EXTRACTING INFORMATION FROM BUILDING INFORMATION MODELS FOR ENERGY CODE COMPLIANCE OF BUILDING ENVELOPE

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ABSTRACT

Building Information Modeling (BIM) is indispensable for efficient management of infrastructure and building projects. With the introduction of mandatory energy conservation codes in several countries, project managers, designers and construction teams need to ensure that the building models comply with criteria for sustainable and energy efficient design. Various BIM platforms and model-checking interfaces allow assessment of building models with respect to conceptual analysis, heating and cooling loads, hourly heat transmission and daylight. Based upon the research in this field, a framework can be developed for directly extracting the parametric data in BIM models for automated checking against energy-code criteria. The research methodology involves identification of building parameters to be analysed as per climatic zones in India, conversion of prescriptive code requirements into program logic, selection of appropriate BIM platform, and development of the extraction framework bases on BIM tool's API to get intended outcomes. The effort aims to facilitate simultaneous evaluation during design for the purpose of expediting the process of reviews and updates through automated code-checking. The resulting framework could also be helpful for selecting and determining costs of building envelope components and green building materials which enhance the overall performance of the built environment.

Keywords: Automated Code-checking, Building Envelope, Building Information Modeling (BIM), Energy Analysis, Energy Conservation Code.

INTRODUCTION

The rising awareness regarding worldwide climate change and resulting energy regulations has led project managers and designers to emphasize the importance of energy performance in buildings. The project manager of today is required to manage the project in a most efficient and effective manner with respect to sustainability. Particularly during the design development stage, which encompasses a vast gamut of considerations, the design team needs to spend adequate

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time on studying and chalking out the design system performance against the stated green building goals (Hwang and Ng 2012). In this regard, Building Information Modeling (BIM), which entails rich geometric, topological, and semantic information of a building for enhanced communication and coordination (Nepal, et al. 2012), can perform a vital role by helping to expedite the simulation and energy-analysis of building models, and therefore achieve compliance through automated code-checking with greater speed and accuracy.

Rising Energy Consumption in Buildings

Buildings account for more than 30% of the total electricity consumption in India, the second highest share of consumption after industries. Estimates reveal that the total built space in the country would increase over five times in the 25-years period from the year 2005 to 2030. This would also lead to more than 60% of the commercial built-space being air-conditioned (McKinsey & Company 2010).

Energy Code in India and Germany

The Energy Conservation Code in India (ECBC, 2007) was developed for promoting energy efficiency in the building sector in India, and is published by the Bureau of Energy Efficiency, Government of India. The code is applicable to five major areas of energy consumption in buildings which are Building envelope, Heating, ventilation and air conditioning, Service water heating, Lighting, and Electric power and motors. The code specifies few mandatory requirements and provides two alternate routes for buildings to comply with it: prescriptive route and the whole building performance route. Detailed procedure for modeling the proposed design and the standard design are provided in the code (Tulsyan, et al. 2012). Similarly in Germany, In order to mitigate the adverse impact of increasing energy demands, the Energy Conservation Regulation (EnEV) in prescribes methods which can be applied as statistical mathematical models to estimate energy gains and losses (Schuelter and Thesseling 2008). The regulation is mandatory for the calculation of energy demand of new and existing buildings. In the month of May 2011, the Bureau of Energy Efficiency (BEE) in India had announced that the implementation of ECBC would become mandatory for eight states in the country, from April 2012. The Code is applicable to all new constructions in the states of Delhi, Maharashtra, Uttar Pradesh, Haryana, Tamil Nadu, Andhra Pradesh, Karnataka and West Bengal (IBNLive n.d.).

Energy-savings through Code Compliance

It is estimated that ECBC compliant buildings may consume about 40% less energy than conventionally practiced buildings in India and nationwide enforcement of the building code could result in annual saving of 1.7 billion kWh units. A study was carried out of a set of more than 80 existing commercial buildings in Hong Kong and their energy savings potential were calculated, assuming the building energy code becomes mandatory (Chan and Yeung 2007).

Table 1. Energy-saving Potential through ECBC Compliance in India (Tulsyan, et al. 2012)

	Government Building	**Private Office Building**
Specific Energy Consumption (kWh/m^2/y)	137	386
Energy Saving Potential (kWh/m^2/y)	44	128
% Energy Savings	32%	33%
	Institutional Building	**Hospital Building**
Overall Energy Savings	17%	42%

A study of six different buildings in the city of Jaipur (Rajasthan, India) was carried out by Tulsyan, et al. (2012). They concluded that by adopting the energy Conservation Measures

(ECMs) specified in the ECBC, annual energy savings upto 17% was possible in institutional buildings and upto 42% savings could be achieved for a hospital (see Table 1).

Applicability and enforcement of the ECBC creates the backdrop for implementation of energy conservation measures in the design process, especially by utilizing the features of BIM in the automated code-checking process.

ENERGY ANALYSIS USING B.I.M.

Building information models are capable of storing multi-disciplinary information within one virtual building representation. These types of information include geometric, semantic and topological parameters. The capability of BIM models to store wide array of information present in parametric objects can be utilized to retrieve various indices and their values necessary for performance calculations. Eastman, et al. (2011) have noted that improvement of energy efficiency and sustainability**,** by way of linking the building model to energy analysis tools, allows evaluation of energy use during the early design phases..

Requirements and BIM Tools for Energy Simulation and Analysis

Performing the automated energy analysis requires all information relevant to the energy load calculation to be explicit in the preliminary concept model, including the thermal properties of the building, such as the thermal resistance of the external walls and other surfaces and the number of occupants in a space (Sanguinetti, et al. 2012). In a standard energy-evaluation process, Industry Foundation Classes (IFC) components of the parent BIM model can facilitate exchange of information to the system architecture of the thermal model in the energy analysis tool. In the intermediate thermal model, relevant parametric information is converted to input data set, from where energy analysis files and reports can be generated. The capability to capture a wide range of geometric and toplogic representations also make it a promising candidate as a "native information model" for tools that support spatial design (Bhatt, et al. 2013).

Table 2. Basic Categories of Performance-related Energy Analysis Tools (Schuelter and Thesseling 2008)

	Physical Calculation Models	**Statistic Calculation Models**
Function	Calculate overall energy consumption	Simplified models
Special Features	Perform highly precise calculations of detailed tasks such as zone loads, day-lighting and solar computations, and even multi-zone airflows	Estimate total energy demand, heating or lighting demand.
Example of BIM Tools	TRNSYS, IES Virtual Environment, EnergyPlus, Solibri Model Checker, e-QUEST	Employed in Regulations such as German Energy Savings Regulation EnEV or the Swiss Minergie

The most important design decisions concerning building sustainability are generally made in the preliminary design stages by the architect or the building designer. The building energy codes can be used by designers as guiding tools to develop an energy efficient building (Schuelter and Thesseling 2008). The modeling tools can also be used to predict a cost effective energy efficiency retrofit to an existing building. The accuracy of the building energy simulations relies heavily on the user input data such as building geometry and orientation, construction details, geographic location, mechanical equipment, type of building (residential or commercial), etc. Schuelter and Thesseling (2008) classified commonly-used performance analysis tools into two groups: Physical Calculation Models and Statistic Calculation Models (see Table 2).

Importance of Building Envelope in Energy Analysis

The ECBC has established mandatory and prescriptive criteria for the thermal performance of building systems, of which, one is the building envelope, defined as the interface between the indoor and outdoor environments of a building. It also controls indoor conditions irrespective of transient outdoor conditions (Sadineni, et al. 2011). Building components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, and external shading devices constitute the envelope.

To incorporate the building envelope criteria of ECBC for evaluating energy efficiency in warm climatic conditions of India, Dhaka, et al. (2012) made use of simulation programs like DesignBuilder (2.100.25) and EnergyPlus (V4.0.0.024). In their analysis, Dhaka et al. considered five measures recommended by ECBC and then chose two measures based on their performance, for instance, a combination of ECBC Glass + ECBC Roof, and ECBC case. With the combination of all individual ECMs (termed as ECBC Case), 40% energy could be saved against common practice. Of all the building envelope related conservation measures, thermal indices like U-value, R-value and SHGC were found to have maximum impacts on the savings potential. The values of these indices can be derived directly from the Building Information Model to facilitate decision-making and automated reviews during the early design stage itself.

AUTOMATED CODE-CHECKING PROCESS IN B.I.M.

Building Information Modeling (BIM) enables automatic parametric generation of designs that are equipped to respond to important criteria of building models. Therefter, it also enables computerized interpretation and automated checking of designs. “Automated rule checking” could be defined broadly as a “software functionality that does not modify a building design, but rather assesses a design on the basis of the configuration of objects, their relations or attributes” (Eastman, et al. 2009). The process of rule-checking can be classified into four broad stages, namely, rule interpretation, building model preparation, rule execution and reporting of checking results. For assessment purposes, the required information in a building model can be made available through one mode, or a combination of modes such as manual entry, data derived from computer, or thirdly, through application of an analysis model which automatically derives complex information and applies the stored rules to the analytically derived data for compliance checking (Eastman, et al. 2009). The third mode is the basis of the research framework that aims to automatically retirieve data to evaluate its compliance with energy codes.

Recent Works in Automated Code-checking

LicA, developed in August 2012 by Martins & Monteiro, performs automated code-checking of domestic water system networks projects, according to the regulations and codes in Portugal. The main components are included in a single SQL Server database named LicA. which includes a set of tables with all the objects needed to represent the network and calculation preferences (Martins and Monteiro 2012). It also includes hydraulic analysis tools and code-checking routines, developed in T-SQL. Results are gathered in tables for post-processing. The database can be accessed through ODBC (Open Data Base Connectivity).

Zhang, et al. (2013) suggested an approach which allows users to check the model directly from the BIM tool. The automated rule-checking system for assessing designs with OSHA (Occupational Safety and Health Administration) Safety Norms in the USA, has been implemented in BIM software using the open application programming interface (API). A test model was created in Tekla Structures, showing a construction project in progress. The model contained different types of openings that would pose a potential fall hazard. The implementation platform incorporates OSHA safety rules, best construction practices, and project schedules to create rules applicable to the building model. After evaluation with respect to a library of safety actions, corrective measures could be found and an action report could be generated.

Based on the study of recent ongoing efforts in the field of automated code reviews, a research framework could be established for addressing thermal and analytical properties to evaluate BIM models with respect to ECBC, during the design stage.

INFORMATION EXTRACTION FOR ENERGY-CODE COMPLIANCE

The Research Methodology

The research work comprises major steps as follows (1) Identifying specific ECBC rules pertaining to building envelopes, (2) Referring to the standard threshold limits for every rule (prescriptive requirements in this case), (3) Identifying all associated object classes, families and properties of building components used in the BIM model of a live project, (4) Writing algorithms and program codes for extracting parametric information, and (5) Testing and validation through a live project, and result-reporting.

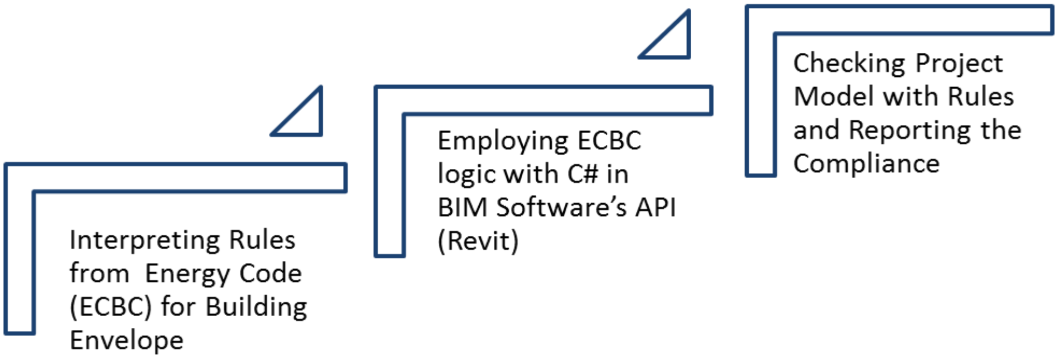


Fig. 1. Outline of Methodology for the Research Framework

The BIM-based live project chosen for validation of the framework is the design and construction of a Lecture Theatre Complex in IIT Delhi, New Delhi, India. This was a pilot project for implementation of Virtual Design and Construction (VDC) in public sector projects in India. Autodesk Revit was used for preparing the building model, as Revit is the best-known and current market leader for BIM tool in architectural design (Eastman, et al. 2011). The primary objectives of the framework are to provide code-compliant information during the design-stage, reduce the time required for checks and updates, and to facilitate material selection, life-cycle analysis, eventually leading to better thermal performance for user-comfort and energy savings.

Identification of Requirements from Energy Code

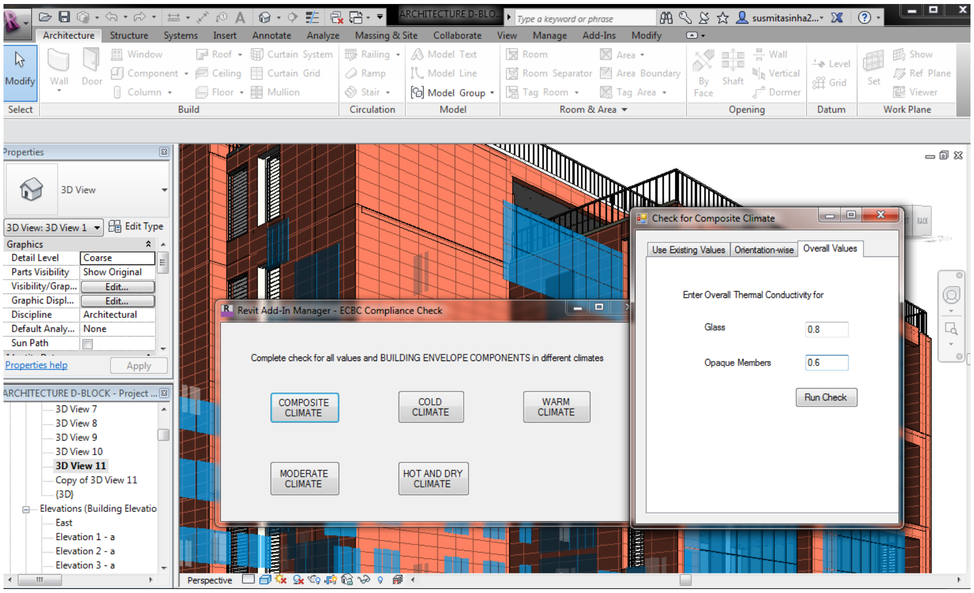
The ECBC provides two methods for building performance analysis : (1) Prescriptive criteria, and (2) Trade-off method for building envelopes. With respect to the ECBC guidelines, required minimum and maximum conformance values for Building envelope thermal indices like U-value, R-Value, and other numeric constraints were recorded from the energy codes. All criteria referred were applicable to the composite type of climate in which New Delhi is situated. The information was grouped as per climate zones to streamline the values for easier conversion into program logic for C# code. These values were referred directly from the ECBC 2007.

Energy Analysis Capabilities of the selected BIM Platform

The existing energy analysis features of Revit 2013 are useful for the whole building performance method (WBPM) of ECBC, which include building performance factors, monthly heating and cooling loads, electricity consumption, and monthly peak demand. However, thermal performance and day-lighting are not supported by the current version. The focus of the current research endeavor is to provide a mechanism to check for the prescriptive criteria of the ECBC 2007, which are not covered exclusively in the existing energy analysis features of the latest version of Revit 2013 used in the study. The intended plug-in and the existing features could be used in combination for achieving compliance with preliminary mandatory criteria (for early design stages), as well as energy-simulation (for detailed design) respectively.

Implementation in the Programming Interface

For the purpose of information extraction, the Application Programming Interface (API) of Autodesk Revit was addressed using the .NET framework of Microsoft Visual Studio 2010 in C# programming language. The pre-existing families, classes and types of elements in the Revit model were studied in order to determine the kind of information to be extracted.



Revit Add-In Manager - ECBC Compliance Check

Complete check for all values and BUILDING ENVELOPE COMPONENTS in different climates

Check for Composite Climate

Enter Overall Thermal Conductivity for

Glass 0.8

Opaque Members 0.6

Detail Level: Coarse

Parts Visibility: Show Original

Discipline: Architectural

Default Analy...: None

Fig. 2. A simple user-interface for starting compliance check

Extraction of Required Information

The required information for energy code compliance was streamlined from the ECBC compliance forms to develop the program logic for the API. The various levels of information fields required were identified as (1) project information, (2) project description (3) compliance option, (4) type of building, (5) climate zone, and (6) building systems, with special emphasis on building envelope components (roof, wall, vertical fenestration, skylight). In order to extract the dimensional and geometric properties of aforementioned components, their associated methods and parameters from the API were identified. User input was kept minimal for a simple user interface of the external command (see Fig. 2). Applicable arithemetic and logical operators and formulae were incorporated in the programming code to derive thermal indices values from the building model being tested for energy performance. With the use of logical operators, the derived values were checked against compliance limits for composite type of climate. The computational framework is described briefly in Table 3. Due to coding limitations, the full framework is undergoing development for execution and validation.

Table 3. Information Extraction Steps and Corresponding API Functionalities

	Information Extraction Step	**Revit Built-In Parameters and Methods; C# Methods for logical and arithmetic operations**
1	Inputs in User Interface	Windows Forms; Class Libraries to run the code for DLL
2	Project Description	Element – ProjectInfo; Access in property of Document as Document.ProjectInformation
3	Selecting Compliance Option & Climate Zone	Through interface created by Windows Forms and Buttons. Switch-Case and If-Else conditions
4	Calculating Window to Wall Ratio (WWR) • Sum of all opening areas • Sum of exterior Wall Area Finding % Glazing	FilteredElementCollector(uiDocument.Document) Ilist<Element> walls, OfClass(typeof(Wall) CategoryFilter(BuiltInCategory.OST_Walls) for-each loop Calculating gross areas area with Element.GetMaterialArea() method in Revit API Arithmetic operator / and * to find % glazing GetInfo_Opening, Opening.BoundaryRect.get_Item()
5	Constraint – not exceed 40%	If-Else condition
6	Steps 4 & 5 for Skylight-Roof Ratio	Same methods for Wall and Skylight Types
7	Calculating R-Value of Wall and Roof	HostObjectAttributes
a	Input for Thermal Conductivity	Form is prompted for user's input (double type)
b	Extracting Thickness of component and dividing by Conductivity	CompoundStructure.GetLayers() CompoundStructure.GetLayerWidth()
c	Checking against threshold value	For Minimum case
8	Calculating U-Value for as Steps 7 a, c. ; instead dividing conductivity by thickness	
	Checking against threshold value	For Maximum case
9	Obtaining SHGC (not provided in model instances in this project)	Edit for each component in Read-only properties and then retrieve ThermalProperties
10	Reporting stored value result as Excel file	Use of .csv format and unit conversions; XmlWriter

Relevance of Outcomes

In the first phase of development, the Revit plug-in could be run for extracting pre-requisite volumetric and area ratios upon which gives scope for further criteria of thermal indices values to be analyzed. Different design-alternatives could also be developed in the BIM tool and analyzed during early stages. The extraction process is relevant for validating the design with respect to building envelope components, and making changes and updates where necessary in the case of non-compliance. This also has implications on selection and costing of green building components that command a significant share of the overall budget.

Limitations and Further Scope

The first stage of information extraction was restricted to checking against the prescriptive requirements of ECBC. The framework could be extended to more detailed analysis with respect to trade-off method that allows conseideration of the effect of individual thermal performance factors seen in totality. Multi-layered construction for walls and fenestration would be taken into account for the next phase of data retrieval, along with checks for lighting, electrical and HVAC criteria that would cover all aspects of building services.

CONCLUSIONS

This research framework makes an attempt to access parametric properties of Revit families and components in order to extract information to check for energy-code compliance. The use of the programming interface of BIM software plays a key role in providing access to a vast repository of stored parametric data in the building models. The validation of the building envelope with respect to the energy code criteria could speed up the design process and can help construction managers and other stakeholders to make decisions regarding material selection. This shall in turn affect the overall costs and budget of the project. The basic framework for information extraction can be extended to include different types of detailed requirements from the code, and to test the framework on other live projects.

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