USABILITY AND INFORMATION MANAGEMENT OF ENERGY SIMULATION INPUTS: A COMPARISON BETWEEN 3 TOOLS

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ABSTRACT

Energy simulation software is a key enabler in building design to optimise energy efficiency, reduce operating costs, comply with code requirements and qualify for incentive programs. However, numerous software are available and it could be difficult to choose the most suitable one. This paper presents a comparative study of three very popular tools among firms in the province of Quebec, Canada: EE4, SIMEB, and eQUEST. Based on a simulation experiment (using case study), these tools were evaluated based on their Usability and Information Management. Qualitative and quantitative outcomes are used to assess the characteristics of the tools.

INTRODUCTION

Energy simulation tools support better understanding of building elements by visualizing design ideas, analysing building performance and predicting energy consumption. They allow designers to make more energy conscious decisions.

Multiple building energy simulation tools exist with different Graphical User Interface (GUI), calculation engines, features and capabilities. Some of these tools are commonly used among the Quebec industry. However, selecting the most appropriate simulation tool is still one of the biggest challenges among users. Different characteristics of the tool at various stages of the design process need to be taken into account. Based on a survey conducted by Attia et al. (2009) and presented in Figure 1, various aspects have been proposed for the selection of building performance simulation (BPS) tools. The generic tool comparison was completed for 10 different BPS tools. Among all the proposed aspects, Usability and Information Management of interface (UIM) was rated as one of the most important to designers (Attia et al., 2009). Hereof, this paper aims to adjust the evaluation process proposed by Attia et al. (2009) for three of Quebec's most used BPS tools. Furthermore, a more detailed approach is proposed to evaluate the UIM criteria by specifying sub-criteria. In addition to the detailed evaluation of the UIM for the three tools, the applicability, specific capabilities and mapping of the simulation workflow of the tools are proposed for different user types (architects and engineers) as well as their relevance at each of the design phases.
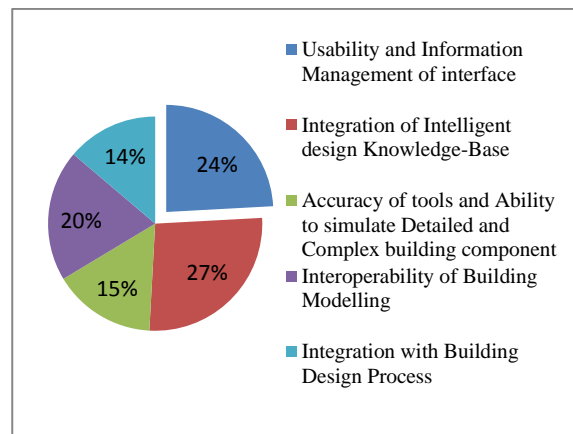

Figure 1 Five important criteria for selecting BPS tools [adapted from Attia, Beltrán, De Herde, & Hensen (2009)]

First, general definition of the tools will be briefly described, followed by a presentation of the evaluation index: the Usability and Information Management (UIM) criteria, as described in the literature.

The simulation workflow and the analysing methods will be explained using a case study. Finally, a comparison between the three tools will be completed including recommendations.

OVERVIEW OF THE THREE TOOLS

This section presents the main characteristics of the three tools compared in this study: EE4, SIMEB and eQUEST.

EE4, Version 1.7

EE4 is a simplified user interface for DOE-2.1e and one of the most commonly used software in Québec. EE4 was born out of a need to support compliance checking with performance path options of the Model National Energy Code for Buildings (MNECB) in Canada (Beausoleil-Morrison et al., 2001). An incentive program had been put in place by Natural Resources Canada's (NRCan) to encourage the design of buildings that were projected to reduce their consumption by 25% or more than a standard or "reference" building (NRCan). The results obtained

using EE4 may also be used to obtain LEED (Leadership in Energy and Environmental Design) 2009 credits for the energy performance category.

SIMEB, Version 3.1

SIMEB is an interface developed by Hydro-Québec as part of their program to improve energy efficiency of building. The software has three calculation engine options: DOE-2.1, DOE-2.2 and Energy Plus. This tool provides the necessary information for building team members, such as designers, building professionals, engineers and technicians, to develop integrated concepts for new buildings and energy wise renovations for existing building. SIMEB offers several features including a module to calibrate the simulation based on the billing history, a rapid building generation wizard and an hourly profiles analysis module (Millette, Sansregret, & Daoud, 2011). The archetypal function allows the quick generation of a building by entering a minimum of data at the design stage, such as architectural aspects, thermal envelop characteristics, occupancy schedules, lighting and mechanical systems to analyse energy consumption.

eQUEST, Version 3.55

eQUEST is a user-friendly energy simulation tool used for whole building performance analysis that uses DOE-2.2 as a simulation engine. It produces easy to use results via a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical results display module. The wizards in eQUEST simplify and speed up the simulation process. Creating multiple simulations via the wizard is one of the main advantages of eQUEST, which allows evaluating different alternatives using side-by-side graphical displays. Moreover, energy cost estimation and automatic implementation of energy efficiency measures are possible within the tool. A reference building model in eQUEST consider minimum energy efficiency level (e.g., minimally compliant with California Title24 or ASHRAE 90.1) which can be developed to provide LEED certificate (Hirsch, 2010).

USABILITY AND INFORMATION MANAGEMENT OF INTERFACE (UIM)

The UIM criteria combines presenting information using techniques and media to achieve communicative goals (Maybury & Wahlster, 1998). As it turns out, the two main criteria of UIM are usability and information management, which need to be entirely defined.

The usability is derived from the friendliness aspect of the tool and also includes ease of use (Bevan, 1999). As such, the Common Industry Format (CIF) has identified quality in use as a significant parameter of usability, which entails effectiveness, productivity and satisfaction to meet the goals (Bevan, 1999).

Usability consists of specifications of the tools such as default options transparency, data entry trees, representation of input and output, language, image and graphic capabilities (Maybury & Wahlster, 1998), flexible control and navigation, easy learnability (Attia, et al., 2012), GUI adaptability and error diagnostics (Attia et al., 2009). Attia et al. (2012) also emphasized that adaptability of tools to various users and design phases is one of the striking dimensions of usability. Furthermore, the capability to describe the building model is one of the most significant parameters to examine the tools usability (Crawley, Hand, Kummert, & Griffith, 2008). Moreover, Crawly et al. (2008) refer to the ability of exchanging data and building information from architectural software to energy simulation tools. For example, transferring CAD files to simulation tool makes the modelling and simulation easier and more efficient.

In fact, quickly evaluating alternative options is one of the priorities for modellers. Therefore, multiple reports, flexible graphs and presentation of key output can facilitate and improve the evaluation of alternative design options within the optimisation process (Mahdavi, Martens, & Scherer, 2014).

The second UIM aspect to consider is information management of interface. In general, information management is responsible for collection, organisation and distribution of data within the tools. For instance, using default values, templates, library and online help support (forum or guideline) are related to information management of tools that can facilitate data entry (Donn, 2001). Furthermore, information management's features cover quality control, possibility to validate the results by embedded benchmark, input modification and level of documentation (Bevan, Claridge, Maguire, & Athousaki, 2002). The knowledge about these conditions allows users to understand which tool can meet the user needs.

The user preferences for usability based on the survey conducted by Attia et al. (2009) is *graphical representation of output* with *22.9%*. In terms of Information Management, *creation of comparative reports for multiple alternatives* was rank as the most important criterion with *28.8%*. The rating numbers are used to evaluate the total UIM in this paper.

METHODOLOGY

The case study, a four stories hotel, was used to evaluate the modelling process and the main features of the three simulation tools. The evaluation of the selected simulation tools is based on (1) data collection, (2) data entry and building modelling process, (3) simulation, (4) visualisation of outputs and (5) validation and interpretation of result. In some cases, interviews were done with architects and engineers to clarify missed and vague information.

Case study

The building has a total floor area of 7416 m^2 and includes 135 guest rooms, offices, interior swimming pool, gym, conference room, kitchen, restaurant, public spaces such as washrooms and corridors on the first floor (Table 1). The other guest rooms are located on floors two to four. The 3D model created in eQUEST is illustrated in Figure 2. The occupancy was expected to be 290 persons.

Table 1
Different zone's area of the hotel

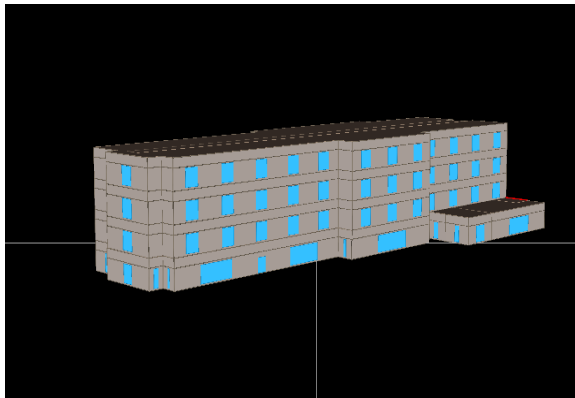| FLOOR	ZONE	AREA (m^2)
1st floor:	Zone perimeter rooms	879
	Corridors	152
	Pool area	121
	Office area	428
	Dining room area	229
	Conference room area	165
2nd to 4th floor:	Zone perimeter rooms	4622
	Corridors	681
	Lobby	139

Figure 2 3D plan of the Hotel in eQUEST (the case study)

Table 2 presents the Hotel building characteristics and thermal conductivities.

Table 2
Thermal resistance properties of the case study

ENVELOPE COMPONENT	PARAMETERS	VALUES
Exterior wall	Absorbency	0.70
	U-value	0.21 (W/m^2°C)
Roof (flat, white)	Absorbency	0.45
	U-value	0.14 (W/m^2°C)
	U-value, pool	0.30 (W/m^2°C)
Slab	R- value	1.76 (W/m^2°C)
Window: Double glasses, Argon gas inside, Aluminum frame	U-value	2.21 (W/m^2°C)
	Solar Heat Gain Coefficient (SHGC)	0.47

In addition, a description of the mechanical systems including types of central plant (Table 3) and HVAC systems (Table 4) is presented.

Table 3
Central plant systems of the Hotel

SYSTEM	EQUIPMENT DESCRIPTION
DHW	Condensing boiler combined with indirect water heaters
Central heating	Electric Packaged Terminal Air Conditioner (PTAC)
Cooling tower	Centrifugal chillers

Table 4
HVAC systems of the Hotel

SPACE TYPE	EQUIPMENT DESCRIPTION
Guest rooms	Fan Coil 2 pipe/ window wall unit
Conference room	Single zone, VAV parallel fan
Restaurant	DX multiple zones, one distribution system, baseboard
Office	Single zone, packaged VAV, baseboard
Pool	DX single zone, VAV terminal

Tool evaluation

The first step to evaluate the tools consisted in collecting the required data for energy analysis (such as architectural and mechanical plans).

The second step was to model the building using the available architectural drawings. The modeling was completed in parallel for the three tools in order to compare the data entry process, the data exchange proficiency, the variability/range of default values, the input options, the flexible of data storage, the input quality control and the online help (or guideline).

Libraries of construction properties, components, materials, central plant and HVAC systems were evaluated to analyse the data entry trees. Moreover, some characteristics of the interface were assessed such as units (SI or IP), multi model inputs and modeling time.

The third step included evaluating the tools level of details and obtained outputs for different building design strategies such as form, orientation, openings (windows), composition of the building envelope, and the choice of mechanical systems and schedule to optimize energy efficiency. After ensuring the integrity of the building model, the simulations were completed. During the calculation and simulation part, processing time was recorded and error diagnostics completed.

In step four, the representation of output was assessed to clearly evaluate the efficient of graphical or 3D representation of the results, the capabilities of producing different graphs, the document structure and the multiple separate reports. A comparison was made in terms of easily finding key outputs, the easiness of input review and modification, especially for the optimisation process that required the review of results for multiple design iterations.

In the final step, the assessment of the tools was completed by evaluating the following: learnability, flexibility of use, link to other programs and adaptability to different design phases using the UIM criteria. The simulation workflows for each tool are illustrated in Figure 3, Figure 5 and Figure 7.

Figure 3 presents the simulation workflow in EE4 that began with selecting the weather data, defining the building envelope, specifying the thermal spaces and thermal zones, modelling the correct central plant, HVAC equipment and their schedule to meet the building loads. All these steps were completed manually using architectural plans. This process allowed the development of suitable building model to complete the energy simulation.
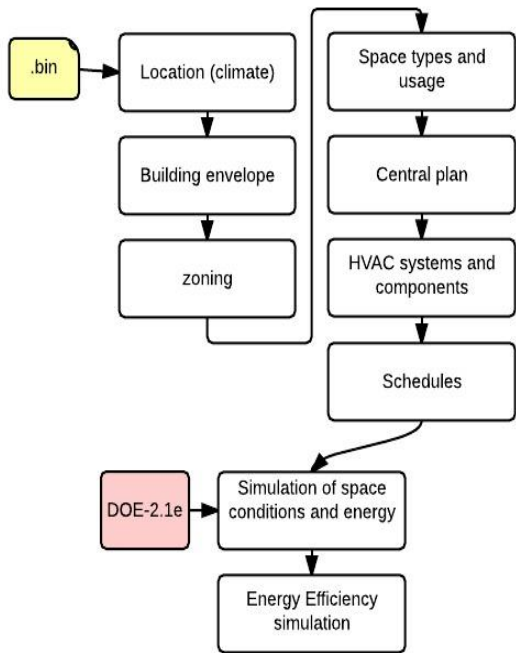

Figure 3 General workflow for energy simulation in EE4

Figure 4 shows an overview of the GUI and of the data entry tree in EE4. The results of EE4 are available in tabular form only.

Figure 5 shows the workflow of SIMEB which began by selecting the weather data file between two options either *bin or *.epw file to match the simulation engine, DOE 2.1/2.2 or EnergyPlus, respectively.
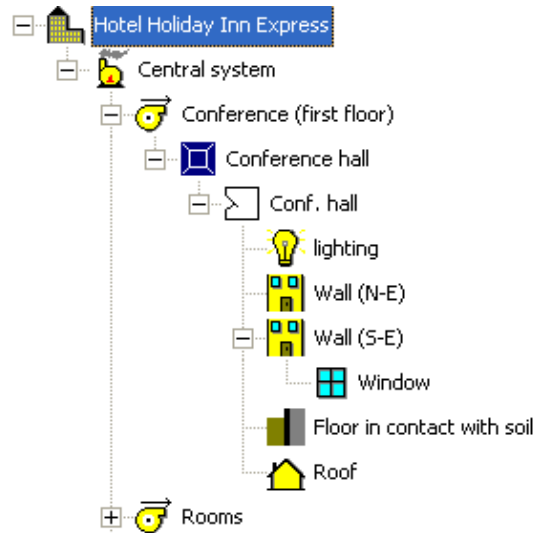

Figure 4 An overview of EE4 interface for the case study

Modelling of the building in SIMEB can be completed either manually, using data exchange or interoperability with eQUEST or Google SketchUp.

The main differences between the modelling process of EE4 and SIMEB lies within the data entry process to describe the building components.
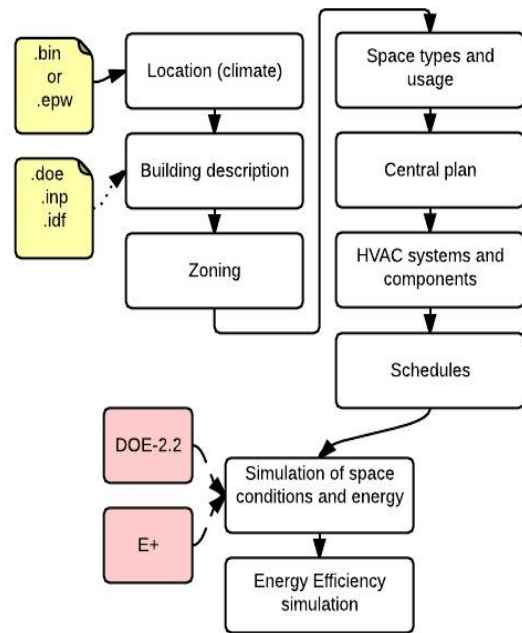

Figure 5 General workflow for energy simulation in SIMEB

Comparative graphs are available in SIMEB such as the one presented in Figure 6 that shows annually electricity consumption of the Hotel for different working schedule, estimated using the DOE-2.2 calculation engine and EnergyPlus. Also, as displayed in Figure 6, the interface and report creation of SIMEB are in French.
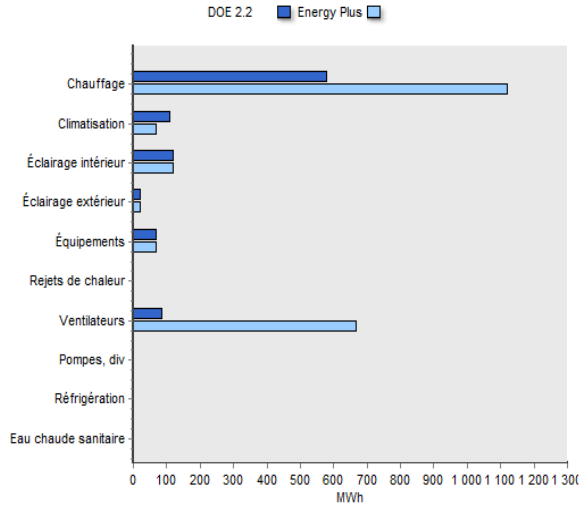
Figure 6 An overview of SIMEB interface and output report: DOE-2.2 vs Energy Plus for the case study

The simulation time was longer in the EnergyPlus calculation engine. This can be explained by the difference in calculation method used for heat transfer between the two calculation engines.

The workflow of eQUEST is illustrated in Figure 7. The weather data can be selected from *.bin file and general information about the building can be input manually. There are several options to create the geometry of the building, either manually or by transferring CAD file (*.dwg). However, interoperability issues were encountered by this latest approach with inappropriate scaling of the building geometry. To improve the importation of the CAD drawing into eQUEST, the CAD model was simplified by removing unrequired elements such as interior walls and partitions. Thermal zoning can be directly specified within the geometric model, while space types and construction properties are specified separately. The characteristic that distinguishes eQUEST from the other tools is that the user can define a detailed envelope composition using a building material library. The eQUEST GUI provides a 3D representation of the building, created using simplified CAD file and the construction information (Figure 2).

There are possibilities to create full set reports in eQUEST such as baseline-run, comparative, single-run and parametric-run reports. The graphical single-run report for the case study is displayed in Figure 8. It contains comparative stacked bar charts of yearly gas and electricity consumption for the different building systems. Creating Hourly Reports is also possible for getting detailed results. Furthermore, complete demand and utility cost, incremental and cumulative results are available in parametric reports.
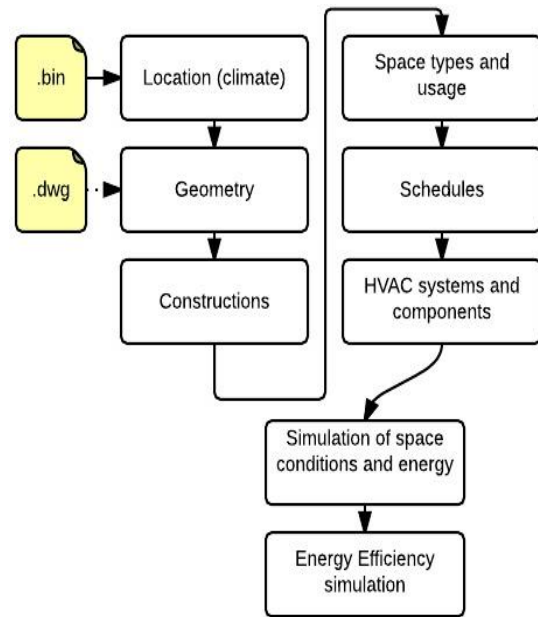

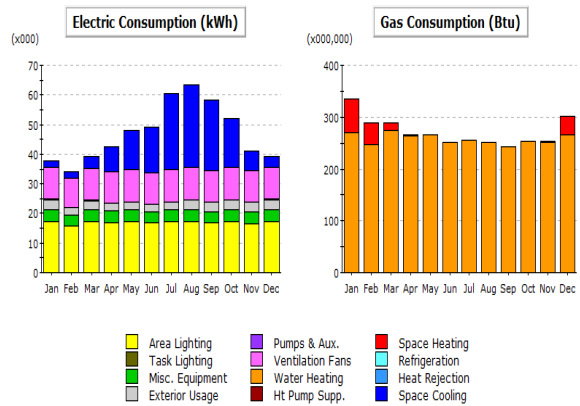*Figure 7 General workflow for energy simulation in eQUEST*

Figure 8 An overview of graphical output report in eQUEST for the case study

RESULTS AND DISCUSSION

The obtained results from investigation and assessment of the simulation tools were based on experimental, observational and review of the literature.

Table 5 and Table 6 present evaluation and comparison of the tools using specific criteria and sub-criteria that define Usability and Information Management. The total UIM rate (*T*) was calculated by Equation (1):

$$T = \sum_{j=1}^{m} f_j * \left[\frac{\sum_{i=1}^{n} C_{i(x,P)}}{n} \right] \qquad (1)$$

Where:

$C_{i(X,P)}$ are the criteria as listed in columns 5 to 7 of Table 5 and Table 6, where (X) are features or capabilities available and in common use; (P) are features or capabilities that partially implemented. The value of (X) equal 1, (P) equal 0.5 and (—) equal 0.

f_j are the criteria coefficient based on the survey by Attia et al. (2009).

i is the numbers of criteria within a category.

j is the numbers of category.

Usability criteria

The obtained results presented in Table 5 indicate that eQUEST has the highest score of 74.0% and EE4 has the minimum score of 40.4% in terms of usability. The assessment was first completed for *representation of input data,* which includes 6 sub-criteria. Analyzing data exchange proficiency of the tools shows that SIMEB and eQUEST have the ability to import data from other programs and application, while EE4 is unable to transfer data with other tools. The next criterion is capability of graphical input and modeling. Except for eQUEST, which has 3D modeling ability and graphical inputs capabilities, the other tools do not support this feature.

Table 5 Usability comparison between popular energy simulation tools in Quebec

j	CATEGORY	f_j^1	CRITERIA, $C_{i(X,P)}$	EE4	SIMEB	eQUEST
1	Representation of input data	0.153	Data exchange proficiency	—	X	X
			Graphical input capability	—	—	X
			Support both SI/IP	—	X	—
2	Representation of output result	0.229	Short running time	P	X	X
			Error diagnostics	X	P	X
			Clear text report	X	X	X
			Graphical report	—	X	X
			Flexible graphs	—	X	P
			Finding easily key output	P	X	X
3	Graphical 3D result	0.157		—	—	—
4	Flexibility of use and navigation	0.173		—	P	X
5	Easy follow-up structure	0.153		X	X	X
6	Easy learnability	0.137	Short learning curve period	X	X	P
			Help support (online, forum, guideline)	X	X	X
[T]	Total usability (%)			40.4	68.8	74.0

Table 6 Information Management comparison between popular energy simulation tools in Quebec

j	CATEGORY	f_j^1	CRITERIA, $C_{(X,P)}$	EE4	SIMEB	eQUEST
1	Allowing assumptions and default values to facilitate data entry:	0.177	Data entry tree	X	X	X
			Library of construction properties	X	P	X
			Library of material	X	—	X
			Library of central plant and HVAC system	P	P	X
			Range of default values	X	P	X
			Simple input options	X	X	X
2	Flexible data storage and user customizable	0.160	Tools adaptability to different design phase	X	X	X
			Tools adaptability to different user	P	X	P
3	Simple input review	0.145		X	X	X
4	Simple input modification			X	X	P
5	Quality control of simulation input	0.237		X	X	X
6	Creation of comparative reports for multiple alternatives	0.281		—	X	X
[T]	Total Information Management (%)			63.0	92.7	84.8

[1] Estimated from the survey results conducted by Attia et al. (2009)

One of the other important characteristics is displaying both metric and imperial units, since both systems are currently used in Québec. SIMEB is the only tools among these three that support this feature. The default values that are currently available in EE4 are based on the metric system. In terms of easy to use and easy learnability, almost all the tools are getting good feedbacks. Also, there are guidelines, help icons, online help and forum to support fast learning for all the tools. The help services for each tool was useful to clarify and correct data entry, structure of tools, default value options and modelling process. The *representation of output* results, which has particular importance for users, illustrate that characteristics such as short running time, error diagnostics and clear text report for the defined tools are acceptable. However, in terms of other criteria such as creating graphical report and flexible graph, EE4 has limited options, while SIMEB and eQUEST have further capabilities. From the aspect of flexibility of use and navigation, eQUEST performs as the most appropriate tool.

Information Management criteria

Table 6 presents the analysed results for the rate of Information Management. For this aspect, SIMEB got top ranking with a value of 92.7%, while eQUEST was evaluated at 84.8% and EE4 at 63.0%. The detailed comparison begins with ability of tools in terms of *allowing assumptions and default values to facilitate data entry*. Several tests were completed to accurately evaluate these features.

Among these three tools, SIMEB could not pass all the test completely for this criterion. For example, the library of material, construction and some of the systems are not complete. Range of default values in SIMEB is very limited. Creation and modification of default values is also impossible in this tool. Nevertheless, it has well-structured data entry tree and simple input option. The other feature refers to *flexible data storage and user customizable* that includes adaptability to different user and design stage, which both criteria being addressed by SIMEB. The results from interviews with both architects and engineers confirm that eQUEST and EE4 are not easy adaptable to the users. For the *Input review and Input modification* factor, which should be considered in the optimisation process, it is obvious that the iteration process for optimisation purposes is in some cases difficult and time consuming. For verification of the GUIs results within the tools, eQUEST has some issues with modification of some inputs data. In some cases, changing some of the values lead to re-model and re-entering of the other values and assumptions. For example, modifying the geometry requires re-customizing thermal zones and spaces from the beginning. The other important requirement in the optimisation process is *quality control of inputs*, which is supported by all the evaluated tools. The last

and most important criterion is *creation of comparative reports for multiple alternatives*. SIMEB and eQUEST both are capable to produce and present multiple comparative results simplifying the design decision process.

The average rate of the overall UIM is determined for each energy simulation tools as the weighted average of both criteria presented in Table 5 and Table 6 (Figure 9). SIMEB with 80.7% has the higher rating and eQUEST with a small difference of 1.3% came second. However, detailed evaluating of eQUEST in this study presents lower UIM compared with the survey results of Attia et al. (2009). EE4 got the lowest rating since it could not deal with the most important criterion of UIM, which is *representation of output*.
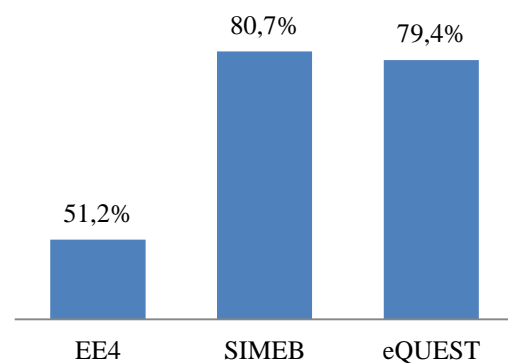

Figure 9 Total UIM rate

CONCLUSION

This paper outlines functional capabilities of three common energy simulation tools used in Quebec. The results obtained demonstrate the applicability of the tools, which users can benefit from at different design phases. A four stories hotel was modelled in each tool. Assessments and examinations of the data entry method and simulation steps were evaluated at each stage. The advantages and limitations of these tools were compared using the UIM criteria. Each tool has weaknesses and strengths; however, one significant aspect is which criteria are most important to the users and will help them meet the project requirements. For this reason, a detailed evaluation of the tools was completed to evaluate the capability of each program. Also, the quantitative effects of total UIM were calculated using the criteria coefficient (the importance factor) for each tool.

The top ranking (74.0%) in terms of Usability belongs to eQUEST and in the area of Information Management of interface to SIMEB. The results show that these two tools have many common strong points together. The third tool, EE4 was known as easy to use software; however, in comparison with the other tools, it obtained lower rating for both criteria. This is explained by the fact that one of the

most important aspects to architects and engineers are the ability of the tools to generate graphical representation of outputs and inputs, create comparative reports and its flexibility of use, which are limited in EE4.

In general, the results can vary depending on users' proficiency and the complexity of project. The evaluation procedure was based on one users experience with the three tools. This limited the evaluation of certain aspects such as *easy learnability* and *tools adaptability to different user*. For those items, interviews with architects and engineers were conducted to confirm the obtained results. The objective of this evaluation process was to identify the capabilities and limitations of the energy simulation tools for the users. The obtained results can guide the tool selection process based on the user needs. Furthermore, the resutls can provide the developers insight into possible improvement of the tools GUI. The findings of this paper also show that there are a great potential for further research to compare the tools in terms of other building simulation tools criteria, such as ability to simulate and accuracy of tools to guide the user into selecting the most appropriate tool for the required tasks.

NOMENCLATURE

T = total Rate for Usability or Information Management.

i = is the numbers of criteria within a category.

j = is the numbers of category.

f_j = is the criterion coefficient.

$C_{(X,P)}$ = is criterion shown as X, P or —.

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