gbXML BIM Export Level 3 Testing Scenario Development Phase 1 Report

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DBL Working Paper #WP_____

September 2018

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1 Introduction

The Green Building XML schema, or "gbXML", was developed to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building design and engineering analysis software tools. Interoperability between Building Information Modeling (BIM) and Building Energy Modeling (BEM) can positively impact the workflows of the Architecture, Engineering and Construction (AEC) industry, since energy modelers can potentially utilize architectural BIM models developed by the architectural team as input for building energy simulation and analysis activities.

Differences in design and system intentions between architects developing BIM models and energy modelers consuming this design information present challenges to the promise of streamlined BIM – BEM data exchange. Partly these issues stem simply from differences in the focus of outcomes between the developers and consumers of BIM in this exchange. Architects are principally concerned with drawing production and, by extension, the development of schedules of quantities for bidding. The enhanced requirements for building energy simulation may not be part of the data development and QA process of this model development. Deeper differences are topological: architectural design BIM is principally concerned with the representation of building components and macro level building systems, while BEM is fundamentally driven from a space and boundary view of the building. Supporting both of these distinct sets of requirements with common modeling functionality in an integrated workflow is a challenge for software product development.

The gbXML data exchange standard has been developed partly to mitigate this translation of data and intent between different design disciplines, by distilling down the necessary common data requirements in an open data exchange format. As part of its efforts to facilitate smooth exchange among design parties, the gbXML.org has developed a series of compliance criteria and associated tests for commercial BIM software to be validated as gbXML compliant at increasing levels of sophistication. The Level 1 criteria tests basic generation of valid gbXML standard compliant files. Level 2 tests address specific geometric complexities in the development of well-formed gbXML files and associated energy models.

gbXML is now beginning the development a Level 3 compliance test that would validate software's capabilities in automatically generating certain advanced aspects of the gbXML file and associated energy model. These advanced requirements are specifically intended to address the topological and other modelling differences between architectural / structural models of buildings and the requirements of energy modeling. These software capabilities involve aspects of automation and modeling assistance beyond pure object level translation.

The DBL has been retained by gbXML to assist in the development of these Level 3 software requirements with the ultimate goal of developing a certification program for BIM software supporting this level of sophistication of data exchange. As an initial step, the DBL has developed a series of tests of the BIM – gbXML – BEM data exchange pipeline in order to assess current software capabilities for Level 3 model processing and data export.

This first phase of the Level 3 testing program involved developing a series of specific tests for assessing specific aspects of automated model processing and gbXML export. Both *unit tests* – (assessing specific modeling and export criteria) and *system tests* (testing overall process performance in the context of realistic modelling scenarios) were created. The functionality of the modeling software was used to model and export gbXML files which then imported into an energy solver. Specific data content as well as geometric and modeling intent were reviewed and compared at each step of the exchange pipeline. Revit 2018 was utilized for model development and to export gbXML instance files and OpenStudio (version 2.5.0) was employed to import the gbXML instance files into EnergyPlus. If gbXML instance files had to be compared with the gbXML schema, gbXML schema version 6.01 was referred.

A number of issues were identified in the translation process that highlight differences in the various softwares' interpretation of the geometry and data at different steps of the exchange. In some cases these differences have only minor impacts on the quality of the analysis - well within the tolerance level of the energy modeling approach. Others represent significant loss of geometry or data. Of these more significant issues, some of these can be traced to minor differences in interpretation of model elements between the applications that may be addressed by alternative modeling approaches or minor software enhancements. Still others suggest larger scale conceptual issues between modeling applications that may present challenges to establishing straight forward compliance criteria.

This report provides detailed results and interpretations of the test criteria, background technical requirements and initial results of the tests.

1.1 Test regimen overview

Six specific exchange criteria were identified in initial discussions with gbXML leadership and the Autodesk Revit environmental modeling team. These criteria go beyond those specified in the GBXML Level 1 and 2 tests, addressing conditions where automated processing of model geometry is needed to support energy modeling applications. For each of these exchange criteria, a unit test was developed, comprised of a small test model in Revit with associated features that captured the criterion. The criteria tested were:

1) Material Thermal Properties. The main objective of the test is to identify whether thermal properties of materials (e.g., thermal conductivity, the length of wall (or height of wall), density and specific heat) are translated from BIMs to BEMs correctly or not.
2) Sandwiched Elements. This tests whether the order of wall materials in the BIM model is represented correctly in OpenStudio model.
3) Thermal Zone Properties. The target of the third unit test is to examine whether internal heat gain parameters (e.g., appliance, people, lighting) and their schedules are converted as expected in both the gbXML instance file and OpenStudio model.
4) Exterior Shading. The goal of this unit test is to check whether BIM geometry representing roof overhangs were correctly interpreted as exterior shading devices in the export.
5) Exterior & Interior Columns. The criterion requires the impacts of columns on building spaces to be correctly represented.
6) Ceiling Void. This test investigates whether ceiling void space are correctly represented as plenum spaces in the gbXML export and associated BEM import.

These tests are described in Section 2 through 7 below. A detailed explanation of each unit test will be introduced at the beginning of each unit test, with test results to follow.

Table 1 - The list of unit tests

Item	Task title
1	Material Thermal Properties
2	'Sandwiched' Elements
3	Space & Zone Thermal Properties
4	Exterior Shading
5	Exterior & Interior Columns
6	Ceilings Voids

In addition to the six unit tests, two "system level tests" were conducted using overall building models developed roughly to the expected standards of architectural practitioners developing professional BIM models. These system tests were intended to test the capabilities of the modeling tools and exchange capabilities in a more realistic context than the controlled conditions of the unit tests. The setup and results of these system level tests are provided in System test 1: Small House through System test 2: Urban House. Finally, conclusions and recommended next steps for the development of the Level 3 compliance test are included at the end of this report.

1.2 BIM based energy modeling principles

In order to enable the interoperability between BIMs and BEMs, the resulting BIM translations have to satisfy building energy simulation's input requirements. Given the fact that dynamic building energy simulation software such as EnergyPlus (OpenStudio) calculates the simulation result based on the 1-dimentional heat balance equation, the heat balance equation (eq 1) and (eq 2) indicate what specific requirements have to be met to achieve the interoperability between BIMs and BEMs. The left term of (eq 1) and (eq 2) indicate heat storage and the right term of the equations describes heat transfers.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \sum Q_{SWR} + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{internal\ gains} \quad \cdots \text{(eq 2)}$$

Where, A: Area (m^2)

L: Thickness of wall or height of space (m)

ρ: Density (kg/m^3)

C_p: Specific heat (J/(kg·K))

T: Temperature (K)

t: Simulation time-step

Q: Heat flux (W)

k: Thermal conductivity (W/(m·K))

h_{conv}: Convective heat transfer coefficient ($W/(m^2 \cdot K)$)

h_{rad}: Radiative heat transfer coefficient ($W/(m^2 \cdot K)$)

F: View factor

$\dot{V}$: Volume flow

To assure the overall energy model's results, it can be inferred from the (eq 2) that accurate surface identification in BIM software plays an important role because conduction, convection and long-wave radiation heat transfers are proportional to surface areas. In addition, EnergyPlus currently requires closure of building space through exact coordinate points matching of exterior and interior surfaces for the heat transfer calculations as depicted in Figure 1. This requirement represents a fundamental challenge for BIM – BEM translation, as offsets among thickened wall floor and roof elements can present difficult geometric closure conditions. It will be noted that Revit's current Level 3 gbXML export strategy involves reinterpreting the BIM component geometry in ways that produce small variations in surface boundary and coordinate geometry. These variations do not represent significant variations to the building geometry from an overall surface and space quantity perspective, but create challenges with the current version of EnergyPlus' capabilities for model import and QA. For this reason, for the system (whole

building) tests, the two system tests were focused on identifying whether the surface data is translated correctly from Revit to gbXML to OpenStudio.

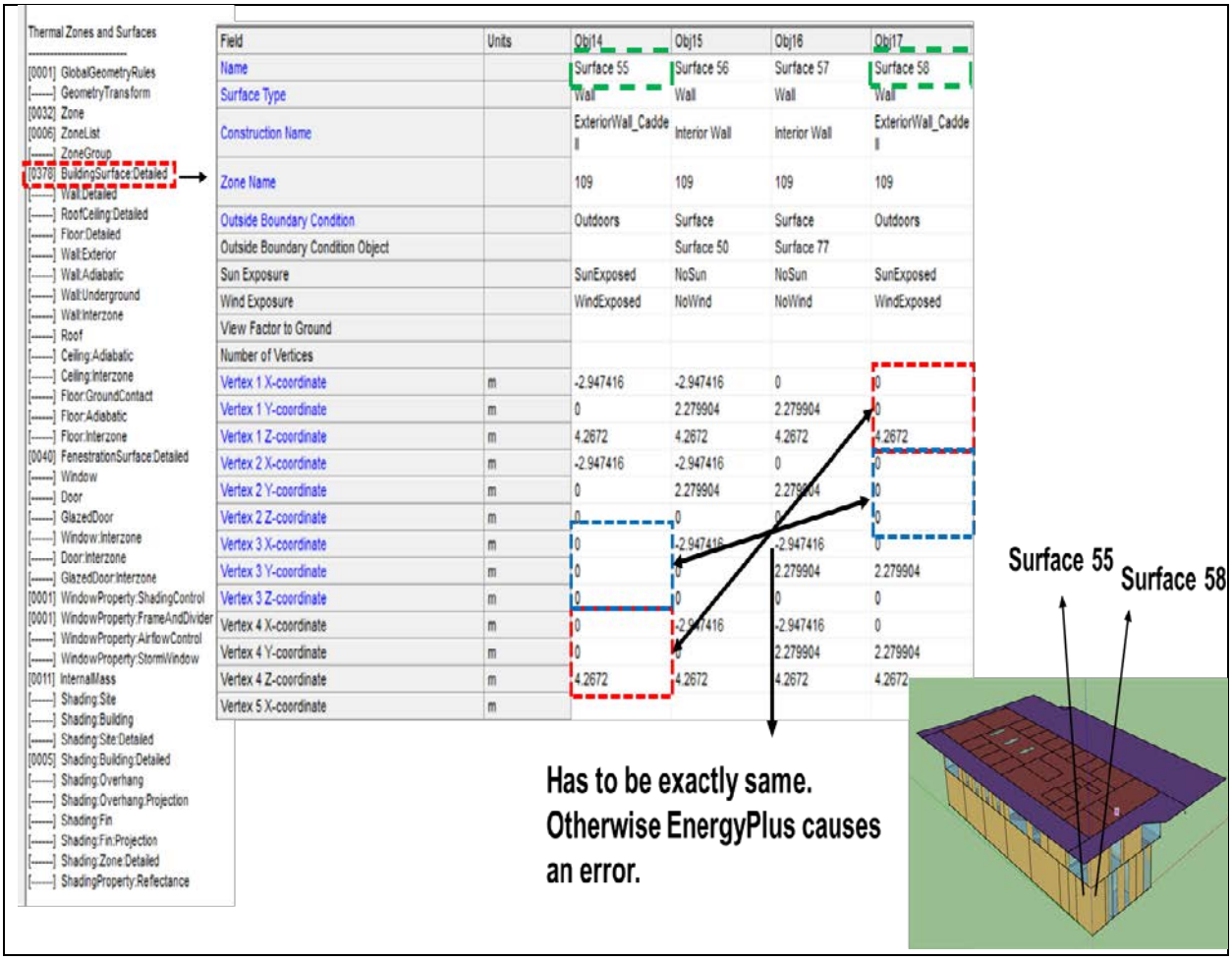

Figure 1 - The “BuildingSurface” object in EnergyPlus

2 Methodology of unit test 1 to 3

In order to test the interoperability between Revit/gbXML/OpenStudio, the methodology is as follows.

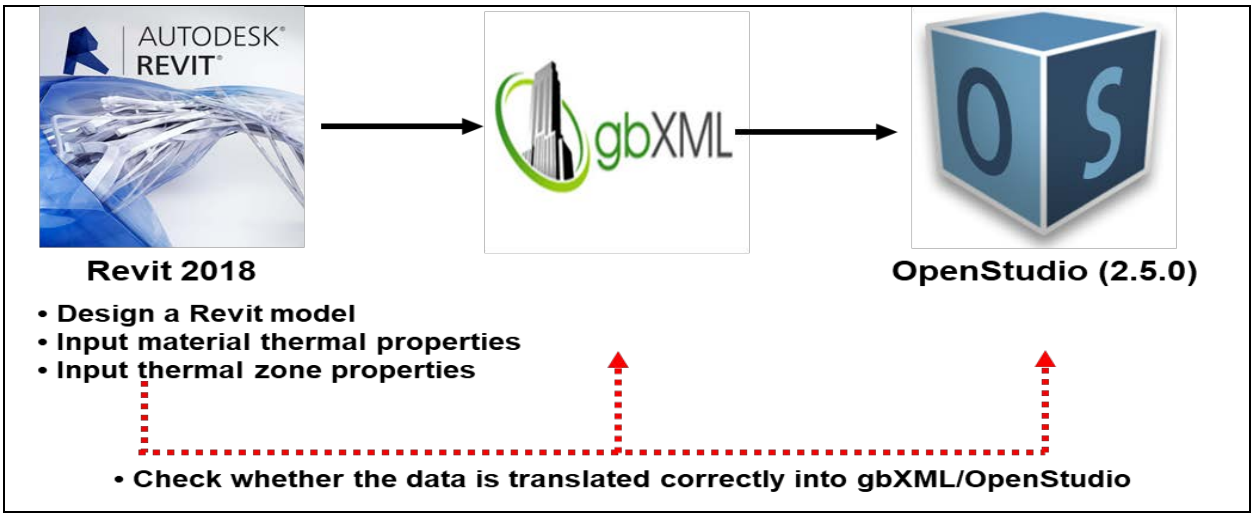

Figure 2 - Project methodology

1. Design a Revit model which contains data related to a unit test.

2. Examine whether the data was translated into gbXML and OpenStudio correctly. If Revit does not provide a function to specify all the input parameters required for dynamic building energy simulation (e.g., OpenStudio), specify which parts need to be revised.

3. Examine whether the current gbXML schema (v 6.01) can satisfy dynamic building energy simulation input parameters' requirements.

For this project's experiment, Revit 2018 was utilized to export gbXML instance files and OpenStudio (version 2.5.0) was employed to import the gbXML instance files. If gbXML instance files had to be compared with the gbXML schema, gbXML schema version 6.01 was referred.

Furthermore, since the two settings in Revit (energy settings and room/volume settings) generate material parts and thermal zone properties in gbXML in the same way, it was decided not to divide into the two settings for the unit test 1 through 3.

2.1 Introduction of the Revit instance model

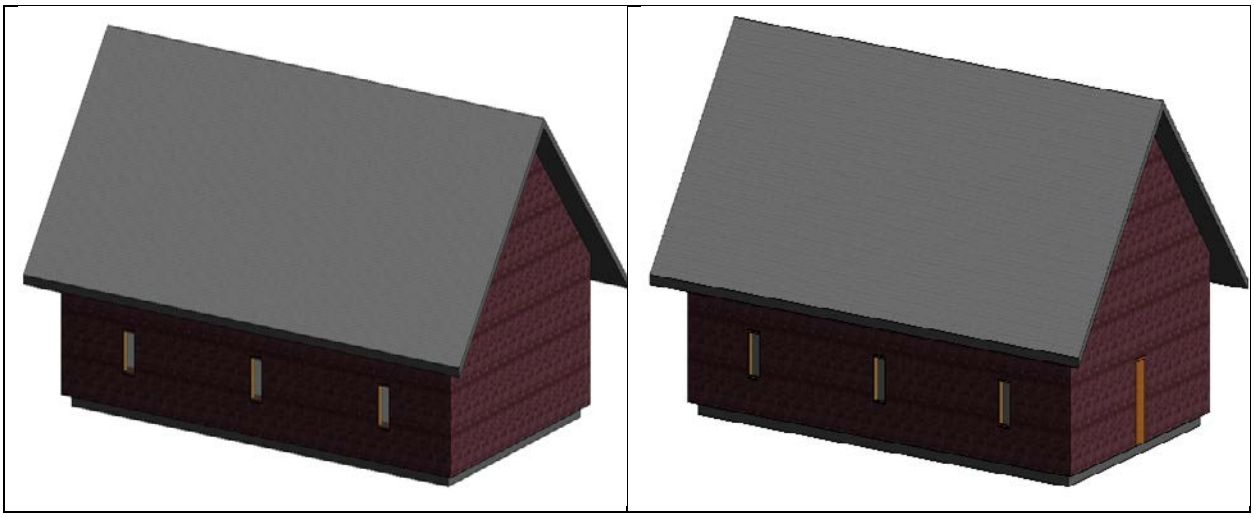

Figure 3 - (Left) South East (Right) North West

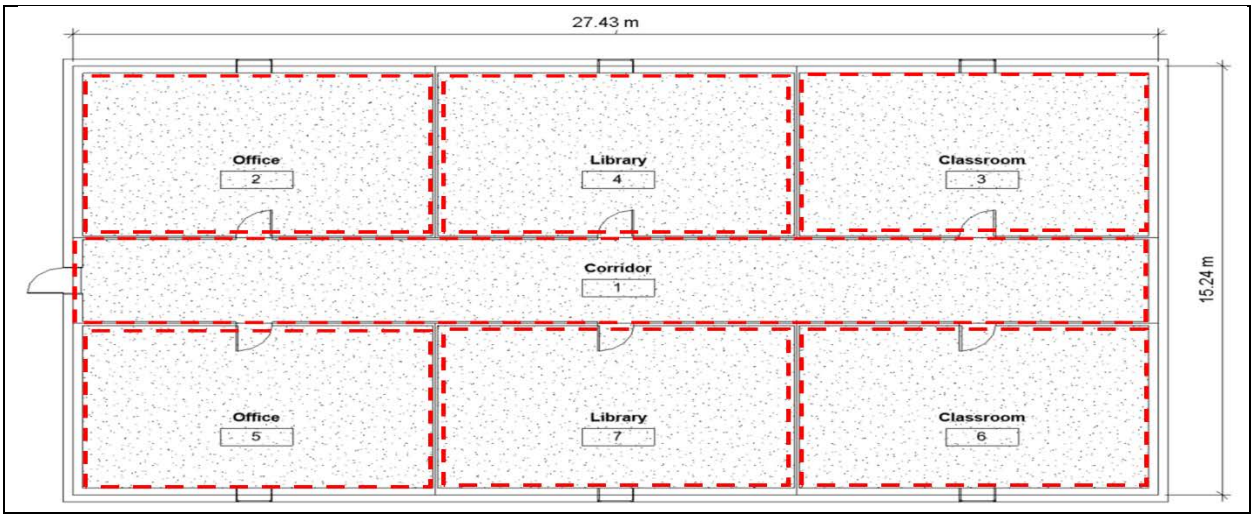

Figure 4 - Floor plan (Red box represents a thermal zone)

Figure 3 illustrates the one-story building utilized for the unit test 1,2 and 3. The building has a sloped-roof and consists of six rooms and a corridor. In Figure 4, there are four different types of spaces, office, library, classroom and corridor assigned for the unit-test cases. Each space type is set as one thermal zone. For example, office spaces were set as one individual thermal zone and similarly library spaces were assigned as another individual thermal zone and so on. The main reason is that considering the geometry, the amount of solar radiation in the office space (No.2) and the library (No.4) is different because the office (No.2) is exposed to the north and west orientations but the library (no. 4) is only exposed to the north orientation.

3 Unit test 1: Material Thermal Properties and Unit test 2: 'Sandwiched' Elements

3.1 The role of thermal properties and layer's order in building energy simulation

For dynamic building energy simulation, it is crucial to input correct material properties in the simulation because the material properties have an impact on heating/cooling load and electrical energy consumption results. It is essential to have materials' thermal properties (e.g., thermal conductivity, density, specific heat) and dimensions (e.g., area and thickness) because dynamic building simulation is based on the heat balance equation (eq 1 and 2). The highlighted variables in yellow in (eq 1 and 2) below indicate the related variables in heat balance equation in the unit test 1 and 2.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \sum Q_{SWR} + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 2)}$$

Where, A: Area (m^2)
L: Thickness of wall (m)
ρ: Density (kg/m^3)
C_p: Specific heat (J/(kg·K))
T: Temperature (K)
t: Simulation time-step
Q: Heat flux (W)
k: Thermal conductivity (W/(m·K))
h_{conv}: Convective heat transfer coefficient ($W/(m^2 \cdot K)$)
h_{rad}: Radiative heat transfer coefficient ($W/(m^2 \cdot K)$)
F: View factor
$\dot{V}$: Volume flow

Based on the heat balance equation (eq 1 and 2), the required input parameters regarding materials for dynamic building energy simulation are thermal conductivity, density, specific heat and thickness. To test whether the first unit-test works correctly or not, the thermal properties of exterior walls, interior walls, roof and floor were assigned in the Revit model. Then, the materials' properties were checked in the gbXML instance file and OpenStudio model.

Besides, it is essential to describe the order of materials correctly because incorrect material order translation could affect heating/cooling load because of the thermal mass's time lag. Thus,

similar to the unit test 1, the material order is examined in the gbXML instance file and OpenStudio model in the unit test 2.

Since the test process of exterior wall, interior wall, roof and floor's parts is exactly same, the exterior wall is set as an example case in this section. For other parts (e.g., interior wall, roof and floor), the results are only introduced in Appendix A.

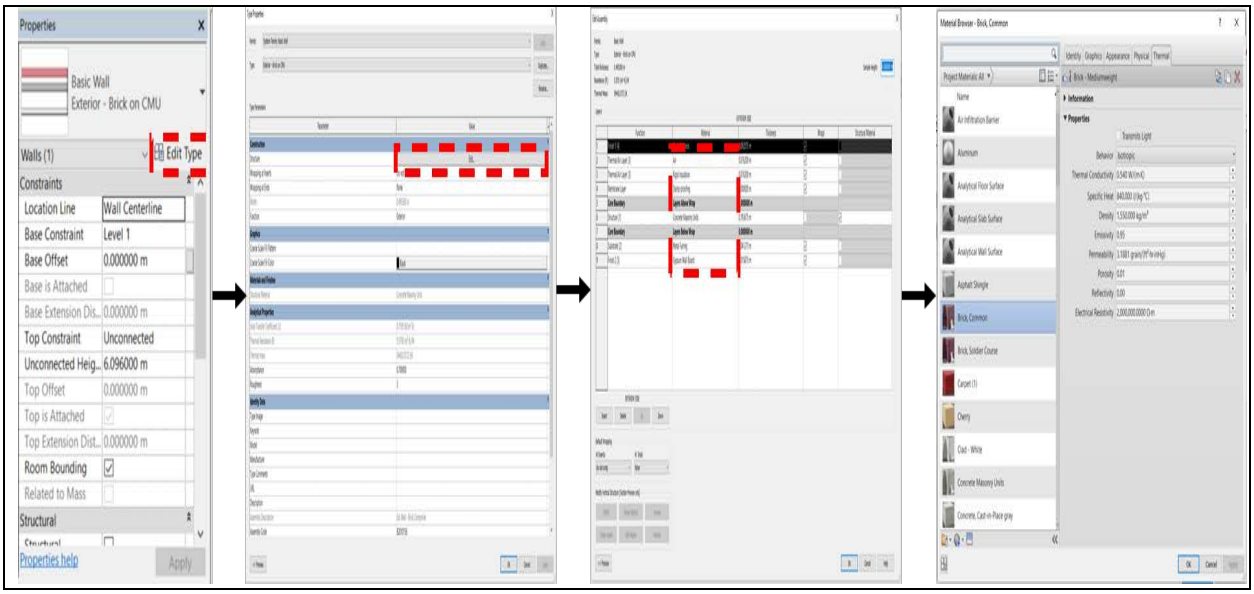

Figure 5 - Material thermal property and material order checking process

In the Revit model, the "Brick on CMU" wall type was utilized. The material thermal properties and the material order can be seen in the properties window in Revit. More details about the exterior wall information are available in Appendix A.

3.2 Material/Construction/Layer parts of gbXML schema (v 6.01)

```
<xsd:element name="Material">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="Absorptance" minOccurs="0"/>
      <xsd:element ref="Roughness" minOccurs="0"/>
      <xsd:element ref="Albedo" minOccurs="0"/>
      <xsd:element ref="Reflectance" minOccurs="0"/>
      <xsd:element ref="Transmittance" minOccurs="0"/>
      <xsd:element ref="Emittance" minOccurs="0"/>
      <xsd:element ref="ImageTexture" minOccurs="0"/>
      <xsd:element ref="R-value" minOccurs="0"/>
      <xsd:element ref="Thickness" minOccurs="0"/>
      <xsd:element ref="Conductivity" minOccurs="0"/>
      <xsd:element ref="Density" minOccurs="0"/>
      <xsd:element ref="SpecificHeat" minOccurs="0"/>
      <xsd:element ref="Permeance" minOccurs="0"/>
      <xsd:element ref="Porosity" minOccurs="0"/>
      <xsd:element ref="RecycledContent" minOccurs="0"/>
      <xsd:element ref="Fire" minOccurs="0"/>
      <xsd:element ref="Cost" minOccurs="0"/>
      <xsd:element ref="IndoorAirQuality" minOccurs="0"/>
      <xsd:element ref="CADMaterialId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="Reference" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="DOELibIdRef" type="xsd:string"/>
  </xsd:complexType>
</xsd:element>
```

```
<xsd:element name="Layer">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="Cost" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="InsideAirFilmResistance" minOccurs="0"/>
      <xsd:element ref="MaterialId" maxOccurs="1"/>
      <xsd:element ref="HOutside" minOccurs="0" maxOccurs="1"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="DOELibIdRef" type="xsd:string"/>
  </xsd:complexType>
</xsd:element>
```

```
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  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="U-value" minOccurs="0"/>
      <xsd:element ref="Absorptance" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="Roughness" minOccurs="0"/>
      <xsd:element ref="Albedo" minOccurs="0"/>
      <xsd:element ref="Reflectance" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="Transmittance" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="Emittance" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="Cost" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="PercentExisting" minOccurs="0"/>
      <xsd:element ref="FireFace" minOccurs="0" maxOccurs="2"/>
      <xsd:element ref="LayerId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="ExtEquipId" minOccurs="0" maxOccurs="1"/>
      <xsd:element ref="LoadCalcInputParameters" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="DOELibIdRef" type="xsd:string"/>
    <xsd:attribute name="programId" type="xsd:IDREF" use="optional"/>
  </xsd:complexType>
</xsd:element>
```

Figure 6 - gbXML schema elements regarding material thermal properties and the order of materials

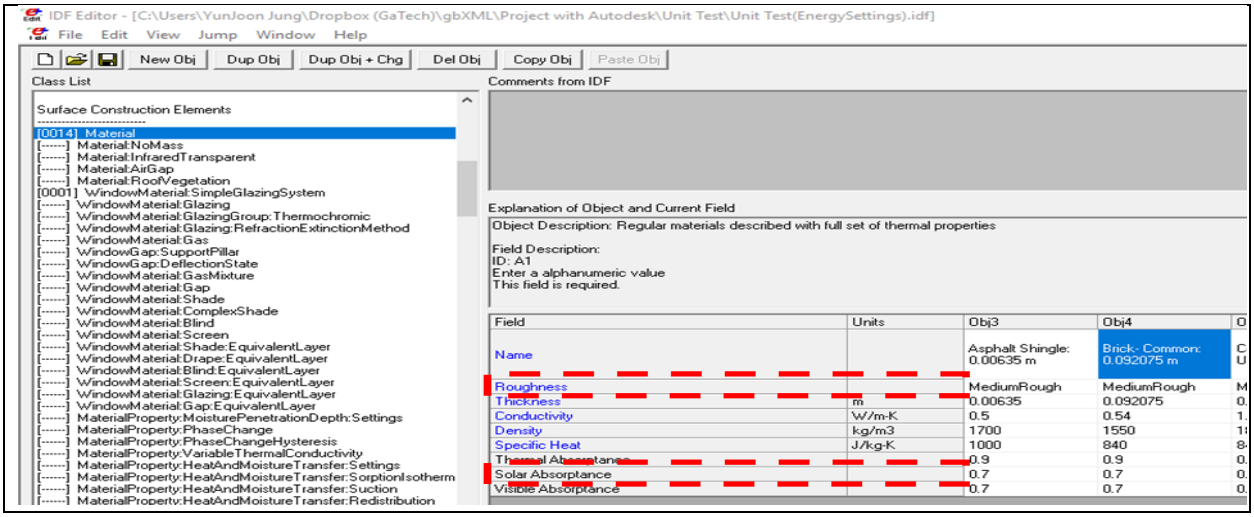


Figure 7 - The “Material” object in EnergyPlus

There are three elements (Material, Layer and Construction) in gbXML associated with material properties. Firstly, the “Material” element describes material’s thermal properties such as R-Value, thermal conductivity, density and specific heat as well as dimensions such as thickness, etc. Secondly, the “Layer” element explains the order of materials. For instance, the brick on CMU wall used in the unit-test’s layer is brick-air-rigid insulation-CMU-metal furring-gypsum wall board. Thirdly, the “Construction” element includes material’s absorptance and roughness values, which are necessary data in the “Material” object in EnergyPlus, as shown in Figure 56.

Overall, the current gbXML schema satisfies the material input requirements of dynamic building energy simulation.

3.3 Import results in OpenStudio (EnergyPlus)

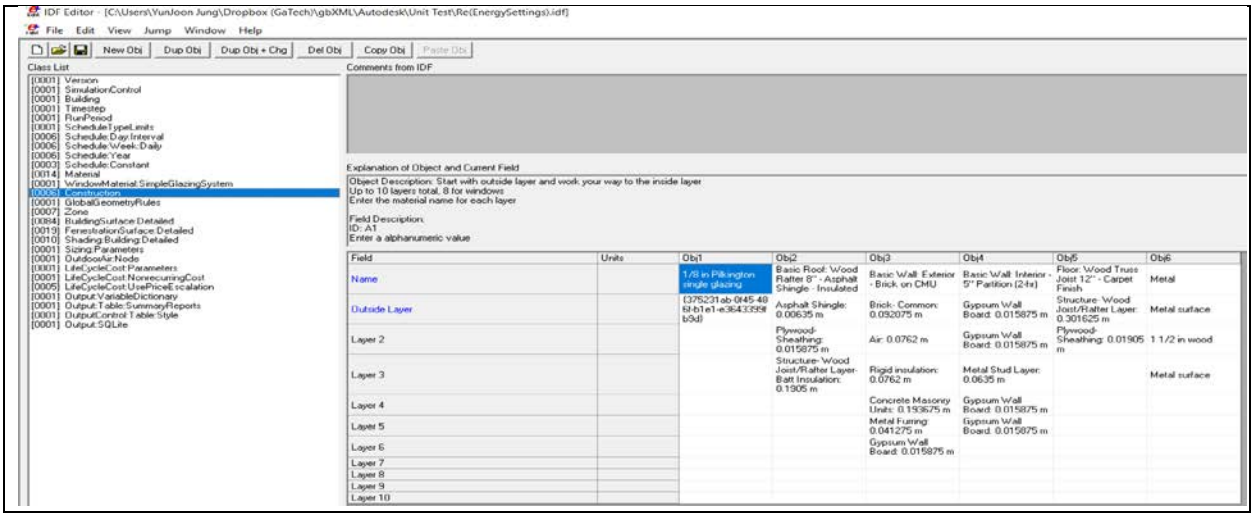


Figure 8 - Material Import Result in EnergyPlus

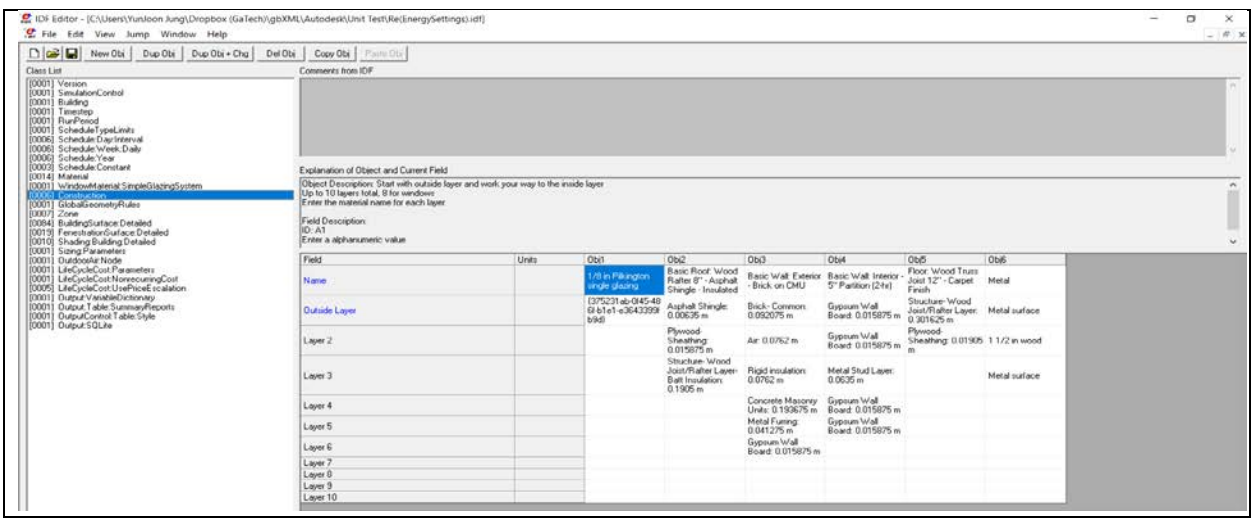


Figure 9 - The material order (construction) import result in EnergyPlus

As a result, Revit converts material thermal properties perfectly in the “Material” element in the gbXML instance file and OpenStudio model. Moreover, the order of the materials is checked to be translated correctly in the gbXML instance file and OpenStudio model as well. Please see Appendix A for the detail results.

4 Unit test 3: Thermal Zone Properties

4.1 The role of thermal zone properties

The thermal zone properties from occupants, appliances, lighting, etc. have to be accounted for carefully because the internal heat gains increase the amount of heat in the space and thus impact on total heating and cooling loads. The highlighted term in yellow in (eq 1 and 2) below suggests that the internal heat gains term in heat balance equation.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \sum Q_{SWR} + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{internal\ gains} \quad \cdots \text{(eq 2)}$$

Where, A: Area (m^2)
L: Thickness of wall or height of space (m)
ρ: Density (kg/m^3)
C_p: Specific heat (J/(kg·K))
T: Temperature (K)
t: Simulation time-step
Q: Heat flux (W)
k: Thermal conductivity (W/(m·K))
h_{conv}: Convective heat transfer coefficient ($W/(m^2 \cdot K)$)
h_{rad}: Radiative heat transfer coefficient ($W/(m^2 \cdot K)$)
F: View factor
$\dot{V}$: Volume flow

4.2 Thermal zone set-up in Revit

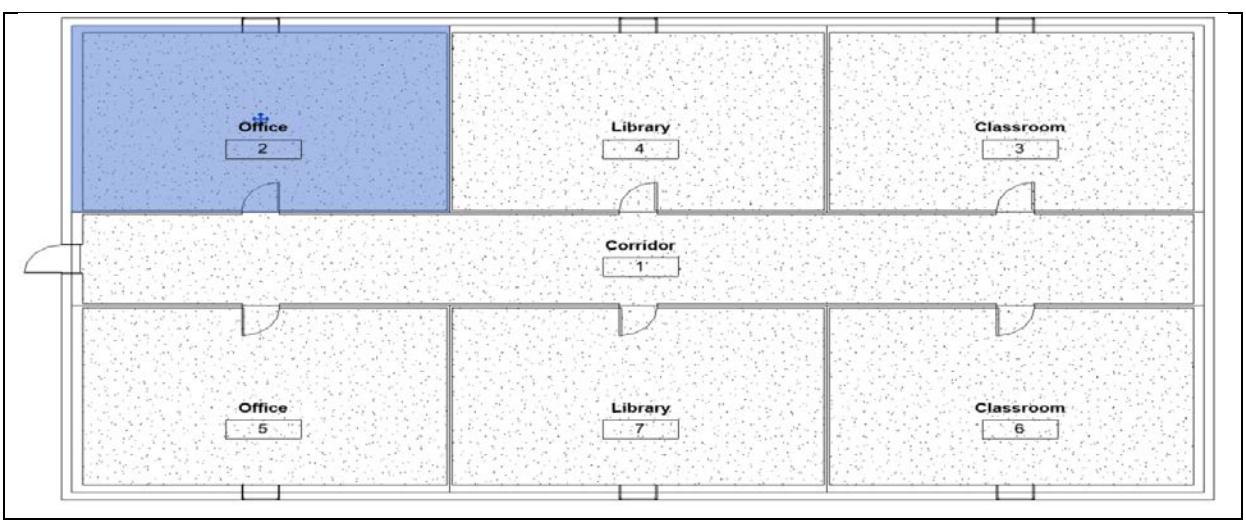


Figure 10 - Unit-test model's floor plan (Office (No.2) thermal zone is highlighted)

The office space (No.2), colored in blue in Figure 1Figure 10, was assigned as an example case in this section.

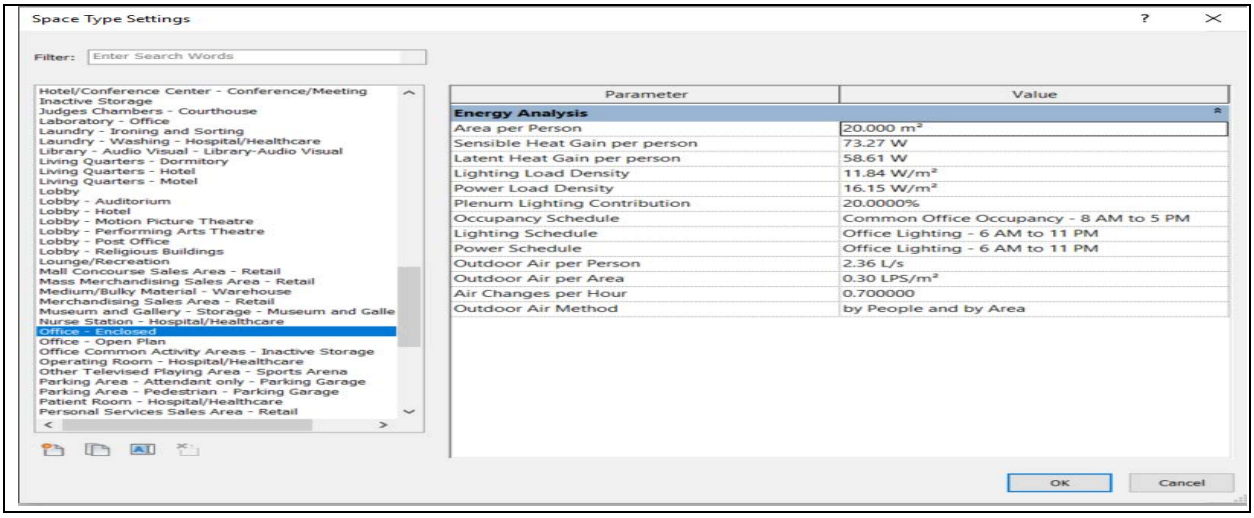


Figure 11 - Thermal zone property set up in Revit

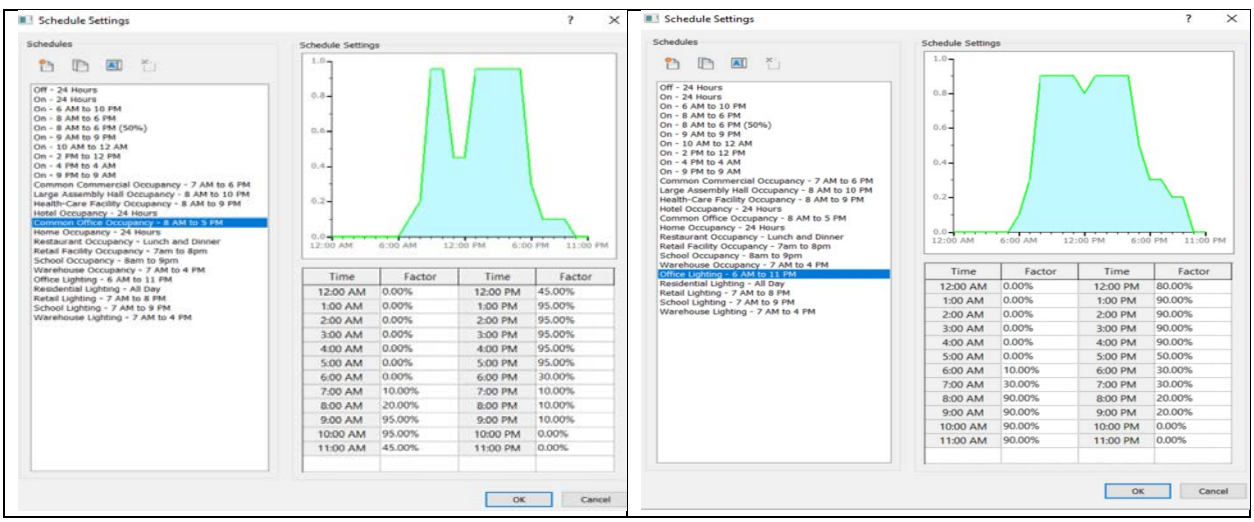


Figure 12 - Office occupancy schedule in Revit (Right) Office lighting schedule in Revit

Figure 11 illustrates the internal heat gains in the office (No.2) thermal zone. Additionally, occupancy/lighting/power schedules were set up and shown in Figure 12.

4.3 Thermal zone data translation in the gbXML instance file

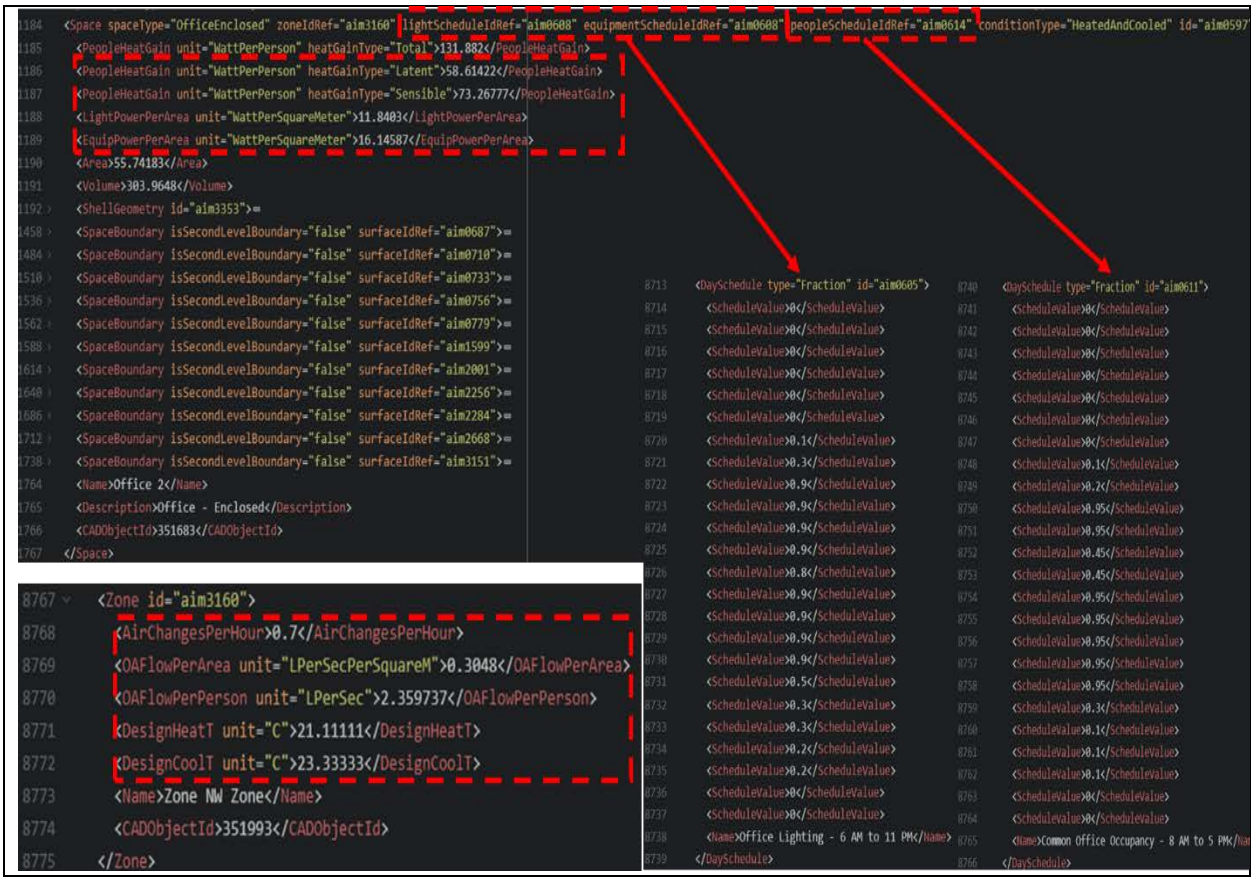


Figure 13 - Office (No. 2) thermal zone translation in the gbXML instance file

The first part which needed to be checked was whether Revit generates the gbXML instance file correctly or not. From Figure 13, most internal heat gain input parameters and schedules were translated as done in Revit. However, it was found the “Area per Person” parameter in Revit was not translated into the gbXML instance file. The “Area per Person” parameter was supposed to be written in the “Space” element in gbXML instance file, but it was not translated. More detail about occupants’ density will be explained more in detail in the next section.

4.4 Import Result in OpenStudio

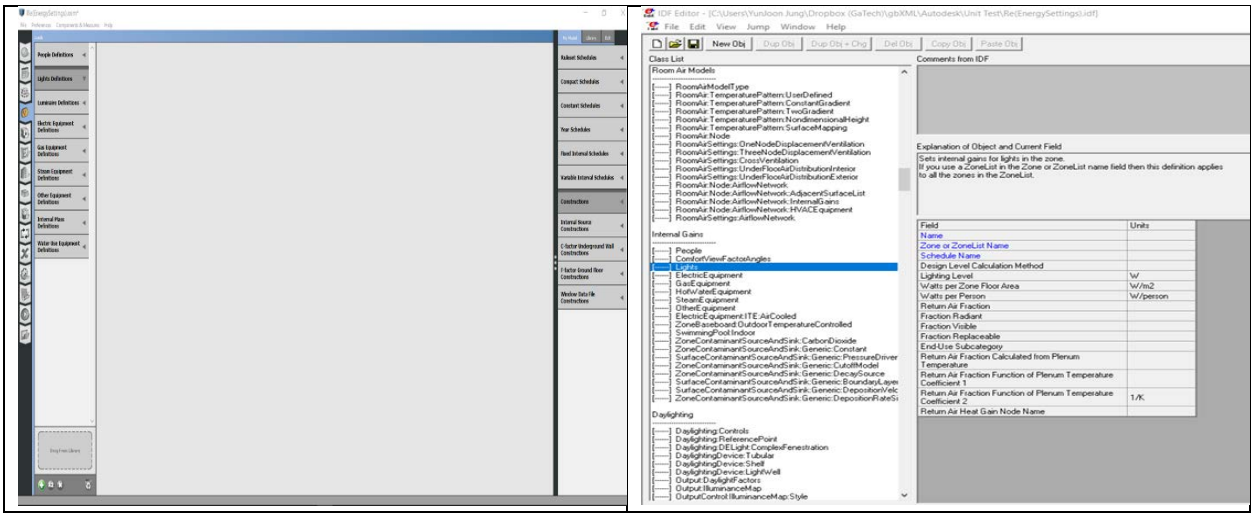


Figure 14 - (Left) Internal gains in OpenStudio (Right) Internal gains in EnergyPlus

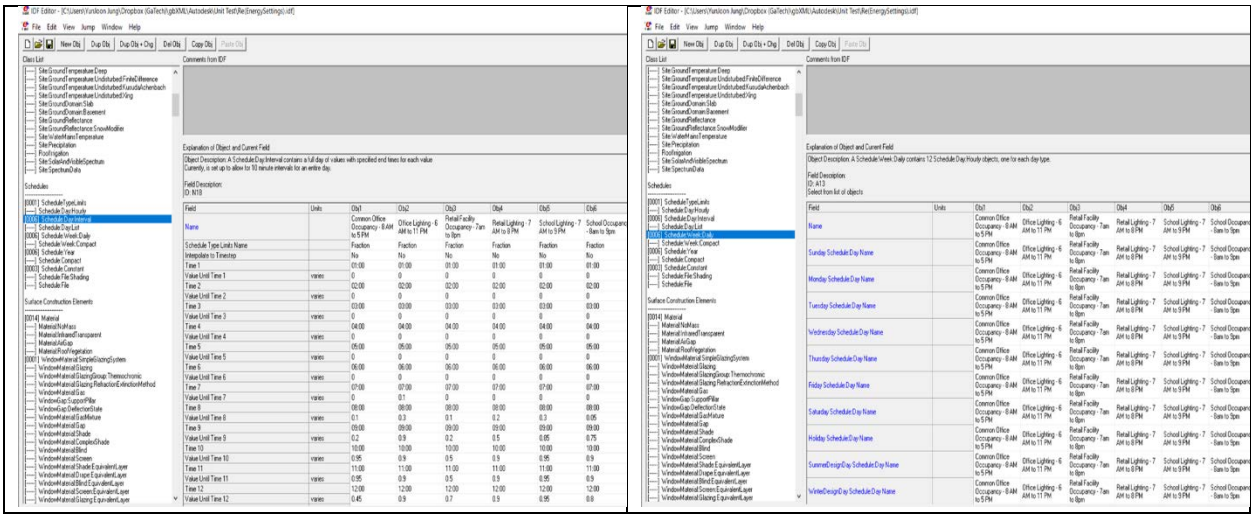


Figure 15 - Schedule in EnergyPlus

Figure 14 illustrates all the heat gain data in gbXML instance file was not translated into OpenStudio. To double-check the internal load data, the IDF file was examined but the internal heat gain part was not filled up either. However, the schedule data in the gbXML instance file was translated into the IDF file correctly.

Since the internal gain data was not converted into the OpenStudio model from the gbXML instance file, the accuracy from the Revit model to the gbXML instance file was only specified in Table 2.

Table 2 - Translation accuracy between the Revit model and the gbXML instance file

	Office-Enclosed		
	Revit	gbXML	Percentage Difference (%)
Area per Person (m2/Person)	20	-	-
Sensible Heat Gain per Person (W)	73.27	73.27	0.0
Latent Heat Gain per Person (W)	58.61	58.61	0.0
Lighting Load Density (W/m2)	11.84	11.84	0.0
Power Load Density (W/m2)	16.15	16.15	0.0
Outdoor Air per Person (L/S)	2.36	2.36	0.0
Outdoor Air per Area (LPS/m2/Person)	0.3	0.3	0.0
Air Change per Hour (1/h)	0.7	0.7	0.0
Heating Set Point (°C)	21.11	21.11	0.0
Cooling Set Point (°C)	23.33	23.33	0.0

It can be said that all the thermal zone data written in the Revit model were translated correctly.

4.5 Occupant's density object in EnergyPlus

```
<xsd:element name="Space">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="Lighting" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="LightingControl" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="InfiltrationFlow" minOccurs="0"/>
      <xsd:element ref="PeopleNumber" minOccurs="0"/>
      <xsd:element ref="PeopleHeatGain" minOccurs="0" maxOccurs="3"/>
      <xsd:element ref="LightPowerPerArea" minOccurs="0"/>
      <xsd:element ref="EquipPowerPerArea" minOccurs="0"/>
      <xsd:element ref="AirChangesPerHour" minOccurs="0"/>
      <xsd:element ref="Area" minOccurs="1"/>
      <xsd:element ref="Temperature" minOccurs="0"/>
      <xsd:element ref="Volume" minOccurs="1"/>
      <xsd:element ref="PlanarGeometry" minOccurs="0"/>
      <xsd:element ref="ShellGeometry" minOccurs="0"/>
      <xsd:element ref="AirLoopId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="HydronicLoopId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="MeterId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="IntEquipId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="AirLoopEquipmentId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="HydronicLoopEquipmentId" minOccurs="0" maxOccurs="unbounded"/
      <xsd:element ref="CADObjectId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="TypeCode" minOccurs="0"/>
      <xsd:element ref="SpaceBoundary" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="spaceType" type="spaceTypeEnum"/>
    <xsd:attribute name="zoneIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="scheduleIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="lightScheduleIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="equipmentScheduleIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="peopleScheduleIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="conditionType" type="conditionTypeEnum"/>
    <xsd:attribute name="buildingStoreyIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="ifcGUID" type="xsd:string" use="optional"/>
  </xsd:complexType>
</xsd:element>
```

```
<xsd:element name="Zone">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="Flow" minOccurs="0"/>
      <xsd:element ref="SecondaryFlow" minOccurs="0"/>
      <xsd:element ref="AirChangesPerHour" minOccurs="0"/>
      <xsd:element ref="FlowPerArea" minOccurs="0"/>
      <xsd:element ref="FlowPerPerson" minOccurs="0"/>
      <xsd:element ref="OAFlowPerArea" minOccurs="0"/>
      <xsd:element ref="OAFlowPerPerson" minOccurs="0"/>
      <xsd:element ref="OAFlowPerZone" minOccurs="0"/>
      <xsd:element ref="MaxOAFlowPerZone" minOccurs="0"/>
      <xsd:element ref="MinOAFlowPerZone" minOccurs="0"/>
      <xsd:element ref="MinimumOutdoorAirControlType" minOccurs="0"/>
      <xsd:element ref="DesignHeatT" minOccurs="0"/>
      <xsd:element ref="DesignCoolT" minOccurs="0"/>
      <xsd:element ref="IndoorAirQuality" minOccurs="0"/>
      <xsd:element ref="HydronicLoopId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="AirLoopId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="CADObjectId" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="TypeCode" minOccurs="0"/>
      <xsd:element ref="CoolingSizingFactor" minOccurs="0"/>
      <xsd:element ref="HeatingSizingFactor" minOccurs="0"/>
      <xsd:element ref="BaseboardHeatingType" minOccurs="0"/>
      <xsd:element ref="BaseboardHeatingCapacity" minOccurs="0"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="heatSchedIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="coolSchedIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="outAirSchedIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="airChangesSchedIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="fanSchedIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="fanTempSchedIdRef" type="xsd:IDREF" use="optional"/>
    <xsd:attribute name="ifcGUID" type="xsd:string" use="optional"/>
    <xsd:attribute name="programId" type="xsd:IDREF" use="optional"/>
  </xsd:complexType>
</xsd:element>
```

Figure 16 - The "Space" and "Zone" elements in the current gbXML schema (v 6.01)

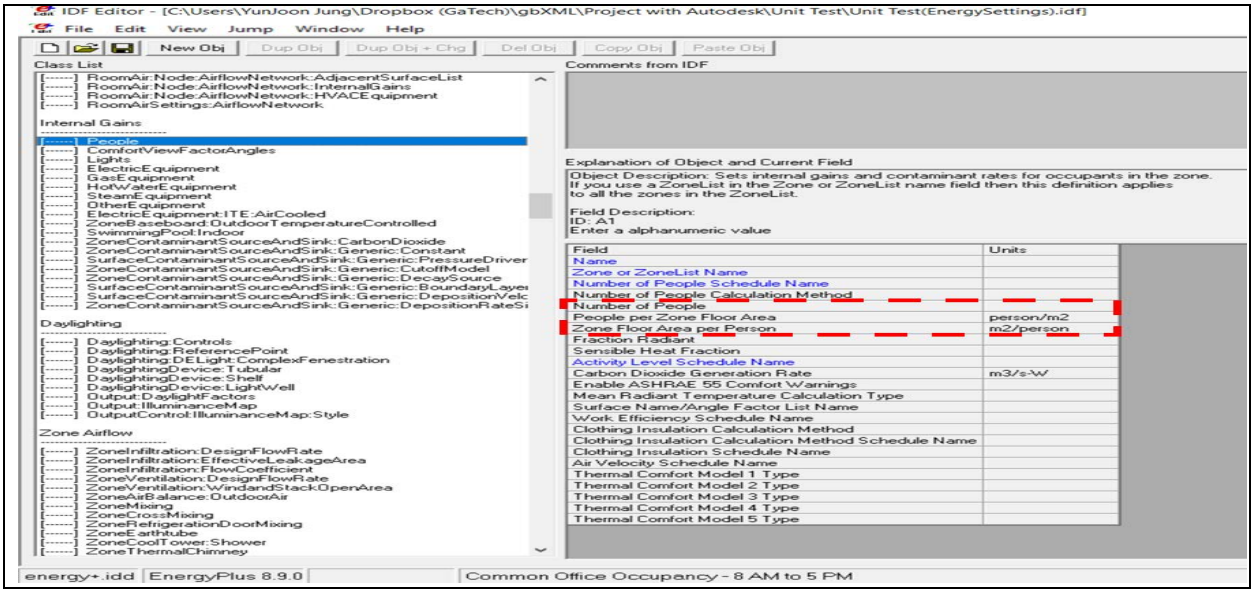


Figure 17 - People object in EnergyPlus

The "Space" element, shown in the red box in the left of Figure 16, can have the "PeopleNumber" element under the "Space" element. For now, the best way to describe the "Area per Person" parameter (m^2/person) in a gbXML instance file from Revit would be to calculate the total number of occupants (e.g., (Area (m^2) * 1/Area per person(m^2/person)). However, for the future updated gbXML schema, it is recommended the current gbXML schema to have a few more elements which allow users to have more occupants' density options (e.g., people per zone floor area (person/m^2) or zone floor area per person (m^2/person), etc.). It is because as the red box in Figure 16 illustrates, EnergyPlus allows to have a few different options to have occupant's density.

4.6 Issues about thermal zone properties

A few parts which did not reflect the dynamic building energy simulation input requirements were found while thermal zone properties were studied.

4.6.1 Occupancy/Lighting/Equipment schedule

Figure 12 illustrates that occupancy/lighting/power schedule settings in Revit. The main issue is Revit does not allow each thermal zone to have various schedules in different times during a year. In other words, one thermal zone must have only one schedule throughout the year. However, OpenStudio and other dynamic building simulation software allow to adjust schedule any time of the year. For example, the users can allocate schedules differently between week and weekend. More extremely, the users should be allowed to assign different schedules for each day.

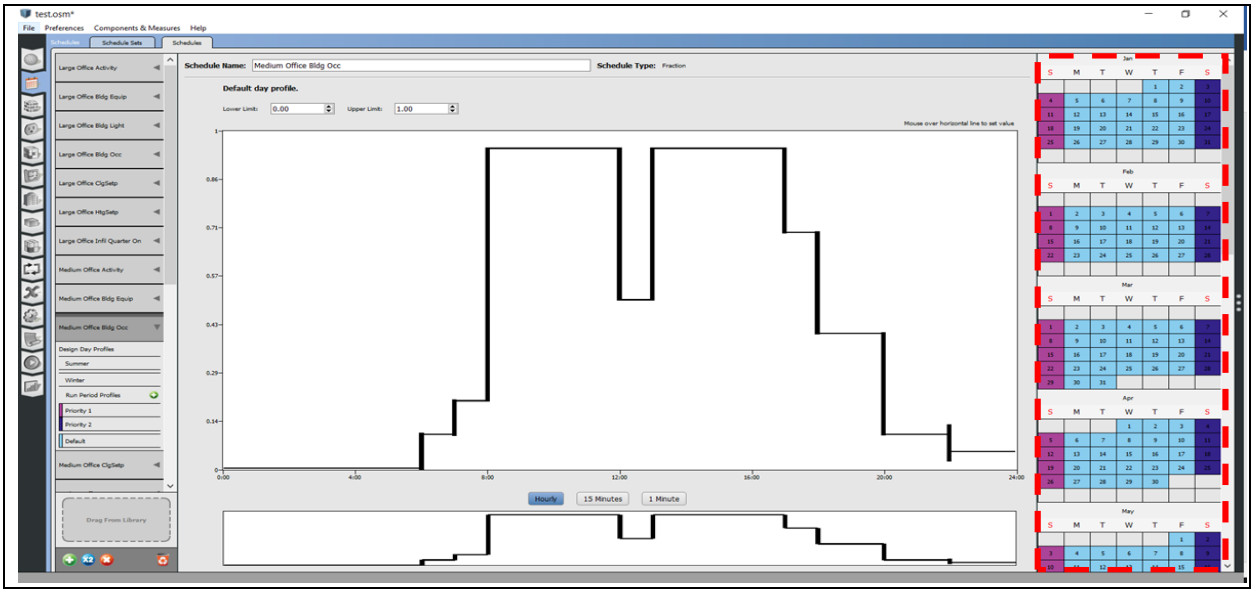


Figure 18 - One example of occupancy schedule in OpenStudio

Figure 18 illustrates schedule part in OpenStudio. As shown, the right part in the red box allows users to alter schedules by days. In Figure 18, week days, Saturday and Sunday occupancy schedules were set up differently.

```
<xsd:element name="Schedule">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="YearSchedule" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="type" type="scheduleTypeEnum" use="required"/
    <xsd:attribute name="programId" type="xsd:IDREF" use="optional"/>
  </xsd:complexType>
</xsd:element>
```

```
\
<xsd:element name="YearSchedule">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="BeginDate"/>
      <xsd:element ref="EndDate"/>
      <xsd:element ref="WeekScheduleId"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="scheduleTypeLimitsId" type="xsd:string"/>
  </xsd:complexType>
</xsd:element>
```

```
<xsd:element name="WeekSchedule">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="Day" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="scheduleType" type="scheduleTypeEnum" use="required"/>
    <xsd:attribute name="scheduleTypeLimitsId" type="xsd:string"/>
  </xsd:complexType>
</xsd:element>
```

```
<xsd:element name="DaySchedule">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="ScheduleValue" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="scheduleType" type="scheduleTypeEnum" use="required"/>
    <xsd:attribute name="scheduleTypeLimitsId" type="xsd:string"/>
  </xsd:complexType>
</xsd:element>
```

Figure 19 - gbXML schema elements related to schedule

However, Figure 19 shows the gbXML schema (v 6.01) is capable of dealing with complex schedules. The “YearSchedule” element can specify start/end date. Also, the “WeekSchedule” element can choose specific day/weekday/weekend, etc. Therefore, as long as Revit allows to have more complex schedules, gbXML can handle them.

4.6.2 Heating/Cooling set point and infiltration

Similar to the occupancy/lighting/equipment schedule section, Revit allows users to only specify heating/cooling set point as one constant number.

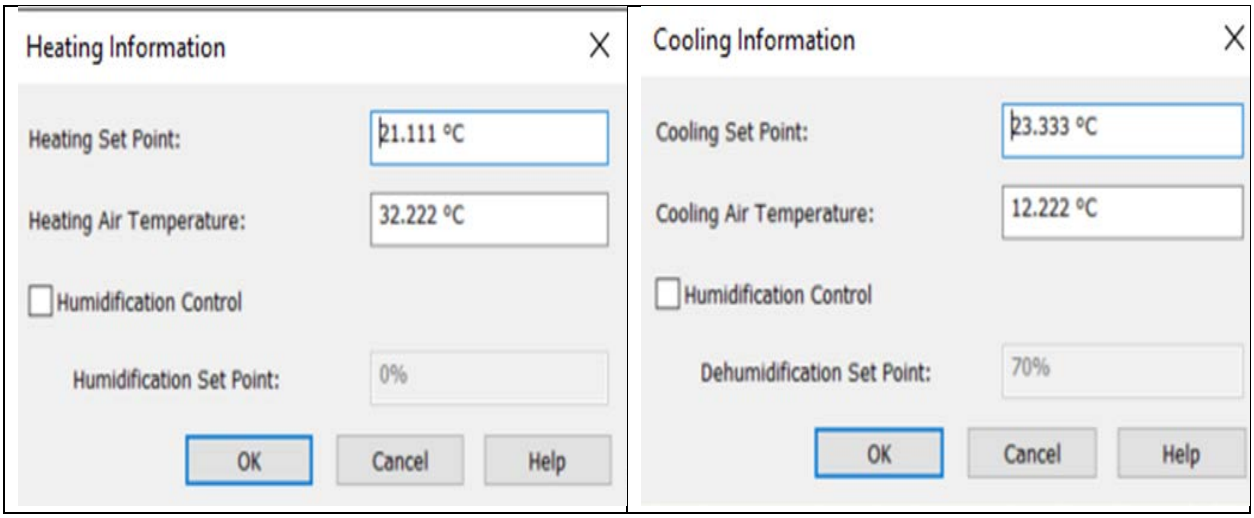


Figure 20 - Heating/Cooling set point window in Revit

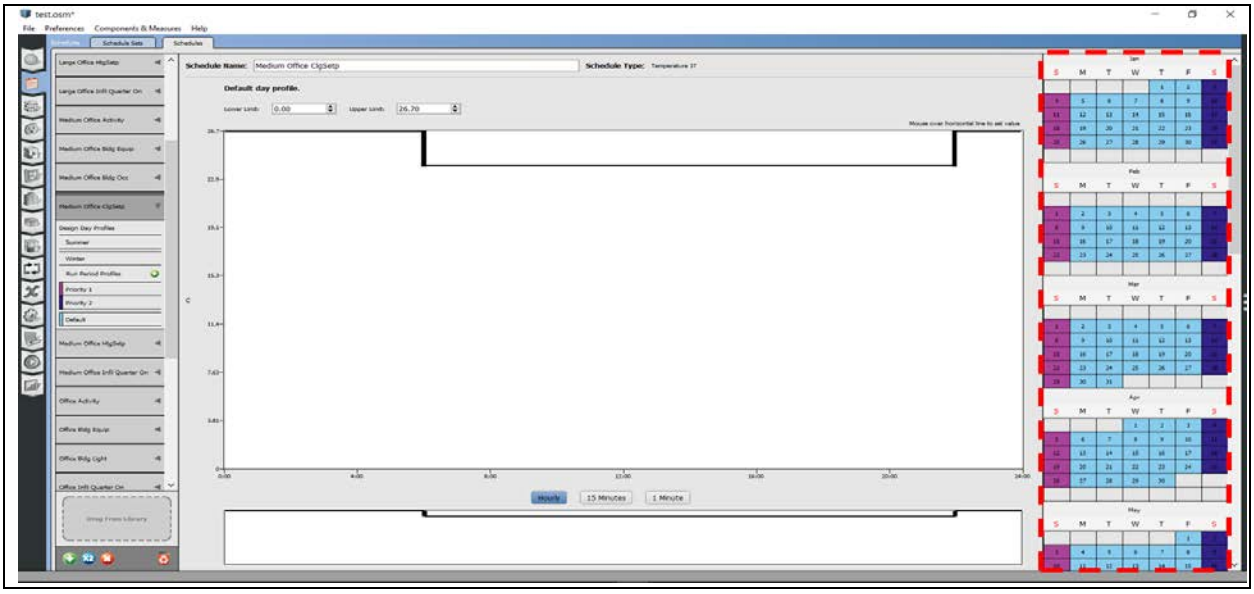


Figure 21 - One example of cooling set point schedule in OpenStudio

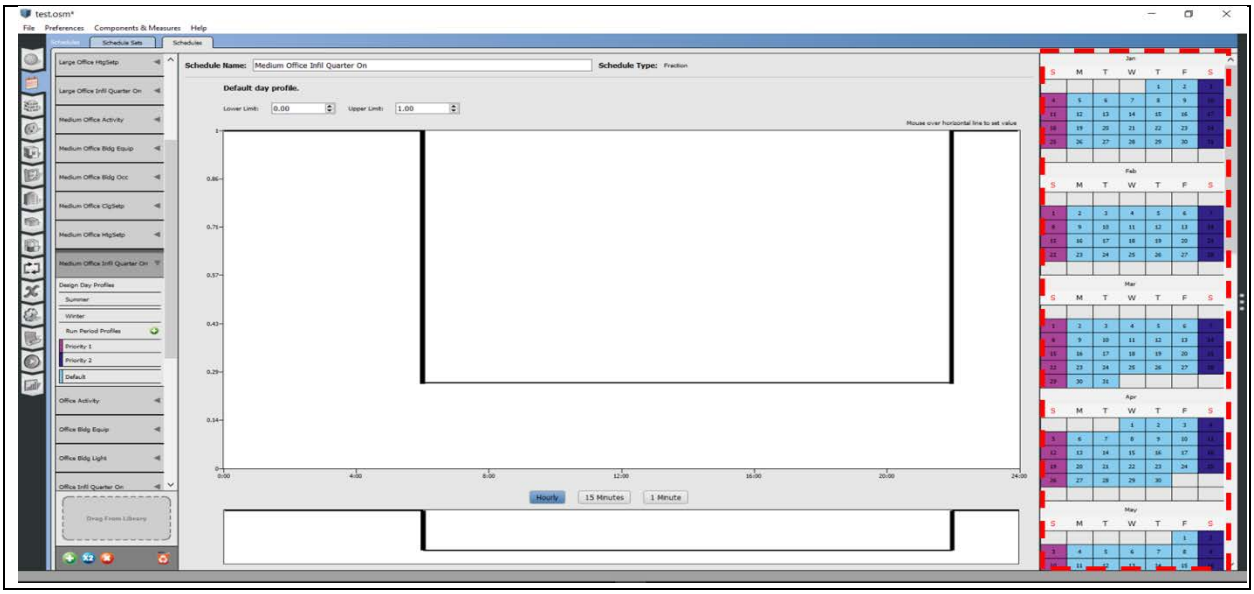


Figure 22 - One example of infiltration schedule in OpenStudio

Figure 21 and Figure 22 illustrate cooling set point and infiltration schedule parts in OpenStudio, respectively. As shown, the right part in the red box allows users to alter schedules by days. In Figure 21 and Figure 22, week days, Saturday and Sunday schedules were assigned differently.

In the right of Figure 16, the zone element can include heating/cooling set point schedule (in green box), outdoor airflow schedule (in red box) and infiltration rate schedule (in blue box) as an attribute, meaning gbXML can handle more diverse schedules.

5 Unit test 4: Exterior Shading

5.1 The role of exterior shading

The goal of the unit test 4 is to check whether exterior shading devices are translated correctly. The reason why correct exterior shading conversion is important is if the amount of solar radiation passing through exterior surfaces changes, heating/cooling load changes accordingly. The highlighted term in yellow in (eq 1 and 2) below shows how the solar radiation term influences on heat balance equation.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \sum Q_{SWR} + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 2)}$$

Where, A: Area (m^2)

L: Thickness of wall or height of space (m)

ρ: Density (kg/m^3)

C_p: Specific heat (J/(kg·K))

T: Temperature (K)

t: Simulation time-step

Q: Heat flux (W)

k: Thermal conductivity (W/(m·K))

h_{conv}: Convective heat transfer coefficient ($W/(m^2 \cdot K)$)

h_{rad}: Radiative heat transfer coefficient ($W/(m^2 \cdot K)$)

F: View factor

$\dot{V}$: Volume flow

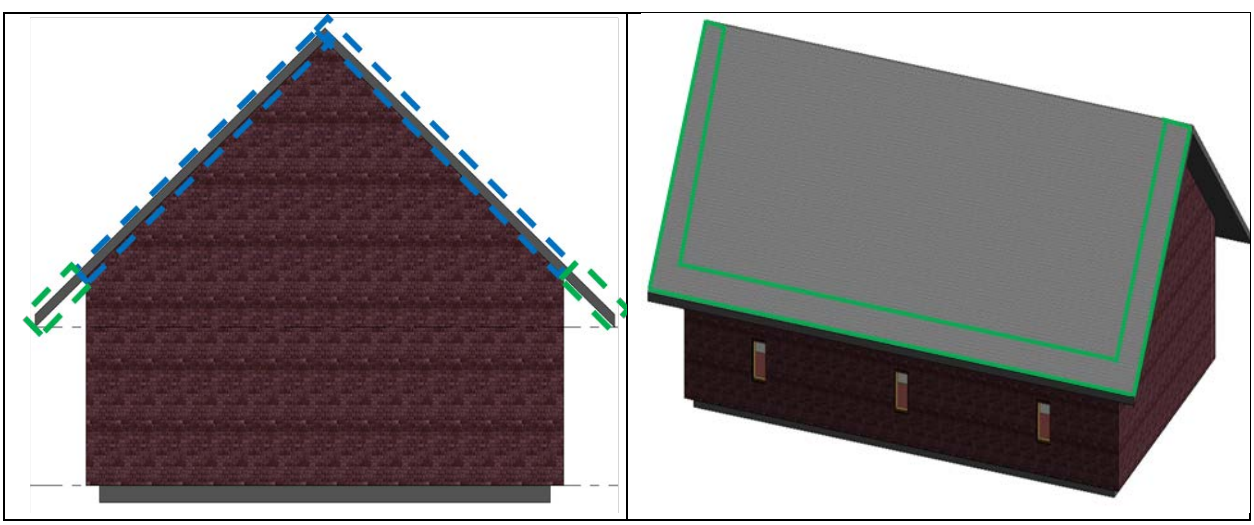


Figure 23 - Roof categorization

As an example, on the left of Figure 23, the blue rectangles represent the parts which must be translated into roof and green rectangles represent the parts that need to be translated into shading devices. The main reason is the blue rectangles are the parts which are directly affected by conduction, convection, solar radiation (short wave radiation) and long-wave heat transfers. In contrast, the green rectangles only reduce the amount of solar radiation.

5.2 Methodology

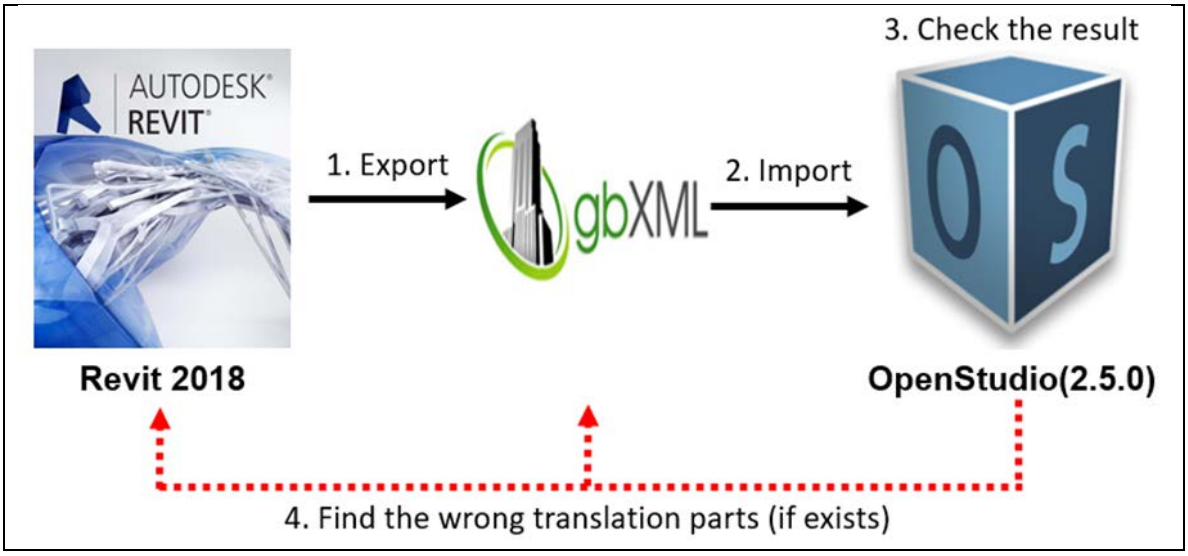


Figure 24 - Unit test 4's methodology

The unit test 4's methodology is as follows:

1. Export the gbXML instance files from Revit 2018 (both energy and room/volume settings).
2. Import the gbXML instance files into OpenStudio 2.5.0.
3. Check whether the architectural part is translated correctly in OpenStudio.
4. If there are discrepancies found in the OpenStudio model, go back to the gbXML instance file and Revit to find the origin of the problems.

Furthermore, it is necessary to point out the difference between the gbXML instance files from the energy and the room/volume settings.

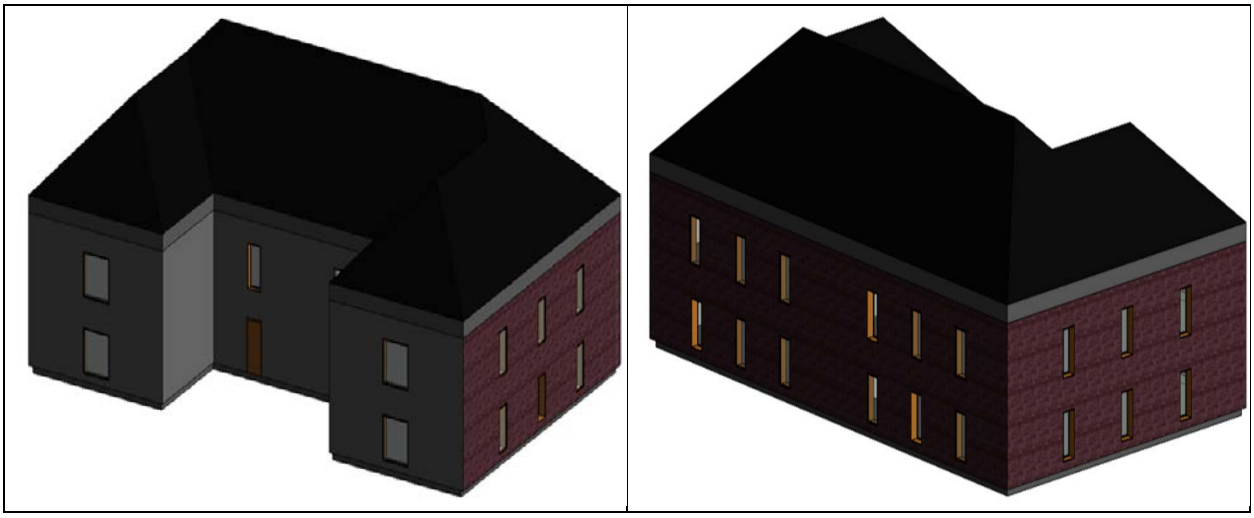


Figure 25 - (Left) Southeast view (Right) Northwest view


```
<?xml version="1.0" encoding="UTF-16"?>
<gbXML useSIUnitsForResults="false" temperatureUnit="F" lengthUnit="Feet" areaUnit="SquareFeet" volumeUnit="CubicFeet" version="0.37" xmlns
  <Campus id="aim0002">
    <Location>=
    <Building buildingType="Office" id="aim0013">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0361">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0384">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0407">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0430">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0453">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0476">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0499">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0522">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0545">=
    <Surface surfaceType="ExteriorWall" constructionIdRef="aim0014" exposedToSun="true" id="aim0568">
      <AdjacentSpaceId spaceIdRef="aim0187" surfaceType="ExteriorWall" />
      <RectangularGeometry id="aim7758">=
      <PlanarGeometry>=
      <CADObjectId>1</CADObjectId>
    </Surface>
    <Surface surfaceType="ExteriorWall" exposedToSun="true" id="aim0591">
      <AdjacentSpaceId spaceIdRef="aim0187" surfaceType="ExteriorWall" />
      <RectangularGeometry id="aim7767">=
      <PlanarGeometry>=
      <Opening interiorShadeType="Operable" exteriorShadeType="Fixed" windowTypeIdRef="aim0177" openingType="OperableWindow" id="aim0614">=
      <CADObjectId>2</CADObjectId>
    </Surface>
```

```
<?xml version="1.0" encoding="UTF-16"?>
<gbXML useSIUnitsForResults="false" temperatureUnit="F" lengthUnit="Feet" areaUnit="SquareFeet" volu
  <Campus id="aim0002">
    <Location>
    <Building buildingType="Office" id="aim0013">
      <Surface surfaceType="ExteriorWall" constructionIdRef="aim0319" exposedToSun="true" id="aim0458"
        <AdjacentSpaceId spaceIdRef="aim0051" />
        <RectangularGeometry id="aim0459">
        <PlanarGeometry>
        <Opening windowTypeIdRef="aim0448" openingType="OperableWindow" id="aim0469">
          <RectangularGeometry id="aim0470">
          <PlanarGeometry>
          <CADObjectId>Fixed: 36" x 72" [333352]</CADObjectId>
          <Name>N-101-E-W-1-W-1</Name>
        </Opening>
        <Opening windowTypeIdRef="aim0448" openingType="OperableWindow" id="aim0479">
          <RectangularGeometry id="aim0480">
          <PlanarGeometry>
          <CADObjectId>Fixed: 36" x 72" [333420]</CADObjectId>
          <Name>N-101-E-W-1-W-2</Name>
        </Opening>
        <Opening windowTypeIdRef="aim0448" openingType="OperableWindow" id="aim0489">
          <RectangularGeometry id="aim0490">
          <PlanarGeometry>
          <CADObjectId>Fixed: 36" x 72" [333441]</CADObjectId>
          <Name>N-101-E-W-1-W-3</Name>
        </Opening>
        <CADObjectId>Basic Wall: Exterior - Brick on CMU [331915]</CADObjectId>
        <Name>N-101-E-W-1</Name>
      </Surface>
```

Figure 26 - (Top) One instance gbXML file from the energy settings (Bottom) One instance gbXML file from the room/volume settings

Figure 25 depicts one Revit instance model to explain the difference between the energy and room/volume settings in Revit. The top of Figure 26 illustrates the gbXML instance file from the energy settings in the Revit instance model in Figure 25 and the bottom of Figure 26 describes the gbXML instance file from the room/volume settings in the Revit instance model in Figure 25.

First of all, in the energy settings, it can be found that each element has one “Surface” element in gbXML instance file. For example, in the top of Figure 26, the upper white-dashed line box represents one exterior wall part in the Revit instance model. Further, the lower white-dashed line box represents one opening part in the Revit instance model. It can be inferred because the lower white-dashed line box’s surface element does not have the “constructionIdRef” attribute and includes the “Opening” element.

In contrast, in the room/volume settings, the gbXML instance file was created in the way that if one surface element includes multiple opening elements, the surface element includes all the opening elements as child elements.

For these reasons, the energy and room/volume settings make geometric differences in gbXML instance files and building energy models.

5.3 Result from Energy Settings

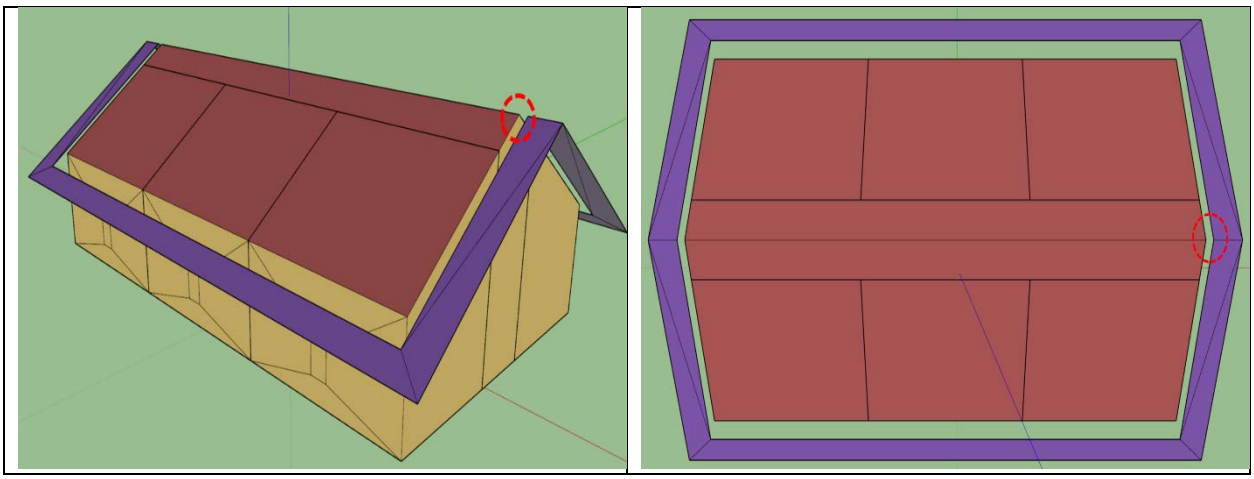


Figure 27 - Energy settings import result

Although the roof was divided correctly, the gaps between the roof and shading device were found. To find the reason, two surfaces in red-circle in Figure 27 will be examined.

```
7977    <Surface surfaceType="Roof" constructionIdRef="aim0116" exposedToSun="true" id="aim2967">
7978      <AdjacentSpaceId spaceIdRef="aim0864" surfaceType="Roof" />
7979      <RectangularGeometry id="aim4242">=
7990      <PlanarGeometry>
7991        <PolyLoop>
7992          <CartesianPoint>
7993            <Coordinate>-14.49386</Coordinate>
7994            <Coordinate>-0.2192058</Coordinate>
7995            <Coordinate>7.928684</Coordinate>
7996          </CartesianPoint>
7997          <CartesianPoint>
7998            <Coordinate>12.93814</Coordinate>
7999            <Coordinate>-0.2192058</Coordinate>
8000            <Coordinate>7.928684</Coordinate>
8001          </CartesianPoint>
8002          <CartesianPoint>
8003            <Coordinate>12.93814</Coordinate>
8004            <Coordinate>1.304794</Coordinate>
8005            <Coordinate>8.808754</Coordinate>
8006          </CartesianPoint>
8007          <CartesianPoint>
8008            <Coordinate>-14.49386</Coordinate>
8009            <Coordinate>1.304794</Coordinate>
8010            <Coordinate>8.808754</Coordinate>
8011          </CartesianPoint>
8012        </PolyLoop>
8013      </PlanarGeometry>
8014      <CADObjectId>152</CADObjectId>
8015    </Surface>
```

```
7827    <Surface surfaceType="Shade" constructionIdRef="aim0116" exposedToSun="true" id="aim2821">
7828      <RectangularGeometry id="aim4206">=
7839      <PlanarGeometry>
7840        <PolyLoop>
7841          <CartesianPoint>
7842            <Coordinate>13.34947</Coordinate>
7843            <Coordinate>-7.21313</Coordinate>
7844            <Coordinate>3.889875</Coordinate>
7845          </CartesianPoint>
7846          <CartesianPoint>
7847            <Coordinate>14.86854</Coordinate>
7848            <Coordinate>1.304794</Coordinate>
7849            <Coordinate>8.808754</Coordinate>
7850          </CartesianPoint>
7851          <CartesianPoint>
7852            <Coordinate>13.34947</Coordinate>
7853            <Coordinate>1.304794</Coordinate>
7854            <Coordinate>8.808754</Coordinate>
7855          </CartesianPoint>
7856        </PolyLoop>
7857      </PlanarGeometry>
7858      <CADObjectId>148</CADObjectId>
7859    </Surface>
```

Figure 28 - (Left) Roof surface part of red-circle (Right) Shading device part of red-circle

To prevent the gaps between surfaces, the two surfaces must share at last two exact same cartesian points. However, in Figure 28, it was found that the two cartesian points in the white box did not share the same points (roof (12.93814, 1.304794, 8.808754), shading device (14.86854, 1.304794, 8.808754)).

5.4 Result from Room/Volume Settings

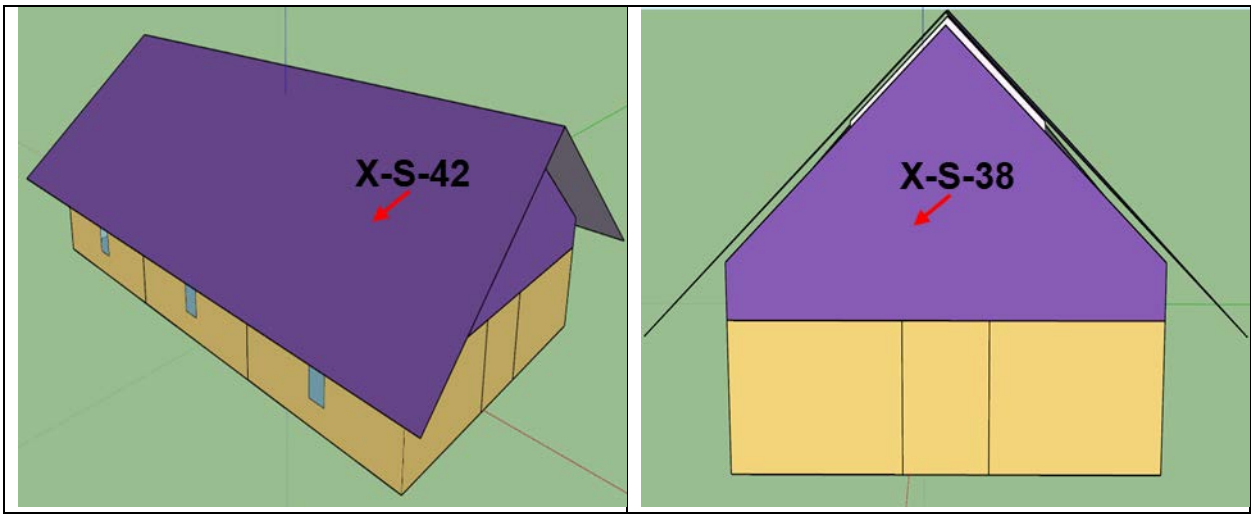


Figure 29 - Room/Volume settings import result

The main issue of result from room/volume settings is roof and shading device parts were not divided correctly. For instance, X-S-42 surface was supposed to be partly roof and be partly shading device. Yet, the surface was converted completely into shading device. Furthermore, X-S-38 surface was supposed to be translated into exterior wall type because of construction type. However, the surface was translated into a shading surface. To find the reason, the gbXML instance file was also checked.

```
4678      <Surface surfaceType="Shade" exposedToSun="true" id="aim1169">
4679 >      <RectangularGeometry id="aim1170">
4690 >      <PlanarGeometry>
4714        <CADObjectId>Basic Roof: Wood Rafter 8" - Asphalt Shingle - Insulat
4715        <Name>X-S-42</Name>
4716      </Surface>
```

```
4512        <Surface surfaceType="Shade" exposedToSun="true" id="aim1127">
4513 >        <RectangularGeometry id="aim1128">
4524 >        <PlanarGeometry>
4553          <CADObjectId>Basic Wall: Exterior - Brick on CMU [350701]</CADObje
4554          <Name>X-S-38</Name>
4555        </Surface>
```

Figure 30 - (Top) X-S-42 surface (Bottom) X-S-38 surface

X-S-42 (entire) surface was translated into shading device and X-S-38's surface type attribute was translated into "Shade".

5.5 Examine the gbXML schema (v 6.01)

```
<xsd:element name="Surface">
  <xsd:complexType>
    <xsd:choice minOccurs="0" maxOccurs="unbounded">
      <xsd:element ref="Name" minOccurs="0"/>
      <xsd:element ref="Description" minOccurs="0"/>
      <xsd:element ref="FamilyName" minOccurs="0"/>
      <xsd:element ref="AdjacentSpaceId" minOccurs="1" maxOccurs="2"/>
      <xsd:element ref="RectangularGeometry"/>
      <xsd:element ref="PlanarGeometry"/>
      <xsd:element ref="Opening" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element ref="CADObjectId" minOccurs="0" maxOccurs="unbounded"/>
    </xsd:choice>
    <xsd:attribute name="id" type="xsd:ID" use="required"/>
    <xsd:attribute name="surfaceType" type="surfaceTypeEnum" use="required"/
    <xsd:attribute name="constructionIdRef" type="xsd:IDREF" use="required"/
    <xsd:attribute name="scheduleShadeIdRef" type="xsd:IDREF"/>
    <xsd:attribute name="exposedToSun" type="xsd:boolean" default="true"/>
    <xsd:attribute name="ifcGUID" type="xsd:string" use="optional"/>
  </xsd:complexType>
</xsd:element>
```

```
<xsd:simpleType name="surfaceTypeEnum">
  <xsd:restriction base="xsd:NMTOKEN">
    <xsd:enumeration value="InteriorWall"/>
    <xsd:enumeration value="ExteriorWall"/>
    <xsd:enumeration value="Roof"/>
    <xsd:enumeration value="InteriorFloor"/>
    <xsd:enumeration value="ExposedFloor"/>
    <xsd:enumeration value="Shade"/>
    <xsd:enumeration value="UndergroundWall"/>
    <xsd:enumeration value="UndergroundSlab"/>
    <xsd:enumeration value="Ceiling"/>
    <xsd:enumeration value="Air"/>
    <xsd:enumeration value="UndergroundCeiling"/>
    <xsd:enumeration value="RaisedFloor"/>
    <xsd:enumeration value="SlabOnGrade"/>
    <xsd:enumeration value="FreestandingColumn"/>
    <xsd:enumeration value="EmbeddedColumn"/>
  </xsd:restriction>
</xsd:simpleType>
```

Figure 31 - "Surface" and "SurfaceTypeEnum" elements in gbXML schema

No specific issues were found in the surface part in the gbXML schema.

6 Unit test 5: Exterior & Interior columns

6.1 The role of structural elements (e.g., columns) in building energy simulation

Before investigating how structural elements are translated from Revit to gbXML to OpenStudio, it is necessary to describe how structural elements have an impact on building energy simulation results. In (eq 1 and 2), the terms related to exterior structural elements were highlighted in green and the terms related to interior structural elements were colored in yellow.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{SWR} + \sum Q_{internal\ gains} \quad \cdots\cdot \text{(eq 2)}$$

Where, A: Area (m^2)

L: Thickness of wall or height of space (m)

ρ: Density (kg/m^3)

C_p: Specific heat (J/(kg·K))

T: Temperature (K)

t: Simulation time-step

Q: Heat flux (W)

k: Thermal conductivity (W/(m·K))

h_{conv}: Convective heat transfer coefficient ($W/(m^2 \cdot K)$)

h_{rad}: Radiative heat transfer coefficient ($W/(m^2 \cdot K)$)

F: View factor

$\dot{V}$: Volume flow

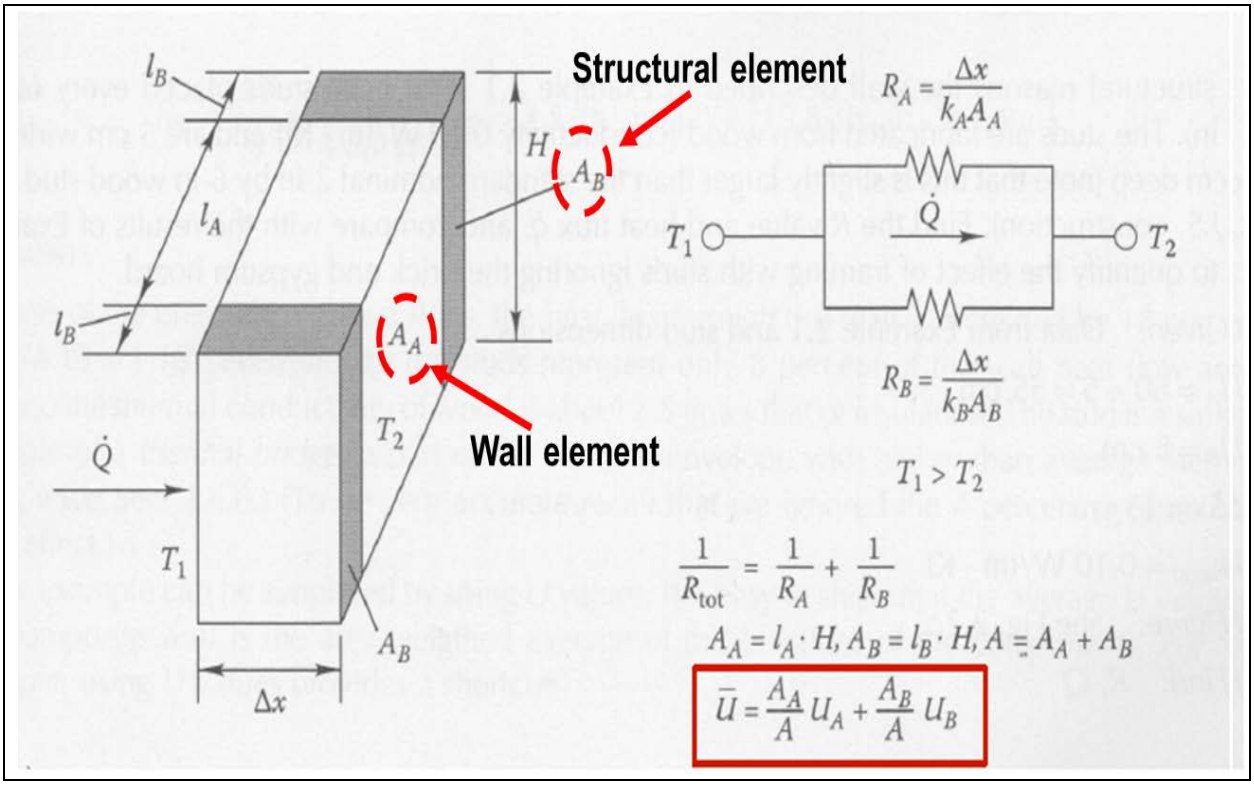
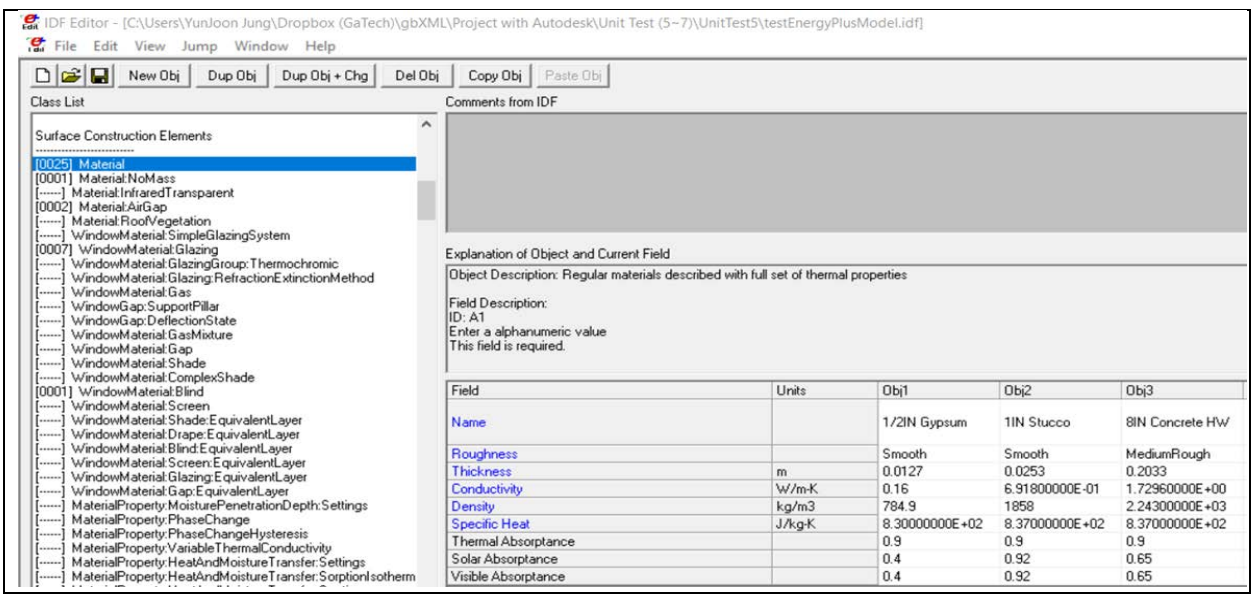


Figure 32 - Accounting for structural elements[1]



Field	Units	Obj1	Obj2	Obj3
Name		1/2IN Gypsum	1IN Stucco	8IN Concrete HW
Roughness		Smooth	Smooth	MediumRough
Thickness	m	0.0127	0.0253	0.2033
Conductivity	W/m-K	0.16	6.91800000E-01	1.72960000E+00
Density	kg/m3	784.9	1858	2.24300000E+03
Specific Heat	J/kg-K	8.30000000E+02	8.37000000E+02	8.37000000E+02
Thermal Absorptance		0.9	0.9	0.9
Solar Absorptance		0.4	0.92	0.65
Visible Absorptance		0.4	0.92	0.65

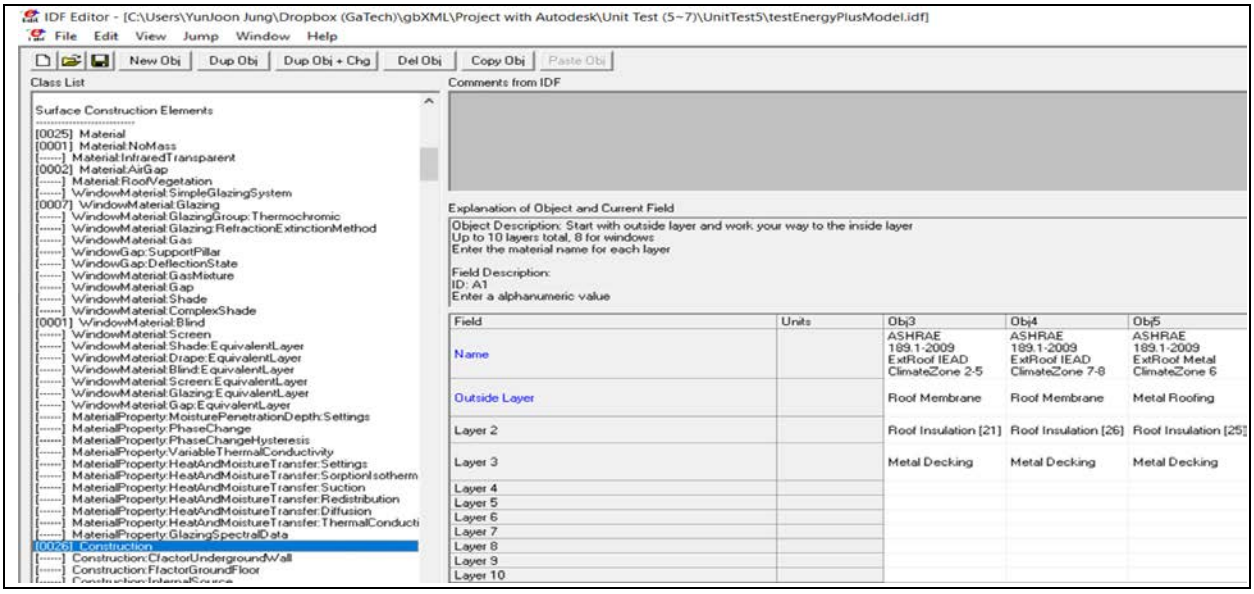


Figure 33 - (Top) “Material” object in EnergyPlus (Bottom) “Construction” object in EnergyPlus

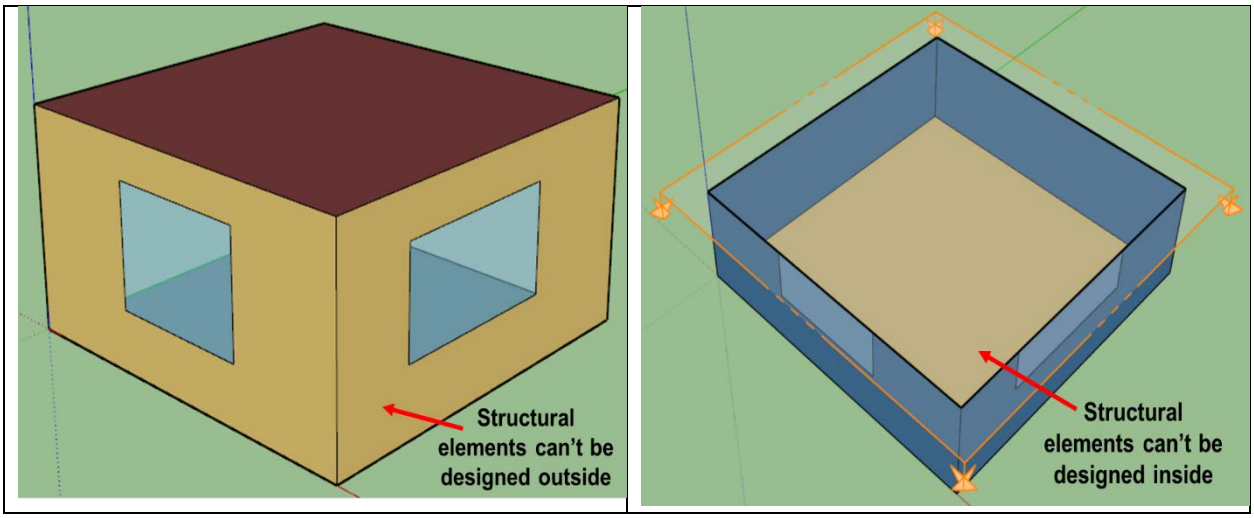


Figure 34 - An example EnergyPlus model

For exterior columns, they have an impact on the overall thermal properties (e.g., unit thermal conductance (U-value)) of the exterior wall. For example, as shown in Figure 32, when one layer of the wall consists of two or more materials, the overall thermal properties should be calculated based on the weighted average method. However, Figure 33 illustrates EnergyPlus allows to have only one material’s thermal properties in each layer of the wall. Therefore, when BIM software exports a gbXML instance file, it is legitimate to say that Revit should calculate the overall thermal properties of materials and translate the overall thermal properties into the instance file. Additionally, since exterior structural elements can’t be designed in EnergyPlus as depicted in Figure 34, Revit should not describe exterior columns as they are in Revit into a gbXML instance file.

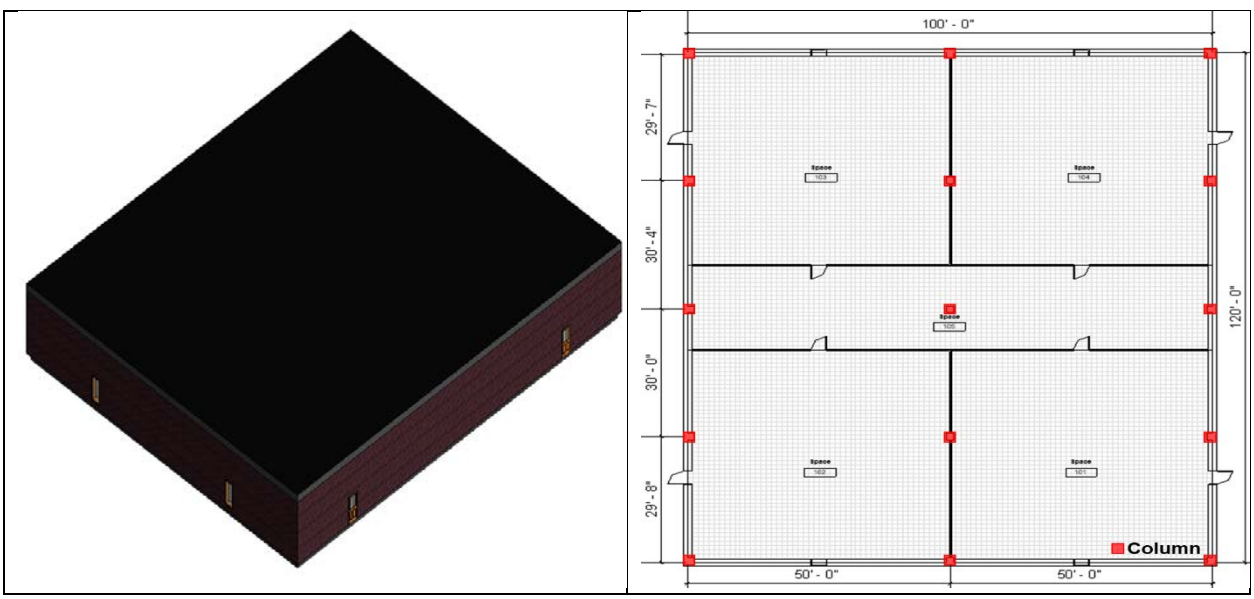
For interior columns, they affect gross floor area/volume of the space and the amount of the total internal heat gains if the parameters were set up in W/m^2. Firstly, for the variations in gross area/volume of the space issue, the error caused from different perspectives between BIM and BEM may have to be acknowledged. It is because for BIM models, interior columns are vital elements for supporting dead and live loads, etc. In contrast, for BEM models, EnergyPlus can't account for the difference originated from interior columns because interior columns can't be designed in EnergyPlus as depicted in Figure 34, considering the that interior columns do not emit heat. Secondly, for the variation in total internal heat gain value issue, one way to solve this issue would be Revit calculates total amount heat gain (W) without interior column areas rather than using normalized heat gain value (W/m^2).

In conclusion, for both exterior and interior column cases, the exterior/interior columns' data must not be described in a gbXML instance file and OpenStudio Model. For this section, the main focus of this unit test is whether columns are removed into OpenStudio models correctly because material thermal properties and internal heat gain parameters can be easily changed from BEM users. However, once the BIM model's geometry is translated inappropriately, BEM users can't fix the geometry.

6.2 Methodology

The methodology utilized from the unit test 1 to 3 was also used again in this unit test.

6.3 Revit instance model introduction



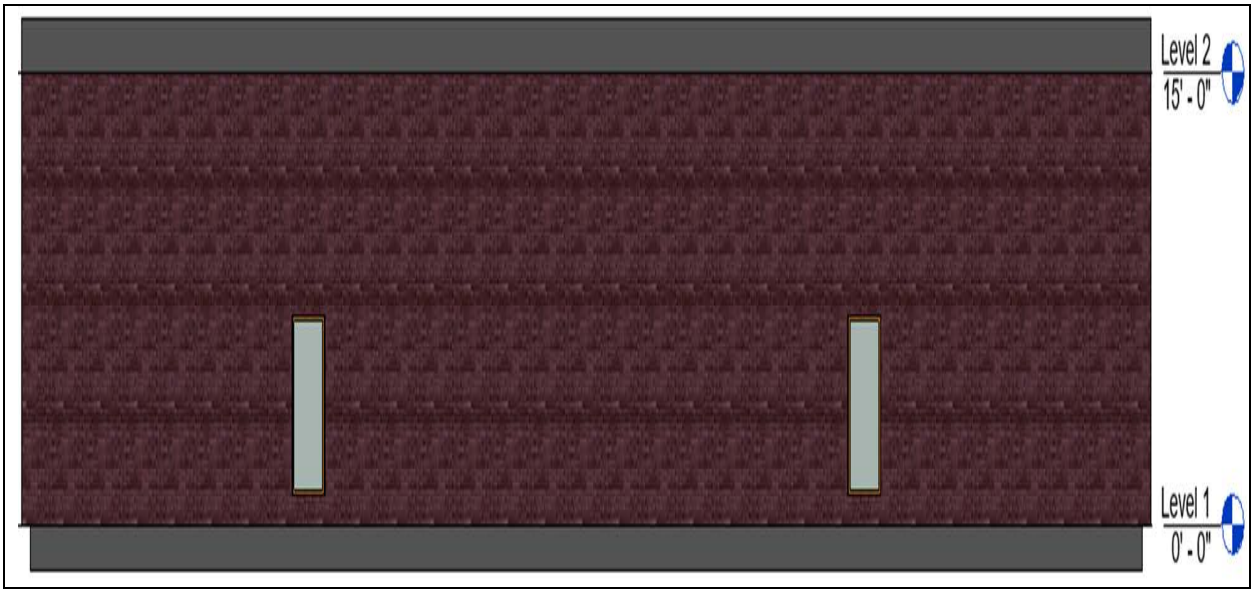


Figure 35 - (Top-left) Axon view of the Revit model (Top-right) Floor plan of the model (red box: the location of columns) (Bottom) South elevation view

The size of the Revit instance model is 100 feet (width) by 120 feet (length) by 15 ft (height) and the model has architectural 18”x18” rectangular-shaped columns where the red boxes are located in the top-right of Figure 35.

6.4 Import result in OpenStudio

6.4.1 Energy settings result

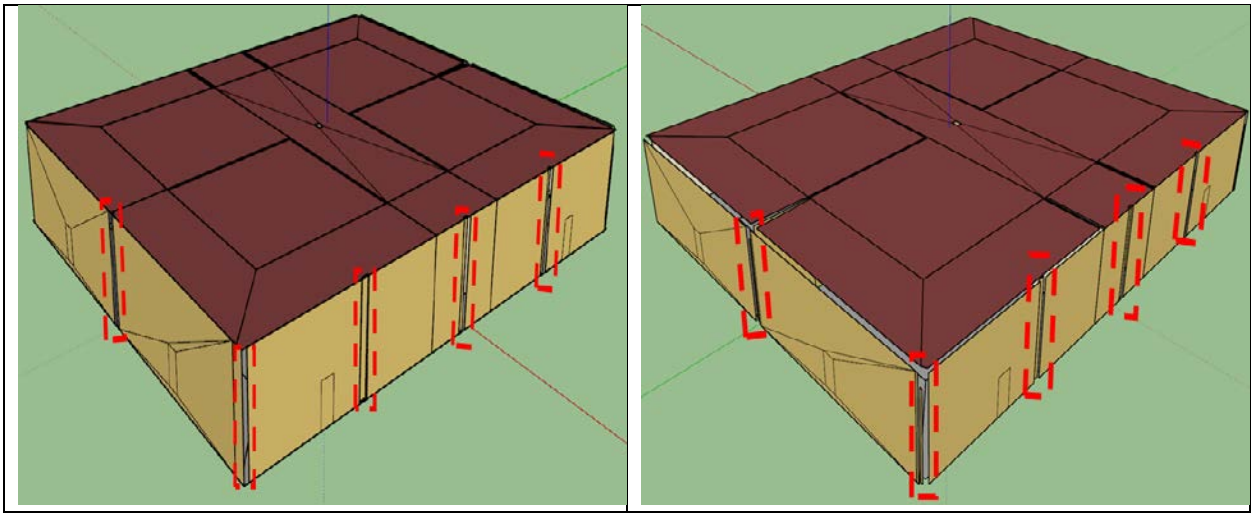


Figure 36 - Import results from the energy settings (Axon view)

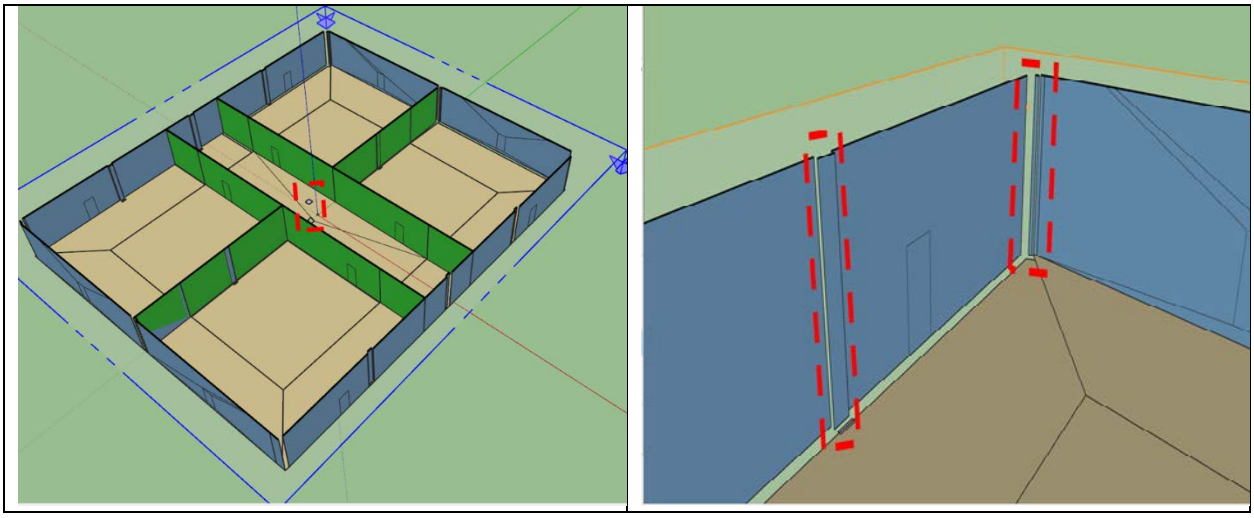


Figure 37 - Import result from the energy settings (inside view)

When energy settings were used, most gaps were found where the columns are located. Further, in the left of Figure 36, the small area of floor surface where the interior column is located was lost. It might be because voxelization was applied inconsistently to the columns. For the future improvements, it would be crucial to have a gbXML algorithm which can ignore architectural columns in Revit.

6.4.2 Room/volume settings result

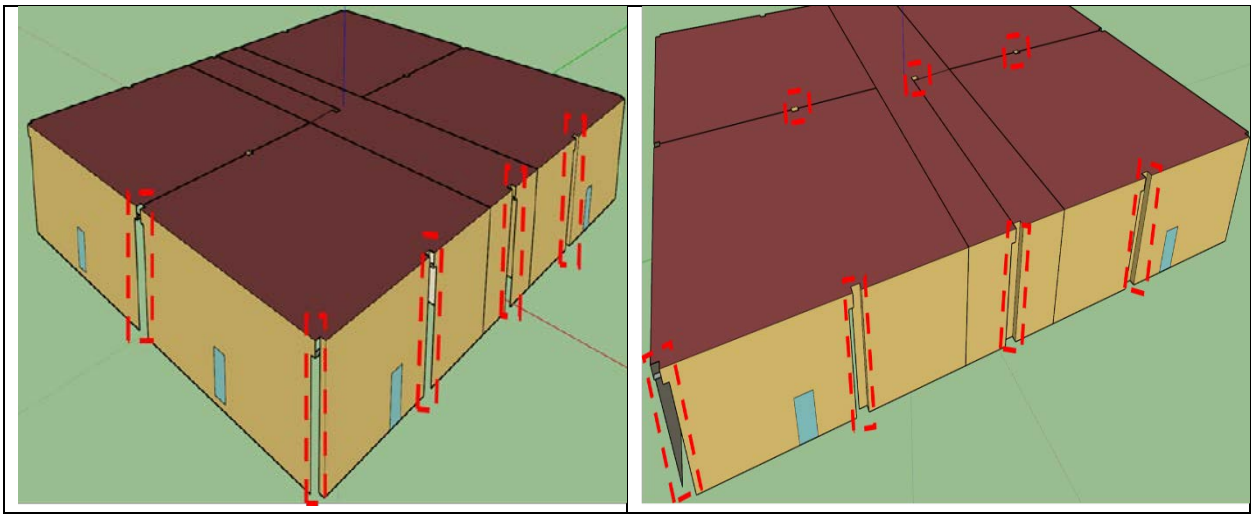


Figure 38 - Import result from the room/volume settings (Axon view)

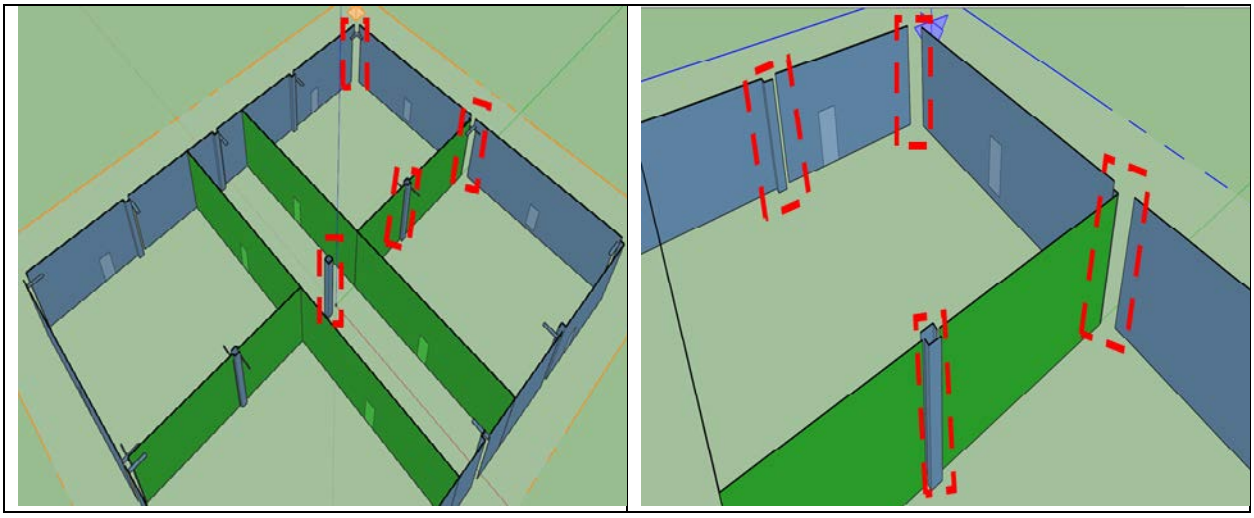


Figure 39 - Import result from the room/volume settings

From Figure 38 and Figure 39, most gaps were found where the columns are located in the room/volume settings. Some gaps were found from the surfaces which include the exterior columns. For the interior columns, the columns were translated into OpenStudio model as were in Revit.

7 Unit test 6: Ceiling voids

7.1 The role of ceiling voids in dynamic building energy simulation

When it comes to ceiling void (plenum) space, the ceiling void space has to be taken into consideration because ceiling void space could make huge difference of building energy simulation results because of the variation of space's volume. As shown in (eq 1 and 2) below, whether ceiling space is included makes differences of the volume term (= Area (m^2) · Height of the space (m)), which was highlighted in yellow.

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \sum Q_{cond} + \sum Q_{conv} + \sum Q_{LWR} + \sum Q_{SWR} + \sum Q_{air\ exchange} + \sum Q_{internal\ gains} \quad \cdots \text{(eq 1)}$$

$$A \cdot L \cdot \rho \cdot C_p \cdot \frac{dT}{dt} = \frac{k}{L} \cdot A \cdot \Delta T + h_{conv} \cdot A \cdot \Delta T + h_{rad} \cdot A \cdot F \cdot \Delta T + \sum Q_{SWR} + \dot{V} \cdot \rho \cdot C_p \cdot \Delta T + \sum Q_{internal\ gains} \quad \cdots \text{(eq 2)}$$

Where, A: Area (m^2)
L: Thickness of wall or height of space (m)
ρ: Density (kg/m^3)
C_p: Specific heat (J/(kg·K))
T: Temperature (K)
t: Simulation time-step

Q: Heat flux (W)
k: Thermal conductivity (W/(m·K))
h_{conv}: Convective heat transfer coefficient (W/(m^2·K))
h_{rad}: Radiative heat transfer coefficient (W/(m^2·K))
F: View factor
$\dot{V}$: Volume flow

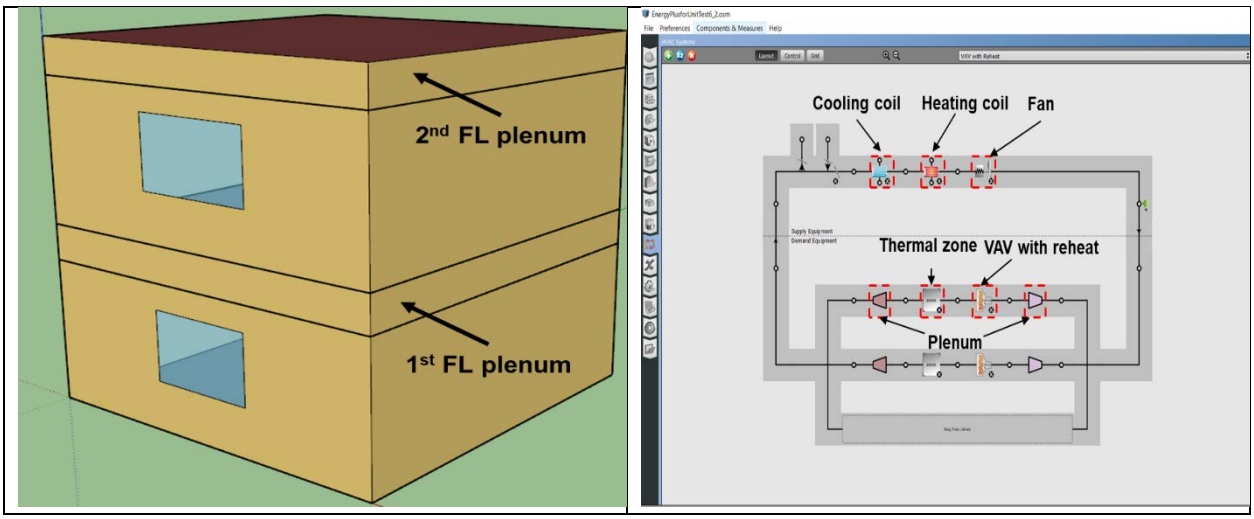


Figure 40 - (Left) One example OpenStudio model that has plenum spaces (Right) HVAC system design in OpenStudio

Moreover, OpenStudio is capable of designing plenum space and building energy modelers are supposed to take ceiling void space into consideration. For instance, the left of Figure 40 illustrates an example two-story OpenStudio model which consists of plenum space on each floor. The right of Figure 40 shows an air-handling-unit which is equipped with cooling/heating coil and a fan and the heating/cooling coil serves warm/cool air to the thermal zones through the VAV with reheat boxes. When the HVAC systems are modeled in OpenStudio, plenum space (90-degree rotated trapezoid in pink and brown boxes) should be added to expect the accurate simulation results.

7.2 Methodology

The methodology utilized from the unit test 1 to 3 was also used again in this unit test.

7.3 Revit geometry introduction

As Figure 41 and Figure 42 depict, the same Revit instance model from the unit test 5 was utilized. However, 12-feet high ceiling was added to the model and thus the model has 3-feet

plenum space. Besides, the columns in the model was removed to prevent the errors created from the columns.

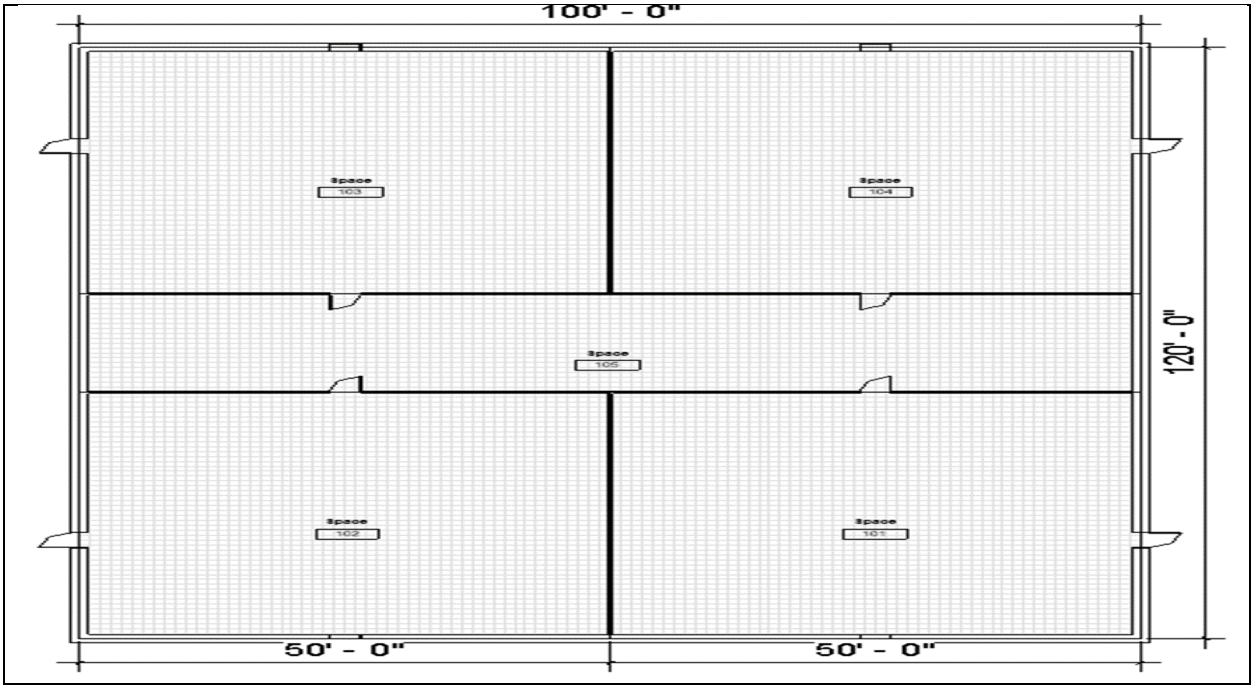


Figure 41 - Floor plan of the unit test 6 (Same as the model from the unit test 5 but the columns were removed)

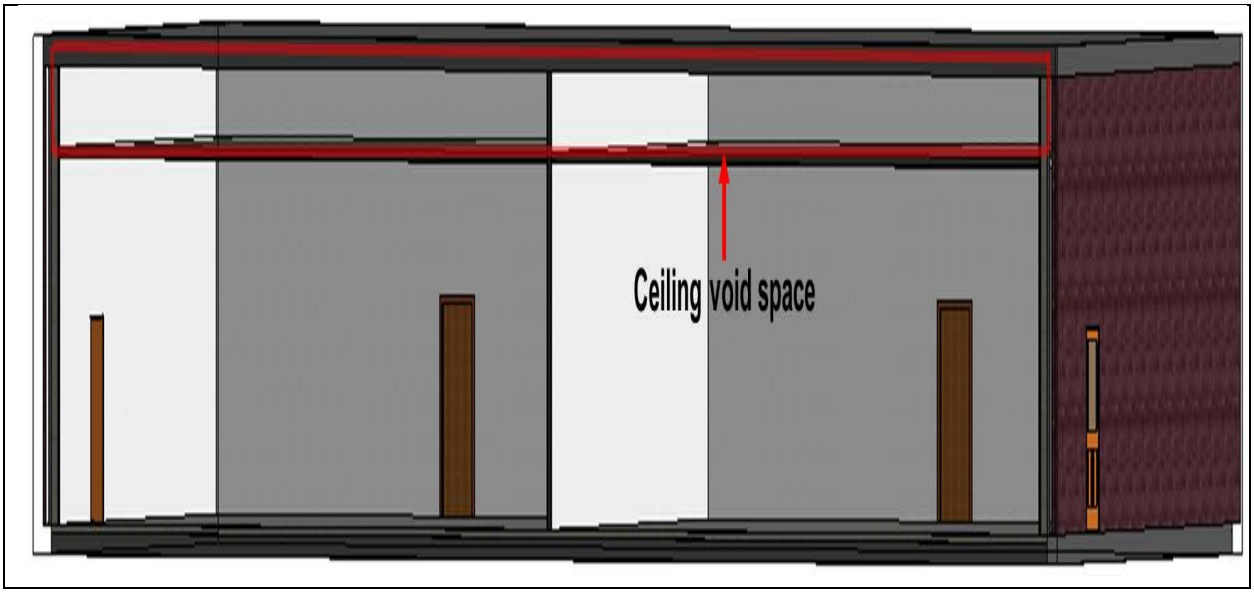


Figure 42 - Ceiling void space in the model

7.4 Import result in OpenStudio

7.4.1 Energy settings result

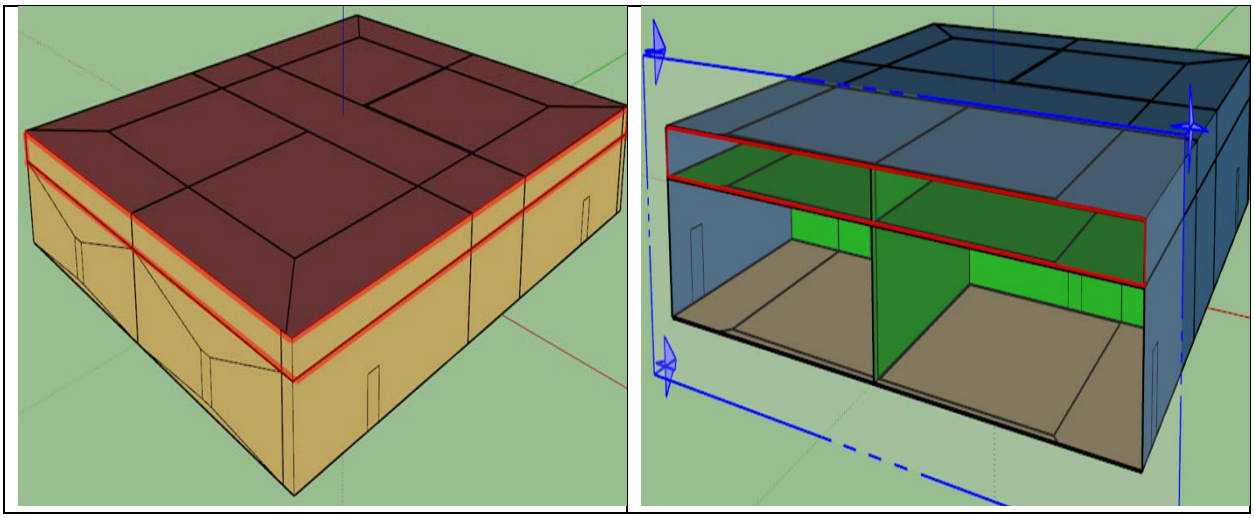


Figure 43 - Import result from the energy settings

The ceiling void space was converted perfectly into the OpenStudio model. As the surfaces in the right of Figure 43 illustrate, the ceiling surfaces were translated correctly in the OpenStudio model.

7.4.2 Room/volume settings result

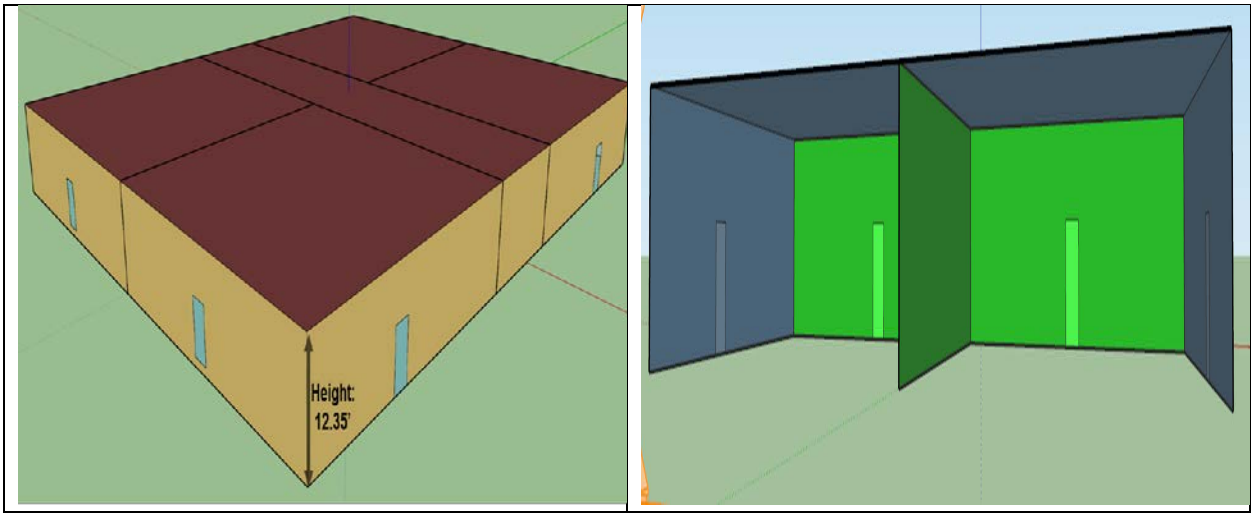


Figure 44 - Import from the room/volume settings

When the room/volume settings were used, it was found that the ceiling void space was not translated into the gbXML instance file and thus into the OpenStudio model. The height of the OpenStudio model is 12.35' (The original model's height is 15 feet), which does not include the

ceiling space. To double-check the result, the upper-limit settings were changed from ceiling to 2nd floor in the Revit model but the new result was exactly same as the former result.

8 Summary of Unit Test Results

Table 3 - Summary of the unit tests

Unit Test No.	Name of Unit Test	Revit	gbXML	OpenStudio	Comment
1	Material Thermal Properties	O	O	O	• Perfectly works between Revit/gbXML and gbXML/Openstudio. • Revit has all the required dynamic building energy simulation in terms of materials.
2	'Sandwiched' Elements layer properties	O	O	O	• The order of exterior/interior materilas is translated correctly into gbXML. •gbXML schema doesn't have any issues. • OpenStudio read 'Sandwiched' Elements (construction) correctly.
3	Space & Zone Thermal Properties	Δ	Δ	Δ	• Revit doesn't allow users to input complex schedules (e.g., occupancy/lighting/equipment/heating cooling set point/infiltration). • "Area per Person" is not written in gbXML. • gbXML schema can't have "Area per Person" element. • OpenStudio doesn't read internal heat gain parameters but reads schedule correctly.
4	Exterior Shading	Δ	Δ	O	• When energy settings used, some gaps between roof and shading devices are found. • When room/volume settings used, some of exterior wall parts are translated into shading devices and roof part is not correctly translated into roof and shading device.
5	Exterior & Interior Columns	Δ	O	O	• Gaps occurred where columns are located. • Columns were not ignored from Revit.
6	Ceilings Voids	Δ	O	O	• Ceiling void is lost when the room/volume settings were used.

O: works Perfectly Δ: works with some limitations X: Huge problems

9 System test: Introduction and methodology

The main objective of the system tests is to assess how the translation pipeline performed on larger models corresponding to realistic professional BIM exchange scenarios. Geometry information (e.g., exterior/interior surfaces, space, slab-on-grade, etc.) and metadata (object type, material properties, etc.) were developed in Revit and then translated into the gbXML instance file and OpenStudio Model.

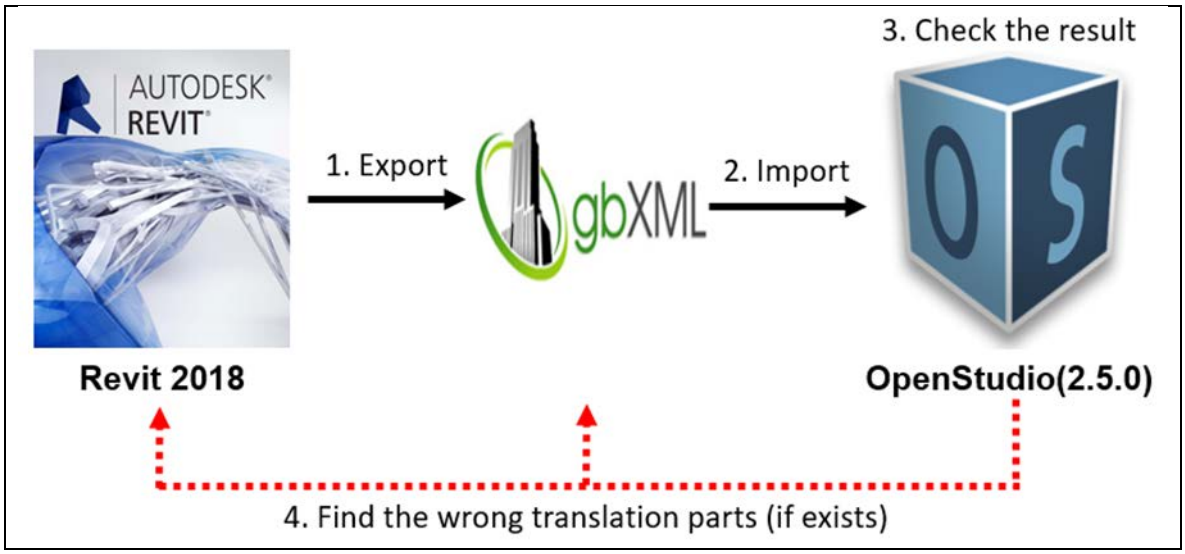


Figure 45 - The system test's overall strategy

The overall system test strategy is as follows:

1. Export the gbXML instance file from Revit 2018.
2. Import the gbXML instance file into OpenStudio 2.5.0.
3. Check whether the architectural parts are translated correctly in OpenStudio.
4. If there are discrepancies found in the OpenStudio model, go back to the gbXML instance file and Revit to find the origin of the problems.

Lastly, since two different settings in Revit (e.g., energy and room/volume settings) produce gbXML instance files differently, the following sections will describe the gbXML instance file import results respectively.

10 System test 1: Small House

10.1 Revit instance file - Small House

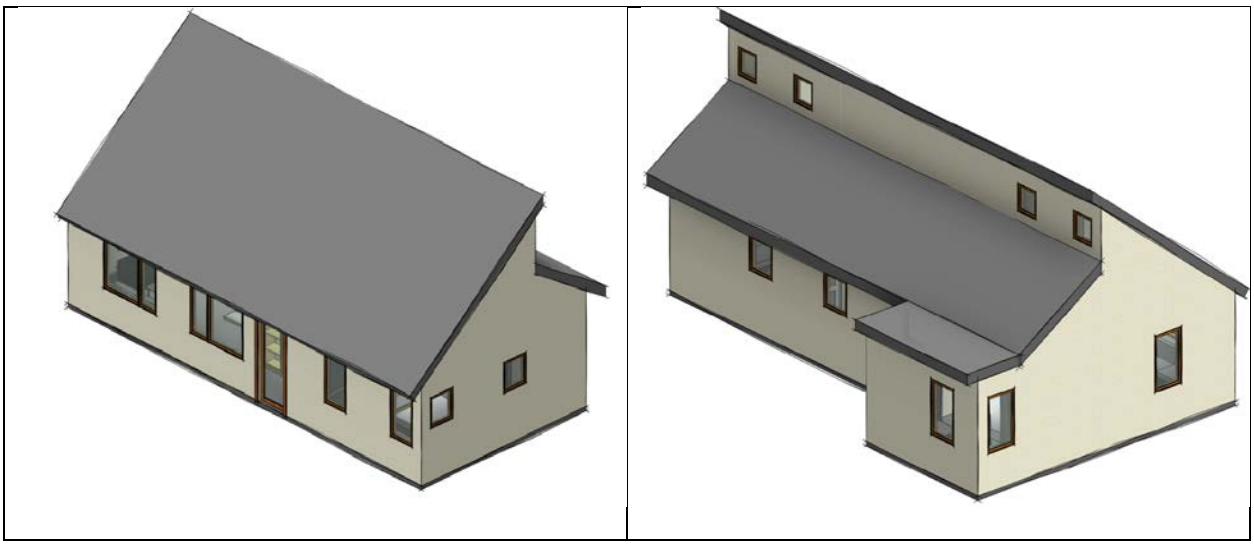
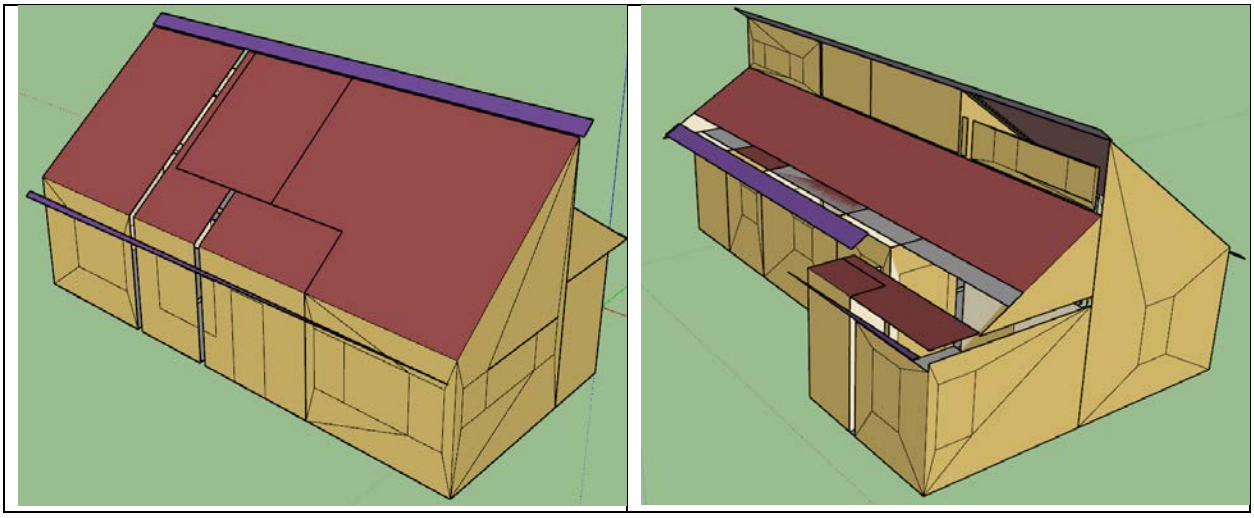


Figure 46 - (Left) South-East orientation (Right) North-West Orientation

The Small House Revit instance file will be firstly tested. The instance building is a 1-story residential building which has a sloped-roof and consists of ten spaces.

10.2 gbXML instance file generated from energy settings



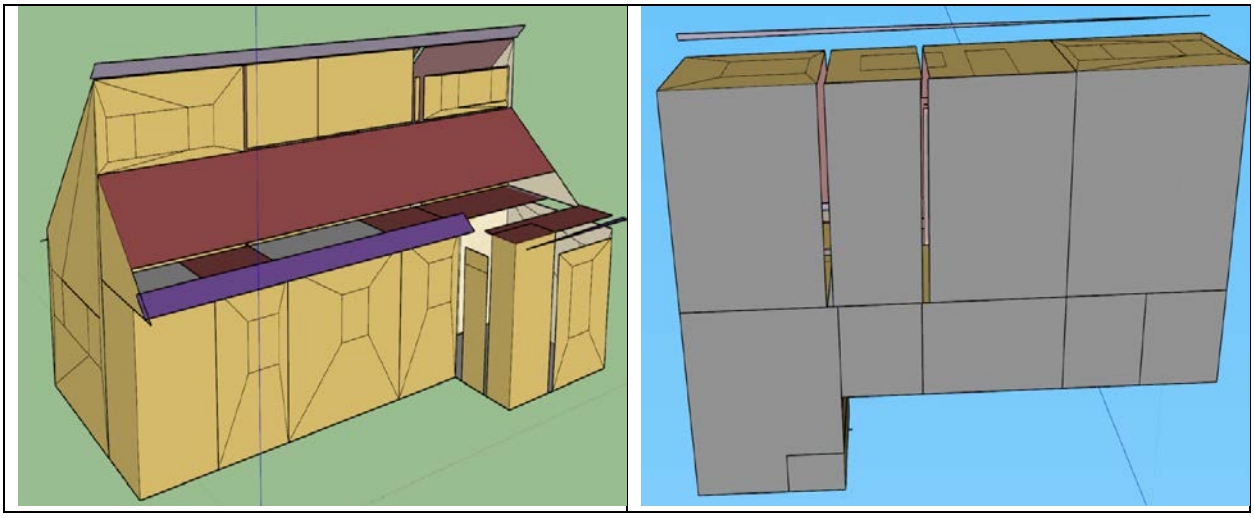


Figure 47 - Import result in OpenStudio

Figure 47 illustrates the import results in OpenStudio using energy settings in Revit. There are a few issues with this import:

• Gaps between Spaces

• All the windows are not shown in the OpenStudio model

• Loss of accuracy in shadow devices

• Space height misrepresentation

The following sections will inspect these four issues in more depth.

10.2.1 Gap between Spaces

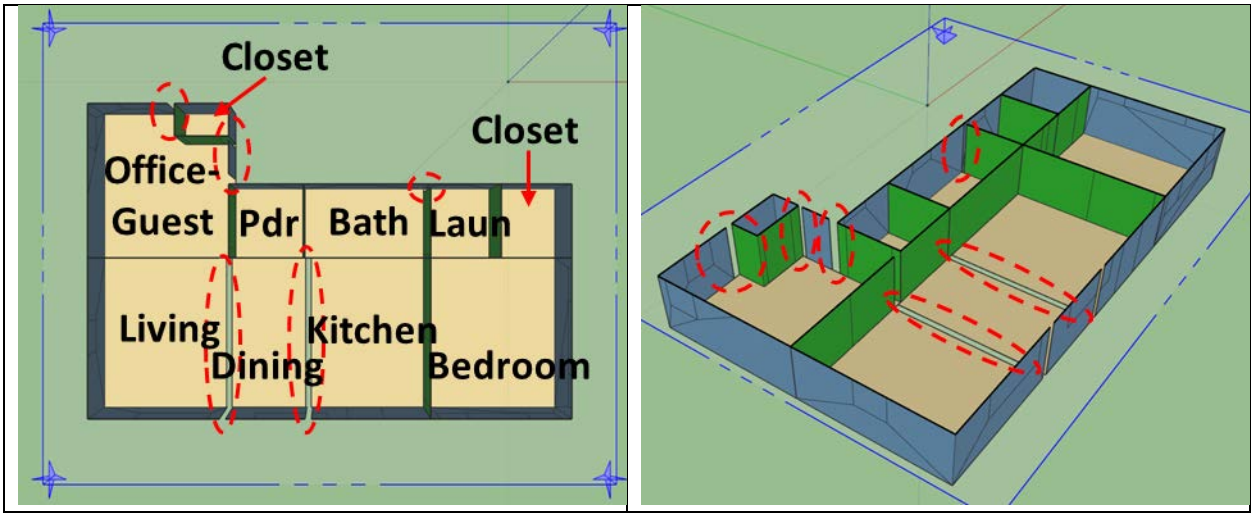


Figure 48 - (Left) Floor plan (Right) Axon view (The gaps between spaces are rea-dotted circled)

Most space gaps occurred between two spaces. As an example, in Figure 49, the way the living room and dining room parts in the gbXML instance file was exported will be checked.


```
15021    <Surface surfaceType="SlabOnGrade" constructionIdRef="construction-29" id="aim4746">
15022      <AdjacentSpaceId spaceIdRef="aim0262" surfaceType="SlabOnGrade" />
15023      <RectangularGeometry id="aim8099">=
15034      <PlanarGeometry>
15035        <PolyLoop>
15036          <CartesianPoint>
15037            <Coordinate>-35.42215</Coordinate>
15038            <Coordinate>-26.09909</Coordinate>
15039            <Coordinate>0</Coordinate>
15040          </CartesianPoint>
15041          <CartesianPoint>
15042            <Coordinate>-35.42215</Coordinate>
15043            <Coordinate>-14.09909</Coordinate>
15044            <Coordinate>0</Coordinate>
15045          </CartesianPoint>
15046          <CartesianPoint>
15047            <Coordinate>-24.74047</Coordinate>
15048            <Coordinate>-14.09909</Coordinate>
15049            <Coordinate>0</Coordinate>
15050          </CartesianPoint>
15051          <CartesianPoint>
15052            <Coordinate>-24.74047</Coordinate>
15053            <Coordinate>-26.09909</Coordinate>
15054            <Coordinate>0</Coordinate>
15055          </CartesianPoint>
15056        </PolyLoop>
15057      </PlanarGeometry>
15058      <CADObjectId>66</CADObjectId>
15059    </Surface>
```

```
15060    <Surface surfaceType="SlabOnGrade" constructionIdRef="construction-29" id="aim4783">
15061      <AdjacentSpaceId spaceIdRef="aim2172" surfaceType="SlabOnGrade" />
15062      <RectangularGeometry id="aim8108">=
15073      <PlanarGeometry>
15074        <PolyLoop>
15075          <CartesianPoint>
15076            <Coordinate>-24.24358</Coordinate>
15077            <Coordinate>-26.09909</Coordinate>
15078            <Coordinate>0</Coordinate>
15079          </CartesianPoint>
15080          <CartesianPoint>
15081            <Coordinate>-24.24358</Coordinate>
15082            <Coordinate>-14.09909</Coordinate>
15083            <Coordinate>0</Coordinate>
15084          </CartesianPoint>
15085          <CartesianPoint>
15086            <Coordinate>-17.78395</Coordinate>
15087            <Coordinate>-14.09909</Coordinate>
15088            <Coordinate>0</Coordinate>
15089          </CartesianPoint>
15090          <CartesianPoint>
15091            <Coordinate>-17.78395</Coordinate>
15092            <Coordinate>-26.09909</Coordinate>
15093            <Coordinate>0</Coordinate>
15094          </CartesianPoint>
15095        </PolyLoop>
15096      </PlanarGeometry>
15097      <CADObjectId>67</CADObjectId>
15098    </Surface>
```


Figure 49 - (Left) Living room slab-on-grade surface (Right) Dining room slab-on-grade

In Figure 48, the reason why there is a gap between living and dining spaces is two surfaces do not share two same cartesian points. More specifically, the two cartesian points which were supposed to have two exact same points are slightly different. The two points in the living room ((-24.74047, -14 .09909, 0) and (-24.74047, -26.09909, 0)) and the two points in the dining room ((24.24358, -26.09909, 0) and (24.24358, -14.09909, 0)) have different cartesian points.

10.2.2 Missing windows

Figure 50 - (Left) Exterior wall information note (Right) Opening information note

Figure 50 shows window translation in OpenStudio was not conducted correctly. It is because the right figure of Figure 50 shows window surface is also imported as wall surface type. To double-check the result, the gbXML instance file will be checked to see how the gbXML instance file was exported.

```
11908  <Surface surfaceType="ExteriorWall" exposedToSun="true" id="aim2132">
11909    <AdjacentSpaceId spaceIdRef="aim0262" surfaceType="ExteriorWall" />
11910    <RectangularGeometry id="aim7568">
11921    <PlanarGeometry>
11945    <Opening interiorShadeType="Operable" exteriorShadeType="Fixed" windowTypeIdRef="PwindowType-158" openingType="OperableWindow" id="aim2155">
11946      <RectangularGeometry id="aim2163">
11957      <PlanarGeometry>
11958        <PolyLoop>
11959          <CartesianPoint>
11964          <CartesianPoint>
11969          <CartesianPoint>
11974          <CartesianPoint>
11979        </PolyLoop>
11980      </PlanarGeometry>
11981    </Opening>
11982    <CADObjectId>25</CADObjectId>
11983  </Surface>
```

Figure 51 - The window part in the gbXML instance file

In Figure 51, it is shown opening element is a child element of the “ExteriorWall” surface type. For the opening parts, it is suspected OpenStudio might read the “ExteriorWall” element instead of “Opening” element for openings.

10.2.3 Loss of shading device accuracy

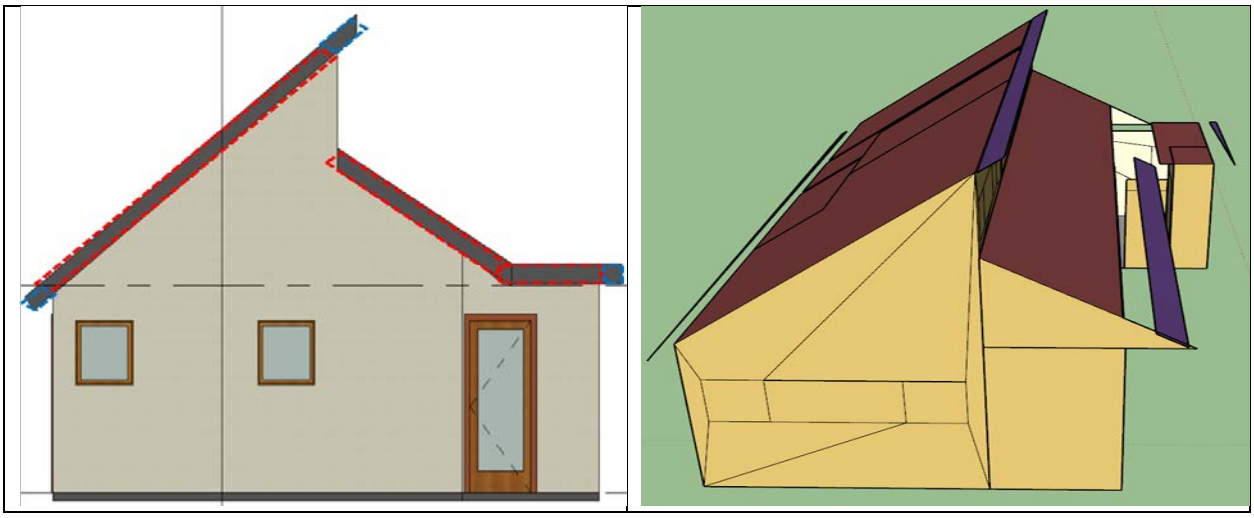
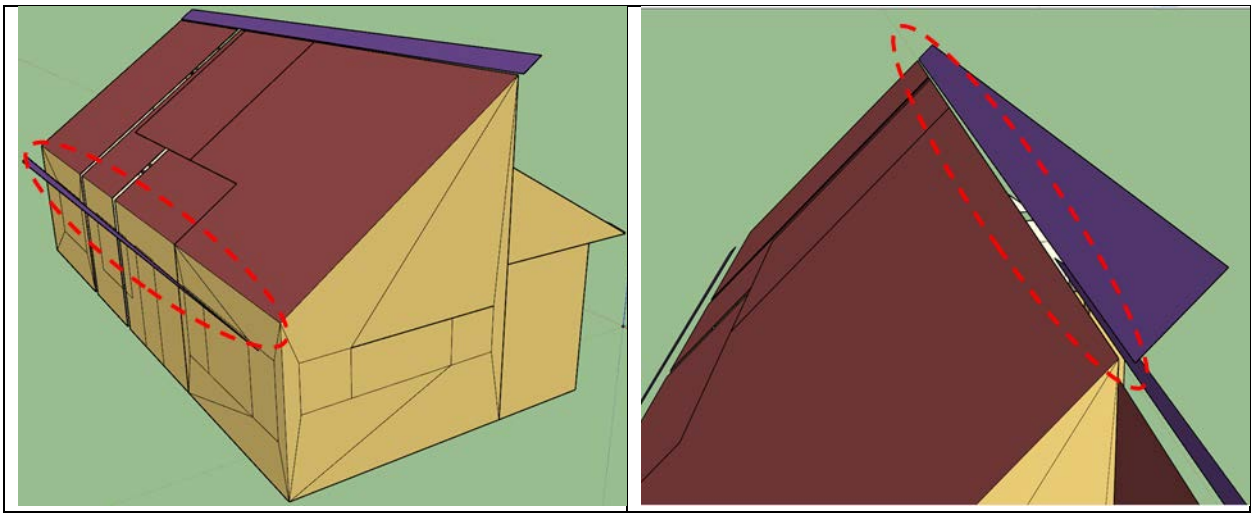


Figure 52 - (Left) East elevation view in Revit (Right) birds-eye view in OpenStudio

In the left of Figure 52, the red rectangles represent the parts which must be translated into roof and blue rectangles the parts that need to be translated into shading devices. The main reason is the red parts are directly affected by conduction, convection, solar radiation (short wave radiation) heat transfers. In contrast the blue parts only reduce the amount of solar radiation in building energy simulation.



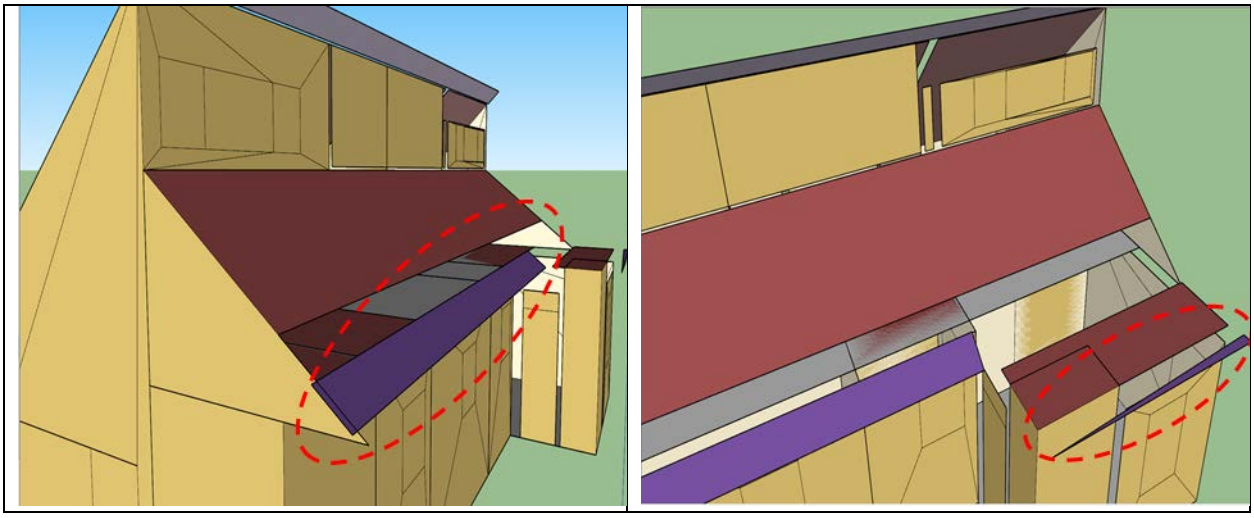
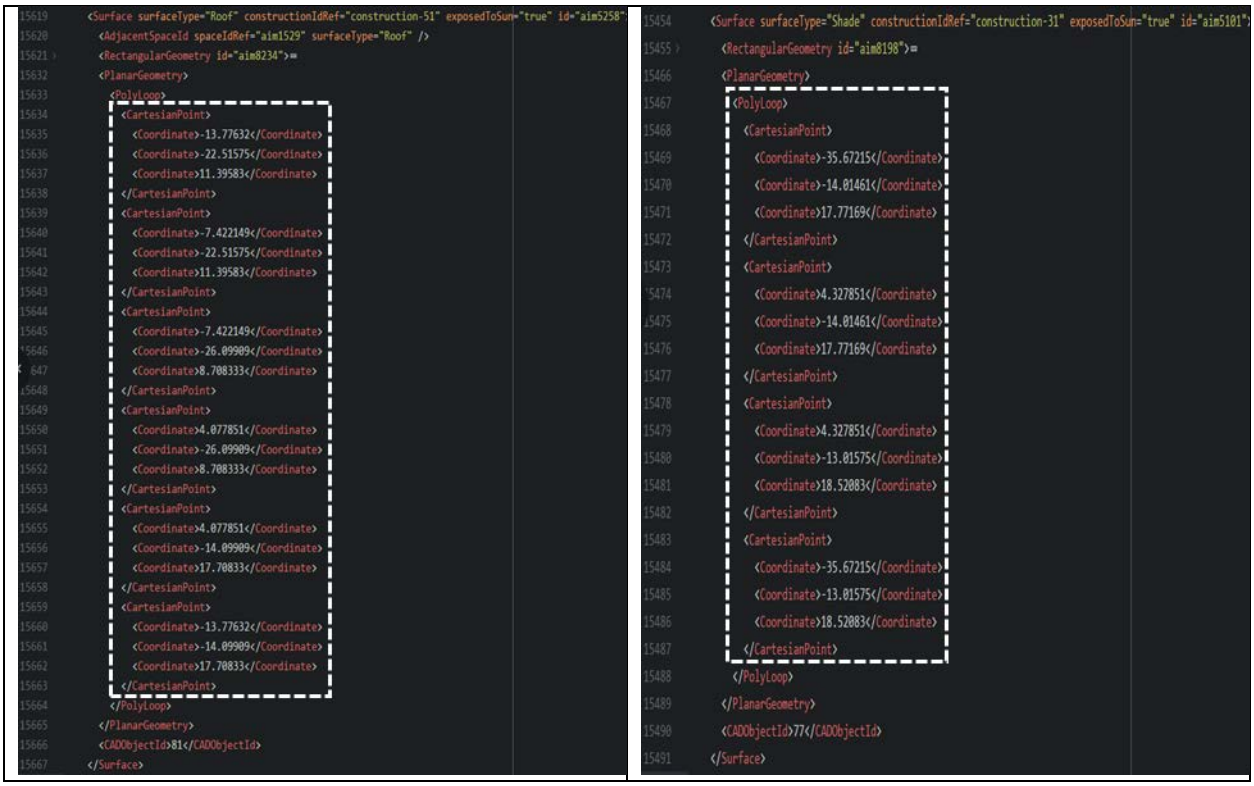


Figure 53 - Misrepresentation of shading devices

In the right of Figure 53 illustrates the misrepresentations of shading devices in OpenStudio. Two main issues were found in the shading device translation part. First is a roof surface and a shading device have some gaps and second is shading device's shape is mistranslated. The two problems will be examined in Figure 54 and Figure 55.



```
<Surface surfaceType="Roof" constructionIdRef="construction-51" exposedToSun="true" id="aim5258">
  <AdjacentSpaceId spaceIdRef="aim1529" surfaceType="Roof" />
  <RectangularGeometry id="aim8234">=
  <PlanarGeometry>
    <PolyLoop>
      <CartesianPoint>
        <Coordinate>-13.77632</Coordinate>
        <Coordinate>-22.51575</Coordinate>
        <Coordinate>11.39583</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>-7.422149</Coordinate>
        <Coordinate>-22.51575</Coordinate>
        <Coordinate>11.39583</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>-7.422149</Coordinate>
        <Coordinate>-26.09909</Coordinate>
        <Coordinate>8.708333</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>4.077851</Coordinate>
        <Coordinate>-26.09909</Coordinate>
        <Coordinate>8.708333</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>4.077851</Coordinate>
        <Coordinate>-14.09909</Coordinate>
        <Coordinate>17.70833</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>-13.77632</Coordinate>
        <Coordinate>-14.09909</Coordinate>
        <Coordinate>17.70833</Coordinate>
      </CartesianPoint>
    </PolyLoop>
  </PlanarGeometry>
  <CADObjectId>81</CADObjectId>
</Surface>
```

```
<Surface surfaceType="Shade" constructionIdRef="construction-31" exposedToSun="true" id="aim5101">
  <RectangularGeometry id="aim8198">=
  <PlanarGeometry>
    <PolyLoop>
      <CartesianPoint>
        <Coordinate>-35.67215</Coordinate>
        <Coordinate>-14.01461</Coordinate>
        <Coordinate>17.77169</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>4.327851</Coordinate>
        <Coordinate>-14.01461</Coordinate>
        <Coordinate>17.77169</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>4.327851</Coordinate>
        <Coordinate>-13.01575</Coordinate>
        <Coordinate>18.52083</Coordinate>
      </CartesianPoint>
      <CartesianPoint>
        <Coordinate>-35.67215</Coordinate>
        <Coordinate>-13.01575</Coordinate>
        <Coordinate>18.52083</Coordinate>
      </CartesianPoint>
    </PolyLoop>
  </PlanarGeometry>
  <CADObjectId>77</CADObjectId>
</Surface>
```

Figure 54 - (Left) Roof part of upper-right in Figure 51 (Right) Shading device part of upper-right in Figure 51

The roof and the shading device in Figure 54 do not have any same coordinate points. Thus, the roof and the shading device have gaps in the OpenStudio model.

```
15421  <Surface surfaceType="Shade" constructionIdRef="construction-31" exposedToSun="true" id="aim5094">
15422    <RectangularGeometry id="aim8189">=
15433    <PlanarGeometry>
15434      <PolyLoop>
15435        <CartesianPoint>
15436          <Coordinate>-35.67215</Coordinate>
15437          <Coordinate>-27.59909</Coordinate>
15438          <Coordinate>7.583333</Coordinate>
15439        </CartesianPoint>
15440        <CartesianPoint>
15441          <Coordinate>4.327851</Coordinate>
15442          <Coordinate>-27.19954</Coordinate>
15443          <Coordinate>7.882991</Coordinate>
15444        </CartesianPoint>
15445        <CartesianPoint>
15446          <Coordinate>-35.67215</Coordinate>
15447          <Coordinate>-27.19954</Coordinate>
15448          <Coordinate>7.882991</Coordinate>
15449        </CartesianPoint>
15450      </PolyLoop>
15451    </PlanarGeometry>
15452    <CADObjectId>76</CADObjectId>
15453  </Surface>
```

```
15823  <Surface surfaceType="Shade" constructionIdRef="construction-31" exposedToSun="true" id="aim5388">
15824    <RectangularGeometry id="aim8279">=
15835    <PlanarGeometry>
15836      <PolyLoop>
15837        <CartesianPoint>
15838          <Coordinate>-35.67215</Coordinate>
15839          <Coordinate>-1.825279</Coordinate>
15840          <Coordinate>8.84375</Coordinate>
15841        </CartesianPoint>
15842        <CartesianPoint>
15843          <Coordinate>-23.67215</Coordinate>
15844          <Coordinate>-1.349088</Coordinate>
15845          <Coordinate>8.84375</Coordinate>
15846        </CartesianPoint>
15847        <CartesianPoint>
15848          <Coordinate>-35.67215</Coordinate>
15849          <Coordinate>-1.349088</Coordinate>
15850          <Coordinate>8.84375</Coordinate>
15851        </CartesianPoint>
15852      </PolyLoop>
15853    </PlanarGeometry>
15854    <CADObjectId>86</CADObjectId>
15855  </Surface>
```

Figure 55 - (Left) Shading device part in upper-left of Figure 51 (Right) Shading device part in lower-right of Figure 51

The second issue of shading device translation is the shape transformation. The small house instance file has rectangular shape shading devices in Figure 46. However, in Figure 53 (top-left and bottom-right), two shading devices' shapes were transformed into a triangular shape in the OpenStudio model. In order to find the reason, the two shading devices' parts were investigated in the gbXML instance file. The left and right of Figure 55 show that the gbXML instance file has only three coordinate points, respectively, which is why the shape of shades was represented as the triangle shapes.

10.2.4 Space height mistranslation

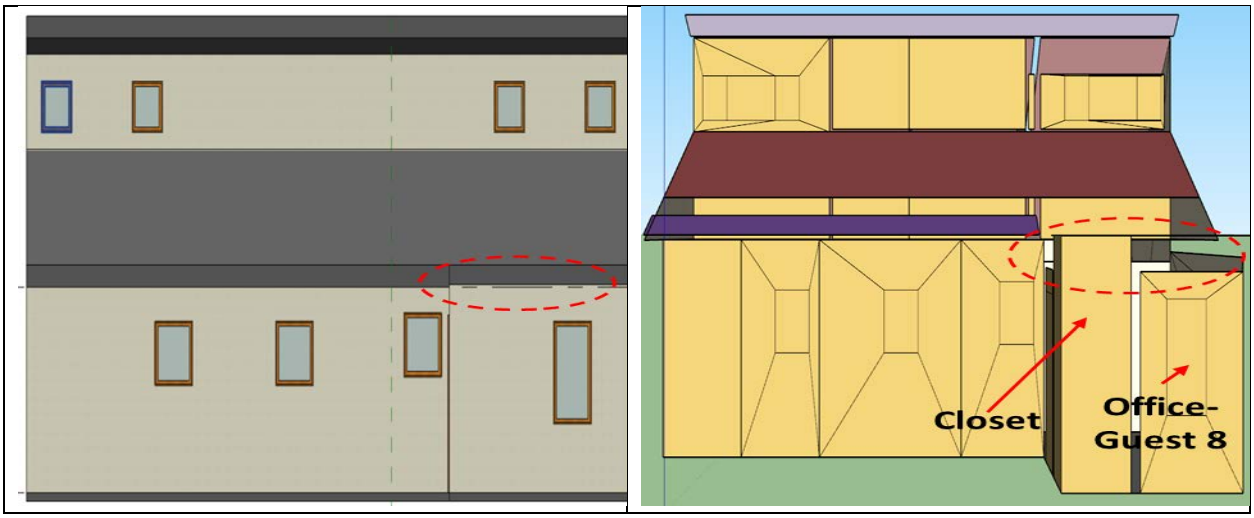


Figure 56 - (Left) North elevation view in Revit (Right) North elevation view in OpenStudio

It was also observed the height of closet space was translated incorrectly. In the Revit model, the height of closet and Office-Guest 8 spaces have same heights in the Revit model but not in the OpenStudio model.

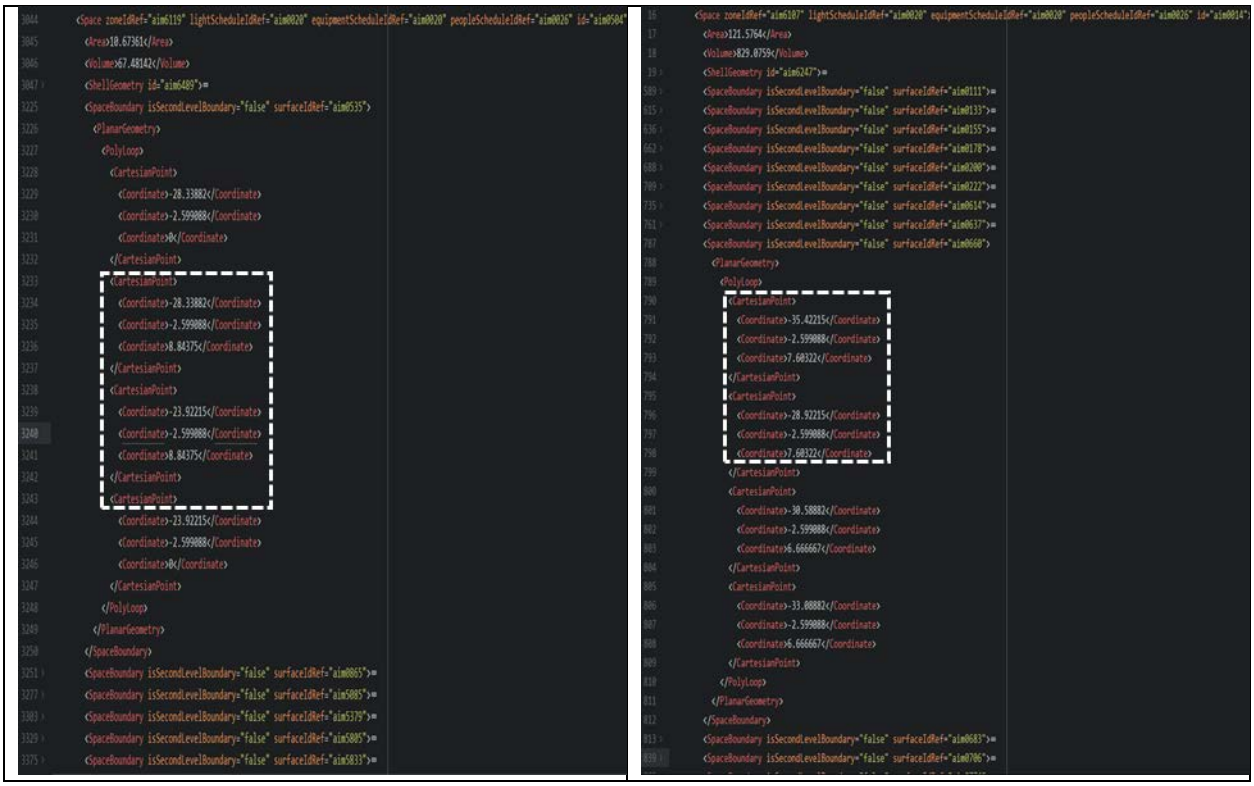


Figure 57 - (Left) Closet part in the gbXML instance file (Right) Office-Guest 8 part in the gbXML instance file

While the gbXML instance file are exported, the height of closet (8.84375) and that of Office-Guest 8 (7.60322) is incorrect.

10.3 gbXML instance file generated from Room/Volume Settings

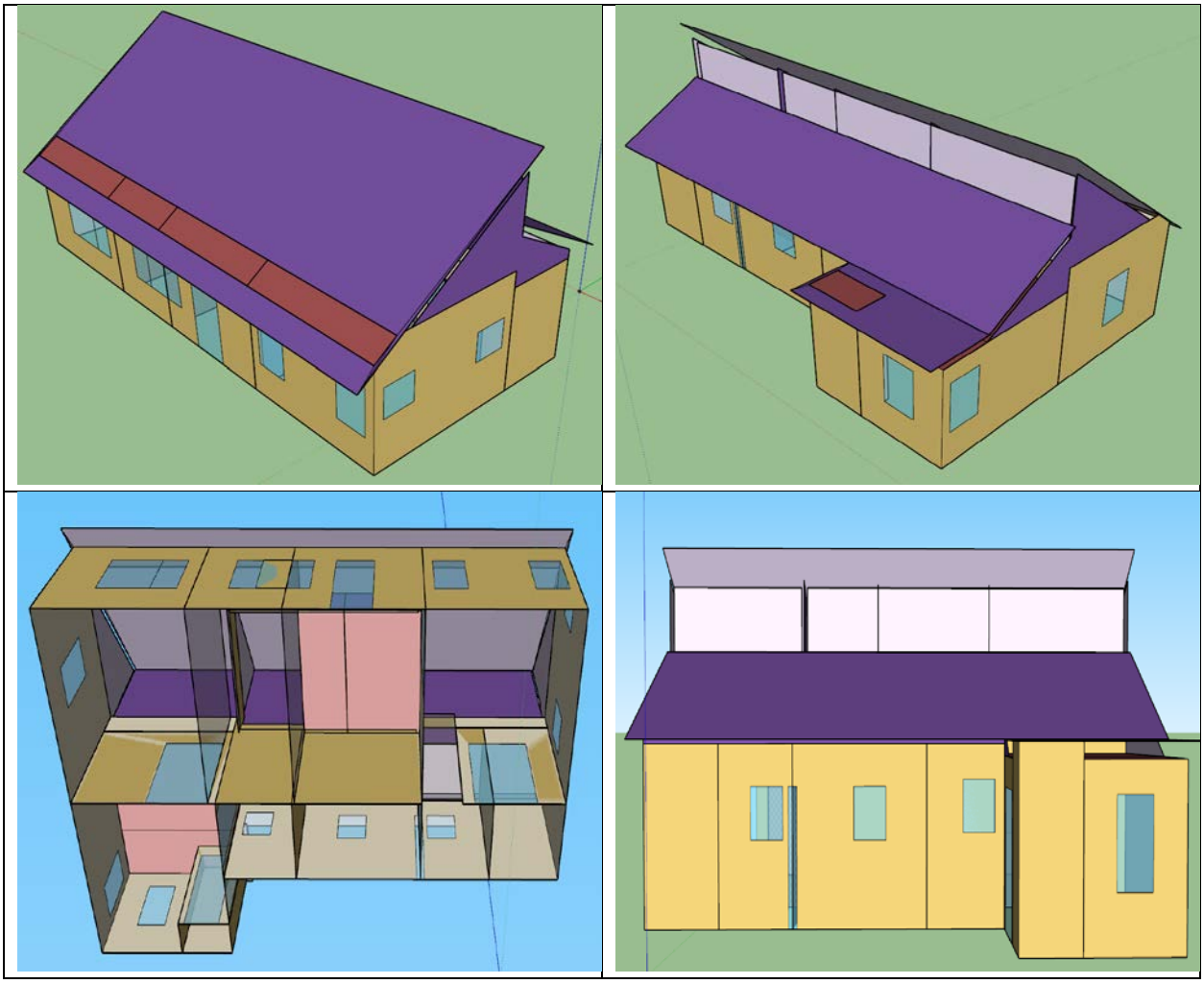


Figure 58 - gbXML import result in OpenStudio

Figure 58 illustrates the import results in OpenStudio using Room/Volume settings in Revit. There are a few issues identified in this translation:

• Roof was translated into mostly shading surfaces (purple color) and gap between roof surfaces

• slab-on-grade is lost

• Space height misrepresentation

Therefore, the following sections will inspect three bullet points mentioned above.

10.3.1 Inaccurate roof translation

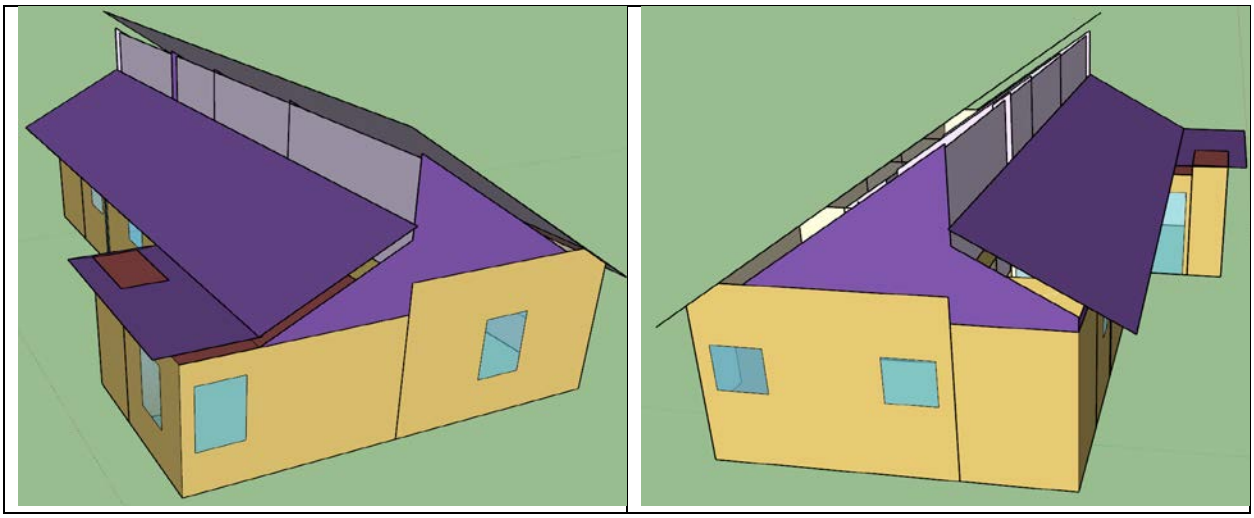


Figure 59 - Misrepresentation of roof in the OpenStudio model

In an OpenStudio model, purple color surface represents a shading device. In Figure 59, most roof parts are shown in purple color (shading devices) instead of red color (roof).

```
10526 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim1984">
10575 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim1996">
10619 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2007">
10658 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2017">
10712 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2030">
10746 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2039">
10785 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2049">
10824 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2059">
10863 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2069">
10912 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2081">
10951 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2091">
10985 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2100">
11019 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2109">
11053 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2118">
11087 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2127">
11126 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2137">
11165 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2147">
11204 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2157">
11263 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2171">
11302 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2181">
11341 >     <Surface surfaceType="Shade" exposedToSun="true" id="aim2191">
```

Figure 60 - gbXML instance file from line 10526 to 11341

Intuitively, there are more “Shade” surface types than they should be in the gbXML instance file in Figure 60. In Revit, when room/volume settings are used, roof surface type is exported as “Shade” surface types instead of “Roof” surface types. Not only does this translation cause errors in OpenStudio simulation but the simulation result would also have significant differences from

"correct" building energy simulation. It is because if roof is switched to a shading device, there is a significant difference in radiation heat transfer, especially the amount of solar radiation.

As an example, two surfaces are examined how the surfaces are described in the gbXML instance file.

```
10526        <Surface surfaceType="Shade" exposedToSun="true" id="aim1984">
10527 >        <RectangularGeometry id="aim1985">
10538 >        <PlanarGeometry>
10572          <CADObjectId>Basic Wall: Generic - 6" [308900]</CADObjectId>
10573          <Name>X-S-92</Name>
10574        </Surface>
10575 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim1996">
10619 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2007">
10658 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2017">
10712 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2030">
10746 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2039">
10785 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2049">
10824 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2059">
10863 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2069">
10912 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2081">
10951 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2091">
10985 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2100">
11019 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2109">
11053 >      <Surface surfaceType="Shade" exposedToSun="true" id="aim2118">
11087        <Surface surfaceType="Shade" exposedToSun="true" id="aim2127">
11088 >        <RectangularGeometry id="aim2128">
11099 >        <PlanarGeometry>
11123          <CADObjectId>Basic Roof: Generic - 8" [309972]</CADObjectId>
11124          <Name>X-S-106</Name>
11125        </Surface>
```

Figure 61 - Roof part of the gbXML instance file

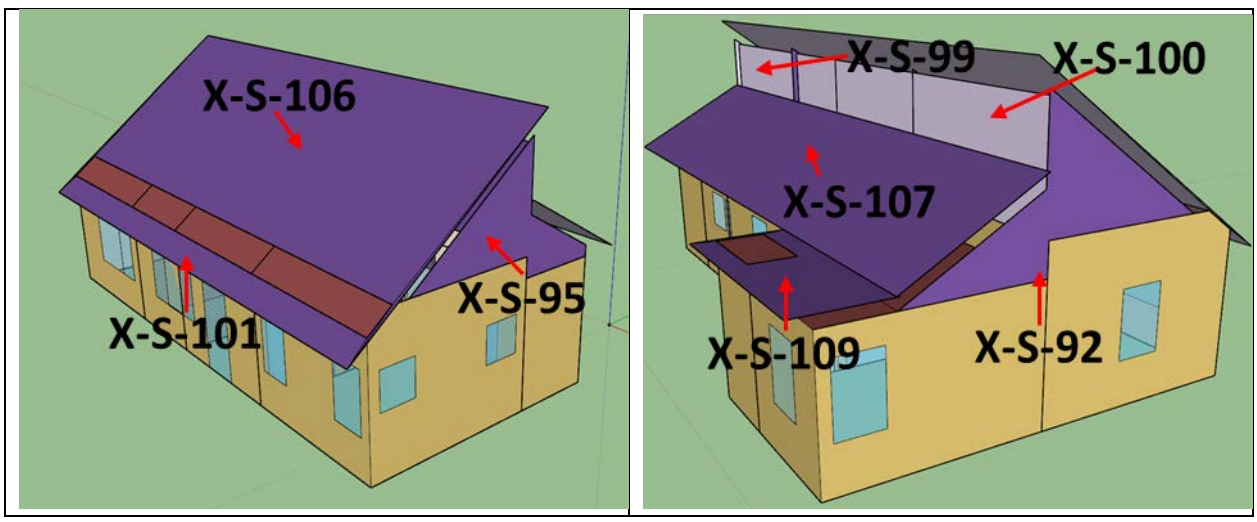


Figure 62 - The names of shade surfaces

In Figure 61 and Figure 62, X-S-(Number) represents surface name in the gbXML instance file. Figure 63 shows X-S-92 and X-S-106 (white-boxed) incorrectly illustrate the surface type as "Shade". In energy modeling perspective, X-S-106, X-S-107 and X-S-109 surfaces should have been translated into a "Roof" surface type in the gbXML file. Further, X-S-92, X-S-95, X-S-100

and X-S-99 should have been converted into “ExteriorWall” surface types in the gbXML file because the surfaces share the same construction type as the exterior wall type in the Revit instance file. However. Only X-S-101 surface was correctly translated in the OpenStudio model.

Besides, since there are some gaps between shade surface types, the second part in this section reports inaccurate coordinate points in the shade surfaces. For instance, in Figure 62, it is obvious there is a gap between X-S-92 and X-S-107, X-S-95 and X-S-106, X-S-95 and X-S-106. In this report, one example (surface X-S-92 and X-S-107) part is to be checked in the gbXML file.

```
10526      <Surface surfaceType="Shade" exposedToSun="true" id="aim1984">
10527        <RectangularGeometry id="aim1985">=
10538        <PlanarGeometry>
10539          <PolyLoop>
10540            <CartesianPoint>
10541              <Coordinate>-35.42215</Coordinate>
10542              <Coordinate>-23.26575</Coordinate>
10543              <Coordinate>10</Coordinate>
10544            </CartesianPoint>
10545            <CartesianPoint>
10546              <Coordinate>-35.42215</Coordinate>
10547              <Coordinate>-13.84909</Coordinate>
10548              <Coordinate>17.0625</Coordinate>
10549            </CartesianPoint>
10550            <CartesianPoint>
10551              <Coordinate>-35.42215</Coordinate>
10552              <Coordinate>-13.84909</Coordinate>
10553              <Coordinate>12.47222</Coordinate>
10554            </CartesianPoint>
10555            <CartesianPoint>
10556              <Coordinate>-35.42215</Coordinate>
10557              <Coordinate>-6.343136</Coordinate>
10558              <Coordinate>8.09375</Coordinate>
10559            </CartesianPoint>
10560            <CartesianPoint>
10561              <Coordinate>-35.42215</Coordinate>
10562              <Coordinate>-14.09909</Coordinate>
10563              <Coordinate>8.09375</Coordinate>
10564            </CartesianPoint>
10565            <CartesianPoint>
10566              <Coordinate>-35.42215</Coordinate>
10567              <Coordinate>-14.09909</Coordinate>
10568              <Coordinate>10</Coordinate>
10569            </CartesianPoint>
10570          </PolyLoop>
10571        </PlanarGeometry>
10572        <CADObjectId>Basic Wall: Generic - 6" [308900]</CADObjectId>
10573        <Name>X-S-92</Name>
10574      </Surface>
```

```
11126      <Surface surfaceType="Shade" exposedToSun="true" id="aim2137">
11127        <RectangularGeometry id="aim2138">=
11138        <PlanarGeometry>
11139          <PolyLoop>
11140            <CartesianPoint>
11141              <Coordinate>-35.67215</Coordinate>
11142              <Coordinate>-13.84909</Coordinate>
11143              <Coordinate>13.3405</Coordinate>
11144            </CartesianPoint>
11145            <CartesianPoint>
11146              <Coordinate>4.327851</Coordinate>
11147              <Coordinate>-13.84909</Coordinate>
11148              <Coordinate>13.3405</Coordinate>
11149            </CartesianPoint>
11150            <CartesianPoint>
11151              <Coordinate>4.327851</Coordinate>
11152              <Coordinate>-6.182422</Coordinate>
11153              <Coordinate>8.868278</Coordinate>
11154            </CartesianPoint>
11155            <CartesianPoint>
11156              <Coordinate>-35.67215</Coordinate>
11157              <Coordinate>-6.182422</Coordinate>
11158              <Coordinate>8.868278</Coordinate>
11159            </CartesianPoint>
11160          </PolyLoop>
11161        </PlanarGeometry>
11162        <CADObjectId>Basic Roof: Generic - 9" [310813]</CADObjectId>
11163        <Name>X-S-107</Name>
11164      </Surface>
```

Figure 63 - (Left) X-S-92 part in the gbXML file (Right) X-S-107 part in the gbXML file

In order for surface X-S-92 and X-S-107 to meet each other, they have to have at least two exact same coordinate points in the given geometry. However, in Figure 63, two surfaces, surface X-S-92 and X-S-107, do not share any coordinate points in the gbXML file. Thus, the surfaces have a gap between each other in the OpenStudio model.

10.3.2 Lost Slab-on-Grade

```
6073        <Surface surfaceType="InteriorFloor" id="aim0740">
6074          <AdjacentSpaceId spaceIdRef="aim0026" />
6075          <AdjacentSpaceId spaceIdRef="aim0026" />
6076          <RectangularGeometry id="aim0741">
6077            <Azimuth>0</Azimuth>
6078 >          <CartesianPoint>…
6083            <Tilt>180</Tilt>
6084            <Width>6.89583349227905</Width>
6085            <Height>12</Height>
6086          </RectangularGeometry>
6087          <PlanarGeometry>
6088            <PolyLoop>
6089              <CartesianPoint>
6090                <Coordinate>-24.50548</Coordinate>
6091                <Coordinate>-26.09909</Coordinate>
6092                <Coordinate>0</Coordinate>
6093              </CartesianPoint>
6094              <CartesianPoint>
6095                <Coordinate>-24.50548</Coordinate>
6096                <Coordinate>-14.09909</Coordinate>
6097                <Coordinate>0</Coordinate>
6098              </CartesianPoint>
6099              <CartesianPoint>
6100                <Coordinate>-17.60965</Coordinate>
6101                <Coordinate>-14.09909</Coordinate>
6102                <Coordinate>0</Coordinate>
6103              </CartesianPoint>
6104              <CartesianPoint>
6105                <Coordinate>-17.60965</Coordinate>
6106                <Coordinate>-26.09909</Coordinate>
6107                <Coordinate>0</Coordinate>
6108              </CartesianPoint>
6109            </PolyLoop>
6110          </PlanarGeometry>
6111          <CADObjectId>Floor: Generic - 4" [309868]</CADObjectId>
6112          <Name>B-1-1-I-F-9</Name>
6113        </Surface>
6114 >      <Surface surfaceType="Ceiling" id="aim0752">…
```

Figure 64 - Interior floor part in the gbXML

Even though there are ten “InteriorFloor” surface types in the gbXML file, none of them is shown in the OpenStudio model. It might be because OpenStudio has some problems reading “InteriorFloor” surface type. However, when energy settings are used, the “InteriorFloor” surface types are written into a “SlabOnGrade” surface type and the “SlabOnGrade” surface type are imported correctly in OpenStudio.

10.3.3 Space height misrepresentation

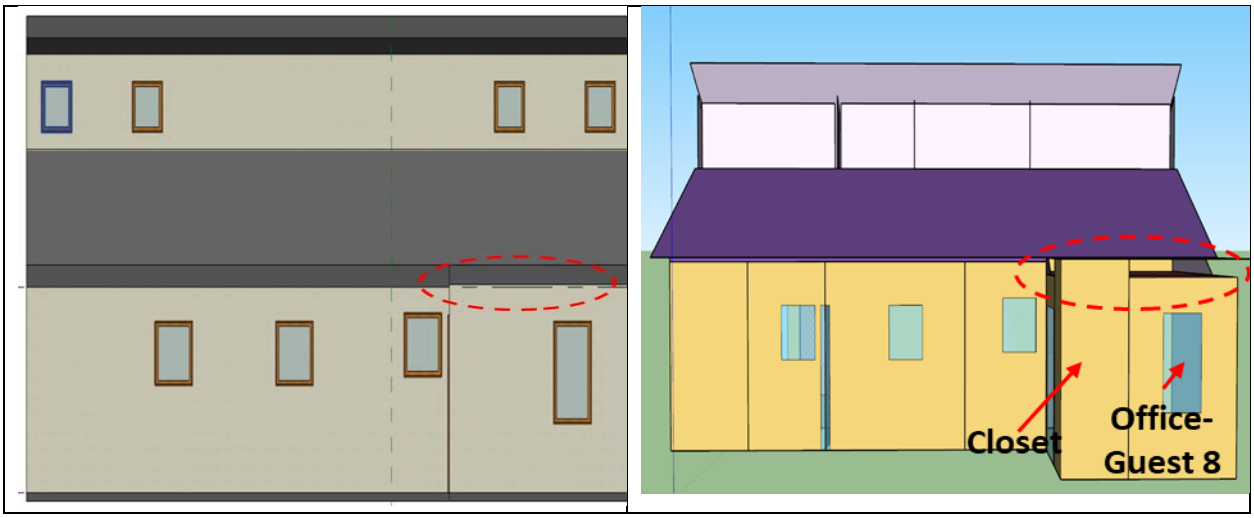
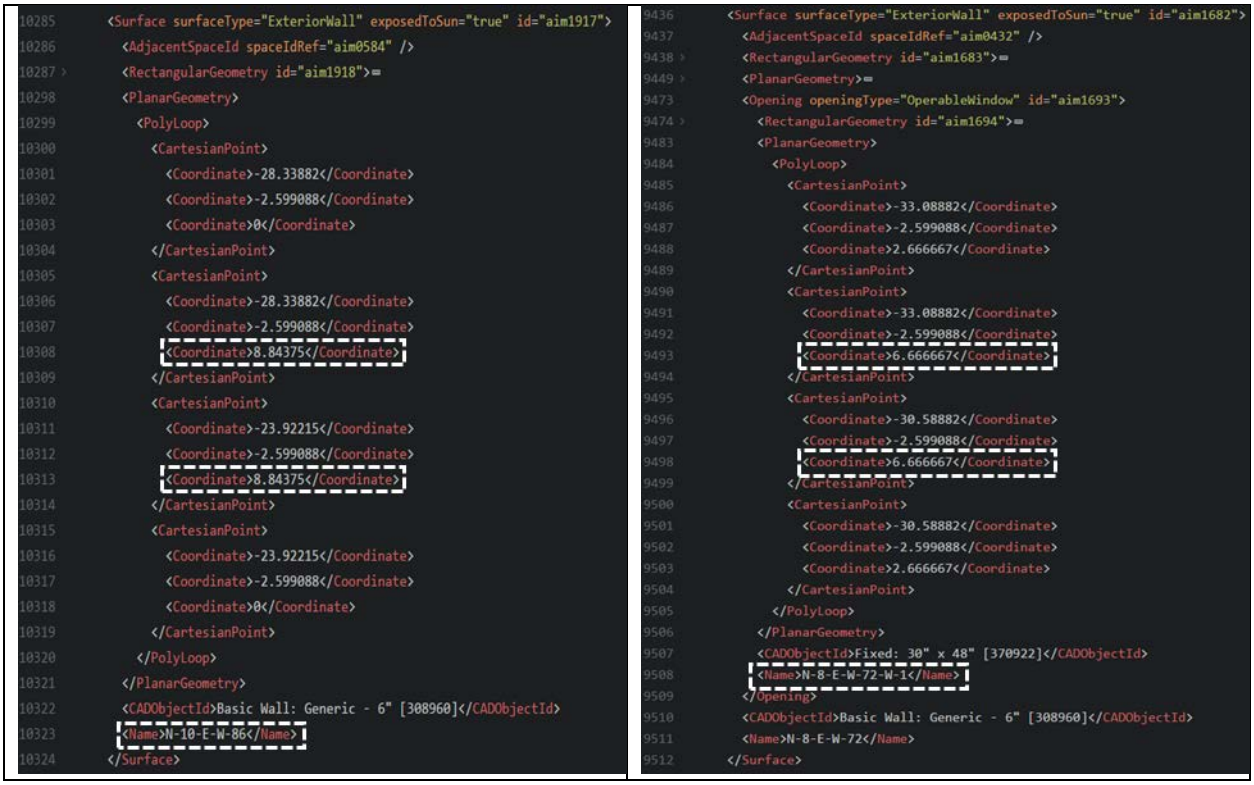


Figure 65 - (Left) North elevation view in Revit (Right) North elevation view in OpenStudio



```
10285    <Surface surfaceType="ExteriorWall" exposedToSun="true" id="aim1917">
10286      <AdjacentSpaceId spaceIdRef="aim0584" />
10287 ›    <RectangularGeometry id="aim1918">⊟
10298      <PlanarGeometry>
10299        <PolyLoop>
10300          <CartesianPoint>
10301            <Coordinate>-28.33882</Coordinate>
10302            <Coordinate>-2.599088</Coordinate>
10303            <Coordinate>0</Coordinate>
10304          </CartesianPoint>
10305          <CartesianPoint>
10306            <Coordinate>-28.33882</Coordinate>
10307            <Coordinate>-2.599088</Coordinate>
10308            <Coordinate>8.84375</Coordinate>
10309          </CartesianPoint>
10310          <CartesianPoint>
10311            <Coordinate>-23.92215</Coordinate>
10312            <Coordinate>-2.599088</Coordinate>
10313            <Coordinate>8.84375</Coordinate>
10314          </CartesianPoint>
10315          <CartesianPoint>
10316            <Coordinate>-23.92215</Coordinate>
10317            <Coordinate>-2.599088</Coordinate>
10318            <Coordinate>0</Coordinate>
10319          </CartesianPoint>
10320        </PolyLoop>
10321      </PlanarGeometry>
10322      <CADObjectId>Basic Wall: Generic - 6" [308960]</CADObjectId>
10323      <Name>N-10-E-W-86</Name>
10324    </Surface>
```

```
9436     <Surface surfaceType="ExteriorWall" exposedToSun="true" id="aim1682">
9437       <AdjacentSpaceId spaceIdRef="aim0432" />
9438 ›     <RectangularGeometry id="aim1683">⊟
9449 ›     <PlanarGeometry>⊟
9473       <Opening openingType="OperableWindow" id="aim1693">
9474 ›       <RectangularGeometry id="aim1694">⊟
9483         <PlanarGeometry>
9484           <PolyLoop>
9485             <CartesianPoint>
9486               <Coordinate>-33.08882</Coordinate>
9487               <Coordinate>-2.599088</Coordinate>
9488               <Coordinate>2.666667</Coordinate>
9489             </CartesianPoint>
9490             <CartesianPoint>
9491               <Coordinate>-33.08882</Coordinate>
9492               <Coordinate>-2.599088</Coordinate>
9493               <Coordinate>6.666667</Coordinate>
9494             </CartesianPoint>
9495             <CartesianPoint>
9496               <Coordinate>-30.58882</Coordinate>
9497               <Coordinate>-2.599088</Coordinate>
9498               <Coordinate>6.666667</Coordinate>
9499             </CartesianPoint>
9500             <CartesianPoint>
9501               <Coordinate>-30.58882</Coordinate>
9502               <Coordinate>-2.599088</Coordinate>
9503               <Coordinate>2.666667</Coordinate>
9504             </CartesianPoint>
9505           </PolyLoop>
9506         </PlanarGeometry>
9507         <CADObjectId>Fixed: 30" x 48" [370922]</CADObjectId>
9508         <Name>N-8-E-W-72-W-1</Name>
9509       </Opening>
9510       <CADObjectId>Basic Wall: Generic - 6" [308960]</CADObjectId>
9511       <Name>N-8-E-W-72</Name>
9512     </Surface>
```

Figure 66 - (Left) Closet part in the gbXML instance file (Right) Office-Guest 8 part in the gbXML instance file

When room/volume settings are used there is also an error in the closet space's height. It is because the gbXML file has two different heights (closet space: 8.84375 and Office-Guest: 6.666667).

10.4 Summary of Small House instance file

Table 4 - Summary of the Small House test

	Energy settings	Room/Volume Settings
Exterior	• Gaps between exterior/roof surfaces. • Windows not shown in the OpenStudio model. • Incorrect shading deveces' translation. • Space height misrepresentation	• Incorrect translation of roof and shading surfaces. • Lost slab-on-grade • Space height misrepresentation
Interior	• Gaps between floor spaces.	

11 System test 2: Urban House

11.1 Revit instance file – Urban House

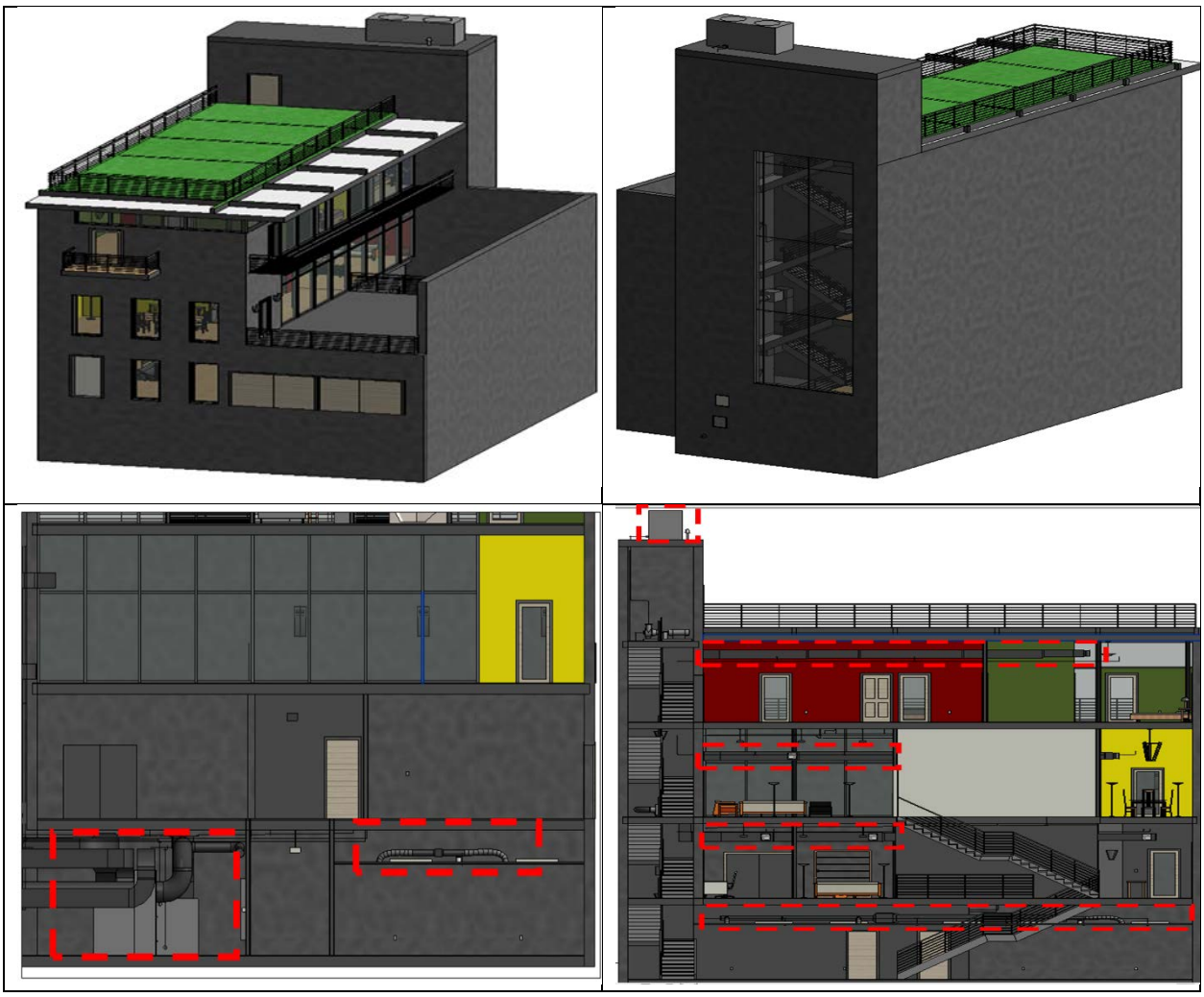


Figure 67 - Urban House Revit instance model

Urban House building is the three-story building with a basement. The Revit instance model is also equipped with HVAC systems (Air-source chiller, Air Handling Unit (AHU) and Variable Air Volume (VAV) air terminal system).

11.2 Urban House gbXML file generated from energy settings

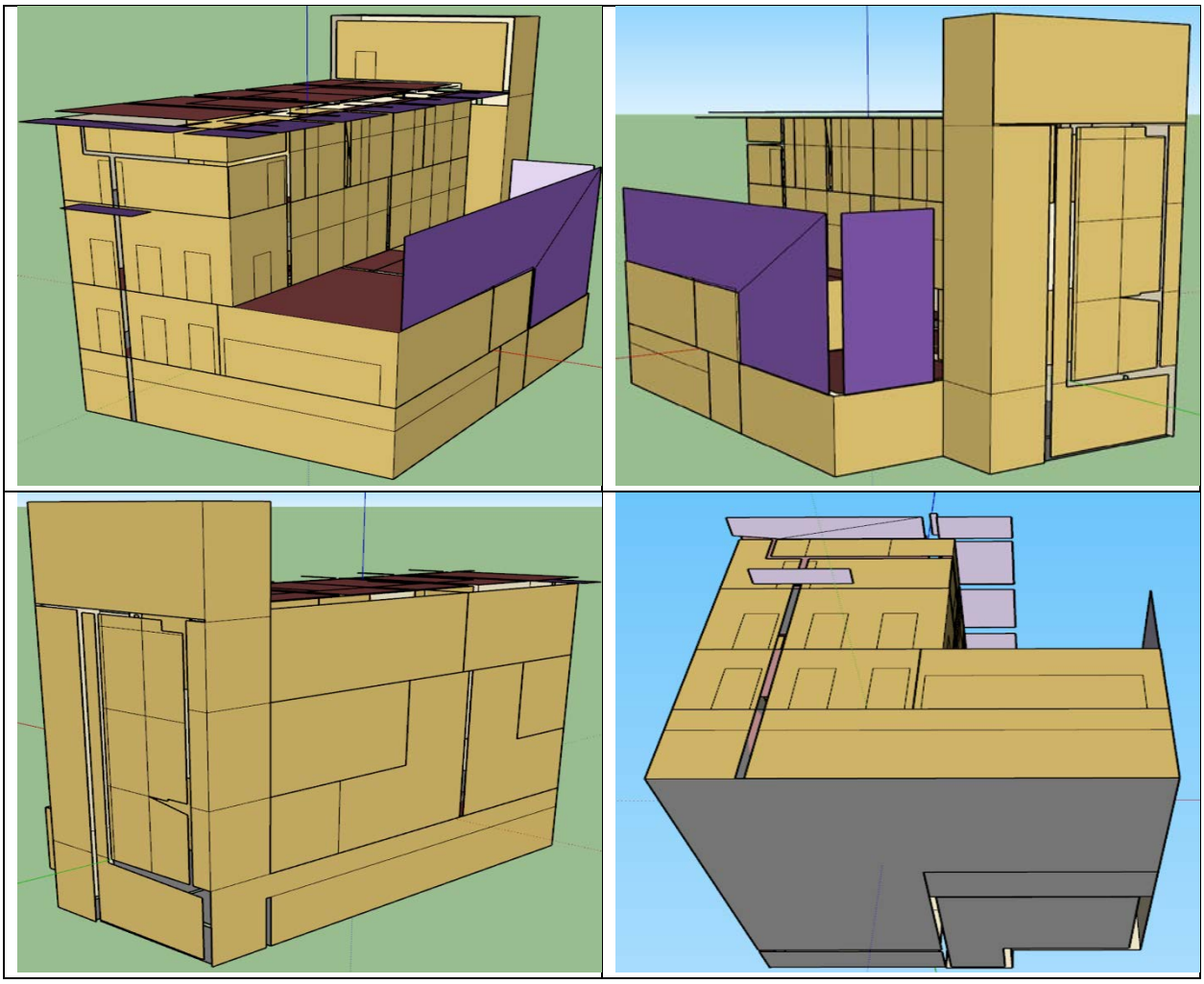


Figure 68 - Import result from energy settings (Exterior screenshots)

Figure 68 illustrates the import result in OpenStudio using energy settings in Revit. For the exterior part, there were issues identified with the translation:

• Gaps between exterior surfaces

• Gaps between roof surfaces

• All the windows are not shown in the OpenStudio model

• Loss of shading device accuracy

Furthermore, the Interior part will be investigated as well.

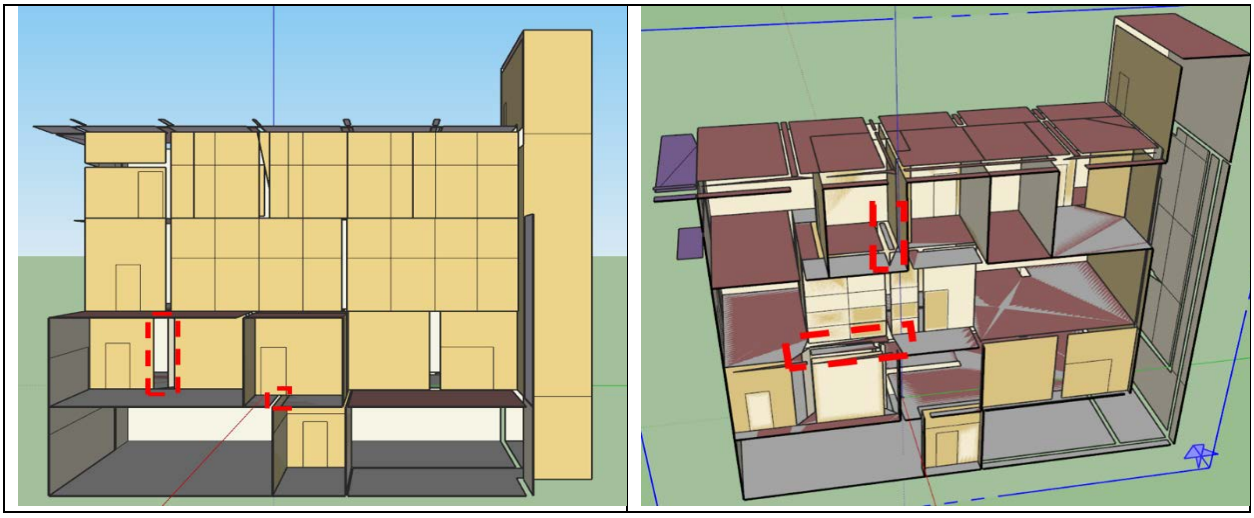


Figure 69 - Import results from energy settings (Interior)

For the interior part, there was an issue identified as follow:

• Gaps between floor surfaces

The following sections will inspect each bullet point.

11.2.1 Exterior investigation from the energy settings

11.2.1.1 Gaps between exterior surfaces

Figure 70 - Gaps in the exterior wall

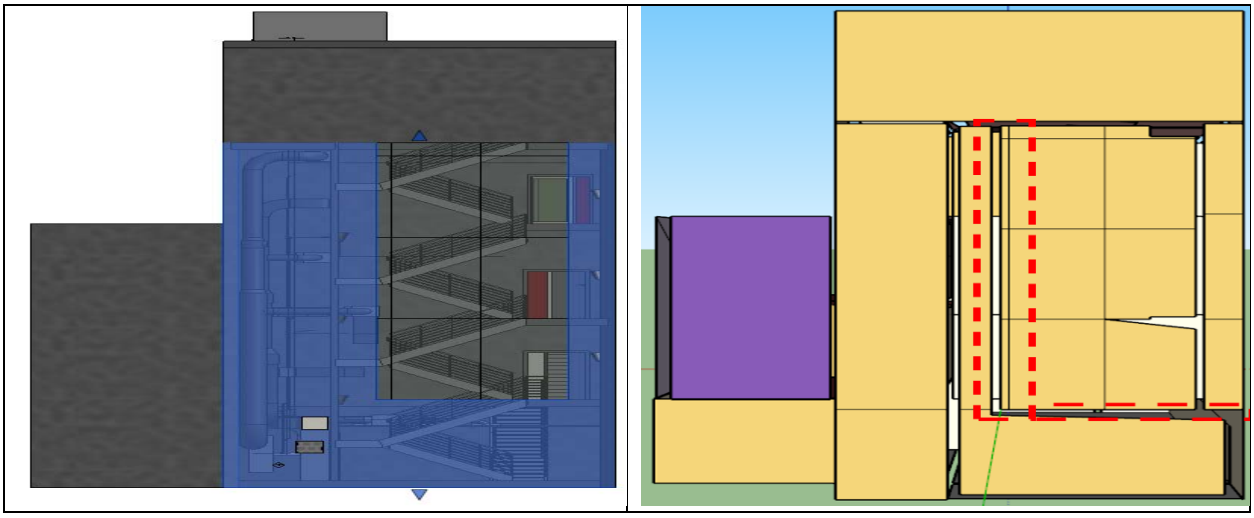


Figure 71 - The back side of Urban House model

Most gaps were found a boundary line between two exterior wall surfaces. For instance, in Figure 70 and Figure 71, the gaps were found where two exterior walls met. Also, in Figure 70, the gaps took place between the curtainwall and exterior wall surfaces. The reason why the gaps were found in the gbXML instance file will be specified. As an example, only the basement façade parts, which are surface “aim8529” and “aim0057” will be examined.

```
31596  <Surface surfaceType="UndergroundWall" constructionIdRef="construction-36" id="aim8529">
31597    <AdjacentSpaceId spaceIdRef="aim0014" surfaceType="UndergroundWall" />
31598    <RectangularGeometry id="aim16517">
31599      <Azimuth>180</Azimuth>
31600      <CartesianPoint>
31601        <Coordinate>-11.90566</Coordinate>
31602        <Coordinate>-22.43091</Coordinate>
31603        <Coordinate>-7.90625</Coordinate>
31604      </CartesianPoint>
31605      <Tilt>90</Tilt>
31606      <Width>6.5</Width>
31607      <Height>8.1875</Height>
31608    </RectangularGeometry>
31609    <PlanarGeometry>
31610      <PolyLoop>
31611        <CartesianPoint>
31612          <Coordinate>-15.15566</Coordinate>
31613          <Coordinate>-22.43091</Coordinate>
31614          <Coordinate>-12</Coordinate>
31615        </CartesianPoint>
31616        <CartesianPoint>
31617          <Coordinate>-8.655656</Coordinate>
31618          <Coordinate>-22.43091</Coordinate>
31619          <Coordinate>-12</Coordinate>
31620        </CartesianPoint>
31621        <CartesianPoint>
31622          <Coordinate>-8.655656</Coordinate>
31623          <Coordinate>-22.43091</Coordinate>
31624          <Coordinate>-3.8125</Coordinate>
31625        </CartesianPoint>
31626        <CartesianPoint>
31627          <Coordinate>-15.15566</Coordinate>
31628          <Coordinate>-22.43091</Coordinate>
31629          <Coordinate>-3.8125</Coordinate>
31630        </CartesianPoint>
31631      </PolyLoop>
31632    </PlanarGeometry>
31633    <CADObjectId>194</CADObjectId>
31634  </Surface>
```

```
20861  <Surface surfaceType="UndergroundWall" constructionIdRef="construction-36" id="aim0057">
20862    <AdjacentSpaceId spaceIdRef="aim0014" surfaceType="UndergroundWall" />
20863    <RectangularGeometry id="aim14762">
20864      <Azimuth>180</Azimuth>
20865      <CartesianPoint>
20866        <Coordinate>7.675977</Coordinate>
20867        <Coordinate>-22.43091</Coordinate>
20868        <Coordinate>-7.90625</Coordinate>
20869      </CartesianPoint>
20870      <Tilt>90</Tilt>
20871      <Width>31.33673</Width>
20872      <Height>8.1875</Height>
20873    </RectangularGeometry>
20874    <PlanarGeometry>
20875      <PolyLoop>
20876        <CartesianPoint>
20877          <Coordinate>-7.992391</Coordinate>
20878          <Coordinate>-22.43091</Coordinate>
20879          <Coordinate>-12</Coordinate>
20880        </CartesianPoint>
20881        <CartesianPoint>
20882          <Coordinate>23.34434</Coordinate>
20883          <Coordinate>-22.43091</Coordinate>
20884          <Coordinate>-12</Coordinate>
20885        </CartesianPoint>
20886        <CartesianPoint>
20887          <Coordinate>23.34434</Coordinate>
20888          <Coordinate>-22.43091</Coordinate>
20889          <Coordinate>-3.8125</Coordinate>
20890        </CartesianPoint>
20891        <CartesianPoint>
20892          <Coordinate>-7.992391</Coordinate>
20893          <Coordinate>-22.43091</Coordinate>
20894          <Coordinate>-3.8125</Coordinate>
20895        </CartesianPoint>
20896      </PolyLoop>
20897    </PlanarGeometry>
20898    <CADObjectId>1</CADObjectId>
20899  </Surface>
```

Figure 72 - The “aim8529” and “aim0057” surfaces in the gbXML instance file

It is obvious that the two surfaces, aim8529 and aim0057 in Figure 72, did not share two exact same cartesian points. The cartesian points (-8.655656, -22.43091, 12) and (8.655656, -22.43091, -3.8125) from the “aim8529” surface and the cartesian points (-7.992391, -22.43091, -12) and (7.992391, 22.43091, -3.8125) from the “aim0057” surface had slight differences.

11.2.1.2 Gaps between roof surfaces

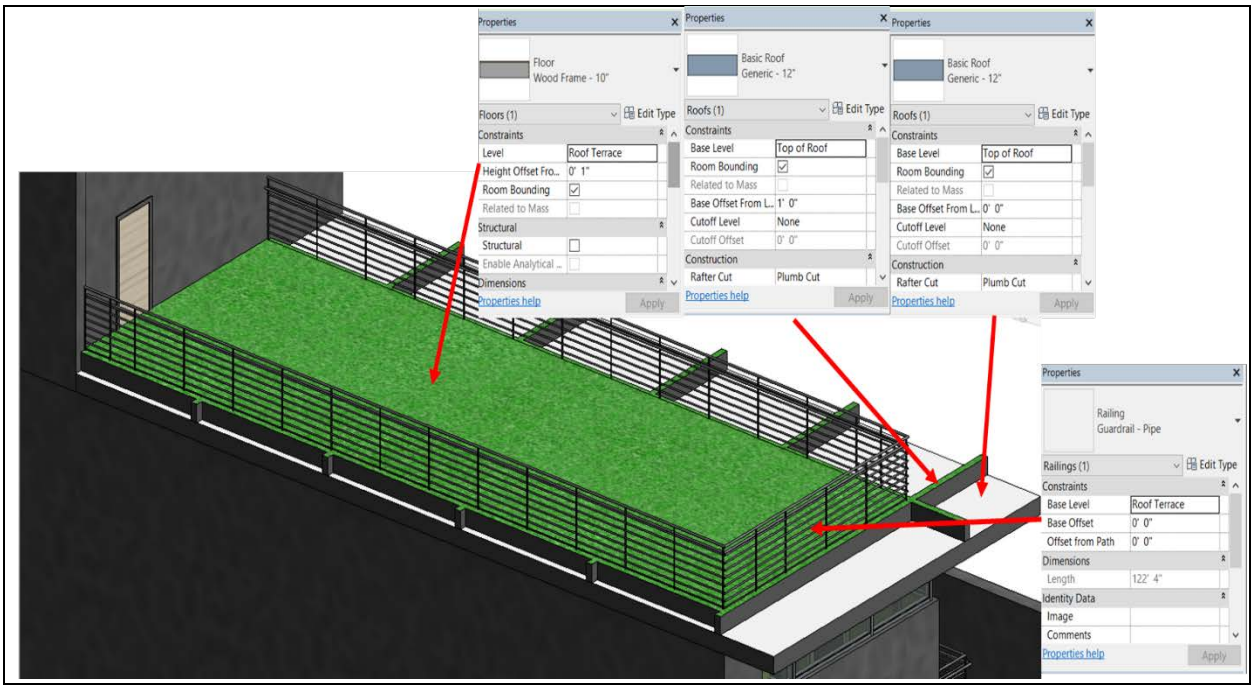


Figure 73 - Roof part in the Urban House

Before the gbXML instance file was examined, it was necessary to inspect how the Revit model was designed. In Figure 73, the roof parts consist of a series of different layers. For example, there is a basic roof layer on top of another basic roof. Further, the other floor surface is located on the roof surfaces. In terms of architectural perspective, it could make sense but in energy modeling perspective, it does not. This issue would cause significant issues of interoperability between the BIM and BEM.

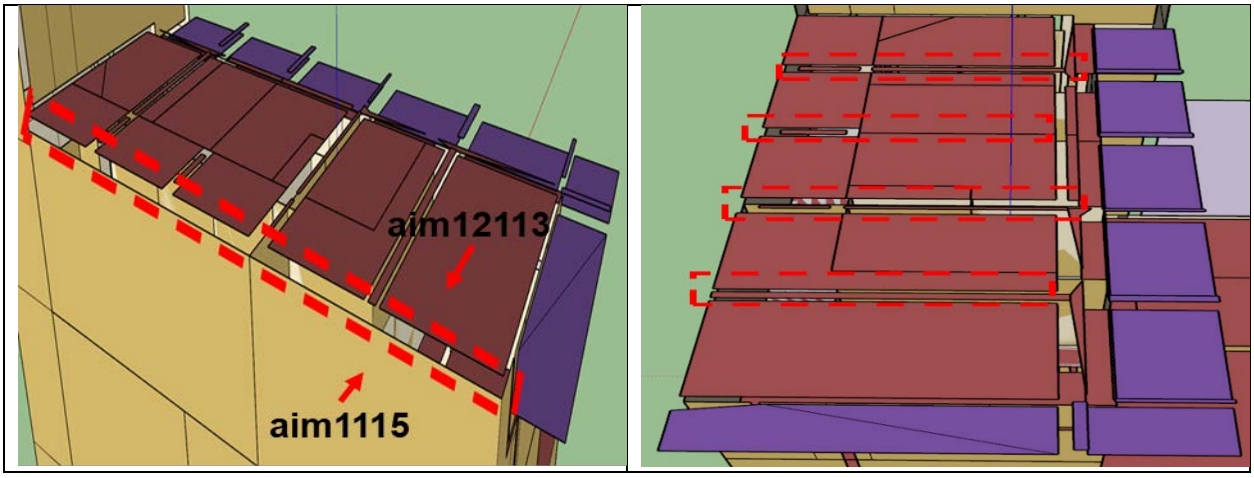


Figure 74 - OpenStudio model (roof)

```
22120    <Surface surfaceType="ExteriorWall" constructionIdRef="construction-70" exposedToSun="true" id="aim1115">
22121      <AdjacentSpaceId spaceIdRef="aim0553" surfaceType="ExteriorWall" />
22122      <RectangularGeometry id="aim14969">
22123        <Azimuth>270</Azimuth>
22124        <CartesianPoint>
22125          <Coordinate>-15.15566</Coordinate>
22126          <Coordinate>-11.16441</Coordinate>
22127          <Coordinate>32.5</Coordinate>
22128        </CartesianPoint>
22129        <Tilt>90</Tilt>
22130        <Width>22.533</Width>
22131        <Height>13</Height>
22132      </RectangularGeometry>
22133      <PlanarGeometry>
22134        <PolyLoop>
22135          <CartesianPoint>
22136            <Coordinate>-15.15566</Coordinate>
22137            <Coordinate>-22.43091</Coordinate>
22138            <Coordinate>26</Coordinate>
22139          </CartesianPoint>
22140          <CartesianPoint>
22141            <Coordinate>-15.15566</Coordinate>
22142            <Coordinate>-22.43091</Coordinate>
22143            <Coordinate>39</Coordinate>
22144          </CartesianPoint>
22145          <CartesianPoint>
22146            <Coordinate>-15.15566</Coordinate>
22147            <Coordinate>0.1020914</Coordinate>
22148            <Coordinate>39</Coordinate>
22149          </CartesianPoint>
22150          <CartesianPoint>
22151            <Coordinate>-15.15566</Coordinate>
22152            <Coordinate>0.1020914</Coordinate>
22153            <Coordinate>26</Coordinate>
22154          </CartesianPoint>
22155        </PolyLoop>
22156      </PlanarGeometry>
22157      <CADObjectId>24</CADObjectId>
22158    </Surface>
```

```
36264    <Surface surfaceType="Roof" constructionIdRef="construction-51" exposedToSun="true" id="aim12113">
36265      <AdjacentSpaceId spaceIdRef="aim0553" surfaceType="Roof" />
36266      <RectangularGeometry id="aim17273">
36267        <Azimuth>0</Azimuth>
36268        <CartesianPoint>
36269          <Coordinate>-6.296281</Coordinate>
36270          <Coordinate>-17.51948</Coordinate>
36271          <Coordinate>40.08333</Coordinate>
36272        </CartesianPoint>
36273        <Tilt>0</Tilt>
36274        <Width>17.71875</Width>
36275        <Height>9.822855</Height>
36276      </RectangularGeometry>
36277      <PlanarGeometry>
36278        <PolyLoop>
36279          <CartesianPoint>
36280            <Coordinate>-15.15566</Coordinate>
36281            <Coordinate>-22.43091</Coordinate>
36282            <Coordinate>40.08333</Coordinate>
36283          </CartesianPoint>
36284          <CartesianPoint>
36285            <Coordinate>2.563094</Coordinate>
36286            <Coordinate>-22.43091</Coordinate>
36287            <Coordinate>40.08333</Coordinate>
36288          </CartesianPoint>
36289          <CartesianPoint>
36290            <Coordinate>2.563094</Coordinate>
36291            <Coordinate>-12.60805</Coordinate>
36292            <Coordinate>40.08333</Coordinate>
36293          </CartesianPoint>
36294          <CartesianPoint>
36295            <Coordinate>-15.15566</Coordinate>
36296            <Coordinate>-12.60805</Coordinate>
36297            <Coordinate>40.08333</Coordinate>
36298          </CartesianPoint>
36299        </PolyLoop>
36300      </PlanarGeometry>
36301      <CADObjectId>274</CADObjectId>
36302    </Surface>
```

Figure 75 - (Left) The “aim1115” surface part in Figure 72 (Right) The “aim12113” surface part in Figure 72

Similar to the previous part, the two surfaces, the “aim1115” and “aim 12113” surfaces in Figure 75, were inspected. As shown in Figure 32, the two cartesian points from the “aim1115” ((-15.15566, -22.43091, 39), (-15.15566, 0.1020914, 39)) surface and the two cartesian points from the “aim12113” ((-15.15566, -22.43091, 40.08333), (-15.15566, 12.60805, 40.08333)) do not have same cartesian points.

11.2.1.3 Lost windows in the OpenStudio Model

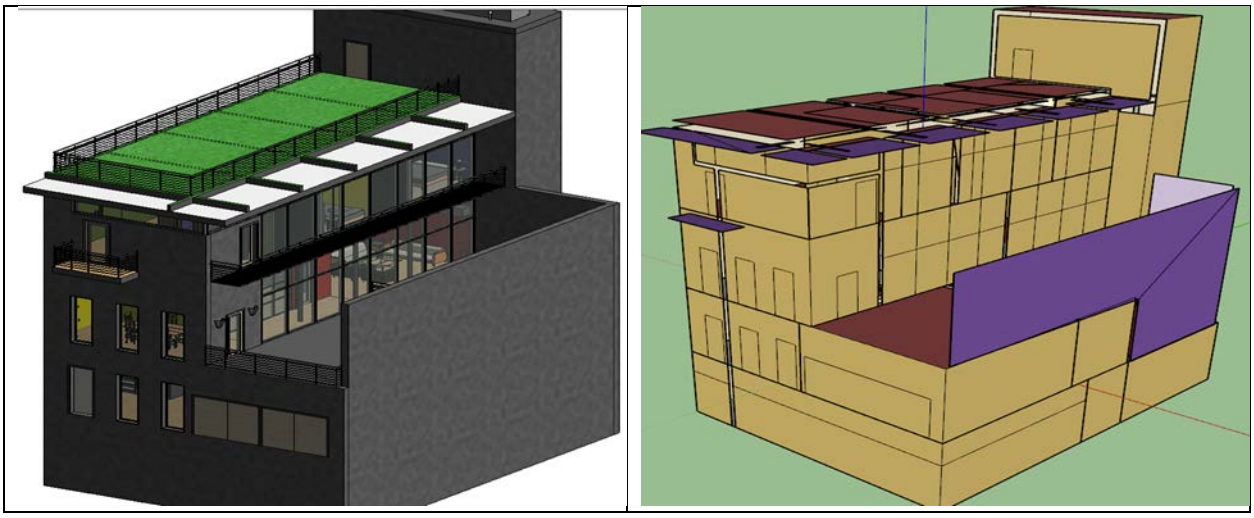
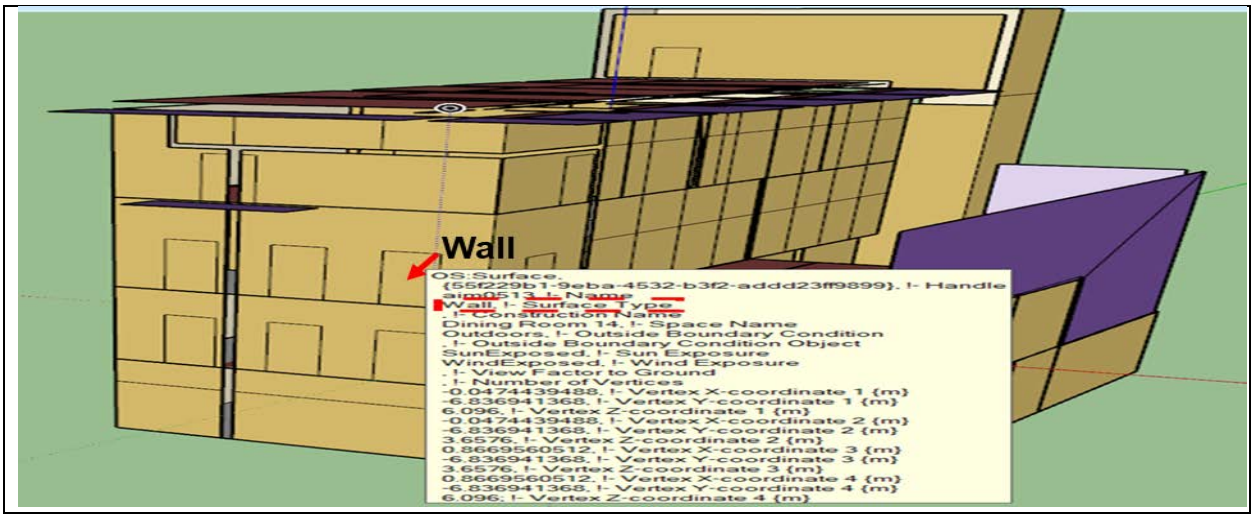


Figure 76 - (Left) Axon view in Revit (Right) Axon view in OpenStudio

Ignoring window translation would have a huge impact on heating/cooling and electrical energy consumption results because U-Value of window is relatively greater than the U-Values of opaque wall and roof. In other words, windows cause more conduction heat transfers than opaque walls and roofs.



```
21460    <Surface surfaceType="ExteriorWall" exposedToSun="true" id="aim0513">
21461      <AdjacentSpaceId spaceIdRef="aim0381" surfaceType="ExteriorWall" />
21462      <RectangularGeometry id="aim14843">
21463        <Azimuth>180</Azimuth>
21464        <CartesianPoint>
21465          <Coordinate>1.344344</Coordinate>
21466          <Coordinate>-22.43091</Coordinate>
21467          <Coordinate>16</Coordinate>
21468        </CartesianPoint>
21469        <Tilt>90</Tilt>
21470        <Width>3</Width>
21471        <Height>8</Height>
21472      </RectangularGeometry>
21473      <PlanarGeometry> ...
21496      </PlanarGeometry>
21497      <Opening interiorShadeType="Operable" exteriorShadeType="Fixed" windowTypeIdRef="PwindowType-158" openingType="OperableWindow" id="aim0536">
21498        <RectangularGeometry id="aim0544">
21499          <Azimuth>180</Azimuth>
21500          <CartesianPoint>
21501            <Coordinate>1.344344</Coordinate>
21502            <Coordinate>-22.43091</Coordinate>
21503            <Coordinate>16</Coordinate>
21504          </CartesianPoint>
21505          <Tilt>90</Tilt>
21506          <Width>2.97</Width>
21507          <Height>7.92</Height>
21508        </RectangularGeometry>
21509        <PlanarGeometry>
21510          <PolyLoop> ...
21531          </PolyLoop>
21532        </PlanarGeometry>
21533      </Opening>
21534      <CADObjectId>10</CADObjectId>
21535    </Surface>
```

Figure 77 - (Top) OpenStudio model import result (Bottom) One example of opening surface in the gbXML instance file

In Figure 77, it is shown opening element is a child element of the “ExteriorWall” surface type. For the opening parts, it is suspected OpenStudio might read the “ExteriorWall” element instead of “Opening” element for openings.

11.2.2 Interior investigation of energy settings

11.2.2.1 Gaps between floor surfaces

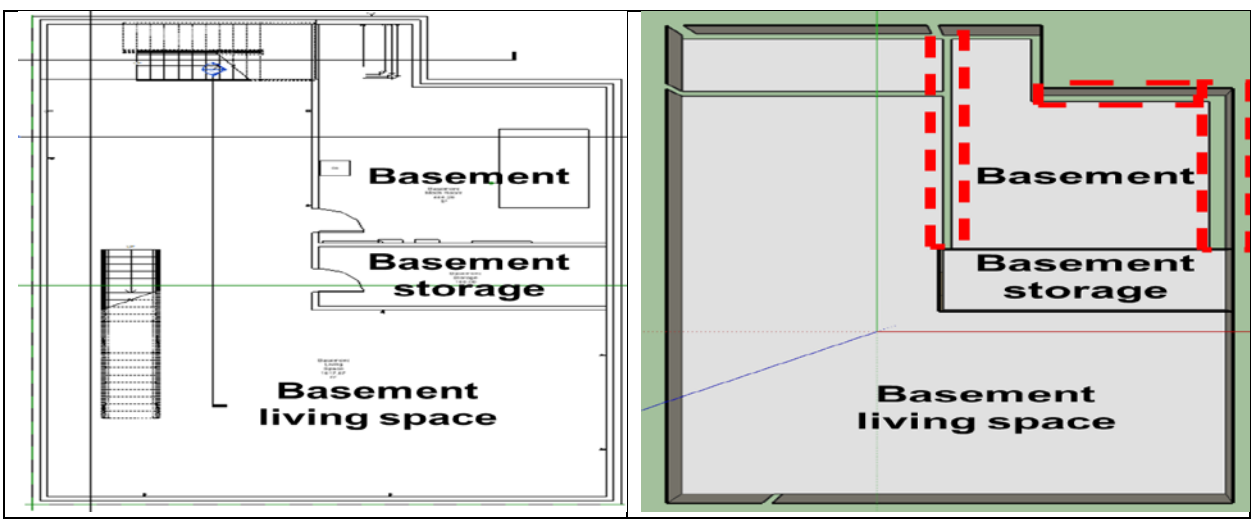


Figure 78 - (Left) Basement floor plan in Revit (Right) Basement floor plan in OpenStudio

```
32991   <Surface surfaceType="UndergroundSlab" constructionIdRef="construction-23" id="aim9640">
32992     <AdjacentSpaceId spaceIdRef="aim0014" surfaceType="UndergroundSlab" />
32993     <RectangularGeometry id="aim16724">
32994       <Azimuth>0</Azimuth>
32995       <CartesianPoint>
32996         <Coordinate>11.89302</Coordinate>
32997         <Coordinate>26.02489</Coordinate>
32998         <Coordinate>-12</Coordinate>
32999       </CartesianPoint>
33000       <Tilt>180</Tilt>
33001       <Width>16.26775</Width>
33002       <Height>24.81784</Height>
33003     </RectangularGeometry>
33004     <PlanarGeometry>
33005       <PolyLoop>
33006         <CartesianPoint>
33007         <Coordinate>3.928415</Coordinate>
33008         <Coordinate>10.22379</Coordinate>
33009         <Coordinate>-12</Coordinate>
33010         </CartesianPoint>
33011         <CartesianPoint>
33012         <Coordinate>3.928415</Coordinate>
33013         <Coordinate>38.06909</Coordinate>
33014         <Coordinate>-12</Coordinate>
33015         </CartesianPoint>
33016         <CartesianPoint>
33017         <Coordinate>9.570007</Coordinate>
33018         <Coordinate>38.06909</Coordinate>
33019         <Coordinate>-12</Coordinate>
33020         </CartesianPoint>
33021         <CartesianPoint>
33022         <Coordinate>9.570007</Coordinate>
33023         <Coordinate>29.7818</Coordinate>
33024         <Coordinate>-12</Coordinate>
33025         </CartesianPoint>
33026         <CartesianPoint>
33027         <Coordinate>22.18063</Coordinate>
33028         <Coordinate>29.7818</Coordinate>
33029         <Coordinate>-12</Coordinate>
33030         </CartesianPoint>
33031         <CartesianPoint>
33032         <Coordinate>22.18063</Coordinate>
33033         <Coordinate>10.22379</Coordinate>
33034         <Coordinate>-12</Coordinate>
33035         </CartesianPoint>
33036       </PolyLoop>
33037     </PlanarGeometry>
33038     <CADObjectId>217</CADObjectId>
33039   </Surface>
```

```
33128   <Surface surfaceType="UndergroundSlab" constructionIdRef="construction-23" id="aim9759">
33129     <AdjacentSpaceId spaceIdRef="aim1508" surfaceType="UndergroundSlab" />
33130     <RectangularGeometry id="aim16751">
33131       <Azimuth>0</Azimuth>
33132       <CartesianPoint>
33133         <Coordinate>13.34434</Coordinate>
33134         <Coordinate>6.027427</Coordinate>
33135         <Coordinate>-12</Coordinate>
33136       </CartesianPoint>
33137       <Tilt>180</Tilt>
33138       <Width>20</Width>
33139       <Height>8</Height>
33140     </RectangularGeometry>
33141     <PlanarGeometry>
33142       <PolyLoop>
33143         <CartesianPoint>
33144         <Coordinate>3.344344</Coordinate>
33145         <Coordinate>2.027427</Coordinate>
33146         <Coordinate>-12</Coordinate>
33147         </CartesianPoint>
33148         <CartesianPoint>
33149         <Coordinate>3.344344</Coordinate>
33150         <Coordinate>10.02743</Coordinate>
33151         <Coordinate>-12</Coordinate>
33152         </CartesianPoint>
33153         <CartesianPoint>
33154         <Coordinate>23.34434</Coordinate>
33155         <Coordinate>10.02743</Coordinate>
33156         <Coordinate>-12</Coordinate>
33157         </CartesianPoint>
33158         <CartesianPoint>
33159         <Coordinate>23.34434</Coordinate>
33160         <Coordinate>2.027427</Coordinate>
33161         <Coordinate>-12</Coordinate>
33162         </CartesianPoint>
33163       </PolyLoop>
33164     </PlanarGeometry>
33165     <CADObjectId>220</CADObjectId>
33166   </Surface>
```

Figure 79 - (Left) Basement's slab-on-grade surface (Right) Basement storage's slab-on-grade surface

In the left of Figure 78, three spaces (Basement, Basement storage, Basement living space) in the Revit model are seamlessly closed. However, in the OpenStudio Model, some gaps were found between the floor plans. Figure 79 describes the basement's slab-on-grade surface and basement storage's slab-on-grade surface. It can be found that the two cartesian points from each surface do not share the same cartesian points.

In addition, some gaps were also found on the 3rd and 4th interior floors.

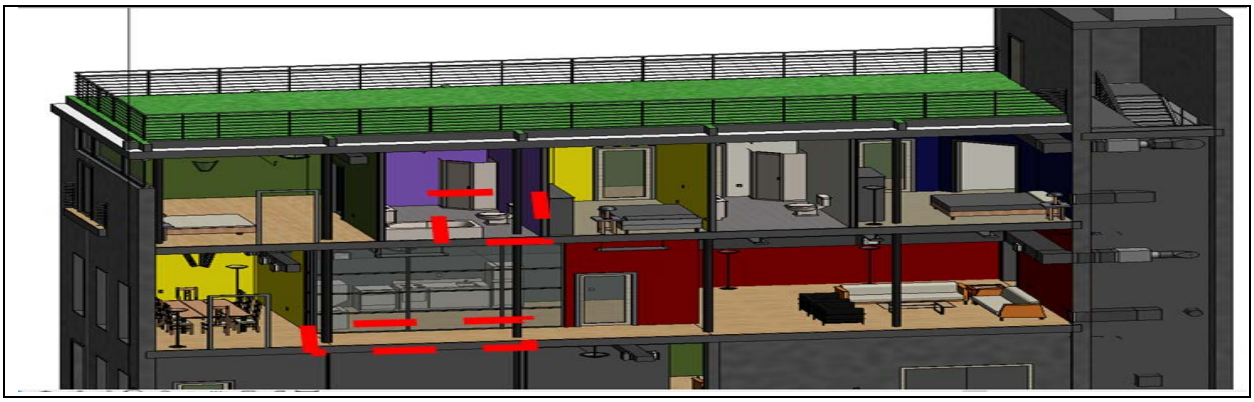


Figure 80 - Section views in Revit

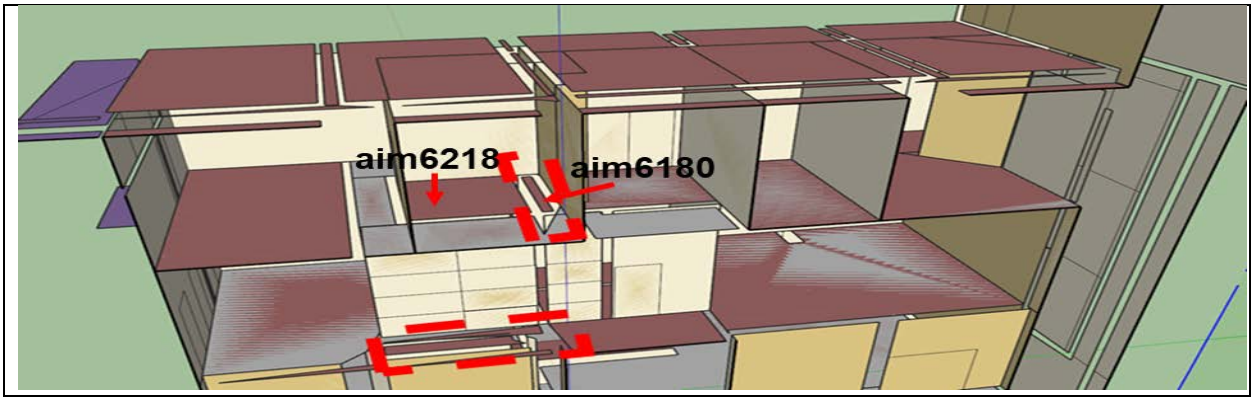


Figure 81 - Section view in OpenStudio

Figure 81 shows that some misrepresentations occurred on the interior surfaces.

```
28780 ▼   <Surface surfaceType="InteriorFloor" constructionIdRef="construction-23" id="aim6218">
28781       <AdjacentSpaceId spaceIdRef="aim2625" surfaceType="Ceiling" />
28782       <AdjacentSpaceId spaceIdRef="aim4022" surfaceType="InteriorFloor" />
28783 ▼     <RectangularGeometry id="aim15950">
28784         <Azimuth>0</Azimuth>
28785 ▼       <CartesianPoint>
28786           <Coordinate>-5.032643</Coordinate>
28787           <Coordinate>-5.482098</Coordinate>
28788           <Coordinate>26</Coordinate>
28789         </CartesianPoint>
28790         <Tilt>180</Tilt>
28791         <Width>8.433142</Width>
28792         <Height>7.308567</Height>
28793       </RectangularGeometry>
28794 ▼     <PlanarGeometry>
28795 ▼       <PolyLoop>
28796 ▼         <CartesianPoint>
28797             <Coordinate>-9.249214</Coordinate>
28798             <Coordinate>-9.136381</Coordinate>
28799             <Coordinate>26</Coordinate>
28800           </CartesianPoint>
28801 ▼         <CartesianPoint>
28802             <Coordinate>-9.249214</Coordinate>
28803             <Coordinate>-1.827814</Coordinate>
28804             <Coordinate>26</Coordinate>
28805           </CartesianPoint>
28806 ▼         <CartesianPoint>
28807             <Coordinate>-0.8160727</Coordinate>
28808             <Coordinate>-1.827814</Coordinate>
28809             <Coordinate>26</Coordinate>
28810           </CartesianPoint>
28811 ▼         <CartesianPoint>
28812             <Coordinate>-0.8160727</Coordinate>
28813             <Coordinate>-9.136381</Coordinate>
28814             <Coordinate>26</Coordinate>
28815           </CartesianPoint>
28816         </PolyLoop>
28817       </PlanarGeometry>
28818       <CADObjectId>132</CADObjectId>
28819     </Surface>
```

```
28740     <Surface surfaceType="InteriorFloor" constructionIdRef="construction-23" id="aim6180">
28741       <AdjacentSpaceId spaceIdRef="aim2508" surfaceType="Ceiling" />
28742       <AdjacentSpaceId spaceIdRef="aim4022" surfaceType="InteriorFloor" />
28743       <RectangularGeometry id="aim15941">
28744         <Azimuth>0</Azimuth>
28745         <CartesianPoint>
28746           <Coordinate>-4.770239</Coordinate>
28747           <Coordinate>-0.8303912</Coordinate>
28748           <Coordinate>26</Coordinate>
28749         </CartesianPoint>
28750         <Tilt>180</Tilt>
28751         <Width>7.908334</Width>
28752         <Height>0.6649484</Height>
28753       </RectangularGeometry>
28754       <PlanarGeometry>
28755         <PolyLoop>
28756           <CartesianPoint>
28757             <Coordinate>-8.724406</Coordinate>
28758             <Coordinate>-1.162865</Coordinate>
28759             <Coordinate>26</Coordinate>
28760           </CartesianPoint>
28761           <CartesianPoint>
28762             <Coordinate>-8.724406</Coordinate>
28763             <Coordinate>-0.497917</Coordinate>
28764             <Coordinate>26</Coordinate>
28765           </CartesianPoint>
28766           <CartesianPoint>
28767             <Coordinate>-0.8160727</Coordinate>
28768             <Coordinate>-0.497917</Coordinate>
28769             <Coordinate>26</Coordinate>
28770           </CartesianPoint>
28771           <CartesianPoint>
28772             <Coordinate>-0.8160727</Coordinate>
28773             <Coordinate>-1.162865</Coordinate>
28774             <Coordinate>26</Coordinate>
28775           </CartesianPoint>
28776         </PolyLoop>
28777       </PlanarGeometry>
28778       <CADObjectId>131</CADObjectId>
28779     </Surface>
```

Figure 82 - (Left) The “aim6218” surface in gbXML (Right) The “aim6180” surface in gbXML

Similar to the previous sections, the main reason why the misrepresentation took place was the cartesian points did not have same points.

11.3 Urban House gbXML file generated from Room/Volume settings import result

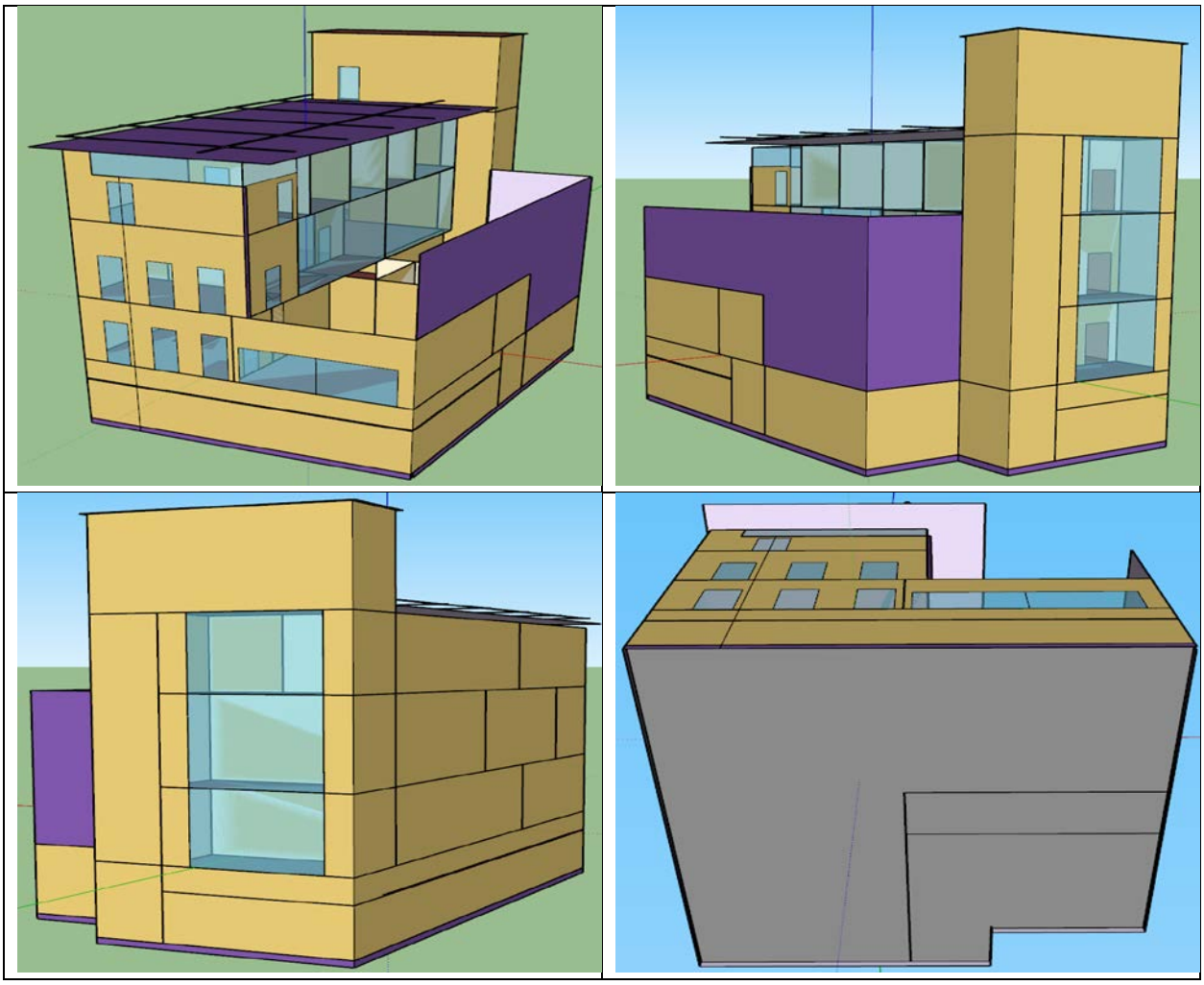


Figure 83 - Room/Volume settings import result (Exterior)

Figure 83 illustrates the import results in OpenStudio using Room/Volume settings in Revit. Despite the fact that most parts were imports correctly, there are a few issues:

• Missing roof surface

• Loss of shading device dimensional accuracy

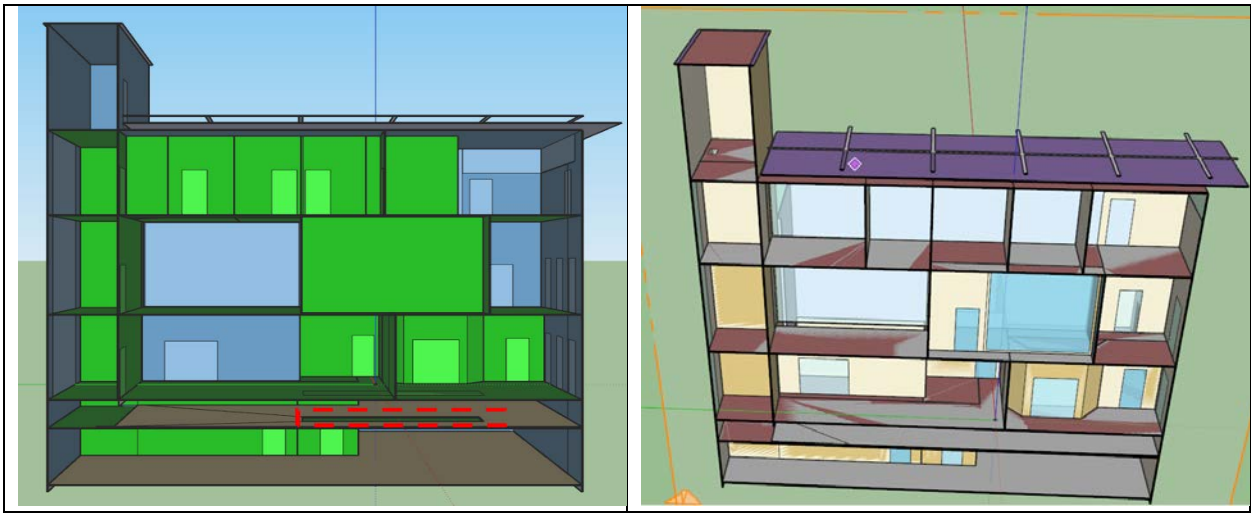


Figure 84 - Room/Volume settings import result (Interior)

For the interior part, the following issues were identified:

• One same surface was translated into two different surfaces

Thus, the following sections will inspect each bullet point mentioned above.

11.3.1 Exterior investigation of Room/Volume settings

11.3.1.1 Lost roof surface

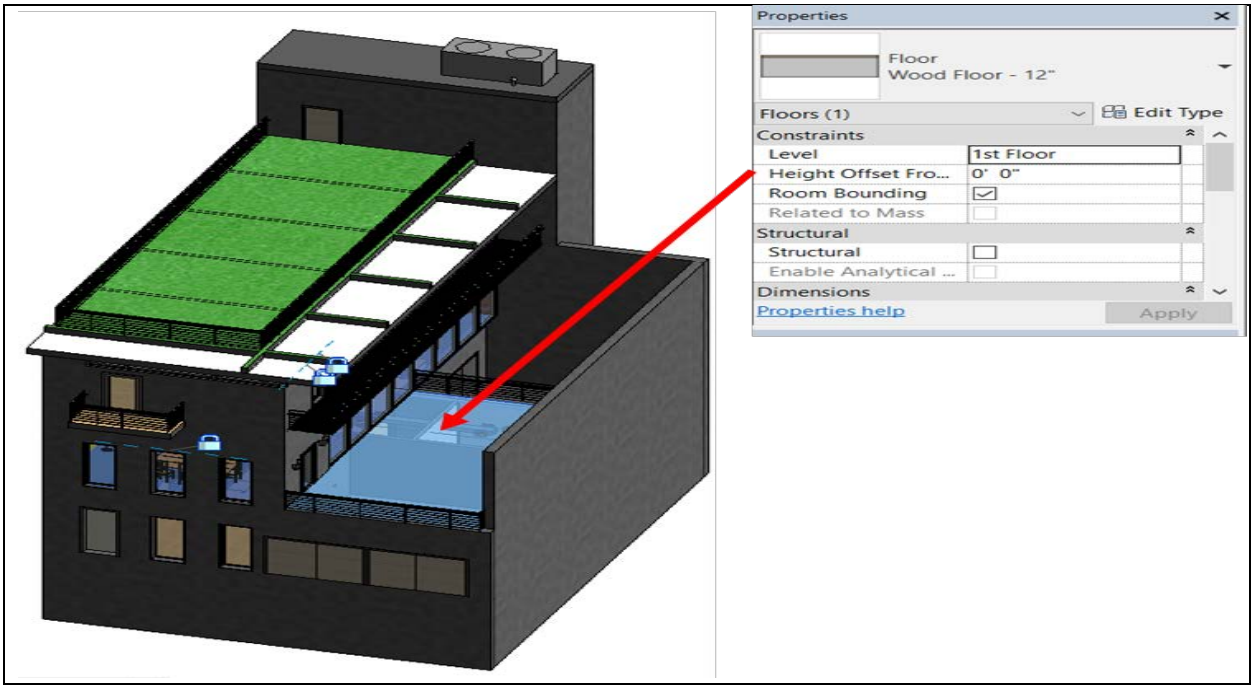


Figure 85 - Axon view of the Urban House

As shown in Figure 85, the floor from the west part of the building is extended to the east part. Thus, the Revit model does not recognize the “roof” surface as actual “roof” surface. Instead, the roof surface is recognized as the floor surface in Revit. This could be the reason that the roof surface is lost.

11.3.1.2 Incorrect shading devices’ translation

11.3.1.2.1 Roof shading mistranslation

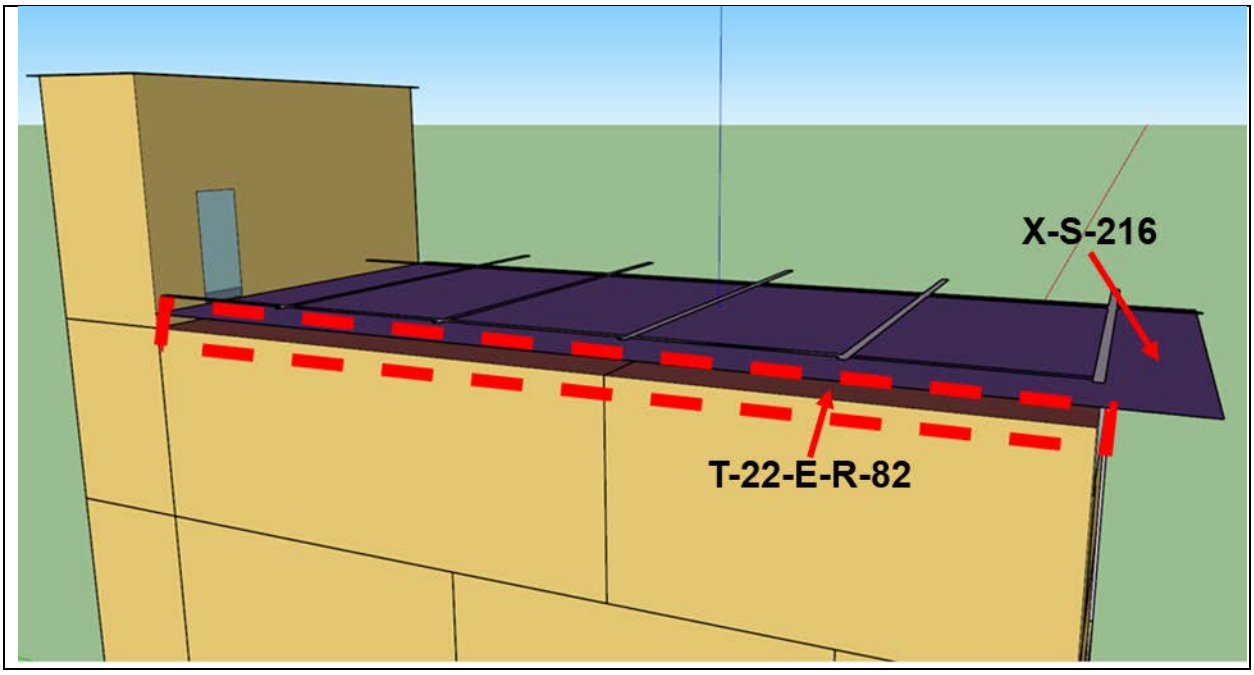


Figure 86 - Roof in OpenStudio

First of all, as shown in Figure 86, there were some gaps found. To find the reason, two surfaces, one roof surface (T-22-E-R-82) and shading device (X-S-216) will be checked.

```
21260    <Surface surfaceType="Roof" exposedToSun="true" id="aim3297">
21261      <AdjacentSpaceId spaceIdRef="aim0672" />
21262      <RectangularGeometry id="aim3298">
21263        <Azimuth>180</Azimuth>
21264        <CartesianPoint> ...
21268        </CartesianPoint>
21269        <Tilt>0</Tilt>
21270        <Width>20.5</Width>
21271        <Height>15.9563064575195</Height>
21272      </RectangularGeometry>
21273      <PlanarGeometry>
21274        <PolyLoop>
21275          <CartesianPoint>
21276            <Coordinate>-15.15566</Coordinate>
21277            <Coordinate>-22.43091</Coordinate>
21278            <Coordinate>38</Coordinate>
21279          </CartesianPoint>
21280          <CartesianPoint>
21281            <Coordinate>5.344344</Coordinate>
21282            <Coordinate>-22.43091</Coordinate>
21283            <Coordinate>38</Coordinate>
21284          </CartesianPoint>
21285          <CartesianPoint>
21286            <Coordinate>5.344344</Coordinate>
21287            <Coordinate>-9.136381</Coordinate>
21288            <Coordinate>38</Coordinate>
21289          </CartesianPoint>
21290          <CartesianPoint>
21291            <Coordinate>-9.249214</Coordinate>
21292            <Coordinate>-9.136381</Coordinate>
21293            <Coordinate>38</Coordinate>
21294          </CartesianPoint>
21295          <CartesianPoint>
21296            <Coordinate>-9.249214</Coordinate>
21297            <Coordinate>0.1020914</Coordinate>
21298            <Coordinate>38</Coordinate>
21299          </CartesianPoint>
21300          <CartesianPoint>
21301            <Coordinate>-15.15566</Coordinate>
21302            <Coordinate>0.1020914</Coordinate>
21303            <Coordinate>38</Coordinate>
21304          </CartesianPoint>
21305        </PolyLoop>
21306      </PlanarGeometry>
21307      <CADObjectId>Basic Roof: Generic - 12" [64124]</CADObjectId>
21308      <Name>T-22-E-R-82</Name>
21309    </Surface>
```

```
27665    <Surface surfaceType="Shade" exposedToSun="true" id="aim5092">
27666      <RectangularGeometry id="aim5093">
27667        <Azimuth>180</Azimuth>
27668        <CartesianPoint>
27669          <Coordinate>-15.65566</Coordinate>
27670          <Coordinate>-26.93091</Coordinate>
27671          <Coordinate>39</Coordinate>
27672        </CartesianPoint>
27673        <Tilt>0</Tilt>
27674        <Width>26.5</Width>
27675        <Height>56.9583320617676</Height>
27676      </RectangularGeometry>
27677      <PlanarGeometry>
27678        <PolyLoop>
27679          <CartesianPoint>
27680            <Coordinate>-15.65566</Coordinate>
27681            <Coordinate>-26.93091</Coordinate>
27682            <Coordinate>39</Coordinate>
27683          </CartesianPoint>
27684          <CartesianPoint>
27685            <Coordinate>10.84434</Coordinate>
27686            <Coordinate>-26.93091</Coordinate>
27687            <Coordinate>39</Coordinate>
27688          </CartesianPoint>
27689          <CartesianPoint>
27690            <Coordinate>10.84434</Coordinate>
27691            <Coordinate>30.02743</Coordinate>
27692            <Coordinate>39</Coordinate>
27693          </CartesianPoint>
27694          <CartesianPoint>
27695            <Coordinate>-15.65566</Coordinate>
27696            <Coordinate>30.02743</Coordinate>
27697            <Coordinate>39</Coordinate>
27698          </CartesianPoint>
27699        </PolyLoop>
27700      </PlanarGeometry>
27701      <CADObjectId>Basic Roof: Generic - 12" [64124]</CADObjectId>
27702      <Name>X-S-216</Name>
27703    </Surface>
```


Figure 87 - (Left) Roof surface (T-22-E-R-82) (Right) shading device (X-S-216)

From Figure 87, there is 1-foot height difference between the roof surface and shading device surface.

11.3.1.2.2 Basement shading mistranslation

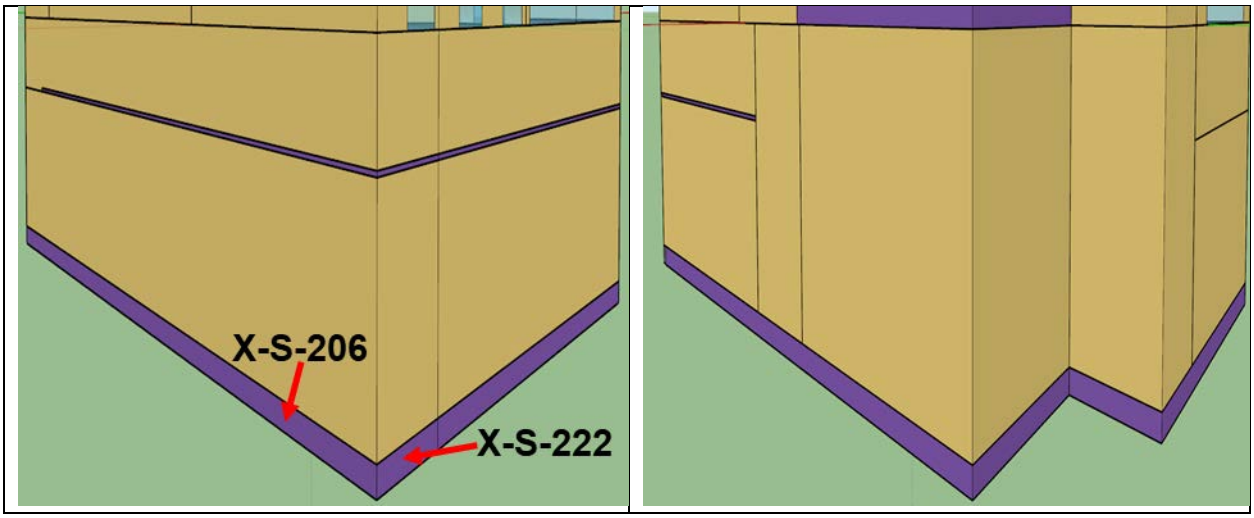


Figure 88 - Basement part in the OpenStudio Model

```
27255    <Surface surfaceType="Shade" exposedToSun="true" id="aim4988">
27256      <RectangularGeometry id="aim4989">
27257        <Azimuth>270</Azimuth>
27258        <CartesianPoint>
27259          <Coordinate>-15.15566</Coordinate>
27260          <Coordinate>38.56909</Coordinate>
27261          <Coordinate>-13</Coordinate>
27262        </CartesianPoint>
27263        <Tilt>90</Tilt>
27264        <Width>61</Width>
27265        <Height>1</Height>
27266      </RectangularGeometry>
27267      <PlanarGeometry>
27268        <PolyLoop>
27269          <CartesianPoint>
27270            <Coordinate>-15.15566</Coordinate>
27271            <Coordinate>-22.43091</Coordinate>
27272            <Coordinate>-13</Coordinate>
27273          </CartesianPoint>
27274          <CartesianPoint>
27275            <Coordinate>-15.15566</Coordinate>
27276            <Coordinate>-22.43091</Coordinate>
27277            <Coordinate>-12</Coordinate>
27278          </CartesianPoint>
27279          <CartesianPoint>
27280            <Coordinate>-15.15566</Coordinate>
27281            <Coordinate>38.56909</Coordinate>
27282            <Coordinate>-12</Coordinate>
27283          </CartesianPoint>
27284          <CartesianPoint>
27285            <Coordinate>-15.15566</Coordinate>
27286            <Coordinate>38.56909</Coordinate>
27287            <Coordinate>-13</Coordinate>
27288          </CartesianPoint>
27289        </PolyLoop>
27290      </PlanarGeometry>
27291      <CADObjectId>Basic Wall: Cast Concrete Wall 12" [49749]</CADObjectId>
27292      <Name>X-S-206</Name>
27293    </Surface>
```

```
28139    <Surface surfaceType="Shade" exposedToSun="true" id="aim5200">
28140      <RectangularGeometry id="aim5201">
28141        <Azimuth>180</Azimuth>
28142        <CartesianPoint>
28143          <Coordinate>-15.15566</Coordinate>
28144          <Coordinate>-22.43091</Coordinate>
28145          <Coordinate>-13</Coordinate>
28146        </CartesianPoint>
28147        <Tilt>90</Tilt>
28148        <Width>6.5</Width>
28149        <Height>1</Height>
28150      </RectangularGeometry>
28151      <PlanarGeometry>
28152        <PolyLoop>
28153          <CartesianPoint>
28154            <Coordinate>-15.15566</Coordinate>
28155            <Coordinate>-22.43091</Coordinate>
28156            <Coordinate>-13</Coordinate>
28157          </CartesianPoint>
28158          <CartesianPoint>
28159            <Coordinate>-8.655656</Coordinate>
28160            <Coordinate>-22.43091</Coordinate>
28161            <Coordinate>-13</Coordinate>
28162          </CartesianPoint>
28163          <CartesianPoint>
28164            <Coordinate>-8.655656</Coordinate>
28165            <Coordinate>-22.43091</Coordinate>
28166            <Coordinate>-12</Coordinate>
28167          </CartesianPoint>
28168          <CartesianPoint>
28169            <Coordinate>-15.15566</Coordinate>
28170            <Coordinate>-22.43091</Coordinate>
28171            <Coordinate>-12</Coordinate>
28172          </CartesianPoint>
28173        </PolyLoop>
28174      </PlanarGeometry>
28175      <CADObjectId>Basic Wall: Cast Concrete Wall 12" [72000]</CADObjectId>
28176      <Name>X-S-222</Name>
28177    </Surface>
```

Figure 89 - (Left) X-S-206 shading device (Right) X-S-222 shading device

In the OpenStudio model, shading devices which were not supposed to be in the floor were found. Also, the shading devices (X-S-206) and (X-S-222) were discovered in the gbXML instance file but the shading devices' information should not have translated into the gbXML instance file.

11.3.1.3 Interior investigation of Room/Volume settings

11.3.1.3.1 Basement Ceiling

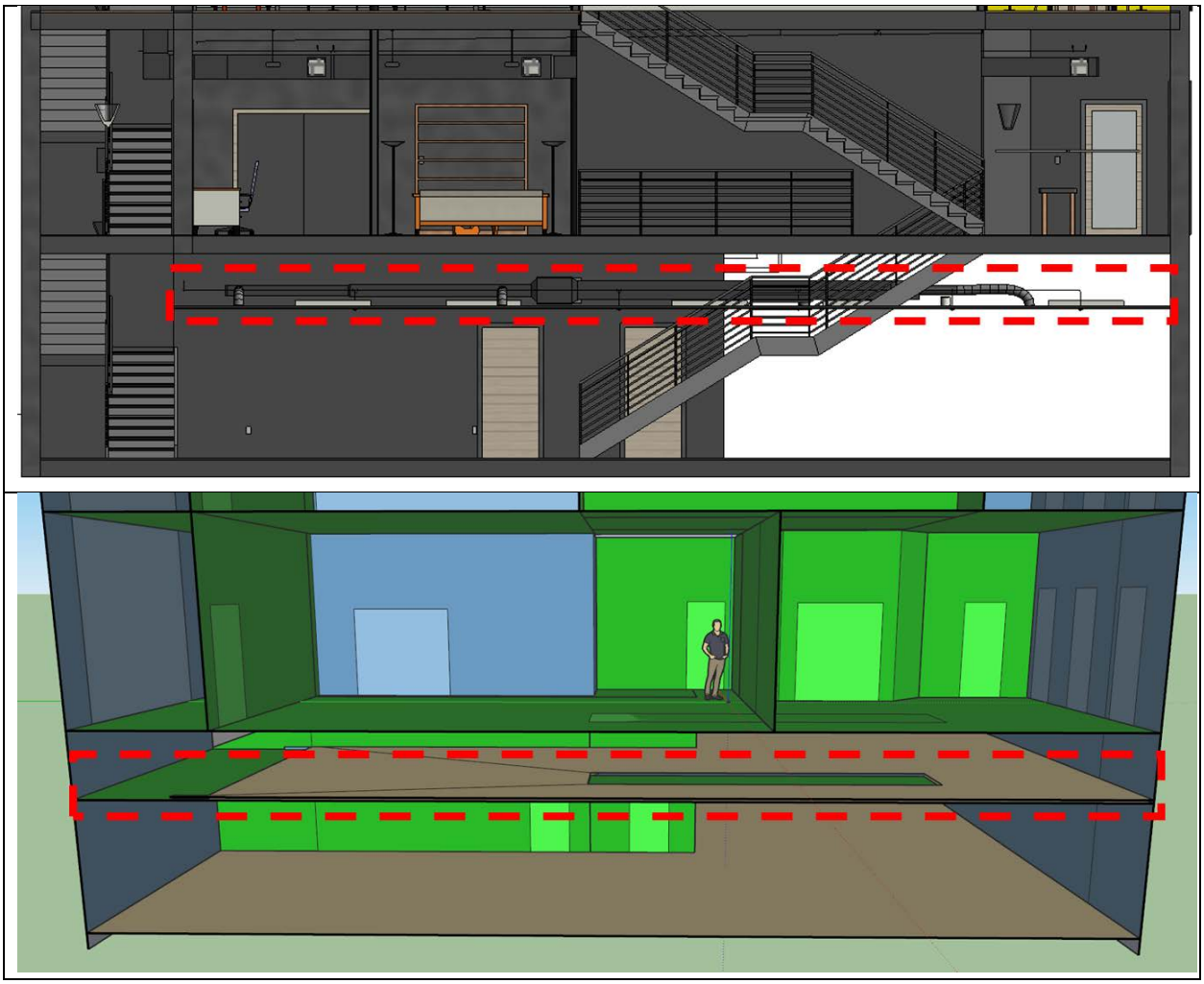


Figure 90 - (Top) Section view in Revit (Bottom) Section view in OpenStudio

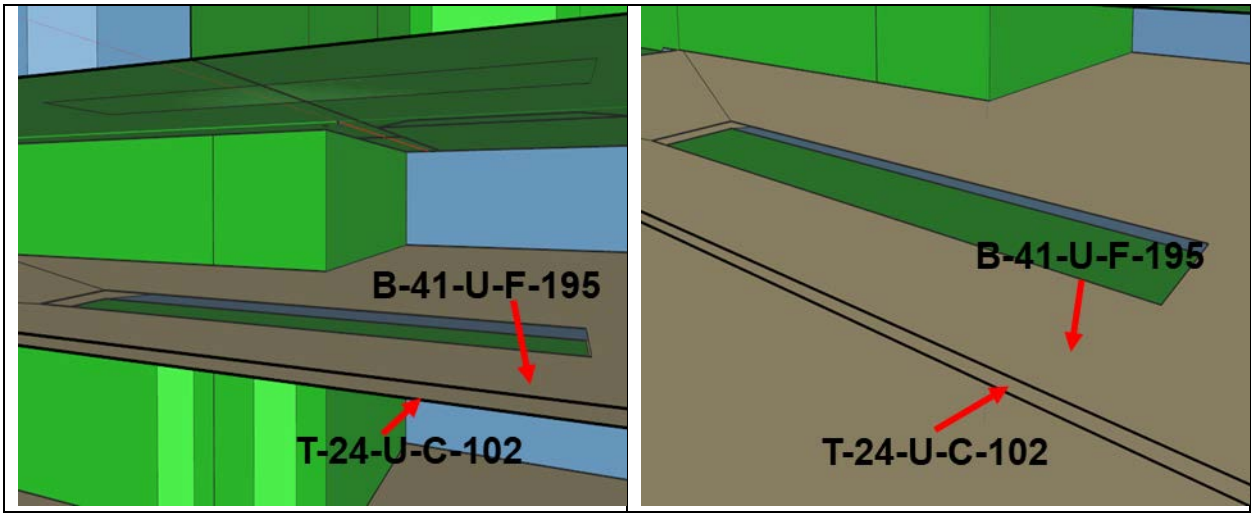


Figure 91 - Close view of basement ceiling in OpenStudio

```
26778      <Surface surfaceType="UndergroundSlab" id="aim4855">
26779        <AdjacentSpaceId spaceIdRef="aim1840" />
26780        <RectangularGeometry id="aim4856">
26781          <Azimuth>0</Azimuth>
26782          <CartesianPoint>
26783            <Coordinate>23.34434</Coordinate>
26784            <Coordinate>-22.43091</Coordinate>
26785            <Coordinate>-3.8125</Coordinate>
26786          </CartesianPoint>
26787          <Tilt>180</Tilt>
26788          <Width>30.5</Width>
26789          <Height>38.0010795593262</Height>
26790        </RectangularGeometry>
26791        <PlanarGeometry>
26792          <PolyLoop>
26793            <CartesianPoint>
26794              <Coordinate>-15.15566</Coordinate>
26795              <Coordinate>-22.43091</Coordinate>
26796              <Coordinate>-3.8125</Coordinate>
26797            </CartesianPoint>
26798            <CartesianPoint>
26799              <Coordinate>-15.15566</Coordinate>
26800              <Coordinate>33.02743</Coordinate>
26801              <Coordinate>-3.8125</Coordinate>
26802            </CartesianPoint>
26803            <CartesianPoint>
26804              <Coordinate>-14.65566</Coordinate>
26805              <Coordinate>33.02743</Coordinate>
26806              <Coordinate>-3.8125</Coordinate>
26807            </CartesianPoint>
26808            <CartesianPoint>
26809              <Coordinate>-14.65566</Coordinate>
26810              <Coordinate>31.02743</Coordinate>
26811              <Coordinate>-3.8125</Coordinate>
26812            </CartesianPoint>
26813            <CartesianPoint>
26814              <Coordinate>-10.98899</Coordinate>
26815              <Coordinate>9.464927</Coordinate>
26816              <Coordinate>-3.8125</Coordinate>
26817            </CartesianPoint>
26818            <CartesianPoint>
26819              <Coordinate>-10.98899</Coordinate>
26820              <Coordinate>-11.95174</Coordinate>
26821              <Coordinate>-3.8125</Coordinate>
26822            </CartesianPoint>
26823            <CartesianPoint>
26824              <Coordinate>-7.155656</Coordinate>
26825              <Coordinate>-11.95174</Coordinate>
26826              <Coordinate>-3.8125</Coordinate>
26827            </CartesianPoint>
```

```
22276      <Surface surfaceType="UndergroundCeiling" id="aim3600">
22277        <AdjacentSpaceId spaceIdRef="aim0813" />
22278        <RectangularGeometry id="aim3601">
22279          <Azimuth>180</Azimuth>
22280          <CartesianPoint> ...
22284          </CartesianPoint>
22285          <Tilt>0</Tilt>
22286          <Width>4.16666603088379</Width>
22287          <Height>185.349182128906</Height>
22288        </RectangularGeometry>
22289        <PlanarGeometry>
22290          <PolyLoop>
22291            <CartesianPoint>
22292              <Coordinate>3.115177</Coordinate>
22293              <Coordinate>31.02743</Coordinate>
22294              <Coordinate>-4</Coordinate>
22295            </CartesianPoint>
22296            <CartesianPoint>
22297              <Coordinate>3.115177</Coordinate>
22298              <Coordinate>33.02743</Coordinate>
22299              <Coordinate>-4</Coordinate>
22300            </CartesianPoint>
22301            <CartesianPoint>
22302              <Coordinate>3.344344</Coordinate>
22303              <Coordinate>33.02743</Coordinate>
22304              <Coordinate>-4</Coordinate>
22305            </CartesianPoint>
22306            <CartesianPoint>
22307              <Coordinate>3.344344</Coordinate>
22308              <Coordinate>2.027427</Coordinate>
22309              <Coordinate>-4</Coordinate>
22310            </CartesianPoint>
22311            <CartesianPoint>
22312              <Coordinate>-7.155656</Coordinate>
22313              <Coordinate>9.464927</Coordinate>
22314              <Coordinate>-4</Coordinate>
22315            </CartesianPoint>
22316            <CartesianPoint>
22317              <Coordinate>-10.98899</Coordinate>
22318              <Coordinate>9.464927</Coordinate>
22319              <Coordinate>-4</Coordinate>
22320            </CartesianPoint>
22321            <CartesianPoint>
22322              <Coordinate>-10.98899</Coordinate>
22323              <Coordinate>-11.95174</Coordinate>
22324              <Coordinate>-4</Coordinate>
22325            </CartesianPoint>
22326            <CartesianPoint>
22327              <Coordinate>-7.155656</Coordinate>
22328              <Coordinate>-11.95174</Coordinate>
22329              <Coordinate>-4</Coordinate>
```

Figure 92 - (Left) The “B-41-U-F-195” surface (Right) The “T-24-U-C-102” surface

Although the basement ceiling surface was supposed to be translated into one single surface, the surface was converted into two surfaces in the OpenStudio Model.

11.4 Summary of the Urban House test

Table 5- Summary of the Urban House

	Energy settings	Room/Volume Settings
Exterior	• Gaps between exterior surfaces. • Gaps between roof surfaces. • Windows not shown in the OpenStudio model. • Incorrect shading deveces' translation.	• Lost roof surface. •Incorrect shading devices' translation.
Interior	• Gaps between floor spaces.	• One same surface translated into two different surfaces.

12 Conclusion

The Phase I testing program has disclosed several distinct issues in the gbXML based exchange pipeline between Revit and Open Studio. Several minor issues (such as 10.2.2 - Missing windows and 10.3.2- Lost Slab-on-Grade) appear to result from different interpretations of the gbXML specification in terms of object type and tagging. These issues could be resolved through minor enhancement of either or both softwares to resolve this difference in interpretation, or potentially addressed by users with the existing software by using alternative modeling practices.

However, a number of the identified issues – specifically those involving loss of geometric precision in the boundary geometries boundary surfaces – result from the geometric processing in the BIM export, as complex configurations of BIM space partitioning objects are resolved into energy boundary surfaces at spaces. Of the two export options provided in the Revit gbXML export – *Energy* and *Room / Volume*, the newer Energy settings did a better job of breaking Revit partition geometry into boundary surfaces at the transitions between interior spaces or at the interior / exterior boundary, but resulted in loss of geometric coordinate precision. This produced gaps between surfaces and in some cases of small components had substantial geometric variation. Through our discussions with the Revit Building Performance Analysis developers it is clear that this results from the approach taken to address the topological differences between architectural modeling and energy modeling, is performing “as designed”, and is deemed to be well within the tolerances of professional energy modeling and analysis. However, the current production version of EnergyPlus performs coordinate checking on import that prevents this exported model from solving.

These examples make clear that significant differences in interpreting model design and organization requirements persist between different exporting and importing software – the mitigation of which are beyond the intentions of gbXML in its current form. The tests further suggest it is unlikely that a simple text based test - comparing exported files to an official benchmark, or even the automated software approach developed for Level 2 are likely to work for Level 3 compliance testing. A performance based test – that requires software vendors to provide written documentation of results, and potentially using one or more identified open source solvers such as EnergyPlus – seems to be a more feasible approach. It is suggested that subsequent phases of the Level 3 validation program focus on developing this performance based approach along with specification of unit and system tests and the means and criteria for performance review by gbXML.

Appendix A

Table 6 - Material thermal properties' test result

	Material Name	Thickness (m)			Difference1*	Difference2*	Thermal Conductivity (W/(m·K))			Difference1*	Difference2*	R-Value ((m2·K)/W)			Difference1*	Difference2*
	-	Revit	gbXML	OpenStudio	%	%	Revit	gbXML	OpenStudio	%	%	Revit	gbXML	OpenStudio	%	%
Exterior Wall	Brick, common	0.09	0.09	0.09	0.0	0.0	0.54	0.54	0.54	0.0	0.0	0.17	0.17	0.17	0.0	0.0
	Air	0.08	0.08	0.08	0.0	0.0	0.03	0.03	0.03	0.0	0.0	3.05	3.05	3.05	0.0	0.0
	Rigid Insulation	0.08	0.08	0.08	0.0	0.0	0.04	0.04	0.04	0.0	0.0	2.18	2.18	2.18	0.0	0.0
	Concrete Masonry Units	0.19	0.19	0.19	0.0	0.0	1.30	1.30	1.30	0.0	0.0	0.15	0.15	0.15	0.0	0.0
	Metal Furring	0.04	0.04	0.04	0.0	0.0	45.0	45.0	45.0	0.0	0.0	0.001	0.001	0.001	0.0	0.0
	Gypsum Wall Board	0.02	0.02	0.02	0.0	0.0	0.65	0.65	0.65	0.0	0.0	0.02	0.02	0.02	0.0	0.0
Interior Wall	Gypsum Wall Board	0.02	0.02	0.02	0.0	0.0	0.65	0.65	0.65	0.0	0.0	0.02	0.02	0.02	0.0	0.0
	Gypsum Wall Board	0.02	0.02	0.02	0.0	0.0	0.65	0.65	0.65	0.0	0.0	0.02	0.02	0.02	0.0	0.0
	Metal Stud Layer	0.06	0.06	0.06	0.0	0.0	0.03	0.03	0.03	0.0	0.0	2.54	2.54	2.54	0.0	0.0
	Gypsum Wall Board	0.02	0.02	0.02	0.0	0.0	0.65	0.65	0.65	0.0	0.0	0.02	0.02	0.02	0.0	0.0
	Gypsum Wall Board	0.02	0.02	0.02	0.0	0.0	0.65	0.65	0.65	0.0	0.0	0.02	0.02	0.02	0.0	0.0
Roof	Asphalt Shingle	0.01	0.01	0.01	0.0	0.0	0.50	0.50	0.50	0.0	0.0	0.01	0.01	0.01	0.0	0.0
	Plywood, Sheathing	0.02	0.02	0.02	0.0	0.0	0.11	0.11	0.11	0.0	0.0	0.15	0.15	0.15	0.0	0.0
	Wood Joist/Rafter Layer, Batt Insulation	0.19	0.19	0.19	0.0	0.0	0.02	0.02	0.02	0.0	0.0	10.03	10.03	10.03	0.0	0.0
Floor	Wood Joist/Rafter	0.30	0.30	0.30	0.0	0.0	0.03	0.03	0.03	0.0	0.0	12.07	12.07	12.07	0.0	0.0
	Plywood, Sheathing	0.02	0.02	0.02	0.0	0.0	0.11	0.11	0.11	0.0	0.0	0.18	0.18	0.18	0.0	0.0
		Density (kg/m3)			Difference1*	Difference2*	Specific heat (J/(kg·°C))			Difference1*	Difference2*					
		Revit	gbXML	OpenStudio	%	%	Revit	gbXML	OpenStudio	%	%					
Exterior Wall	Brick, common	1550.0	1550.0	1550.0	0.0	0.0	840.00	840.00	840.00	0.0	0.0					
	Air	1.2	1.2	1.2	0.0	0.0	1,003.5	1,003.5	1,003.5	0.0	0.0					
	Rigid Insulation	23	23	23	0.0	0.0	1,470.0	1,470	1,470.0	0.0	0.0					
	Concrete Masonry Units	1,800.0	1,800	1,800	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
	Metal Furring	7,850.0	7,850	7,850	0.0	0.0	480.0	480.0	480.0	0.0	0.0					
	Gypsum Wall Board	1,100.0	1,100	1,100	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
Interior Wall	Gypsum Wall Board	1,100.0	1,100	1,100	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
	Gypsum Wall Board	1,100.0	1,100	1,100	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
	Metal Stud Layer	1.2	1.2	1.2	0.0	0.0	1,003.5	1,003.5	1,003.5	0.0	0.0					
	Gypsum Wall Board	1,100.0	1,100	1,100	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
	Gypsum Wall Board	1,100.0	1,100	1,100	0.0	0.0	840.0	840.0	840.0	0.0	0.0					
Roof	Asphalt Shingle	1,700	1,700	1,700	0.0	0.0	1,000	1,000	1,000	0.0	0.0					
	Plywood, Sheathing	552	552	552	0.0	0.0	1,420	1,420	1,420	0.0	0.0					
	Wood Joist/Rafter Layer, Batt Insulation	32	32	32	0.0	0.0	920	920	920	0.0	0.0					
Floor	Wood Joist/Rafter	1.2	1.2	1.2	0.0	0.0	1,004	1,003.5	1,003.5	0.0	0.0					
	Plywood, Sheathing	552	552	552	0.0	0.0	1,420	1,420	1,420	0.0	0.0					

Difference1*: Percentage difference between Revit and gbXML
Difference2*: Percentage difference between gbXML and OpenStudio

Table 7 - The layer test result

		Material	Layer	materialIdRef
	Material Name	id	id	materialIdRef
Exterior Wall	Brick, common	aim0019	aim0018	aim0019
	Air	aim0026		aim0026
	Rigid Insulation	aim0033		aim0033
	Concrete Masonry Units	aim0040		aim0040
	Metal Furring	aim0047		aim0047
	Gypsum Wall Board	aim0054		aim0054
Interior Wall	Gypsum Wall Board	aim0054	aim0086	aim0054
	Gypsum Wall Board	aim0054		aim0054
	Metal Stud Layer	aim0089		aim0089
	Gypsum Wall Board	aim0054		aim0054
	Gypsum Wall Board	aim0054		aim0054
Roof	Asphalt Shingle	aim0121	aim120	aim0121
	Plywood, Sheathing	aim0128		aim0128
	Wood Joist/Rafter Layer, Batt Insulation	aim0135		aim0135
Floor	Wood Joist/Rafter	aim0067	aim0066	aim0067
	Plywood, Sheathing	aim0074		aim0074

Table 8 - Construction element result

	U-Value (W/(m2·K))		Absorptance	
	Revit	gbXML	Revit	gbXML
Exterior Wall	0.18	0.18	0.7	0.7
Interior Wall	0.38	0.38	0.7	0.7
Roof	0.10	0.10	0.7	0.7
Floor	0.08	0.08	0.7	0.7

Reference

1. Stephens B, 2017, Building Science course, Heat transfer in buildings lecture slide, page 35 (url: http://built-envi.com/wp-content/uploads/cae331_513_lecture03_conduction-part1.pdf).