 3 HiPerWin LCC Analysis Function IDEF0 model

3.2. Determining HiPerWin LCC analysis requirements

The outputs of the planning function are used as the inputs of the second function in which HiPerWin LCC analysis requirements are determined. The objective of the LCC analysis requirement determination is basically as follows (Davis Langton, 2006):

- available LCC analysis approaches and techniques,
- current information technology tools,
- data requirements,
- cost calculating and estimating methods and techniques,
- risk and sensitivity analysis requirements.

Not only the purchase or owning costs but also a number of costs including operating, maintaining and disposing costs as well as the benefits occurring throughout the life-cycle of the window alternatives which are crucial for the performance prediction of windows are considered as the life-cycle cost issues.

One of the main outputs of the function is HiPerWin cost breakdown structure (CBS) in which cost data can be classified are essential in the life-cycle cost analysis. HiPerWin CBS can be summarized as follows:

- Capital Costs
  - Purchase Cost: It consists of the construction costs of each window component (glazing unit, frame etc.) as well as the professional fees of the designer and engineer.
  - Installation Cost: Material, labour, equipment, fixtures and fittings costs arising from the fitting out of window components including overhead and profit rate.
  - Finance Cost: It consists of non-construction costs of purchase phase such as interest, cost of money, rates, insurance costs, fees and local taxes etc.
- Operating Costs
  - Ownership Cost: Regular or periodical operating costs, such as cleaning, security, waste management, facilities management, etc.
  - Maintenance Cost: Annual or periodical repair and maintenance costs, such as periodic replacement or planned renovation costs.
  - Selling or Disposing Cost: Salvage value of replaced window components which will be used as second hand.
  - Energy Consumption Cost: Annual or periodical energy consumption costs.

Requirement determination function is controlled by the standards (such as ISO 15686-5 draft), performance and quality criteria and finally LCC analysis plan developed in the planning function. Available cost models and classification systems (such as Uniclass, Uniformat II etc.) can be used as the mechanisms as well as advisory and expertise in order to determine HiPerWin CBS.

3.3. Grouping window alternatives

Outputs of the requirement determination function are used to group window components to be used in life-cycle cost calculations. Recent technological advances in window systems offer many alternatives in the energy and cost efficient window design. In the context of the research project, a set of glazing unit alternatives with various glass types, coatings, thickness of the gap and infill gas are obtained from one of the leading glass company in Turkey. The window dimensions are defined according to window to wall ratio (WWR) of 45%, 30% and 15% representing large, moderate and small area windows, respectively. Timber, aluminium and PVC frames are the frame options considered in the project. Both interior and exterior shading devices are taken into account in the window system combinations. Annual heating and cooling energy consumption of each housing unit having various properties with the combination of these different window components is calculated with a whole building simulation program, EnergyPlus Software. Window alternatives in the evaluation can be increased by adding new window parameters such as advanced glazing types, composite frame types or different shading types, etc.

3.4. Performing HiPerWin LCC analysis

Performing HiPerWin LCC analysis is the last function of the upper level decomposition. HiPerWin CBS which is one of the outputs of determining analysis requirements function and the LCC analysis plan are used as the main inputs of this function. LCC analysis reports and tables are the outputs of the implementation function. Economics and time data are used to convert cost to a common base. Cost data is used to identify the cost of each window alternative of each particular housing unit. Sensitivity analysis, such as Monte-Carlo simulation, can be used to evaluate the effects of a parameter on the value of another one. As investment decisions often made under uncertainty and risk, different methods such as Delphi technique or operations research method can be employed in dealing with uncertainties and in preventing from the effects of the possible variations. Although these methods are out of the context of this paper which mainly covers the interactions of the LCC analysis functions, the effects of uncertainty and risks will be taken into account during the implementation phase. LCC analysis output tables and documents are used as feedback signals to select new alternatives and/or to refine existing alternatives or to take corrective actions in the LCC analysis plan.

Since the ultimate objective is to develop a relational database, cost issues related to window components have to be integrated in the “conceptual model”. For this aim, HiPerWin LCC analysis function is decomposed by the child boxes in A54 diagram at the next lower level until all of the relevant detail of the whole viewpoint can be adequately exposed (See Figure 4). HiPerWin “information model” will be carried out by using IDEF1X “Integration Definition for Information Modeling” method after completing “function model” mentioned above. Up-to-date, consistent, reliable time and cost issues are the two major data class used in the calculation of LCC. In LCC calculations cost data is classified by using CBS, while time data is taken into account in terms of analysis period and service life of window components in concern. The data is provided mainly from manufacturers, contractors and research institutions. There is a lack of structured data collection mechanism in Turkey where real time and cost data are stored; hence the data have been collected from the current local market individually.

3.4.1. Identifying Cost of Each Alternative

The capital and operating unit costs of window systems used in each housing unit are determined. The sub-costs within capital and operating unit costs are classified and expressed in HiPerWin CBS to satisfy the specific requirements of the window system alternatives. The capital unit cost includes purchase, installation and finance costs, while operating unit cost includes ownership, maintenance and energy consumption costs and salvage value if applicable.

The unit cost identification of each option is carried out under the control of specific project information. Square and rectangular shaped 7 residential block types consisting 100 m2 housing units are considered in the project. Each block is 5-storey high, faces different orientations and has 2 or 4 housing units at one floor. The capital costs of each window option are calculated according to 3 different WWRs of each housing unit. In the calculation of the unit capital cost of a window system, all components such as window frame, window ledge and hardware (casement, sash, hinges, handle etc.), double glazing, window sill, sealant, gaskets and weather strips are taken into account. The unit prices of the material and the installation are obtained by having an average of the offers of four Turkish leading vendors. Window areas of each façade are multiplied by the unit capital cost acquired from the market search. Overhead and taxes are included in the unit costs; however design and engineering costs are not demanded by the contractors. Total price is calculated by considering the purchase of the windows for cash. In case of monthly payments 1% interest is added for the finance cost.

Operating costs are the costs arising from the regular and periodical operations which have to be incurred by the occupant after the installation of the window systems. Ownership, maintenance and energy consumption costs and salvage value are the basic items in the procedure of calculating the operating cost of the window systems. Periodical cleaning and security costs are included in the ownership costs for each housing unit. Maintenance costs are the replacement costs of windows at the end of their service life. The salvage value is added to operating costs depending on window frame material, for instance PVC is not a recyclable material while timber and aluminium frames can be reused.

Heating systems with natural gas and wall-mounted split air conditioner are assumed to be used in each housing unit in heating and cooling periods of each climatic region. Heating and cooling energy demands are simulated for housing units with different window systems, facing various orientations and having different shading strategies in different climatic regions with the help of EnergyPlus software. 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. The heating system efficiency factor (HEFF) is taken as 0.8. Natural gas unit price used in housing and commercial buildings in Turkey is announced as 0.569220 YKr/m3 which is equivalent to 0.0535 YTL/KWh (Web Link 2) for March 2008. However, the valid current price on the invoice, which is 18-20% above the nominal unit price, is determined by adding taxes and the other factors. 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. Electricity unit price used in housing in Turkey is announced as 0.121050 YTL/KWh while the valid current electricity unit price is 0.19 YTL/KWh by adding taxes and the other factors.

3.4.2. Grouping Cost of Each Alternative

The costs determined for each option must be grouped by year over a number of years equal to economic service life of the window systems. Determining the life of window systems and the analysis period in years are crucial in grouping the cost of each alternative. The life of window systems and their components can be described in different ways such as design life, working life, service life, economic life, useful life and technological life. The estimated number of years during which a window system will perform its functions required is the useful life of it. It is a well-known fact that there are significant differences between the useful or service life of window components and the design life which is introduced by the manufacturers depending on different materials used in window systems. A database in which cost and time data of window components are stored is necessary in acquiring historical and realistic data.

On the other hand, the analysis period is the period of time, over which the life cycle cost is to be analysed. The length of analysis period is dependent on the users' preference and the life of the product. In addition, the analysis period should not be too long, since the discounting factor applied in the analysis tends to make the future costs less significant and besides, the risks and uncertainties in the future cannot be effectively defined based on the existing data. Window systems can be handled as "repairable or replaceable with some more efforts" along with the "assumed working lives of works and construction products" table of EOTA (EOTA 1999). Thus, analysis period is assumed as 25 years regarding the service life of window systems and time requirements.

3.4.3. Converting Cost to a Common Base

The costs of alternatives must be converted to a common base using a discounted cash flow method which incorporates interest rates and inflation in order to account for different operations taking place during the analysis period. The present value of future cost of window system can be calculated by using the factors and indices, especially those related to operational energy costs. However there is a lack of national source of factors and indices that will be used in LCC analysis in Turkey. Therefore it is assumed that a nominal discount rate can be determined by using long-term Treasury bond rates averaged over 12 months as described in Federal Energy Management and Planning Programs of Department of Energy in the USA (Fuller & Rushing, 2006). The nominal Treasury bond rate, i.e. market rate is converted to a real discount rate by subtracting the long-term average rate of inflation from nominal rate to correspond with the constant-dollar analysis approach. The nominal discount rate, i.e. Treasury bond rates averaged over 12 months is 16.25%, long-term average rate of inflation is 8.39%, and therefore real discount rate is approximately 8%.

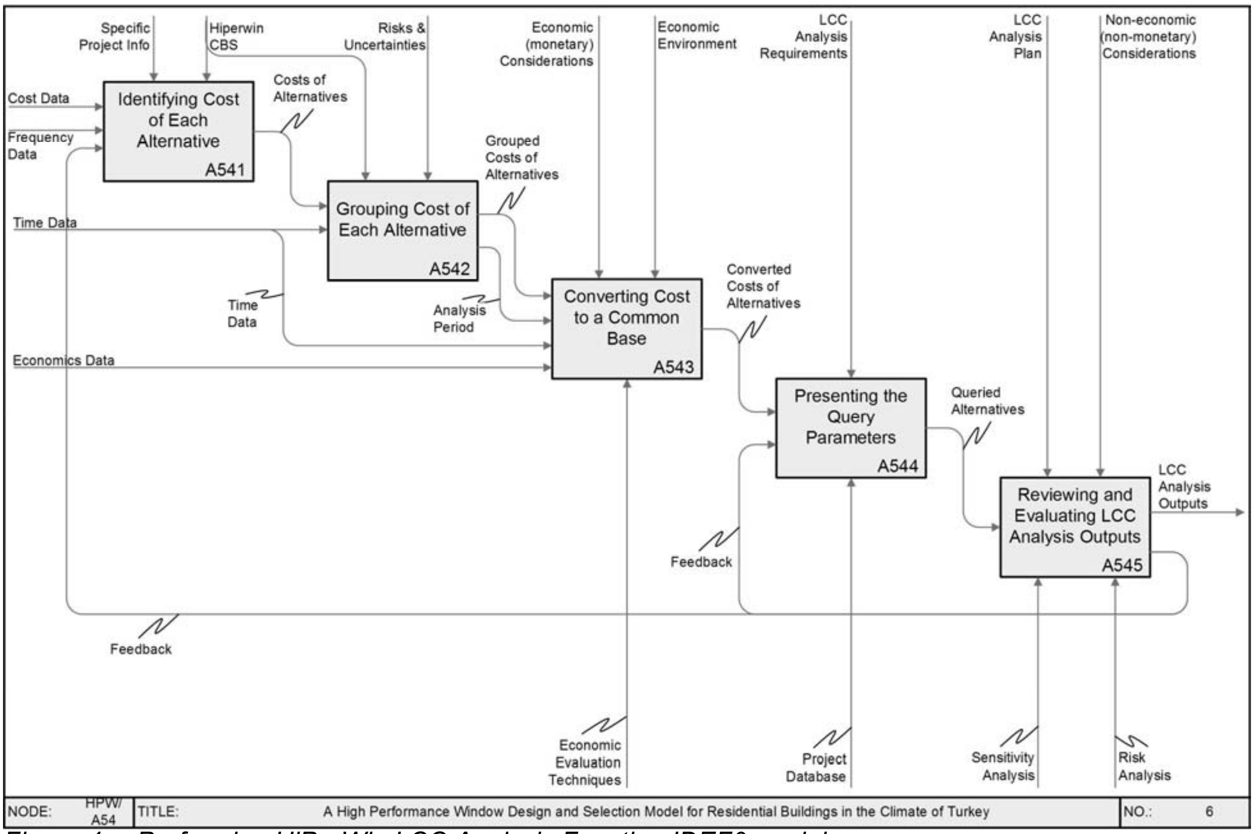

Figure 4 Performing HiPerWin LCC Analysis Function IDEF0 model.

3.4.4. Presenting 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 consumption 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 directing the user to retrieve the appropriate alternatives through the database. The query parameters and LCC analysis requirements are integrated at this function.

3.4.5. Evaluating and Reviewing LCC Analysis Outputs

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 evaluations and outputs will be presented for different users such as designer, owner, contractor, vendor, etc. Energy consumption, cost information and life cycle cost of the window alternatives for specific cases will be attained by the guidance of the query parameters. 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, he/she can specify another case by changing the query parameters in the design process.

Conclusion

HiPerWin model aims to assist the owners, designers, manufacturers, vendors and contractors to provide their understanding about the potential and performance implications of the new window products in different climatic regions of Turkey. The challenge is to attain a basic source which provides the required energy and cost data for the decision making in the design and selection of the residential window systems. Cost issues are evaluated by LCC analysis. The paper explains the HiPerWin LCC process model for residential window systems in detail which covers planning the LCC analysis, determining LCC analysis requirements, grouping window alternatives and performing LCC analysis.

HiPerWin "information model" will be carried out by using IDEF1X "Integration Definition for Information Modelling" method after completing "function model" mentioned above. For improving the conceptual model information modelling is a significant phase in developing the relational database which is the ultimate objective of this research. Although HiPerWin process analysis comprises the post-construction phase, the model will be utilized at design, construction and operating phases of the building production process. The model can be employed window system selection both in new and retrofitted buildings. Appropriate window systems will be selected among the alternatives by the designer, contractor and owner during the design, construction and operation process, respectively. While the designer can use all the query parameters such as orientation, block type, window area, shading strategy and all window components for the decision making in schematic design and design development phases, the owner only can use the parameters related with the window components and shading strategies for retrofitting. Besides, the vendors can guide their customers and the manufactures can provide feedbacks from the users and develop their products.

Making the energy and cost efficient window system selection prevalent will contribute to the national economy by enabling the usage of the limited resources which supports the sustainable design on country base. Since there is a lack of source which can be used in LCC calculations of the window systems in Turkey, the implementation of the model will serve as a basis of such a source.

Acknowledgements

This paper is a part of the research project numbered 11-05-140 which was supported by Istanbul Technical University Scientific Research Projects Fund.

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