THE EVOLUTION OF THE EE4 SOFTWARE FOR MEETING CHANGING NEEDS AND NEW PROGRAMMES

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ABSTRACT

EE4 has evolved into a family of software since its original development in the late 1990's. EE4 CODE, EE4 CBIP, EE4 Russia and EE4 MURB are all siblings that the CANMET Energy Technology Centre (CETC) has developed to support varying needs and programmes. State of the art technology in software development and simulation tools has certainly changed since EE4's original development. After considering the new tools available for simulating buildings today, the availability of third-party supporting software, our improved understanding of the needs of EE4 users, and the drawbacks in its current design, we have prepared a wish list of changes for the next generation of EE4: making EE4 source code more modular so that functionality can be added or removed as plug and play components without affecting other parts of the program; making EE4 data structures more accessible to other third party software; pushing it further towards it being a cross-platform tool; re-evaluating the simulation engine and re-evaluating its mandate as a compliance-checking tool. Such changes would be a major undertaking spanning several years.

INTRODUCTION

EE4 was born out of a need to support compliance checking with the performance path option of Canada's Model National Energy Code for Buildings (MNECB) (Beausoleil-Morrison et al 2001). This was its primary objective. Over the course of time, objectives and goals of a software application may change in parallel with changing needs of the programmes which it supports. Such is the case with EE4. State of the art technology for simulation tools and software development tools is also constantly changing. Such tools should be reconsidered and re-evaluated at periodic intervals during the life cycle of the software.

Over the course of 5+ years, the CANMET Energy Technology Centre (CETC) has taken EE4 and turned it into a family of related products meeting similar but varying needs. Effective project management and quality control approaches were instrumental in maintaining multiple variants of EE4 (Calla et al 2001). Here is an overview of the EE4 family:

EE4 CODE

EE4 CODE is a software application that determines compliance of a building design with the performance path option of the Model National Energy Code for Buildings (MNECB). The MNECB specifies 3 paths for compliance: prescriptive, trade off and performance in much the same way ASHRAE90.1-89 does. The performance path option requires that certain mandatory requirements of the MNECB be fulfilled and that the overall yearly energy consumption of the proposed building is less than that of a reference building created according to the rules set out by the performance path of the MNECB. This allows more flexibility in the building's design than do the other compliance paths. EE4 CODE automates the creation of the reference building model based on the user's inputs for the proposed design. The DOE2.1e (v133) simulation engine is used to estimate the performance of both building models, and the simulation results are compared to see if the overall proposed design is more energy-efficient than the reference case.

EE4 CBIP

EE4 CBIP is software that builds on EE4 CODE but supports the Commercial Buildings Incentive Programme (CBIP) administered by Natural Resources Canada. Its requirements are more stringent than the MNECB as the proposed design must be at least 25% more efficient than a CBIP reference building. If this is the case, the building owner is entitled to a cash incentive of up to $60 000. Several of the compliance rules have been modified and additional modelling features have been implemented in EE4 CBIP to support the compliance criteria of CBIP, which differs somewhat from that of the MNECB.

EE4 Russia

EE4 Russia is an energy retrofit analysis tool developed for the Canadian International Development Agency (CIDA) in support of promoting energy efficiency for multi-unit residential buildings (MURBs) in Russia. The development of this software was part of a larger process of promoting awareness of building energy efficiency retrofits and their potential savings. A training course was developed that was aimed at promoting awareness, teaching building zoning and other techniques for modeling a building and performing a simulation using the EE4 Russia software. Some of the distinct features of this software include implementation of a detailed air infiltration model based on ALCAP (Air Leakage Control Assessment and Procedure) developed by Scanada Consultants Limited (Parekh 1992) and an economic calculator to determine the feasibility of energy retrofits based on calculations such as payback and payoff periods, net present value and internal rate of return. Figure 1 presents inputs required by the EE4 Russia's economic calculator.

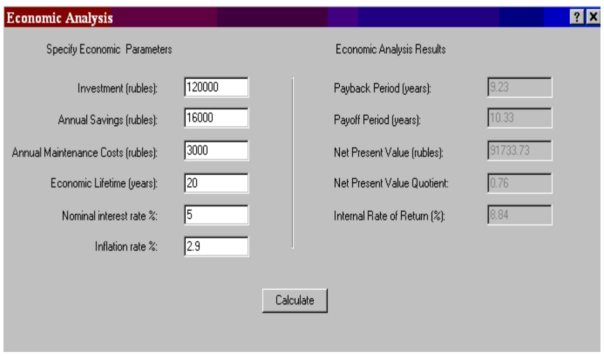

Figure 1: Economic analysis calculator in EE4 Russia

Unlike EE4 CODE and EE4 CBIP, there is no reference building created by the software as there are no compliance requirements. The user enters the building information into EE4 and performs a simulation. Changes are then made to account for possible energy-based retrofits (for example, increased insulation levels, better windows and doors or HVAC systems, etc.), another simulation is performed and a comparison of the results is made.

It was decided to focus on the implementation of ALCAP since many older buildings in Russia are deemed to be "leaky". Air infiltration-related retrofits on leaky buildings are usually cost-effective but difficult to quantify in most building simulation programs. ALCAP is an airflow model based on the network method and is influenced by factors such as inside/outside temperature difference, design wind speeds and directions (wind pressure distribution), mechanical system, building characteristics such as exposure, shielding, orientation, and air leakage characteristics of the building. Stack pressure, wind pressure and mechanical ventilation influences are determined as well as an assessment of the air leakage paths occurring at basement and ground floors, typical floors and top floors. An airflow balance on the building is performed so that the pressure profile on the building and neutral pressure plane can be determined. Identifying and assessing the leakage paths and effective leakage area are critical to properly modeling airflow using ALCAP.

EE4 Russia applied a variation of ALCAP which allowed for a more detailed description of the infiltration characteristics of a building for the DOE2 engine to process. The user interface was modified to allow the entry of detailed information with respect to various air leakage paths within the building (aspects of the potential air path and length of the crack/joint). Characteristics such as building height and terrain data for characterizing wind shielding and climactic factors such as exterior temperature and windspeed allowed us to calculate average daily infiltration rates for an entire year. These average daily rates were assigned to an infiltration schedule to be used for the DOE2 simulation.

The hourly infiltration values were determined by calculating a stack coefficient (based on the above grade height of the building), a wind coefficient (also based on the above grade height of the building and a shielding class specified by the user), a total equivalent leakage area by summing up the characteristics of each air path specified by the user in the interface and hourly outdoor temperatures and wind speeds for the specified locations. Because hourly weather data files were not available for the Russian cities that we wished to be available to the EE4 Russia users, we used the Meteonorm software developed by a Swiss company named Meteotest[1] as a means of generating approximate yearly weather data for each of these cities. Meteonorm uses monthly station data or interpolated data to calculate hourly values of various weather-related parameters using a stochastic model.

Figure 2 presents several inputs required by EE4 Russia to describe an exterior wall element for the ALCAP model.

Implementation of models into EE4 such as ALCAP add extra value to the DOE simulation in that the infiltration component of energy consumption is better quantified. The original method of implementation into EE4 however is a good case for why segmenting this functionality into a distinct module which is separate from other functionality would have been advantageous. As it stands, the required user-specified inputs touch various parts of the interface; the building dialogue box, exterior walls, underground walls and roofs. Should we wish to implement a different air infiltration module in the future, undoing all these inputs would be rather messy.

[1] http://www.meteotest.ch/

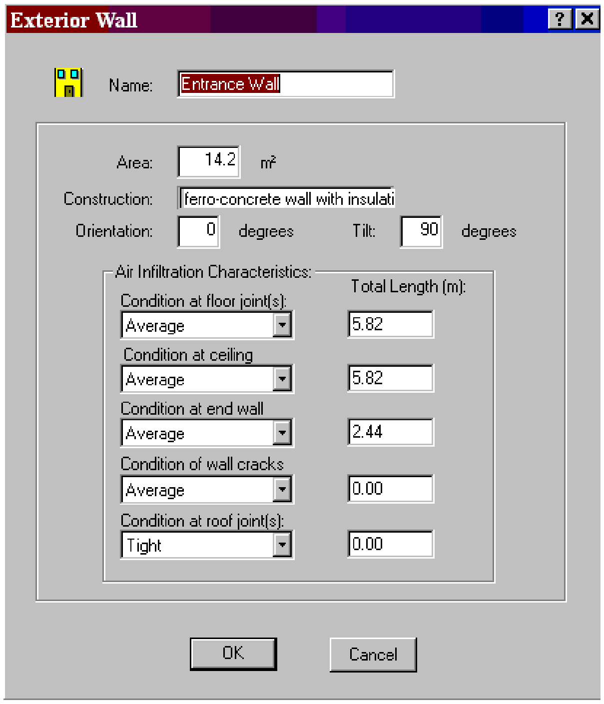

Figure 2: Implementation of aspects of the ALCAP model

EE4 MURB

EE4 MURB is a compliance-checking software developed to support a weatherization program focusing on multi-unit residential buildings – primarily concerned with aspects of air infiltration. The ALCAP-based air infiltration model that was implemented in EE4 Russia was also implemented in this derivative.

THE CASE: THEN VS NOW

The original version of EE4 was developed in the late 1990's with the following considerations in mind:

- The EE4 software was intended primarily as a compliance-checking tool. It was decided that simplicity of setting up a building model was important so that the software could be accessible to users who may be inexperienced with using building simulation tools. This requirement was more important than developing a flexible tool that allowed the simulation of complex systems, as this sort of application would inevitably require specialized knowledge of and experience in modeling buildings and systems.

- Interface and on-line help were required to run on the Microsoft Windows operating system (Win95/98/NT).

- The report generating software (Visual Forms for Windows by Bytech Business Systems Inc and R.F. Holcombe) was an obscure tool but the only one of its kind that met EE4's design requirements at the time. Although no support for the reporting software is currently available, it has fulfilled the application-reporting needs.

Since EE4's initial development, new issues have emerged namely:

- The scope of EE4 users ranges from those who are novices to building simulation to advanced users who wish that some of the potential powers of EE4 could be unleashed to model complex building systems. Several of these complex systems cannot be modelled easily by EE4's current simulation engine and therefore a new simulation engine may be required. New simulation engines such as DOE2.2, EnergyPlus and ESP-r, offer expanded and improved modeling capabilities over DOE2.1e.

- Requests for EE4 to import building information from files created with CAD applications (building footprint, wall lengths, window and door dimensions, etc.).

- There are advanced report-generating tools available today based on HTML that can provide reports in tabular and/or graphical formats.

- Applications that run off the internet are becoming more popular.

- The MNECB is up for review and a revised energy code can potentially lead to significant changes in the performance path compliance rules.

- Several users have expressed a desire and have attempted to use EE4 as a design tool but are hindered because of EE4's function as a compliance-checking tool.

INCREASING EE4'S CAPABILITIES

If we take into consideration the factors that have changed since EE4's original development and the trends that are occurring as described in the previous section, we can make a wish list of future modifications. This list would include:

Segmenting EE4 source code along the lines of functional modules

Modifying EE4 so that functionality is encapsulated into distinct plug and play components would go a long way towards streamlining maintenance of the source code. Isolating and segmenting sections of the source code that are functionally distinct from other sections would also result in more controlled communication between modules. For example, sections of source code to create proposed, reference and non-compliance DOE2 models would be distinct (preferably in separate files) and wouldn't share any common functions.

This would provide the ability to make many variations of the reference case and proposed case to suit varying compliance and incentive programmes without having to create entirely new software and modify the proposed and reference case rules in the source code. All that would need to be done is to specify the case that needs to be activated or deactivated. Ideally, one could also have different compliance "buttons" so that the proposed building input could be used to determine compliance to MNECB, CBIP, and/or other programmes within the same environment.

If we were to regroup EE4 along functional lines, the modules would probably look as shown in Figure 3. The shaded modules represent those that are currently coded and present in EE4. Those with broken lines represent modules that can potentially be added at some future time. The big challenge would be the time required to rearrange and rewrite various sections of source code and test it to make sure that no new bugs have been introduced as a result.

Making EE4 data structures more accessible to third party software

This means permitting EE4 to communicate and transfer data back and forth with other related or supporting software and vice versa. It also means attempting to make it a cross-platform tool. The current user interface was developed for use with Microsoft Windows. Although the current simulation engine runs on a Windows platform, there is no need to tie down the interface to any particular platform anymore. A web-based interface accessible over the internet is a possibility and its advantages include the possibility of data entry from any computer regardless of platform/operating system resulting in a fully portable front end.

Communicating with CAD-based programs is also a consideration. In order for a CAD-based system to export some of its building information to the EE4 interface, some sort of intermediary data structure must be common between both software. One way to accommodate this is to follow the same type of procedure used by EnergyPlus namely making use of Industry Foundation Classes (IFC). Any CAD program that makes use of the IFC classes would be able to share information with EE4 assuming that EE4 is modified to accommodate this. Although our experience with IFC is limited, a thorough study of the issues related to development using IFC would be necessary before we decided to use this approach. This would involve learning from the experiences of those who have and are currently using IFC classes in their applications.

Adding new functionality and new modules

Since the original EE4 development, addressing climate change has taken on a more prominent position within the policy of the Canadian government. Reduction of greenhouse gas emissions is a quantitative measure of how well an energy efficient design is doing in addressing the climate change situation. Although a greenhouse gas calculator can act well enough as a stand-alone tool and does not necessarily have to be integrated into EE4, doing so puts a new integrated tool into the EE4 user's toolbox.

Convincing a building owner to implement certain systems or apply certain building designs to his building may require more than just the energy efficiency incentive. If a design is more energy-efficient than another but the cost to maintain it is substantially higher, the argument to implement the energy-efficient design becomes weaker. Having an integrated tool in EE4 that helps calculate life cycle costs of various building components may be a useful tool in the future. The life cycle cost calculator could draw upon a database of various types of costs for the component (initial capital cost, preventive maintenance, repair, replacement, etc) for calculating costs during the course of the component's life.

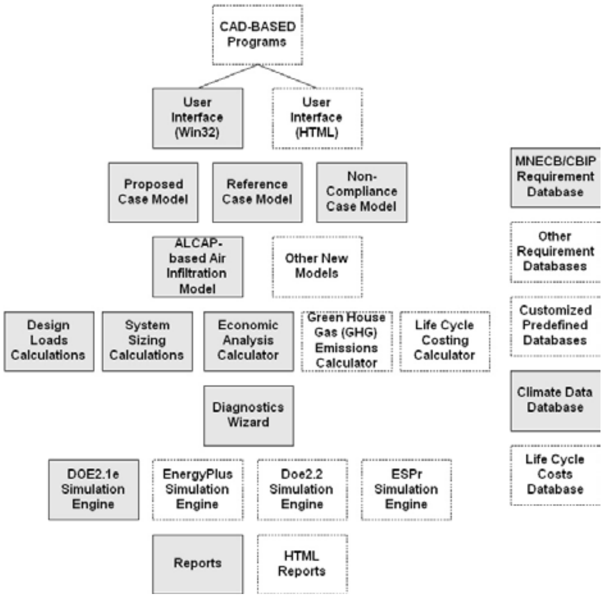

Figure 3: Actual and potential functional components of EE4

SUPPORTING NEW APPLICATIONS

EE4 includes capability to calculate a building's heating and cooling loads for HVAC design purposes, and provides users the option of performing a non-compliance simulation. However, there are several features of EE4 that limit it's use as a non-compliance energy analysis tool and as a HVAC design tool at the present time. These features were initially included in EE4 because of its primary role as a compliance-checking tool but as more and more users are attempting to apply EE4 for energy analysis and design, these features hinder its use for these purposes. Several of these issues are described in this section.

EE4 requires that each space or zone that is defined in the building model be assigned a function. The space function is used to determine the appropriate default values for the proposed building and to set the characteristics of the reference building. Although this input should have no influence in a non-compliance simulation, it is a required input nonetheless and impacts the diagnostic wizard function, seen in Figure 3 and explained below.

The diagnostic wizard function verifies that user inputs are valid and also checks that user inputs meet a number of compliance rules. For example, the MNECB sets minimum outdoor air rates for each space that depend on the space's function (for example, office space, hotel lobby, etc.), chosen by the user. The outdoor air rate that is input by the user for a certain space must be greater than the MNECB's minimum requirement for that space in order for a simulation to proceed. This diagnostic check thus requires that all spaces be ventilated, which may be appropriate for compliance purposes but inappropriate for non-compliance simulations where the actual energy performance, heating load and/or cooling load are required. Non-ventilated spaces and/or spaces with ventilation rates less than the MNECB requirement cannot be modelled, even in a non-compliance simulation.

In addition to the diagnostic check for a space's minimum outdoor air rate described above, EE4 verifies that all of the spaces within a zone have the same default operating schedules. Although this is suitable for compliance simulations as default operating schedules are often specified, this requirement is tedious for non-compliance simulations which require operating schedules to be explicitly defined (i.e. no default schedules are assumed).

The issues thus mentioned relate specifically to the way in which the diagnostic wizard function was implemented, and how this hinders the use of EE4 as a non-compliance energy analysis and design tool. Other issues are also present. Specifically, EE4 supports the simulation of fifteen HVAC system types with fixed configurations. Any building HVAC system that is unlike one of the system types available in EE4 or that operates differently than the way the corresponding EE4 HVAC system is configured needs to fit into one of the available system types. For example, the 4-pipe fan coil system type assumes that a central make-up air unit supplies heated and/or cooled outside air to the zones directly while the individual fan coil units respond to the zone's heating and cooling loads. The HVAC sizing calculations performed by EE4 assume this configuration. If a user needs to model a radiant floor heating system, a system type not available in EE4, the user must specify a fan coil system with no fan energy and appropriate airflow rates for each zone (these airflow rates can be determined from EE4's HVAC sizing calculations). Although this is not an exact representation of a radiant floor heating system, it is the only possibility to model such a system in EE4. This may be an appropriate approximation for a compliance checking simulation, however it may be over-simplifying the actual energy performance of the radiant floor heating system.

Any energy-saving technologies that were not taken into account during the development of the MNECB performance path compliance rules were not considered during the initial development of EE4. For example, photovoltaic solar panels that provide both electric power and heat to a building are not specifically considered in the MNECB and thus the ability to model such systems was not a consideration in the choice of EE4's simulation engine. At the present time, there is a need to model such systems, both for compliance and non-compliance purposes, however EE4's current simulation engine does not have this capability. This leads us to consider other simulation engines for EE4 that can provide the capability of modelling renewable energy systems.

OTHER SIMULATION ENGINES

EE4 was designed for compatibility with the DOE2.1e simulation engine. While the DOE2.1e engine remains adequate for compliance checking of traditional HVAC technologies, the simulation of some innovative building construction and energy supply technologies of interest to EE4 users is beyond its capabilities.

In recent years, the DOE2.1 engine has been supplanted by DOE2.2, which offers improved modelling of HVAC systems. Additionally, the EnergyPlus and ESP-r simulation engines are being used more frequently to model commercial buildings in Canada and abroad. As the present and future needs of EE4 users are considered, it is clear that coupling the EE4 interface to a modern simulation engine will be a priority in upcoming releases. In this section, the DOE2.2, EnergyPlus and ESP-r simulation engines are briefly described, and some relevant issues regarding each are discussed.

DOE2.2

DOE2.2 is a substantially more capable version of the DOE2.1 simulation engine used in EE4 (Simulation research group & Hirsch, 1998). Notable improvements include the coupling of building and HVAC system simulation. Whereas DOE2.1 first characterizes the building's response to the thermal loads over the simulation period and then determines the plant's response to the building's loads, DOE2.2 models the interactions between the building and the HVAC systems throughout the simulation period, permitting the impact of innovative technologies on occupant comfort to be determined.

DOE2.2's HVAC systems model is also more versatile than DOE2.1's. Users can precisely define the mechanisms by which energy is produced and transported to the building by the plant Additionally, DOE2.2 provides improved models of ground source heat pump systems and hydronic heating systems in comparison to those currently available in EE4/DOE2.1.

Of the three programs considered here, the data structures of DOE2.2 are the most similar to those used in EE4. Many of the inputs have not changed between DOE2.1 and 2.2, and a methodology has been defined for migrating DOE 2.1 simulation files to DOE2.2 (Hirsch 1997). Finally, DOE2.2's broad user base ensures that many resources are available describing the development and use of DOE2.2 models.

However, the unstructured nature of DOE2.1's source code has hampered the development of EE4; researchers require many years of experience working in the code before they can make substantial modifications to this software. Since DOE2.2 inherits much of DOE2.1's structure, it's likely that the EE4 team will be unable to make significant changes within DOE2.2 to accommodate EE4 user needs. Indeed, this deficiency is cited as one of the principle motivations for the development of EnergyPlus (Crawley et. al 1999).

EnergyPlus

EnergyPlus is a new building simulation engine that incorporates the capabilities of the BLAST and DOE2.2 engines, and adds new functionality (Crawley et. al 2001). Addressing complaints regarding the poor documentation and maintainability of DOE2 code, EnergyPlus developers rewrote substantial portions of the DOE and BLAST simulation engines, to create a modular and extensible structure (US Department of Energy 2004b). Since its release in 2001, EnergyPlus has been adopted in North America as a versatile and accurate commercial building simulation software (US Department of Energy 2004a)

Modifying EE4/DOE2.1 data structures for use with EnergyPlus would be more difficult than with DOE2.2. While a translator has been written to convert DOE2 input files into formats suitable for EnergyPlus, the translator cannot handle HVAC systems descriptions. Several HVAC system templates have been developed to easily describe standard HVAC systems in EnergyPlus, though additional templates would be required to handle all of the system types currently available in EE4. Thus the EE4 team would likely have to invest considerable time to match EE4 and EnergyPlus inputs.

ESP-r

The ESP-r building simulation environment is the result of over twenty years of research, and is widely regarded as a state of the art simulator that provides rigorous, first-principle treatment for all relevant building physics. ESP-r has been extensively validated in studies comparing its results with the predictions of other simulation software and measurements taken in real buildings. (Strachan 2000).

ESP-r provides a partitioned approach that separates components of the simulation environment into building thermal, airflow, HVAC, electrical and control domains. These domains can be coupled together as required; detailed research efforts may only focus on one modelling domain, while holistic modelling studies may use all domains to obtain a complete performance appraisal of an entire building.

ESP-r's building thermal, airflow and control domains are widely used in Europe. Part of the success of these components can be attributed to the varying levels of resolution that they provide. For instance, ESP-r permits the building airflow to be described using user-defined schedules, a pressure-driven network, or with comprehensive CFD analysis. This approach permits each user to determine and apply the level of resolution appropriate to the problem at hand.

However, ESP-r's HVAC domain is not widely used in commercial building simulation (Clarke 2001). The limited use of the HVAC domain largely results from the vast amount of data required by ESP-r to meaningfully simulate the HVAC systems commonly found in commercial buildings. For instance, to model an air-handler system that circulates conditioned air to several building zones, an ESP-r user must describe the fully balanced air flow network used to distribute the conditioned air, and control functions that actuate the position of the dampers used to regulate flow to each zone. While the HVAC domain provides powerful modelling facilities enabling detailed research into heat and mass transport through an HVAC network, it also requires exact knowledge of the network characteristics, which are tedious to describe and may not be known at the time of simulation. Instead, most ESP-r users rely on idealized system models that predict the energy and fuel required by generic HVAC systems to meet the building's loads, but are incapable of modelling innovative technologies.

If EE4 is to use the ESP-r simulation engine in the future, development of another plant modelling strategy will be required. This approach should provide sufficient resolution to permit users to model the interactions between HVAC systems without requiring a detailed description of the flow network and its associated controls.

ESP-r has been the subject of numerous graduate projects, and is well documented in various student theses. Additionally, the EE4 team has substantial experience with the ESP-r source code that forms the basis for NRCan's next generation residential building simulator, and can take advantage of models developed for this work.

Recommendations

It is clear that the DOE2.1 simulation engine used in EE4 is inadequate to meet the growing needs of EE4 users. A thorough appraisal of the suitability of the DOE2.2, EnergyPlus and ESP-r simulation engines is beyond the scope of this paper. However, a procedure for the evaluation of simulation engines has been outlined previously (Haltrecht et al 1999), and it is recommended that a similar procedure be used to identify an appropriate simulation engine and development strategy for the next generation EE4 commercial simulator. When designing this procedure, the issues identified in the present paper should be considered carefully. Another consideration in the selection of a simulation engine will be the relative ease in adding new modelling capabilities or modifying existing models on our own.

ACCOMODATING ALL USERS OF EE4

EE4 users can be generally categorized as follows:

- Those who use the software as is. They are aware of EE4's simplicity in setting up the proposed model in DOE2 format and the automatic creation of the reference model. They know of EE4's limitations with respect to it being used as a design tool but this makes no difference to them as they are interested in using it as a compliance-checking tool for EE4 CBIP/EE4 CODE as it was originally intended. They have some knowledge of modeling and using EE4 either by having attended an EE4 training course or by having learned to use EE4 on their own.

- Those who are new to simulation and know the purpose of EE4 but are technically challenged at using it. They need to use it to develop a model of their building for determining compliance with EE4 CBIP/EE4 CODE however they wish there would be an easier version of the tool. Chances are they have used the CBIP pre-screening tool which is available on-line or one of the wizards that have been developed as a preamble to using EE4 to confirm the compliance of their design and wish that it could be that simple.

- Professional or experienced building simulators. They know the purpose of EE4 and its current limitations (along with those of DOE2) but wish that it could be used as a design tool or for simulating new or innovative systems.

CETC has resisted the temptation to change the scope of EE4 from a compliance-checking tool to a design-oriented tool or for that matter to a watered-down version that is overly simple so as to make simulations too approximate. Unfortunately EE4 cannot be all things to all people. Instead the focus was placed on making sure that EE4 was a good compliance-checking tool for the programmes that is was required to support. Practitioners that would like to have specialized design features would best use EE4 for now in conjunction with an off-the-shelf package that offers them the design tools they are looking for.

However, the needs for the next generation of EE4 will be re-evaluated and requests from users with various levels of experience will have to be considered. If the next generation of EE4 does go the route of having more design capabilities, then the added value in using EE4 over other off-the-shelf-packages would be its function as a compliance-checking tool for the MNECB and CBIP.

CONCLUSION

EE4 has evolved into a family of software that is being used to meet the varying needs of several programmes. Although originally developed as a compliance-checking tool, should a next generation of EE4 be envisioned, many considerations would need to be evaluated; one of which is the very nature of the original software as a compliance-checking tool only. Another equally important consideration is the core simulation engine to be used for calculations. DOE2.2, EnergyPlus and ESP-r are all worthy of investigation. Taking into consideration the maintenance aspects of EE4 and the possibility that a revision to the MNECB or CBIP may be on the horizon, some restructuring of source code to make it more modular and therefore more easily maintainable is also worth some consideration. The development of the next generation of EE4 would be a significant undertaking spanning several years. The new development would most probably be taken on in phases in parallel with the ongoing maintenance of the current EE4. Once launched, the new generation of EE4 would most probably continue to support all the programmes that EE4 is currently supporting such as the MNECB and CBIP. The emphasis would be on minimizing the number of software that we develop for supporting programmes so that time devoted to maintenance activities is also kept to a minimum.

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