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MAPPING OF INDUSTRY BUILDING PRODUCT MODEL FOR THERMAL SIMULATION AND ANALYSIS

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ABSTRACT

The Industry Foundation Classes (IFC) has established a standard for defining interchangeable data formats among various computer models in Architecture/Engineering/Construction (AEC) domains. Researchers and practitioners are encouraged to make their data models compliant to the IFC standard through either adopting new data structures or creating bridges that can convert IFC data to be used by the various proprietary models. SEMPER II (S2), which is an active, multi-domain, spaced-based, object-oriented design support tool for integrated building performance computing, was developed before the IFC standard was established. An add-on data mapping engine has been integrated to extract embedded information in the IFC compliant data models based on eXtensible Markup Language (XML) format. This paper demonstrates a seamless link between IFC compliant industry building product model (e.g., CAD) and the Shared Object Model (SOM) of S2 to facilitate building performance simulations.

INTRODUCTION

There is a growing trend in building design towards a performance-based rather than the conventional prescriptive-based approach. To support this, it is desirable to be able to conduct building performance simulations for "real world" projects based on generic data models accepted by building industries globally. In October 2000, the Building and Construction Authority of Singapore (BCA) awarded two contracts to novaCITYNETS Pte Ltd, Singapore, to build the Integrated Plan Checking System for Building Plans and Building Services (IBP and IBS Systems, now termed ePlanCheck) and the One-Stop Submission Center (OSSC, now termed eSubmission), which facilitates electronic submissions, processing and approval of building project documents over the Internet. The automated plan submission cum checking systems are part of the Construction and Real Estate Network (CORENET), a major Information Technology (IT) initiative spearheaded by the BCA, a statutory board under the Ministry of National Development, in collaboration with several public and private organizations. It aims to re-engineer the business processes of the construction industry to achieve a quantum leap in turnaround time, productivity and quality. Within the scope of eSubmission and ePlanCheck systems, building performance-based simulation is envisaged to be a feature in the framework in the future.

SEMPER-II, which is a collaborative research project between the National University of Singapore (NUS), Temasek Polytechnic (TP) and Carnegie Mellon University (CMU), involves the development of an internet-based building design and performance simulation environment. It provides a dynamic "real-time" simulation and performance prediction environment over the Internet for conducting virtual collaborative design, modeling and engineering processes. The research aims to establish an industry standard for performance-based design support involving multiple collaborating parties in a distributed environment [Lam, et. al. 2001 and 2002; Mahdavi, et. al. 1995, 1996, 1998, 1999, and 2000; novaCITYNETS 2001; Wong, et. al. 2000].

This paper discusses the key findings of a research project entitled "Mapping of Industry Building Product Model for Detailed Thermal Simulation and Analysis", which is a collaborative effort between novaCITYNETS and the SEMPER-II research team (NUS, TP and CMU). It involves a study of the potential of mapping the information model of ePlanCheck developed by novaCITYNETS with the Shared Object Model (SOM) of SEMPER-II to establish a seamless link between the information model of ePlanCheck and the Integrated Thermal Modeler (ITM) of SEMPER-II for thermal simulation and analysis.

The ePlanCheck Information Model and the Shared Object Model of SEMPER-II

The novaCITYNETS ePlanCheck information model refers to an Industry Foundation Class (IFC) 2x compatible model used for plan submission and checking, with CAD customization for ePlanCheck within the BCA's CORENET framework [IAI Modelling Support Group; Mahdavi et. al. 1999]. The drawing files will be submitted in IFC format into the ePlanCheck Model server. The ePlanCheck application has the capability to provide a view to the IFC data in XML format [Flynn 2002] that contains geometry and attribute data. The Internet deployment faciliates convenient and easy access to online plan submission. The novaCITYNETS ePlanCheck information model also makes plan checking for prescriptive regulatory compliance an integrated part in the approval process. In future, the thermal simulation server can receive this data through the Web-Services front-end from the ePlanCheck server for building performance related simulations (Figure 1).

The Shared Object Model (SOM) is a hierarchically structured template representing building elements in the SEMPER-II (S2) simulation environment. The SOM is designed to capture the essential elements of a building and their properties, to the extent required by the simulation applications in the S2 environment [Mahdavi 1996]. One of the common approaches for exchanging information among two or more parties in the building design and construction processes is via drawings, both in the physical and digital forms. However, the raw digital information in the drawings invariably cannot be directly interpreted by the simulation engine. An industry standard, viz., the Industry Foundation Classes (IFC), has emerged in recent years. It calls for the adoption of a generic hierarchical object model to abstract building components and processes [IAI Modelling Support Group 2001; Liebich, et. al. 1998]. With the support of information technology, the IFC standard can be implemented with some internet-based technologies such as the eXtensible Markup Language (XML) data technology which provides neutral and structured data format for exchanging data among different computer models [Wix, et. al. 1998].

In this project, the S2 application is used as the "back-end" thermal simulation engine. However, it currently lacks the ability of importing IFC compatible data files generated by novaCITYNETS ePlanCheck Information Model, which are presented in XML format. Therefore, it is necessary to evaluate the potential of mapping the XML data of the novaCITYNETS ePlanCheck model to the S2 SOM with the development of a "model mapping engine". It is also crucial to study what other types of information, besides geometry attributes, are required for conducting the thermal and energy simulation.

As shown in Figure 2, the CAD drawing needs to be converted to an XML file that encapsulates all the information with hierarchical structure which is compliant with the IFC standard. Therefore, it requires a model mapping engine in the S2 Graphic User Interface (GUI) to read and translate the XML data to be used for thermal and energy simulation. The intention is to feedback the simulation results to the designer so that improvement to the design can be made accordingly, where necessary.

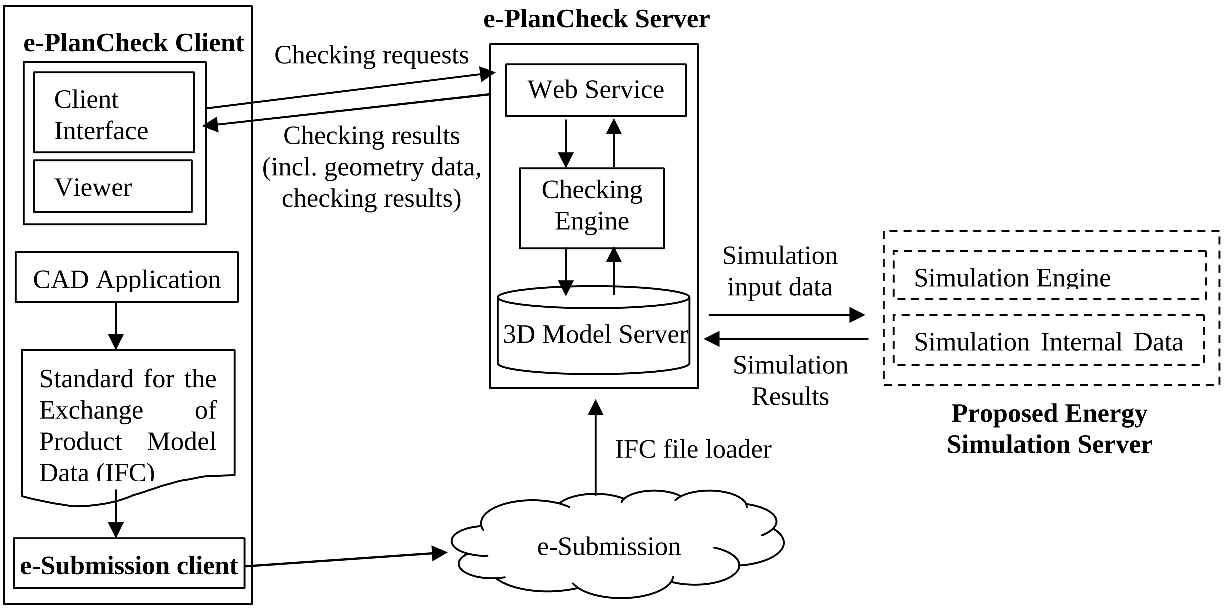

Figure 1 Application data flow of novaCITINETS ePlanCheck information model

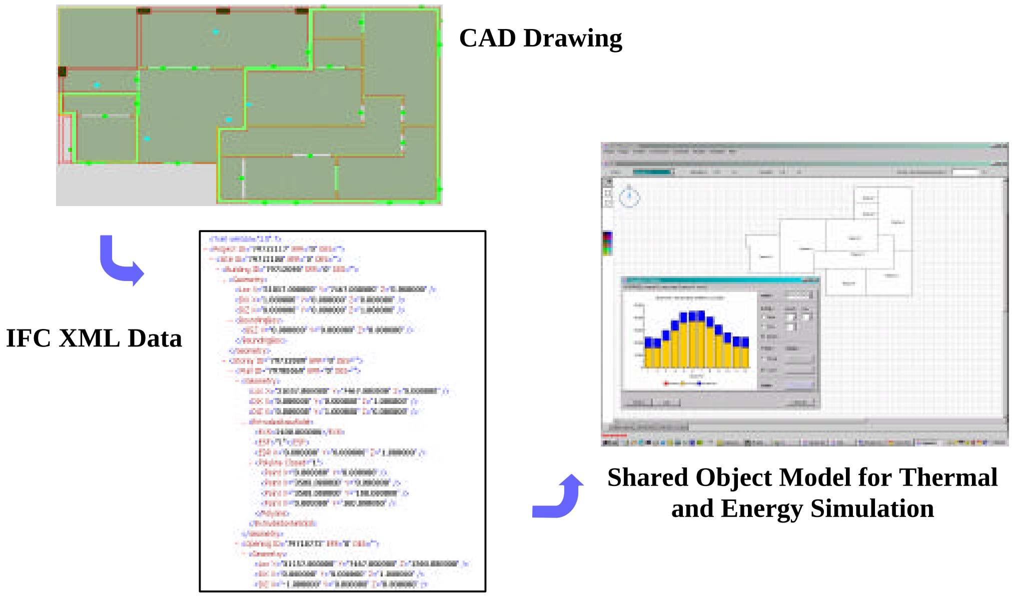

Figure 2 The linkage between CAD drawings and the simulation engine through the XML data mapping.

DATA MAPPING BETWEEN THE TWO MODELS

The actual mapping process involves the development of a bridge that allows the transfer of building information from the novaCITYNETS model to the internal data store of the S2 SOM. This bridging, though automated to a certain extent, requires a data translator as well as some level of user intervention and additional information before the thermal simulation can be performed.

The Model Mapping Engine

The S2 application comprises the SOM, a GUI where users draw building spaces and input relevant parameters, and a hub through which users connect to the server and run the simulation. The application is written in the Java language. The output from the novaCITYNETS ePlanCheck Information model is an IFC compatible XML file, the format of which represents a neutral and structured data type exchangeable amongst two or more different computer models.

A front-end model mapping engine has been developed to read the XML data, filter out irrelevant information and translate into the S2 application. Material properties are then assigned and the simulation environment is set up for the subsequent simulations in S2. This dedicated model mapping engine provides the ability for seamless data mapping. This model mapping engine is written in Java and can be invoked directly from the S2 GUI in the same way as opening another supported data format. The model mapping engine has been developed with Java 2 v1.2.2 and Apache Xerces XML Parser v1.2 which implements JAXP.

Data Mapping

The data mapping flow is shown in Figure 3. It includes the following processes:

- The NovaCITYNETS ePlanCheck Information model generates an IFC compatible XML file which records geometry information of the building from a

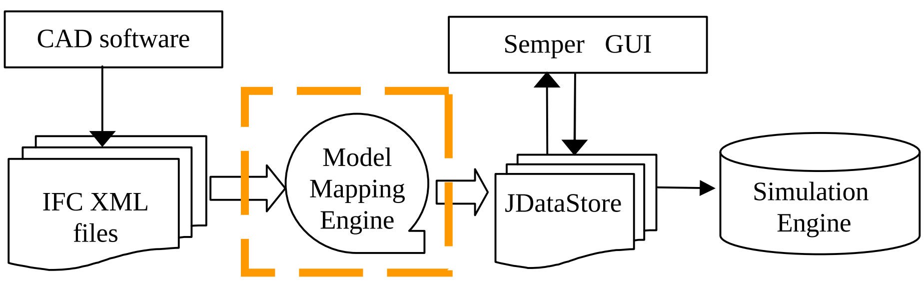

Figure 3 Data mapping flow.

CAD drawing, in this case, an ArchiCAD drawing format;

- In the S2 GUI a user opens the XML file. The S2 application invokes the XML Parser automatically to populate the SOM with the translated XML data. All geometry information related to the simulation will be stored in the SOM. Data parsing is via the XML SAX API;
- The user saves the SOM into a .jds file which is an intermediary data storage format used by the S2 application, uploads the .jds file into the S2 server and performs the thermal and energy simulation.

It requires no additional effort from the user during the mapping process. However, within the S2 application, the user may change a few default settings, or change certain material properties before uploading to the S2 server. At present the S2 application supports three data formats, i.e. the local .jds data format, the IFC compatible XML format, and another "generic" ArchiCAD generated data format.

Table 1 shows the detailed data mapping between the NovaCITYNETS IFC compliant data components and the S2 SOM elements. The present support of building performance simulation from comercialized CAD models is unfortunately insufficient. Much required data, e.g. material properties and some geometry components, are not available in the submitted drawings. In general, the object hierachy of S2 SOM is similar to that of the IFC standard. Practically, the novaSprint CAD model does not include all the geometry object components, e.g., shade. The mapping process is quite straightforward as shown in the Table 1. All other missing data can be manually assigned in the S2 GUI as user customization. In the future implementation, those important missing data should be integrated in the original CAD models.

Nodal Representation of Spaces

After mapping the XML data into the SOM, post processing is required to remove all the "gaps" between spaces which the CAD model generates. This is because the S2 simulation engines require the nodal representation of spaces derived from the physical geometry information of spaces and enclosing surfaces (i.e., walls and floors). In other words, the original geometry data in a CAD drawing cannot be used directly by the simulation engines. One of the functions of the model mapping engine is to adopt an algorithm to abstract the CAD drawing into its nodal representation without affecting the validity of the simulation results. At present, various CAD software in the market employ different means in drawing the walls. A common way is to draw the walls based on their reference lines, which could be the center lines, inner lines or outer lines, depending on the preference of the users. The solution implemented in this project is to adhere to the center lines of walls and recalculate the intersection points (i.e., vertices) of spaces. Another potential problem we have encountered is that the geometry data in the XML files may have precision discrepancies with those in the original CAD drawings. More specifically, the output of an integer value may turn out to be a double (e.g. xxx.999), which consequently may generate errors in constructing the space in the SOM. Our solution is to round the value with some kind of tolerance. The model mapping engine takes care of this process during the parsing phase. This will not affect the geometrical configuration of the building significantly since the thickness of the enclosing elements is very small compared to the width/height of the spaces. Figure 4 demonstrates how to convert the actual geometry information into its nodal representation. Once this process is executed, it is then ready for performing the simulation.

Table 1 Mapping between the novaCITYNETS IFC and the S2 SOM elements.

novaCITYNETS XML Data	SOM of S2
Project (ID)	SOMProject (Name)
Site (ID, Type*)	SOMSite (Name, Type)
Building (ID, Type*, Geometry, Azimuth*)	SOMBuilding (Name, Type, Geometry-SOMPolyhedron, Azimuth)
Story (ID)	SOMSection (Name)
Space (ID, Geometry)	SOMSpace (Name, Type, Geometry-SOMPolyhedron)
Wall (ID, Geometry)	SOMSpaceEnclosure, SOMEnclosure (Type, Geometry-SOMPolygon)
Opening	SOMAperture (Type, Geometry-SOMPolygon)
	SOMShade (Type, Geometry-SOMPolygon)

*Note: * indicates data currently does not exist in the model.*

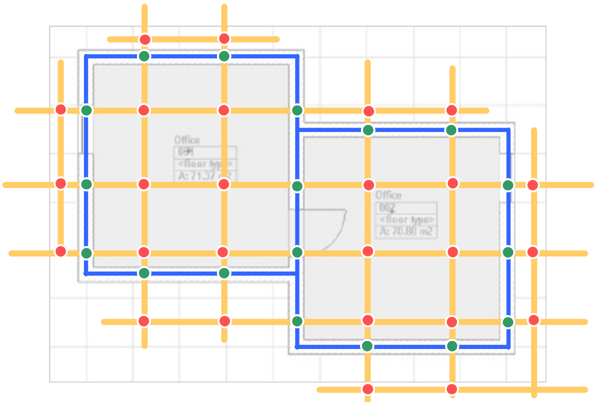

Figure 4 Nodal Representation of a CAD Drawing

THERMAL AND ENERGY SIMULATION

Data Requirement

The fundamental requirements for conducting the thermal and energy simulation in the S2 environment include:

- Geometry information of spaces, walls, openings and their nodal representations;
- Material properties of walls, floors, ceilings, and openings;
- Internal and external boundary conditions;
- A distributed computing environment.

The above data can be obtained from either within the S2 application or external data sources (e.g., the IFC compliant CAD models). The SOM of S2 provides a hierarchical data depository of building elements and the GUI of S2 offers entries for the customization of simulation settings.

Work flow

The project case demonstrated here was supplied by novaCITYNETS. Figure 5 shows the ArchiCAD drawing of a single-storey bungalow with 11 spaces. The original data from novaCITYNETS is an XML file, with all the geometry information regarding the project, e.g., spaces, walls, slabs, columns, openings, doors and windows, etc. The XML data file is opened in the S2 GUI through the model mapping engine. Redundant data are ignored and the geometry information is recalculated and converted to its nodal representation. Figure 6 shows the "raw" geometry representation after completing the first phase of data mapping. There are gaps, which represent the walls between spaces. This representation cannot be used for the thermal and energy simulation. Hence, the model mapping engine executes a second phase process to convert it to a nodal representation, as shown in the Figure 7. It can be seen that all the gaps between spaces are removed.

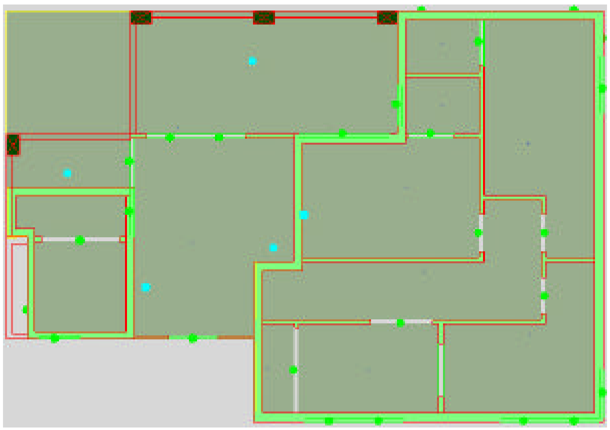

Figure 5 A demonstrative project case – single story bungalow

This mapping process has only dealt with the geometrical data so far. The NovaCITYNETS ePlanCheck Information model has not implemented other necessary data input for simulation, such as the thermal properties of the wall materials, as the current IFC implementation in CAD tools is still under development, towards capabilities for thermal Simulation. Such data are currently not available and have to be obtained from a separate database within the S2 environment. Other simulation settings can also be set or changed accordingly in the S2 GUI. Figure 8 shows the GUI for making changes to the weather data input, selecting spaces for simulation, simulation domain(s), duration, grid size resolution, etc. These settings are saved in a .jds data storage file locally in the user's computer.

The S2 GUI provides network capability for connecting to the simulation server through CORBA agent. Once connected, the .jds file is uploaded and the simulation is executed consequently.

Simulation Result

After completing the simulation, the result is downloaded and displayed, as shown in the Figure 9. This result can be used for analyzing the design and ultimately for regulatory plan checking purposes. The above procedures successfully demonstrate the seamless link between the novaCITYNETS ePlanCheck Information model and the SOM of SEMPER-II for building performance simulation.

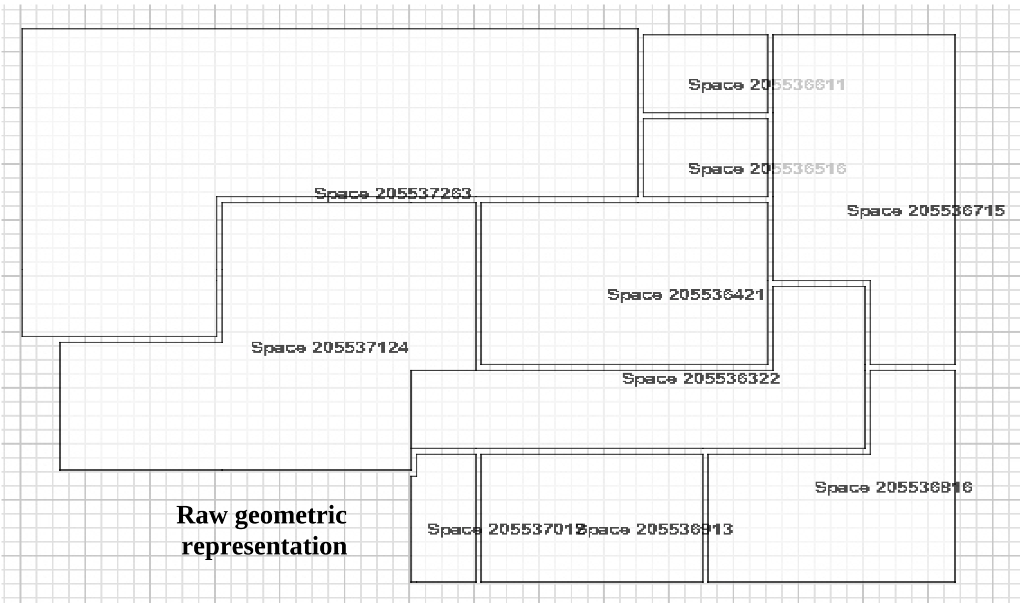

Figure 6 The raw geometric representation after the first phase of mapping the XML data

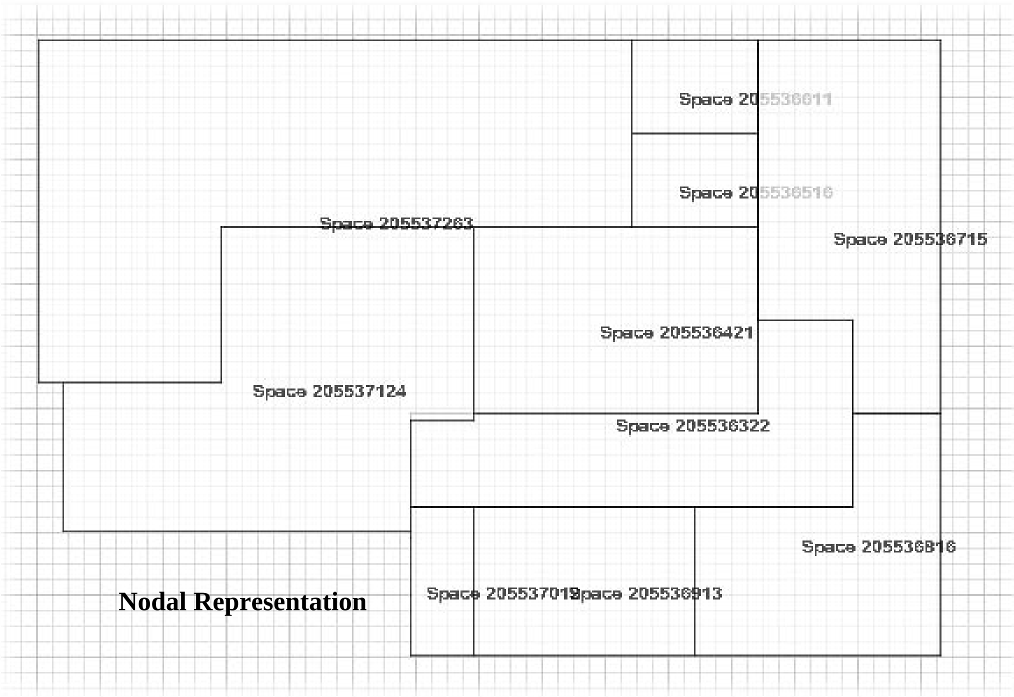

Figure 7 The nodal representation after the second phase of mapping the XML data

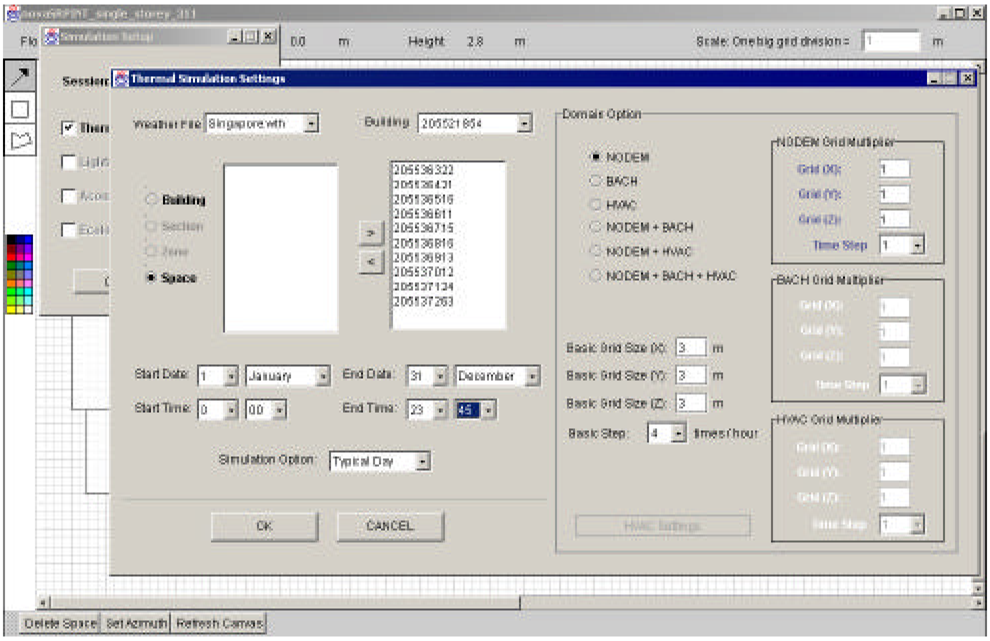

Figure 8 GUI for making changes to the simulation settings

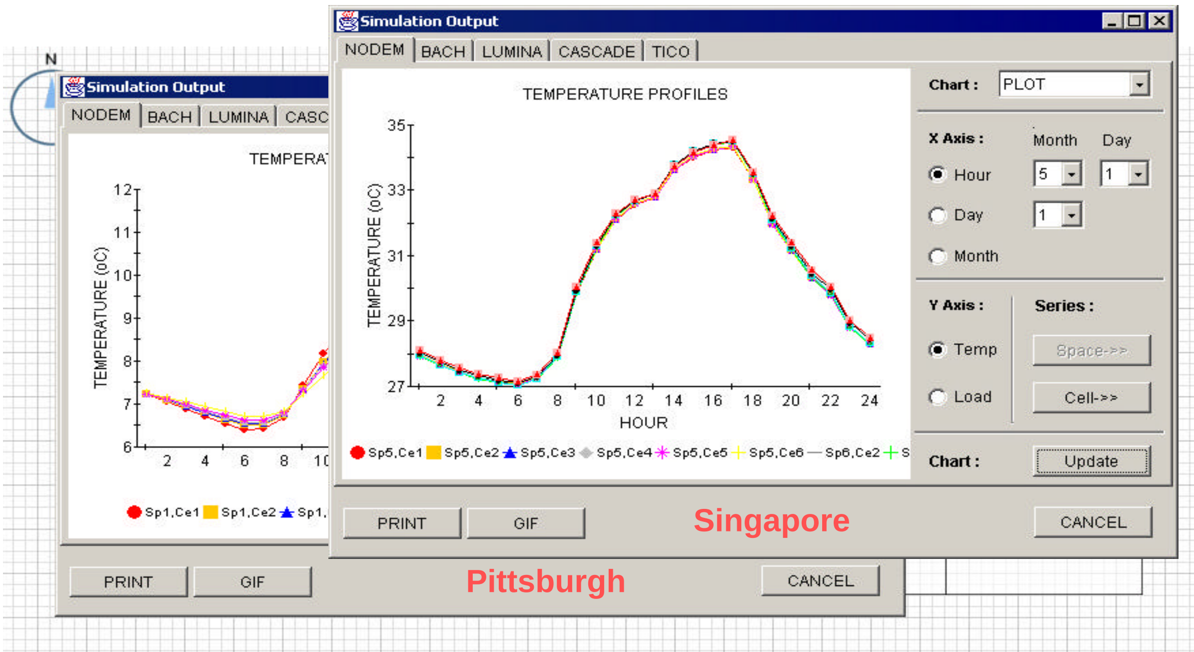

Figure 9 S2 thermal and energy simulation results

CONCLUSION

The research on "Mapping of Industry Building Product Model for Thermal Simulation and Analysis" aims to create a bridge between the IFC compatible CAD model and the Shared Object Model of the SEMPER-II. A dedicated model mapping engine, which is based on the Java and XML technology, has been developed to accomplish the task of translating external CAD-generated model data into the SEMPER-II model for performing thermal and energy simulation. The project has achieved its objectives and has successfully implemented the following:

Mapping of novaCITYNETS ePlanCheck information model and the Shared Object Model of SEMPER-II, thus enabling building performance simulation to be conducted, based on the geometry information extracted from the commercially available CAD drawings; and

Development of a front-end model mapping engine for the SEMPER-II SOM which provides a seamless link between the IFC compatible XML data and the SEMPER-II simulation environment.

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