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COMPUTER TOOL TO ACHIEVE BETTER PERFORMANCE AND INTEGRATION OF BUILDING ENVELOPES WITH STRUCTURAL AND MECHANICAL SYSTEMS

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ABSTRACT: Like the structure of the building, the building envelope accounts for 20% of the total building cost, A holistic approach to performance evaluation will not only ensure that the numerous criteria of the building envelope, such as structural, thermal, moisture, acoustics, etc. are all satisfied, but also ensure that good integration is established between the envelope and the structure as well as with the ventilation system of the building. This multi-disciplinary performance checking can greatly benefit from the new developments in Information Technology (IT) and Industry Foundation Classes (IFC) from the International Alliance for Interoperability (IAI) for the building industry. This paper describes the development of a computer tool or framework which includes a preprocessor, an application integrator, and a postprocessor. The framework extracts the basic geometric data of a house from CAD drawings based on an IFC data model, links to performance evaluation applications such as MOIST3.0 and HOT2000, and compares evaluation results with a set of criteria.

1. INTRODUCTION

Building designers (Architects, structural and mechanical engineers) have typically focused on the conventional elements, such as aesthetics, structural strength, and HVAC, and much less on the building envelope, which functions as a barrier or filter protecting the occupants from cold and hot weathers, wind, rain, water vapor, solar radiation, outside noise, pollution, smoke and fire propagation (Hutcheon, 1963). Yet, like the structural system, the building envelope system typically accounts for 20% of the building cost. Moreover, the building envelope continues to influence the operating costs of the life cycle of the building. Thus, unlike building structures, the building envelope is specified in the architecture design drawings based more on rules of thumb than on an engineering approach.

In the 1990's in Vancouver, extensive failures of envelopes occurred in buildings which were less than five years old. The repair cost per each condominium averaged between $25,000 and $35,000. The total loss was originally estimated at one billion dollars but it is said that it may have reached much higher. The "leaky condo crisis", as it came to be known, created an awareness for the need of effective knowledge and tools to move the design of building envelopes towards an engineering approach as it is done for other building subsystems such as structures.

The building envelope is an integral part of the building system and must be well integrated with the structure and the HVAC for the efficient performance of the building. The envelope should not be treated as a separate part when being designed, and the performance characteristics and construction details of these subsystems should be taken into consideration concurrently (Fazio, 1990). Accordingly, a holistic approach to performance evaluation will ensure that the numerous criteria of the building envelope, such as structural, thermal, integrity, moisture, acoustics, etc., are all satisfied and will ensure that good integration is established between the envelope and the structure as well as with the HVAC and lighting systems of the building. The body of knowledge required to integrate these disciplines is known as Building Engineering.

The performance of building envelopes can be evaluated through experiments or computer simulation. Experiments could be carried out in laboratories and in the field, but usually they are more expensive and time consuming. Computer simulation, on the other hand, may require less money and time, but require validation. A large number of computer-based applications are already available, e.g., HOT2000 (Buildings Group NRCan, 2004), Energy Plus (U.S. Department of Energy, 2004), RIUSKA (Granlund, 2004), WUFI-ORNL/IBP (ORNL/IBP, 2004), hygIRC (IRC/NRC, 2004), MOIST3.0 (BFRL/NIST, 2004), CONDENSE, and Airpak (Fluent, 2004). However, the data input in these applications is complex and time consuming; people who run the applications need advanced computer skills and professional experience. In addition, these applications cannot read the geometry data that are part of the data input from CAD drawings, which results in low efficiency and data input errors (Suter et al., 2004). Therefore, these applications are typically developed by researchers and used mainly by researchers, and are infrequently used in actual designs. When evaluating the performance of the building envelope, building owners, manufacturers, designers and evaluators need to know if a specific envelope system performs under a series of climatic loads for specific regions and the performance requirements of the target markets where the system would be built. Existing computer programs address different functions of the building envelope and typically do not address the performance criteria for the different regions of the world. Therefore, the evaluation of performances of buildings needs a set of rules or clauses as a comparative standard or criteria at the design and evaluation stages. Based on criteria developed in Canada and a number of other countries, the BEPA (Building Envelope Performance Assessment) Protocol is being developed at Concordia University and Ryerson. It integrates many codes about building envelope including structural and mechanical systems as well as energy conservation (Horvat and Fazio, 2004 &2005).

The research presented in this paper aims to develop a computer-based framework for evaluating the building envelope which integrates Information Technology (IT), Industry Foundation Classes (IFC) (IAI, 2004), evaluation applications, and evaluation criteria. This framework can be extended to a whole housing system. The objectives of this project are: (1) to investigate and compare the criteria and tools used in evaluating building envelope performance in different countries, and identify typical sets of criteria that must be met by Canadian houses in general and houses in Quebec in particular; (2) to investigate a conceptual framework for integrating tools for evaluating building envelope performance and comparing this performance with a set of criteria; and (3) to develop a proof-of-concept system to test and validate the conceptual framework.

2. CURRENT STATE OF APPLICATION OF IT AND IFC IN BUILDING ENGINEERING

Information Technology (IT) has been widely used in ACE/FM (Architecture, Construction, and Engineering/Facility Management). However, when practitioners use engineering software applications, they need to transfer and share data among different applications developed by different software developers. Therefore, interoperability among them is difficult to achieve without an international standard that enables software developers to develop their software based on the same data format.

IFC are developed by the IAI (International Alliance for Interoperability) (IAI, 2004) as an international standard for building data exchange for AEC/FM objects including physical objects, e.g., walls, or abstract objects, e.g., a project. Based on Express language which is used in ISO STEP project (ISO, 1999), data in IFC are organized into a hierarchy structure following the object-oriented method. Furthermore, it is free, open and available to all AEC/FM software developers; thus, interoperability among AEC/FM software applications is achievable. Since the first IFC version released, many software developers have developed their applications to be compatible with IFC, such as Architecture Desktop and ArchiCAD in CAD drawing, Robot with Robin Building Modeler (ISS, 2004) in structure design, Energyplus (US Department of Energy,

2004) and RIUSKA (Granlund, 2004) in energy simulation, AirPack (Fluent, 2004) in indoor quality control, and Timberline Office (Timberline, 2004) in cost estimate. Meanwhile, many researchers have carried out their work on the application of IFC in building engineering. For example, Romberg et al. (2004) used geometric models based on IFC for the finite element analysis in structural design.

In energy simulation, Bazjanac (2004) discussed a new IFC HVAC extension schema that is integrated in the latest version of IFC (IFC2X2). It takes the 3-D building model of a one-story bank branch building as an example to demonstrate the usage of IFC. The model is defined using ArchiCAD and saved in IFC format, EnergyPlus then imports the building geometry data from the IFC format by using BS Pro COM Server. Data about HVAC system are entered manually according to EnergyPlus definition. Bazjanac et al. (2004) introduced a new IFC HVAC interface to EnergyPlus which is used to translate HVAC data from IFC2x2 file into corresponding definitions in EnergyPlus Input Data Files (IDF). Furthermore, it can also transfer and add HVAC data in EnergyPlus IDF to IFC2x2 data files. Earlier instance of energy simulation with IFC could be shown in RIUSKA software. It has an AutoCAD-based space-modeling tool called SMOG (Space Modeler by Olof Granlund Oy). It creates 3-D objects of walls, windows, doors and spaces and also creates connections between these objects. It can import and export IFC 1.5 files and transfer building geometry and construction data from IFC-compliant architectural software into other applications such as energy and comfort simulation, visualization and lifecycle cost analysis. Also, results calculated in RIUSKA can be exported to other IFC-compliant software (Karola et al., 1999).

In code compliance checking, CORENET (COnstruction and Real Estate NETwork) in Singapore has developed a code-checking approach based on IFC. Their Integrated Building Plan and Integrated Building Services (IBP/IBS) e-Plan Checking will enable the government to approve building plans submitted by architects and building services engineers on the Internet (Liebich et al., 2002). It may be extended to offer performance-based code checking. A model-mapping engine called eThermal has been developed within the novaCITYNETS ePlanCheck framework (FORNAXTM) to accomplish the task of translating CAD models to EnergyPlus model for thermal and energy simulation (WONG, 2004). IFC is an evolving international standard. With its various extension schema which also can be developed by IFC implementers, it can describe objects in ACE/FM industry which are not included in the current IFC version. Taking the CORENET project as an example. Because not all the required facilities which support automated code compliance checking within the e-Plan Checking project are included within IFC 2x version, an IFC extension called IFC Extension Project CAS (Codes and Standards) is developed. It is fully coordinated with other parts of IFC 2x2, such as IAI BS8 project, which is related to building services, and IAI EL1 project, which is related to electrical services. This guaranties that the effort in developing a data model in CORENET project would be accepted internationally (Liebich et al., 2002).

3. DEVELOPMENT OF THE BUILDING ENVELOPE EVALUATION FRAMEWORK

The project presented in this paper is a computer-based integrated tool or framework to evaluate the performance of the building envelope subsystem. With the application of IFC, it can not only import data from CAD drawing and exchange data between the preprocessor and the simulation programs, but also interoperate with other frameworks and software. The flowchart of the framework is shown in Figure 1. It consists of three components: preprocessor, application integrator, and postprocessor. The conceptual discussion about this framework in terms of IT and IFC is presented in He (2005). The following sections will focus on its implementation.

3.1. Data Transfer from CAD to IFC

CAD applications, such as AutoCAD, are widely used in the building industry. AutoCAD files are usually saved in DraWinG (DWG) and Data eXchange Format (DXF) file formats. Nevertheless, these file formats are created by software developers, and their resources are not open to the public due to commercial competition. In many cases, this results in interoperability problems among different applications. Fortunately, some CAD developers have developed new applications which are compatible with IFC, e.g., the AutoDesk's Architectural Desktop with its IFC2x utility and Graphicsoft's ArchiCAD with its add-on interface.

3.2. Preprocessor

Preprocessor is a functional unit in the framework that processes the input data for the building envelope. It is used to import IFC files from CAD software, input data from end-users, store data to, and retrieve data from, the database, and build middle layer to transfer data to its receptor, the Application Integrator.

3.2.1. Importing IFC Files

When the user runs the preprocessor, it asks whether to import an IFC file which is generated by an IFC-compatible CAD application, such as Architectural Desktop or ArchiCAD. If the user answers “yes”, the system will display an interface in which the user could search for IFC files from the database and then import data from the selected IFC file. At present, only geometric data, such as height and perimeter of the walls can be extracted. In the future, the preprocessor will extract other data, such as material layers of walls and the roof, thermal zone or HVAC components of the buildings. Accessing IFC data file needs the assistance of a toolbox. There are several of them available so far, such as Eurostep, Olof Granlund Oy-BSPro COM Server, EPM-EXPRESS Data Manager, and Secom Ltd’s Yoshinobu Adachi-IFCsvr ActiveX Component and IFC Model Server. Eurostep Active Toolbox is selected as the toolbox in the framework. It is an Active X component which provides an interface to access IFC data model. Since it applies COM technology, it is very easy to be incorporated into almost any application running on 32-bit MS Windows ix86 platforms. Accordingly, it can be used in VBA, Visual Basic, Delphi and different C++ IDE environments. So far it has several versions which comply to all major releases of the IFC schemas, such as IFC1.5.1, 2.0, 2x, and 2x2 (Eurostep Group, 2004). Eurostep Active Toolbox in IFC 2x2 version has functionality such as creating IFC text files, creating, retrieving, deleting IFC instances, setting or editing attribute values for IFC instances, listing all attributes for an IFC instance, listing all entity names in the IFC 2X2, etc.

3.2.2. General Data Input

General Data Input is an interface for users to input data manually. There are two scenarios to use it. First, after the user has imported geometric data from IFC file, s/he can use it to input data other than geometry. Second, if the user does not select importing IFC file, s/he can use this interface to input all data including geometric data for the framework. One of the tap pages (Step 3) in this interface is shown in Figure 2. On the left-hand side, the user can use the combobox to input information such as name, thickness, and initial moisture content of material layer in a wall. S/he also can input text attributes to identify whether the layer is wood-based material. Moreover, the user can input information about the interior and exterior finishes of the wall. The example is the input data for a wall with four material layers such as gypsum board, glass-fiber insulation, fireboard sheathing, and sugar pine. Both the interior and exterior finishes are latex paint. A graphical cross section of this wall is illustrated on the right-hand side. As for the table in the bottom of the window, it is the list of the material names which exist in the database of the framework.

3.2.3. Database for Data Input

There is a database in the preprocessor to manage the input data such as geometry data, weather data and material information. The user can access this data by the interface of General Data Input. So far, the user can interact with the database to list the material names, add a new material, modify, delete, or update a material. In the future, the preprocessor will not only extract data from the IFC file, but also add new IFC objects to, or update the existing objects in an IFC file.

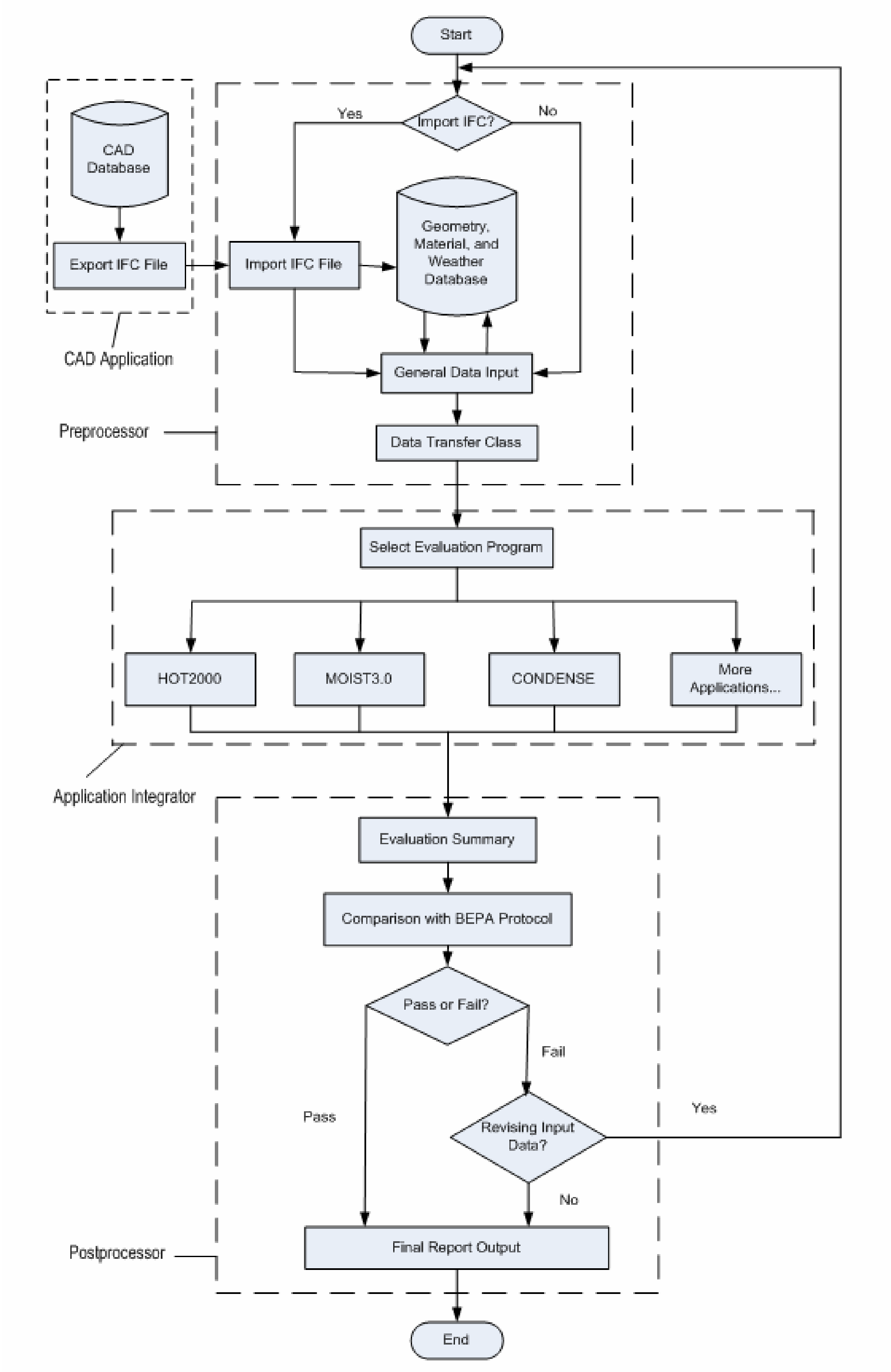
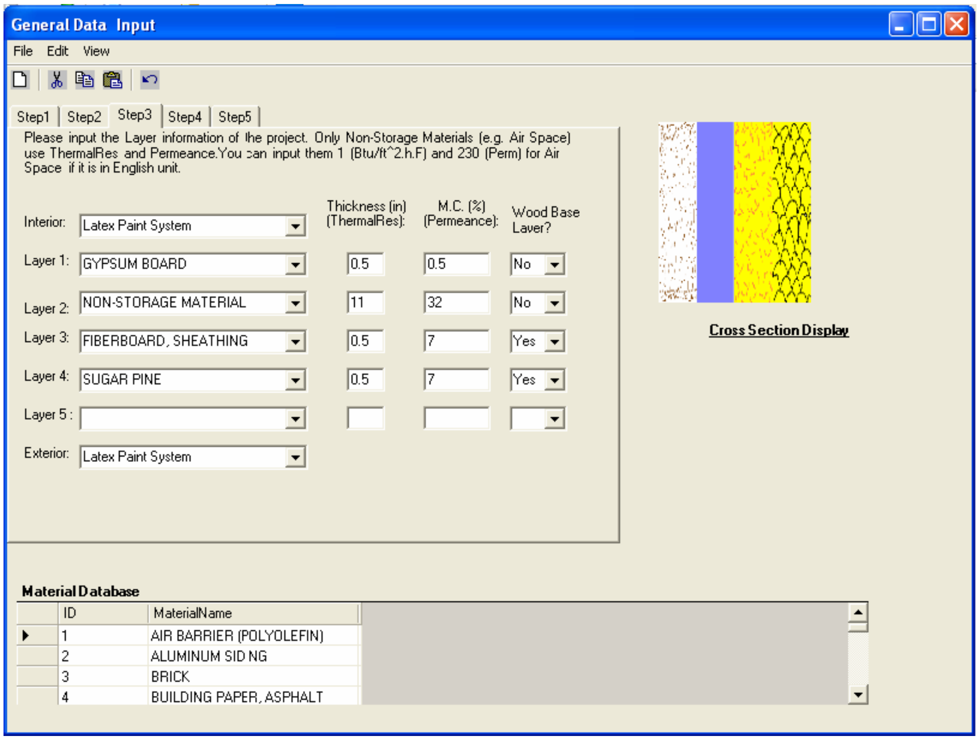


Figure 1. Building Envelope Evaluation Framework



Please input the Layer information of the project. Only Non-Storage Materials (e.g. Air Space) use ThermalRes and Permeance.You can input them 1 (Btu/ft^2.h.F) and 230 (Perm) for Air Space if it is in English unit.

		Thickness (in) (ThermalRes):	M.C. (%) (Permeance):	Wood Base Layer?
Interior:	Latex Paint System			
Layer 1:	GYPSUM BOARD	0.5	0.5	No
Layer 2:	NON-STORAGE MATERIAL	11	32	No
Layer 3:	FIBERBOARD, SHEATHING	0.5	7	Yes
Layer 4:	SUGAR PINE	0.5	7	Yes
Layer 5 :				
Exterior:	Latex Paint System			

Material Database

ID	MaterialName
1	AIR BARRIER (POLYOLEFIN)
2	ALUMINUM SIDING
3	BRICK
4	BUILDING PAPER, ASPHALT

Figure 2 General Data Input

3.2.4. Data Transfer Class

Data Transfer Class is the internal data structure of the framework. It could be a single class or a set of classes depending on how many applications have been linked in the Application Integrator. This internal data structure is to map the data which is imported from the IFC file and the General Data Input. It defines all the data in the framework as well as the functions that these data invoke. Moreover, it is an extensible structure which can be scaled to suit the applications that the framework includes in the Application Integrator.

3.3. Application Integrator

Application Integrator integrates the simulation programs such as HOT2000 and MOIST3.0. It is a linkage between the preprocessor and the simulation programs as well as a receptor for the data that are transferred from the preprocessor. In the long term, it is planned to make it possible to link to any necessary applications, such as HOT2000, Energy Plus, WUFI-ORNL/IBP, hygIRC, MOIST, CONDENSE, and Airpak. Nonetheless, linking to the simulation applications needs technical support from their developers by providing APIs (Application Programming Interfaces) so that the framework could access the applications. Currently, only the APIs for MOIST3.0 and HOT2000 (Batch version) are available.

3.3.1. HOT2000 Linkage

HOT2000 is developed by NRCan (Natural Resource of Canada) and is an energy analysis tool for low-rise residential buildings. It can evaluate the building design accurately by its heat loss or gain and system performance models including the thermal effectiveness of the building and its components, the passive solar heating owing to the location of the building and the operation and performance of the building's ventilation, and heating and cooling systems (Buildings Group NRCan, 2004). HOT2000's Windows version can be downloaded freely in the public domain, but the framework could not link to it directly because the Windows version has no API. However, NRCan has provided two methods to link to HOT2000. One is HOT2000 API with DLL (Dynamic Link Library) (Haltrecht et al., 1999); the other is

BATCH HOT2000 (Bradley, 2003). In this research, the framework links to HOT2000 by BATCH HOT2000 since it is simpler than by the DLL in terms of programming. The BATCH HOT2000 version's original purpose is to estimate the space heating requirements for a large number of houses. Both the input and output data are written in ASCII files. The input data for a house are stored in a pair of files, *.V71 and *.V80. The data input in the preprocessor of the framework are transferred to the HOT2000 by overwriting the *.V71 and *.V80 input files (Bradley, 2003). The framework invokes the BATCH HOT2000 program, and then calculates and outputs the result.

3.3.2. MOIST 3.0 Linkage

MOIST3.0 is a computer model and a user-friendly window application developed by NIST. It predicts the transfer of heat and moisture in a multi-layer wall under non-isothermal conditions. It calculates the moisture content of the construction layers as a function of time using a one-dimensional moisture transfer model with diffusion and capillary flow. It simulates the moisture-transfer permeance offered by vapor retarder and paint layers. Convective moisture transfer induced by air cavities is included in the model (Burch et al., 2001, 1997). MOIST3.0 has a simulation sub-program (analyze.exe) that loads the input files, performs heat-moisture calculations and saves results to the output files. Both the input and output files are in ASCII format. In our framework, after the end-user inputs data by the interface General Data Input or Import IFC Text File, the input data are mapped in the memory by the Data Transfer Class. Then, the framework transfers data from Data Transfer Class to MOIST's input files, invokes analyze.exe, and then writes the results to MOIST's output files. The results in the output files are extracted by the Evaluation Summary in the Postprocessor.

3.4.Postprocessor

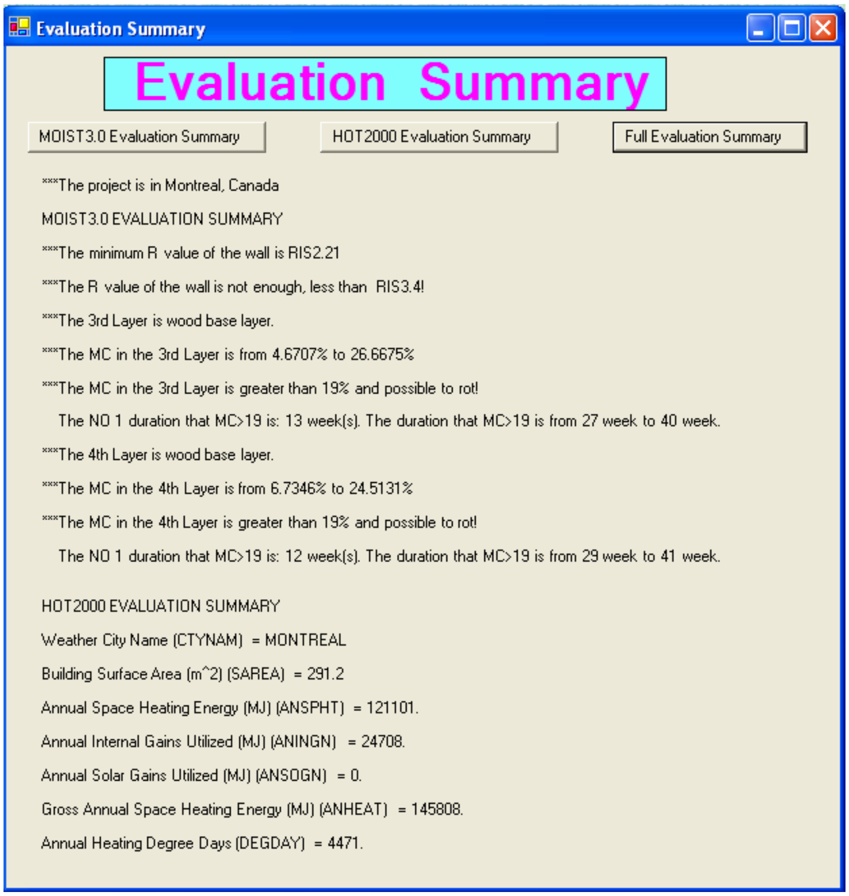
Postprocessor is a function unit in the framework that processes the output from Application Integrator. It is used to summarize the performance evaluation results from the simulation programs such as HOT2000 and MOIST3.0, retrieve performance evaluation criteria from the database, compare the evaluation summary with the retrieved criteria and create a final report.

3.4.1. Evaluation Summary

In the Application Integrator, each application evaluates the house from its respective aspects, for instance, HOT2000 is focusing on energy simulation in a house and MOIST3.0 is focusing on thermal and moisture analysis in a wall or roof. However, the output of these applications is very complicated and large in size. Therefore, it is very difficult for a user who has no expertise in these applications to interpret the results. The Evaluation Summary is to simplify the results by selecting the contents that the user may be most interested in. These selected results will be used to compare with a set of criteria which will be discussed in the next section.

3.4.2. Evaluation Criteria

The results from the Evaluation Summary need a set to criteria to be evaluated. Several protocols in the world already exist to evaluate the overall or part of the performance of a house, for example, the P-mark in Sweden (SP, 2004), the Housing Quality Assurance Law (HQAL) in Japan (Eastin et al., 2000), the European Technical Approval Guidelines ETAG 007 in Europe (EOTA, 2002), and the Partnership for Advancing Technology in Housing (PATH) in the United States (PATH, 2004). In Canada, there is the R-2000 program (NRCan, 2004) and the Novoclimat from Quebec (Quebec Agency for Energy Efficiency, 2004; Horvat, 2002). To advance the concept of overall building performance, the research group on the building envelope at Concordia University first undertook the classification of the requirements and standards governing building performance resulting in the Building Envelope Performance Assessment (BEPA) Protocol which is under development (Horvat & Fazio, 2004a, 2004b). Its purpose is to evaluate the overall performance for light-frame site-built or prefabricated residential and



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***The project is in Montreal, Canada
MOIST3.0 EVALUATION SUMMARY
***The minimum R value of the wall is RIS2.21
***The R value of the wall is not enough, less than  RIS3.4!
***The 3rd Layer is wood base layer.
***The MC in the 3rd Layer is from 4.6707% to 26.6675%
***The MC in the 3rd Layer is greater than 19% and possible to rot!
   The NO 1 duration that MC>19 is: 13 week(s). The duration that MC>19 is from 27 week to 40 week.
***The 4th Layer is wood base layer.
***The MC in the 4th Layer is from 6.7346% to 24.5131%
***The MC in the 4th Layer is greater than 19% and possible to rot!
   The NO 1 duration that MC>19 is: 12 week(s). The duration that MC>19 is from 29 week to 41 week.

HOT2000 EVALUATION SUMMARY
Weather City Name (CTYNAM)  = MONTREAL
Building Surface Area (m^2) (SAREA)  = 291.2
Annual Space Heating Energy (MJ) (ANSPHT)  = 121101.
Annual Internal Gains Utilized (MJ) (ANINGN)  = 24708.
Annual Solar Gains Utilized (MJ) (ANSOGN)  = 0.
Gross Annual Space Heating Energy (MJ) (ANHEAT)  = 145808.
Annual Heating Degree Days (DEGDAY)  = 4471.
```

Figure 3 Evaluation Summary

small commercial building envelopes. The following functional requirements are included in this protocol: structural stability, air tightness, moisture management performance, thermal performance, energy performance, acoustic performance and fire control of the building envelope. At present, the criteria are based on Montreal's climatic, technical and social environment. However, it is envisioned to represent a framework for developing similar protocols and assessment tools for examining performance of building envelopes under different parameters, priorities, technologies and building traditions that exist in various regions and countries in the world (Horvat & Fazio, 2004 &2005).

3.4.3. Comparison between the Evaluation Summary and the BEPA Protocol

The BEPA Protocol is used to evaluate the results in this research since it focuses on the building envelope of a house and relates to not only durability but also energy conservation. Although it is limited to Montreal area so far, it may be applied to other areas in Canada and other countries in the future. With the BEPA Protocol, the framework can search for the rules corresponding to the results in the Evaluation Summary; then the results are checked against the retrieved rules. If the results meet the requirement of the rules, they are accepted and the framework will output the final report. Otherwise, the user can go back to the very beginning of the framework flow and revise the input data. During this process, knowledge-based code checking with IFC technology is applied. So far, the comparison is limited to one part of BEPA Protocol by extracting the rules (clauses) within the framework, so the above code compliance process is only at the conceptual stage and the implementation of the concept will be integrated into the framework in the near future. Figure 3 is the interface of the evaluation summary and the compared results with part of BEPA Protocol. The user can view information from the MOIST3.0 Summary including the R-value of the wall and comparison of this result with the respective criterion. For wood based material, the summary shows the range of moisture content in the layer. If moisture contents are greater that 19% or 29%, the summary indicates the duration in which the moisture contents are greater than these two values. The information from the HOT2000 summary includes: name of the city, building surface area, annual space heating energy, annual internal gains utilized, annual solar gains utilized, gross annual space heating energy, and annual heating degree days.

4. CONCLUSIONS AND FUTURE WORK

The research presented in this paper has developed a building envelope evaluation framework which can readily used to evaluate the total performance of a housing system by integrating existing applications in structural and mechanical systems. In order to provide the framework with interoperability, the international standard IFC has been selected as the data model, and geometric data of the building have been extracted by Eurostep toolbox from the IFC model. So far, MOIST 3.0 and HOT2000 have been successfully linked due to the availability of APIs. The summary result from the evaluation applications has been partially compared with a developing protocol BEPA to offer the end-user a professional evaluation.

The current project succeeded in extracting geometric data from IFC. The latest IFC2x2 version has integrated many data related to building service, code checking, and electrical service, which will be useful to integrate with the building envelope. Moreover, when data are not included in IFC2x2, it is possible to extend IFC to include these data. Therefore, beside the geometric data, it is possible to extract any kind of data that the framework needs from the IFC data file.

Theoretically speaking, data can be read from (extracted) and written to (stored) an IFC file in the framework. Currently, the framework can only extract data from the IFC file. In the future, it is planned to enable the framework to add new IFC objects to or update the existing objects in an IFC file.

The comparison between the criteria and the evaluation results is limited to one part of BEPA Protocol by extracting the clauses and adding them in the framework, so the code compliance process is only at the conceptual stage. In the future, a database storing all the clauses of the BEPA will be introduced in the framework and the knowledge-based and code compliance checking with IFC technology may be applied to demonstrate the full concept.

5. ACKNOWLEDGEMENT

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6. REFERENCES

Bazjanac, V. (2004). Building energy performance simulation as part of interoperable software environments.
Bazjanac, V. and Maile, T. (2004). IFC HVAC Interface to EnergyPlus-a Case of Expanded Interoperability for Energy.
BFRL/NIST (2004). http://www.bfrl.nist.gov/863/moist.html.
Buildings Group NRCan (2004). http://www.buildingsgroup.nrcan.gc.ca/software/hot2000_e.html
Bradley, B. (2003). BATCH HOT2000, Draft for Version 9.2.
Burch, D. and George T. (2001). MOIST: A numerical method for design.
Burch, D. and Chi, J. (1997). MOIST a PC program for predicting heat and moisture transfer in building envelopes Release 3.0.
BFRL (2004) http://www.bfrl.nist.gov/863/moist.html.
Eastin, I. and Boardman, P. (2000). Regulatory Change in the Japanese Residential Construction Industry, CINTRAFOR News, Vol. 16, No.2, http://forests.org/archive/asia/jahosect.htm.
Eurostep Group (2004). http://www.eurostep.com/.

EOTA (2002). Draft ETAG007 http://www.cmhcschl.gc.ca/en/homadoin/excaprex/suexin/suexin_024.cfm
Fluent (2004). Airpak http://airpak.fluent.com/.
Fazio, P. (1990). A case study in integrated building design Canadian Journal of Civil Engineering.
Granlund (2004). RIUSKA software http://www.granlund.fi/granlund_eng/ohjelmistomyynti/frameset.htm.
Haltrecht, D., Bradley, B., and Wise, C. (1999). Application Programmer's Interface, API specification.
He, H.S., Hammad, A., Fazio, P. (2005). Application of IT and international standards to improve building envelope performance
Horvat, M. and Fazio, P. (2004). Comparative Review of Existing Certification Programs and Performance Assessment Tools for Residential Buildings.
Horvat, M. and Fazio, P. (2005). Protocol and Assessment Tool for Performance Evaluation of Light-frame Building Envelopes.
Hutcheon, N.B. (1966). CBD 48: Requirement for Exterior Wall, Canadian Building Digest.
Hydro Quebec (2004) http://www.hydroquebec.com/residential/energywise/index.html.
Horvat, M., Fazio, P. and Poliquin, L. (2002). Durability in Housing: a Review of Quality Certification Programs and Recommendations.
IAI (2004). http://www.iai-international.org/iai_international/.
IRC/NRC (2004). http://irc.nrc-cnrc.gc.ca/.
ISO (1999). International Standard ISO10303-225.
ISS (2004). Robot with Robin Building Modeler http://robotstructures.com/usa/.
Karola, A., Laine, T., Lassila, K., Lahtela, H., and Jokela, M. (1999). Simulation data management in the design process.
Liebich, T., Wix, J., Forester, J. and Qi, Z. (2002). Speeding-up building plan approvals, the Singapore e-Plan checking project offers automatic plan checking based on IFC.
NRCan (2004). R-2000 Standard http://oee.nrcan.gc.ca/english/r2000_standard_tofc.cfm
ORNL/IBP (2004). http://www.ornl.gov/sci/btc/apps/moisture/.
PATH (2004). http://www.pathnet.org/sp.asp?mc=about_about.
Quebec Agency for Energy Efficiency (2004). http://www.aee.gouv.qc.ca/habitation/novoclimat/.
Romberg, R., Niggl, A., van Treeck, C., and Rank, E. (2004). Structural Analysis based on the Product Model Standard IFC.
Suter, G. and Mahdavi, A. (2004). Elements of a representation framework for performance-based design.
SP (2004). http://www.sp.se/eng/spenergi/kvalitetssakring.htm.
Timberline (2004). http://www.timberline.com/software/estimating/applications/cad_integrator.aspx.
U.S. Department of Energy (2004). http://www.eere.energy.gov/buildings/EnergyPlus/.
Wong, N. H. (2004). Integration of CAD and Thermal Simulation through Industry Foundation Classes (IFC) Product Model.