Developing an OpenStudio Script for Simpler Compliance Validation for the Energy Conservation Code for Buildings in Mexico

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Abstract

This paper shows how a customized OpenStudio script was developed, based on the Mexican standard for energy efficiency in residential building envelopes.

Currently existing validation tools impose a burden for CAD-oriented building designers; they require long sessions for the calculation of thermal characteristics of each component, as well as tedious data-capturing without the aid of a graphical user interface (GUI).

OpenStudio's built-in capabilities and GUI, allowed for the creation of a robust and simpler method for compliance validation.

This paper shows that, compared to the existing validation tools, this script improves both the time consumed and accuracy of the calculations.

Lastly, alternative ways to increase the scripts capabilities and practicality for widespread use in Mexico are discussed.

Introduction

The Energy Conservation Code for Buildings in Mexico (IECC-MX) is the most recent governmental effort to facilitate the adoption of the existing Mexican Official Norms (NOM) on building energy efficiency ("Presentan el código," 2016).

NOMs cover a wide variety of topics related to building energy efficiency, from technology-specific minimum efficiency requirements to system-wide performance testing methods.

The regulations with the most direct impact on building design are those that regulate thermal gains through the envelope: NOM-020-ENER-2011 for residential buildings and NOM-008-ENER-2008 for non-residential buildings ("Norma Oficial Mexicana," 2011).

These NOMs evaluate thermal heat gain trough the envelope of a proposed building and compare it to that of a baseline building.

To show compliance the designer must calculate, for each individual component of the thermal envelope, the amount of heat passing through in the form of conduction and radiation. Heat gains must be calculated under reference design conditions, specified by the NOM for the building's location.

For each of six possible orientations (North, South, East, West, Up and Down) and for each thermal envelope component, the designer must use tabular reference data to determine reference temperature differentials, solar heat gains and exterior shading reduction factors.

The normative text requires repeating this calculation process for a baseline building, using the same geometry and orientation as the proposed design, but with pre-defined transparent-to-opaque surface ratios, as well as site-specific reference values for the thermal characteristics of the envelope.

Although the algebra is relatively simple, this calculation process can be a burden for designers unfamiliar with building energy analysis. Moreover, the lack of GUI on existing compliance tools might further discourage the incorporation of code compliance verification during the design process.

The authors have identified that a visually oriented, robust and free-to-use tool can make code compliance calculations more accessible for building designers, while at the same time facilitating widespread adoption of building energy efficiency NOMs.

Structure of NOM-020-ENER-2011

Comparison against reference building

The main requirement of NOM-020-ENER-2011 is to evaluate the thermal gain through the envelope for the proposed building against a reference building, with the same geometry and orientation, but with pre-defined thermal characteristics for its construction assemblies and pre-defined window-to-wall ratio of 10%.

The NOM requires that the thermal heat gain for the proposed building should be less than that of the reference building. This is,

$$\varphi_p \leq \varphi_r \tag{1}$$

Where:

φ_p : Thermal heat gain trough the envelope of the proposed building.

φ_r : Thermal heat gain trough the envelope of the baseline reference building.

The thermal heat gain through the building envelope shall be considered as the conduction of heat through the opaque and transparent sections, as well as radiative heat passing through the transparent portions:

$$\varphi_p = \varphi_{pc} + \varphi_{ps} \tag{2}$$

$$\varphi_r = \varphi_{rc} + \varphi_{rs} \qquad (3)$$

Where:

φ_{pc} : Conduction thermal heat gain trough the opaque and transparent fractions of the envelope for the proposed building.

φ_{ps} : Solar thermal heat gain trough the transparent fraction of the envelope for the proposed building.

φ_{rc} : Conduction thermal heat gain trough the opaque and transparent fractions of the envelope for the reference building.

φ_{rs} : Solar thermal heat gain trough the transparent fraction of the envelope for the reference building.

In order to calculate the total conduction and solar heat gain values, each envelope component must be analyzed.

The conduction thermal heat gain for the proposed building is defined as:

$$\varphi_{pc} = \sum_{i=1}^{6} \varphi_{pci} \qquad (4)$$

$$\varphi_{pci} = \sum_{j=1}^{n} [K_j \times A_{ij} \times (t_{ei} - t)] \qquad (5)$$

Where:

φ_{pci} : Conduction heat gain trough each individual component of the thermal envelope for the proposed building.

i: Each possible orientation of the component; north, south, east, west, upward or downward.

j: Each individual component of the thermal envelope; wall, door, window, roof, skylight, exposed floor.

K_j : Global conduction heat gain coefficient for each construction assembly, defined as the sum of the thermal conductance of the construction assembly and the reference surface film resistances (inside and outside) defined in the NOM, in W/m²K.

A_j : The area of each individual component of the thermal envelope, in m².

t_{ei} : Interior surface temperature for each individual component of the thermal envelope; this value is defined in the NOM normative annex, based on the building location and on the envelope component orientation, in °C.

t : Building interior temperature, defined in the NOM normative annex, in °C. The NOM assumes air inside the building is perfectly mixed, and has achieved this uniform value.

The radiation or solar thermal heat gain for the proposed building is defined as:

$$\varphi_{ps} = \sum_{i=1}^{5} \varphi_{psi} \qquad (6)$$

$$\varphi_{psi} = \sum_{j=1}^{n} [A_{ij} \times CS_j \times FG_i \times SE_{ij}] \qquad (7)$$

Where:

φ_{psi} : Radiation heat gain trough each transparent component of the thermal envelope for the proposed building.

i: Each possible orientation of the component receiving solar radiation; north, south, east, west or upward.

j: Each transparent individual component of the thermal envelope; window, transparent door or skylight.

A_j : The area of each individual transparent component of the thermal envelope, in m².

CS_j : The shading coefficient of each transparent component, according to manufacturer specification, with a dimensionless value between 0 and 1.

FG_i : Solar exterior radiation factor for each orientation, defined in the NOM normative annex, in W/m².

SE_{ij} : Exterior shading factor for each transparent component in the thermal envelope, defined in NOM normative annex, with a dimensionless value between 0 and 1.

The equivalent expressions for the reference building are:

$$\varphi_{rc} = \sum_{i=1}^{6} \varphi_{rci} \qquad (8)$$

$$\varphi_{rci} = \sum_{j=1}^{n} [K_{ref_j} \times A_{ref_{ij}} \times (t_{ei} - t)] \qquad (9)$$

$$\varphi_{rs} = \sum_{i=1}^{5} \varphi_{rsi} \qquad (10)$$

$$\varphi_{rsi} = \sum_{j=1}^{n} [A_{ref\_ij} \times CS_{ref\_j} \times FG_i] \qquad (11)$$

Where:

φ_{rci} : Conduction heat gain trough each individual component of the thermal envelope for the reference building.

K_{ref_j} : Global conduction heat gain coefficient for each construction in the reference building, defined in the NOM normative appendix according to construction type, orientation and building size, in W/m²K.

A_{ref_j} : The area of each individual component of the thermal envelope in the reference building, calculated considering a pre-defined window-to-wall ratio of 10% for the whole building, in m².

φ_{psi} : Radiation thermal heat gain trough each transparent component of the thermal envelope for the reference building.

CS_{ref_j} : The shading coefficient of each transparent component in the reference building, defined as 1 by the NOM.

Definition of calculation parameters

Many of the above-mentioned variables are defined in normative appendix tables, and can be site, building, or surface-specific.

Site-specific parameters depend on the reference location of the building. There are 58 different Mexican cities defined in the NOM normative annex.

Building-specific parameters depend on the number of stories, grouping projects in two categories: buildings up to three levels and buildings higher than three levels.

Surface-specific parameters depend on surface tilt, construction and orientation. Conduction heat gain coefficients shall be calculated using the construction materials thermal conductivity and thicknesses as well as pre-defined surface resistance values dictated on the NOM.

Calculation of conduction heat gains is relatively straightforward; the most challenging calculations are those related to the conduction heat transfer coefficients.

Exterior shading factors

If the building designer wishes to take credit for shading features such as overhangs, vertical fins or recessed windows, a special exterior shading multiplier factor must be calculated for each transparent element.

In order to determine the multiplier factors, each window and its associated shading devices must be analysed and geometry ratios must be calculated, following the definitions shown in Figure 1.

The NOM normative annex includes tabular values for the appropriate shading multipliers, for the different combinations of the geometric ratios shown in Figure 1 and for the different combinations of building location and window cardinal orientation.

If the proposed building geometry is complex, the process of measuring and calculating geometric ratios for each window can result cumbersome and tedious,

Once all the calculation parameters have been determined, individual heat gains are added using equations (4), (6), (8) and (10).

The calculated total heat gain for the proposed building is compared to that of the reference building; if equation (1) is satisfied, the proposed building design is considered to have achieved compliance with the NOM.

Developing the OpenStudio script

Currently available tools

In order to verify compliance with the NOM, the building designer can rely on manual calculations or use a free-to-use tool, available from the website of the National Commission for Efficient Energy Use (CONUEE) ("Herramienta de cálculo," 2014) .
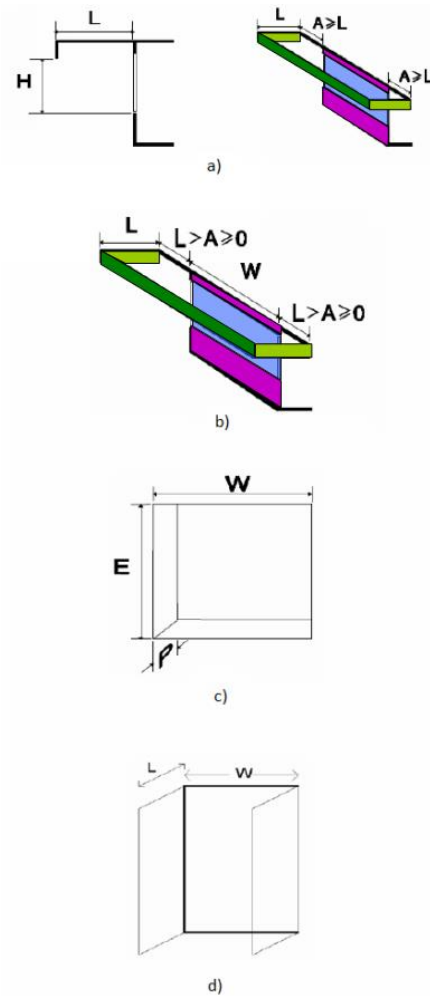

Figure 1: Geometry factors for exterior shading calculations. a) Overhang extends laterally past the window limits more than its outward projection. b) Overhang extends laterally past the window limits less than its outward projection c) Recessed windows d) Side fins.

The tool developed by CONUEE consists of a series of wizards and spreadsheet-like screens, that help the building designer characterise the proposed building.

The tool has built-in capabilities for creating and assigning building constructions, however, it does not include 3D modelling capabilities. This creates the need for the building designer to transit back and forth between the CONUEE tool, a CAD model or spreadsheet data.

Additionally, this tool allows for only one type of exterior shading device per window, which imposes a limitation on achievable solar gain reductions due to passive design.

Advantages of using OpenStudio

In order to make the validation calculation process easier for building designers, the authors decided to develop an automated script in OpenStudio.

The main advantages identified in using OpenStudio instead of other tools were:

1. Graphical user interface fully integrated into SketchUp, which would allow for a very intuitive process for CAD-oriented building designers to create thermal envelope components.
2. Built-in capabilities for creating, editing and assigning customized construction assemblies and building materials.
3. Built-in capabilities for object-oriented manipulation of building parameters using Ruby.

Proposed script workflow

Figure 2 shows the proposed workflow for the script developed for compliance validation with the NOM.

The basic process of the script is to get the required values from the site, building, surface and subsurface objects in the OpenStudio model. Then, the script uses these values to complete equations (5), (7), (9) and (11).

The building object is used to count the number of stories, while the site object is used to determine the latitude and longitude values. Using these parameters, the script looks up the values for K_{ref_j} and t from the NOM reference tables.

Similarly, looping through surface and subsurface object arrays, the current object's tilt and orientation are used to determine t_{ei} and FG_i from the NOM tables, while the current object's thermal characteristics are used to determine, K_j and CS_j.

The current object's area value and the NOM requirements are used to determine A_j and A_{ref_j}.

Automatic sub-routines were programmed to iterate the tabular data for exterior shading multipliers, according to building location, subsurface orientation and user-entered geometric ratios for each shading device type and window object.

Finally, the scrip calculates the proposed building heat gains through the envelope, as well as the reference building heat gain allowance. These two values are compared and the result is prompted as a simple custom report in the "Results Summary" tab in OpenStudio.
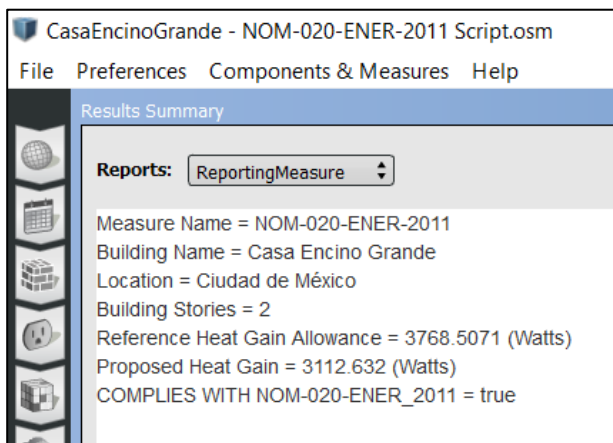

Figure 3: Custom report showing custom measure results.

Current limitations of the script

Although EnergyPlus determines the adjacent surfaces that cast shadows on each subsurface, as well as the shading fractions for specific times of the run-period, the script currently does not have the capability of determining automatically the exterior shading geometric ratios, as they are defined in the NOM.

Instead, it relies on user-entered values for the corresponding geometric ratios for each subsurface.

The way the script gets these values is by looking at the name of each subsurface object. Then, it evaluates if the name contains the specific string of characters corresponding to the desired geometric ratio. If the specific string of characters is found, the script extracts the numeric characters immediately adjacent to that string and stores them as a float value.

For instance, if a subsurface object has the name "SubSurface 42 LW1.25 LH2.04", the script will assign 1.25 and 2.04 to the L/W and L/H relationships for that particular window. The script will then iterate through the tabular data to obtain the exterior shading multipliers for that specific window orientation and building location.

If the script fails to find the values for specific geometric ratios, the exterior shading multipliers are defaulted to 1 and the reduction on solar heat gain for that subsurface does not occur.

Another current limitation of the script is that in order to determine if a construction is a "mass" construction, the script reads the construction name and evaluates if it contains the substring "MASA" (Spanish for "mass"). If this string is not found, the construction type is defaulted to "lightweight" and the calculation is completed using the appropriate values from reference tables.

These string comparison methods are error-prone and future work is projected to address this issue. The authors expect to expand the capabilities of the script, enabling a more complex analysis of construction assemblies and subsurfaces (for instance, by examining the XYZ coordinates of their vertices and comparing them to the adjacent shading surfaces on the virtual space of the model).

Nevertheless, the NOM itself places inherent limitations on how the exterior shading multipliers can be calculated.

The normative text and definitions are limited in scope and are not fully capable of taking into account the shading effects of features like asymmetric or curved shading assemblies (e.g. L-shaped walls, arches, curved overhangs or canopies, etc...). Furthermore, the CONUEE tool does not allow for more than one type of exterior shading per window.

As long as the definitions in the NOM are not expanded, to include alternative and more general methods to acknowledge the solar heat gain reduction of complex building geometries (or different shading features acting simultaneously), full automation of the normative calculations using an OpenStudio script might not be possible.

Accuracy of script

In order to assess the accuracy of the iteration routines programmed to scan the tabular data and set the exterior shading multipliers, two example calculations included in the NOM were tested.

Table 1: Accuracy Comparison

	Input Data		Result in NOM example calculation	Results from script
Example 1	W/H	1.6875	0.5623	0.5620
	L/H	0.8125		
Example 2	L/W	0.5333	0.502	0.5026

Table 1 shows that the results obtained using the script are highly accurate, because all operations are automatically executed using float values directly from the model.

However, the choice of values for the geometric ratios for exterior shading might have a significant effect on the resulting multiplier factors and compliance validation.

Application of automated script

Residential case study in Mexico City

A residential case study in Mexico City was used to test the proposed script and compare it to the existing validation tool from CONUEE.
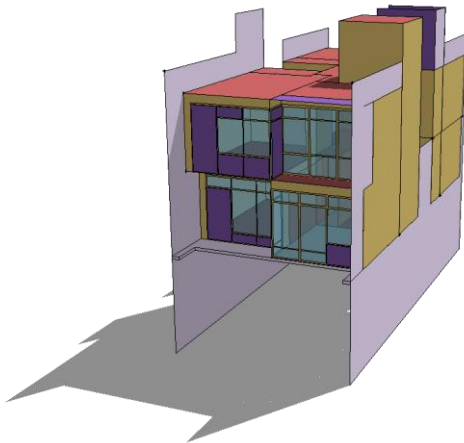

Figure 4: Residential building used for script testing.

As seen in Figure 4, the architectural features of the building generate a geometry far more complex than the CONUEE tool could support. For this reason, the following alternative calculations were compared:

1. CONUEE tool with all windows set to "no exterior shading"
2. Proposed OpenStudio script without exterior shading (all geometric ratios set to zero)
3. Proposed OpenStudio script with simultaneous exterior shading from all architectural features that might apply.
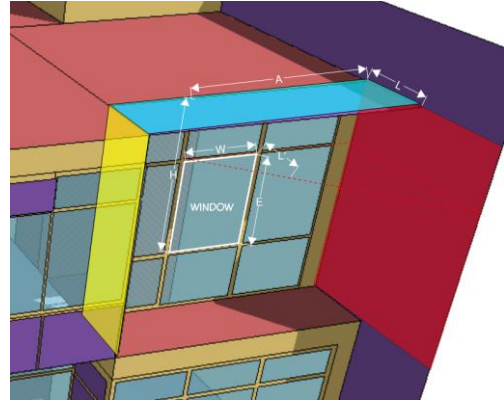

Figure 5: Geometry factors for simultaneous exterior shading from multiple architectural features.

Figure 5 show how exterior shading was considered for alternative 3. Applicable geometry ratios were calculated for each subsurface and applied simultaneously in the script, by including the appropriate acronyms and values into the subsurface names.

Tables 2 shows the resulting reductions in the time consumed to perform different phases of the validation process, for each alternative.

Table 3 shows the resulting thermal heat gains for each alternative.

Table 2: Case Study Results, Time Spent

	Time Spent		
Task	CONUEE tool	Script no shading	Script full shading
Creating 3D model	0	5.5	5.5
Create and assign constructions	6	1.5	1.5
Calculate exterior shading multipliers	9	0	<0.5
Calculate total thermal heat gains	<1	<1	<0.5
Total hours spent	16	<8	<8

Table 3: Case Study Results, Calculated Thermal Gains

	Calculated Thermal Gain		
	CONUEE tool	Script no shading	Script full shading
φ_{rc}	1269.5	1269.5	1269.5
φ_{rs}	2499.0	2499.1	2499.1
φ_r	**3768.5**	**3768.6**	**3768.6**
φ_{pc}	-1191.2	-1189.3	-1189.3
φ_{ps}	7297.5	7297.6	4301.9
φ_p	**6106.3**	**6108.3**	**3112.6**
Pass?	NO	NO	YES

Discussion

The proposed OpenStudio script reduces the time employed to perform the required compliance calculations and improves precision, when compared to the existing validation tools from CONUEE.

When using the script, time spent was reduced by more than 50% the first time the building was simulated. Once the OpenStudio model had already be created, making modifications to exterior shading factors was straightforward and new results were easily calculated.

When comparing alternatives without exterior shading factors, the results obtained with the proposed script were within 0.0325% deviation from the results obtained using the CONUEE tool.

When including the shading effect of the complex geometry in the OpenStudio alternative, solar heat gains were reduced by 49%, allowing the building to comply with the NOM.

Results confirm the critical importance of including all exterior shading features during validation calculations.

Using the OpenStudio script would require designers to create a simple energy model, with at least one OpenStudio space and all the required construction materials and assemblies. Although this could create a burden for some users, the authors consider this script a valuable new alternative, since other existing tools already demand a vast amount of calculations, uncommon to Mexican building designers.

Furthermore, creating a simple energy model for code compliance could represent the parting point for more energy-efficiency focused design practices. In time, this could encourage Mexican building designers to implement the full potential of EnergyPlus into their projects.

Conclusion

An OpenStudio script for compliance validation with NOM-020-ENER-2011 was developed. The goal of this script is to make it easier for CAD-oriented building designers to incorporate energy efficiency and code compliance calculations into their practice.

This script allows building designers to evaluate the heat gain through the envelope of their proposed building, against a virtual baseline reference. The script produces a simple report that that informs if compliance was achieved, as well as the amount of heat transfer going into each building alternative.

Using the script for compliance calculation would allow designers not only to cut time expenditure drastically, it also would allow them to remain within a design environment that results more familiar, further encouraging them to explore the creation of more energy efficient designs.

Introducing Mexican building designers to free-to-use, simple and robust tools for code compliance is a fundamental first step, in order to develop building energy modeling to its maximum potential in the country.

Notwithstanding the current limitations, the development of this tool lays the ground for further research on the implementation of visually-oriented tools for energy-efficient building design and code compliance validation in Mexico.

Future work will focus on expanding the capabilities of this script, developing ready-to-use compliance reports, creating an OpenStudio template with pre-loaded building materials referenced by Mexican NOMs and formally requesting Mexican normative bodies for recognition of the script as a valid compliance validation tool.

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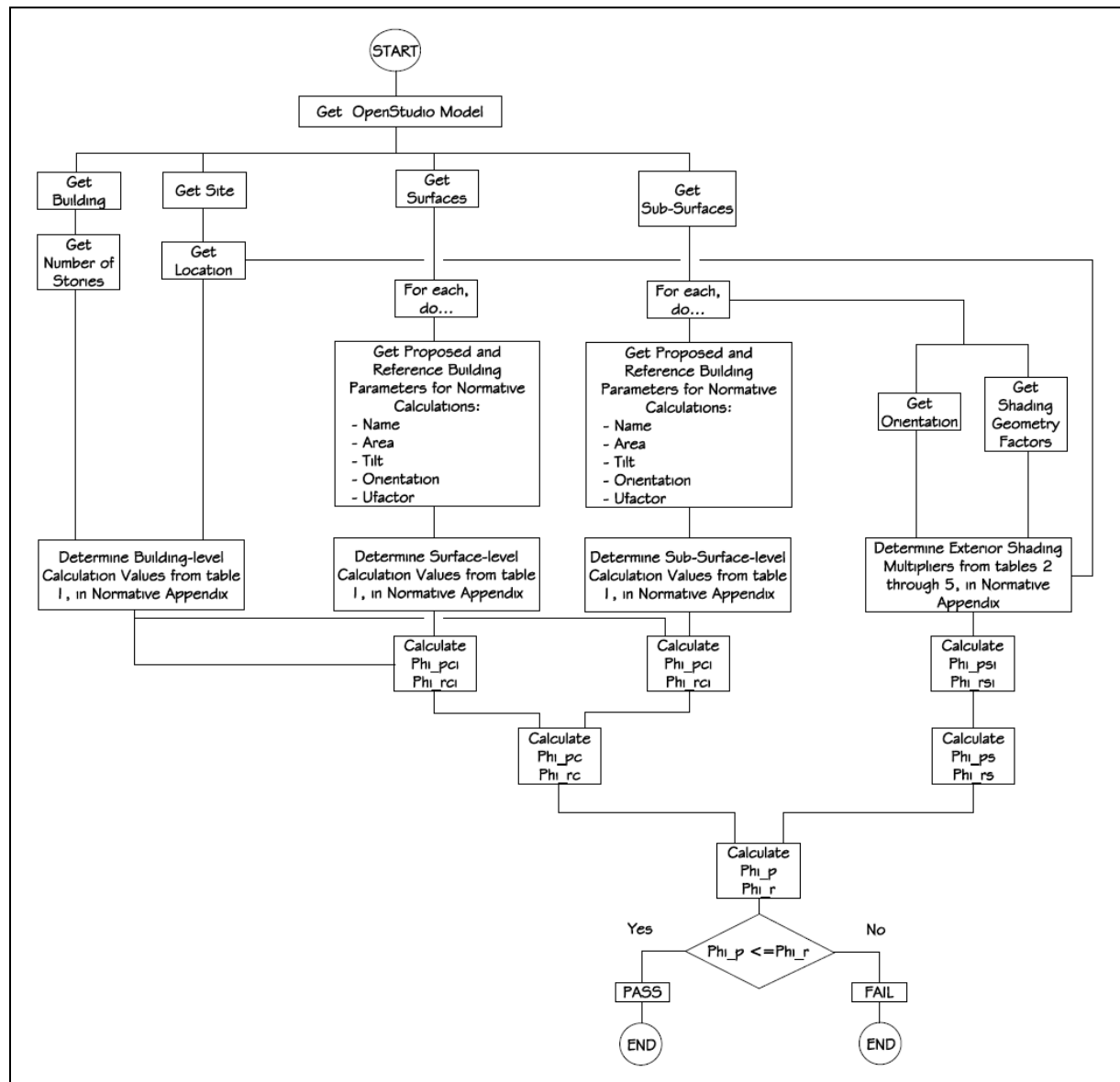
Figure 2 Proposed workflow for automated OpenStudio script.