

A NEW SYSTEM FOR ACCESSING TRANSFER FUNCTION COEFFICIENTS FOR AN ARCHITECTURAL COMPUTER-AIDED THERMAL OPTIMIZATION TOOL

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ABSTRACT

A new system for accessing wall and roof transfer function coefficients has been developed. The system is intended to allow users to quickly and easily retrieve the transfer functions for almost any combination of wall or roof materials, thus simplifying the use of the Transfer Function Method of simulation early in the design process. The new system has been designed as a tool that can be integrated with existing simulation software. The system has been integrated with an intelligent optimization tool that utilizes the Transfer Function Method for its thermal simulation, integrated with multi-expert systems for its problem detection and advice. This user-friendly tool has a Graphical User Interface that constitutes a front-end for a transfer function coefficient database.

INTRODUCTION

Accurate simulation of a proposed building design without correct data is impossible. However, the many variables required for consideration in good simulation often become tedious and force researchers to spend valuable time consulting tables and performing repetitive calculations. This is especially true for the Transfer Function Method (TFM) which pertains this repetitive nature and is identified by ASHRAE as the fundamental methodology of peak cooling load calculation.

Transfer function method was first introduced by Stephenson and Mitalas (Stephenson, 1967), (Mitalas, 1973). This procedure is based on response factors and the interplay of heat exchange between various surfaces and sources of heat. Transfer functions are based on two concepts: the conduction transfer factors (CTF) and the weighting factors (WF). The CTF are used to describe the heat flux at the inside wall, roof, partition, ceiling or floor as a function of previous values of the heat flux and previous values of inside and outside temperatures (McQuiston, 1992). The WF are used to translate the zone heat gain into cooling loads (Sowell, 1984).

As a result of the TFM complexity, ASHRAE developed a method called the cooling load temperature difference/cooling load factor CLTD/CLF that is derived from TFM which depends on tabulated data to simplify its operation for hand use (Rudoy, 1975). This method was soon adopted by the academia due to its promise of emulating the TFM without the mathematical complexity (Romine, 1992). This method was subjected to several revisions to accommodate the problems that rose from approximations and limitations to cover more accurate tabulated data (Sowell, 1984), (Sowell, 1988), (Harris, 1988). Due to the ongoing revision of this method, ASHRAE published the cooling load temperature difference/solar cooling load/cooling load factor (CLTD/SCL/CLF) method (McQuiston, 1992), (ASHRAE, 1993) which is a revised CLTD/CLF method. Despite its simplicity, this method is still restricted by its tabular data and approximation compared to the TFM (Falconer, 1993), (Spitler, 1993).

Due to the complexity, modularity and repetitive nature of the TFM, it is well-suited for computer analysis. For this reason and to facilitate the ease of use of TF extraction for the simulation, ASHRAE introduced the "electronic tables" database which was the result of ASHRAE RP-626 that accompanied the most recent edition of the load calculation manual (Falconer, 1993). Among other things, this database allows the user to find wall and roof transfer function coefficients for the TFM. In order to utilize this database, the user must know what walls or roofs he or she is using in order to prepare the necessary files to be read by a simulation engine. The data base assumes that the user knows the major characteristics about the wall or roof they are using. Wall or roof transfer functions can be retrieved by knowing the correlation parameters. Here, the user has to specify the basic and secondary wall materials, the R-value range and location of the principal wall mass. On the other hand, the user can retrieve TF by knowing the specific wall number as assigned in Harries and McQuiston's study and published in the ASHRAE handbook -Fundamentals (ASHRAE, 1993).

This database was used in the intelligent architectural computer aided thermal system we developed as an external database (Malkawi, 1994). The system utilizes the Transfer Function Method for thermal simulation integrated with multi-expert systems for its problem detection and advice. The system supports thermal simulation in the intermediate to final design stages where the user knows the building characteristics and its material attributes.

Currently, the system's database structure and its relationship to the interface is being redesigned to facilitate early design stage simulation. In order to enhance the system's ability to allow early design stage simulation utilizing the Transfer Function Method, it was necessary to build a new database system other than the ASHRAE database that allows more flexibility to accommodate accessing the transfer function coefficients early in the design process. This is accomplished by designing a new system that allows the user to search for the best matching wall based on minimal wall attribute information that the user might have early in the design process. The goal of this new system is to integrate the extreme detail of wall and roof transfer function coefficients with the existing overall framework of the optimization system in a manner that could be quickly understood and easily manipulated.

The new system is built with an easy to use interface that supports a variety of search capabilities and is fully integrated with the intelligent architectural computer aided thermal system that performs the TFM thermal simulation based on its output. In addition, the new system has been developed as a Dynamic Link Library database and can be accessed by any external computer language which supports this protocol by a simple call of specified functions.

The paper discusses the new system developed. It describes its interface, search method and database structure. It provides a brief overview of the intelligent thermal optimization computer-aided system and its framework of integration with the new system. Conclusions and findings are presented.

THE NEW SYSTEM

The system has a user-friendly Graphical User Interface that constitutes a front-end for a wall and roof transfer function coefficient database. It is an easily operated tool that allows the user to retrieve quickly the transfer functions for almost any combination of wall or roof materials, figure (1). The system makes use of the transfer functions that have been tabulated for forty-one pre-determined combinations of building materials in the case of walls, and forty-two combinations in the case of roofs (ASHRAE, 1993). Therefore, there may not always

exist transfer functions for the precise wall or roof used in the simulation. The system has been designed with this in mind.

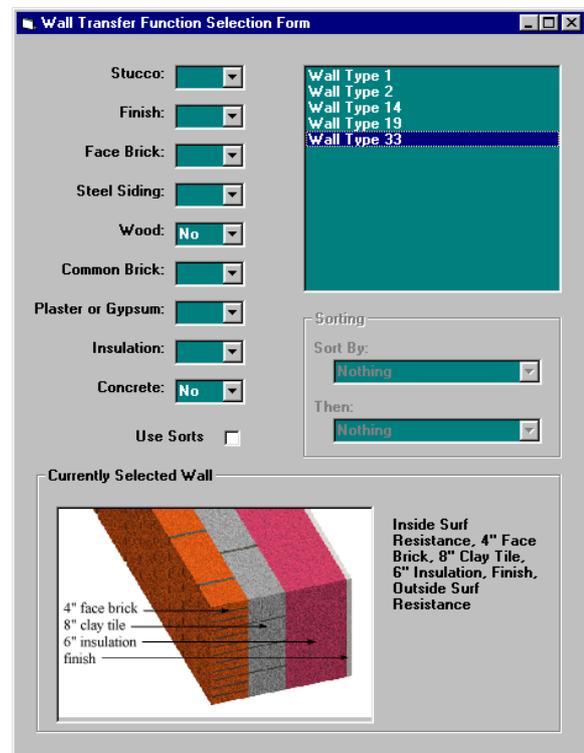


Figure 1 The Graphical User Interface

In the system, There are nine different criteria available to discriminate among the forty-one possible walls/roofs. Each of the nine criteria – stucco, finish, face brick, steel siding, wood, common brick, plaster and gypsum, insulation and concrete – can be set to one of three values – “yes”, “no” or blank. If a criterion is set to “yes”, then the interface will immediately eliminate all walls not containing the criteria element from the list of choices on the right. Conversely, if a criterion is set to “no”, then only entries not containing the criteria element will be added to the list. Finally, if left blank, walls will be added to the list regardless of whether or not they possess the criteria element.

In the case of figure (1), the user has chosen to display only walls containing no wood, and no concrete. These two criteria have narrowed the possibilities from an overwhelming forty-one to an easily manageable five. No sorts have been enabled, so the interface is displaying the cross section and layer sequence of the first entry in the list by default. The user can change this, however, by simply clicking on different entries to browse through them.

The simple, Boolean search is augmented by a more elaborate sort in the case of two common elements of roofs and walls – concrete and insulation. Both of these components vary greatly in the quantity present from entry to entry, therefore it was determined that a simple yes/no criterion would not be sufficient. A secondary sort can be selected that will sort the list possibilities by how much or how little each entry contains. The entry most closely matching the user's specifications is placed at the top of the list and is automatically selected. Because the sort can be done in two steps, it is even possible to, for example, sort the choices selected by the criteria from the entries containing the least amount of concrete to the ones containing the most, and then to sort walls with identical amounts of concrete by the amount of insulation, from high to low, figure (2).

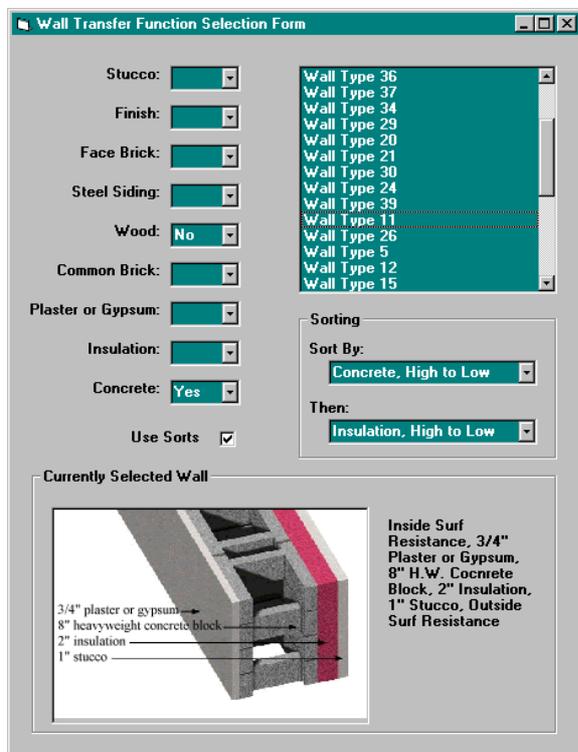


Figure 2 The GUI Using the Sort Function

The list of walls (or roofs) matching the criteria is updated each time a criterion is changed. This is one of the inherent advantages of this system— because the user knows which criterion has just been changed, any time the search returns no matching walls the user can immediately know which of the criteria conflicts with the others to produce this result. In most applications the opposite is true – the software only searches for a match when all criteria are entered, forcing the user to reenter all the criteria with no helpful feedback.

Additionally, the format of the GUI is structured in such a way as to allow very preliminary wall and roof design to be simulated. If the user only knows, for instance, that a design to be simulated will not be using wood, nor steel siding, but should include common brick, then he or she can quickly retrieve the transfer functions for such a wall, despite not knowing exactly how the wall will be constructed. In fact, this is one of the primary areas targeted by this system, as it allows simulation to be done in conjunction with the design process. Even more importantly, the system allows new consideration of the building materials to be made. For instance, after a simulation is conducted, a user might find that a wall with too much concrete is not energy efficient. Whereas without the system he or she would have to spend a great deal of time figuring out the appropriate transfer functions for a wall with less concrete, with the system it is possible to find the appropriate transfer functions with just a few mouse clicks.

SYSTEM SEARCH CRITERIA

As depicted in figure (3), the system manipulates data from databases consisting of two components to retrieve Transfer Functions for simulation usage, the classic table and the abstract table. The first component – the classic table – is a traditional table of wall/roof transfer function coefficients as determined by the layer sequence of the wall. While this table has long been available, only with this system is it easily accessible in a form that can immediately input the necessary variables into a computer simulation.

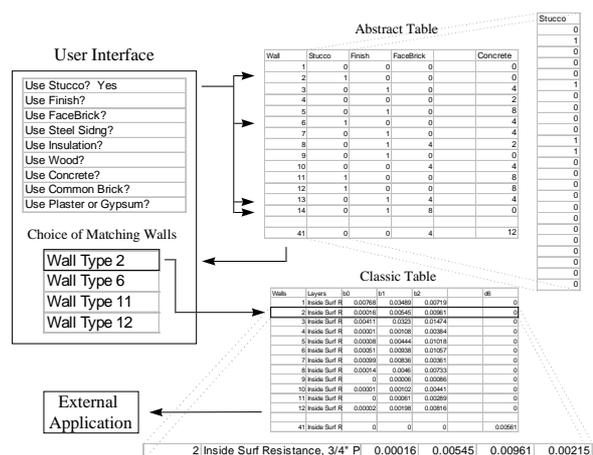


Figure 3 Transfer Function Coefficient Retrieval

The second component – the abstract table – is a new table that abstracts the first traditional table in a way conducive to modern computer searches. It is the second table that allows the user to work efficiently. Essentially, each entry in the abstract table contains a series of logical bits, one for each criteria in the user

interface. If any of a given criteria component is contained in a given entry, regardless of the actual quantity of material present, the table contains a value for that bit. If none of the material is present, then the particular bit is set to 0. This allows the software to quickly eliminate any entry from the user's choice list that does not conform with the criteria entered by the user.

Since the GUI allows the user to implement hierarchical sorts, it should be clear that the abstract contains more than Boolean bits. Actually, in the case of the two sortable criteria, concrete and insulation, the value is not simply 1. Unlike the bits for the other criteria, the value for concrete and insulation reflects the actual quantity present in the entry's layer sequence. These values allow the system to present a sorted list through the GUI.

The classic table is an electronic version of the table of transfer functions which contains the b-values and d-values for the forty-one combinations of wall materials, and another for the forty-two combinations of roof materials. The abstract table is a road map for this classic table. Once an entry has been chosen with the help of the abstract table, the software then retrieves the specific transfer functions for that entry from the classic table.

The implementation of the new roof and wall transfer function system was achieved with the use of two different search methods. When the user first starts the interface, they are presented with all the information necessary to retrieve the transfer functions they need in one easy-to-understand screen. On one side of the screen is a list of all the entries in the traditional table of wall or roof transfer functions. On the other side is a list of all the components possibly present in those entries. Using a mouse, the user can select whether or not the roof or wall they are simulating contains certain components. Each time a new criterion is entered, it is then applied to the abstract form of the transfer function coefficients table, and the computer can quickly eliminate all those entries that do not match from the list of walls or roofs. In this manner, the user can, in a matter of seconds, narrow the list of entries in the table to a few choices that can be represented graphically and closely correspond to the wall or roof the user wishes to simulate. Thus, it is possible to simulate building designs very early on, even if the user only has partial information about the walls or roofs to be simulated. Once the list of possible wall or roof makeups has been shortened to a few entries, the user can then apply the second search option. This is based on ranking the list of entries by quantity. Both searches are made possible by the new, abstracted form of the wall functions table that is quickly searched every time criteria are changed to generate an up to date list.

Specifically, the step-by-step process through which the transfer functions are retrieved, is depicted in figure (4).

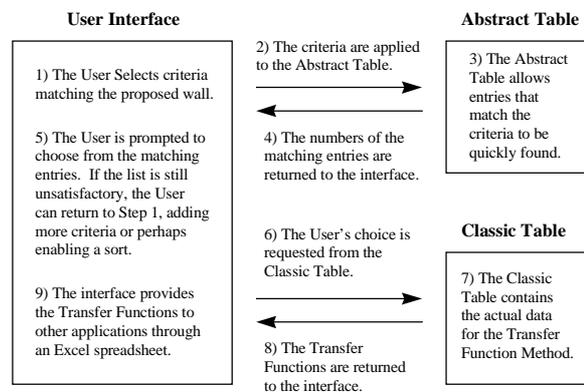


Figure 4 The Step by Step Process

Step One) Using the GUI, the user enters a criterion reflecting the wall or roof they wish to simulate.

Step Two) The abstract table is called up by the software.

Step Three) The selected criteria is applied to each entry in the abstract table. A test of logic will then take place. If the entry does not match the user's criteria then it is not added to the user's list of choices.

Step Four) A list of all entries matching the user's criteria is returned and displayed in the GUI.

Step Five) If the list is unsatisfactory – either containing too many entries or no entries at all – the user can return to Step One and either add or remove criteria, or perhaps enable a sort that would list the same number of entries, but place the one best matching the user's request at the top of the list.

Step Six) Clicking on an entry in the choice list calls the classic table up for use by the system.

Step Seven) The specific entry requested by the user is found in the classic table.

Step Eight) The transfer functions for the entry requested by the user, as well as the specific layer sequence of the entry is returned to the software. The layer sequence is displayed in the GUI.

Step Nine) The specific transfer functions for the selected entry are written to an Excel spreadsheet in a format that can either be read directly through Excel, the simulation engine or be used by other software applications. If the layer sequence does not match

the user's specifications, the user can return to Step Five and select a different entry from the list.

Although seemingly elaborate, the actual retrieval process is very straightforward, and is mostly automated by the system. For the user, it is quite easy to retrieve transfer functions for both specific and nonspecific combinations of materials for walls and roofs.

SYSTEM INTEGRATION WITH SIMULATION

Recently, a project that focused on the relationship between detailed thermal analysis and guidance advice and criticism in the intermediate to final design stages was initiated, (Malkawi, 1994). To design the system, a detailed thermal analysis module utilizing the TFM was developed. All the TFM procedures were fully implemented for the simulation to take place. The TFM in the system uses: 1. sol-air temperature to represent the dynamic nature of outdoor conditions and 2. assumes constant indoor air temperatures. Despite the second factor, the TFM can be set to recognize the variation of indoor temperature after being stabilized utilizing heat extraction rate and space air functions. This allows the simulation to be conducted to determine different sets of schedules and floating temperatures.

The simulation engine is integrated with intelligent agents (artificial intelligence computational methods) that reason about the simulation outcome and provide diagnostics (criticism) and advice to solve potential problems. The system allows users to evaluate, critique and optimize energy use and design in buildings. The system is based on a hierarchical representation of building elements in the simulation mode to establish a well-defined output, taking into consideration possible element interactions and conflicts. This changing output according to the building design is used to build associations with the inference process and related knowledge sources. The inference process is used to optimize the building energy design by providing criticism and advice. The criticism and advice are conducted based on problem detection and their locations using artificial intelligence uncertain reasoning, heuristics and search methods. Their framework utilizes a model that facilitates dynamic multi-expert system interaction and conflict avoidance within problem solving (Malkawi, 1995).

To allow early design building simulation and to ease the input use, the wall and roof TF system has been integrated with the above framework. As the user specifies geometrical information about the building elements, the user is prompted with the TF system's interface that will allow he or she to specify the wall

composition materials as described earlier, figure (5). After the selection is made, the information about the TFs is stored with its associated wall index for the simulation to take place.

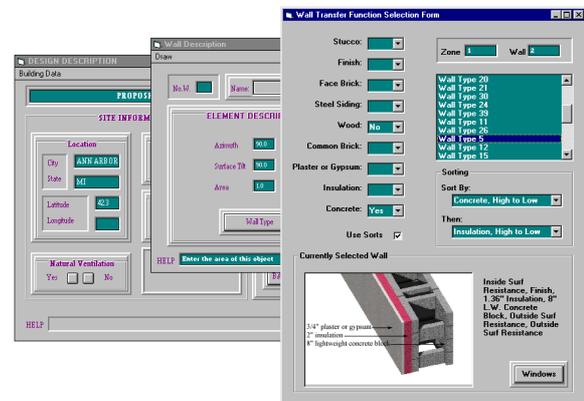


Figure 5 The Interface Integration

THE SYSTEM AS AN OBJECT

In addition to the difficulties of having to know the precise building attributes, simulating buildings early in the design process can be difficult if the user still has to switch between different software environments. For example, retrieving appropriate transfer functions for a wall or roof in one environment and then inputting them into a simulation software. This does not have to be the case, however, with the advances in software technology such as the one utilized in the new system.

The new system has been written using Object Linking and Embedding (OLE) through the creation of Dynamic Link Library (DLL). OLE is an application integration technology that can be used to share information among applications within the windows environment. DLL is a library of routines that is loaded and linked into an application. In short, DLL allows a set of library routines to be used in run time to create an "object" in the computer's memory. This object can be accessed by any software running on the computer through OLE function calls, thus it allows for communication between widely varied software applications.

Depending on how the object is created, it can either be altered by all applications on the computer, or read only by all applications and changed only by the software that created it. Essentially, any simulation software, or any software requiring transfer functions, can run the system by calling either its functions or its GUI. As has been detailed before, the user can then use the GUI to select appropriate transfer functions for the wall or roof to be simulated. Once a set of transfer functions is selected, the system creates an

Excel spreadsheet object, figure (6). This object can then be accessed either through Microsoft Excel, or by any simulation software equipped to read data from spreadsheets.

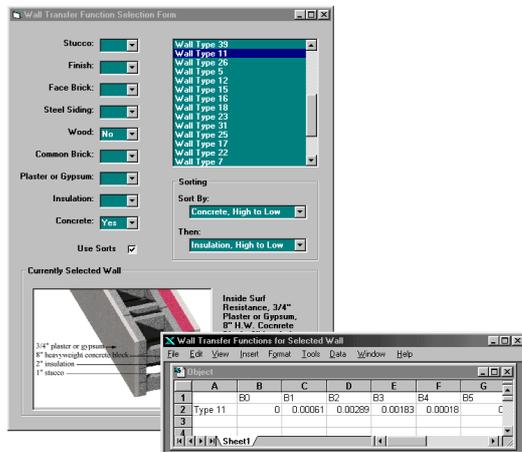


Figure 6 The Excel Object Within the Interface

To facilitate platforms without Microsoft Excel, and to provide extra flexibility for simulation software developers, a dynamic-link library (DLL) has been created, in addition to the user interface. The DLL is a single file that provides the code for transfer function selection to any OLE aware programming language. Essentially, the DLL contains a "class". A class is a definition for an object – it describes the properties belonging to the object and the functions internal to the object that make use of its properties. An object is simply a copy of a class placed into active memory. In this way, a class can be used to create identical objects each time it is used.

The class developed for the system has several properties and a function. The class is designed to provide a passage with which other software communicates. The possible components of a wall are represented as properties of the class. For instance, there is a "Concrete" property that can be set to either "yes" or "no". When all the desired components are configured, a matching wall can be retrieved using findwall, the only function in the class.

It is easy for the features of the DLL to be used by simulation programs. First, the DLL is registered with the external software. This DLL contains the class. When the external software executes, it can use the class definition to create an object. The external software then interacts with the object, setting its properties and eventually calling the function to return a matching wall type, figure (7).

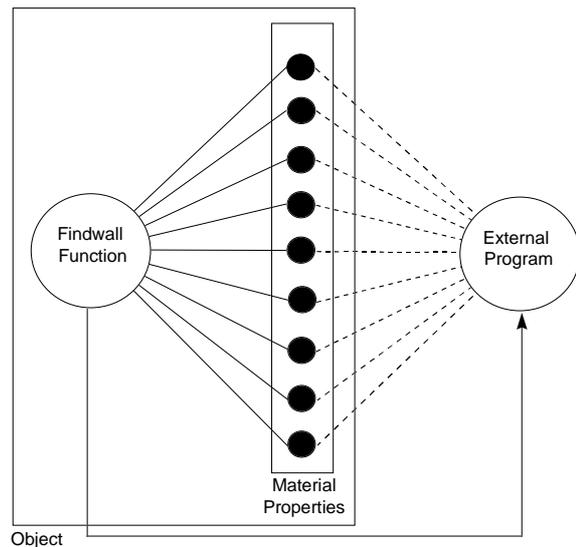


Figure 7 The Object Interaction with External Programs

Since not all software is written to be "OLE aware", the system has the ability to write a copy of the spreadsheet containing the transfer functions to the hard drive upon closing.

CONCLUSIONS

Computer programs utilizing TFM require detailed knowledge about the building materials to be simulated. The system developed allows the user to identify TF based on minimal information about the building materials through its rapid search engine. As a module to an existing building simulation system, it allows users to achieve high accuracy and does not require the user to have an in-depth familiarity with transfer functions. It enables the user to rapidly and easily locate the precise transfer function coefficients he or she needs for his or her simulations, and enter them without the danger of data entry errors. The development of the system utilizing DLL/OLE allows for ease of integration with computer simulation algorithms that utilize this technology. This demonstrates the advantages of utilizing DLL/OLE in building modular computer simulation systems that allow maximum utilization of code modules. In addition, it suggests the potential use of such technology in fostering collaborative work both in designing and implementing computer simulation systems.

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