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Computer Aided Environmental Control

Literature-based analysis of current themes, trends and challenges

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IT tools are currently employed in almost every aspect of our live, and are being interwoven in almost every field of specialization. The enrollment of computer applications in the workflow of the AEC industry's fields, increases the work competition and continuously upgrades the benchmarks of such fields. Computer Aided Environmental Control (CAEC) applications might be well known by architects and designers, however, there are some challenges that limit the use of such applications and it needs to be better understood and challenges need to be resolved to facilitate more engaging approaches and inclusion in the workflow.

Keywords— AEC (Architecture, Engineering, and Construction), CAEC (Computer Aided Environmental Control), computer applications, energy simulation, envelope system, solar/climate analysis

I. Introduction

The building internal environmental and climate conditions are a result of highly complex interaction between many variables such as human nature & activities, building characteristics & materials, and external environmental status & conditions. Those variables are difficult to be manually and adequately considered by architects during the design process.

Current and emerging generations of CAEC applications, have tools to represent and deal with certain aspects of buildings' environmental behavior. Most of such applications rely on digital representation to help the architects and designers to clearly visualize the results of different design scenarios / alternatives and to take the most suitable and efficient design decisions based on the design context. In many cases, such applications are a result of occasional individual university research, while others are commercial programs offered by companies to professional specialized environmental designers.

- The Problem: Despite of its spread in academia and professional market, CAEC applications are still in either infancy or complex, are difficult to be used by architects and designers, need more development to be easy accessible by architects and designers and to become part of the daily work with more user-oriented, efficient, accurate and credible features.

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- Objectives: The main objective of this paper is to present a status of CAEC applications from the architects and designers' viewpoint to assist developers to gain a better understanding of their needs and challenges related to such applications. This paper tries to achieve its objectives through exploring the themes and trends of using CAEC applications by architects and designers and presenting its related challenges.
- Research limitation and hypothesis: This paper will present and analyze selected themes, trends and challenges related to CAEC from Architects' viewpoint, to conclude how could architects and designer get benefit from such applications. The main hypothesis is that there is a relation between the awareness of CAEC challenges and the efforts done by developers to make it more accessible by architects, become indispensable from environmental design, and be part of the daily work of architects and designers.
- Research methodology: This paper will depend on the authors' experience and a literature-based analysis to explore CAEC selected themes and trends and to present its related challenges to reach related conclusions and recommendations.

II. Themes and Trends in CAEC

When discussing CAEC themes and trends, it is worth to mention that most architects are interested in applications that could help them taking the right and effective decisions in the early design stages without waiting for specialists and professionals who will, in most cases, participate in the design process and would be part of the team in next stages.

The paper will explore *selected* CAEC themes and trends related to external environmental conditions (climate and solar analysis), Internal environment (daylight, lighting control, natural ventilation and indoor air quality), the building envelop systems that separate between the external and internal environment, and the energy simulation systems tools that could characterize energy flows connected to a building and predict their impact on comfort parameters and energy demands through mathematical models in all of them.

A. *ENVELOPE SYSTEMS:*

A building envelope is the physical separator between the conditioned and unconditioned environment of a building including the resistance to air, water, heat, light, noise and other environmental aspects. It has an important impact upon energy saving and building running cost.

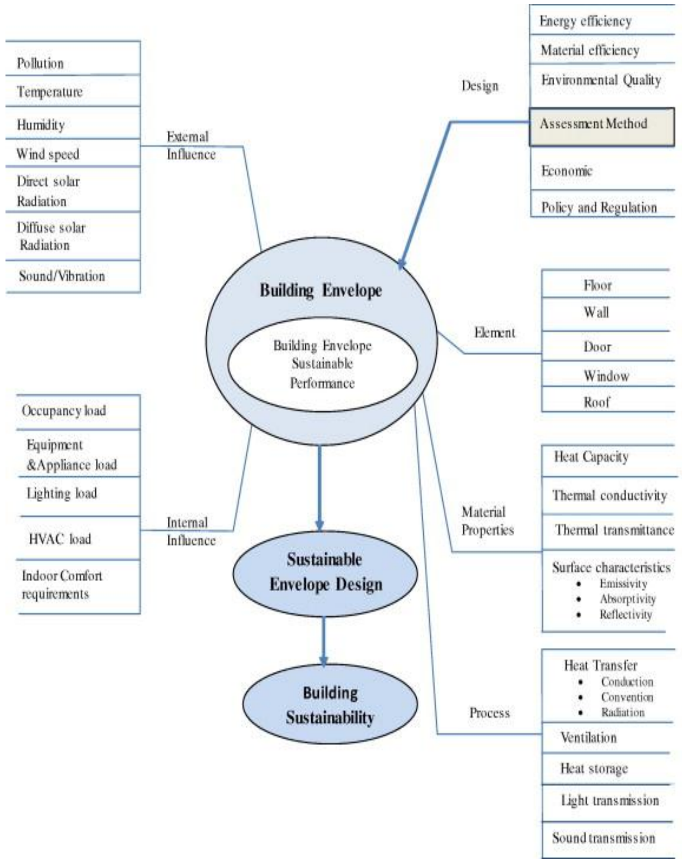

Figure 1. The connection between building envelope and building sustainability. One of the examples that shows the complexity of the envelop related variables (Iwaro, Joesph and Mwasha, Abrahams, 2013)

The measure of building envelop energy efficiency is considered one of the important themes and trends that have been tackled by many researchers. (Sang, Pan, Kumaraswamy, 2014 and Dernie, Gaspari, 2015) explored this trend through the combination of understanding the environment, identifying potential measures, setting up models, running analysis, and making design decisions. (Dernie, Gaspari, 2015) tried to explore how different technologies and design solutions to building envelopes cladding could contribute to the reduction of the heat gains in urban environments, and how appropriate adaptive strategies can further mitigate against accelerated greenhouse emissions. He also tried to answer questions about what is the relationship between individual building performance and consequent effect on external environment. The effects of technological and material choices are evaluated for some design scenarios and conditions in order to develop an indicative impact mode.

The numerous applications for the technology currently being used to inspect building envelopes is another trend explored by (Snell, Spring, 2002) who included validation of structural details, verification of energy performance, location of moisture intrusion, and the identification of structural and system degradation of roofs and facades.

Other important trends are related to Adaptive and Active Building Envelope Systems (ABE). The first was handled by (Papamichael, Birtwhistle, Graeber, 2015) in four primary areas of research: exploring the energy-savings potential of adaptive envelope systems through simulations, laboratory characterization of adaptive envelope systems, developing new strategies and laboratory prototypes, and field installations of commercial technologies. The second, related to Active Building Envelop (ABE), was handled by (Rivas, Khire, Messac, Van Dessel, 2005) who investigated the economic viability of the (ABE) systems through a preliminary cost model and examined diff erent heat absorbing component through different configurations of ABE systems.

In all cases the variables related to the building envelop are wide, complicated and interwoven with many internal and external variables. This is surely reflected in CAEC applications related to this theme through increasing complexity of related variable interface. Such interface complexity seems to be easy to handle by environmental control specialists as part of their daily work, but the case is different for architects who prefer a simple and visual interface and want to see the effect of changing such variables upon the envelop environmental performance.

B. DAYLIGHT MODELLING

Daylighting is a very important subject in the sustainable design. It is an art and science in which natural light is managed to minimize the use of artificial lighting, reduce carbon emissions, and positively affect the performance and the mood of occupants in different types of spaces.

Testing and analyzing daylight applications is one of the themes and trends handled by many researchers such as (Acosta, Navarro, Sendra, 2011) who assessed a number of lighting software applications habitually used in architecture *(such as Lightscape 3.2, Desktop Radiance 2.0, Lumen Micro 7.5, Ecotect 5.5 and Dialux 4.4)*, subjecting them to a series of trials and analyzing the light distribution obtained in situations with different orientations, dates and geometry. In the same context other researches went a step more by comparing and analyzing the performance of daylight related applications as done by (Shikder, Price, Mourshed, 2008) who compared and analysed performance of four lighting simulation programs (AGI32, DIALux, RADIANCE and RELux) that are dedicated to provide physically accurate lighting calculation. Along with the evaluation of modeling ability and software features, they focused on two significant aspects of daylight related to accuracy in calculating illumination level and luminaire number for interior spaces.

The accessibility of daylight applications for architects’ file types is another theme analyzed by researchers as done by (Panitz, Garcia-Hansen, 2012) who explored how tools, that that are likely to be used by architects, are those that import a wide variety of files, or can be integrated into the current 3d modelling software or package that the architect use. They showed that there is a need for open source applications that are able to read raw data (as in the form of spreadsheets) and show that graphically within a 3D medium.

The accurate simulation of the quantity and distribution of daylight in an architectural space was discussed by (Mardaljevic, 2005) who noted that this subject is now a realistic prospect and the Radiance system can be used to predict illumination levels and visual appearance under daylight conditions for virtually any building design.

As presented, CAEC applications in the field of day light have wide varieties and issues that are analyzed and developed by many research agents/researchers over the last period and although there is a challenge about integrating such applications with the used 3d modelers, the file type compatibility with the architects' used applications, and the accuracy of visualizing its effect, it is expected that the new generations of such applications will cover such issues.

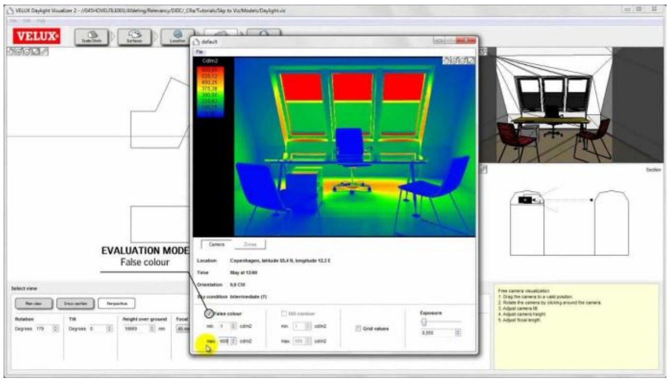

Figure 2. Example of one of the simulation applications for day light:Velux Daylight Visualizer - Daylight simulation of detailed 3D models, Daniel Nelson, https://www.youtube.com/watch?v=q3JI4rFi-wc&t=16s, 2013

C. *1.2 LIGHTING CONTROL SYSTEMS*

Internal lighting is artistic and scientific subjects handled by architects, designers and other specialists, through which the building energy saving could be maximized, building codes could be satisfied, and green buildings and energy conservation principals could be applied. lighting control system is an intelligent network based lighting control solution that incorporates communication between various systems' inputs and outputs related to lighting and controlled by one or more central computing devices and applications.

Maximizing the lighting energy saving is the most important theme and trend initiated by research and developers such as (Havassy, Jackson, Siminovitch, 2015 and Panjaitan, Hartoyo, 2011) who developed and demonstrated an optimized retail lighting control strategy based on a set of control layers specifically designed to deliver maximum lighting energy savings and minimal negative impacts. The feature set includes specific recommendations for retail lighting power density and optimized control settings. In the same context, (Williams, Atkinson, Garbesi, Page, Rubinstein, 2012) provided a meta-analysis of lighting energy savings identified in the literature *(240 savings estimate from 88 papers and case studies)* and categorized into daylighting strategies, occupancy strategies, personal tuning, and institutional tuning.

Relating daylighting with lighting systems to maximize energy saving is tackled by (Kacprzak, Tuleasca, 2012) who presented a technique of quantifying energy savings due to daylight designated to be used in smart buildings or similar applications where daylight harvesting is welcomed, through three stages: the first of which is an optical sensor is evaluated for its P (power)-E (illumination) response characteristics, the second is where the calibration of room properties is carried out, and the final third stage is where the photometric calculations are per- formed, and energy savings are calculated. In the same context (Mukherjee, Birru, Cavalcanti, Shen, Patel, Wen, Das, 2010) focused on the benefits of closed-loop integrated controls of daylight and electric lights over other technologies. simulated and experimental results from a test bed are presented for the following control scenarios: open-loop and closed-loop independent control of window blinds; closed-loop independent control of electric lighting, and closed-loop integrated control of blinds and lighting.

The satisfaction of lighting levels of different spaces with codes and standards is another theme that was handled by (Panjaitan, Hartoyo, 2011) who proposed a building lighting system based on fuzzy logic scheme to automate fluorescent lamps in order to achieve illumination according to Indonesian National Standard (SNI).

Lighting is a complex subject that architects try to balance its artistic and scientific aspects during the design process. It could be said that artistic aspects are supported by applications that could render the selected light types effect within the space, while the scientific aspects related to codes, standards and energy saving are handled by related lighting applications. Although the availability of lighting related CAEC applications, the architects are not fully get use of its scientific aspects due to the complexity of lighting variables and hence the related interface.

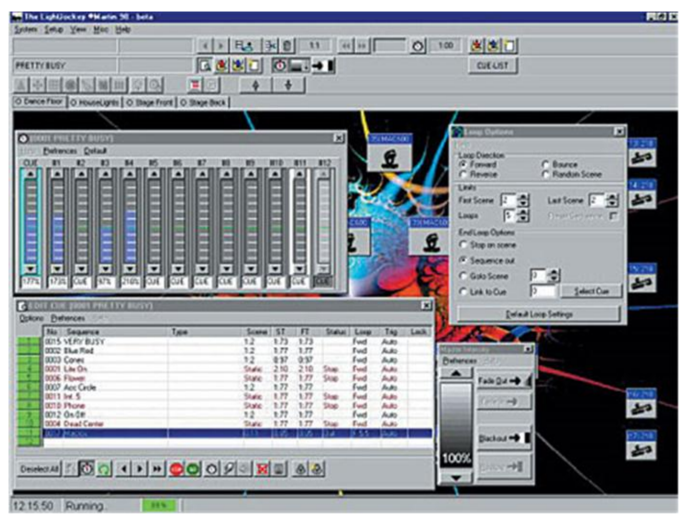

Figure 3. Lighting interface with scientific variables seem to be very complex for architects, Martin DMX-512 Lighting Control Software USB, By Martin Professional.

D. *SOLAR ANALYSIS*

Solar energy is one of the major clean and safe renewable energy sources that has a wide spread of benefits for people and environment. The architect could harvest full advantage of such energy by considering its related variables which could be aided easily by related CAEC applications.

The renewable energy is the major theme and trend related to solar analysis. Some researches explore the effect of solar heat gain as done by (Kocagil, Oral, 2016) who focused on the effect of solar heat gain on heating-cooling loads in courtyard buildings. In the same context, (Garridom, Aparicio, Fort, Anaya, Izquierdo, 2011) explore the effect of solar radiation and humidity on the inner core of walls in historic buildings, while (Kuismanen, 2008) returned to the physics of comfort in buildings and the passive strategies which can help achieve this with a low energy and carbon footprint, and assured that A new architectural sensibility can arise based on modeling the inputs of sunlight, daylight and air temperature in time and space at the early stages of design.

The effect of solar energy on the building internal environment explored by (Garridom, Aparicio, Fort, Anaya, Izquierdo, 2014) who concluded that the structure of historic buildings and its used materials, along with outdoor conditions, affect the building indoor temperature and humidity.

The manipulation of building orientation and shading devices to benefit from the solar energy handled by (Rodriguês, 2010) who analyzed the influence of the prevalent orientation of the building and the predominant fixed shading devices used on buildings of Maputo City and to evaluate their impact on thermal comfort of the buildings occupants. his analysis also provides the optimum building orientation and the ideal dimension of the fixed shading devices for Maputo City buildings in order to improve the indoor thermal comfort in the summer.

Figure 4. “LASERDATA” one of the Solar Potential Analysis applications that could help policy makers to estimate the energy yield of photovoltaic installations and plants, to evaluate the solar heating and cooling of buildings or to plan the positioning of solar thermal or photovoltaic modules. https://www.laserdata.at/services.html

E. ***CLIMATE ANALYSIS***

Climate is the environmental factors that normally be the first to be considered by architects and engineers from the early design stages. CAEC in this field could effectively help architects and designers to achieve a low energy consumption or a net-zero energy building. The the distinction between weather and climate is on of the topics handled by (Trenberth, Miller, Mearns, Rhodes, 2000) who presented how the rich natural variety of weather phenomena can be systematically influenced by climate.

The effect of climate change on the building internal thermal comfort is one of the themes handled by (Nguyen, Reiter, 2014) who examined the potential of improving thermal comfort under the climates of Vietnam passive strategies. In the same direction, (Pretlove, 2004) investigated the impact of climate change over the last two decades may have on the design and performance of buildings by examining a specific impact of the change in temperature and solar radiation on one particular design variable. One of his important conclusion is that, the climatic data currently being used for energy design calculations leads to inaccuracies in predictions of energy use and hence the climatic data used in such calculations should be urgently reviewed as it may be leading designers to adopt solutions which will be inappropriate for future use. A third effort done in the same direction was by (Andrić, Silva, Lacarrière, 2015) who focused on evaluating the impacts of changed climate and building renovation on heating related CO2 emissions on a neighborhood level using A combination of existing tools (EnergyPLAN, ArcGIS, CCWorld Weather Gen) and a tool previously developed by the authors).

Although there is a wide range of CAEC applications that deal with Climate, and that there are many tools that are surprisingly accessible to the average designer or architect, the scientific background of the subject is important for architects and designers to understand the input and output data and how to be effectively employed in the design process. In such cases, architect could use such applications to reach creative and effective climate-responsive solutions

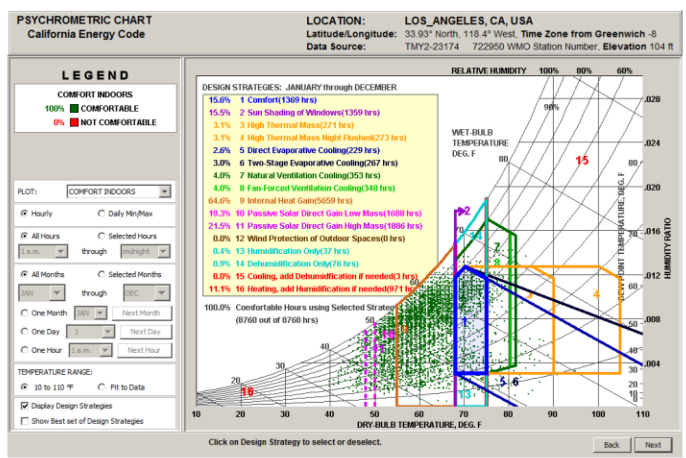

Figure 5. “Climate Consultnat” one of the free, easy-to-use, graphic-based computer program that displays climate data in dozens of ways useful to architects, builders, contractors, and homeowners.

F. ***NATURAL VENTILATION***

Natural ventilation refers to the flow of external air to an indoor space as a result of pressure differences arising from natural forces and without using mechanical systems.

The effect of natural ventilation on the building internal environment and energy saving is one of the themes and trends handled by (Chen, 2001) who concluded that natural ventilation in buildings can create a comfortable and healthy indoor environment, and can save energy used for mechanical ventilation systems. This was also confirmed by (Martin,

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Vandaele, Wouters, 1999) who stated that the aim of the natural ventilation is to cool down the thermal mass of the building to obtain a better thermal comfort during daytime. Matching with that theme, (Tantasavasdia, Srebricb, Chenc, 2001) found that it is possible to use natural ventilation to create a thermally comfortable indoor environment in houses in a Bangkok suburb during 20% of the year.

Natural ventilation and passive cooling is another theme handled by (Bastide, Allard, Boyer, 2008) who focused on the mass transfers for natural ventilation and passive cooling during the summer season, by opening the building. To achieve a well-ventilated and comfortable building, architects ought to have tools that forecast and improve the energy consumption by a building, and the heat and mass transfers through large external openings.

Some trends handle this subject in relation with building type, as done by (Emmerich, Dols, Axley, 2001) who reviewed the application of natural ventilation in commercial buildings, the technology, its potential advantages and related issues that need to be addressed, while (Thomas, Venkatesan, Thomas, 2014) addressed the challenge of evaluating for natural ventilation in modern apartment buildings.

Many of the CAEC applications in this field give a visual maps that give the architect and designers a real-time results based on their design alternative concerning building openings and orientation and its relation to the effective natural ventilation of the internal spaces of the building.

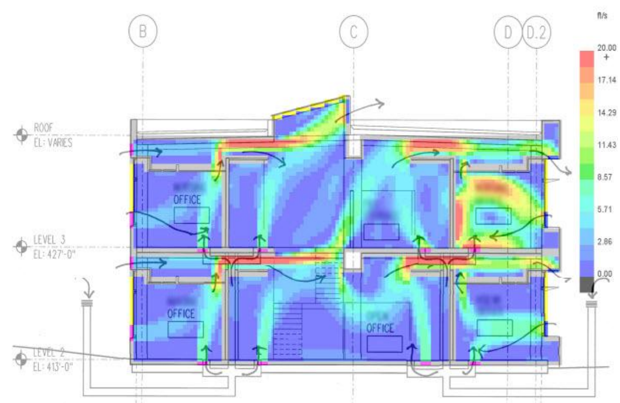

Figure 6. Though Ambiens is technically a piece of CFD software, it allows for rapid modeling and quick simulations, lmnarchitects.com

G. *INDOOR AIR QUALITY*

Buildings are intended to be a healthy shelter for people and should respond actively to all building related systems that determine buildings' Indoor Air Quality.

Building codes and standards related to indoor air quality is one of the themes and trends that has been dealt with on political and institutional levels as stated by (Mudarri, 2010) said that the significant political and institutional momentum toward energy conservation in buildings has led to building codes devoted solely to energy conservation. In the same context, (Spengler, Chen, 2000) stated that the current guidelines for green buildings are cursory and inadequate for specifying materials and designing ventilation systems to ensure a healthful indoor environment,

The effect of natural ventilation on the indoor air quality handled by (Baran, Purcaru, Bliuc, 2011) who emphasized a rate of unorganized ventilation in the classroom, far below the present standard. In the same field (European Commission, 2014) supported future policy actions by formulating guidelines, recommendations and risk management options for better air quality and associated health effects in schools.

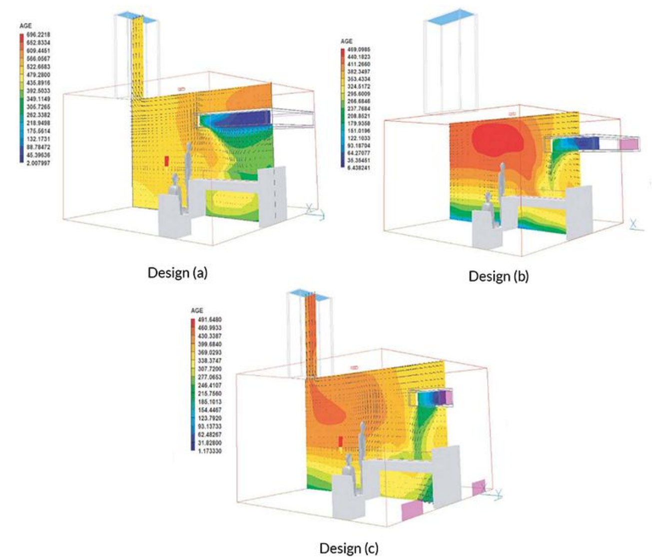

Figure 7. Computer generated alternatives by "Computational Fluid Dynamics (CFD)" for the air quality of a hospital room, Husain, Ahmed, How to Improve Indoor Air Quality for Your Designs with CFD, SIMSCALE, April, 2018, https://www.simscale.com/blog/2017/08/indoor-air-quality-cfd/

H. *ENERGY SIMULATION*

Energy efficient is an important trend connected with almost all presented themes and trends of CAEC applications. With the global trend toward sustainability, green and smart buildings/cities, the energy simulation become one of the most important subjects considered in the developing efforts of CAEC applications. Energy performance goals such as Indoor environmental conditions, energy demand, consumption, and cost. Such goals are considered in CAEC applications to support architects and designers in reaching the most energy efficient and cost effective designs.

The capabilities of Energy simulation tools are one of the research themes handled by (Ugursal, 2014), who focused on the evolution of building simulation software and comparing between them with regard to intended usage, interoperability, complexity, objectives, and ability to perform various parametric simulations. Others ranked the applications due to their capacity of calculating a significant number of variables as done by (Østergård, Jensen, Maagaard, 2016), to capacity of calculating a significant number of variables (Sousa, 2012), or to tool's strengths, weaknesses, and data exchange capabilities and stated that it is crucial to understand limitations of the tools and the complexity of such simulations (Maile, Bazjanac, 2007). In presenting such complexity, (Hong, Buhl, Wetter,

2008) focused on computing run time of a simulation program depends on several key factors, including the calculation algorithm and modeling capabilities of the program, the run period, the simulation time step, the complexity of the energy models, the run control settings, and the software and hardware configurations of the computer used to run the simulation. Other trends concentrated on calibration of energy simulation applications by comparing its results with the results of the field measurements for the same research area as done by (Fabrizio and Monetti, 2015).

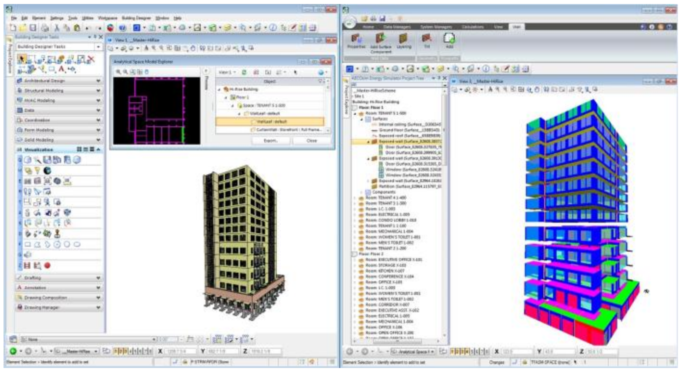

Figure 8. AECOsim Energy Simulator from "Bentley", simulate and analyze building mechanical systems, environmental conditions, and energy performance, https://www.bentley.com/en/products/product-line/building-design-software/aecosim-energy-simulator

In spite of all these efforts, the integration of simulation applications faced several challenges such as limitation, complexity, time-consuming modeling, rapid change of the design and its large related variables, and the energy related conflicting requirements & input uncertainties.

III. Discussion: The Main Challenges facing architects and designer in using CAEC

From the previous presented themes and trends, and in addition to the challenges related to energy simulation, it could be concluded that the main challenges facing architects in using CAEC applications are mainly related to the complexity of interface and the compatibility of such applications to the output of the 3d modelers' applications. The importance to manage these challenges increases with the fact that the users of such applications are not only architects, designers and other specialized professions, but also government agencies, academics, non-governmental organizations, consulting companies, and environmental control related agencies.

The early integration of simulation software faces several challenges, which include time-consuming modeling, rapid change of the design, conflicting requirements, input uncertainties, and large design variability. As an example for energy simulation applications.

The complicated interface and the required knowledge needed for the input and output data are another challenge. CAEC applications should consider the complex and complicated related data in a transparent and easy way that could be used by users with different experience levels. One of the suggestions to handle and solve this issue is to have a flexible interface that could be customized to suit different range of users: from experts to mediocre who have average knowledge about the scientific background of these fields, to the trainer who want to build capacity among young analysts who are embarking on the challenge of understanding the complexity of energy systems.

The issue of files compatibility due to the distributed and scattered applications between different agents and companies is an important challenge that could be considered either by each developer/company to have a file extension accessible by CAEC applications, or by trying to have a unified platform for such applications that could make an excellent step to let such applications well known and well used by every party related to design activities.

IV. Conclusions

- The study has highlighted a selected themes and recent trends of CAEC applications most of which become essential in the process of architecture design and its related activities.
- In spite of the availability of a wide range with different capabilities of CAEC applications to aid designers in the field of building environment control, the complex interface and the required input and the output results need to be more simple, visual, and more user friendly for those who are not specialized in environmental control fields but need it to reach preliminary decisions during the early stages of design process or before the environmental control specialists be part of the design team.
- Starting from the pre-design stage, through conceptual, development, construction, and ending with the post occupancy evaluation, CAEC applications could effectively aid architects and designers in taking right decisions in almost every stage, some of which can't be done without the computational tools available in such applications, especially with the increasing complexity of buildings and the new emerged technologies related to sustainability, green and smart buildings/cities, sustainable design and alike trends.
- MODELING and SIMULATION are considered two of the most important trends in the field of environmental control. It has a very effective potential and impact in improving and increasing the efficiency of the architect design process.
- The main challenges facing architects in using CAEC applications are the complexity of the simulation software, the complexity of most of the applications' interface, and the need to go "visual" for architects and designers. Such challenges need to be considered by developers and related agents.

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