CHAPTER 5

QUANTITATIVE INFORMATION INTEGRATION MODEL

WITH A WORKING EXAMPLE

5.1 OVERVIEW

In Chapter 4, the quantitative data sources, National Residential Efficiency Measures (NREM) Database (NREL 2010), and Building Energy Optimization (BEopt) (NREL 2012) were individually analyzed before being integrated into the intelligent Decision Support System. The quantitative data sources were examined from an integrational point-of-view, with a discussion of which parts of the data sources can be connected to the DSS.

This chapter begins with an explanation of the overall integration procedure. Since the expert system shell program, Exsys Corvid (Exsys 2012), is the core of this integration model, its structure needed to be built first, and then the structure has been applied to the Decision Support System Framework developed by the Task 6.3 research team (Samuel 2011). Based on the Exsys structure and the framework, a working example of the integration model will be developed.

5.1.1   Overall Procedure

The main purpose of this research is to implement an integrated intelligent Decision Support System, combining quantitative cost information and energy simulation information, and to suggest expert knowledge to the users in order to improve the existing residential energy efficiency.

This procedure starts by asking questions of the users, such as homeowners, about their current residential buildings. In order to properly identify the retrofit measures to be improved, the questions should be organized with a logical hierarchy, also called a logic tree. According to this logic tree organization, Exsys asks questions of the users, and selects the retrofit measures to be improved based on their answers. The current retrofit measure components and the suggested improvements become the input options for BEopt, which runs the energy simulation in order to calculate the annual energy saving costs using the input options. This BEopt output cost information goes back to Exsys, and Exsys derives the average cost for improving the retrofit measure from the NREM database. The cost information is then utilized to prioritize the measures. Finally, the prioritized measures and cost information are provided to the users, with additional expert knowledge, by means of text files, images and web links.

In this process, two different software applications, Exsys and BEopt, interchange their input and output information by writing output files and reading the files. For example, the BEopt energy simulation program provides the annual energy cost information. This can be exported as a form of text file. Exsys reads the BEopt output file, and the cost information becomes the input from Exsys for further calculation (see Figure 5.1).
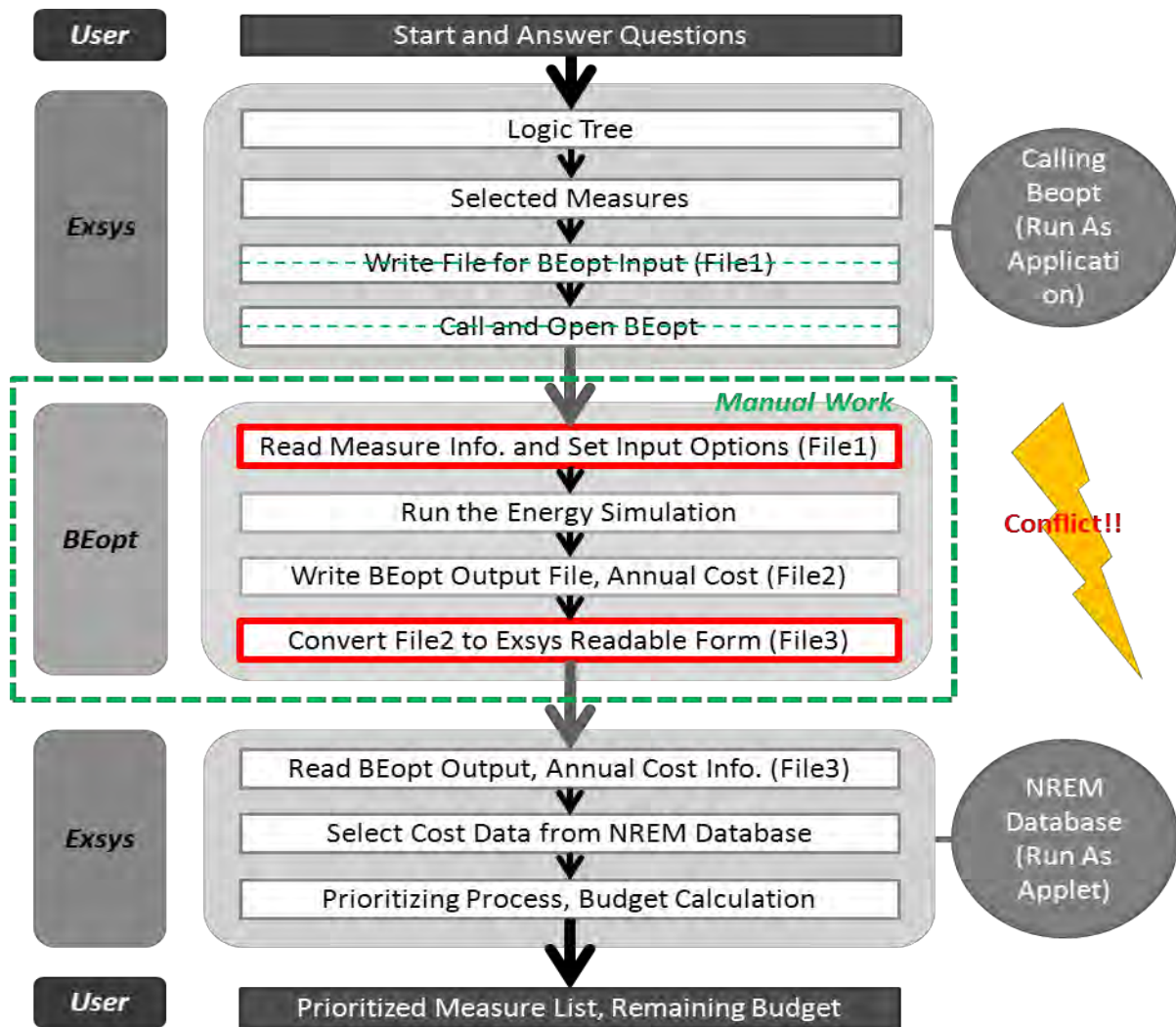
Figure 5.1: Overall Procedure and Limitation

5.1.2   Technical Limitation: Manual Work (BEopt)

Currently, there are technical limitations to simultaneously integrating the Exsys expert system software, BEopt energy simulation software and the NREM XML database.

The first limitation is related to the Exsys running environment settings. While Exsys Corvid must be "run as applet" when it uses the external XML database, it must be "run as application" when it calls the external programs; these two different running environment settings cannot be

compatible. This limitation will be improved when Exsys releases the next version of its Corvid software.

The second limitation is in BEopt. It is related to importing external information and then setting it as an input option. Though BEopt does not provide such a function in the current version, similar tasks will be available in the next version upgrade, which BEopt plans to release in the summer of 2012.

With these current technical limitations, an amended development strategy has been employed in "further steps," by operating BEopt energy simulation manually and importing the BEopt output file into Exsys Corvid. However, a separate BEopt calling example has been developed as well for future development after the limitations are solved.

5.2 STRUCTURAL ANALYSIS

5.2.1　Linking Exsys Corvid Components and Quantitative Data Sources

The core of the integration model is Exsys Corvid, the expert system shell software, with other external quantitative data sources integrated into this core. Therefore, the first step in developing the integration model is to have a comprehensive understanding of the Exsys Corvid system structure.

The basic components of Exsys Corvid are Variable Block, Logic Block, Command Block, and the Result setting in Command Block. As explained in Chapter 3, each component plays a role in incorporating the external data sources, which is a key to implementing the integration model.

First, the NREM database can be connected to Exsys Corvid by means of XPath, when the variables are set at the beginning of the integration. Second, BEopt output, the annual utility bill information, can be incorporated in the Meta Block, which enables the utilization of a table structured data group in the Logic Block. Third, when Command Block is built, external BEopt software can be called from Exsys Corvid, using the "Extern" command. Finally, additional expert knowledge, in the form of text files, images and web page links, is provided on the result screen to help users understand the retrofit measures better. Figure 5.2 shows the relationship between Exsys Corvid components and the external data sources.
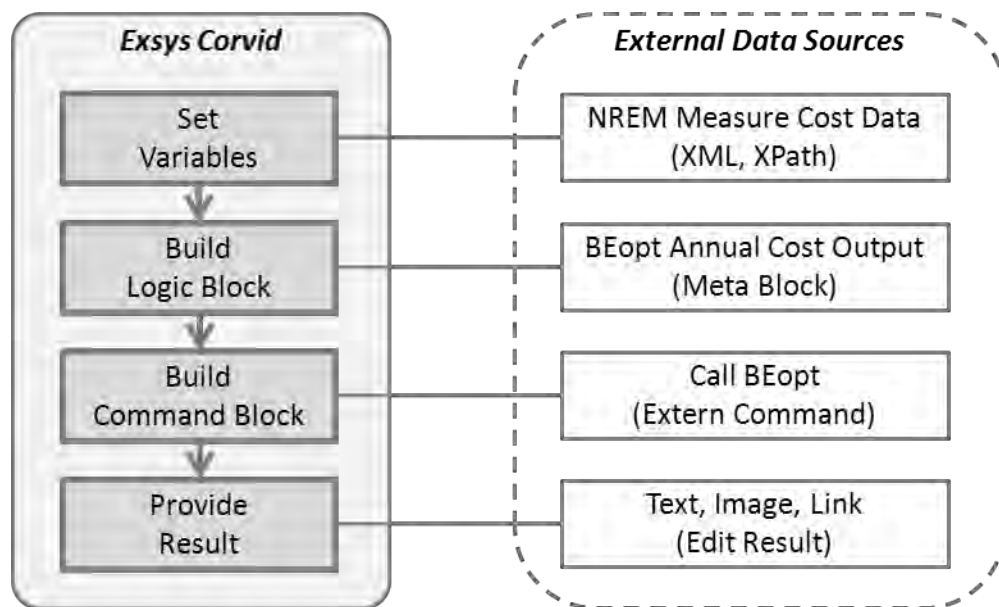
Figure 5.2: Exsys Corvid Components and External Data Sources

5.2.2   Exsys Structure for Integration Model

The integration model development starts by setting variables, which are used for the questions, the answer list, and the systematic value transfers. Then, the questions and the answer lists are organized, and the decision-making logic is defined in the Exsys Corvid components. After this process, the prioritized list is provided on the user interface.

Figure 5.3 explains this process within the Exsys Corvid structure. First, Logic Block deals with general questions about the house and the retrofit measure information, in order to diagnose the current energy efficiency of the user's house, and the immediate needs. Based on the answers, the Decision Support System selects retrofit measures to be improved. The information about the selected measures is used as the input of a second Logic Block, which derives more specific measure names found in the NREM database, by means of backward chaining. In a third Logic Block, the cost information from the external data sources, such as BEopt and the NREM database, forms a Meta Block, and this Meta Block is utilized in the decision support process and the remaining budget calculation. According to the process, the retrofit measures are prioritized, and the remaining budget and other information are displayed on the user interface. The Command Block manages the whole sequence of the system process, controlling which information will be shown and how it will be displayed on the result screen.
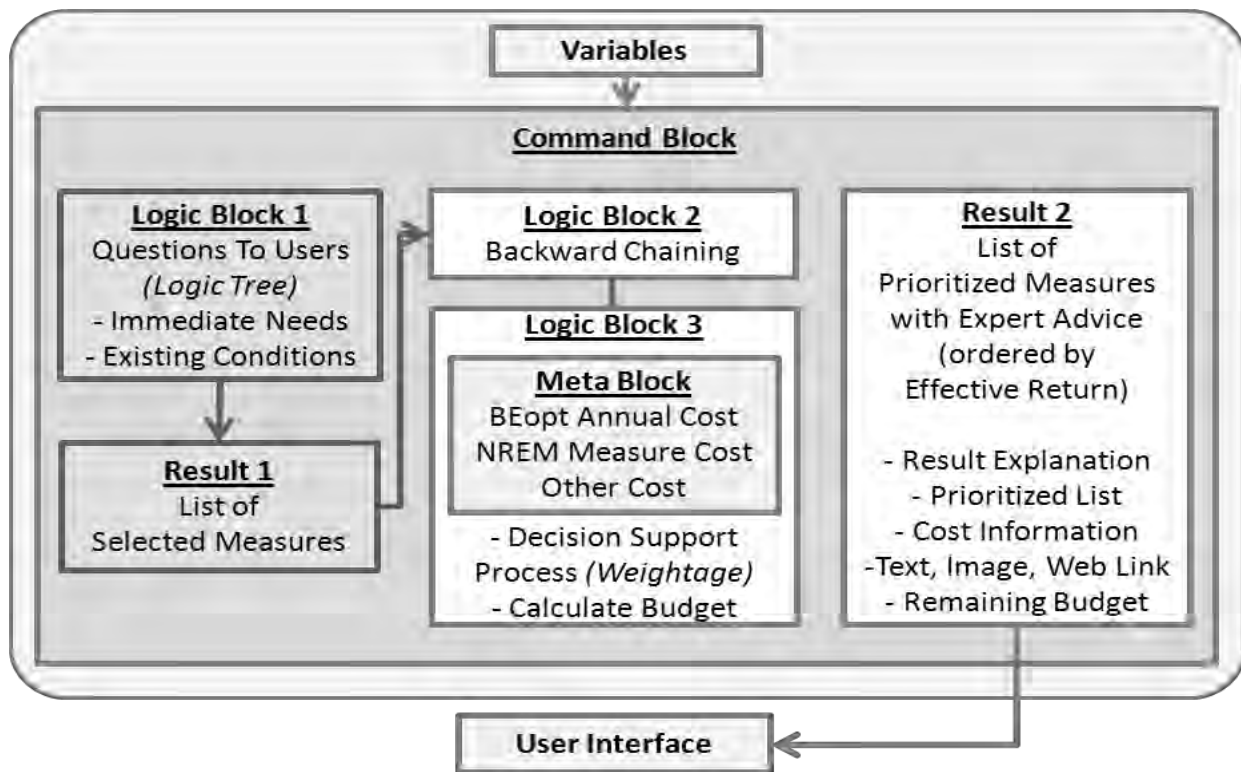
Figure 5.3: Exsys Corvid Developing Structure

5.2.3 Applying Exsys Structure to the Framework

The integration model implementation is based on the Energy Retrofit Decision Process Framework, constituted by the Task 6.3 research team. The decision process framework is implemented by applying the Exsys Corvid Developing Structure (Figure 5.3), with the components in the framework grouped as inputs and outputs by their characteristics.

For example, the questions about user needs and existing retrofit measures can be "input," and the selected measures from the answers can be "output." As a result, all of the framework components are classified into two input groups and two output groups. When this framework is applied to the integration model, the input groups constitute the Logic Blocks, and the output groups are derived from the Result part of the Command Block in Exsys Corvid. Figure 5.4 explains the application of Corvid structure to the framework.
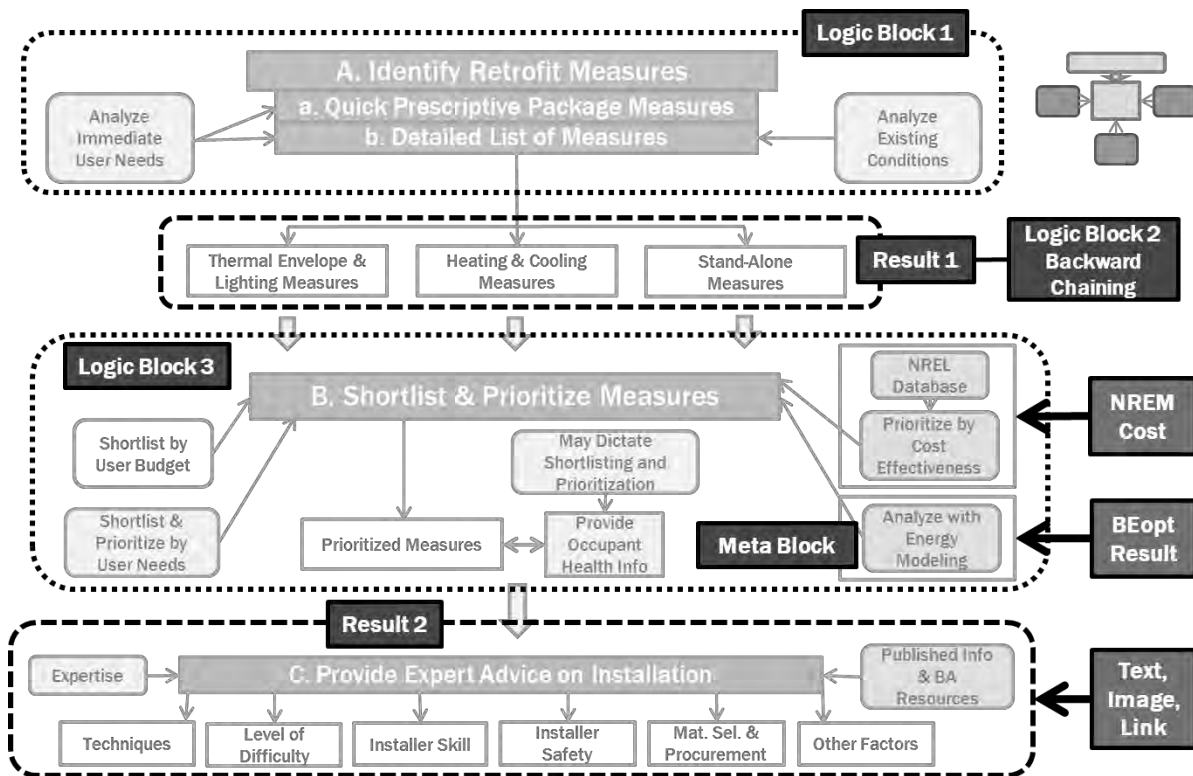
Figure 5.4: The Framework with Corvid Structure (Modified From: Samuel 2011)

5.3 INTEGRATING EXTERNAL QUANTITATIVE INFORMATION

Information flow between Exsys Corvid and other external quantitative data sources is fundamental to the integration model. The information flow can be divided into three steps, as shown in Figure 5.5. The first step is selecting measure information in Exsys Corvid. This information flows into the external data sources. In the next step, the information from Step1 is processed in the different applications, BEopt (Step2A), the NREM database (Step2B), and others (Step2C). Then, the outputs from Step2 go back to Exsys Corvid, where they are utilized as the inputs for the next process.

In this integration model, the information processing methods differentiate according to integration feasibility. While the information flow between Exsys Corvid and the NREM database can be fully integrated, the flow between Exsys Corvid and BEopt is combined with manual standalone work, due to the current technical limitations. Besides the NREM database and BEopt information, annual loan payment and incentive amount information is manually incorporated from other sources, such as DSIRE, in order to calculate the energy efficiency costs.

This section consists of three main parts. Section 5.3.1 explains the integration of the NREM XML database. Section 5.3.2 provides an explanation of how the BEopt running output – the annual utility bill cost information – is incorporated into Exsys Corvid. Section 5.3.3 accounts for how additional text, image and web link information are provided on the result screen. Figure 5.5 demonstrates the information flow among Exsys Corvid and the external data sources.
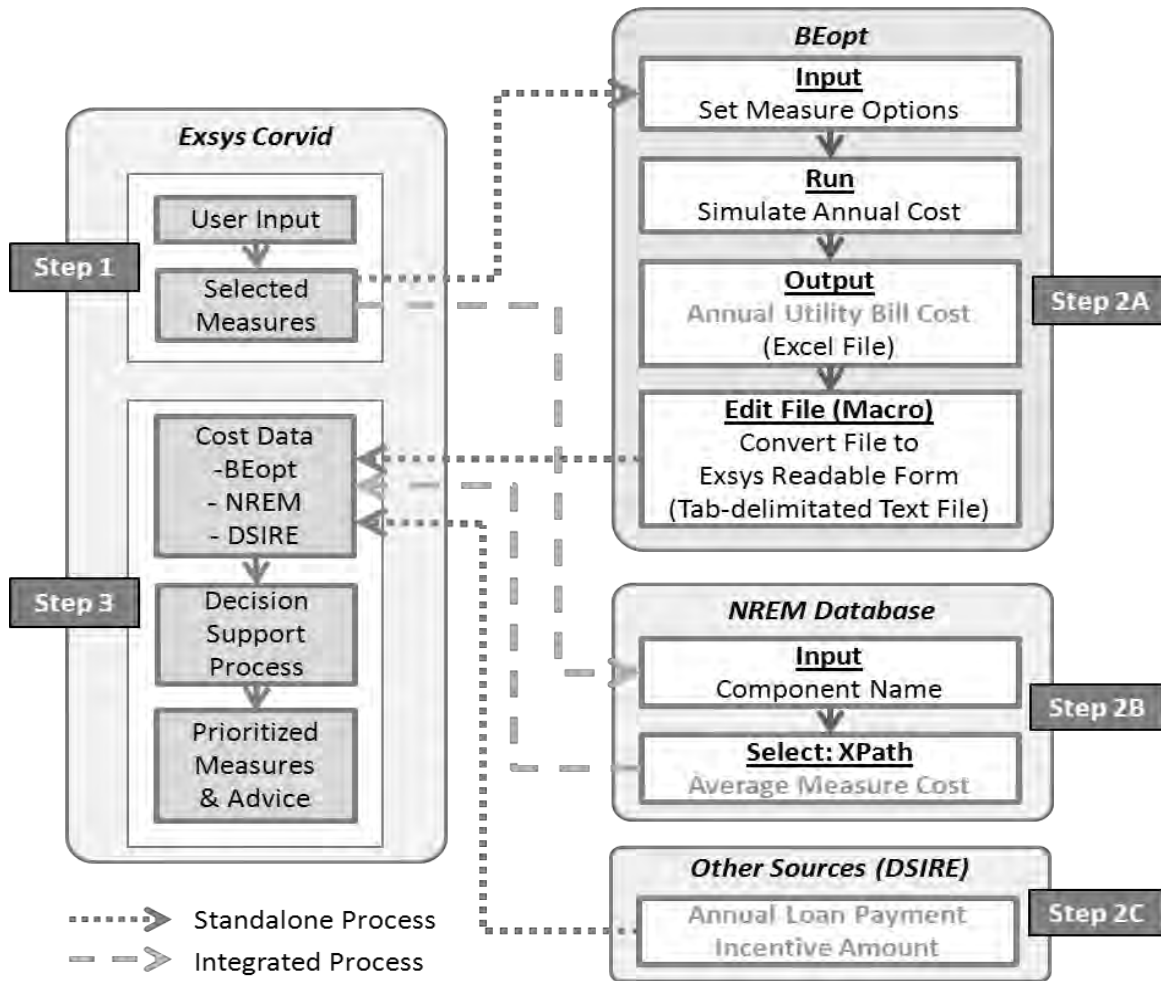
Figure 5.5: Information Flow

5.3.1 Integrating the NREM XML Database

The NREM database delivers the cost information for implementing the retrofit measure improvements from the before-components to the after-components. The NREM XML database can be called from Exsys Corvid, usually during the variable-setting stage. When the external XML database is called from Exsys Corvid, specific XPath query syntax is used to select the target information from the XML node. In this process, the XML file must be located in the same folder as the Exsys Corvid system files. The file name must be in quotes in the Xpath syntax in order to be utilized.
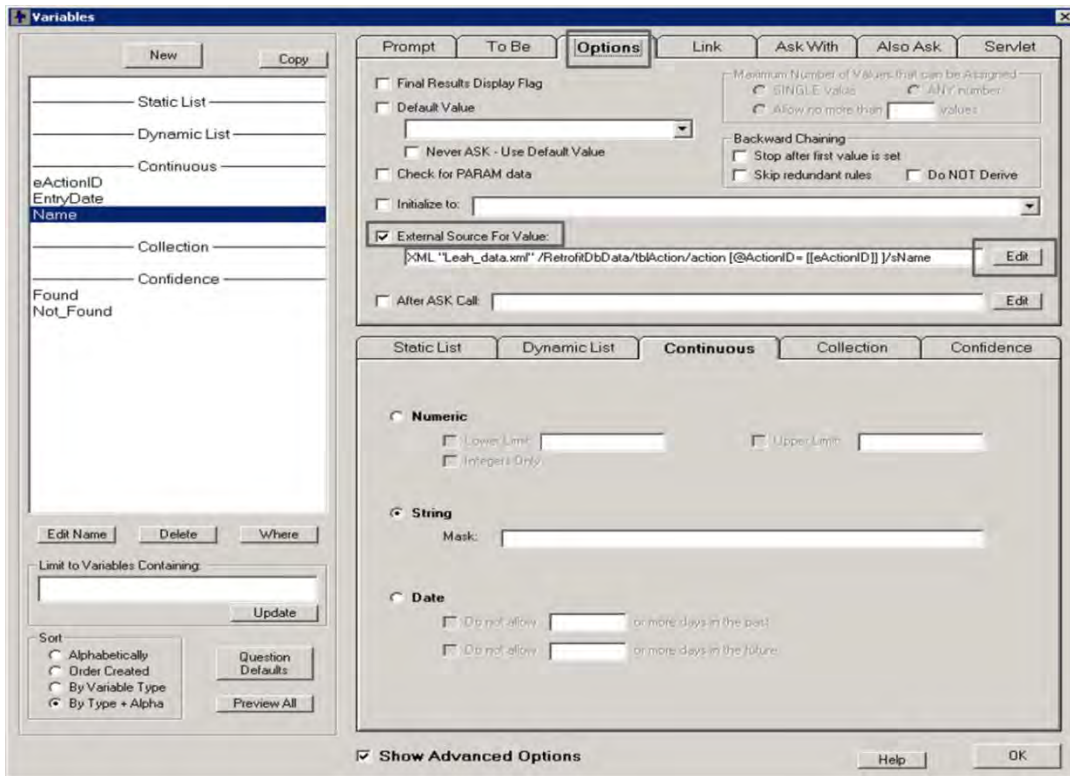
Figure 5.6: Variable Option Setting
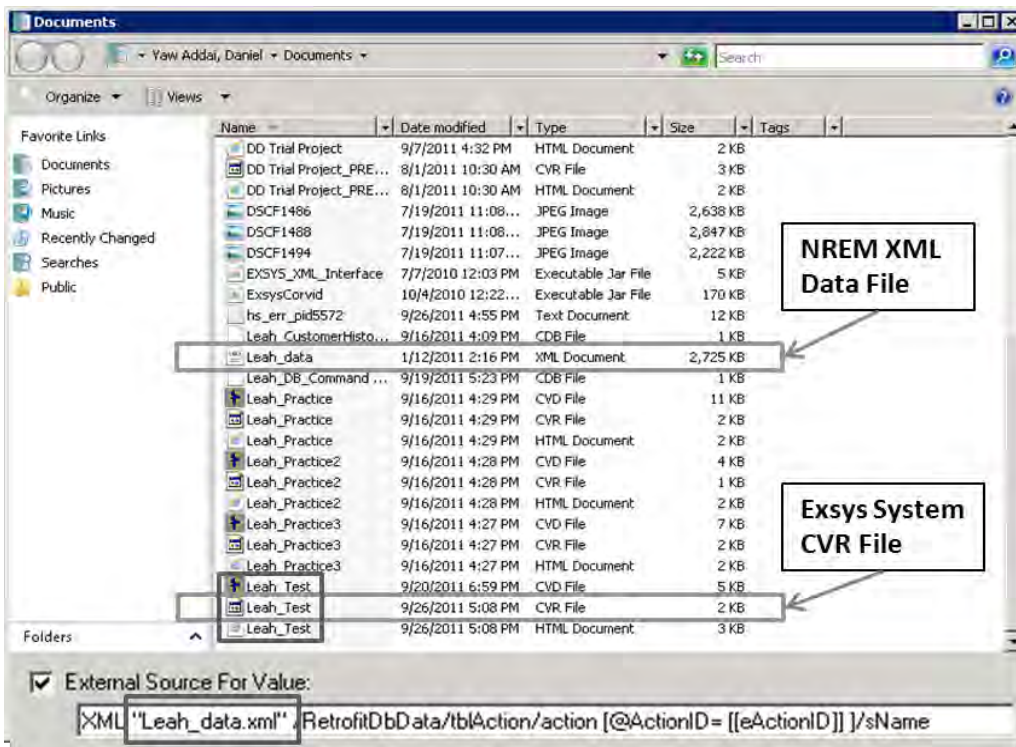
Figure 5.7: XML File Location

131

5.3.2 Integrating BEopt Information

After selecting the measures to be improved, the current retrofit measure information and its improvements are set as the inputs for the BEopt energy simulation program. BEopt simulates the energy efficiency and derives the annual utility bills for each measure application.
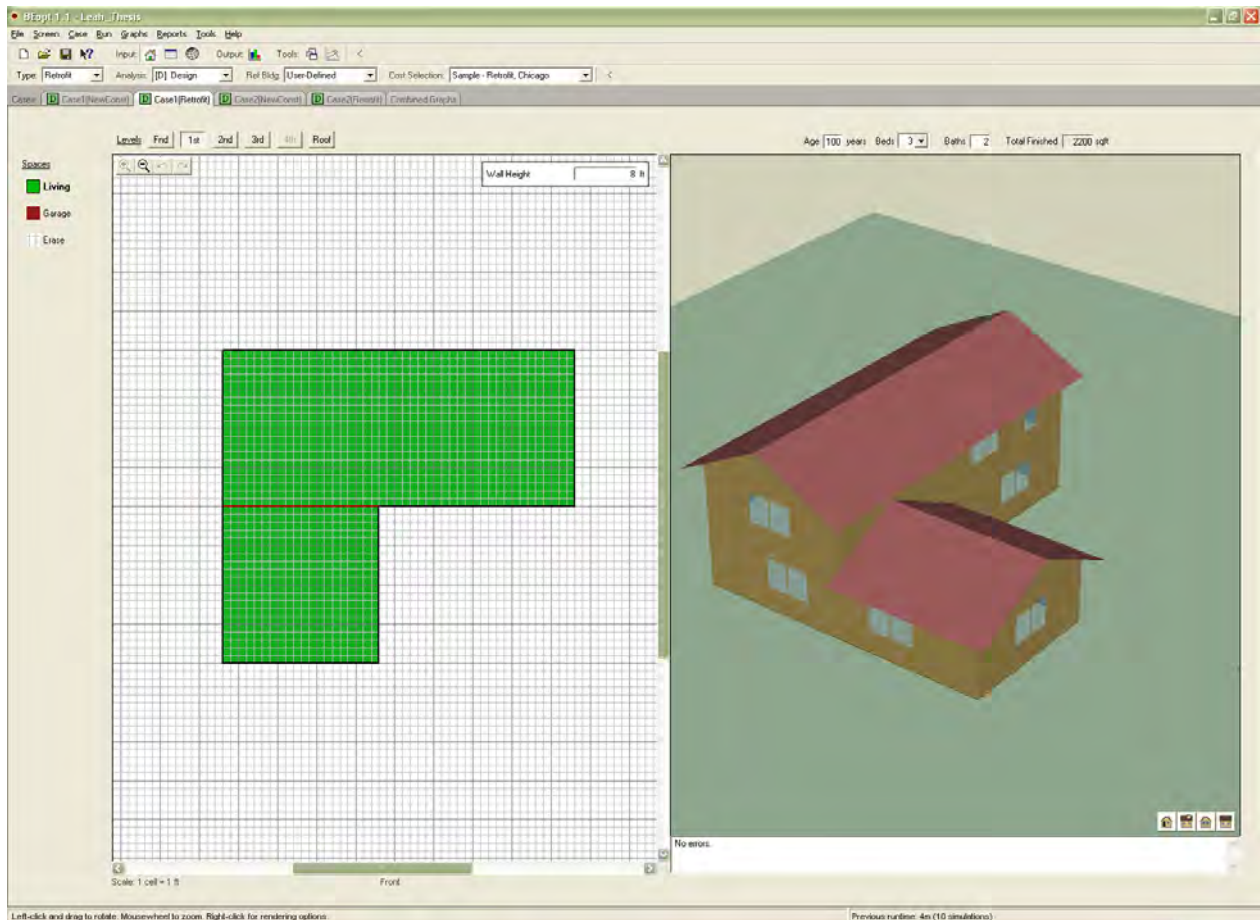
Figure 5.8: BEopt Input Screen

BEopt provides the annualized energy cost, which can be exported as output data in the form of an Excel file. However, this BEopt output file must be modified in order to be utilized in Exsys Corvid more easily.

Figure 5.9 shows the BEopt output, the annualized utility bills graph. This information is
exported in the form of an Excel file, as shown in Figure 5.10. However, Exsys Corvid can
utilize this information more effectively when the columns and the rows are transposed, and are
saved as a tab-delimited text file. This repeated routine is recorded in an Excel Macro as Figure
5.11 presents, and the raw output data is converted into a dexterous text file easily, by using this
Macro as shown in Figure 5.12.
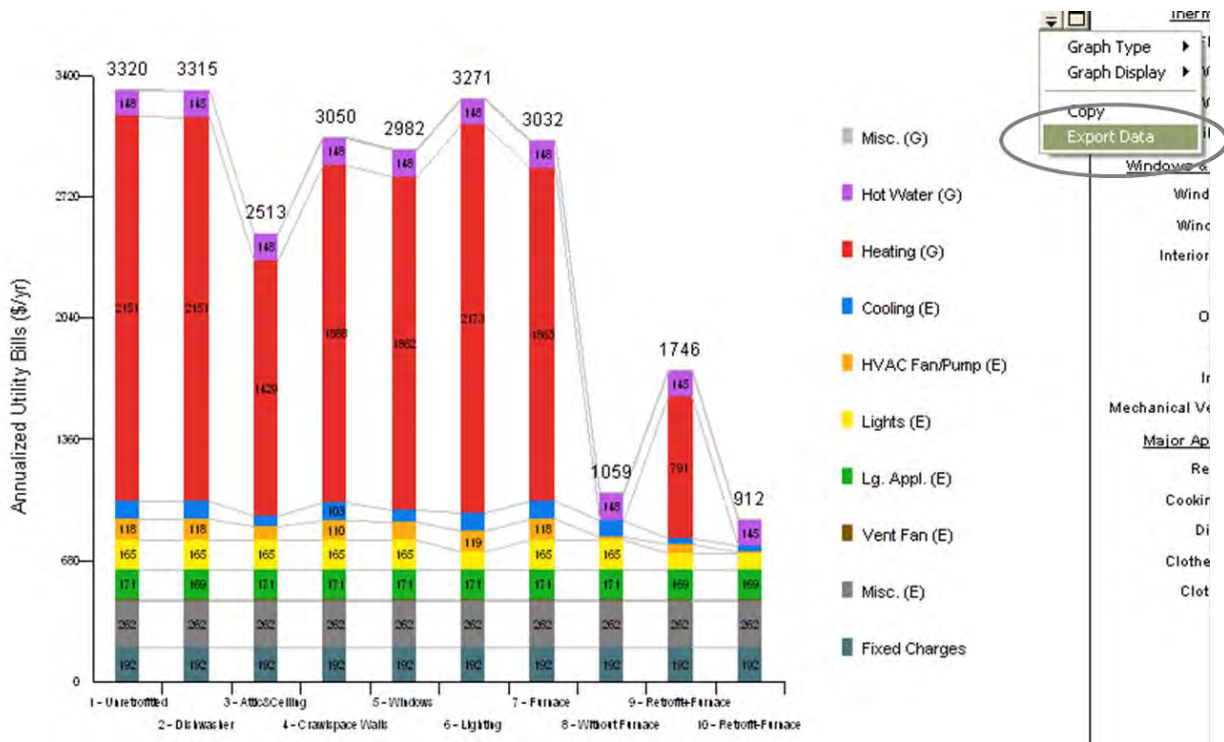
Figure 5.9: BEopt Output Screen

Figure 5.10: Exported BEopt Output Data (Raw File)

Figure 5.11: Converting File Using Excel Macro

134

Figure 5.12: Converted BEopt Output Data

This converted BEopt output file can be imported into the Exsys Corvid Meta Block, to be used for the process of further-prioritizing (see Figure 5.13). When this file is open from the Meta Block section in the Logic Block, the column names and data are automatically placed inside the data block with the columns and the rows (see Figure 5.14). The column headings and the data can be used in Exsys Corvid, in the same ways as the other variables.
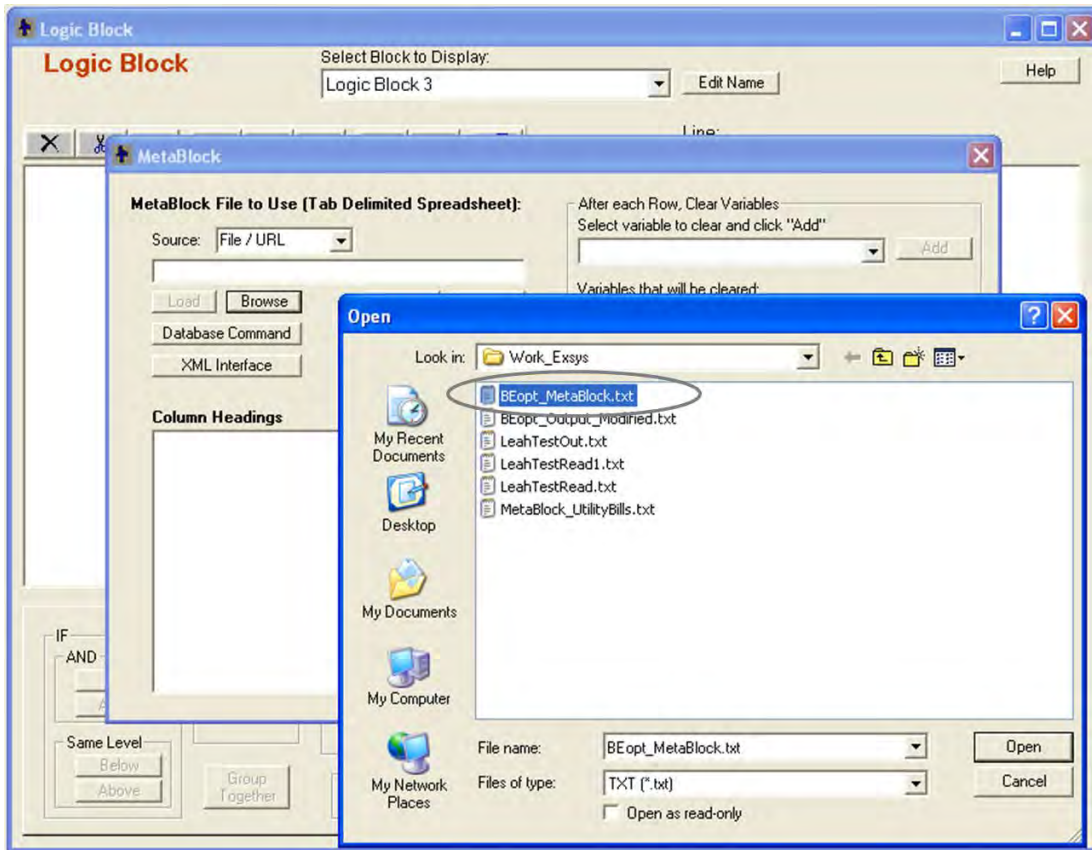
Figure 5.13: Importing BEoput Ouput File from Meta Block
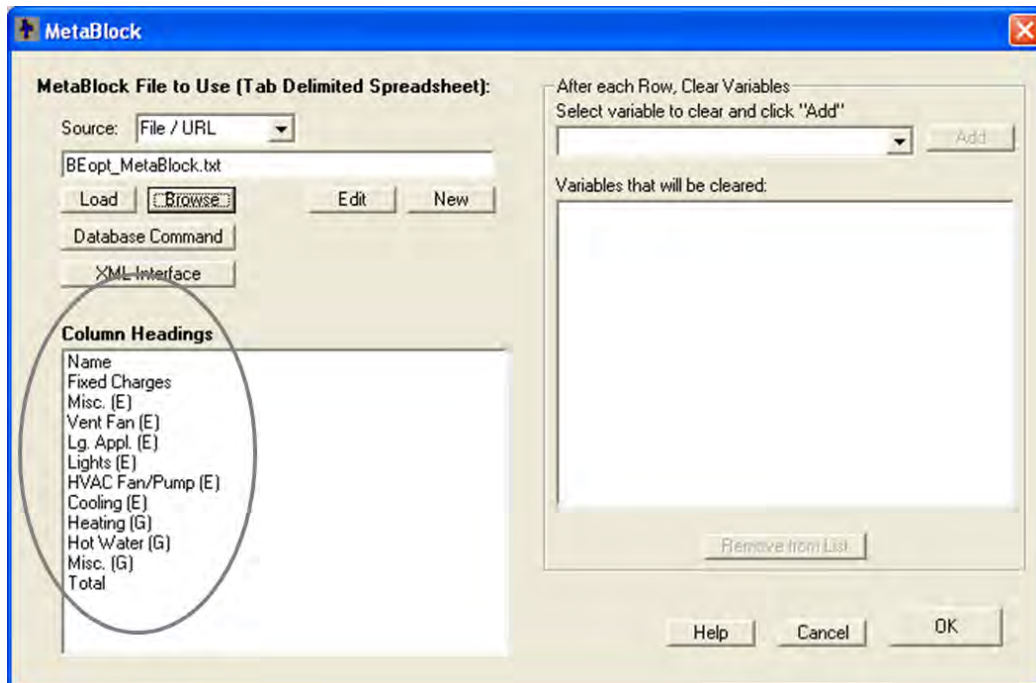
**Figure 5.14: Imported Column Heads in Meta Block**

Figure 5.15: Imported Data in Meta Block

5.3.3 Integrating Text, Image and Link Information

At the end of the integration model running process, additional information is provided in the form of text files, images and web links, in order to help users to understand the retrofit measures, installation techniques and so on. This explanatory information can be delivered in different ways in Exsys Corvid, according to its purpose and the location of the information display.

The first method is to use the Meta Block, which is extensible by adding new columns and new data (see Figure 5.15). In this integration model, the Meta Block method is used to provide the text files, the images and the web links. The file names of the images and the documents specified in the Meta Block can be displayed on the result screen, combined with the program logic and commands. The text and image files must be located in the same folder as the Exsys Corvid system files in order to be referenced by just the file name.

137
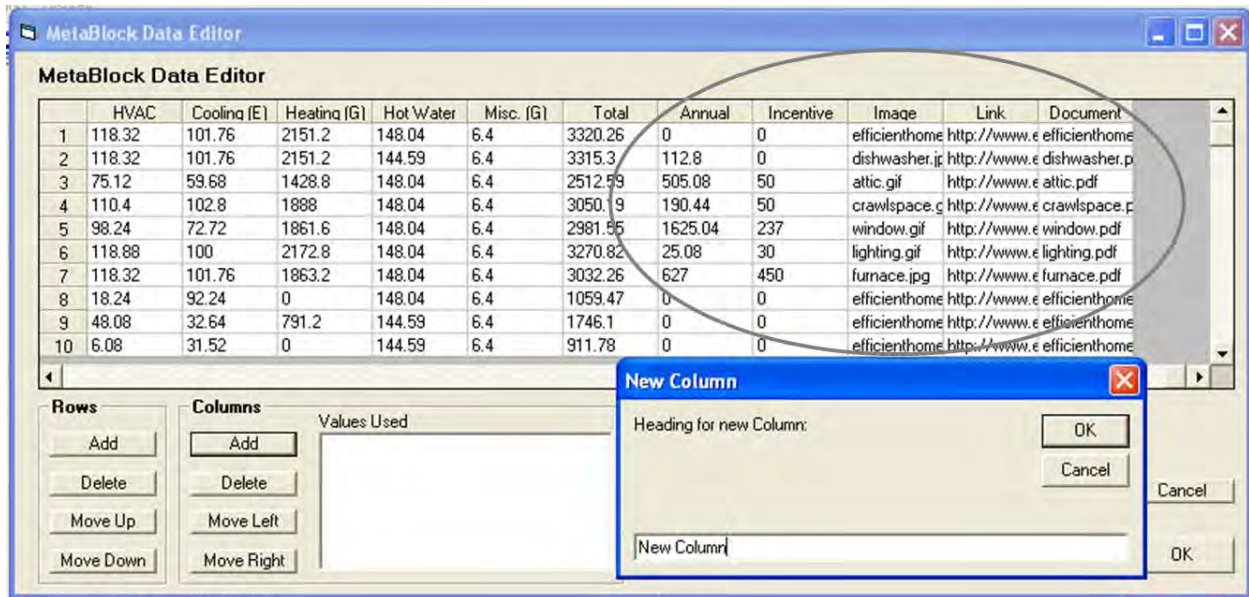
Figure 5.16: Text, Image, Link Information in Meta Block

The second method is to specify the file information in the collection variables, which can demonstrate the process information in the form of a report at the end of process-running (see Figure 5.16). This method provides the same result as the Meta Block method. While the Meta Block method is more useful when the text and image information are needed for every measure, the Logic Block method is useful when only some of the measures need the text and image information.

The last method is to use the Result setting in Command Block. This method is appropriate for general information rather than specific measure-related information. In this integration model, this method is used to explain the meaning of Effective Return and Effective Cost at the beginning of the result screen.

5.4 INTEGRATION MODEL DEVELOPING PROCESS

In this chapter, the integration model is explained, following the sequence of system development. The forepart of the integration modeling is related to the interaction with users, which includes the steps for organizing the questions for users, compositing the answer list for each question, and arranging the result display. The latter part deals more with Exsys Corvid system-related development, which include the steps to set variables, to build logic blocks, and to build command blocks. Each step will be explained in detail.

5.4.1   Organization of Questions

The first thing the integration model must decide is what to ask to users, in order to elicit the current retrofit measure information for their residential buildings. In addition to understanding the general information about residential retrofit measures, the NREM database measures and BEopt input options must also be analyzed. Since the retrofit measure information must be compatible between the NREM database and BEopt for the system integration, the questions must be designed by the measure components that exist in both the NREM database and BEopt.

It is also essential to understand the NREM database measure structure, since the sub-questions for a retrofit measure follow the NREM measure structure. For example, questions about "dishwasher" start by asking about the users' current dishwasher type – "standard" or "energy star" – and ask about the quantity of the measure as well. This current dishwasher type matches with the "before-component" in the NREM measure structure. Then, the integration model provides possible improvements for the current measure, which match with the "after-component" in the NREM measure structure. Based on the selected "before-component" and "after-

component," the "average unit cost" for implementing the improvement is derived from the NREM database. Since the "average unit cost" needs to be multiplied by the quantity fed by users, to calculate the total NREM measure cost, the quantity question must use the same unit as the NREM database. Figure 5.17 explains the M:N relationship between before-component and after-components.
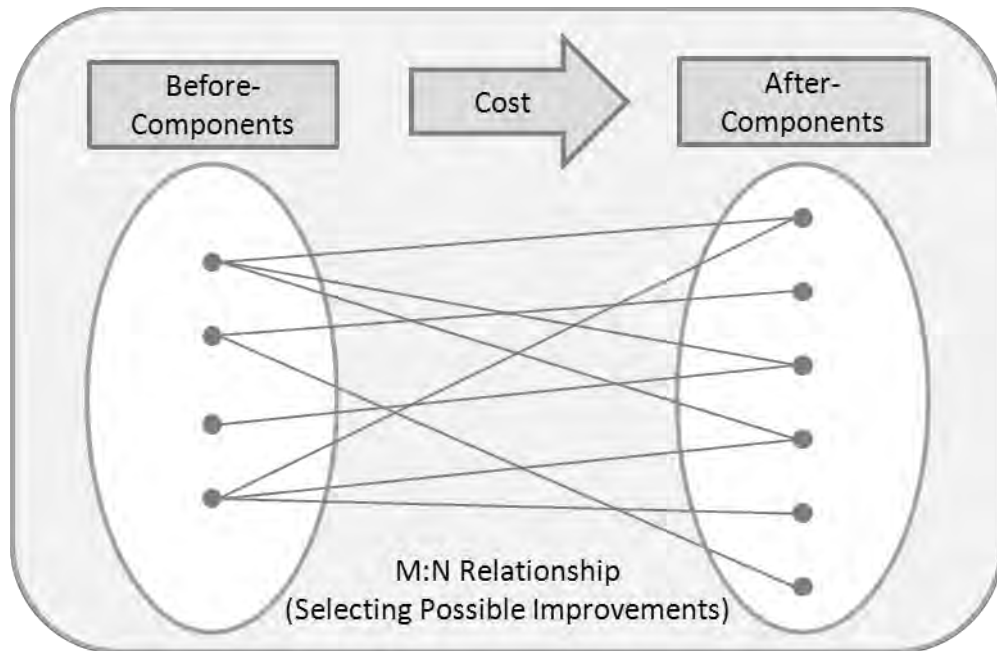

**Figure 5.17: Selecting Possible Measure Improvements from NREM Database**

5.4.2 Composition of Answer List

After deciding what to ask users, the multiple choice answer list under each question needs to be composited. Each answer choice on the list is a measure component of the NREM database, but the components must be also compatible with the BEopt input options, to interchange the retrofit information between them.

This work is intricate, since the NREM database measure components and the BEopt input options are quite different, even though they share same measure data information to some degree. While some measures, such as attic insulation and furnaces, are fairly compatible with each other, other measures, such as lighting types and window area, are nearly incompatible due to the totally different approach each system uses to manage the measure information. Even in some compatible measures, the measure components on the answer list are restricted to those that exist in the BEopt input options, since the NREM database usually contains many more measure components than BEopt.

Figure 5.18 shows an example using the compatible measure components between the NREM database and BEopt, and Figure 5.19 shows the opposite example.
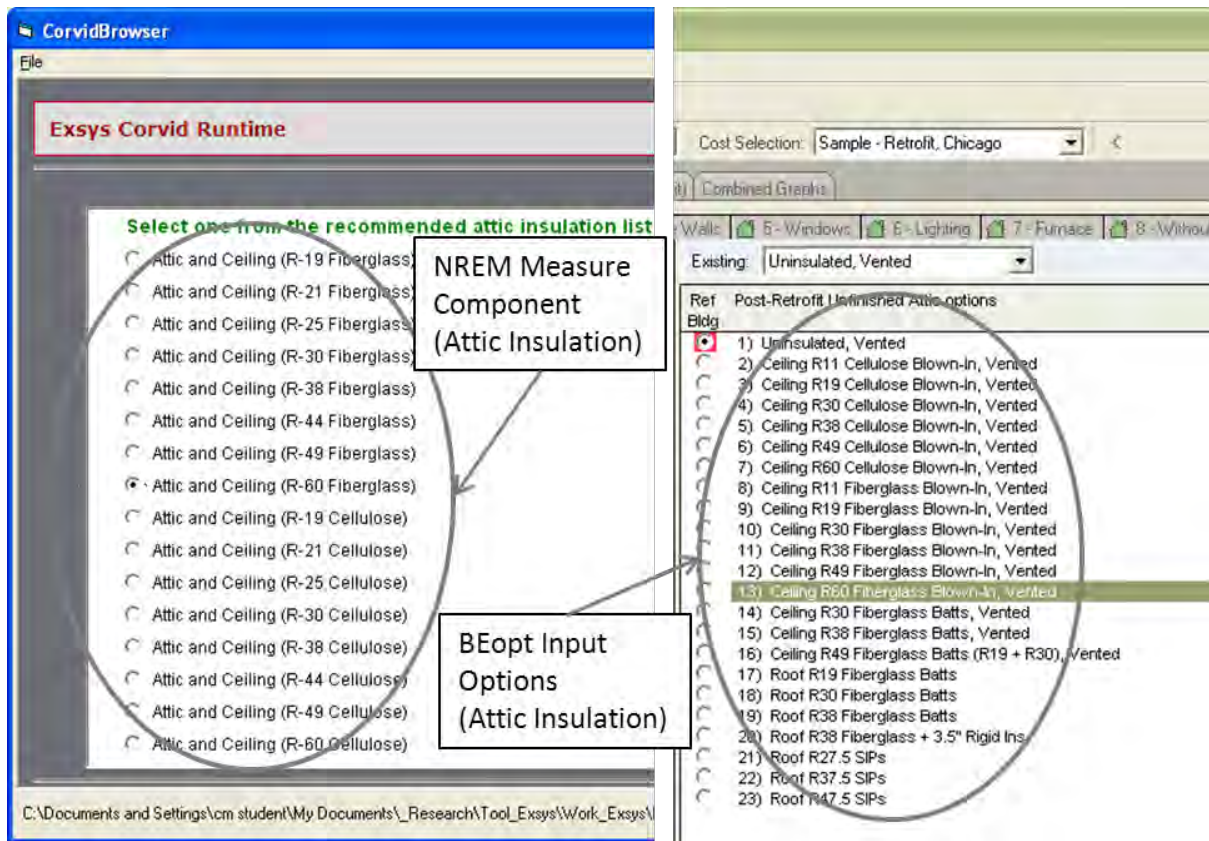
Figure 5.18: Compatible Measure Example between NREM Database and BEopt
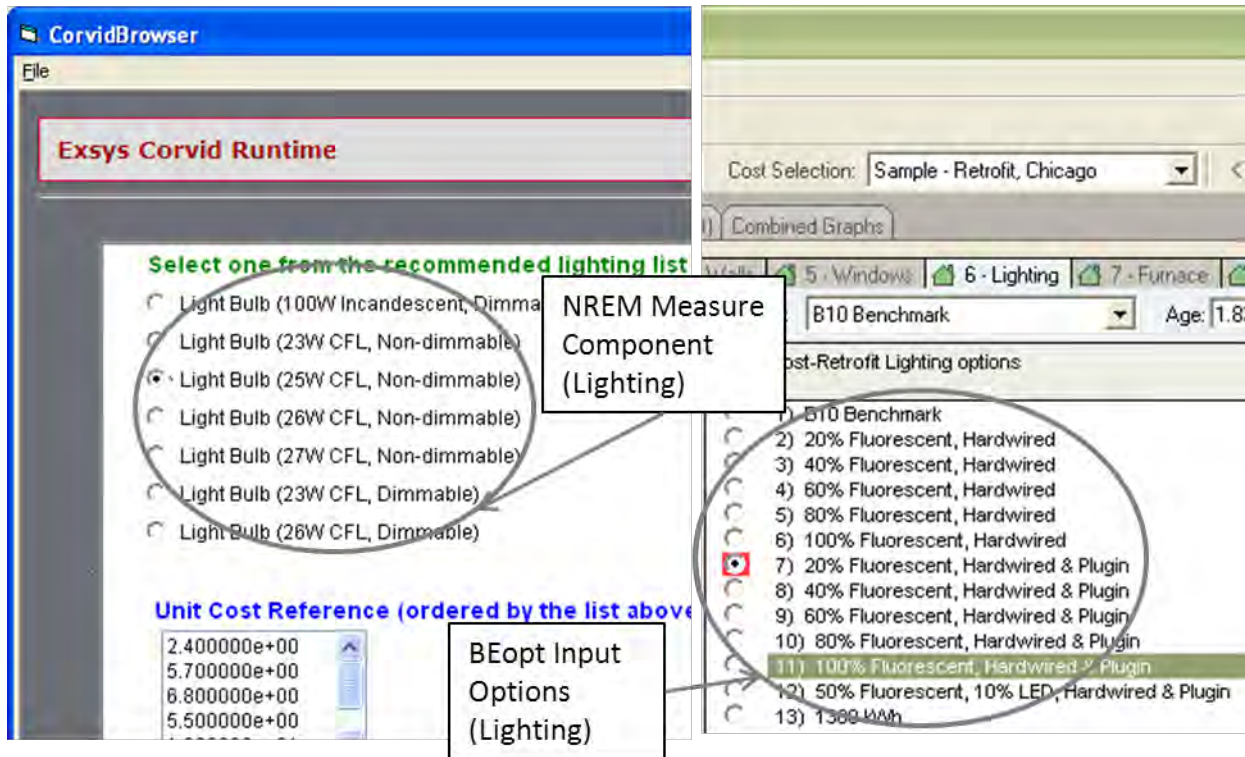
Figure 5.19: Incompatible Measure Example between NREM Database and BEopt

5.4.3 Output Result Arrangement

The next step is to decide which information will be illustrated on the result screen, and in which way. In this integration model, the result screen begins with an explanation about some of the variables, such as Effective Return, Effective Cost and Payback Year. The core information – the prioritized measure list – is then displayed, ordered by the values of the Effective Return variable, with additional images, text, and web link information for each measure. At the end of the list, the remaining budget is provided, calculated with the initial user's budget and the effective cost of each measure.

After deciding the user-interface-related process, the integration model development moves on to building the Exsys Corvid system elements.

5.4.4 Variable Setting

Variable setting is the first step in converting the questions, the answer lists and the prioritizing procedure to the Exsys Corvid system language. According to the properties of the questions and the answer list, variable types are decided upon, and certain variable types are used to perform specialized functions. In this research, Dynamic List Variables, Confidence Variables and Collection Variables play significant roles in the implementation of the integration model. When the variables are set, the external NREM database can also be called.

1) Selecting Variable Types

Dynamic List Variables are used to derive and demonstrate the possible measure improvement list in this model. Dynamic List Variable values can be set at runtime, which means that the values are from the reaction to the prior action. For example, the user chooses one answer from among the several current measure components (before-components), and the chosen current measure component derives its possible improvements (after-components) from the NREM database. The possible after-component values vary, depending on which before-component is selected during the runtime, so they cannot be pre-set during system development.

Confidence Variables are utilized to calculate Effective Return values, Effective Cost values, Payback Year values, and Remaining Budget values. Confidence Variable values are calculated using various rules, which are defined in the Logic Block. According to the formula specified in the logic, the Confidence Variable values can be derived during the runtime. The confidence value can be initialized for each measure or can be cumulated throughout the entire runtime. For example, Effective Return, Effective Cost, and Payback Year values are initialized whenever the

system derives values for a measure component, to assign the calculated value to each component. On the other hand, Remaining Budget values are cumulative, beginning with the user's initial budget, and continuously subtracting the Effective Cost of each measure.

Collection Variables are used to provide the prioritized list on the result screen. Collection Variables can save the processing values during the runtime. The saved values can be displayed on the result screen; this can be also used to debug logic errors during the system development. Collection Variables can be displayed on the result screen, ordered by a specific variable value, which is one of the key elements to prioritizing the retrofit measures. For example, in this integration model, the prioritized measure list is ordered by Effective Return values, which means that as the retrofit measure displays higher, it has a higher Effective Return value.

Since variable types are directly related to the attributes of measure components, both the measure components and the Exsys Corvid variable types must be understood simultaneously in the developing process.

2) Calling External NREM XML Database

As explained in Section 5.3.1, the external database can be called when the variables are set, in order to derive variable values from the database. In this integration model, the NREM database is used to derive the possible measure improvement list, and its cost reference list. It is also used to select the average cost to improve a specific current retrofit measure (before-component) to another energy efficient measure (after-component). The XML database can be handled using XPath. The main XPath query examples used in this integration model are shown below. In

144

Exsys Corvid, double square brackets "[[ ]]" are used for embedded variable values, which means the selected values at runtime.

- Example 1: Selecting possible after-component list (multiple value list)

XML "NREM_data.xml" / RetrofitDbData / tblWebMeasures / webMeasures [sBeforeComponent = "[[_Before_Component1]]"] / sAfterComponent

- Example 2: Selecting cost reference list (multiple value list)

XML "NREM_data.xml" / RetrofitDbData / tblWebMeasures / webMeasures [sBeforeComponent = "[[_Before_Component1]]"] / nAverageCost

- Example 3: Selecting an average cost value for a specific before-component and an after-component (single value)

XML "NREM_data.xml" / RetrofitDbData / tblWebMeasures / webMeasures [sBeforeComponent = "[[_Before_Component1]]" and sAfterComponent = "[[_After_Component1]]"] / nAverageCost

5.4.5   Logic Block

1) Backward Chaining

The original concept of backward chaining was to find a particular value for the current work, by checking whether any other rules in the program can identify its value (Exsys 2012). In this integration model, backward chaining is utilized to find the NREM database component names

for the user-selected measure names. For example, when the integration model asks about a window measure, the user can select the values from among "Single Pane", "Double Pane" and "Low-e". However, these user-friendly simple names must be converted to the component names of the NREM database to derive values from the database. A Logic Block specifies this corresponding rule, and backward chaining helps to match "Single Pane" to "Window (Single-Pane, Clear, Vinyl Frame)" for the NREM database's use. Figure 5.20 explains the concept of backward chaining and Figure 5.21 demonstrates the use of backward chaining in the integration model.
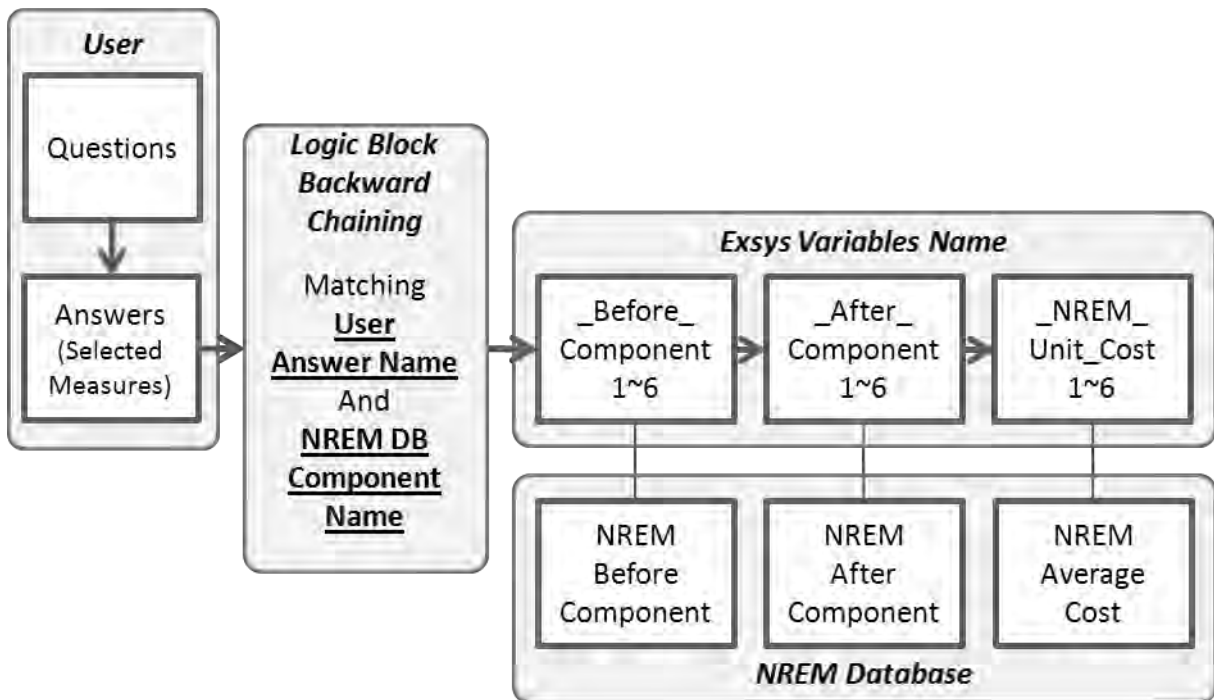
Figure 5.20: The Concept of Backward Chaining
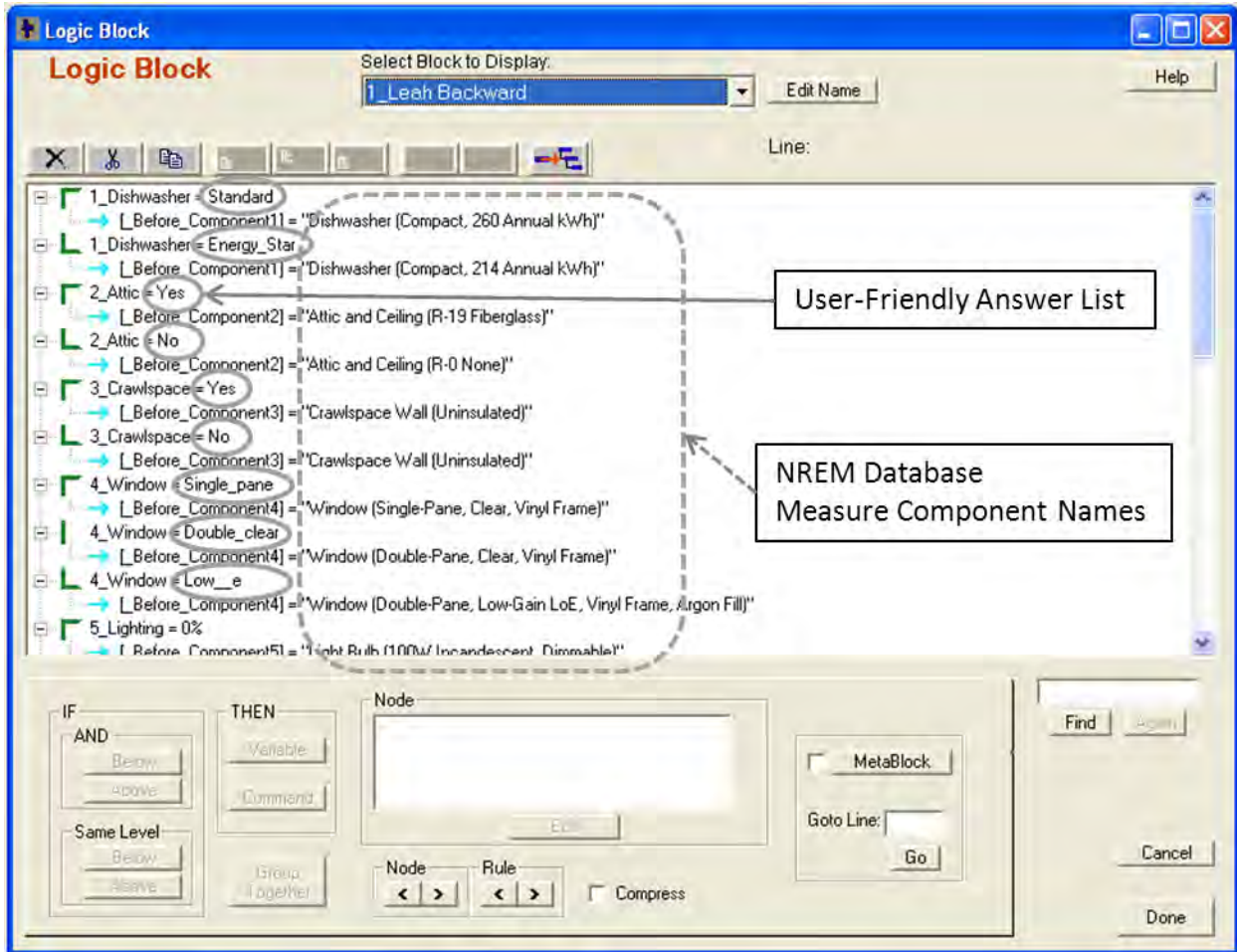
Figure 5.21: The Use of Backward Chaining in Logic Block

2) Meta Block

A Meta Block is expedient for working with a group of data consisting of the column headings and the data rows. Once the Meta Block is set in the Logic Block, the column names and the values can be treated in the same way as the other ordinary Exsys Corvid variables. The difference is that Meta Block variables are identified in curly brackets "{ }," while the ordinary variables are identified in square brackets "[ ]." As explained in Section 5.3.2 and Section 5.3.3, Meta Block is used for the BEopt annual utility bill cost information, and for additional text, image and web link information in this integration model.

3) Prioritizing Process

A	Measure	Ex) Attic Insulation	
B	Existing Efficiency		
C	Upgrade Efficiency		
D	Cost (NREM DB)		← *NREM*
E	Incentive Amount	(From DSIRE)	
F	Effective Cost	D – E	← *Exsys Calculation*
G	Annual Loan Payment	(From DSIRE)	
H	Annual Energy Savings	Un-retrofit – Retrofit	
I	Effective Return	H – G	← *Exsys Calculation*
J	Simple Payback	F / H	← *BEopt & Exsys Calculation*

Figure 5.22: Table of Cost Information (Modified From: Samuel 2011)

The main role of the Logic Block is to define rules for the system using the cost information as shown in Figure 5.22. In this integration model, the calculation formula for Effective Return, Effective Cost, Payback Year and other variables, and the prioritizing procedure of the measures are described in the Logic Block. Some rules are explained below.

- **Basic formula**:

  [_NREM_Calc_Cost] = [_NREM_Unit_Cost] * [_Measure_Quantity]

  [_Effective_Cost] = [_NREM_Calc_Cost] – {Incentive Amount}

  [_Effective_Return] = [_Beopt_Unretrofitted_Total] – {Total} – {Annual Loan}

  [_Payback_Year] = [_Effective_Cost] / {Total}

- **Prioritizing**: The measures are ordered by their Effective Return values; the first measure on the list has the first priority to be improved.

- **Immediate User Need**: Effective Return values are usually calculated by the basic formula, as explained above. If the measure is selected as the user's immediate need at the beginning of the questions, a pre-defined sufficiently big number (9999999) overrides the calculated Effective Return value in order to give the selected measure the first priority.

- **Payback Year**: If the Payback Year value of the selected measure is greater than the number of years the user intends to live at the home, 5000000 is subtracted from the calculated Effective Return value, to give the selected measure less of a priority.

- **"0" value of the quantity**: When the user inputs "0" for the quantity of a retrofit measure, it returns "0" to both Effective Return and Effective Cost.

- **Lighting Measure**: As explained in Section 5.4.2, due to the dissimilar measure structures of lighting components in the NREM database and BEopt, a modified formula is used to derive "_NREM_Calc_Cost" (the NREM measure cost for the selected measure times the input quantity) for lighting. Since the lighting measure question asks the current percentage of Compact Fluorescent Lights (CFL) installed in the user's residential building, the measure quantity needed for the improvement is [(100% − Current CFL %) * unit cost of a bulb * number of bulbs installed]. For example, when the current percentage of CFL is 40%, the number of bulbs installed in the house is 30, and the unit cost of a CFL bulb is $6.80, the NREM measure cost for lighting becomes [(100% − 40%) * $ 6.8 * 30 ea. = $122.4].

- **Calculating Remaining Budget**: As Figure 5.23 illustrates, Remaining Budget can be calculated after the measures and their Effective Cost values are ordered by Effective Return values. The order of the Effective Cost of the measures is saved in Collection

Variables as one group of values [Level 0, raw data group]. At this level, the Effective

Cost values cannot be used for any calculation, therefore each value must be assigned to a

separate variable to keep the order [Level 1, separately assigned values]. However, when

the group of values is divided into each separate variable, they carry systematic garbage

values, which need to be trimmed [Level 2, trimmed values, string attribute]. Since

Collection Variables deal with the variable values as a string attribute, the variable

attribute must be changed to a numeric attribute in order to be used in calculation [Level

3, numeric values]. Each numeric Effective Cost value ordered by Effective Return can

then be calculated to get Remaining Budget. As the next measure cost is applied, the

Remaining Budget value is negatively accumulated.

[_Remaining_Budget] =

[_User_Budget] – [_EffCost_L3_Numeric1] $\leftarrow$ Remaining Budget with 1st measure

– [_EffCost_L3_Numeric2] $\leftarrow$ Remaining Budget with 2nd measure

– [_EffCost_L3_Numeric3] $\leftarrow$ Remaining Budget with 3rd measure

– [_EffCost_L3_Numeric4] $\leftarrow$ Remaining Budget with 4th measure

– [_EffCost_L3_Numeric5] $\leftarrow$ Remaining Budget with 5th measure

– [_EffCost_L3_Numeric6] $\leftarrow$ Remaining Budget with 6th measure
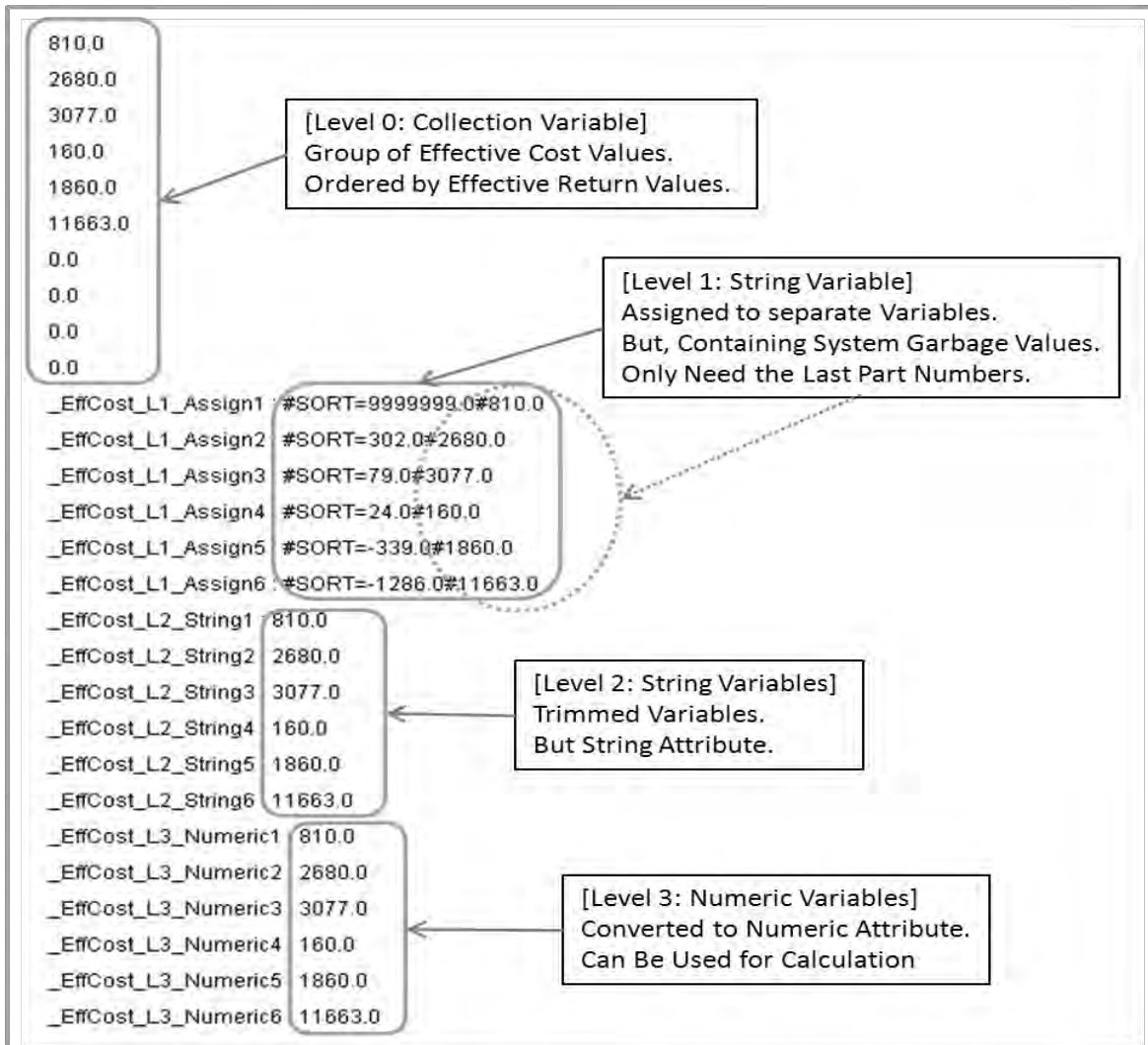
Figure 5.23: Transforming Variables for Remaining Budget Calculation

5.4.6 Command Block

Command Block controls the overall procedure of the integration model. It defines the order of

questions, and organizes the work order using the commands. Figure 5.24 illustrates the

command block built in the integration model. It begins by asking about the user's budget and

moves on, asking questions related to the selected retrofit measures. Finally, it derives the

NREM after-component list for each component. After it is finished asking questions, it derives

the measure cost from the NREM database, based on the selected measure information. The

command block then employs the Logic Block, which contains the prioritizing logic. At the end

of the command block, it specifies the result setting for the user interface.
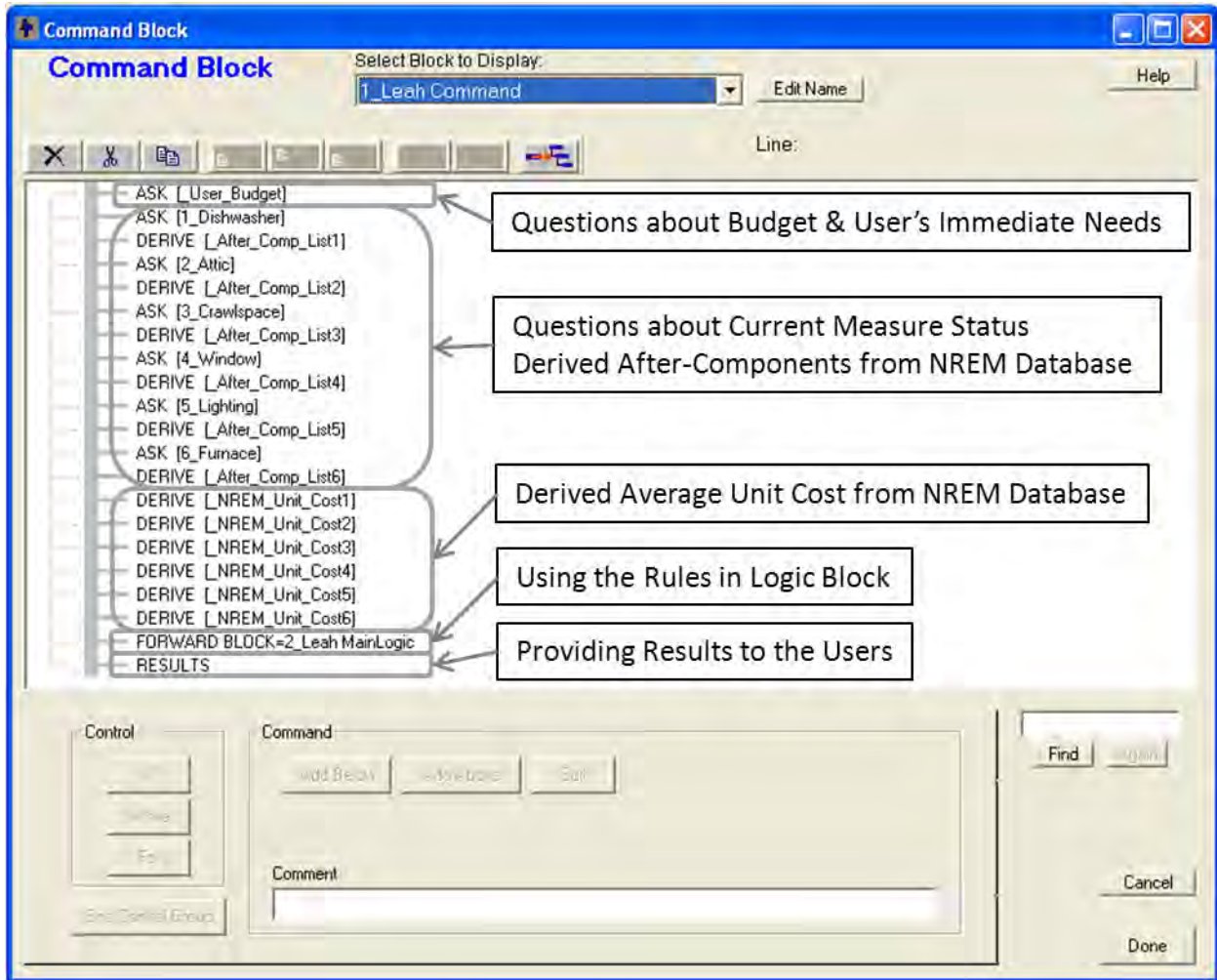
Figure 5.24: Command Block in Integration Model

The result screen can be handled in the Command Block. Figure 5.25 shows the screen setting

for the integration model. The title and the explanation of the concept of Effective Cost and

Effective Return are shown at the top. The prioritized list saved in "Report_Overall," a

Collection Variable, is displayed with an additional image, text, and web-link information.

Finally, the calculated Remaining Budget values are provided to the users.
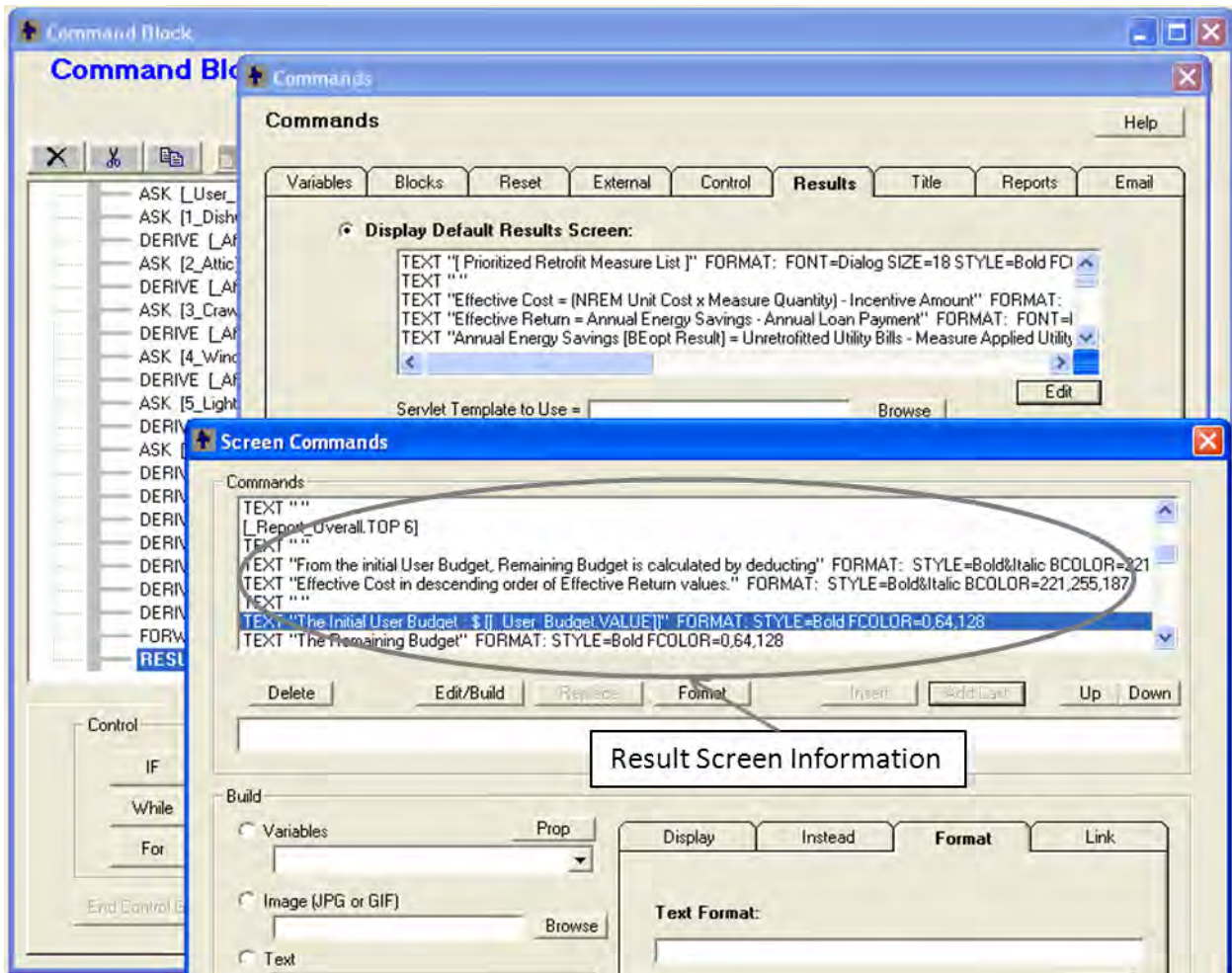
Figure 5.25: Result Setting in Command Block

5.5 WORKING EXAMPLE

In this section, the integration model is demonstrated using a working example, and the running process is explained with the help of selected screen captures of the system. All of the screen captures of the running process are provided in the Appendix.

5.5.1 Basic Questioning Process

The running process begins with questions about the user's budget, the year the home was built, the number of years the user intends to live at the home, and the retrofit measure the user needs

153

immediately. If a measure is selected as the user's immediate need, it has first priority for being improved. In this case, the initial user budget is 8,000 dollars, and the user needs to change the current dishwasher immediately.
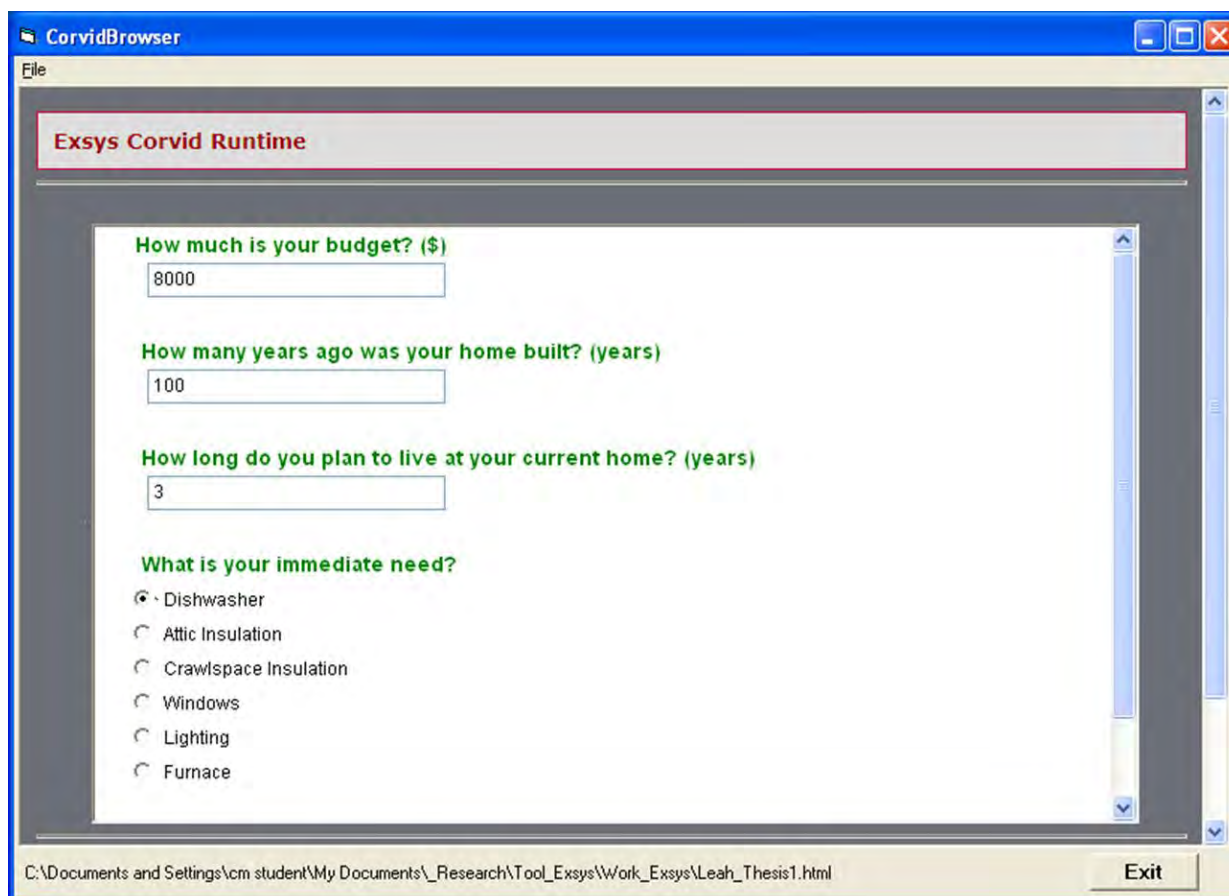
Figure 5.26: Initial Questions in the Running Process

The system then asks about all of the selected measures. In this working example, 6 retrofit measures are selected, including the dishwasher, attic insulation, crawlspace wall insulation, windows, lighting and furnace.

The questions for one retrofit measure consist of the current measure state, the quantity needed, the list of possible improvements and the reference list of the measure unit costs. In Figure 5.27

the first question is about dishwashers; the user's current dishwasher is standard, and he/she

needs one dishwasher.
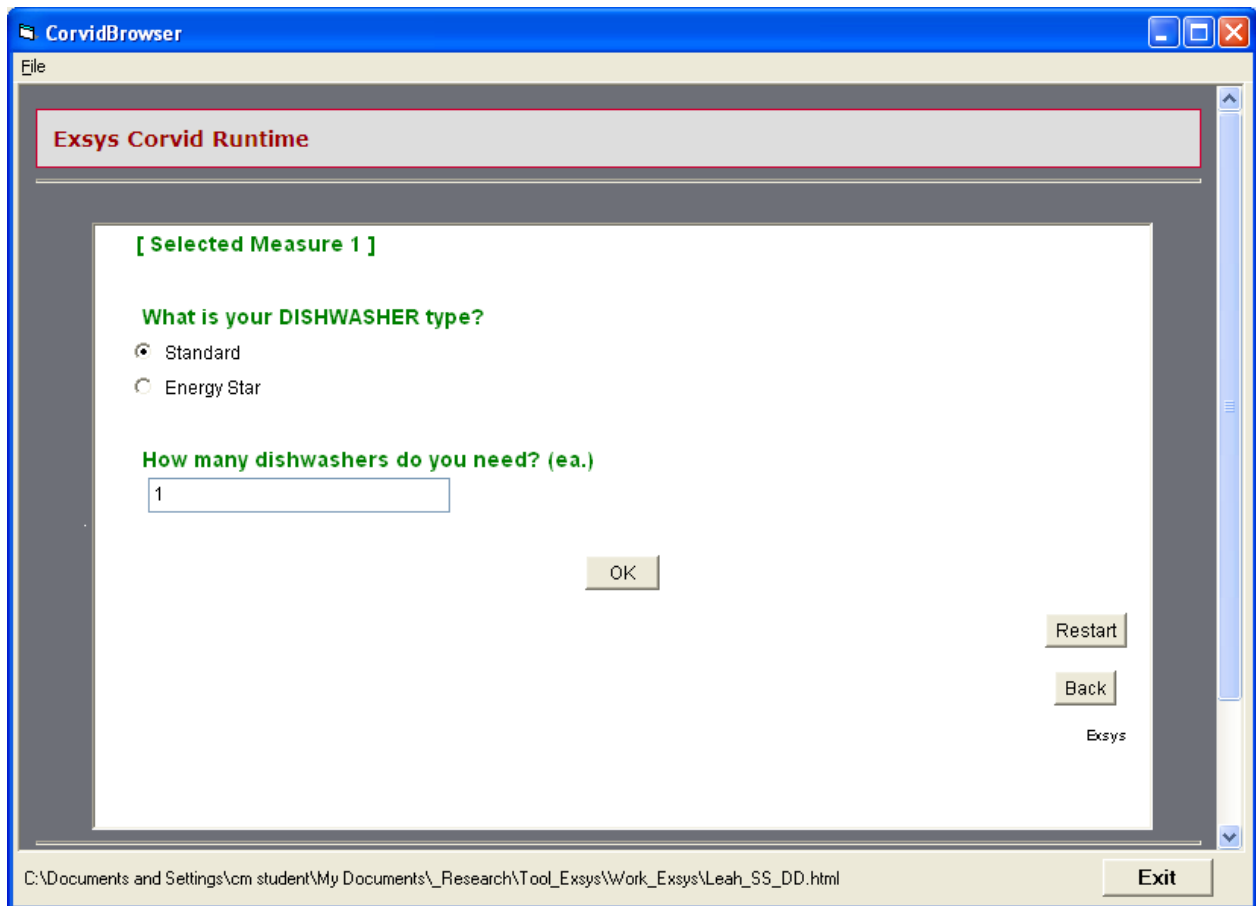
Figure 5.27: Measure Questions (Current State, Quantity)

Based on the selected current measure information (before-component), the integration model

derives possible improvements (after-components) from the NREM database, which are shown

on the next screen. When the user selects "standard" as his/her current dishwasher, the user-

friendly name "standard" is changed into an NREM before-component name, "Dishwasher

(Compact, 260 Annual KWh)" through backward chaining. The NREM database provides 3

possible after-components, with their unit cost list as a reference. Figure 5.28 shows the NREM-

driven list of more energy-efficient dishwashers, and the cost list. When the user selects the first

option, "Dishwasher (Compact, 214 Annual KWh)," the unit cost to replace the before-

component "Dishwasher (Compact, 260 Annual KWh)" to the after-component "Dishwasher

(Compact, 214 Annual KWh)" is 810 dollars.
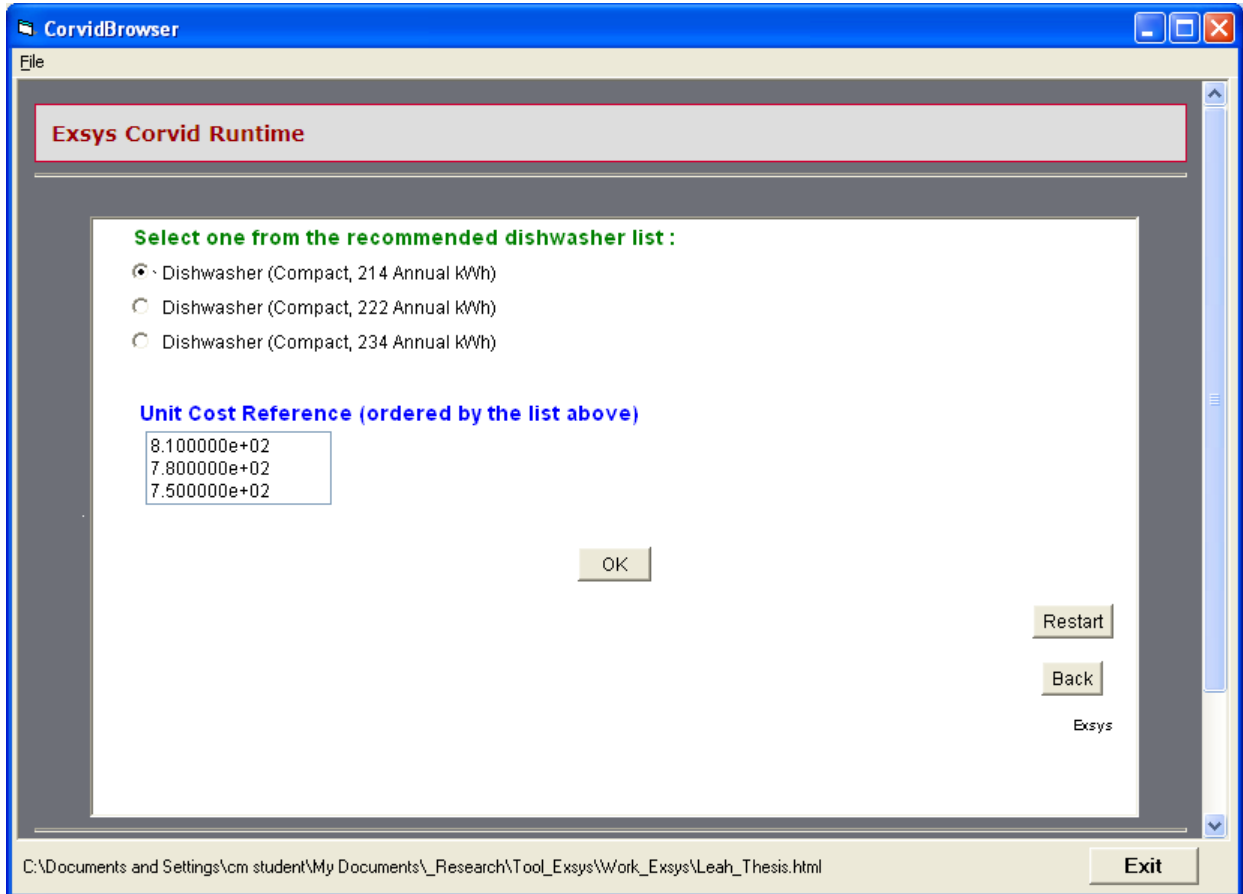
Figure 5.28: Measure Questions (NREM After-Component and Cost Lists)

For more NREM database information, the NREL webpage containing the dishwasher measure

information can be linked by clicking on a "Unit Cost Reference" item.
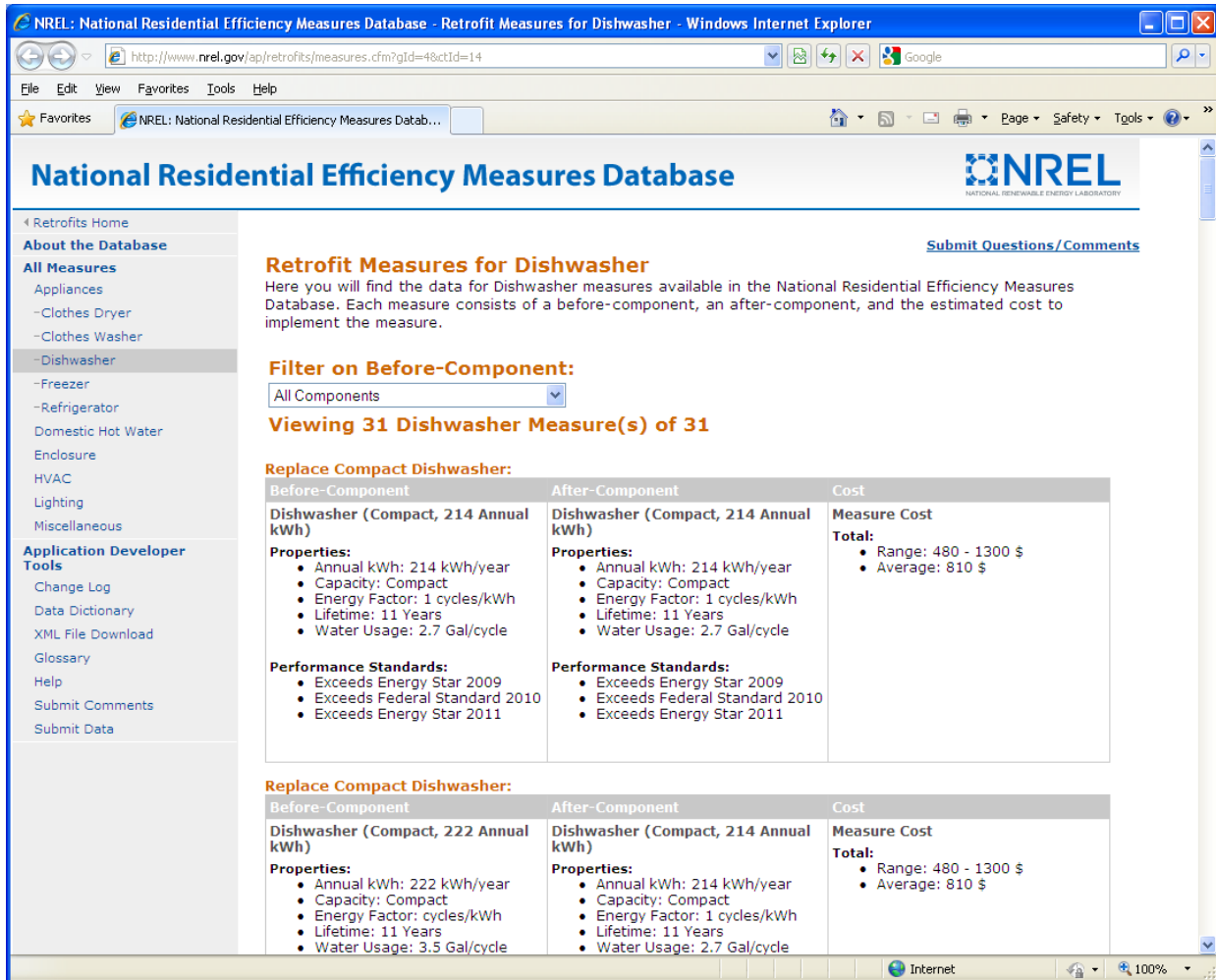
Figure 5.29: NREM Webpage Link with NREM Database Information

The same pattern is repeated for each of the selected retrofit measures. In this research, six

measures are used for the integration model.

5.5.2 Result Screen

The result screen provides the system title, and a basic explanation about Effective Cost,

Effective Return, and Payback Year to help the user understand the results more

comprehensively.
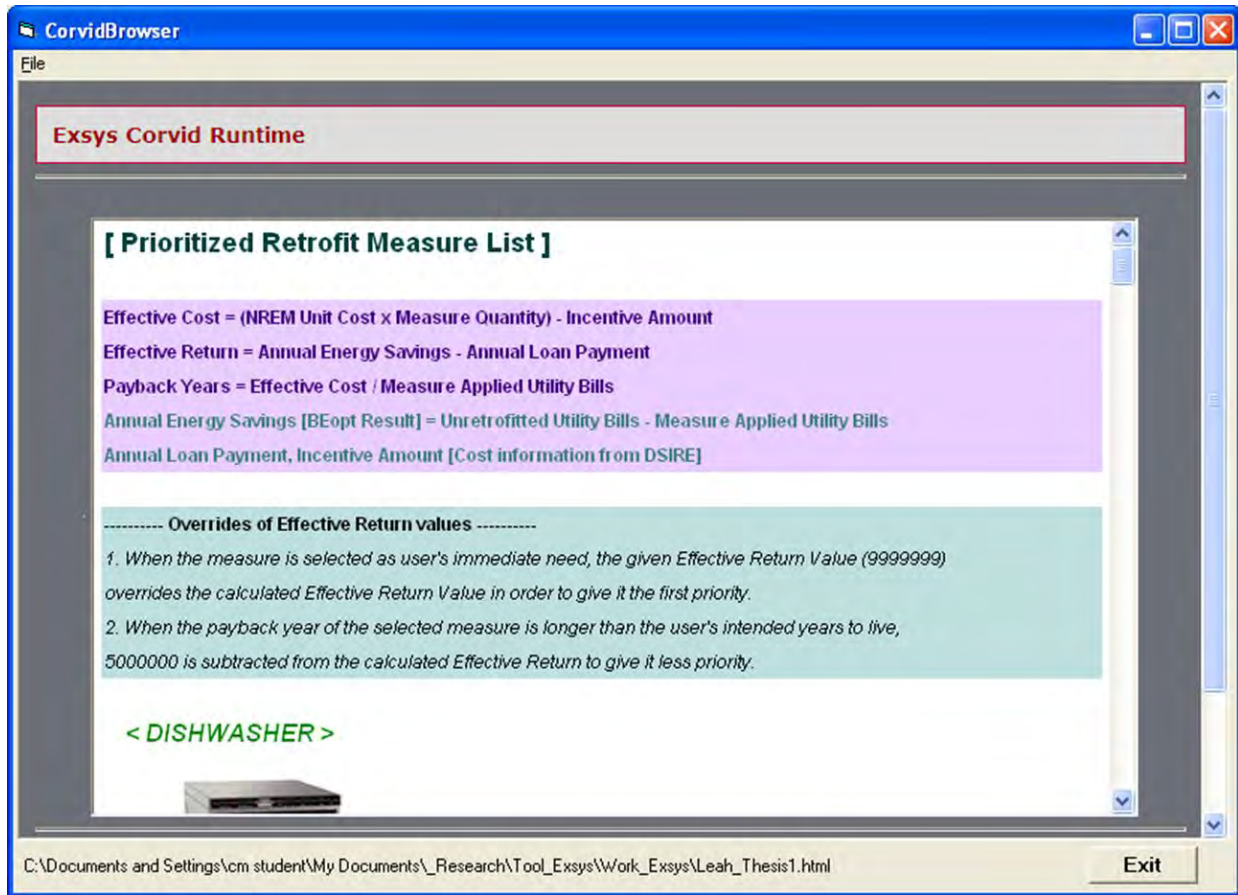
Figure 5.30: The Beginning Part of the Result Screen

In this case, the user selected the dishwasher as his/her immediate need; thus it is shown at the top of the list as the first priority. Since it is the user's immediate need, the pre-defined large value '9999999' overrides the calculated Effective Return value. The result screen also shows which before and after components are selected at runtime, the input quantity and the unit cost of the dishwasher derived from the NREM database. Additional images and text explanation are also provided on the result screen.
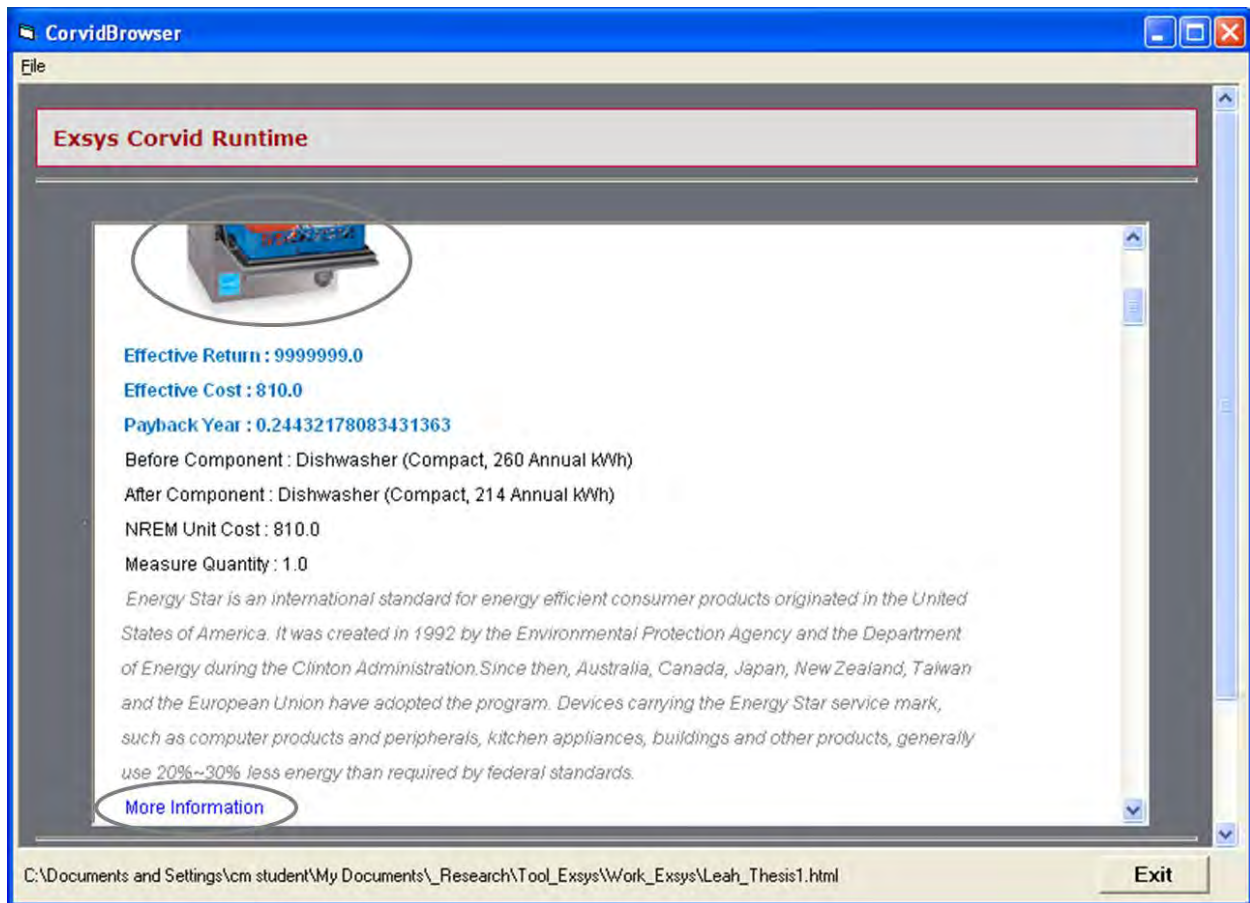
Figure 5.31: Information on the Result Screen

When the user clicks on the image of a dishwasher, as shown in Figure 5.31, the integration model links to a web page related to the selected retrofit measure, which gives further information. Additional documents providing expert knowledge are provided by clicking on "More Information" as shown in Figure 5.31.
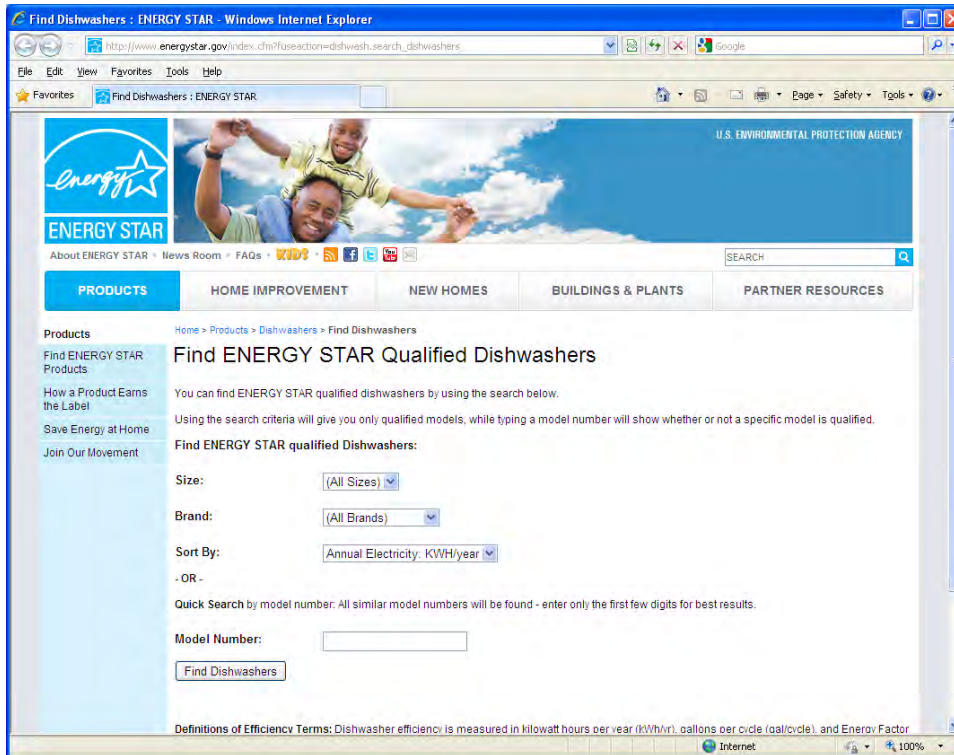
Figure 5.32: Web Link from the Result Screen
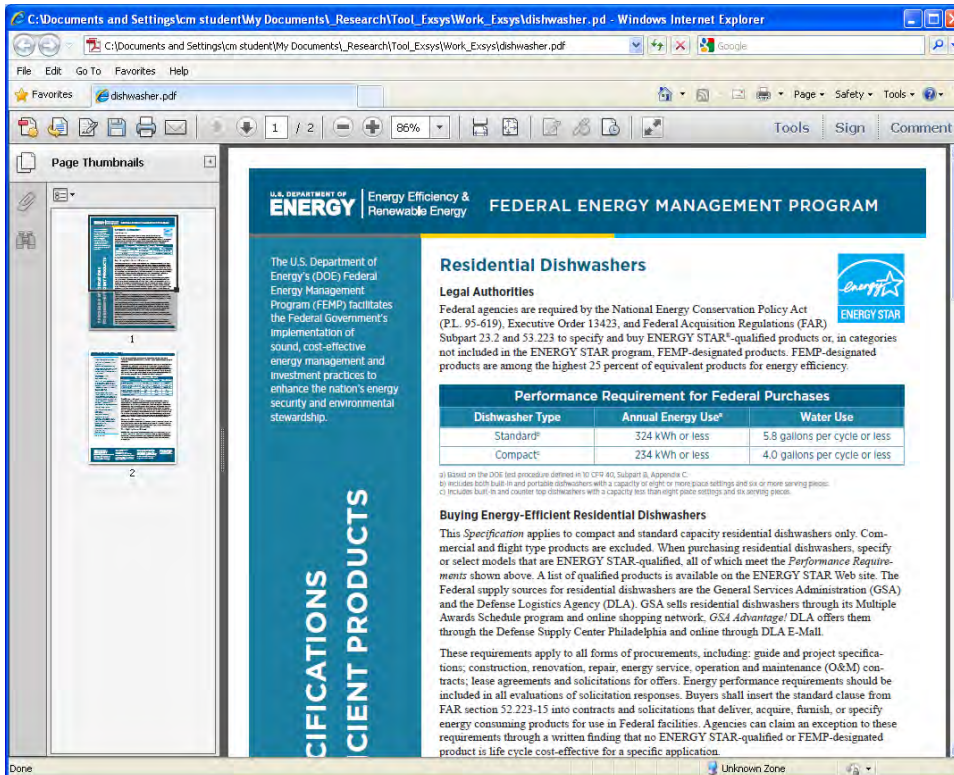
Figure 5.33: Additional Document from the Result Screen

Since the Payback Year value of a windows-type measure, 3.91 years, is larger than the number of years the user intends to live in the current house, 3 years, 5000000 is subtracted from the calculated Effective Return value -1286, in order to give less priority to the retrofit measure. Finally, the Effective Return value of the windows is -5001286, which is the lowest value among the retrofit measures.
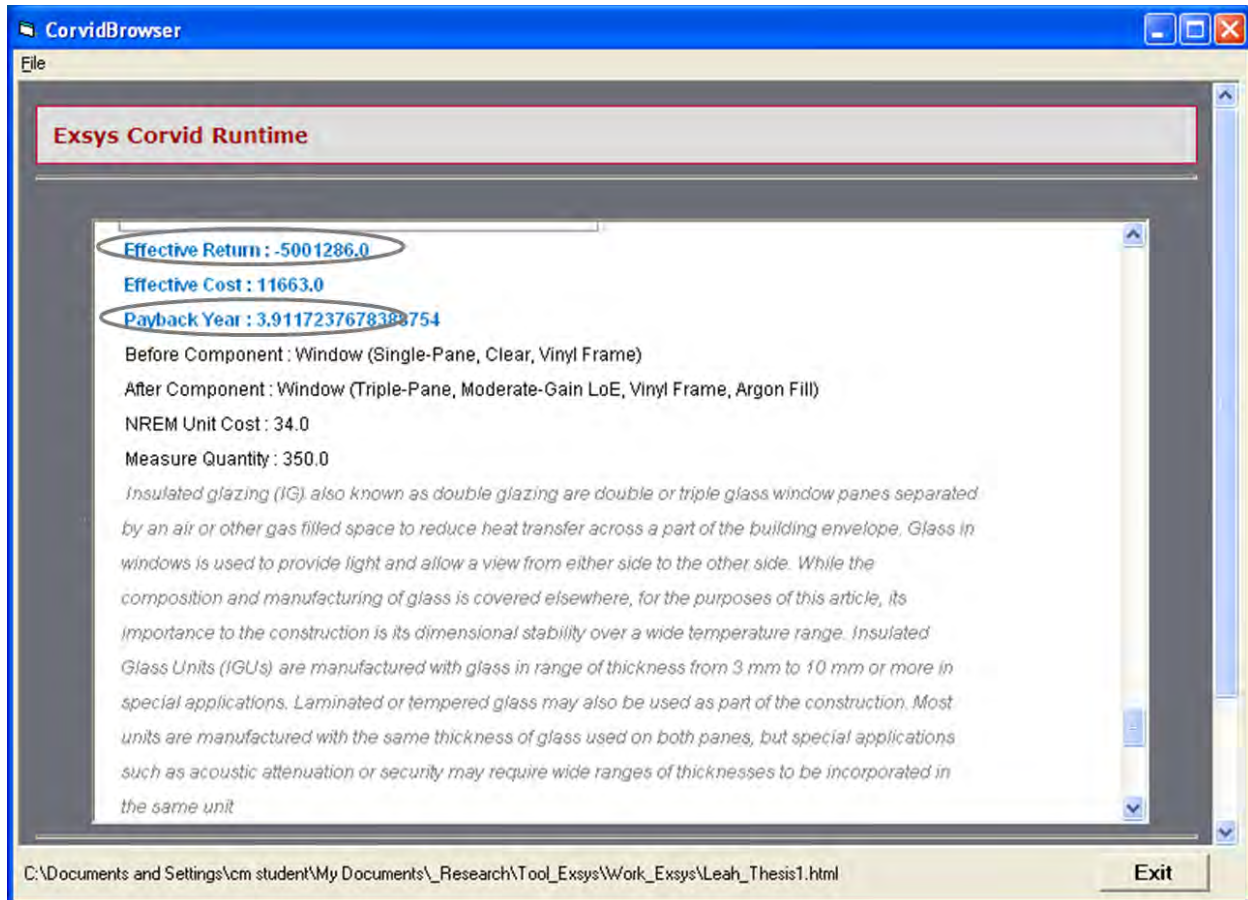
Figure 5.34: Effect of Payback Year Information

5.5.3   Remaining Budget

The prioritized measure list of this working example is as follows:

- Initial User Budget: $ 8000
- Age of the House: 100 years old

- Number of Years User Intends to Live in Home: 3 years

- 1st measure: Dishwasher

  - Effective Return: $ 9999999

  - Effective Cost: $ 810

  - Payback Year: 0.2443

  - Remaining Budget: 8000 – 810 = $ 7190

- 2nd measure: Attic Insulation

  - Effective Return: $ 302

  - Effective Cost: $ 2680

  - Payback Year: 1.0666

  - Remaining Budget: 7190 – 2680 = $ 4510

- 3rd measure: Crawlspace Wall Insulation

  - Effective Return: $ 79

  - Effective Cost: $ 3077

  - Payback Year: 1.0088

  - Remaining Budget: 4510 – 3077 = $ 1433

- 4th measure: Lighting

  - Effective Return: $ 24

  - Effective Cost: $ 160

  - Payback Year: 0.0489

  - Remaining Budget: 1433 – 160 = $ 1273

- 5th measure: Furnace

    - Effective Return: $ – 339

    - Effective Cost: $ 1860

    - Payback Year: 0.6134

    - Remaining Budget: 1273 – 1860 = $ – 587

- 6th measure: Windows

    - Effective Return: $ – 5001286

    - Effective Cost: $ 11663

    - Payback Year: 3.9117

    - Remaining Budget: – 587 – 1860 = $ – 12250

This order is decided by the Effective Return values. The Remaining Budget is calculated by subtracting the cumulative Effective Cost values from the initial user budget, following the descending order of Effective Return values. Figure 5.35 shows the calculated Remaining Budget. The negative value of the Remaining Budget means the cost of the total measures is in excess of the user's initial budget. The user can decide whether to stop applying the retrofit measures before the remaining budget becomes negative, or to expand the budget to apply the next measure, depending on the cost.
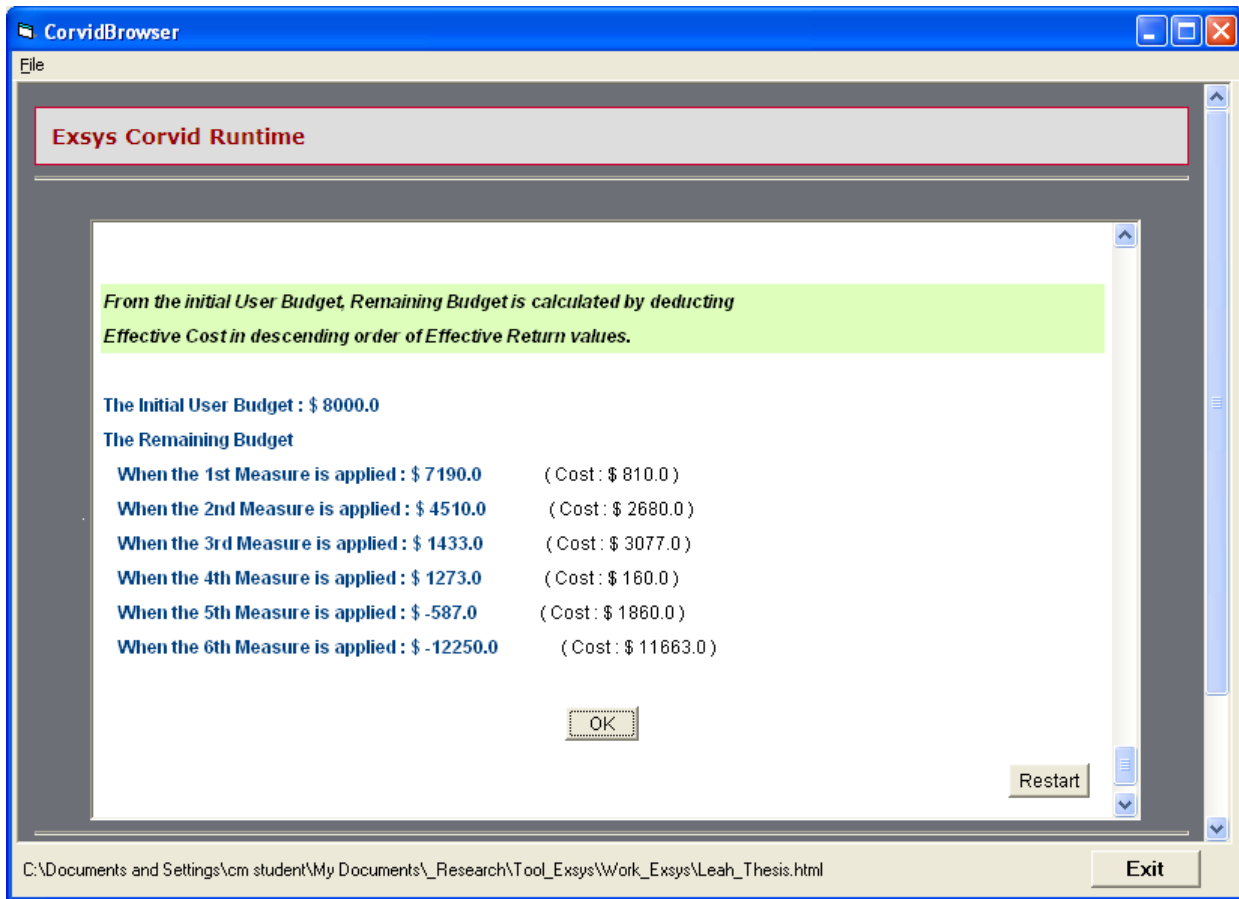
Figure 5.35: Calculated Remaining Budget

5.5.4 Result Values Validation

At the end of the system development, the result values must be validated by comparing the

values in the integration model with the raw database sources. In this example, the result is

validated by checking the result of the XPath query using BaseX software, and by comparing the

NREM XML database source code. For example, the Effective Cost of Attic Insulation is 2680,

which is calculated by multiplying the NREM unit cost and measure quantity, and subtracting

the incentive amount [2.1 * 1300 – 50 = 2680].
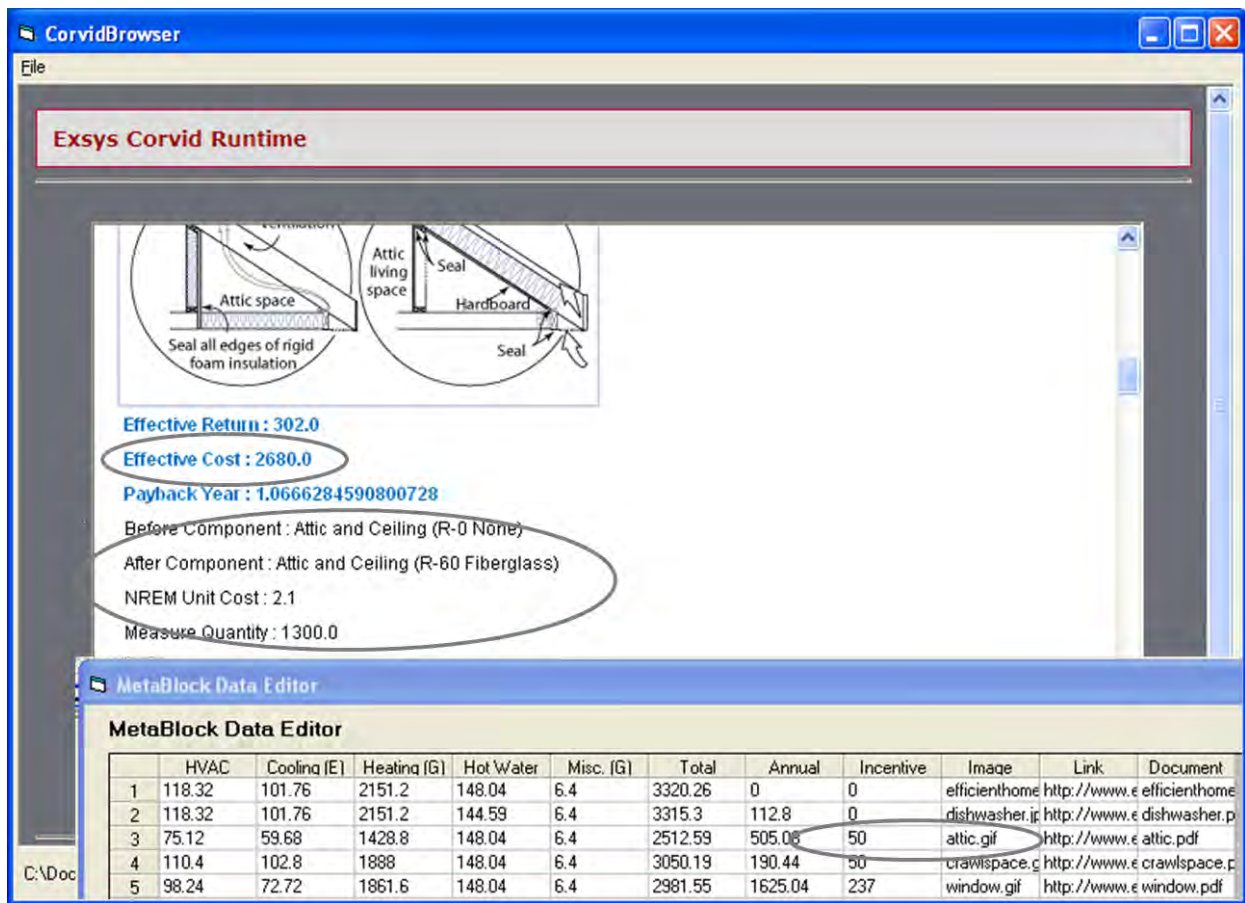
Figure 5.36: Attic Insulation Result

According to the result screen shown in Figure 5.36, the before-component name of the attic insulation is "Attic and Ceiling (R-0 None)," the after-component name is "Attic and Ceiling (R-60 Fiberglass)"; its unit cost is "2.1." As Figure 5.37 illustrates, when the values are selected by XPath query, it returns the same unit cost value, which means the integration model works correctly.
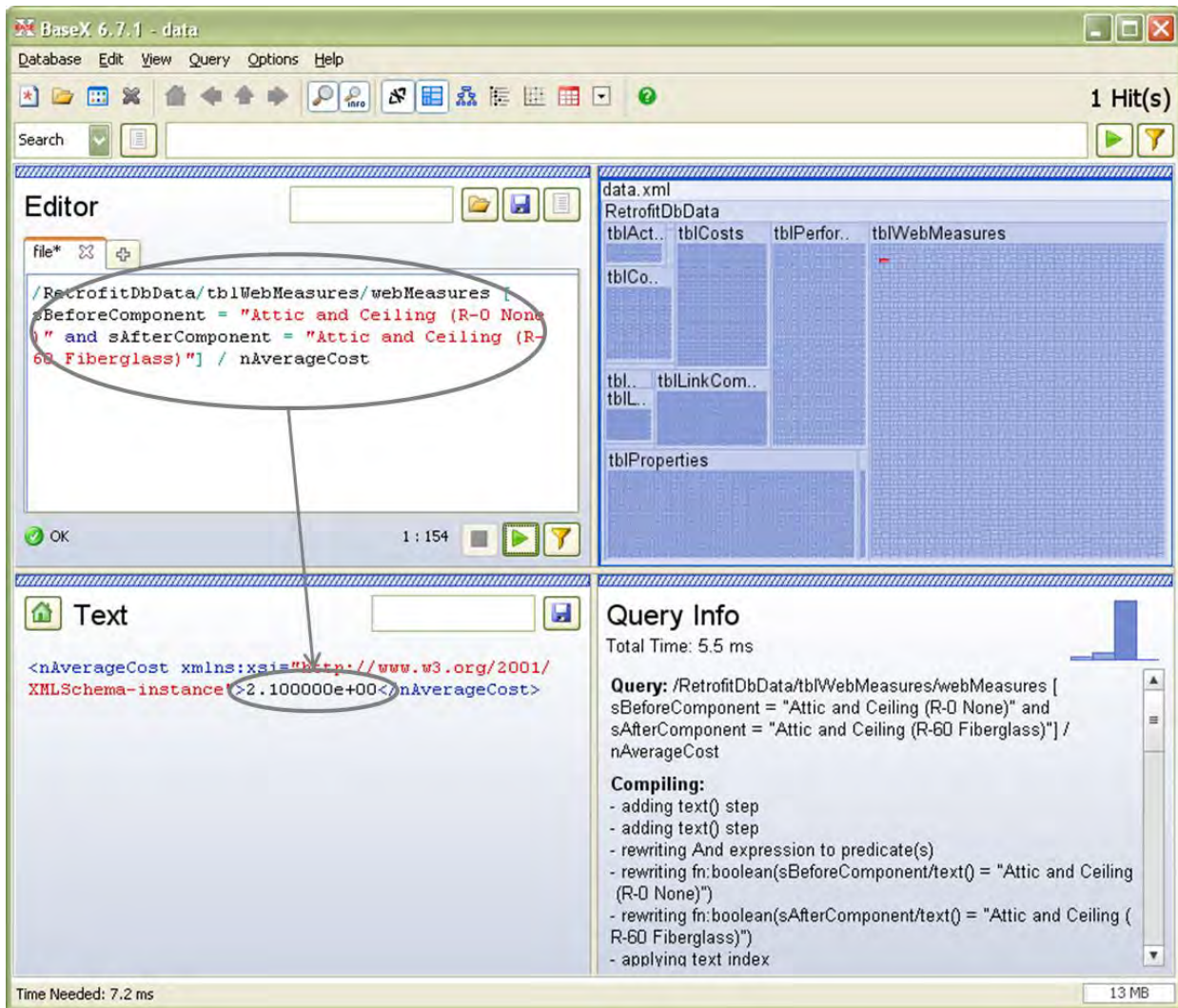
Figure 5.37: Checking Attic Insulation Unit Cost Using XPath

When the measure component values and the cost value are searched in the NREM XML database source file, it also shows the same information (see Figure 5.38).

```
    <sCostUnits>$/(ft^2 Attic Floor Area)</sCostUnits>↵
    <sComponentType>Attic and Ceiling</sComponentType>↵
</webMeasures>↵
<webMeasures idAfterComponentID="18" idBeforeComponentID="6" idActionID="29"
    <sBeforeComponent>Attic and Ceiling (R-0 None)</sBeforeComponent>↵
    <sActionName>Insulate with R-60 Fiberglass </sActionName>↵
    <sAfterComponent>Attic and Ceiling (R-60 Fiberglass)</sAfterComponent>↵
    <nLowCost>7.300000e-01</nLowCost>↵
    <nHighCost>2.800000e+00</nHighCost>↵
    <nAverageCost>2.100000e+00</nAverageCost>↵
    <sCostUnits>$/(ft^2 Attic Floor Area)</sCostUnits>↵
    <sComponentType>Attic and Ceiling</sComponentType>↵
</webMeasures>↵
<webMeasures idAfterComponentID="23" idBeforeComponentID="6" idActionID="30"
    <sBeforeComponent>Attic and Ceiling (R-0 None)</sBeforeComponent>↵
    <sActionName>Insulate with R-19 Cellulose</sActionName>↵
    <sAfterComponent>Attic and Ceiling (R-19 Cellulose)</sAfterComponent>↵
    <nLowCost>2.000000e-01</nLowCost>↵
    <nHighCost>9.100000e-01</nHighCost>↵
    <nAverageCost>6.100000e-01</nAverageCost>↵
```

Figure 5.38: Checking Attic Insulation Unit Cost in the NREM XML Source File

5.6 ADDITIONAL EXAMPLE

As mentioned at the beginning of this chapter, BEopt information can only be integrated into this model manually. Therefore, when the user examines different measure options (see Figure 5.39), a separate BEopt model needs to be run in order to derive the annual utility bill cost, based on the changed measure options (see Figure 5.40). Since the use of the "total" annual utility bill cost information is substantial in the integration model, among the other cost columns in BEopt output, only the cells under the "total" column need to be copied from the BEopt output Excel file (see Figure 5.41), and pasted into the "total" column in the Meta Block of the integration model, in order to apply the changed annual cost (see Figure 5.42). This new BEopt annual utility bill cost is used to calculate the Effective Return, Effective Cost, and Payback Year values for this example.
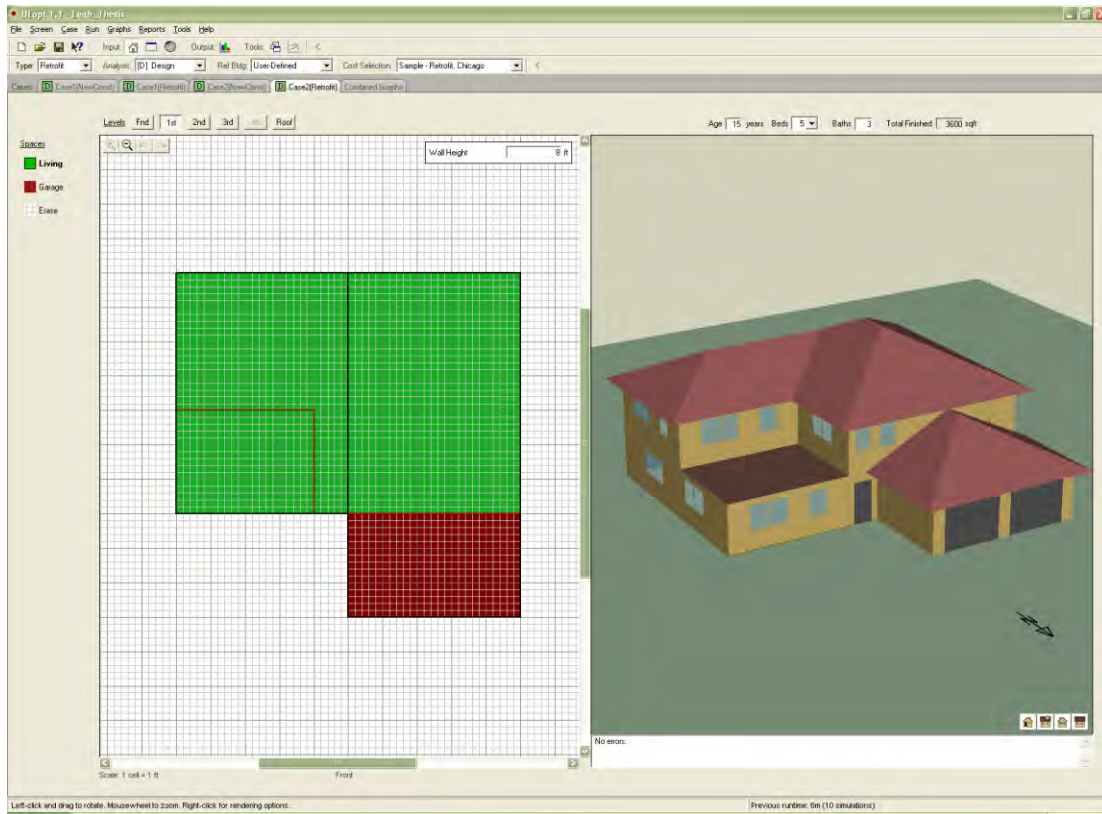
Figure 5.39: Another Example of User's Retrofit Measures
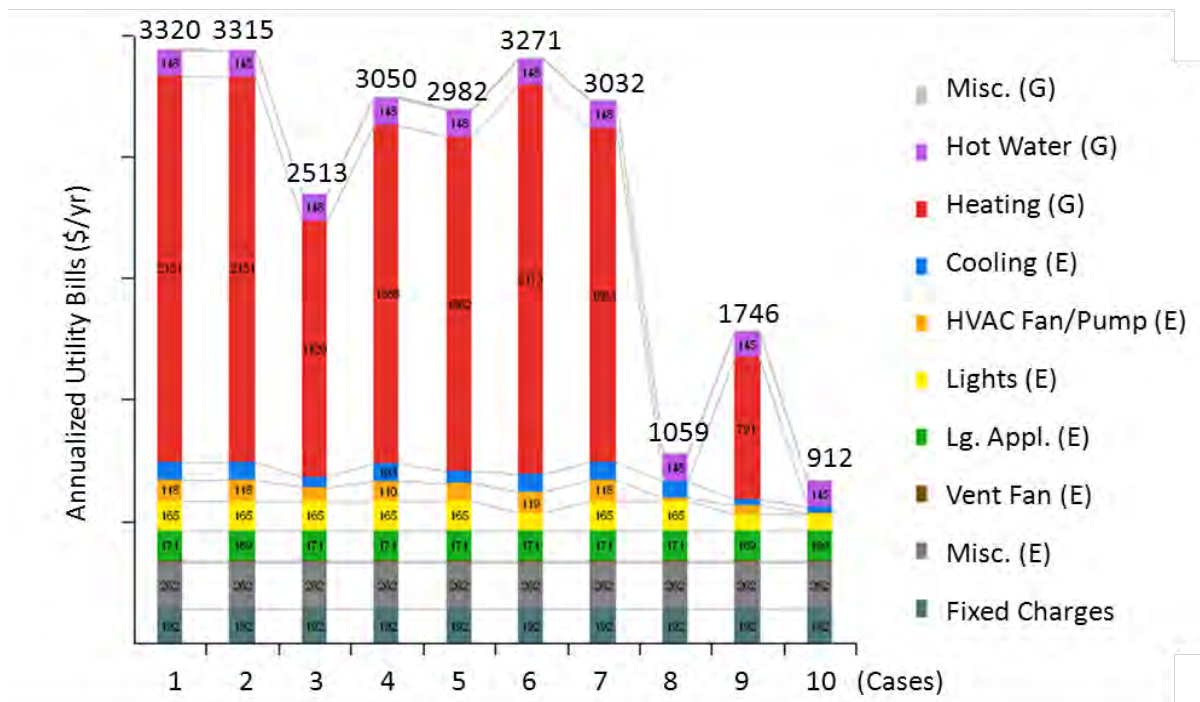
Figure 5.40: Annual Utility Bill Graph
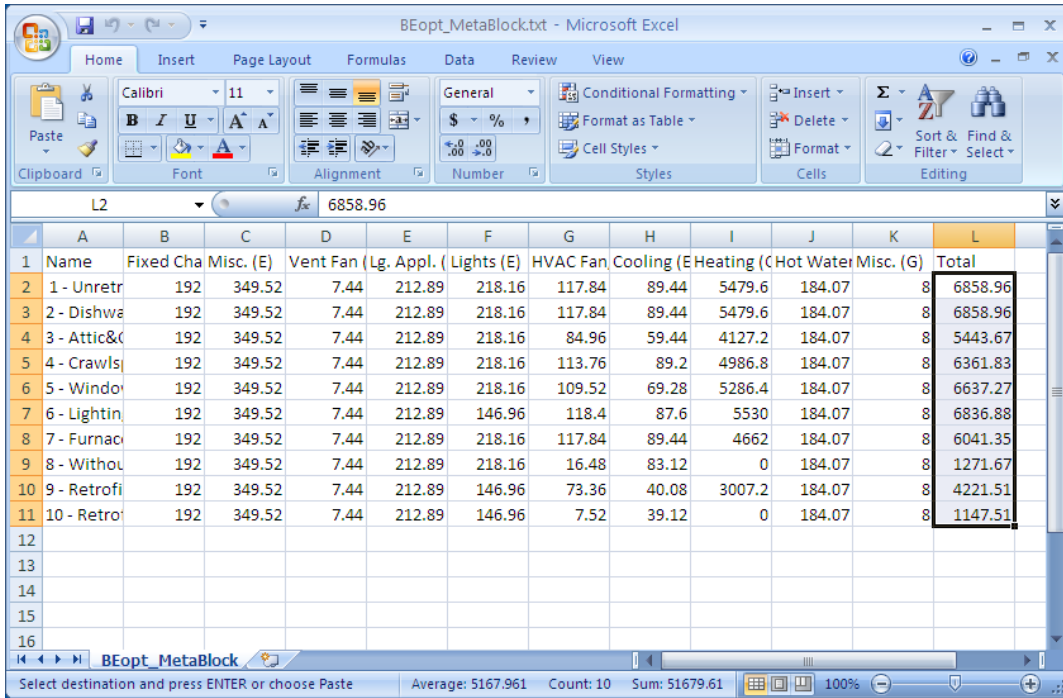
Figure 5.41: Exported Annual Utility Bill Information (Total Column)
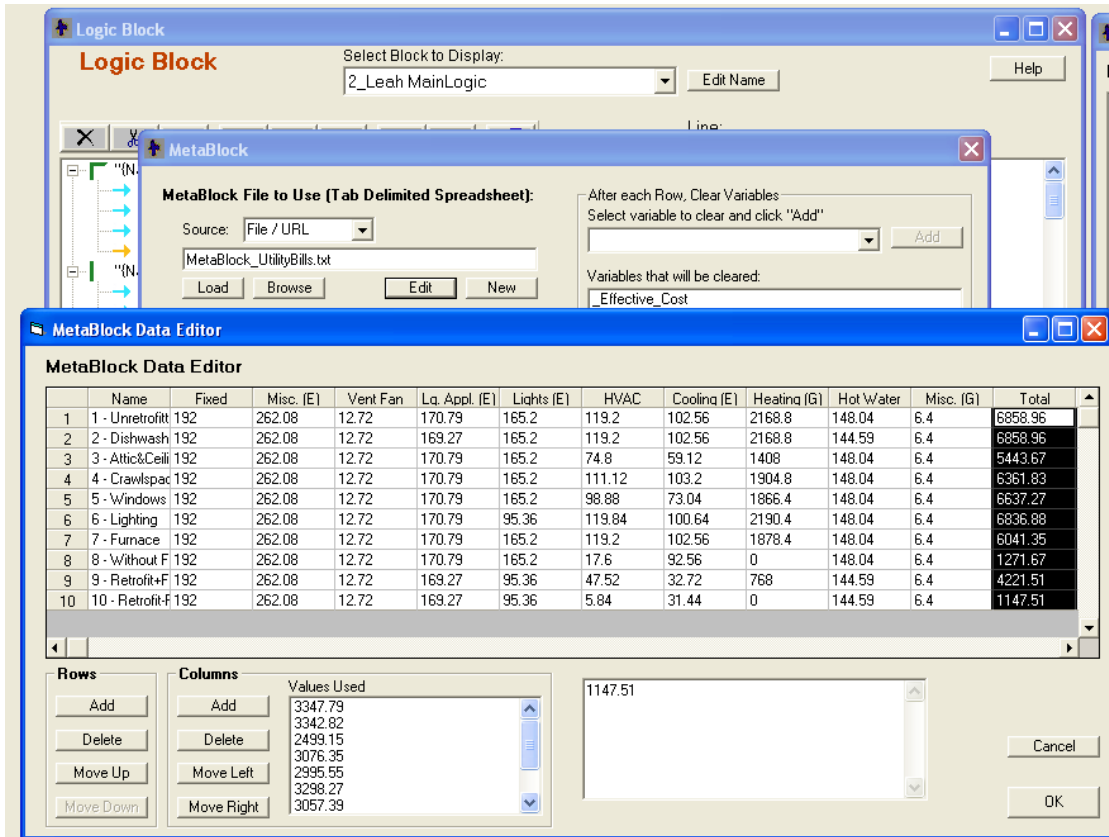
Figure 5.42: Applying the Changed BEopt Information (Total Column)

5.7 BEOPT CALLING EXAMPLE (SEPARATE MODEL)

In this research, the integration model is "run as applet" in order to use the NREM database.

Exsys Corvid, however, must be "run as application" in order to call the external program, BEopt.

Even though the BEopt calling process and the NREM database integration process cannot be

combined due to their incompatible running environment settings, another working example for

calling BEopt is being developed separately for future research. This example will be useable in

the upcoming version of BEopt. Figure 5.43 demonstrates the setting of Test Run type.
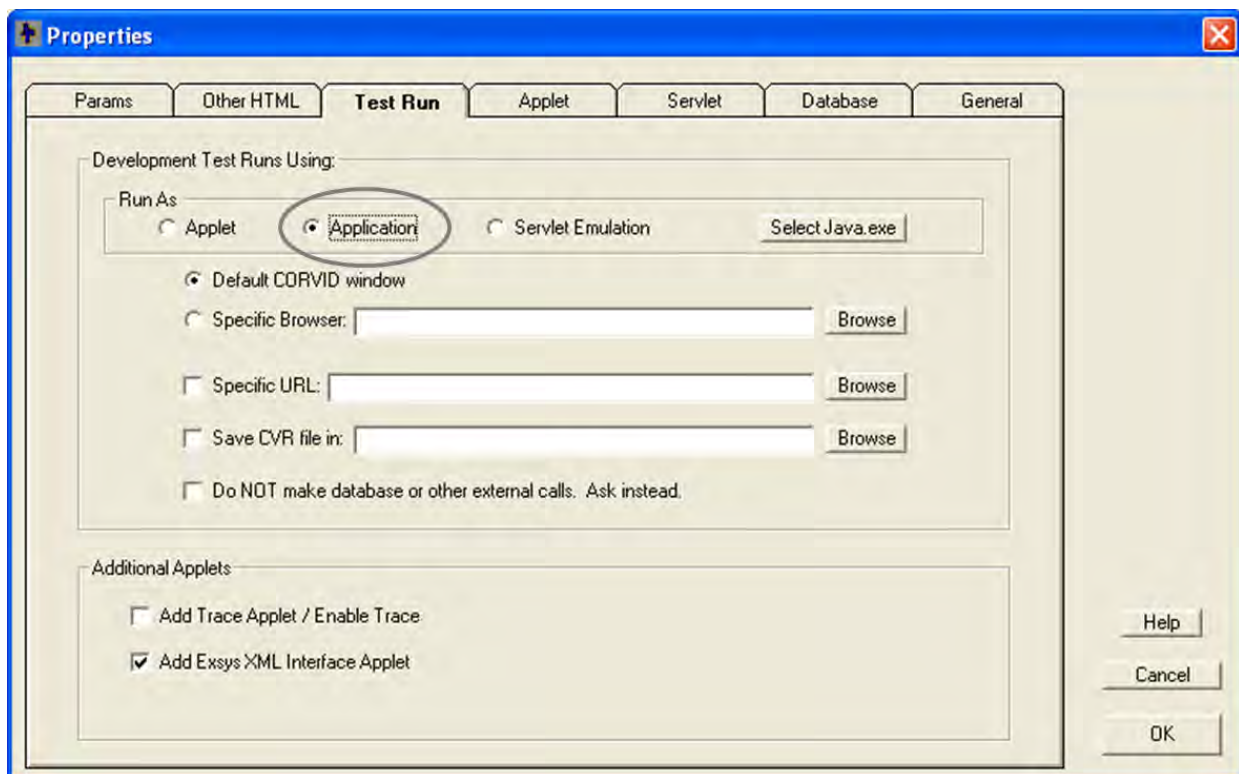
Figure 5.43: Setting Run as Application

As shown in Figure 5.44, this BEopt calling model uses WRITE, READ commands, which can

be used for the information exchange between Exsys Corvid and BEopt by means of input and

output files. The most important command is EXTERN, which enables Exsys Corvid to call the external application, BEopt.
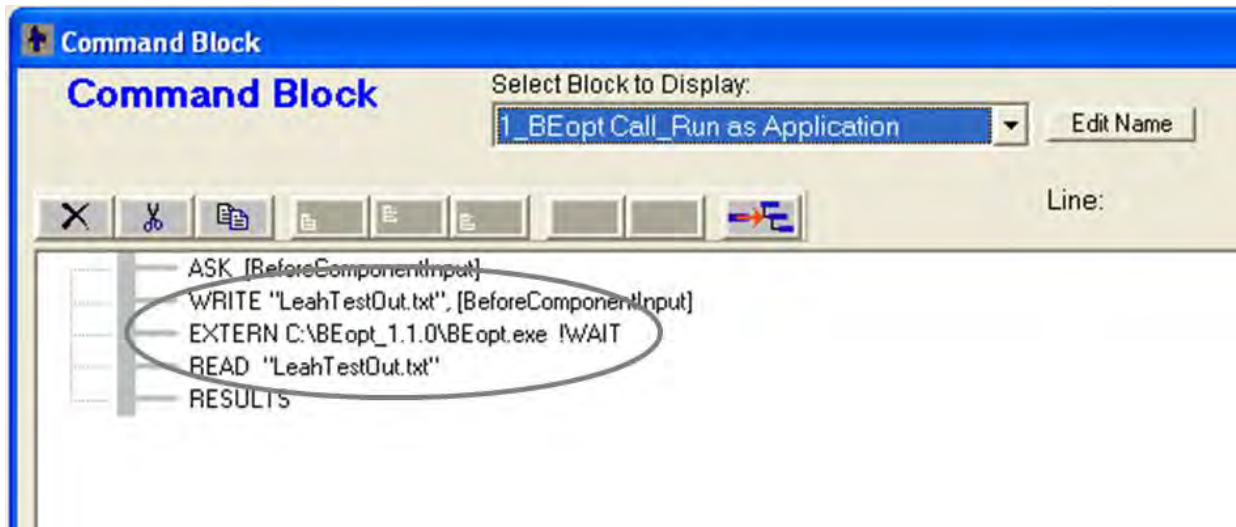
Figure 5.44: Command Block of BEopt Calling Model

The running process starts by asking a simple question related to the retrofit measure (see Figure 5.45). During the runtime, this BEopt calling model writes a text file about this question and the answer typed in by the user. The next step is to call BEopt from Exsys Corvid (see Figure 5.46). According to the procedure defined in the Command Block, BEopt is called automatically; after closing BEopt, Exsys reads the text file which was created at the beginning of this running process, and then shows the result on the screen (see Figure 5.47). It can be verified that the text file is being written as shown in Figure 5.47 by Exsys Corvid during the runtime, which was empty before running as shown in Figure 5.45. If it becomes feasible for Exsys Corvid to be run as both an applet and an application at the same time, or to use another method for dealing with an external XML database and application together, this BEopt calling process can be developed further. It is also necessary for BEopt to be able to set the input options by reading external files, or else an alternative function is required.
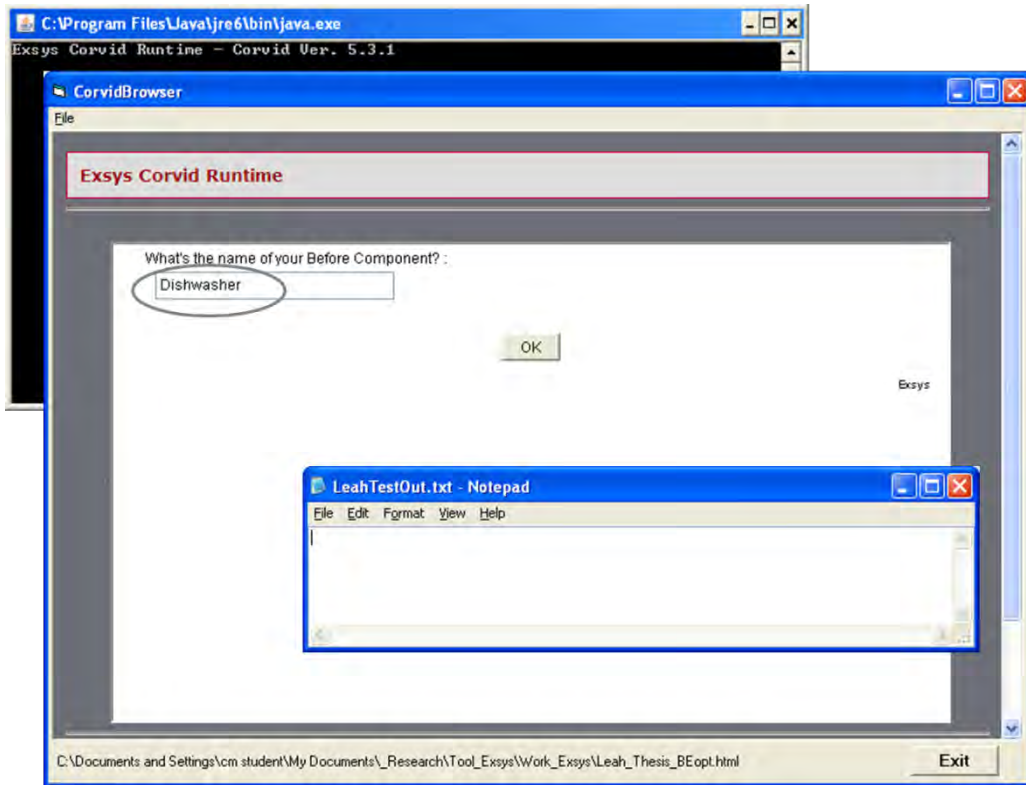
Figure 5.45: Command Block of BEopt Calling Model
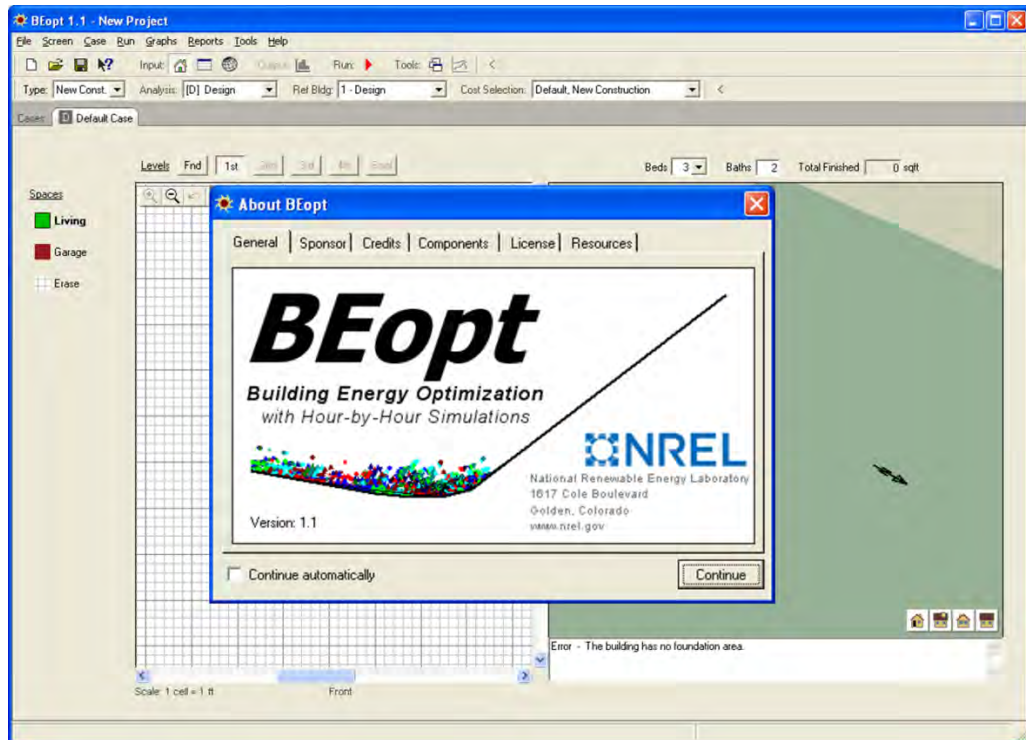
Figure 5.46: Opening BEopt Application within Exsys Corvid
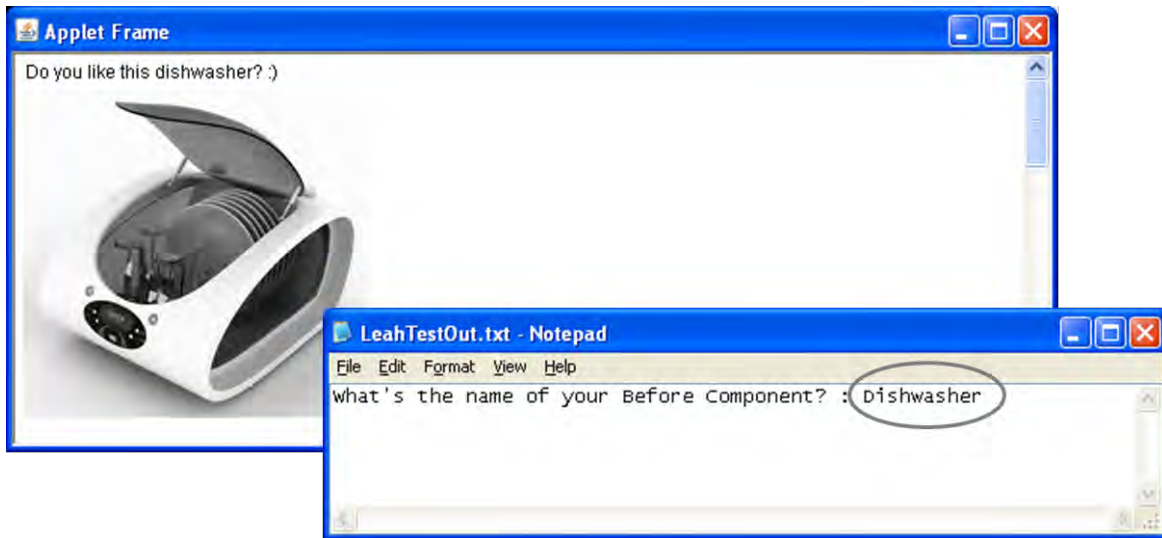
Figure 5.47: Result Screen and Output Text File

5.8 CHAPTER SUMMARY

This chapter explained the whole process for integrating the quantitative data sources into the expert system. Initially, the structure of the integration model is developed by matching the Exsys Corvid components and the external data sources. Then, the special features and functions are examined for the integration of each different data source – the NREM database, BEopt, and additional expert knowledge with text files, images and web links.

After identifying the integration technique for each source, the integration model developing process is explained. The process is based on the organization of the user interface and the Exsys Corvid developing components, which are Variables, Logic Blocks, and Command Blocks. The running process is then described, using an example of a dishwasher and lighting measures.

An additional integration model and BEopt calling model are provided for further consideration, and are suggested for future research. The entire running process is illustrated in Figure 5.48.

173
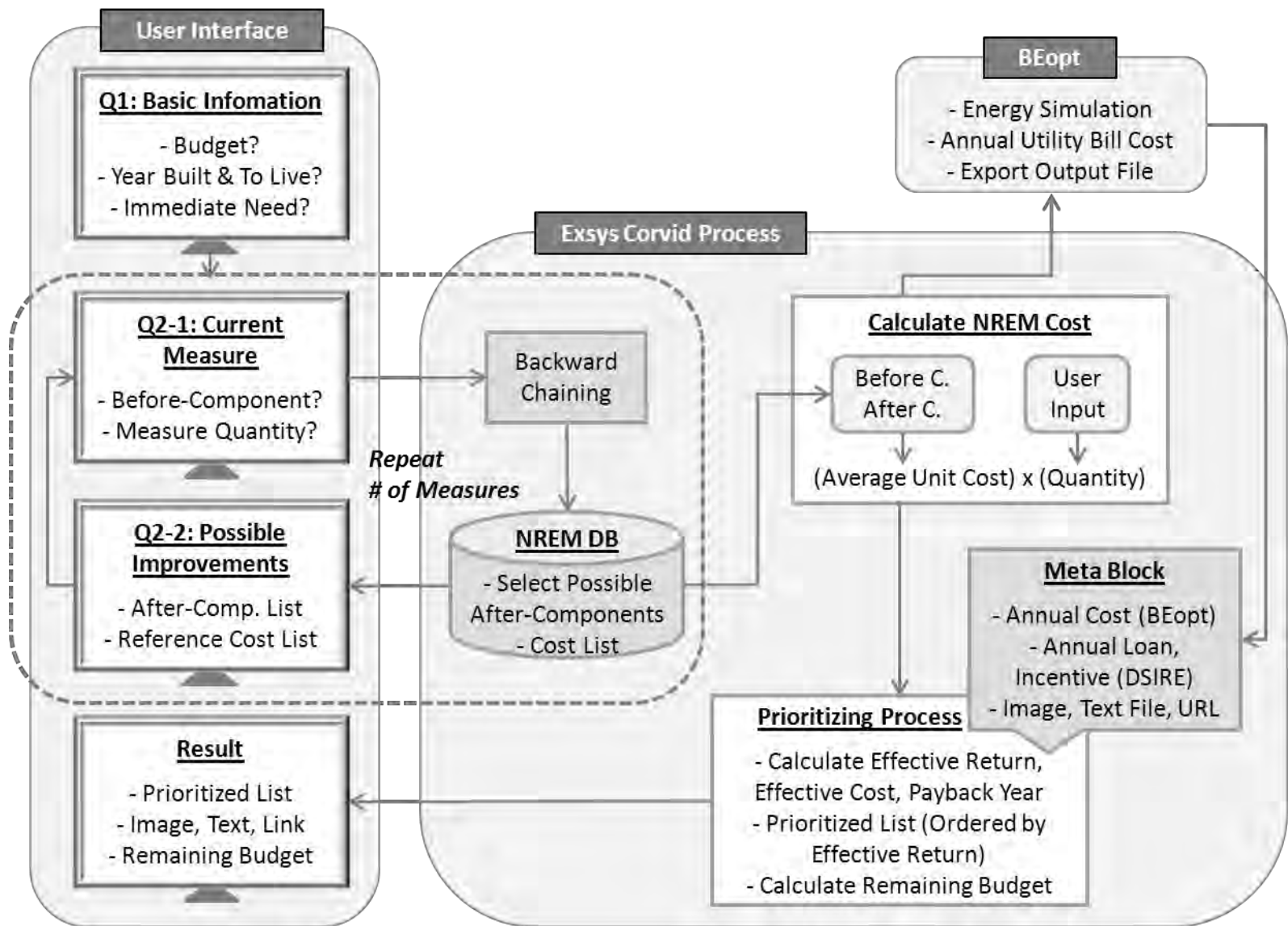
Figure 5.48: Summary of Running Process

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 OVERVIEW

This chapter provides a summary of this research and presents areas for future research. First, a summary of the research will be presented. A review of the objectives and achievements of this research will follow. Finally, areas for potential future research will be explored.

The main goal of this research was to implement an integrated query-based intelligent decision support system, in which quantitative external data sources were integrated into the decision support system. To achieve this goal, the Energy Retrofit Decision Process Framework described in a preceding study was analyzed, together with an examination of the quantitative data sources available and required technical skills for implementing the working example. Expert system shell software, a retrofit measure cost database, and energy simulation software were needed for developing the DSS; Exsys Corvid, the NREM database and BEopt were utilized for implementing the integration model working example.

Chapter 1 provided the needs, goals, objectives, methodologies, scope and limitations of this research. In Chapter 2, the background of energy retrofit decision-making, AI, DSS, ES and some examples were examined. Chapter 3 reviewed the Energy Retrofit Decision Process Framework and analyzed its working example to computerize the framework and the process. Chapter 4 scrutinized the quantitative data sources, the NREM database and BEopt, from an

integrational point-of-view. Finally, Chapter 5 illustrated the development procedure for the integration model working example.

6.2 SUMMARY OF THE OBJECTIVES

The overall goal of this research is to implement an integrated query-based intelligent decision support system for existing residential homes. It is being developed to help homeowners, contractors and other stakeholders acquire appropriate information on energy efficient measures and retrofitting costs. At the beginning of this thesis, research objectives were demonstrated to support this overall goal, and this section evaluates the work performed to achieve the research objectives.

OBJECTIVE 1: To understand the energy retrofit decision process framework

The Energy Retrofit Decision Process Framework was the foundation of the integrated query-based intelligent decision support system developed in this research. Therefore, Chapter 3 analyzed the framework and its working example before developing the integration model. The decision process of the framework, cost sources and formula for the prioritization of retrofit measures were thoroughly explained, and were applied to the computerized integration model working example. The decision process of the framework and the cost formula of its working example are summarized as follows:

- **Decision Process of the Framework**

    1) Identify retrofit measures to be improved.

    2) Shortlist and prioritize measures based on user needs and retrofit effectiveness, which is derived from an energy efficiency simulation and quantitative cost data sources.

3) Provide expert advice on installation with the results of the running process, in the form of images, text files and web links.

- **Cost Formula for Prioritization**

  Effective Cost = NREM Cost – Incentive Amount

  Effective Return = BEopt Annual Energy Savings – Annual Loan Payment

  Remaining Budget = Initial user's budget

             – Effective Cost (of Highest Effective Return)

             – Effective Cost (of Next Highest Effective Return)

             – Effective Cost (of Next Highest Effective Return)

             … (Iterate this process until the user's budget becomes zero)

The original framework (see Figure 3.1) contained the overall working process, and both qualitative and quantitative information sources. This framework was simplified for the computerized integration model to focus on quantitative data, as shown in Figure 3.3. The original framework was also analyzed based on the Corvid structure shown in Figure 5.4, which demonstrated that, in substance, the framework was well-structured for the integration model.

OBJECTIVE 2: To understand the background of energy retrofit decision-making and the use of expert knowledge by means of AI/ES/DSS.

Chapter 2 discussed a literature-based study of the background of energy retrofit decision-making, and an introduction of AI/ES/DSS. The use of expert knowledge by means of AI/ES/DSS was reviewed.

The literature review began with an explanation of the need for energy savings in existing buildings and the barriers to residential energy retrofits. There were some retrofit methods suggested, with a discussion of governmental policies and energy retrofit programs that support the energy retrofitting.

Subsequently, Artificial Intelligence (AI), Expert Systems (ES), and Decision Support Systems (DSS) were introduced as tools that utilize expert knowledge. Following the definition of AI, ES and DSS, the similarities and differences between ES and DSS were explored. The components of ES and DSS were then demonstrated. The uses of database and simulation software in ES were also studied to acquire information on integrated expert systems.

In addition, the application of ES and DSS in the construction management field and in energy retrofits was examined. The uses of ES in construction management, such as estimating, scheduling, site planning, and so forth, were introduced, and the uses of DSS in energy retrofits were explored. Then, the components and structures of some existing DSSs and ESs were demonstrated, as references for the integration model in this research. The National Renewable Energy Laboratory's (NREL) methodology for accessing and improving the accuracy of the energy analysis for residential buildings was also explained.

OBJECTIVE 3: To identify and explain various aspects of quantitative information
Measure cost information, energy simulation software and published expert knowledge were integrated into the query-based intelligent decision support system, and each quantitative data source was explored before implementing the integration model in Chapter 4.

3a. The first data source for objective 3 is the NREM database, for the acquisition of the cost-related information on energy retrofits.

The National Residential Efficiency Measures (NREM) database was the main source of cost information for the integration model. First, the structure and basic objects of the database were analyzed:

- **Database Structure**: Group > Category > Component Type > Component

- **Database Objects**: Measures, Components, Properties, Actions, Costs, and References.

Data configuration, measure construction, overview of actions and cost sources were then explained. Since the NREM database was developed using XML, the basic concept of XML, XSD and XPath were also explored, to assist in the analysis of the various aspects of the NREM XML database. In addition, software applications used for implementing the integration model were introduced.

3b. The second data source is BEopt energy simulation software for prioritizing the retrofit measures initially selected, based on homeowners' need.

Building Energy Optimization (BEopt) was utilized to simulate the energy efficiency of the upgraded retrofit measures; it provided the annualized utility cost information. At the beginning of the BEopt introduction, the concept of Zero Net Energy Homes was explained to convey the general idea of BEopt. Afterward, the BEopt running process, input option settings, energy simulation output information, and report creation methods were demonstrated. Since both the NREM database and BEopt were developed by the National Renewable Energy Laboratory (NREL), and share the same cost information sources to some degree, the cost information sources for BEopt were also demonstrated.

3c. The third source is published text, figures and pictures, to provide various explanations and installation advice for the selected measures.

The published reports, mainly produced by governmental programs and Building America projects, were explored. The report files, images and web links usually provide system users with expert knowledge and advice on the selected measures. They were illustrated on the result screen of the integration model.

OBJECTIVE 4: To integrate various aspects of quantitative information with expert knowledge.

Chapter 5 illustrated the whole process of system integration. First, the structure of the expert system shell software, Exsys Corvid, was analyzed. The Energy Retrofit Decision Process Framework was re-organized based on the structural components of Exsys Corvid. Then, each of the quantitative data sources was analyzed, and combined with the components and information flow of Exsys Corvid, from an integrational point-of-view.

The next step was to implement the integration model working example. The procedure was demonstrated with the following sequence:

- Organization of questions

- Composition of answer lists

- Arrangement of output results

- Setting variables

- Building logic blocks

- Building command blocks

The running process of the integration model working example was illustrated with two examples. The working example began with queries about basic information, such as the user's budget and immediate needs, and moved on to questions about the selected retrofit measures. On the result screen, the integration model provided the prioritized measures with their cost information, expert knowledge, and the remaining budget. Another Corvid working example related to calling BEopt was introduced for future research.

6.3 CONCLUDING OBSERVATIONS AND LIMITATIONS

In this research, the integration model was implemented by integrating the quantitative data sources into the decision support system. The components of this integration model were:

- **Decision support system shell**: Exsys Corvid software

- **Database**: NREM database

- **Energy simulation**: BEopt software

- **Expert knowledge**: Text files, images and web links

This integration model suggested the holistic function of a residential energy retrofit system for existing homes, by providing a prioritized list of retrofit measures with cost information, energy simulation and expert advice. The users, such as homeowners and energy auditors, can acquire all of the necessary retrofit information in this unified system without having to explore several separate systems.

The integration model plays the role of a prototype for the finalized intelligent decision support system. Although this model handled a limited number of retrofit measures, it implemented all of

the necessary functions for the finalized DSS, including integration of the database, energy simulation and expert knowledge.

Some limitations were recognized while developing the integration model. First, the information in the cost database and the energy simulation are not fully compatible. At the beginning of this research, several energy simulation software applications were examined, and BEopt was selected because the retrofit measure components were relatively similar to the ones in the NREM database. Although both the NREM database and BEopt were developed by the NREL, the structures and expressions of the retrofit measures and the measure components are quite different from each other. It was very challenging to match their different measure components under one retrofit measure, such as lighting, as explained in Chapter 5. It was suggested that, in order to be completely integrated, both a fully compatible retrofit measure cost database and energy simulation software using the same measure components be developed.

Second, the unified standard cost database does not contain enough measure information. The development of a national standard cost database is in the beginning step, and the sources of the cost information were fairly limited, and the number of each measure was skewed. In order to provide more reliable cost data sources, the NREM database should collect more comprehensive cost information. RS Means data can be a model, although the characteristics of the data are different. Moreover, the updated NREM database should be applied to the energy simulation software for the synthetic use of retrofit information.

Third, the integration model does not automatically reflect updates to the NREM database. This integration model is a stand-alone application that is not directly connected to the NREM XML database on the Web. Thus, when the NREL updates the NREM database, the newer version of the XML files need to be manually retrieved for the model. To improve this issue, a way to link the integration model to the up-to-date NREM database should be also considered.

Finally, the existing published information is scattered, making it difficult to select the best augmenting information. If the existing reports and visualized information were compiled in a specific database, based on the types of retrofit measures and the components of the NREM database, then users and researchers would be able to utilize them more easily.

6.4 PLANS FOR FUTURE RESEARCH

This integration model is a prototype of a fully functional intelligent decision support system that will be developed in the near future. This research was completed in the middle part of a larger research task, and connects the preceding and subsequent research. The plans for future research are as follows:

- **Overcoming the limitations of BEopt**: Though the current version of BEopt has a limitation in reading information from external files and setting them as input options, similar tasks will be available in the next version upgrade, which BEopt plans to release in the summer of 2012.
- **Overcoming the limitations of Exsys Corvid**: External XML databases and applications cannot currently be utilized at the same time. This limitation will be improved when

Exsys releases the next version of its Corvid software, and BEopt will be able to be

integrated into the DSS automatically, rather than manually.

- **Eliciting the actual expert knowledge**: Following the application of the results of other

  tasks, the system will begin to elicit actual knowledge from experts. This knowledge will

  form the knowledge base of the finalized DSS.

- **Developing the finalized decision support system**: A fully functional intelligent DSS

  will be developed based on this prototype, the results of other tasks, and the knowledge

  base. Both quantitative and qualitative data will be integrated into the finalized DSS. It

  will be released on the web, after training, education, and demonstrations of the system

  are completed.

6.5 CHAPTER SUMMARY

This chapter summarized the overall process and achievements of this research for implementing

the integration model. The main goal and objectives were reviewed, and their achievements were

summarized. Then, the conclusion and role of the integration model were examined, and the

limitations and suggestions for system integration were demonstrated. Finally, the list of relevant

future research was outlined.

APPENDICES 1

Integration Model Working Example Full Process
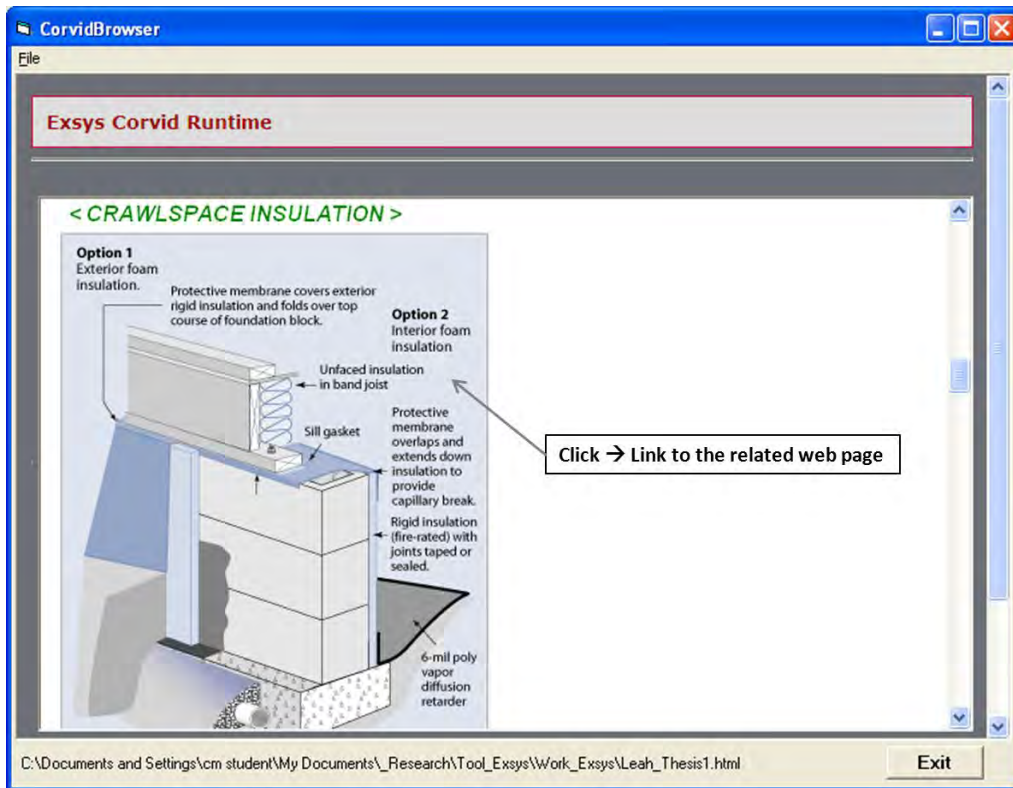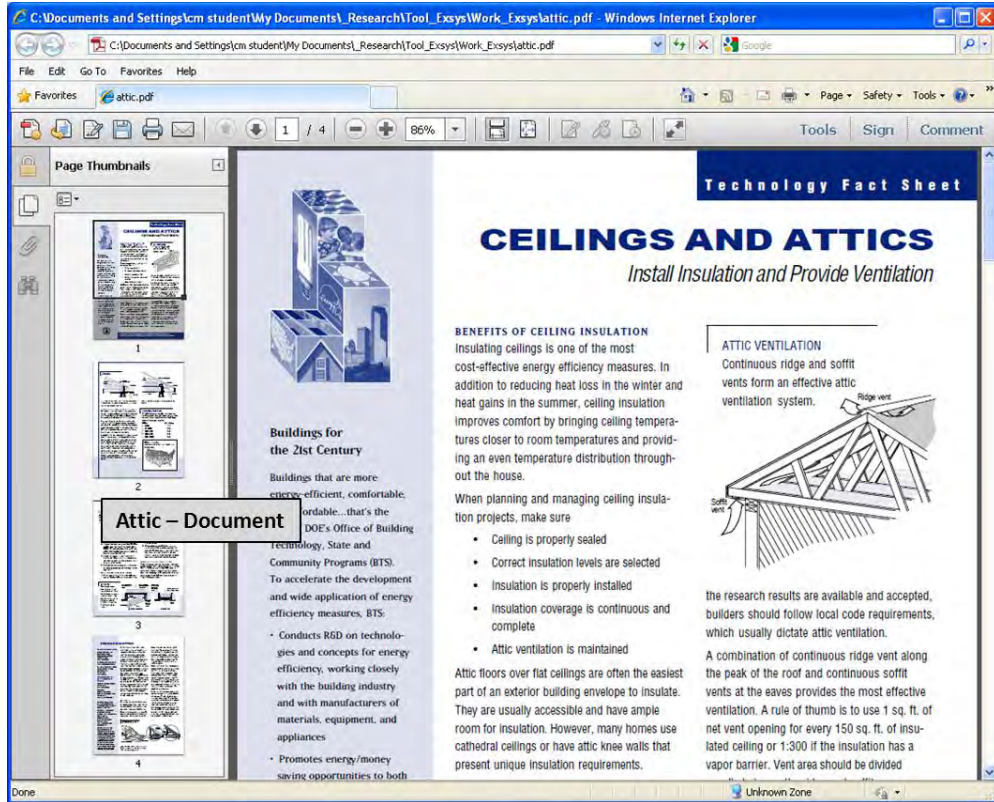
Figure Appendix 1.1: Main Example – Queries

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).
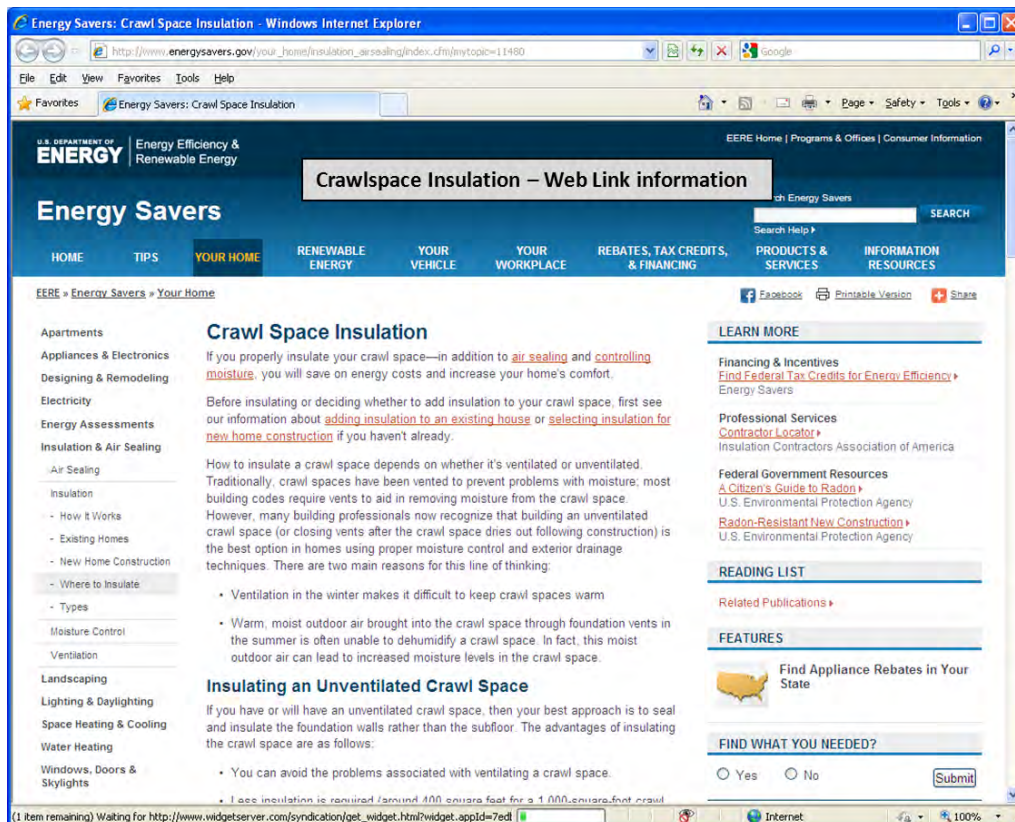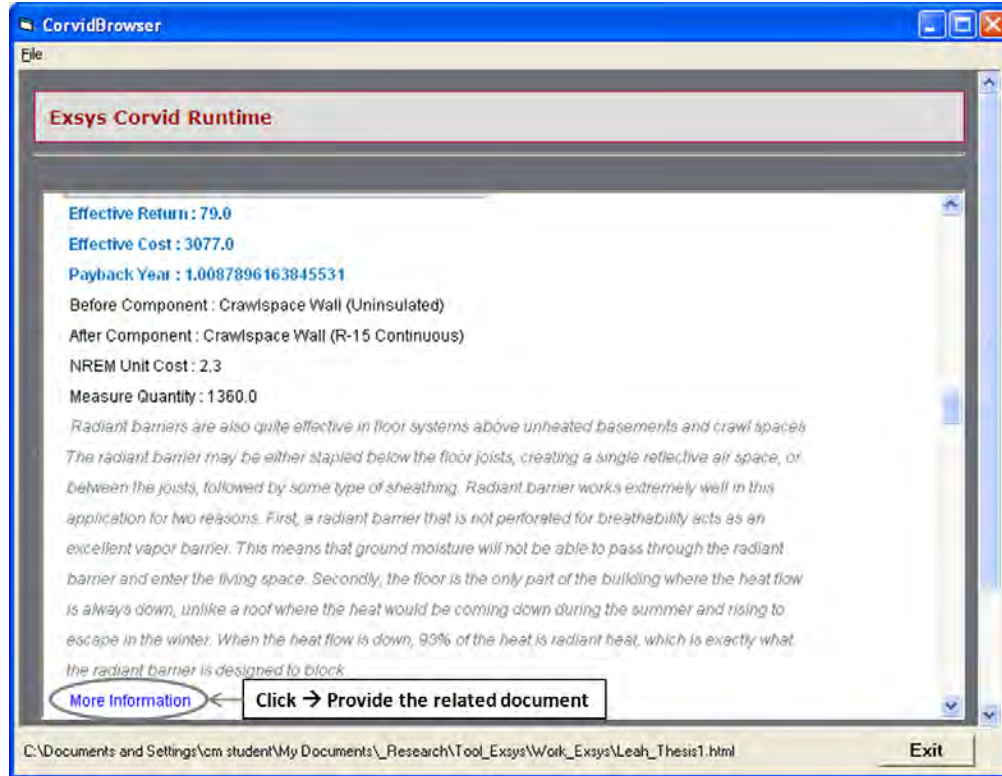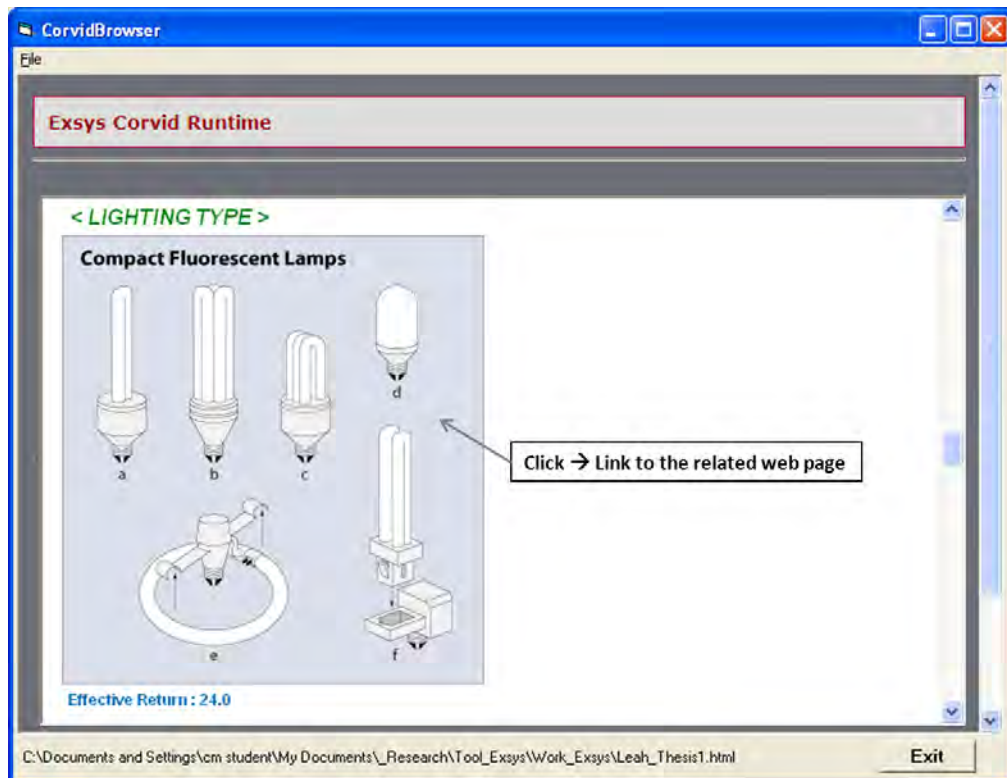
Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.1 (cont'd).

Figure Appendix 1.2: Main Example – Results

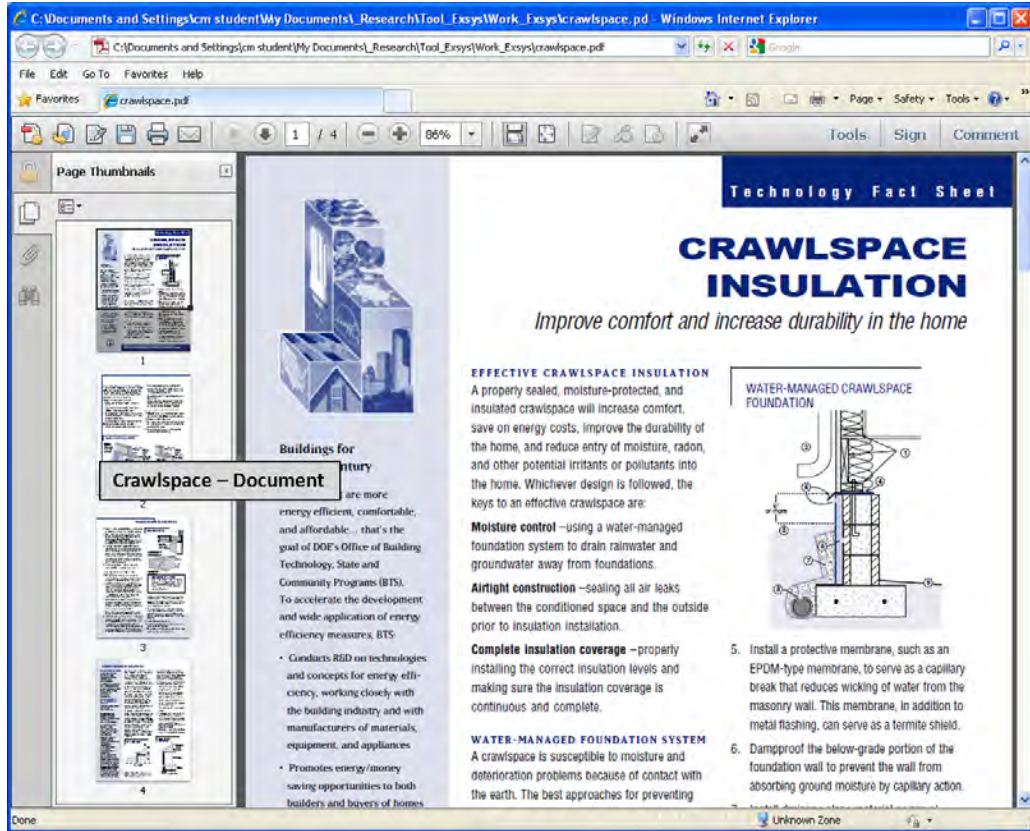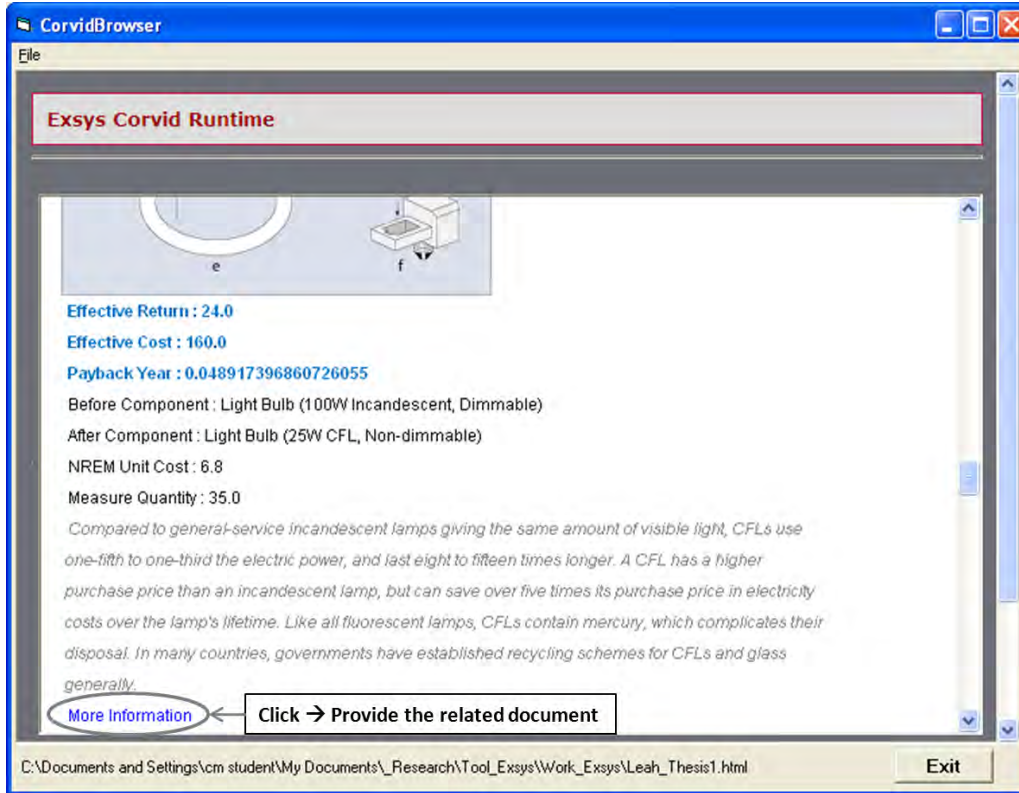**Figure Appendix 1.2 (cont'd).**

Figure Appendix 1.2 (cont'd).

Dishwasher – Document

Click → Link to the related web page

Figure Appendix 1.2 (cont'd).

Figure Appendix 1.2 (cont'd).
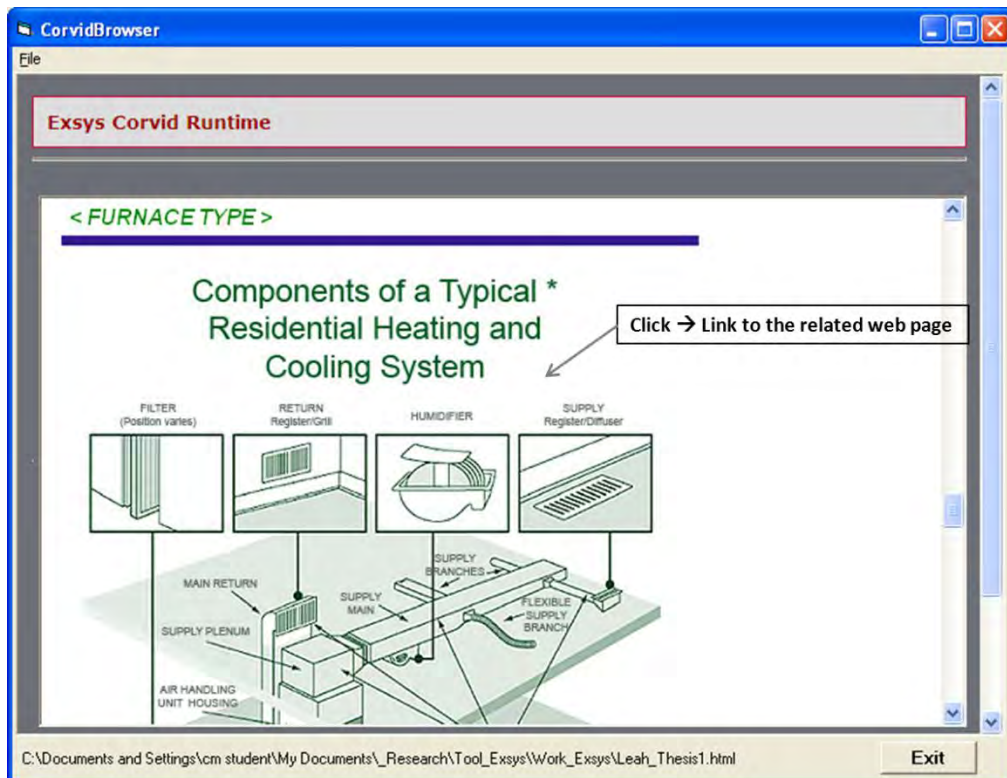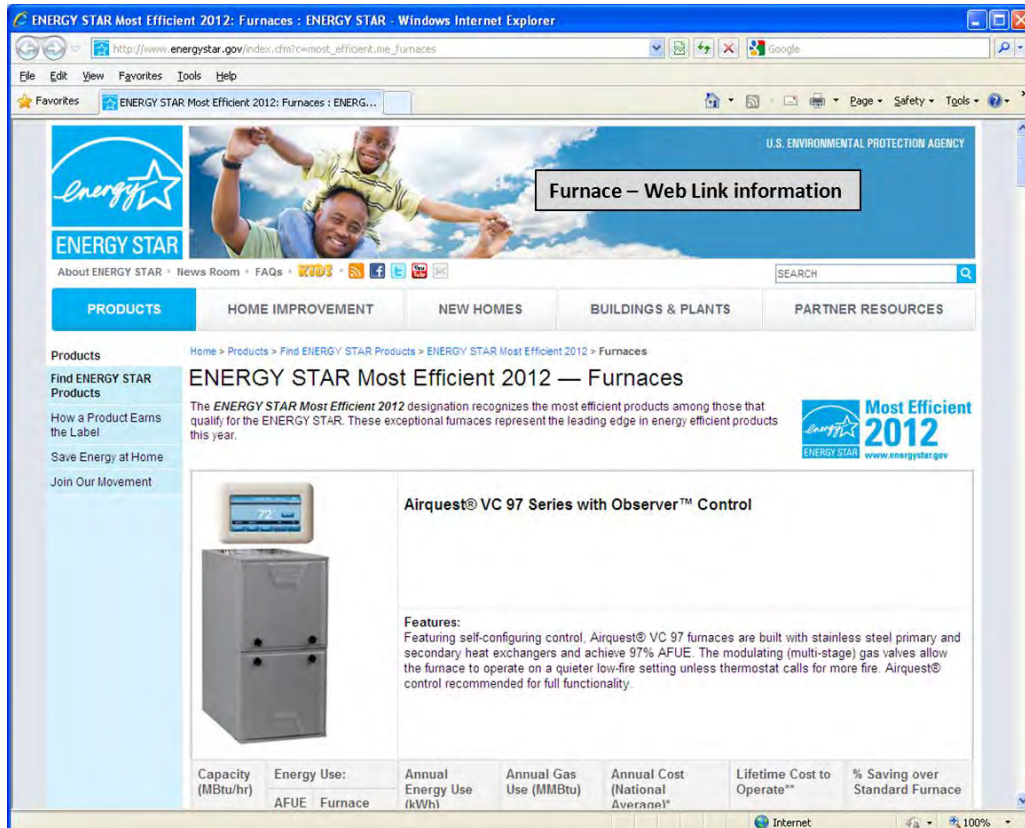
Figure Appendix 1.2 (cont'd).

Figure Appendix 1.2 (cont'd).

Figure Appendix 1.2 (cont'd).

Figure Appendix 1.2 (cont'd).

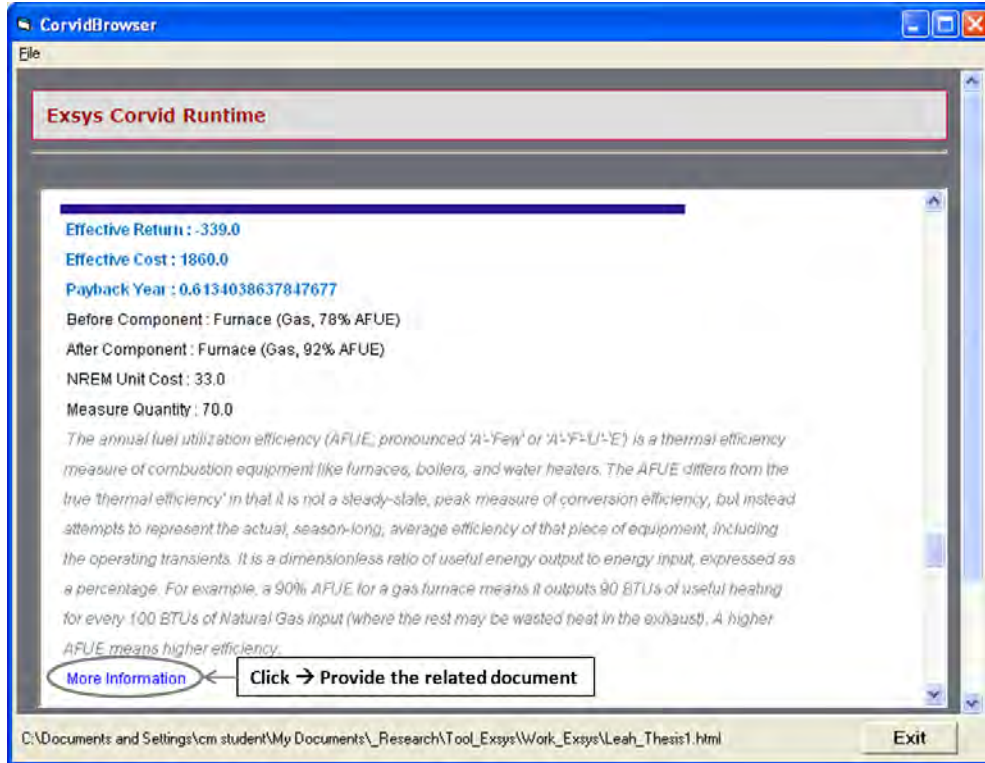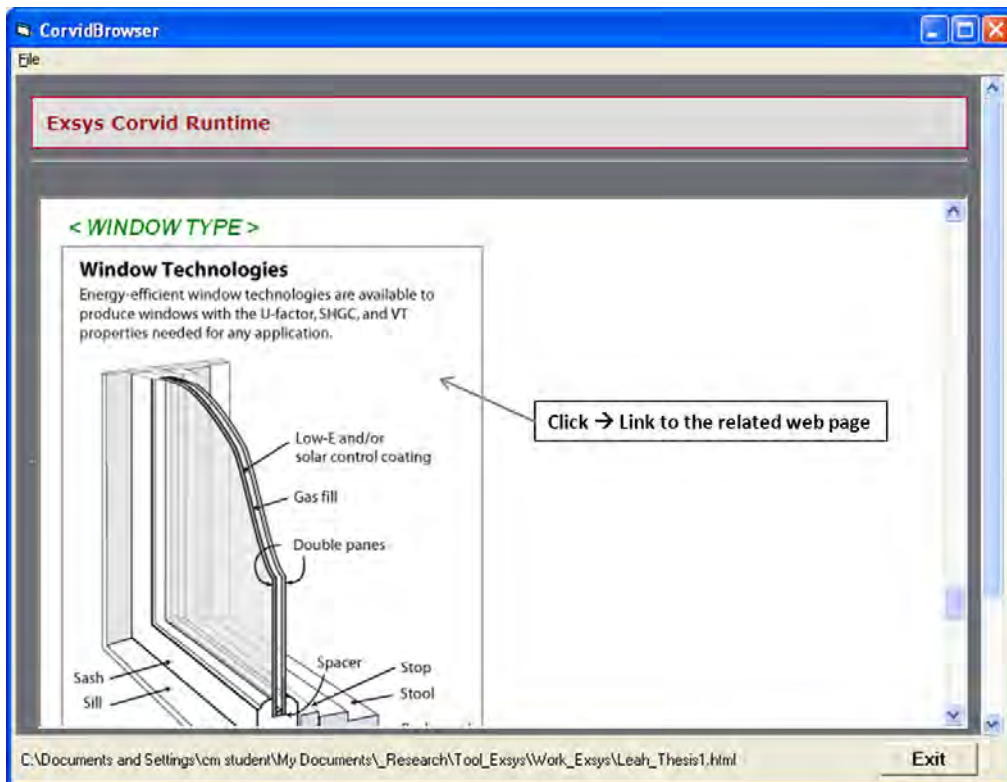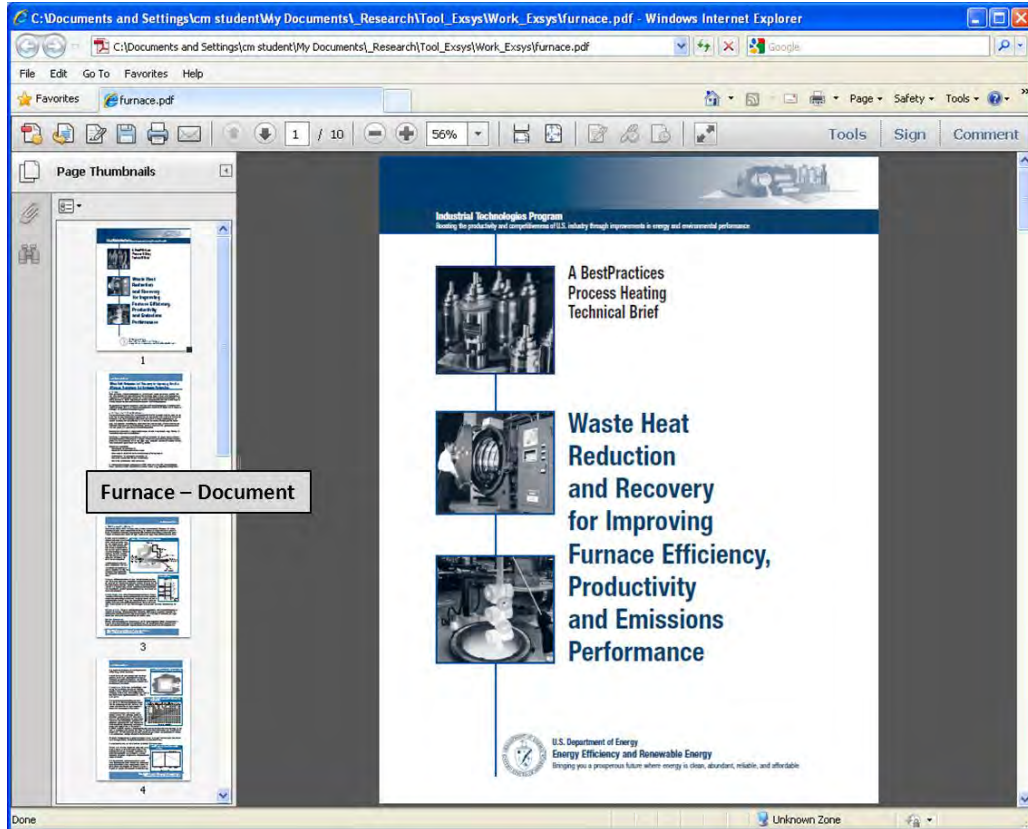**Figure Appendix 1.2 (cont'd).**

Figure Appendix 1.2 (cont'd).
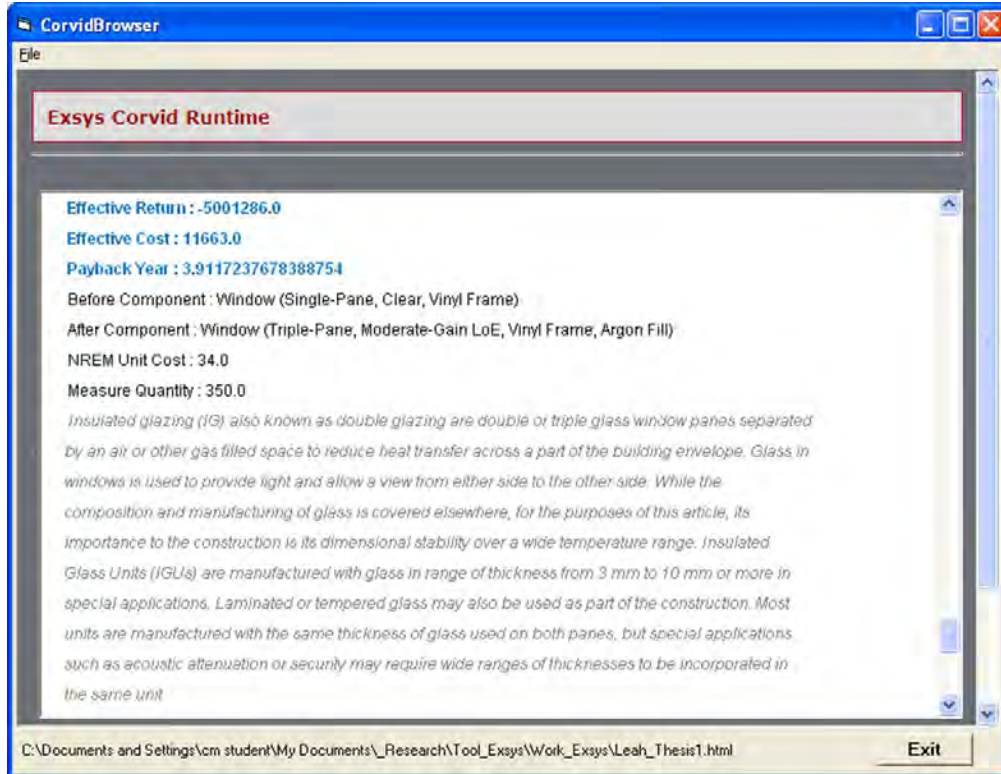
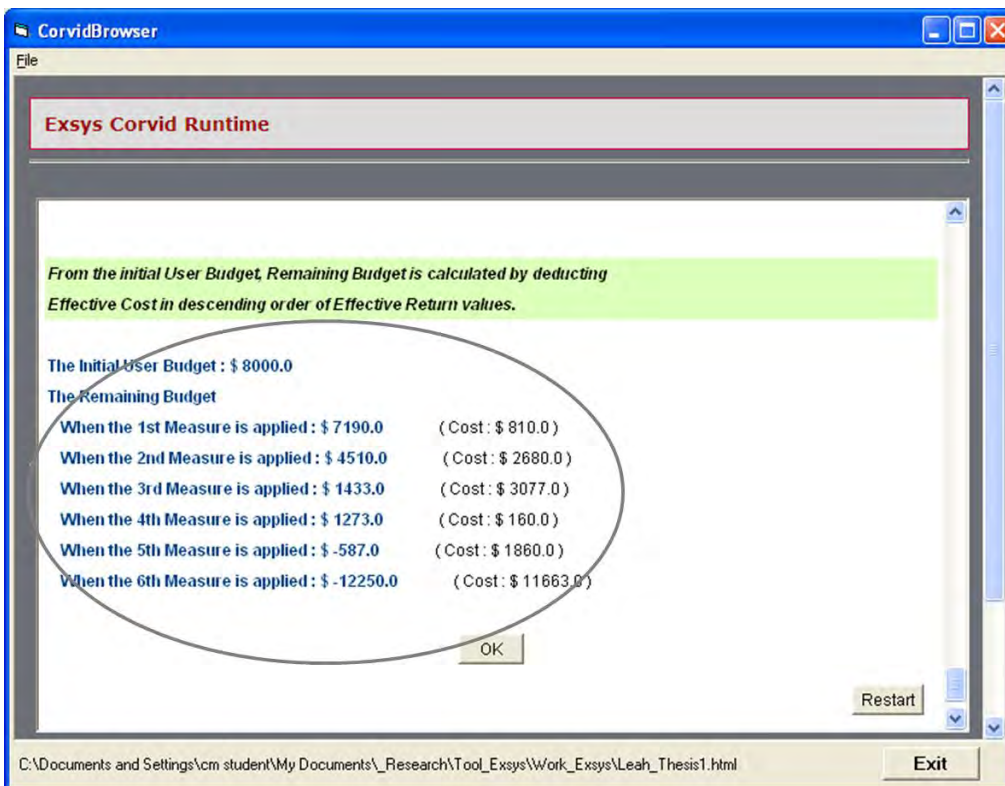**Figure Appendix 1.2 (cont'd).**
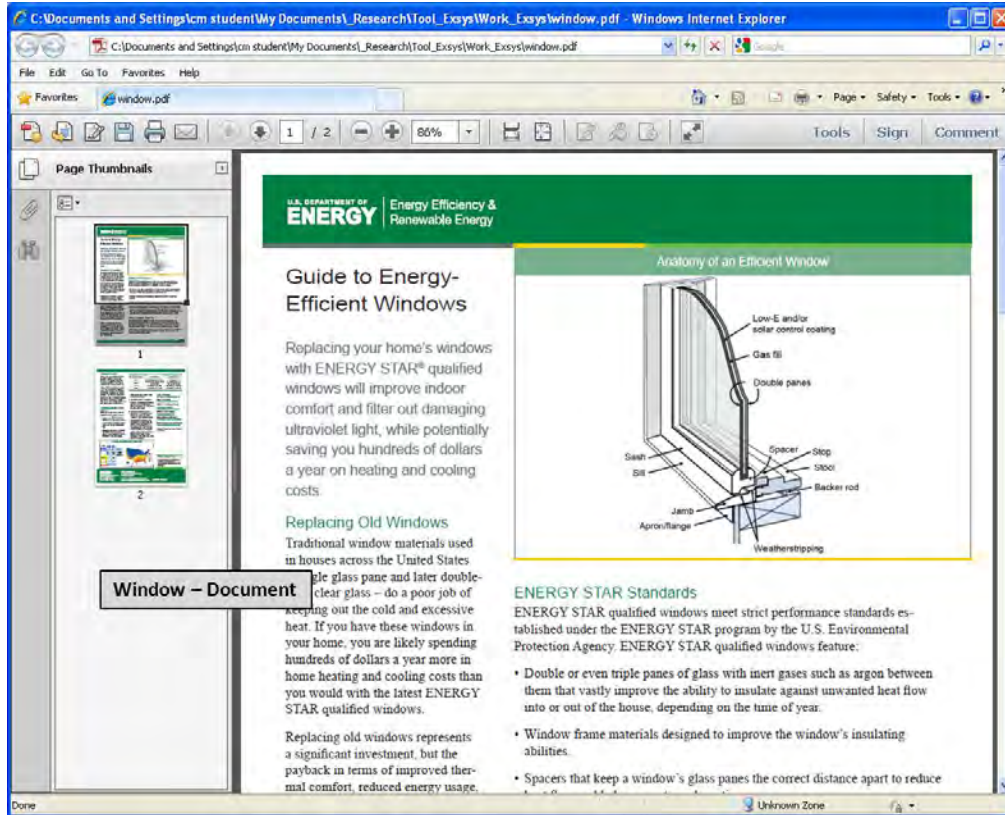
Figure Appendix 1.2 (cont'd).

Figure Appendix 1.3: Main Example – Developed Logic (Backward Chaining)
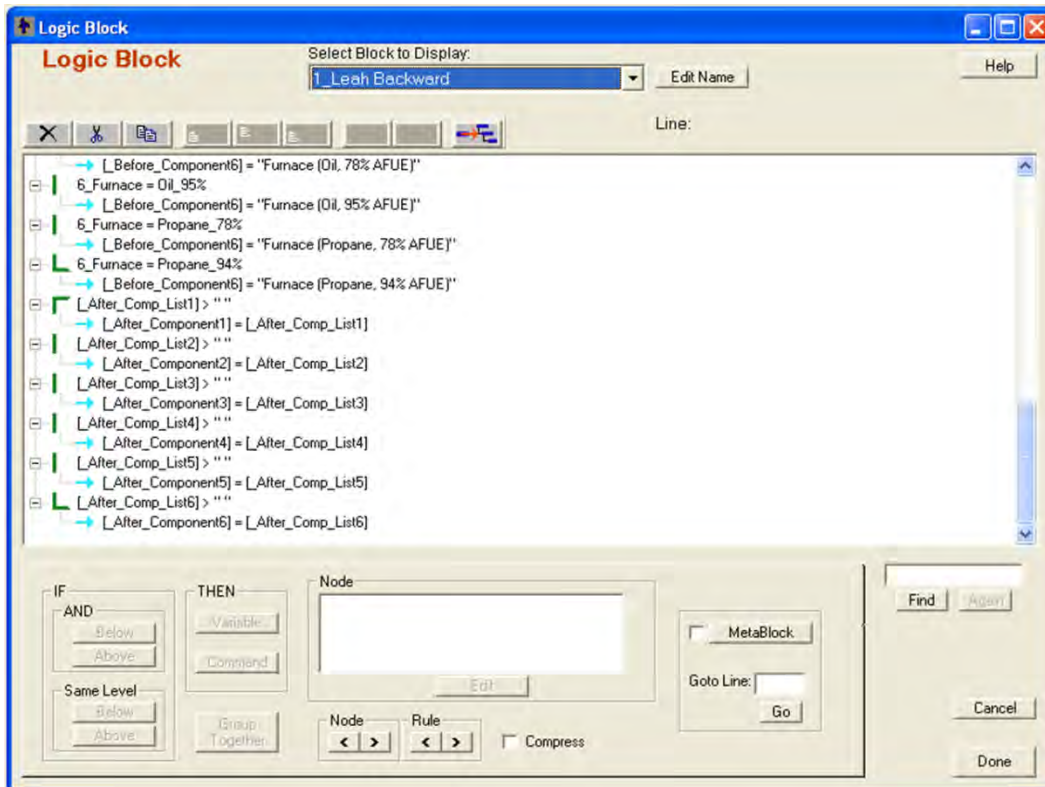
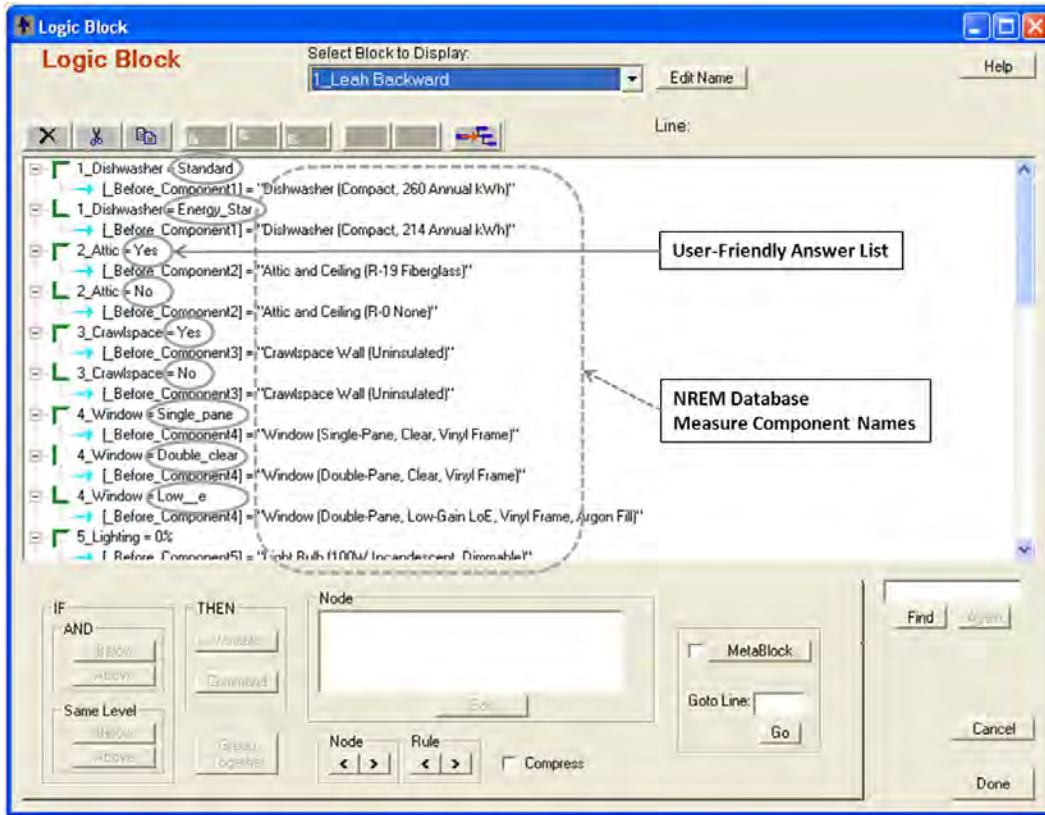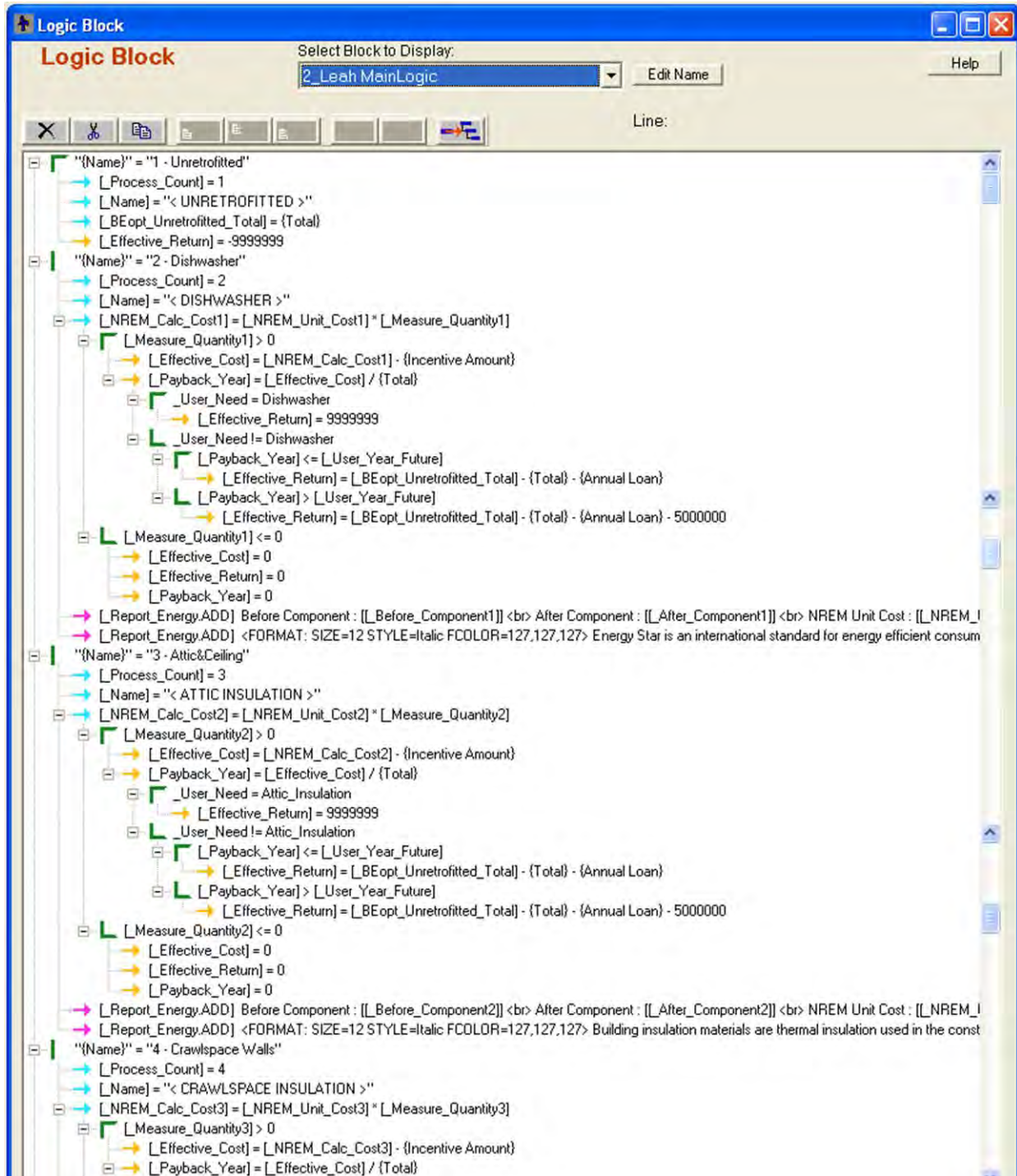**Figure Appendix 1.4: Main Example – Developed Logic (Logic Block)**

Figure Appendix 1.4 (cont'd).

```
         _User_Need = Crawlspace_Insulation
            → [_Effective_Return] = 9999999
         _User_Need != Crawlspace_Insulation
            [_Payback_Year] <= [_User_Year_Future]
               → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan}
            [_Payback_Year] > [_User_Year_Future]
               → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan} - 5000000
      [_Measure_Quantity3] <= 0
         → [_Effective_Cost] = 0
         → [_Effective_Return] = 0
         → [_Payback_Year] = 0
   → [_Report_Energy.ADD] Before Component : [[_Before_Component3]] <br> After Component : [[_After_Component3]] <br> NREM Unit Cost : [[_NREM_I
   → [_Report_Energy.ADD] <FORMAT: SIZE=12 STYLE=Italic FCOLOR=127,127,127> Radiant barriers are also quite effective in floor systems above unh
"{Name}" = "5 - Windows"
   → [_Process_Count] = 5
   → [_Name] = "< WINDOW TYPE >"
   → [_NREM_Calc_Cost4] = [_NREM_Unit_Cost4] * [_Measure_Quantity4]
      [_Measure_Quantity4] > 0
         → [_Effective_Cost] = [_NREM_Calc_Cost4] - {Incentive Amount}
         → [_Payback_Year] = [_Effective_Cost] / {Total}
            _User_Need = Windows
               → [_Effective_Return] = 9999999
            _User_Need != Windows
               [_Payback_Year] <= [_User_Year_Future]
                  → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan}
               [_Payback_Year] > [_User_Year_Future]
                  → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan} - 5000000
      [_Measure_Quantity4] <= 0
         → [_Effective_Cost] = 0
         → [_Effective_Return] = 0
         → [_Payback_Year] = 0
   → [_Report_Energy.ADD] Before Component : [[_Before_Component4]] <br> After Component : [[_After_Component4]] <br> NREM Unit Cost : [[_NREM_I
   → [_Report_Energy.ADD] <FORMAT: SIZE=12 STYLE=Italic FCOLOR=127,127,127> Insulated glazing (IG) also known as double glazing are double or t
"{Name}" = "6 - Lighting"
   → [_Process_Count] = 6
   → [_Name] = "< LIGHTING TYPE >"
      5_Lighting = 0%
         → [_Light_Percentage] = 1
      5_Lighting = 20%
         → [_Light_Percentage] = 0.8
      5_Lighting = 40%
         → [_Light_Percentage] = 0.6
      5_Lighting = 60%
         → [_Light_Percentage] = 0.4
      5_Lighting = 80%
         → [_Light_Percentage] = 0.2
      5_Lighting = 100%
         → [_Light_Percentage] = 0
   → [_NREM_Calc_Cost5] = [_NREM_Unit_Cost5] * [_Measure_Quantity5] * [_Light_Percentage]
      [_Measure_Quantity5] > 0
         [_NREM_Calc_Cost5] > 0
            → [_Effective_Cost] = [_NREM_Calc_Cost5] - {Incentive Amount}
            → [_Payback_Year] = [_Effective_Cost] / {Total}
               _User_Need = Lighting
                  → [_Effective_Return] = 9999999
               _User_Need != Lighting
                  [_Payback_Year] <= [_User_Year_Future]
                     → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan}
                  [_Payback_Year] > [_User_Year_Future]
                     → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan} - 5000000
         [_NREM_Calc_Cost5] <= 0
            → [_Effective_Cost] = 0
            → [_Effective_Return] = 0
            → [_Payback_Year] = 0
      [_Measure_Quantity5] <= 0
         → [_Effective_Cost] = 0
         → [_Effective_Return] = 0
         → [_Payback_Year] = 0
```
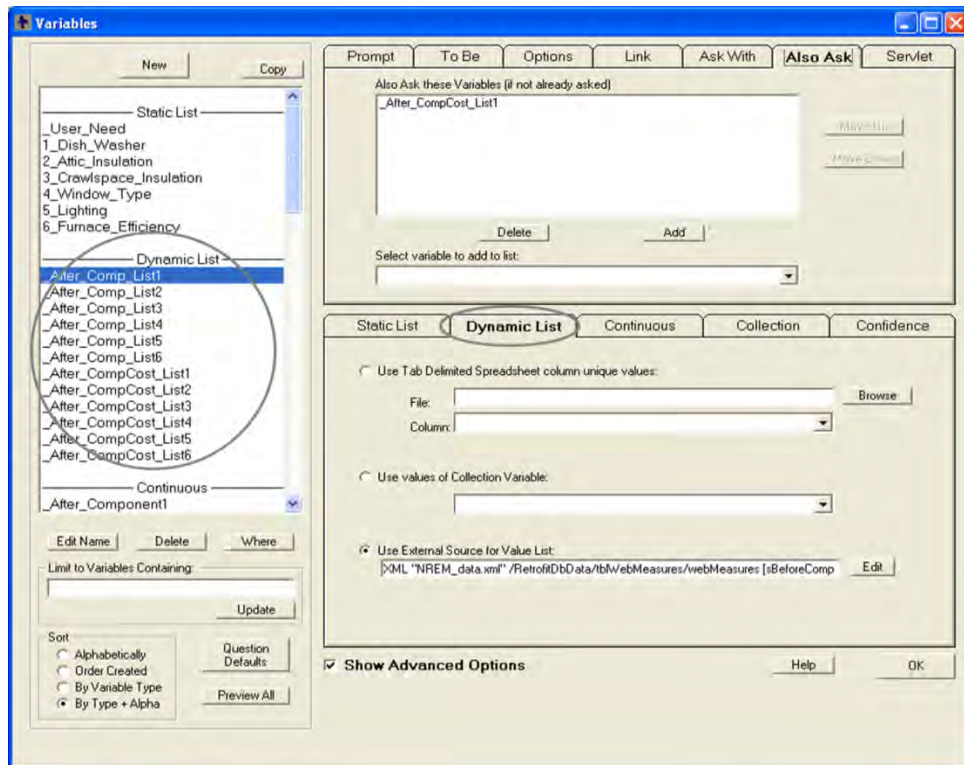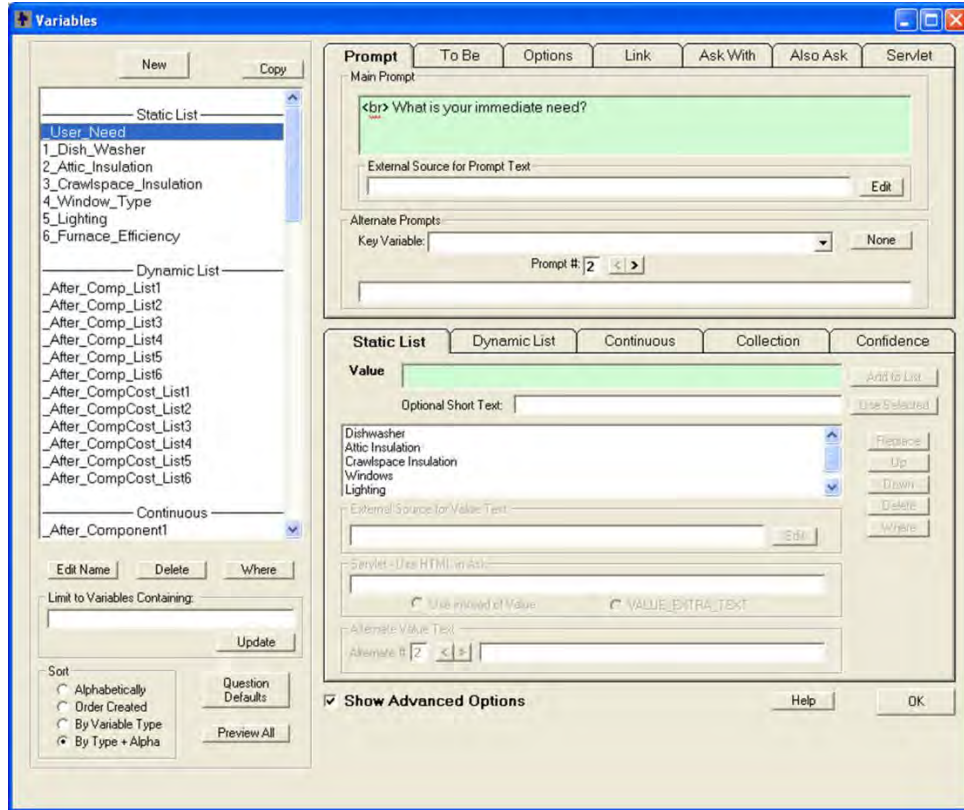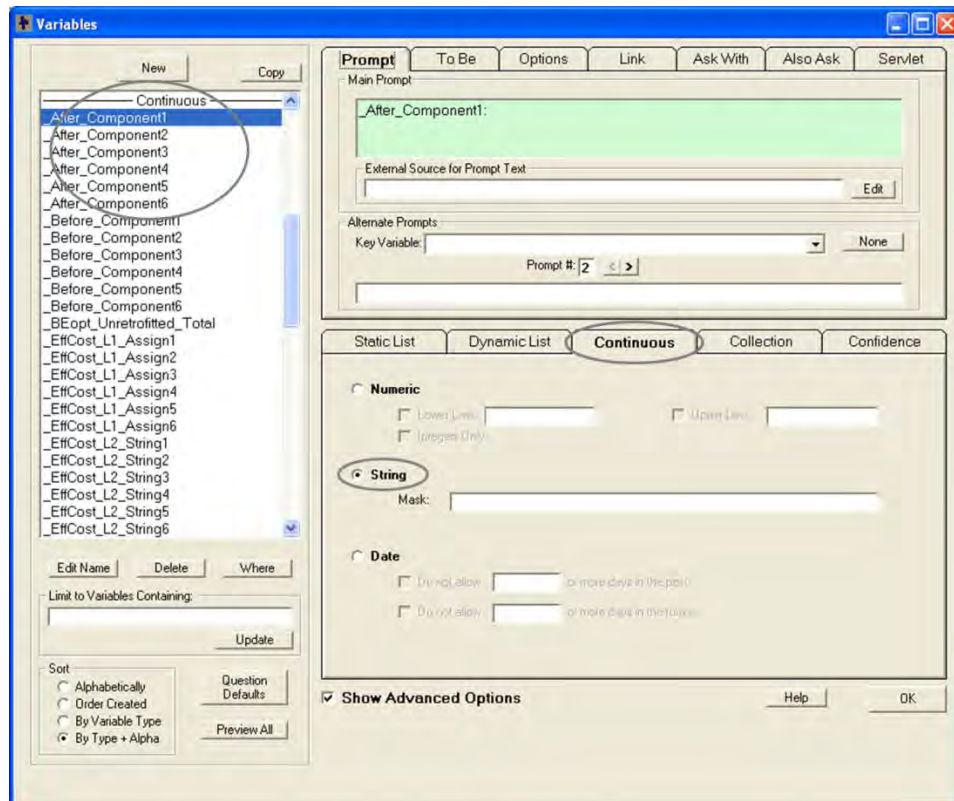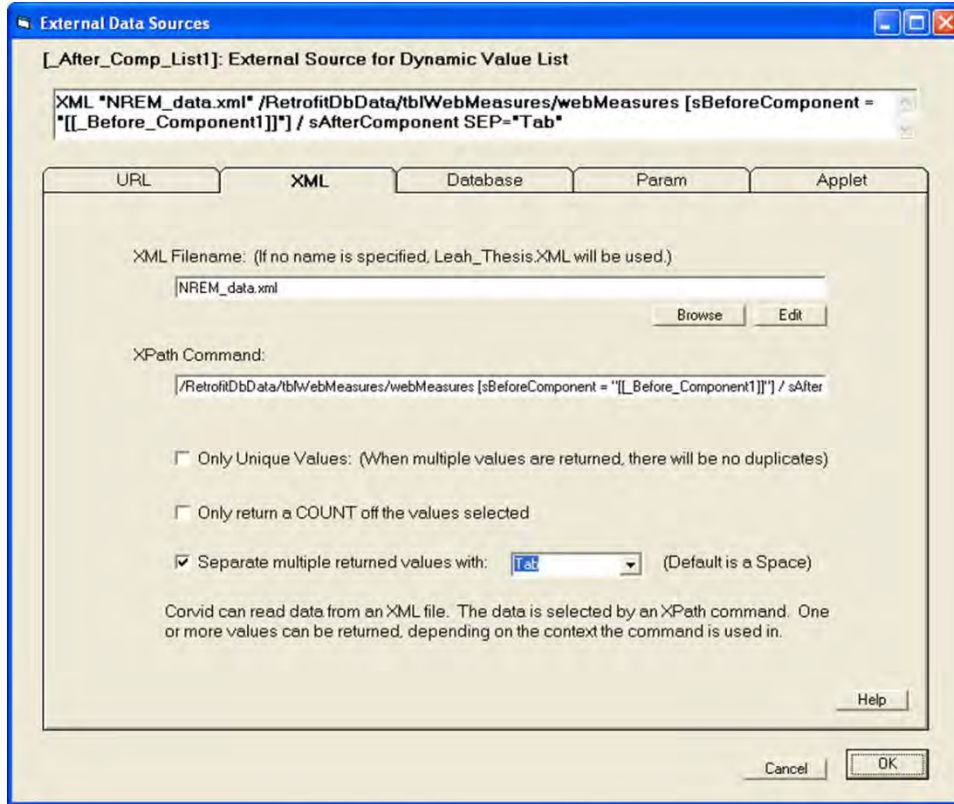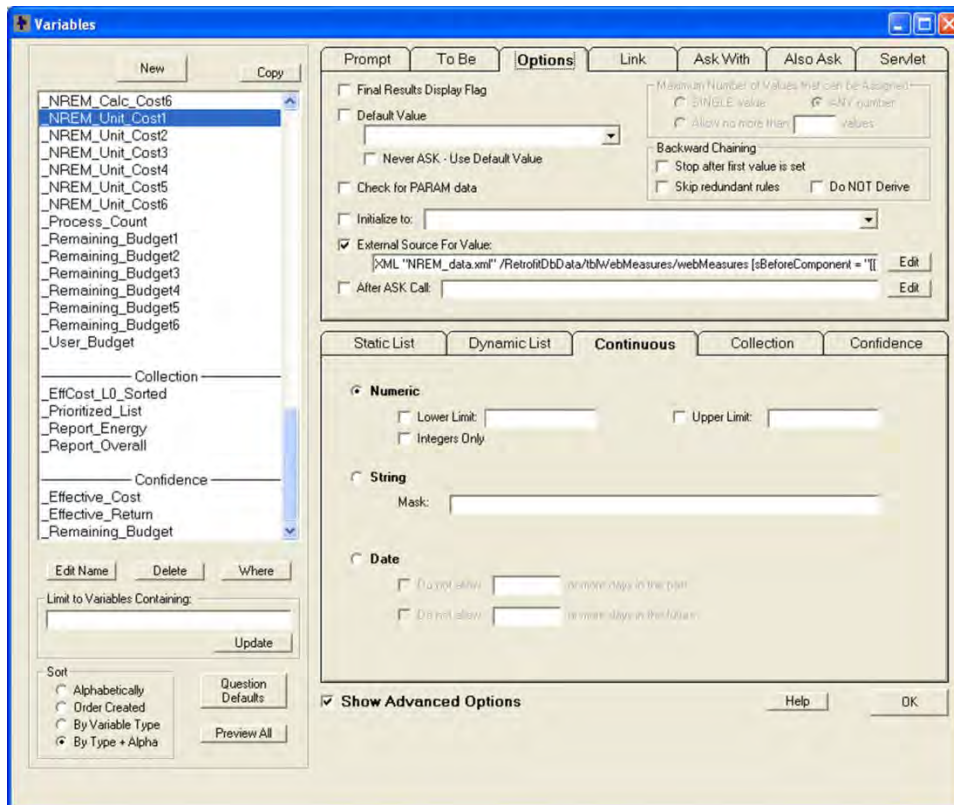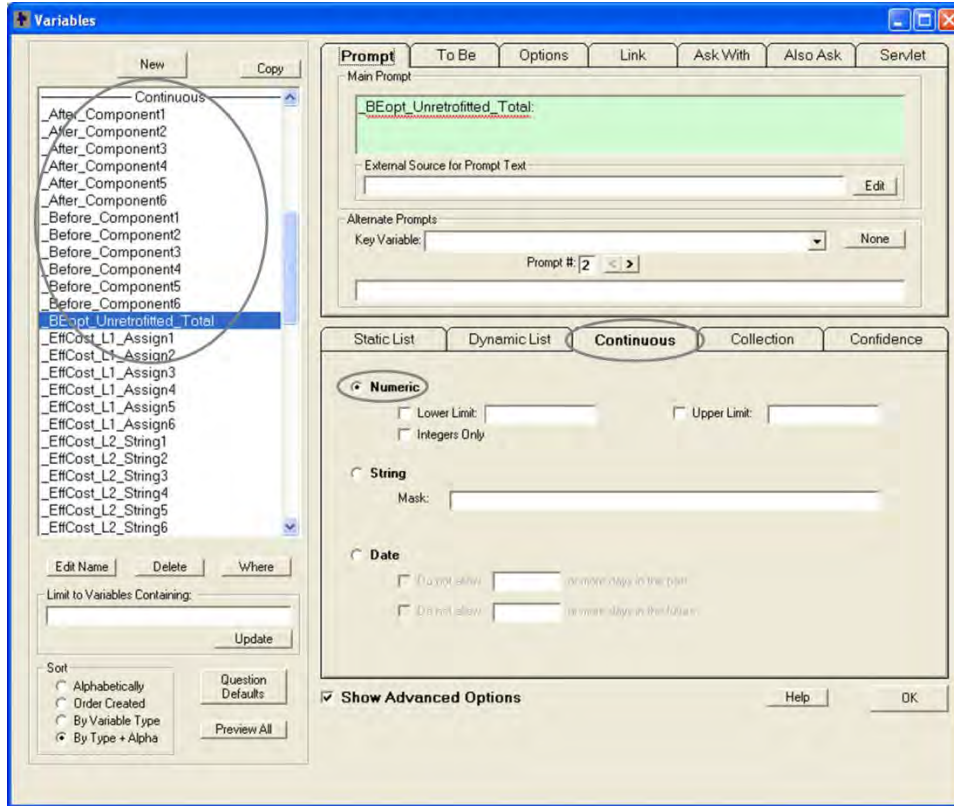
Figure Appendix 1.4 (cont'd).


```
→ [_Report_Energy.ADD] Before Component : [[_Before_Component5]] <br> After Component : [[_After_Component5]] <br> NREM Unit Cost : [[_NREM_I
→ [_Report_Energy.ADD] <FORMAT: SIZE=12 STYLE=Italic FCOLOR=127,127,127> Compared to general-service incandescent lamps giving the same .
"{Name}" = "7 - Furnace"
    → [_Process_Count] = 7
    → [_Name] = "< FURNACE TYPE >"
    → [_NREM_Calc_Cost6] = [_NREM_Unit_Cost6] * [_Measure_Quantity6]
        ┌ [_Measure_Quantity6] > 0
        │   → [_Effective_Cost] = [_NREM_Calc_Cost6] - {Incentive Amount}
        │   → [_Payback_Year] = [_Effective_Cost] / {Total}
        │       ┌ _User_Need = Furnace
        │       │   → [_Effective_Return] = 9999999
        │       └ _User_Need != Furnace
        │           ┌ [_Payback_Year] <= [_User_Year_Future]
        │           │   → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan}
        │           └ [_Payback_Year] > [_User_Year_Future]
        │               → [_Effective_Return] = [_BEopt_Unretrofitted_Total] - {Total} - {Annual Loan} - 5000000
        └ [_Measure_Quantity6] <= 0
            → [_Effective_Cost] = 0
            → [_Effective_Return] = 0
            → [_Payback_Year] = 0
    → [_Report_Energy.ADD] Before Component : [[_Before_Component6]] <br> After Component : [[_After_Component6]] <br> NREM Unit Cost : [[_NREM_I
    → [_Report_Energy.ADD] <FORMAT: SIZE=12 STYLE=Italic FCOLOR=127,127,127> The annual fuel utilization efficiency (AFUE; pronounced 'A'-'Few' c
"{Name}" = "8 - Without Furnace"
    → [_Process_Count] = 8
    → [_Name] = "< WITHOUT FURNACE >"
    → [_Effective_Return] = -9999999
"{Name}" = "9 - Retrofit+Furnace"
    → [_Process_Count] = 9
    → [_Name] = "< RETROFIT + FURNACE >"
    → [_Effective_Return] = -9999999
"{Name}" = "10 - Retrofit-Furnace"
    → [_Process_Count] = 10
    → [_Name] = "< RETROFIT - FURNACE >"
    → [_Effective_Return] = -9999999
TRUE
    → [_Report_Energy.ADDFIRST] <FORMAT: SIZE=16 STYLE=Bold&Italic FCOLOR=0,128,0> [[_Name]] <br> <a href = "{Link}"> <IMG SRC = "{Image}">
    → [_Report_Energy.ADDFIRST] <FORMAT: SIZE=16 STYLE=Bold&Italic FCOLOR=0,128,0> [[_Name]] <br> <a href = "{Link}"> <IMG SRC = "{Image}">
    → [_Report_Energy.ADD] <a href = "{Document}"> More Information </a> <br>
    → [_Report_Overall.ADDSORTED] [_Report_Energy.VALUE], [_Effective_Return]
    → [_EffCost_L0_Sorted.ADDSORTED] [[_Effective_Cost.VALUE]], [_Effective_Return]
    → [_EffCost_L0_Sorted.ASSIGNAFTER] "", [_EffCost_L1_Assign1], [_EffCost_L1_Assign2], [_EffCost_L1_Assign3], [_EffCost_L1_Assign4], [_EffCost_L1
    → [_EffCost_L2_String1] = REPLACECONTENTS("[[_EffCost_L1_Assign1.VALUE]]", "#", "#", "")
    → [_EffCost_L2_String2] = REPLACECONTENTS("[[_EffCost_L1_Assign2.VALUE]]", "#", "#", "")
    → [_EffCost_L2_String3] = REPLACECONTENTS("[[_EffCost_L1_Assign3.VALUE]]", "#", "#", "")
    → [_EffCost_L2_String4] = REPLACECONTENTS("[[_EffCost_L1_Assign4.VALUE]]", "#", "#", "")
    → [_EffCost_L2_String5] = REPLACECONTENTS("[[_EffCost_L1_Assign5.VALUE]]", "#", "#", "")
    → [_EffCost_L2_String6] = REPLACECONTENTS("[[_EffCost_L1_Assign6.VALUE]]", "#", "#", "")
    → [_EffCost_L3_Numeric1] = [[_EffCost_L2_String1.VALUE]]
    → [_EffCost_L3_Numeric2] = [[_EffCost_L2_String2.VALUE]]
    → [_EffCost_L3_Numeric3] = [[_EffCost_L2_String3.VALUE]]
    → [_EffCost_L3_Numeric4] = [[_EffCost_L2_String4.VALUE]]
    → [_EffCost_L3_Numeric5] = [[_EffCost_L2_String5.VALUE]]
    → [_EffCost_L3_Numeric6] = [[_EffCost_L2_String6.VALUE]]
        ┌ [_Process_Count] = 10
        │   → [_Remaining_Budget] = [_User_Budget] - [_EffCost_L3_Numeric1]
        │   → [_Remaining_Budget1] = [_Remaining_Budget]
        │   → [_Remaining_Budget] = -[_EffCost_L3_Numeric2]
        │   → [_Remaining_Budget2] = [_Remaining_Budget]
        │   → [_Remaining_Budget] = -[_EffCost_L3_Numeric3]
        │   → [_Remaining_Budget3] = [_Remaining_Budget]
        │   → [_Remaining_Budget] = -[_EffCost_L3_Numeric4]
        │   → [_Remaining_Budget4] = [_Remaining_Budget]
        │   → [_Remaining_Budget] = -[_EffCost_L3_Numeric5]
        │   → [_Remaining_Budget5] = [_Remaining_Budget]
        │   → [_Remaining_Budget] = -[_EffCost_L3_Numeric6]
        │   → [_Remaining_Budget6] = [_Remaining_Budget]
        └ [_Process_Count] != 10
            → [_Remaining_Budget] = 0
            → [_Remaining_Budget1] = [_Remaining_Budget]
```

Figure Appendix 1.5: Main Example – Developed Logic (Meta Block)

Figure Appendix 1.6: Main Example – Command Block
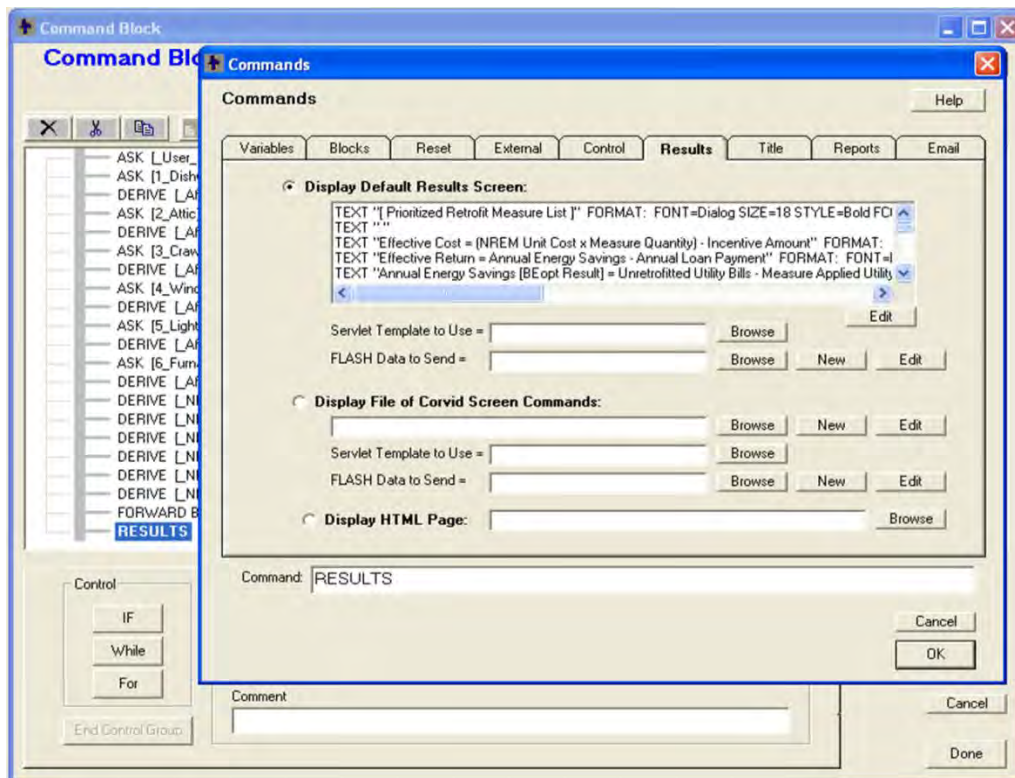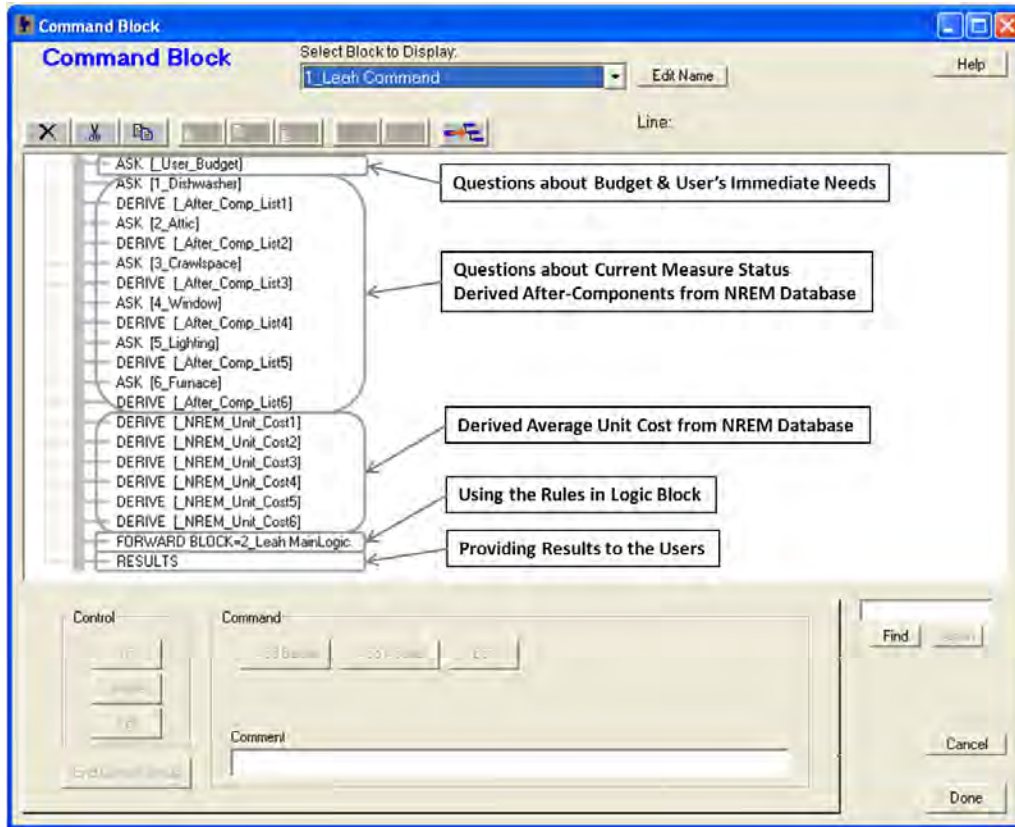
Figure Appendix 1.7: Main Example – Variables

Figure Appendix 1.7 (cont'd).

Figure Appendix 1.7 (cont'd).

Figure Appendix 1.7 (cont'd).
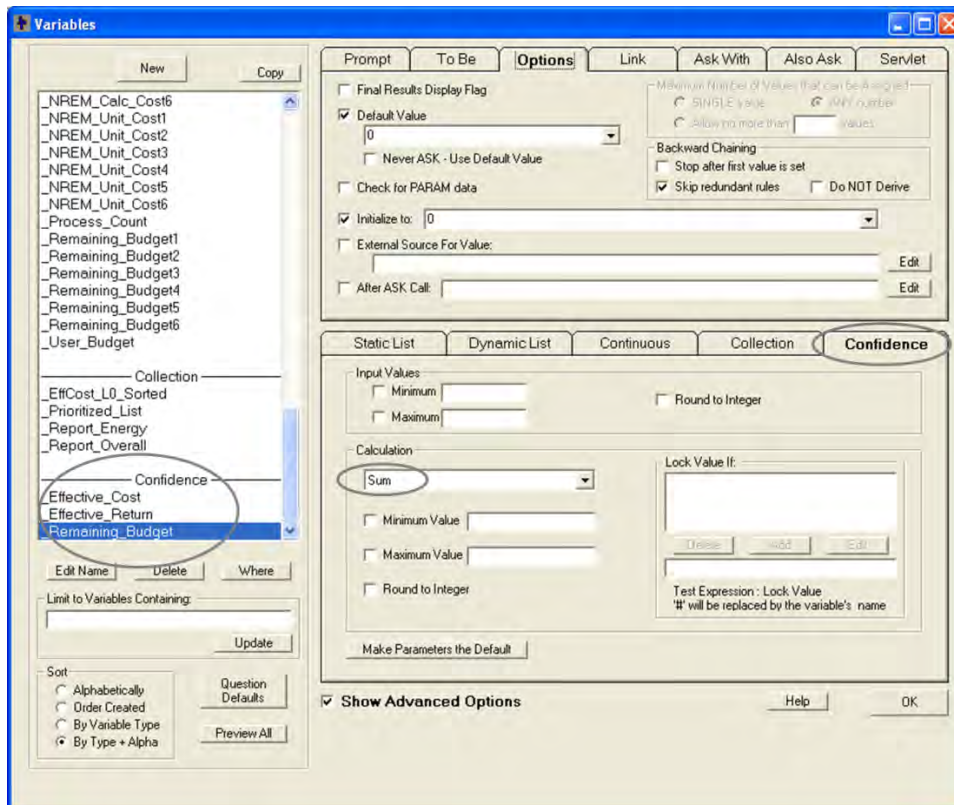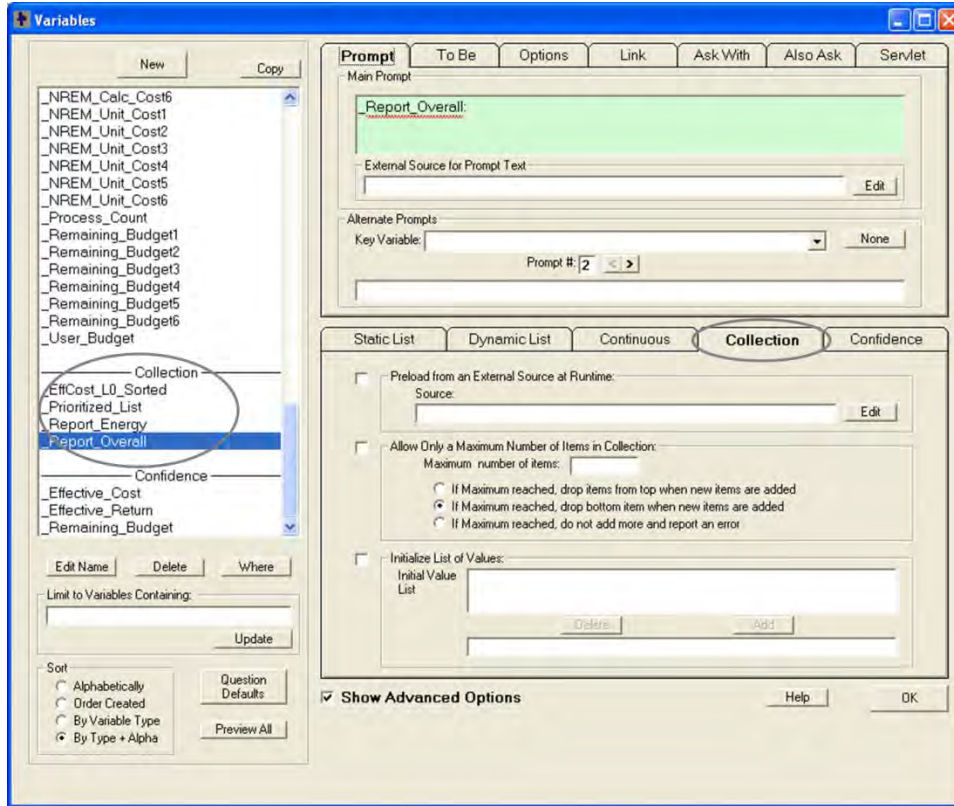
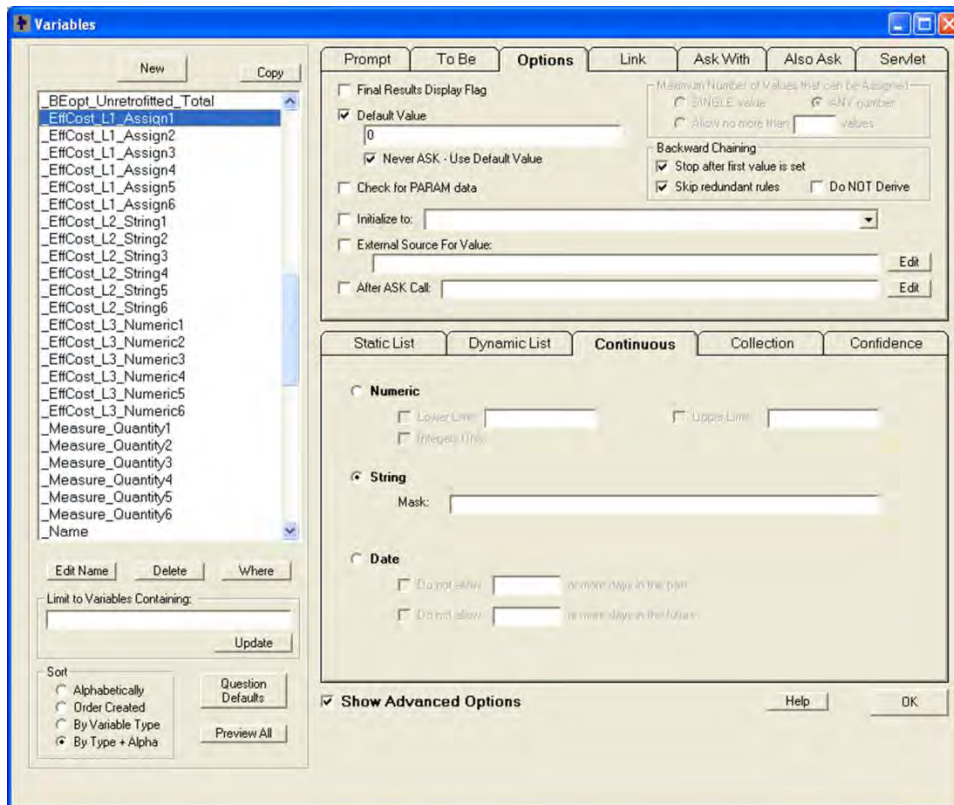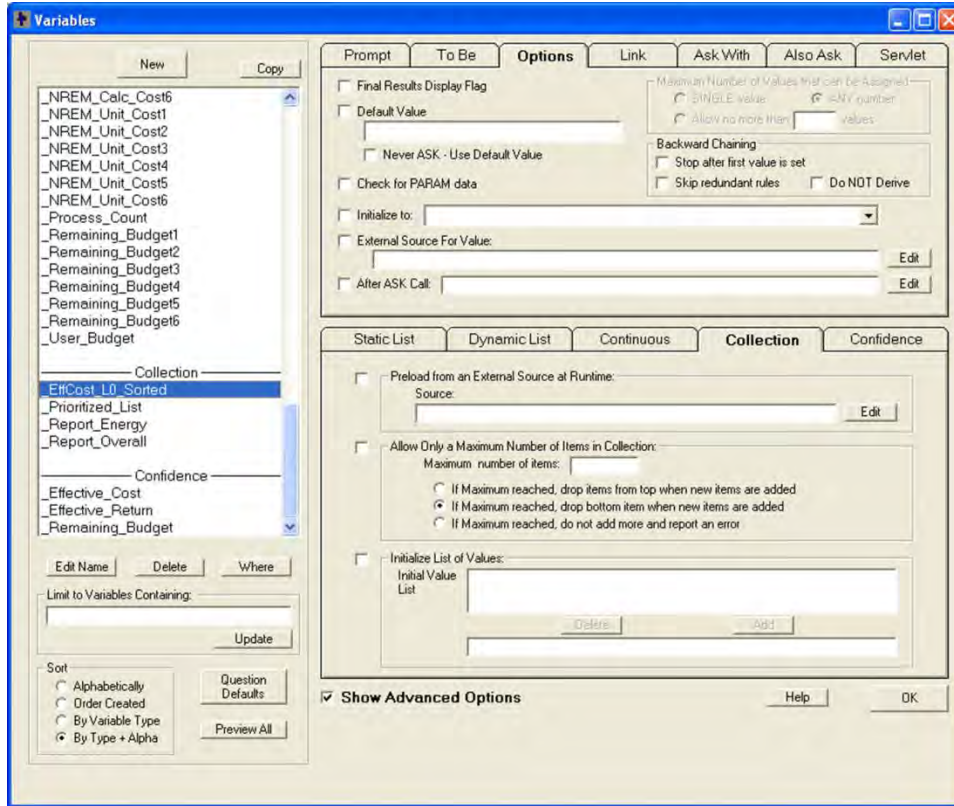**Figure Appendix 1.8: Main Example – Budget Calculation Related Variables**
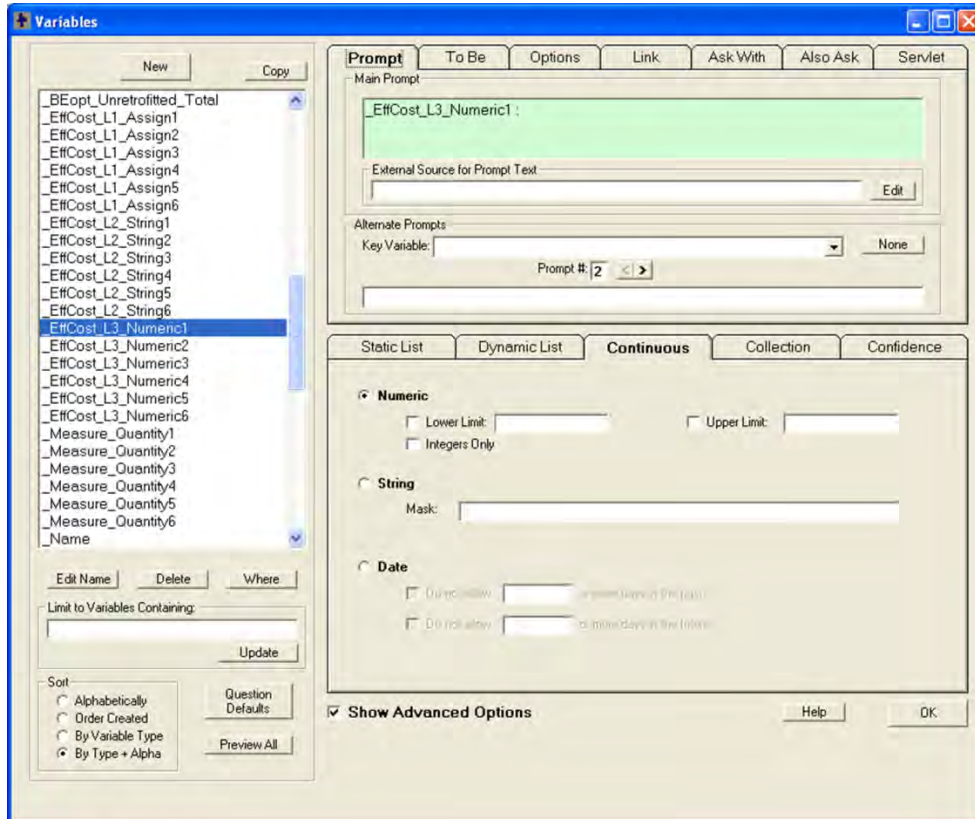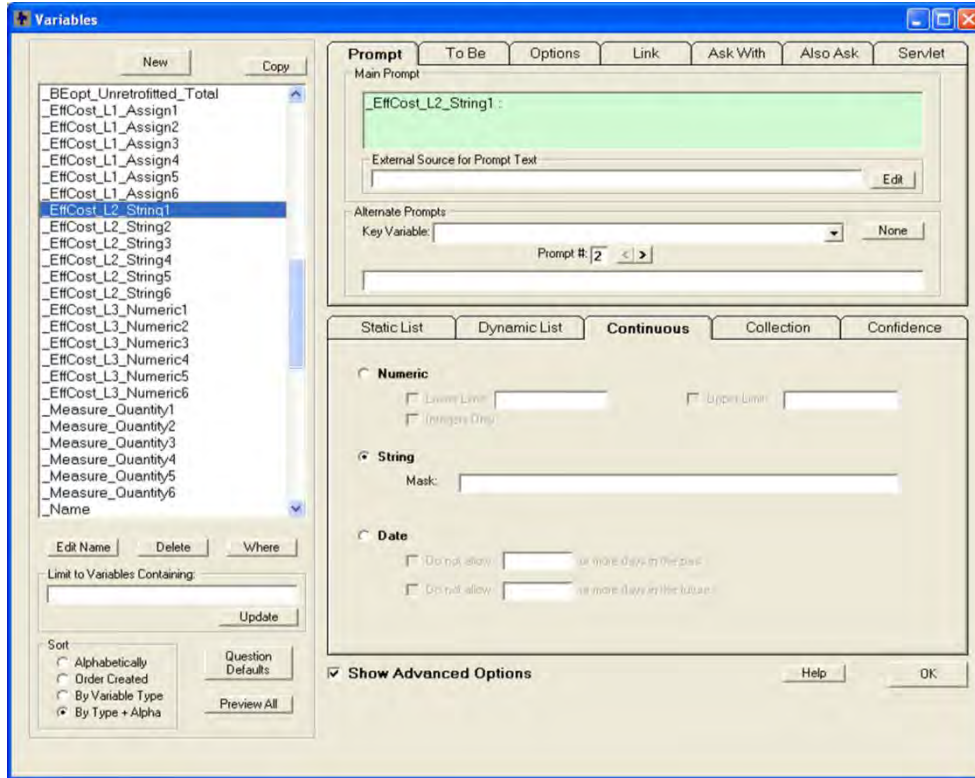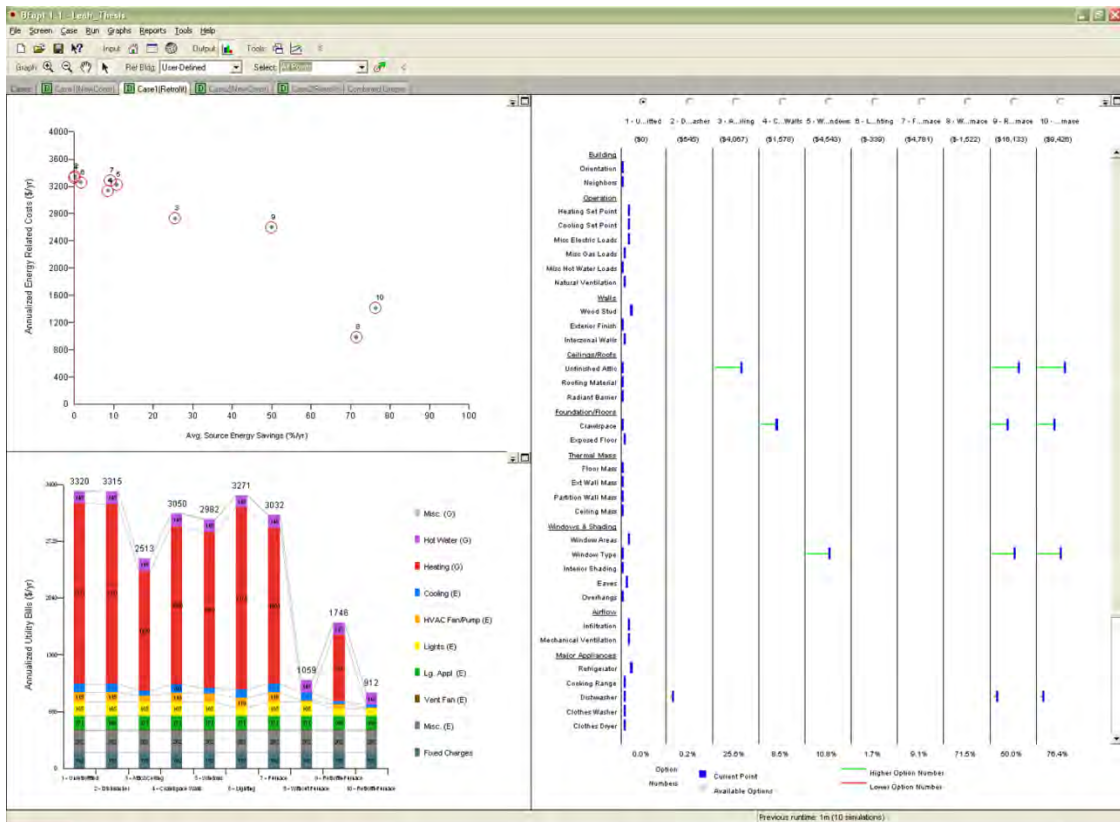
Figure Appendix 1.8 (cont'd).
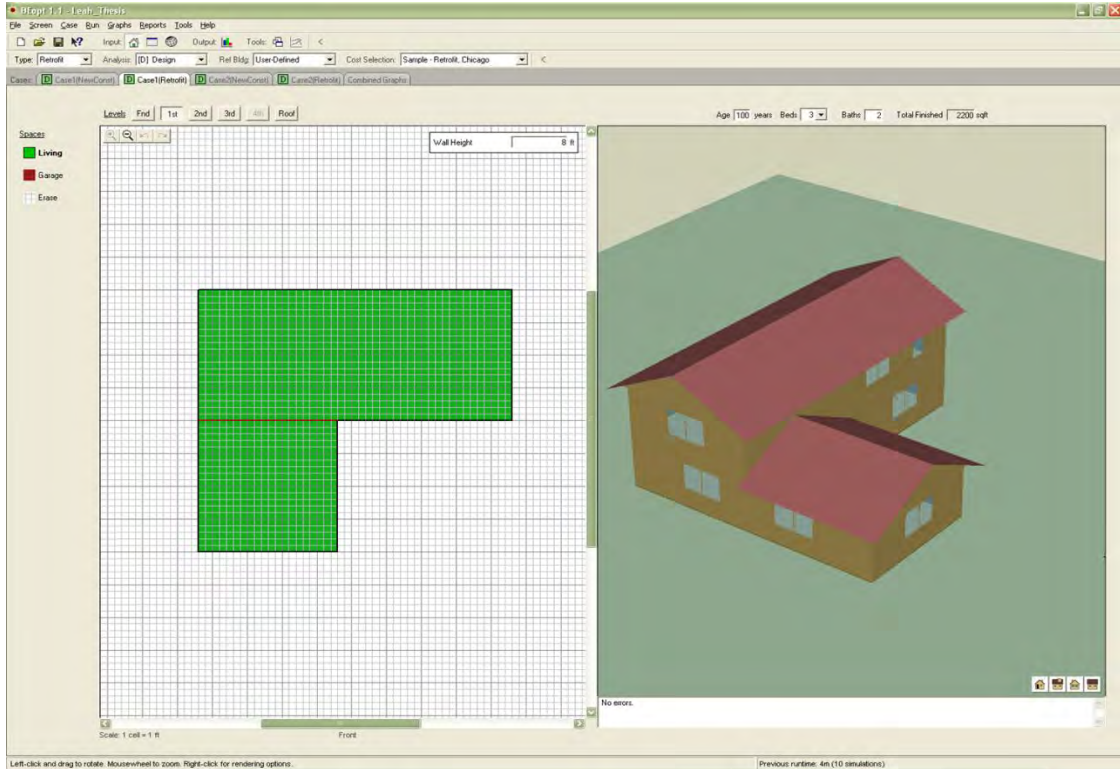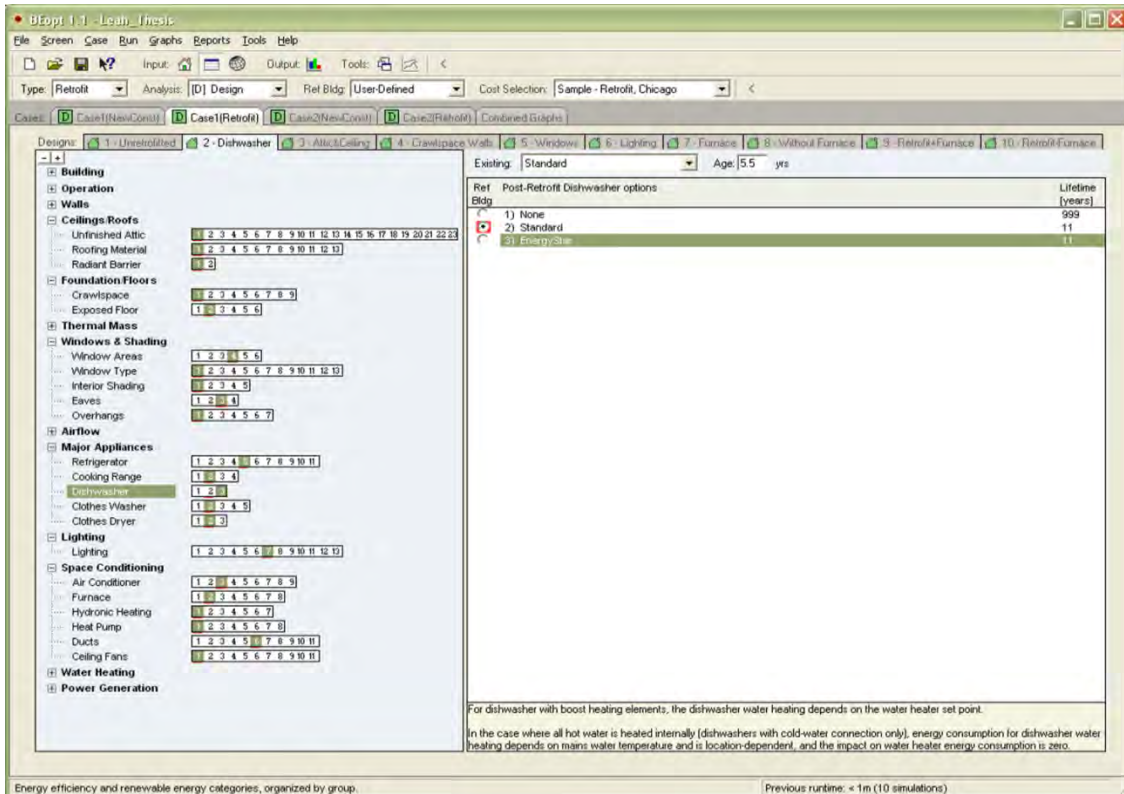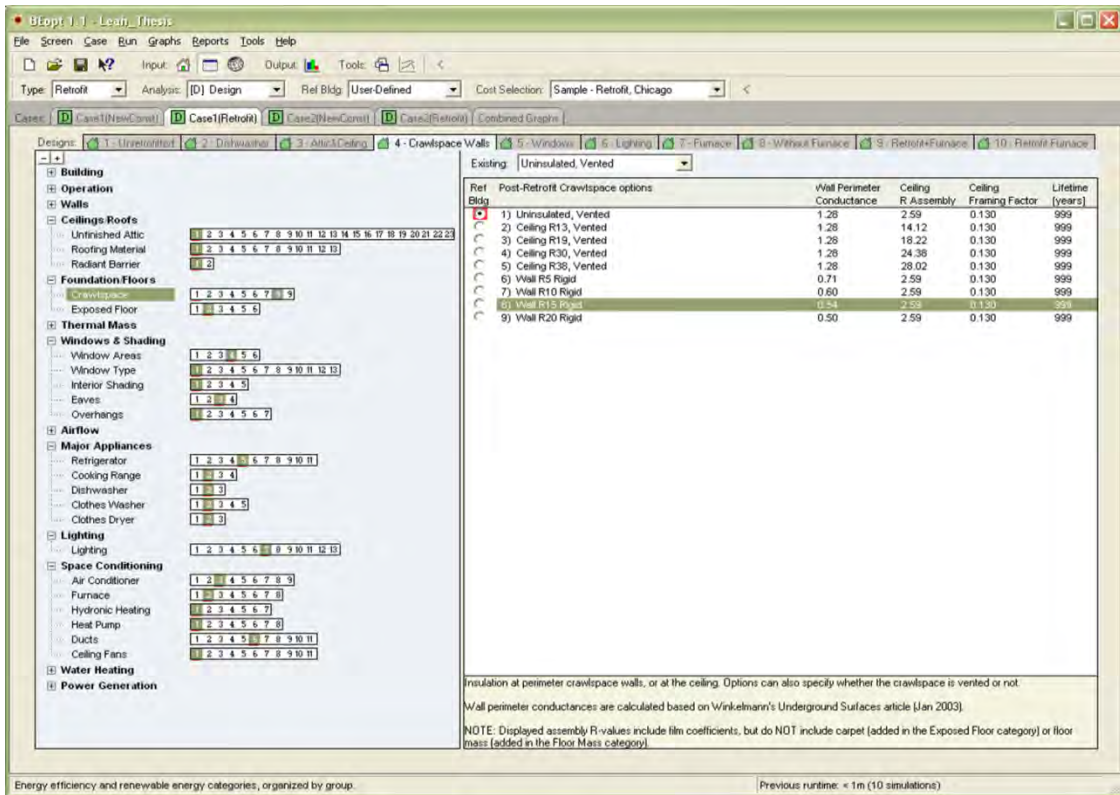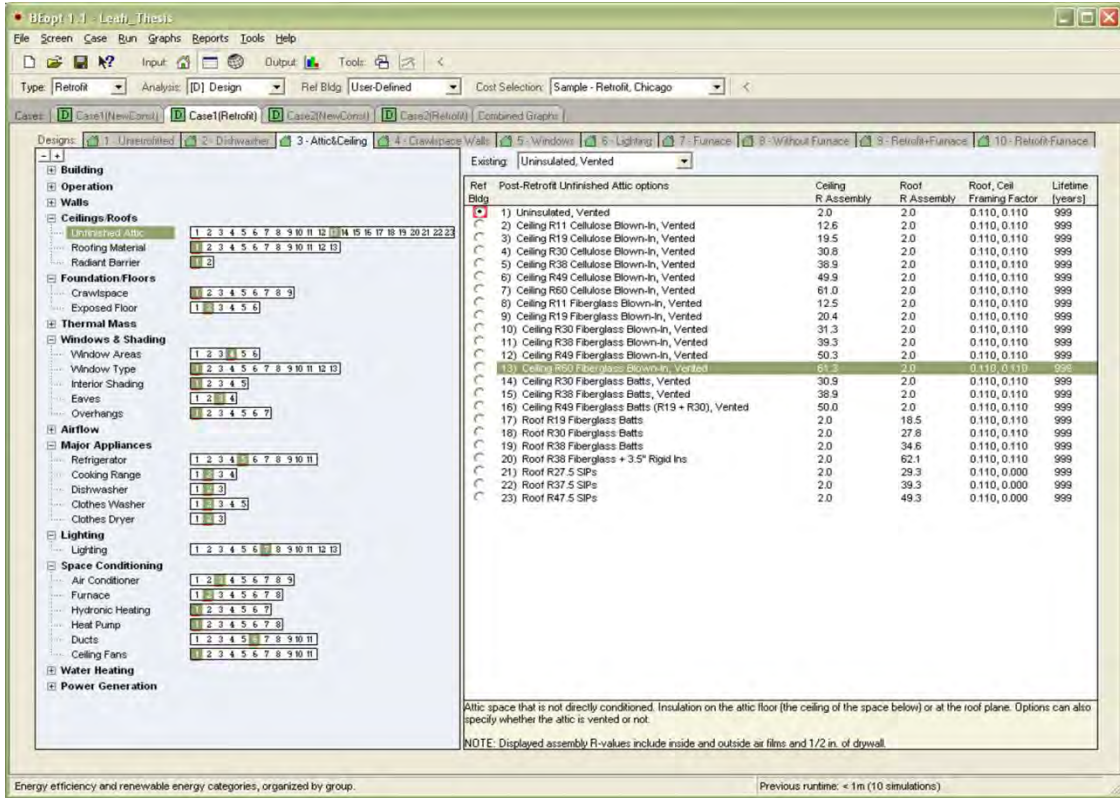
Figure Appendix 1.9: Main Example – BEopt Information

Figure Appendix 1.9 (cont'd).

Figure Appendix 1.9 (cont'd).

Figure Appendix 1.9 (cont'd).

Figure Appendix 1.9 (cont'd).

Figure Appendix 1.9 (cont'd).

Figure Appendix 1.10: Main Example – Creating Meta Block

Figure Appendix 1.10 (cont'd).

Figure Appendix 1.10 (cont'd).

Figure Appendix 1.10 (cont'd).

Figure Appendix 1.11: BEopt Calling Example
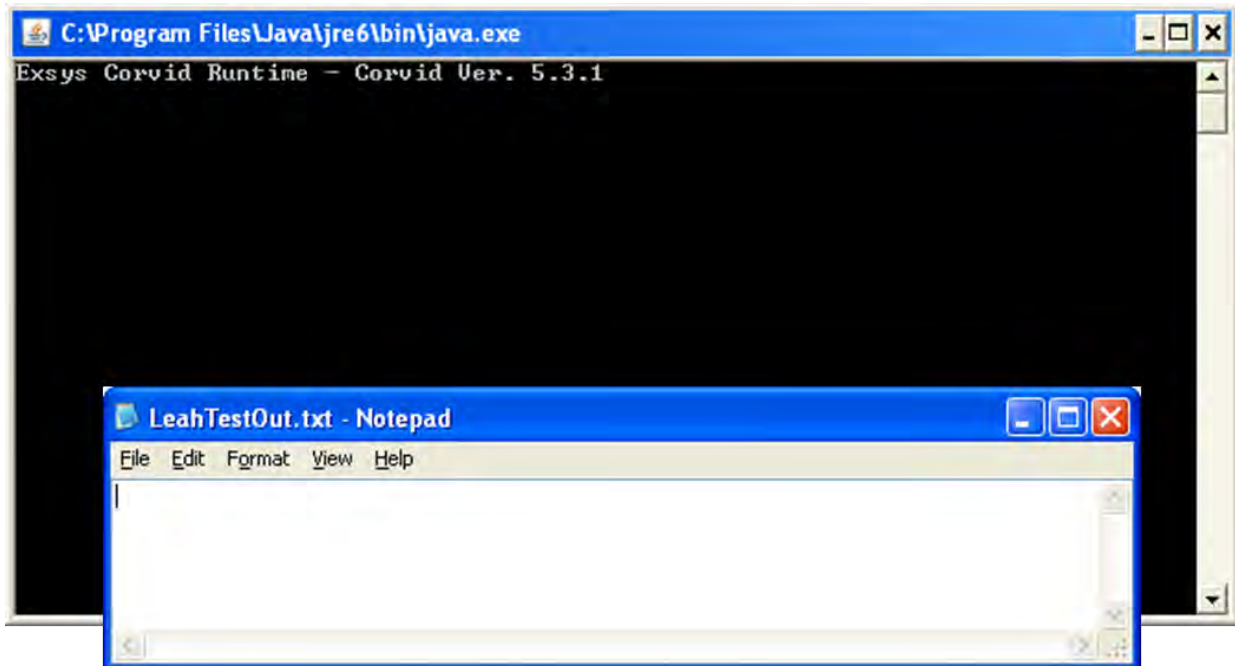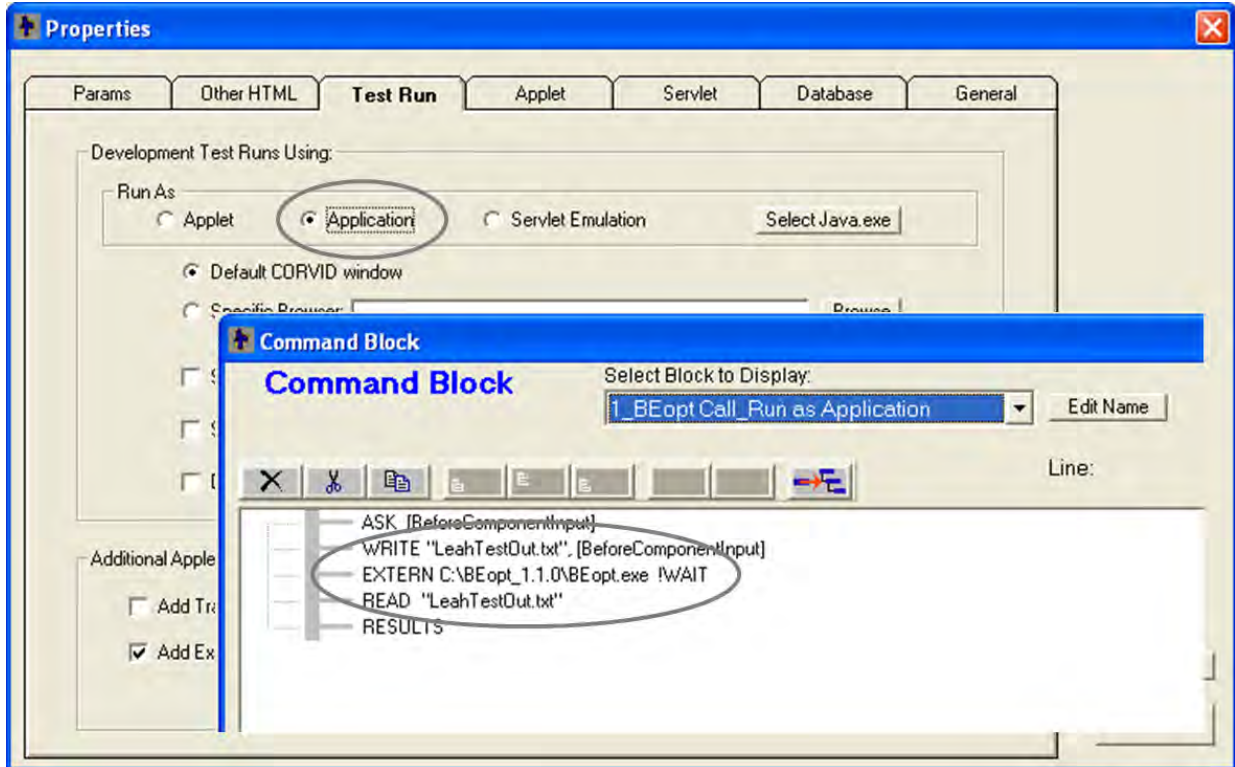
Figure Appendix 1.11 (cont'd).
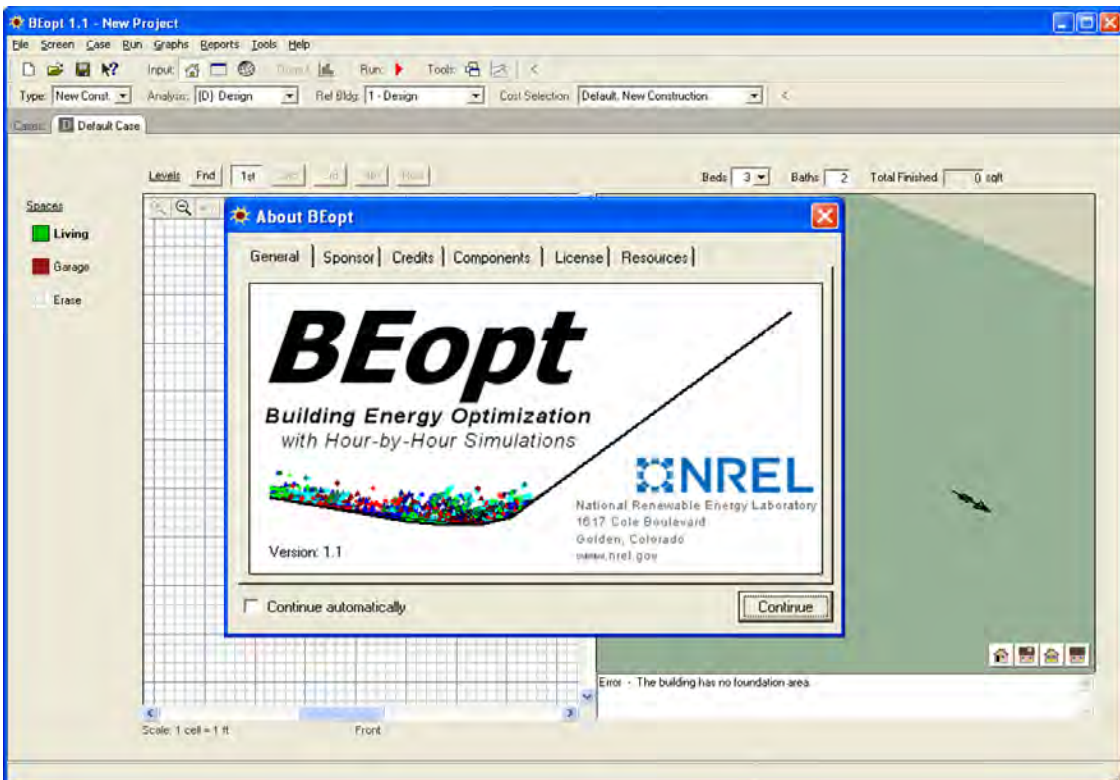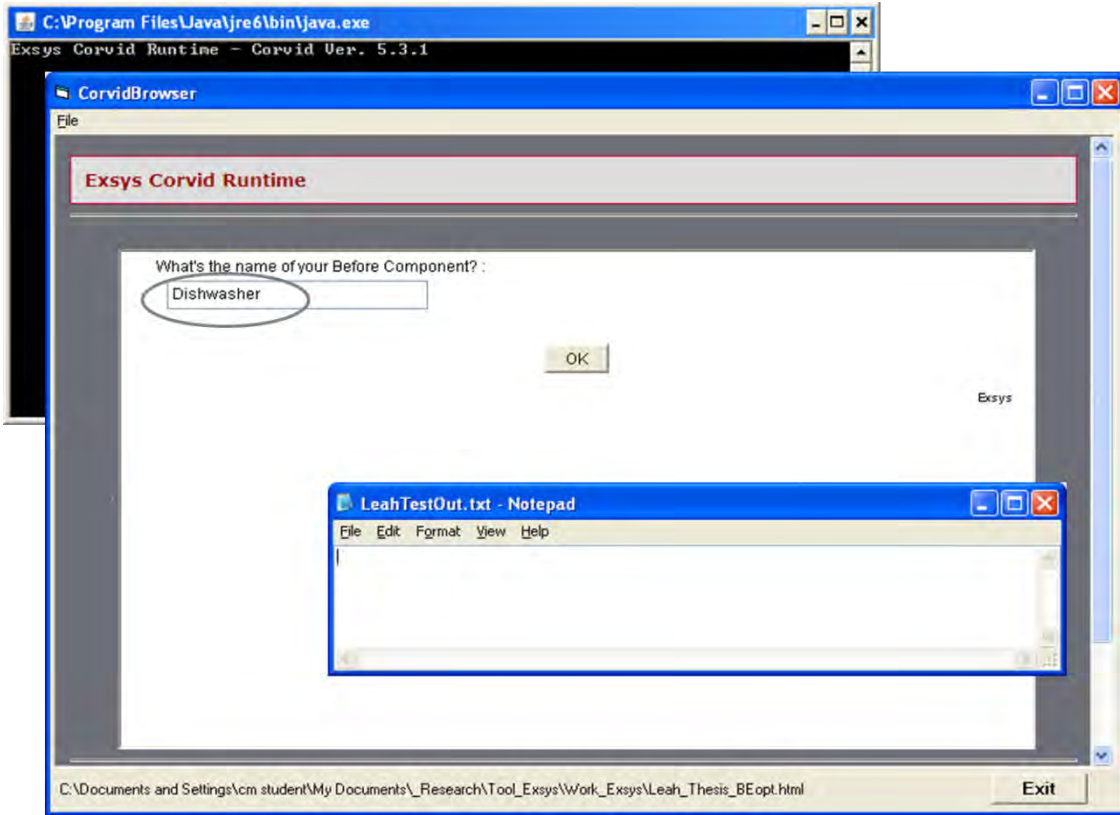
Figure Appendix 1.11 (cont'd).
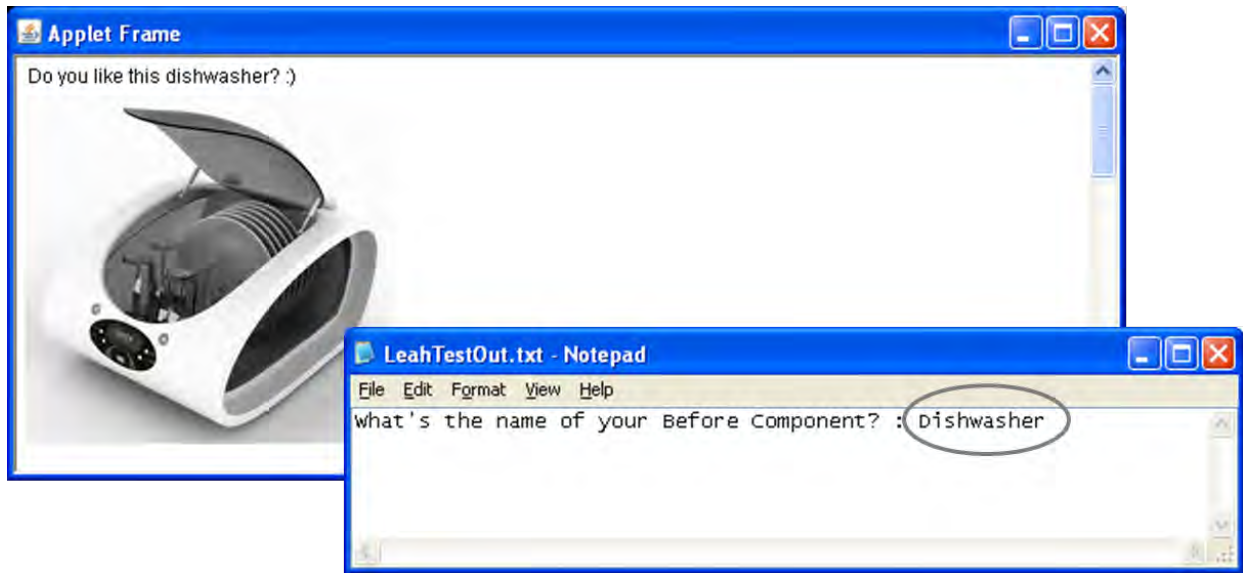
Appendix 1.12: Images, Documents, and Web Link Sources for the Integration Model
(Ordered by Images, Documents, and Web Link Sources, Retrieved on 5/23/2012)

Dishwasher
- http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=COH
- http://www.nrel.gov/docs/fy10osti/48284.pdf
- http://www.energystar.gov/index.cfm?fuseaction=dishwash.search_dishwashers

Attic & Ceiling Insulation
- http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11420
- http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/attic%20floors.pdf
- http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11390

Crawlspace Wall Insulation
- http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11480
- http://www.ornl.gov/sci/roofs+walls/insulation/fact%20sheets/crawlspace%20insulation%20technology.pdf
- http://www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11480

Window Type
- http://www.energysavers.gov/your_home/windows_doors_skylights/index.cfm/mytopic=13370
- http://www.energysavers.gov/pdfs/guide_to_energy_efficient_windows.pdf
- http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WI

Lighting
- http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12050
- http://www1.eere.energy.gov/buildings/openhouse/pdfs/lighting_factsheet29.pdf
- http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=11980

Furnace
- http://www.epa.gov/iaq/pubs/airduct.html
- http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/35876.pdf
- http://www.energystar.gov/index.cfm?c=most_efficient.me_furnaces

APPENDICES 2

Emails about Technical Limitations and Software

Figure Appendix 2.1: Email from BEopt

Date: Tue, 21 Feb 2012 13:56:25 -0700 [02/21/2012 03:56:25 PM EDT]
From: _____@nrel.gov>
To: Yunjeong Mo <moyunjeo@msu.edu>
Cc: _____@nrel.gov>
Subject: RE: Inquiry about BEopt

Show this HTML in a new window?

Hi Leah,

Unfortunately the current version of BEopt has no such capability to be automated based on external files/calls.

BEopt version 2, which is under development and is planned to be released in the summer, will be better suited to this sort of hookup. There are a number of approaches with BEopt 2 in which you could automate certain tasks, but some approaches may be easier than others depending on the specifics of what you want to accomplish (e.g. do you want/need to run BEopt optimizations? perform BEopt costing? etc). You might contact us once BEopt 2 is released if you want to pursue this further.

--

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303.384.

Figure Appendix 2.2: Email from Exsys

Date: Wed, 15 Feb 2012 09:40:31 -0700 [02/15/2012 11:40:31 AM EDT]
From: ExsysSupport <support@exsys.com>
To: Yunjeong Mo <moyunjeo@msu.edu>
Subject: Re: Question about calling external programs

This message was written in a character set (windows-1252) other than your own.
If it is not displayed correctly, click here to open it in a new window.

Show this HTML in a new window?

Hi Leah,

The XML interface in the applet runtime currently works via interapplet comunication. This means it only works with the applet runtime - not running as an application. This may change in ver 6, but that is quite aways off. You would need to either:

1. Run as an application, but get your data from a file in the Corvid syntax [varname] value... rather than XML. You could then do the WRITE, EXTERN comamnds.

2. Run as an application, but call an intermediate program (which you would have to write) to parse your XML data into the form Corvid can read.

3. Run as an applet, in which case your XML will work, but your WRITE and EXTERN would have to be converted to URL calls to a server. The WRITE could probably be handled with Corvid Report, but the EXTERN might be more difficult to run on a server. This would also require a server with Tomcat or comparable program to run the servlets.

Figure Appendix 2.3: Email about Software

Date: Mon, 01 Aug 2011 14:54:25 -0400 [08/01/2011 02:54:25 PM EDT]
From: Prof. Matt Syal <syalm@msu.edu>
To: moyunjeo@msu.edu
Cc:
Subject: XML software

Show this HTML in a new window?

Leah:
I just talked to NREM database person and they suggested XML spy software by Altova (http://www.altova.com/). You can download a 30 day version and try it.
Thanks
MS

_____

Matt Syal, Ph.D., LEED®AP
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School of Planning, Design and Construction
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www.msu.edu/~syalm

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