D3.3 Review and benchmarking of energy simulation tools corresponding to the typology models of energy-efficient healthcare districts

Streamer
European research on energy-efficient healthcare districts

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D3.3

Review and benchmarking of energy simulation tools corresponding to the typology models of energy-efficient healthcare districts

Document history

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Colophon

Publishable executive summary

The objective of this deliverable is to make state of the art energy simulation software associated with BIM and open-standard / open-sources approaches. The deliverable report is structured into three main parts:

In the first part, we present the two main open standards IFC and gbXML which are the best suited, considering their use for energy estimate. The IFC has a few more advantages in its ability to include the entire life cycle as well as other themes (acoustic, structure …).

In the second part, a first feedback is made from simulation tools which are already using partially a BIM format. This first return points out the need for intermediate tools to make the connection between the BIM and thermal simulation worlds, based on standard (especially when commercial tools are considered).

In the third part, to identify a first list of simulation tools, a "bottom up" approach is favored by analyzing the level of integration in a BIM process of software which are planned to be used in the Streamer WP 7 (demonstration and validation). The aim of this approach is to ensure a "smooth" transition to integrate the practices of engineers into a BIM workflow rather than imposing a particular tool. For each of them, we present suggested improvement that will be studied in the deliverable D3.4

List of acronyms and abbreviations

- ACA: AutoCAD Architecture
- BEM: Building Energy Modeling
- BIM: Building Information Modeling
- CAD: Computer aided Design
- gbXML: green building XML definition
- GML: Geography Markup Language
- GUID: Global Unique Identifier
- HVAC: Heating, Ventilation and Air Conditioning
- IFC: Industry Foundation Classes
- LoD: Level of Detail
- MEP: Mechanical, Electrical and Plumbing
- MVD: Model View Definition

Definitions

MVD: a Model View Definition defines a subset of the IFC schema that is needed to satisfy one or many **Exchange Requirements** of the AEC industry (Architecture, Engineering and Construction). There is such a MVD for thermal analysis.

Interoperability: it is the capacity of a product, or system, whose interfaces are fully known to work with other existing products or systems without any restricted access or implementation. It is the possibility for various systems to communicate between them without depending on a particular actor. It relies on the use of an open standard.

Compatibility: it is the possibility for two systems of different types to communicate together.

De facto standard: when an actor becomes dominant in a domain, the other actors manage to be compatible with him. Advantage: all the systems can communicate more or less together. Inconvenience: the dominating actor controls this possibility.

Contents

1. INTRODUCTION

The final goal of the task 3.2 (Assessment tools for energy performance) is to provide the design team (including the BIM manager) with energy performance simulation tools associated with BIM and the open-standard approach. In order to reach this goal, this first deliverable should identify simulation tools, that are either already rather close to achieve interoperability with other BIM software, or are tools widely used by the partners and for which it would be interesting to improve the communication with other BIM tool preferably using open standards.

The BIM manager is the person who, in particular, oversees realization of the virtual models and their coordination by implementing rules to:

- ensure interoperability between different applications used,
- manage databases (materials, equipment, ...),
- manage the division of the project into different zones (depending on context),
- identify object's families to use,
- etc.

He will necessarily be equipped with a set of tools that will allow him to fulfill all of these tasks, including interoperability. The interoperability concerns the capacities of given software to have one or bi-directional communications with other tools, via known interfaces. In practice, full bi-directional interoperability rarely exists and we rather find, or talk about, one way communications from BIM authoring software towards simulation tools.

After a reminder of the different approaches of interoperability [STREAMER-D6.5], a short description of useful open standards (in chapter 3) is presented with also the possible approaches to enable communications between BIM and energy simulation tools (in chapter 4).

In chapter 5, we then explain how we have pre-selected an initial list of energy simulation tools as well as our evaluation criteria. In the perspective of an energy-efficient analysis at the healthcare district, the building represents the basic element. We start the inventory of simulation tools at the building scale. But, given the large number of simulation tools at building level, and the few software at district level, we decided to stay at the building scale (remaining that there is still technological issues about geometric aspects and that the district level was also addressed in the deliverable D6.3 – Energy modeling interface IFC-CityGML). So, based on the first feedback from partner's experience, we identified a number of needs:

- In the data recovery and data transformation from BIM format to the simulation
- To sustain the choices of the design team in a standard format

2. INTEROPERABILITY

Interoperability between BIM and simulation software, can be obtained by using:

- **Full integration** of tools and data models. This approach is mainly implemented by software vendors (based on proprietary formats) whose tools span a large part of building design phases. The aim is to rely on a single building data model, used as a sole reference in all design tasks, including simulation. BIM authoring and simulation tools are fully integrated at the data level, but often also at the user interface level. This approach therefore treats simulation tools as *BIM-aware tools*. Examples of such implementations may be found in commercial suites of CAD tools in which you could find a first approach: Autodesk Revit, ArchiCAD … This approach is clearly the most relevant both from data integrity and from usability perspectives. However, it is also the most rigid and the most demanding: rigid, because only the simulation tool(s) already embedded may be used; demanding, because any extension, e.g. to add simulation capabilities, requires a significant implementation effort.

- **The second approach** to BIM/simulation interoperability advocates "light" integration and, relies on data translation – or, more precisely on model transformation – in order to generate the building model required by the simulation tool from a building model conforming to a given BIM. This approach is the most frequent and could be the one developed in STREAMER for the different test case. Implementing such approach will require multiple data sources (IFC for the architectural building model but also material data …).
  We also invite the reader to read the deliverable D6.5 [STREAMER-D6.5] which presents some more detailed way to manage the interoperability (used both in a full or light integration)
  - o Data enriching
  - o Transformation
  - o Data integration
  - o Linked data

Of course, to ensure interoperability, communications between tools must be done through interfaces known by each tool. The use of open standards is therefore strongly preferred. Therefore, we are primarily interested in the two most widely used formats in terms of interoperability: gbXML and IFC (briefly described in the following paragraph).

Fig. 1 - The concepts of interoperability[1]

3. BIM formats

IFC and gbXML formats are already described in the deliverable D6.5 [STREAMER-D6.5]. So, we just describe here, very briefly, these standards and refer the reader to the appendix 3 and 4 in this document and also to the D6.5

3.1 IFC

The **Industry Foundation Classes (IFC)** [ISO 16739:2013] data model is intended to describe building and construction data. It is a platform neutral, open file format specification that is not controlled by a single vendor or group of vendors. It is an object-based file format with a data model developed by buildingSMART (formerly the International Alliance for Interoperability, IAI) to facilitate interoperability in the architecture, engineering and construction (AEC) industry, and is a commonly used collaboration format in Building Information Modeling (BIM) based projects. The IFC model specification is open and available. It is registered by ISO and is an official International Standard ISO 16739:2013.[2]

With the acceptance of BIM, the IFC format becomes the commonly accepted open standard for all actors to organize the objects of the industry of the construction, the families, around a 3D model. These objects support the complete life cycle of a building, including the design, the construction, and the operation phase, including the management of the installations and, finally, the demolition.

Regarding the use for energy simulation, a large number of properties (in particular material properties or building properties) is defined in the IFC format. We present here a scheme proposed by the Department of Civil Engineering, Tsinghua University, Beijing [TRANS-IFC2IDF-2007], that shows another preview of the possible use of IFC by identifying main IFC objects, and relations, useful for preparing a data set for energy estimation grouped by:

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[1] AFUL source (https://aful.org/gdt/interop)
[2] Wikipedia source (http://www.iso.org/iso/catalogue_detail.htm?csnumber=51622)

- Geometry information
- Material information
- Spatial geometric information
- Internal heat source information
- HVAC information.
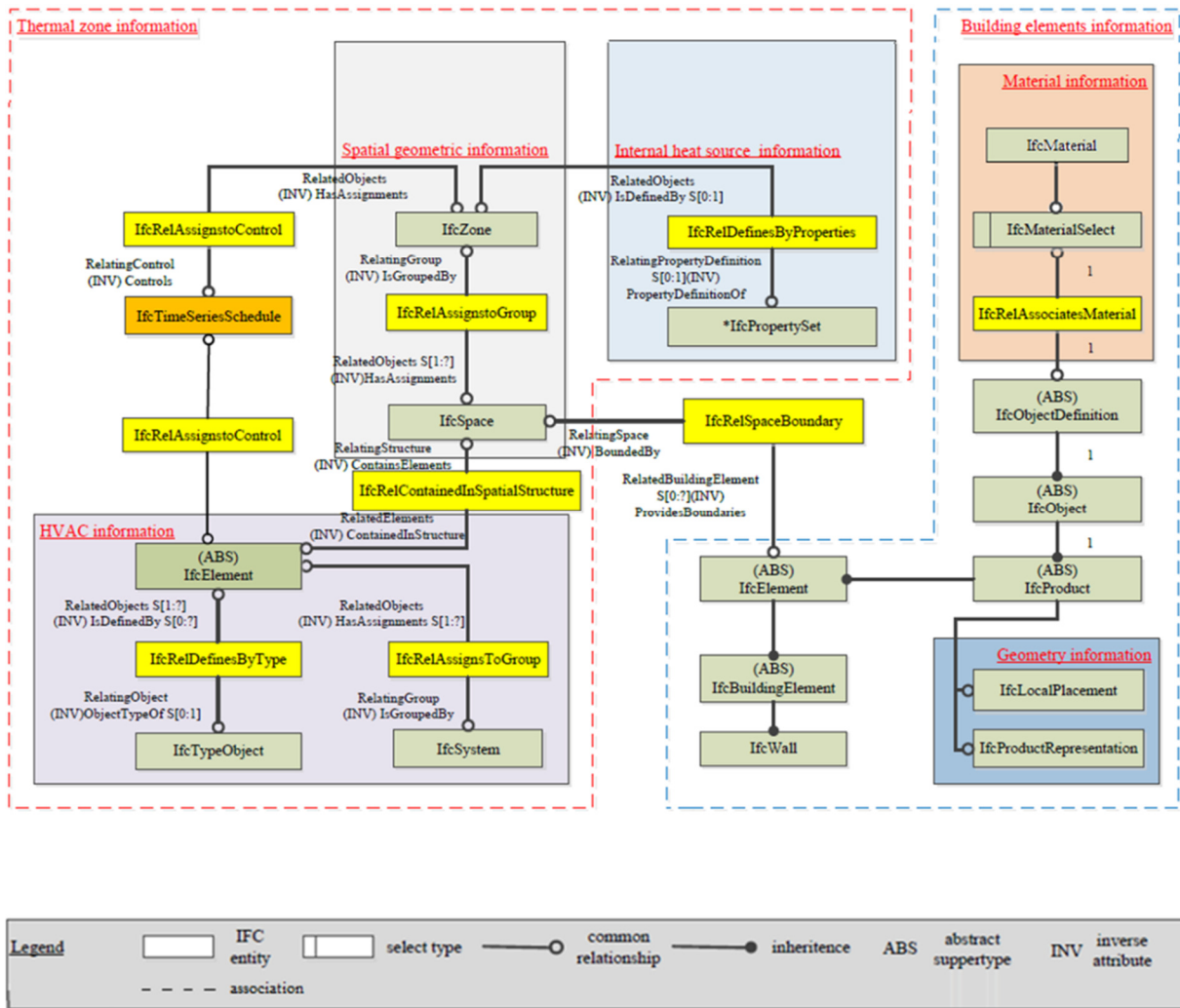
Fig. 2 – IFC-based information model for energy simulation

The reader is also invite to see a more detailed presentation of IFC in appendix 3.

Relevant for Streamer: the IFC format contains all data that define the building envelope and are relevant from energy evaluation point of view.

3.2 gbXML

The Green Building XML schema (gbXML) is an open schema developed to facilitate transfer of building data stored in Building Information Models (BIM) to engineering analysis tools. gbXML is being integrated into a range of software CAD and engineering tools and supported by leading 3D BIM vendors

(e. g. Autodesk, Bentley, Graphisoft) and can be processed by major engineering analysis tools (e.g. EnergyPlus and TRNSYS). Thus, it has become the defacto industry standard schema in this area **Error! Reference source not found.**. The model covers all major aspects for energy and performance simulations, which are the building geometry, the HVAC design, the internal and external environmental influences and the representation of simulation results. The following figure depicts the building geometry of a typical gbXML model.
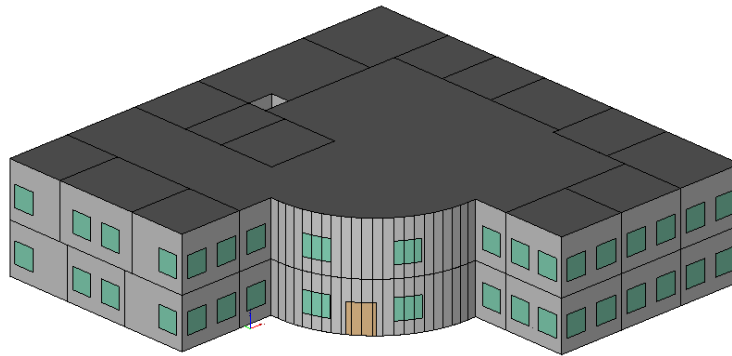
Fig. 3 – Example of the gbXML representation of an office building (33 Spaces, 174 wall surfaces, 36 doors and 72 windows) (source: http://www.gbxml.org/samplegbxmlfiles.php)

The gbXML standard makes it possible to define sets of material properties for thermal analysis:

- SpecificHeat (gbXML:Material).
- Density (gbXML:Material).
- FreezingPoint. Usually measured in Kelvin.
- R-value (gbXML:Material)
- …

As with the standard IFC, we present in the following figure, the main objects related to energetic estimation:
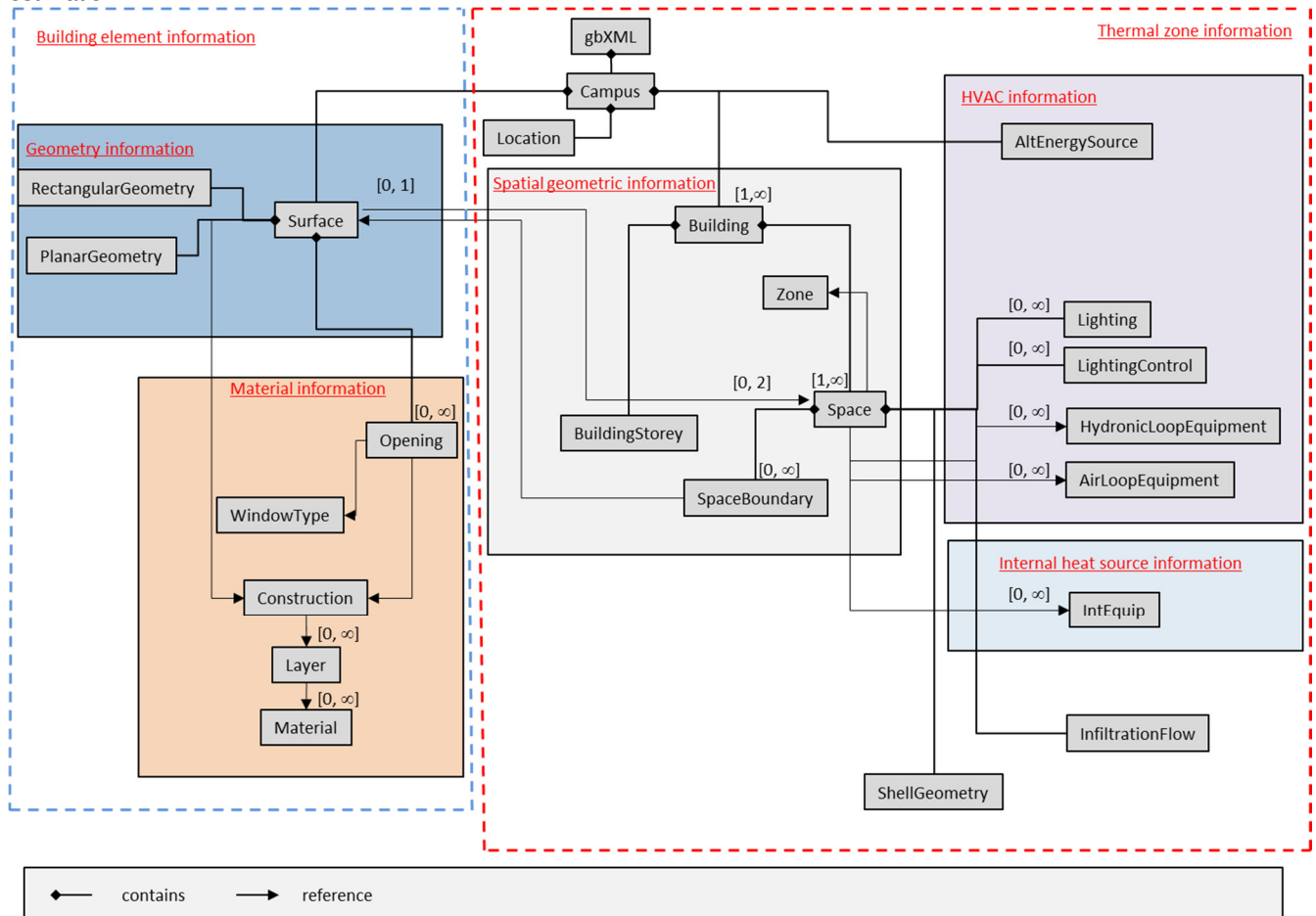
Fig. 4 – gbXML-based information model for energy simulation

4. BIM process for energy simulation tools

4.1 Existing practices

As we will see in Chapter 6, concerning the energy software analysis, some example of the interoperability process between the BIM format and simulation tools already exist. However, some limitations have been identified, which are summarized here:

4.1.1 Additional data

Additional data are data which can be described in a standard format (IFC or gbXML) but not necessarily at the level of detail required by the simulation tool. They also represent data which could be some parameters of the simulation process, i.e. data that a thermal engineer is going to make vary to study various scenarios. In both cases, it may be useful to refer to a data base, external to the standard format.

If we take for example the case of material properties, although the IFC format allows to fully describe their thermal properties (see appendix 3), it is not certain that the IFC file contains these properties, and this for several reasons:

- o Currently, if CAD tools are able to manage material properties, these are still not exported into the resulting IFC file,
- o The architect is able to reference standard or generic materials, but the thermal engineer wishes to consider several variants from its own library of materials (often linked to the simulation tool).

If we take back figure 2, we can see that we should ideally add mechanisms to additional data sources in order to change, or describe in more detail:

- o The physical properties of the materials,
- o The parameters of the equipment.
- o Usage and occupancy of each zone.

Note that the labeling approach developed in the D1.5 (Coherent state-of-the-art design guidelines for energy-efficient healthcare districts) could bring another kind of additional data. This approach is indeed very interesting regarding the simulations in preliminary design phase.

The problem, during these phases, is the relatively poor level of technical data definition. For example, equipment is generally not described. The labeling approach can then be used to define, for each label, target values that could be integrated as input data for simulation tools (e.g. to an ambient comfort label may be associated : value for the temperature, the humidity and air velocity). The enrichment of such additional data should then include as an association of these labels (in the form of numerical values) to the related spaces (or thermal zones).
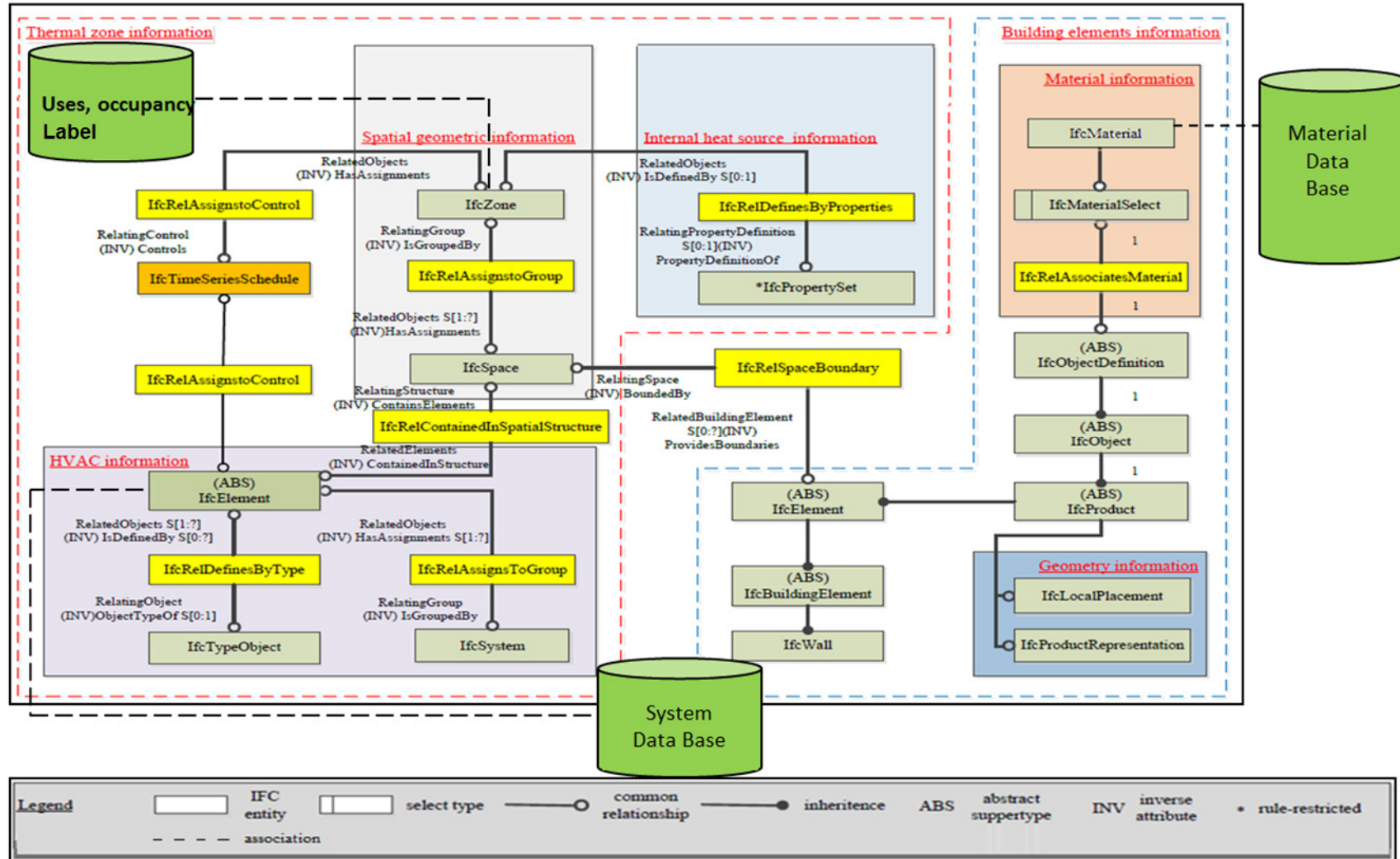
Fig. 5 – IFC-based information model with external database for energy simulation

4.1.2 Thermal zones

It is not always possible to describe Thermal zones as space group in the CAD tools. Furthermore, the Thermal engineer may want to study the impact of the zoning on the simulation. It is thus preferable that the zoning is not a space grouping fixed once for all.

4.1.3 Heat exchange surface

One of the most important concepts of thermal analysis is the concept of exchange surface.

In the gbXML format, these surfaces are named analytic surfaces. They correspond to the central plane of the wall and the upper plane of slab and roofs. They thus define analytical volumes representing thermal zones which are in contact with each other without any gap separation.
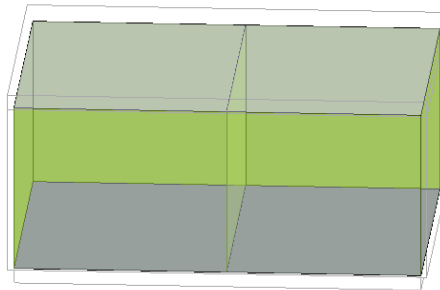
Fig. 6 - Analytical surfaces

In the IFC format, these surfaces could be determined thanks to the IfcSpaceBoundary. A space boundary[3] defines the physical or virtual delimiter of a space as its relationship to the surrounding elements and can be distinguished into 2 categories:

- 1st level space boundaries are characterized by:
  - o Boundaries of a space defined by the surfaces of building elements bounding this space (physical space boundaries) or by virtual surfaces provided by an adjacent space with no dividing wall.
  - o They do not consider any change of material in the bounding building elements, or different spaces/zones behind a wall or slab (floor or ceiling).
  - o Could be virtual or physical and internal or external, or undefined (internal and external) e.g. for a wall that is partially inside and outside.
  - o Form a closed shell around the space (so long as the space is completely enclosed) and include overlapping boundaries representing openings (filled or not) in the building elements.
  - o 1st level space boundaries define a space by its boundary surfaces without taking anything on the other side of the bounding elements into account.

- 2nd level space boundaries are characterized by:
  - o These boundaries still represent building elements that bound the space, but are more granular in that they are subdivided in any of the following cases:

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[3] Ifc2x3 definition

- Differences in materials and/or material assemblies (for example, a wainscot or paneling on the lower portion of a wall).
- Differences in spaces or zones on the other side of the building element (or virtual boundary) represented by the space boundary (for example, two different spaces on the other side of a wall)
  - Could be virtual or physical and internal or external.
  - They represent both sides of a heat transfer surface separated by the thickness of the building element. They can be further differentiated in:
    - Type 2a that occurs when there is a space on the opposite side of the building element providing the space boundary
    - Type 2b occurs if there is a building element on the opposite side of the building element providing the space boundary.
  - The connection geometry of 2nd level space boundaries is restricted to planar surfaces only. This means that curved surfaces must be segmented.

2nd level space boundaries define the heat transfer surfaces on both sides of building elements that separate spaces. The generation of 2nd level space boundaries has to take building elements and spaces on the other side into account.

Most simulation tools use this notion of analytic surface. Regarding the IFC format, it is so necessary to build these surfaces from space boundaries. If all space boundaries are well defined, is then possible to determine the analytic surfaces as shown on the following figure:
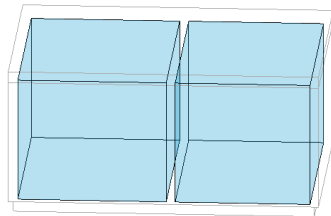
Fig. 7 - IFC space boundaries   Fig. 8 - analytical surfaces
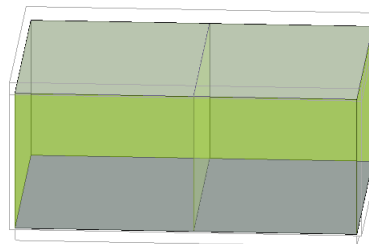
Unfortunately, sometimes, some IfcSpaceBoundary are missing:

- The first reason may be that IfcSpace were not drawn.
- It can also be caused by bad design, as shown in the following figure where the walls are not properly connected:
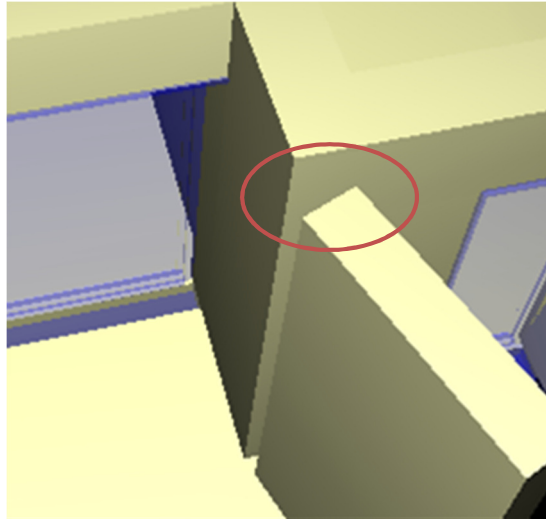
Fig. 9 - incorrect connection

- But sometimes, IfcSpaceBoundaries are also missing in some cases not covered by the notions of 1st and 2nd level as in the following figure where the red hatched area is not identified:
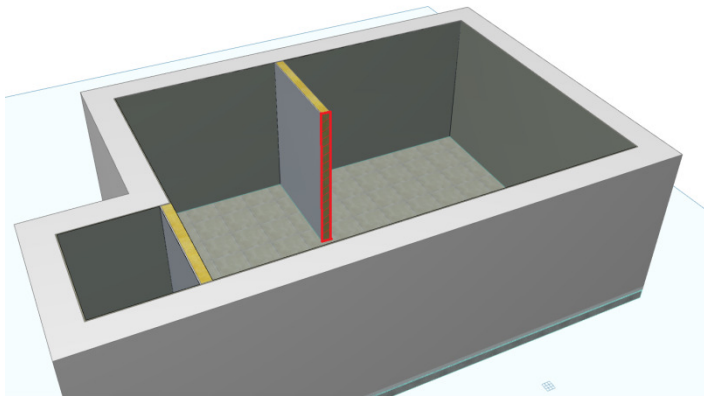
Fig. 10 - example of missing space boundary in first or second level

These issues concerning IfcSpatialBoundary have been identified by several research teams in particular [TRANS-IFC2IDF-2007], [Bentley2011]. We will especially mention research work of Bazjanac [SB-2010], [GeometryGuidelines2013]. In order to address these issues, he defined several new levels for IfcSpaceBoundary (3rdLevel, 4thLevel and 5thLevel).

o   Third level space boundaries

The 3rlLevel space boundaries are surfaces behind which there is no thermal zone to receive the heat transfer. These surfaces are generally neglected in thermal calculations, except when the volume of the zone must be completely closed. The following figure presents all 3rd level space boundaries in purple color:
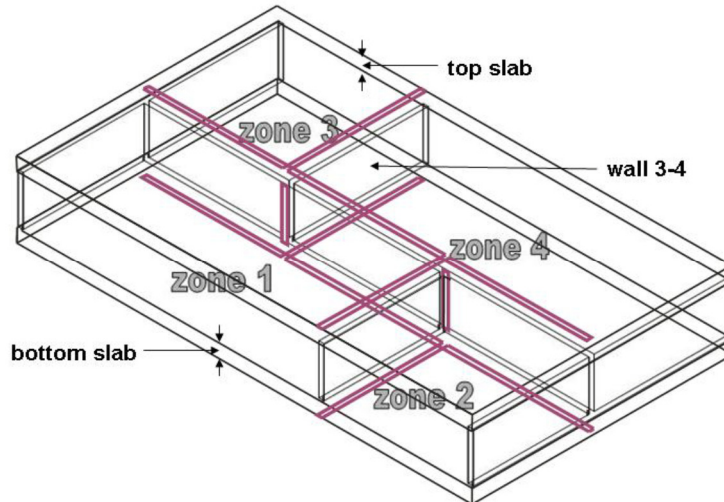
Fig. 11 - example of 3rd level for space boundaries

o   Fourth level space boundaries

Some model-based CAD tools, each wall has a reference line which could be placed outside, inside or at center along the bottom:
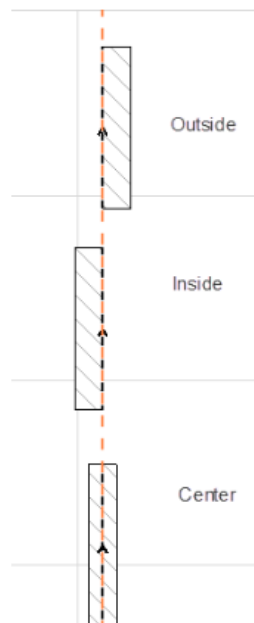
Fig. 12 - reference axis for wall

If the reference line is on the opposite side from which an intersecting wall merges with the wall being defined, the intersecting wall "stops" at the surface where it merges with the wall being defined and does not reach the other side of that wall. This leaves a small rectangle area unaccounted that constitute 4th level space boundaries (see an example on the following figure):
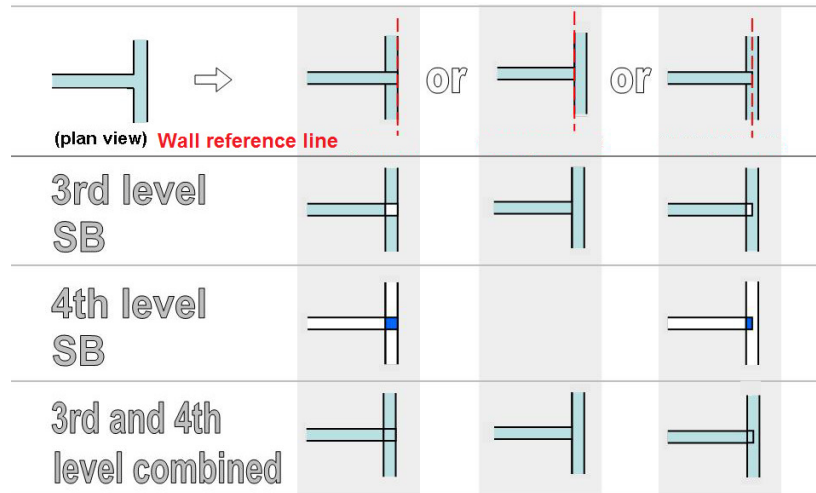
Fig. 13 - example of 3rd and 4th level for space boundaries

o   Fifth level space boundaries

When walls intersect at an angle other than right angle (as is the case with wall 1-3 in the following figure), a narrow sliver of the intersecting wall remains unaccounted for (shown as the yellow area in the cutout). This is because there can be no transmission or (energy) flow through that surface area that is perpendicular to that surface and also reaches another zone. Transmission or flow in direction 'A' shown in the cutout, perpendicular to the surface of wall 1-3, cannot reach zone 3, and in direction 'B' (perpendicular to the surface of the exterior wall) it is not perpendicular to the surface of wall 1-3. The unaccounted area in this case constitutes a 5th level space boundary, which behaves the same way as 3rd level space boundaries do.
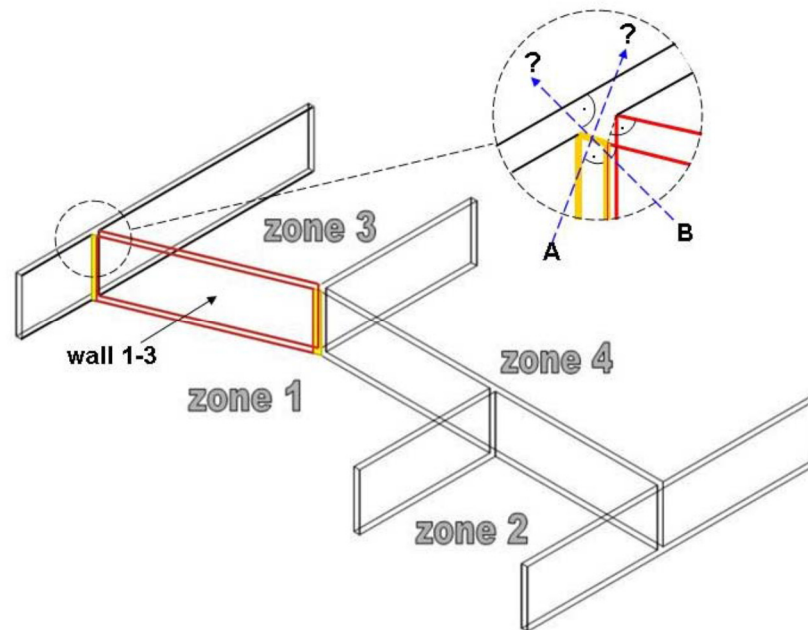
Fig. 14 - example of 5th level for space boundaries

This led to the development of a standalone application that can enrich an IFC file with these new levels in order to completely close the zone's volume: Space Boundary Tool [SBT].

4.1.4 Thermal bridges

There is still no consideration of thermal bridges deduced from the connection geometry and they are generally integrated thanks to a fixed value.

4.1.5 HVAC equipment description

Even if IFC and gbXML formats can describe some properties of HVAC equipment, exports from CAD tools (such as Revit MEP or ArchiCAD MEP) shows that all the information needed for simulation tools is not yet exported [Connection-BIM-Models2014].

Moreover, the description of equipment is quite heterogeneous in the IFC format. Some of them are described with many properties (such as the hot water tank), but others, as the solar panel, does not have any properties (in IFC2x3) or very few (in IFC 4).
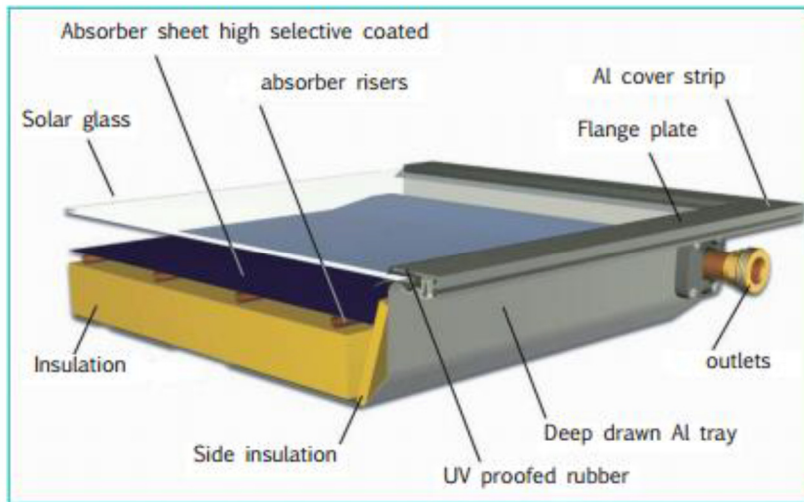
Fig. 15 - solar panel example

To better understand these differences, we chose to show these different levels of detail in terms of parameters for a solar panel according to the following data sources:

- IFC (version 2x3 and 4),
- gbXML,
- Description from the STREAMER WP 2,
- TRNSYS (simulation tool).

In IFC2x3, the solar panel could be described with a generic object called **IfcEnergyConversionDevice** without appropriate type. As a generic object, there cannot be any particular properties for a solar panel.

In IFC 4, this system corresponds to an **IfcSolarDevice** with a type equals to **SOLARCOLLECTOR** - a device that converts solar radiation into thermal energy - heating water, etc., or **SOLARPANEL** - a device that converts solar radiation into electric current. Its properties/quantities are contained in the Pset_SolarDeviceTypeCommon and Qto_SolarDeviceBaseQuantities.

Parameter name	IFC 4 description	Unit	Container
Reference	Reference ID for this specified type in this project (e.g. type 'A-1'), provided, if there is no classification reference to a recognized classification system used	Dimensionless	Pset_SolarDeviceTypeCommon
Status	Status of the element, predominately used in renovation or retrofitting projects. The status can be assigned to as "New" - element designed as new addition, "Existing" - element exists and	Dimensionless	Pset_SolarDeviceTypeCommon

	remains, "Demolish" - element existed but is to be demolished, "Temporary" - element will exists only temporary (like a temporary support structure)		
GrossWeight	Weight of the element	Kg	Qto_SolarDeviceBaseQuantities
GrossArea	Area of the solar device including the outer frame	m²	Qto_SolarDeviceBaseQuantities

Fig. 16: solar panel description in IFC 4

gbXML defines HydronicLoopEquipment with an equipmentType which can take the value **SolarPanels**. There is no special parameter for solar panel but just general parameter for HydronicLoopEquipment. Parameters which are most in relevant to a solar panel are:

Parameter name	gbXML description	Unit
Manufacturer	Name of the manufacturer	String
Temp	Temperature	Complex [value, unit and temp. type]
MinFlow	Minimum flow	Complex [value, name, …]
DeltaP	Difference in pressure	Complex [value, name, …]
DeltaT	Difference in temperature	Complex [value, name, …]
Efficiency	Efficiency measured at standard conditions	
Performance	Used to represent part-load performance and other performance metrics	

Fig. 17: solar panel description in gbXML

For reference, WP 2 identified the followings parameter for this kind of equipment:

Parameters[4]:

Parameter Name	Streamer WP2 description	Units
η_0	Maximum efficiency if there is no heat loss*	[-]
a1	1st order heat loss coefficient	W/ (K·m²)
a2	2nd order heat loss coefficient	W/ (K²·m²)
G	Total (global) irradiance on the collector surface	W/m²
Tm	Mean collector fluid temperature	°C
Ta	Temperature of the ambient air	°C
Aa	Aperture area	m²
Ga	Gross area	m²

Fig. 18: solar panel description from WP 2

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[4] D2.1 STREAMER EeB technologies for MEP systems of healthcare building

Finally, here is an example of the parameters necessary for a simulation of a solar panel in the TRNSYS environment (SolarCollector : theoretical flat plate collector - type 73):

Parameter Name	Trnsys description	Units
Collector area	The total area of the solar collector array consistent with the supplied efficiency parameters (typically gross area and not net area).	m²
Absorber plate emittance	The emittance of the absorber plate of the solar collector. The emittance, or emissivity, is defined as the ratio of the radiation emitted by the surface in question to the radiation emitted by a blackbody (the perfect emitter) at the same temperature. This property is used to calculate radiation losses from the collector	Dimensionless
Absorptance of absorber plate	The absorptance of the absorber plate of the solar collector. The absorptance is a ratio of the amount of radiation absorbed by a surface to the total radiation incident on the surface.	Dimensionless
Bottom, edge loss coefficient	The loss coefficient for the bottom and edges of the solar collector per unit aperature area.	kJ/hr.m².K
Fluid specific heat	The specific heat of the fluid flowing through the solar collector array	kJ/kg.K
Collector fin efficiency factor	The fin efficiency is a measure of the heat transfer from the fin to the maximum possible heat transfer from the fin. The maximum heat transfer from the fin would occur if the fin was uniformly at the base temperature.	Dimensionless
Number of covers	The number of glass covers covering the solar collector absorber plate.	Dimensionless
Index of refraction of cover	The index of refraction of the material covering the solar collector absorber plate.	Dimensionless
Extinction coeff. thickness product	The product of the extinction coefficient and the thickness of one of the glazings covering the solar collector absorber plate.	Dimensionless
Number in series	The solar collector model can simulate an array of identical solar collectors hooked up in series. This parameter is used to specify how many collectors are hooked up in a series arrangement where the output of the first collector is the inlet to the second collector.	Dimensionless

Fig. 19: solar panel description in TRNSYS

With this example, we can observe that the mathematical model of equipment usually requires a lot of parameters to operate. Although these parameters generally have default values, it does not seem very realistic to expect finding these parameters in an IFC file.

Relevant for Streamer: even if some information about equipment could be found in an IFC or

gbXML (the location for example), a more detailed description by using an equipment database linked closely to the simulation tool used appears the preferred approach (the same conclusion as for material properties). This eliminates the process of full and automatic transformation (cited above in interoperability solutions) in favor of data enriching or Integration approaches.

4.2 Towards an integrated approach

To supply energy simulation tools, we have seen two important aspects:

- IFC will be the main data model covering detailed information of a building and supporting the whole life cycle, but access to external data bases (space's use, occupancy, material properties, labels …) is required.
- It could be necessary to simplify, or to modify, the geometry (in particular regarding space boundaries).

Based on these observations, and also based on the MVD for thermal application software proposed by buildingSMART [Concept Design BIM 2010], the Lawrence Berkeley National Laboratory introduced the notion of BEM[5] [BIMtoBEM2013]. The main idea is to build "simulation ready" files by integrating semi-automatic transformation from IFC with, when needed, manual action.
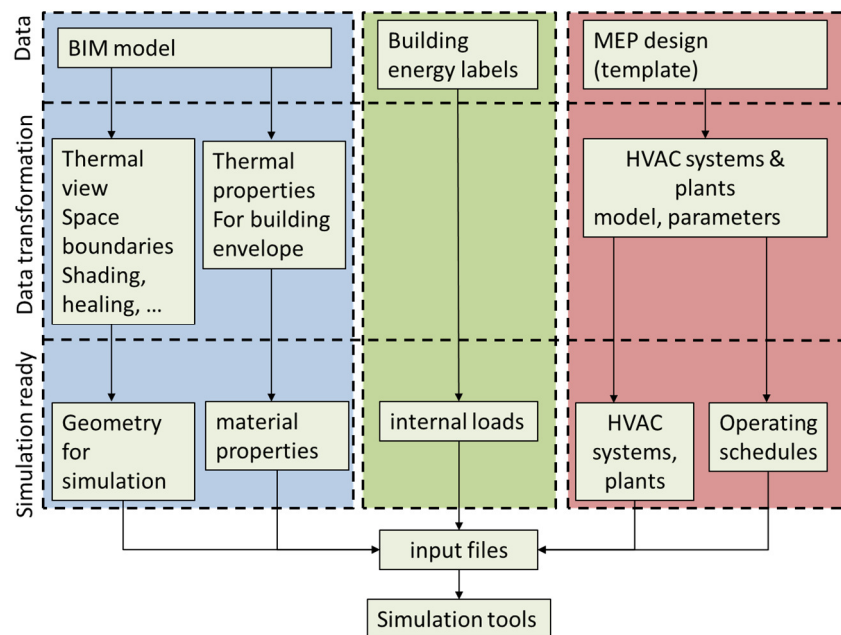
Fig 20: BIM to BEM process

We can also note that in parallel of this approach, specifications for the architect are listed to export the project towards IFC format in order to be closer to MVD [Concept Design BIM 2010].

This following figure shows a similar process with emphasis on connection with external data sources via an intermediate tool:

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[5] Building Energy Modeling
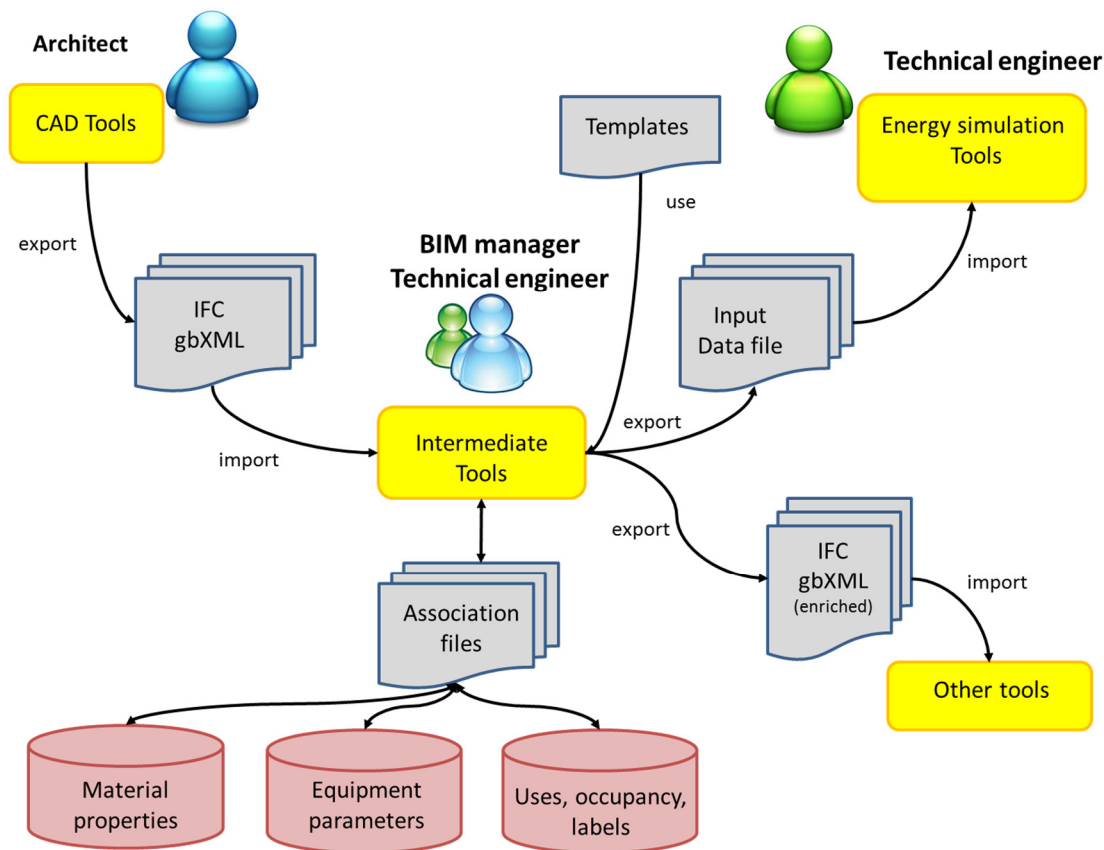
Fig. 21: data enrichment process

The main advantages are:

- The association mechanism between an IFC identifier (called GUID) and an identifier from a technical database (material properties database for example), for a wall for example (or the name of materials contained in the IFC file). This mechanism allows the thermal engineer to keep associations with the objects IFC which are preserved during modifications made by the architect. Contrary to a direct enrichment of the IFC, which can oblige the engineer to enrich the whole file for every modification done by the architect (because some CAD tool do not keep user property set).

- The enrichment of the file IFC with the technical choices of the thermal engineer will have retained is made only at the end of the process to possibly communicate them to other actors.

- This intermediate tool could also use a template, used by the simulation tool. This template describes the HVAC network for the simulation tool in a readable format because it can be quite complex to transcribe the network directly from the IFC.

- Transform space boundaries into analytical surfaces.

- The possibility to build user-defined thermal zones.

- Give a maximum of visual control features to the thermal engineer.

Relevant for Streamer: the IFC format could support all energy simulation requirements with additional processing with external and derived information.

4.3 Relation with KPIs

By definition, BIM is intended to support the use of KPI (see the deliverable D3.1 – Building Oriented EeB KPIs of newly designed and retrofitting buildings), either directly (contained in an IFC file, for example) or indirectly (through association mechanism with an external file).

However, KPI definition was still to detail when this report was written. On one hand, to know how to calculate them, and also how to use them: comparison of calculated indicators on a project to reference values or comparison of calculated indicators from different scenarios of the same project.

This choice will depend on the KPI media type in an IFC file. If reference values are identified, then we could imagine that the contractors select the level they want to reach for each indicator from at the beginning of the project and store as target values into the BIM.

In all cases, the calculation of KPIs from BIM data (after enrichment) can be likened to a post-processing step using the simulation results (see Streamer task 3.3 – LCC and design decision-support tools). These calculated indicators could possibly be stored in IFC, in the same way that the choices made by the thermal engineer. However, it would be essential to keep all links to additional data sources in order to have all the parameters that have led to these results. The idea that emerges would be to store in a dedicated IFC file, the results and all calculation parameters and calculated KPI (keeping a reference to the IFC describing the building).
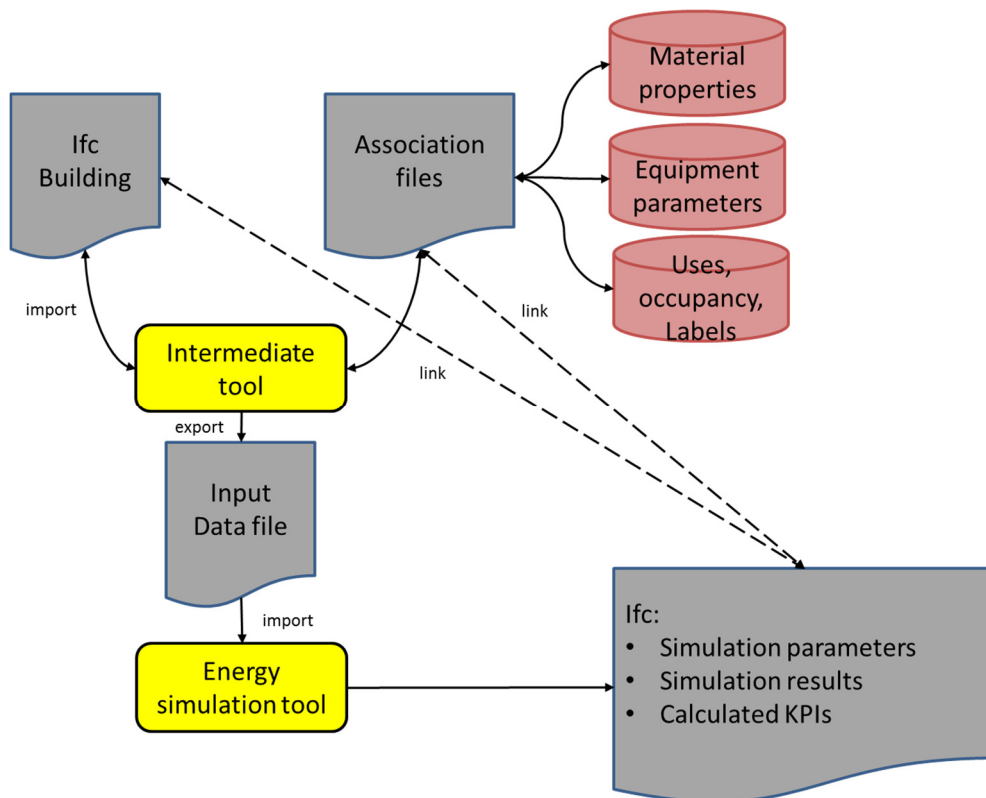

Fig. 22: results saving

5. ENERGY SIMULATION SOFTWARE

5.1 Level of detail

Thermal simulation tools are used at different steps throughout a building design process. The expected results depend the design phase[6] since the level of detail of the available data evolves with the project progress. Thus, for example, we can move from a generic U-value for a wall at the beginning of the project, to material properties when it comes to characterize the real insulation products that will be used.

In addition, the use of a particular tool may depend on the user's skills, the time available, the regulatory aspect, ...

That's why most of the thermal engineers therefore use a range of tools with dedicated to the different stages of the construction process.

In this analysis, we decided to focus on design tools (close to the physical phenomena) and we have left out the regulatory context which introduces some national specificities (living area, occupancy, etc.).

In the Streamer context, we interested in the two following levels:

1. **The early design stage (global level)**

At this stage, there are few data available. This issue concerns the architect who will seek to quickly investigate several ideas by identifying the most interesting "tendencies" and eliminating others. In this case, the precision of the calculation is not a major criterion.

   a. **Inside out approach**

   From Program of Requirement to rooms parameters, main objectives are to find answers to the following questions:

   • How to choose between the different energy sources (based on energy labels)?

   • How to spatially optimize rooms grouping (room with the same typology for example)?

   • How to optimize the distance to technical room?

   • How to have a first idea of HVAC system that could be used (in this context, the database described in the Streamer Task 2.1 could be used as input for the early design configurator from WP 6)?

   b. **Outside in approach**

   Based on the mass study of the architect, it will involve identifying the best building orientation, shading solution, etc.

Among useful simulation (and pre-processing) tools, we can mention:
   • Google Sketchup + Openstudio + Energy+,
   • Google Sketchup + Sefaira + Energy+,
   • Or other simulation tools plug to the early design configurator

---

[6] Annex 2 provides a first list of necessary data for steps 1b, 2a and 2b. In all cases, the Reqcap tool that will be developed in WP 5 is essential to capture data requirements at each phases and step by step and provide a specific Streamer MVD as an xml file. It can also supply the early design configurator with requirements

2. The design stage (detail level)

At this stage, it comes to detail, and first choices made in the previous step are to be confirmed. The amount, and level of detail of the data available thus allow to produce more detailed simulations.

The issue concerns now the thermal engineer who has to control the validity of input data and the different simulation parameters because he must guarantee the results.

a. Architectural

In this first step, architectural description is detailed and energy aspects are described in a simple way (global level).

Among useful simulation (and pre-processing) tools, we can mention:
- Revit + Openstudio + Energy+,
- Revit + Sefaira + Energy+,
- Intermediate tool from CEA with Energy+,
- Revit + internal energy module,
- ArchiCAD + internal energy module,
- VABI-Element,
- Intermediate tool from CSTB with TRNSYS,
- IES-VE,
- RIUSKA,
- IDA-ICE,
- UNIFE/EFAF-MC4HVAC and MS IMPIANTI

b. HVAC engineer

This is the stage to optimize the chosen systems in the early design stage. Energy calculation tools are very accurate and it is definitely the maximum quality.

Among useful simulation (and pre-processing) tools, we can mention:
- Intermediate tool from CEA with Energy+,
- VABI-Element,
- Intermediate tool from CSTB with TRNSYS,
- IES-VE
- RIUSKA,
- IDA-ICE,

5.2 List of criteria

The first idea was to develop a list of criteria that would allowing us to select the most integrated software in a BIM workflow among the rather exhaustive list presented in appendix 1. However, during our discussions, we found that the choice of simulation software was bound, in the most of the cases, to its performances in terms of calculation:

- accuracy of the results compared to reference values (experimental studies, analytical calculation)
- Suitability of the tool with regard to a national regulations
- Calculation time

The idea was not to qualify again the software already tested and used by partners in many studies during the past, or to develop new simulation software.

We thus took a new orientation consisting in identifying tools approved by a large majority by the WP 7 partners who will do the simulations in the different experimental operations. These tools are:

- TRNSYS
- VABI-Elements
- IES-VE
- ENERGYPLUS
- UNIFE/EFAF - MC4HVAC and MC Impianti 11300

In the same time, we also wanted to indicate other interesting tools which all have an import functionality of a BIM format and we invite the reader to have a look on these software and to follow future developments to be made in the coming months by different software editors (this is notably the case of **IDA-ICE** that appears to be the most integrated in BIM workflow).

Criteria, which are presented in the following table, can be summarized in three points:

- Input (geometry, properties component)
  - o The possibility to read BIM format
  - o The kind of data retrieve from BIM format
- Additional data (material, weather, HVAC)
  - o We saw in the chapter 4, the access to external database (via an intermediate tool) can be necessary to build an input file for simulation tool. For this purpose, it is interesting to know if the data concerning the weather, the materials, the equipment and the simulation file are accessible through the only simulation software or by an API either by their text file status. It informs us about their degree of accessibility by external tools.
- Output
  - o The kind of output format
  - o The possibility to have output in BIM format

We present below the list of criteria:

THEME	CRITERION	Example
Building geometry Definition	Possibility to import geometry?	IFC, gbXml, other
	Possibility to define its own thermal zones from "spaces or room"?	
	Is it necessary to define "spaces or rooms", or "thermal zone" to launch the simulation	
	Does the simulation software recognize the "space or room" adjacency, or "thermal zone" adjacency?	
	Is there any restrictions on the shape of "Space or room", or "thermal zone"	no inclined wall, …

	Question	Answer
Weather Data	Is, a floor structuration, mandatory?	
	Weather file format?	Any hourly weather file can be used
	Is there a default weather file?	
	Frequency of weather data sampling (hour, day, …)	
	Weather data are they accessible by using a specific API or via a text file (human readable)?	
Material Data	Material data are they accessible by using a specific API or via a text file (human readable)?	
	Material file format?	
	What kind of recoverable material data ?	U-value for wall, conductivity (if present), …
HVAC equipment	HVAC equipment file format?	
	What level of detail for HVAC equipment?	general requirement, detailed, …
	HVAC equipment data are they accessible by using a specific API or via a text file (human readable)?	
Output	Which kind of output	temperature, Heat and cooling needs, hygrometry / comfort, DHW, …
	Frequency	hourly values, daily values, …
	Results are they accessible by using a specific API or via a text file (human readable)?	
	Are the results post-treatable by an algorithm to calculate KPI's	
	Possible to obtain output of "sensitivity analysis" type?	

This approach has the advantage of offering to thermal engineers a smooth transition towards an integrated approach. Indeed, we have seen in some countries that BIM had difficulty to break into the building process. This is partly explained by the fact that the solutions were often imposed. In the context of simulation tools, this approach is not intended to impose any particular solution, under the pretext that it was better integrated into the BIM process, but rather to estimate the work required so that software used by partners can exploit at best BIM format.

For this purpose, the need for improvement have been identified for most of the selected software and presented below.

Given the number of selected software, we decided to not include in this list those dealing with the neighborhood level, which is also addressed in D6.3.

5.3 Software description
5.3.1 TRNSYS

TRNSYS [TRNSYS] is an energy simulation program whose modular system approach makes it one of the most flexible tools available. It includes a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. This simulation tool is used for analysis and sizing, multi-zone airflow analyses, electric power simulation, solar design, building thermal performance and analysis of control schemes.

Strengths

Due to its modular approach, TRNSYS is extremely flexible for modeling a variety of energy systems in differing levels of complexity. Supplied source code and documentation provide an easy method for users to modify or add components not in the standard library; supplied time step, starting and stopping times allowing choice of modeling periods.

It offers the possibility to the user to create himself his own components.

TRNSYS also interfaces with various other simulation packages such as COMIS, CONTAM, EES, Excel, FLUENT[7], GenOpt[8] and MATLAB.

Figure 23 - TRNSYS environment

Weaknesses

No assumptions about the building or system are made (although default information is provided) so the user must have detailed information about the building and system and enter this information into the TRNSYS interface.

No user friendly interface.

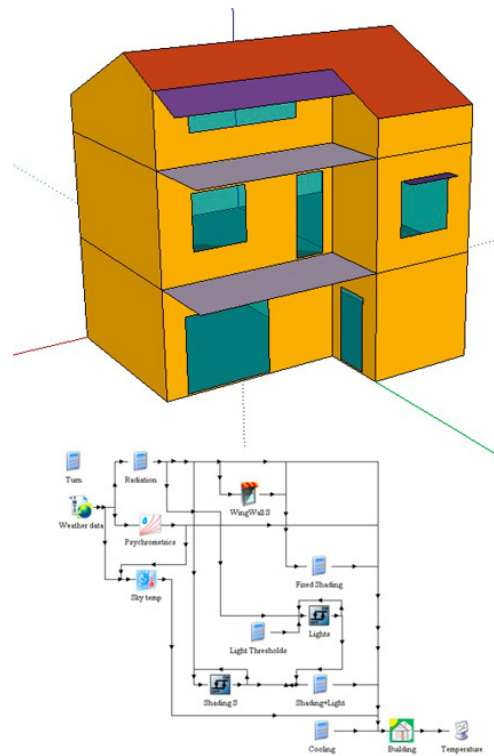
[7] Flow modeling simulation software using CFD
[8] GenOpt is an optimisation program for the minimization of a cost function that is evaluated by an external simulation program.

D3.3 Review and benchmarking of energy simulation tools – February 2015 · 32 - 101

STREAMER

Building geometry definition:

Today, the modular aspect of TRNSYS can mix 2D and 3D description of a building. Generally, the building is not described in full 3d. Only extreme cases will be given special attention (Atrium, top floor facing north and south side ...).

2D description consists in indicating the area (m²) of the exchange surfaces between the different spaces (or thermal zones) and the name of adjacency zone. Space definition is then mandatory because all the energy analysis in based on these spaces.

Google Sketchup is used for the 3D description and/or to visually check the geometry. The model is then described as 3D surfaces (walls don't have any thickness) and we must indicate the 3D coordinates of the exchange surfaces between spaces (or thermal zones).
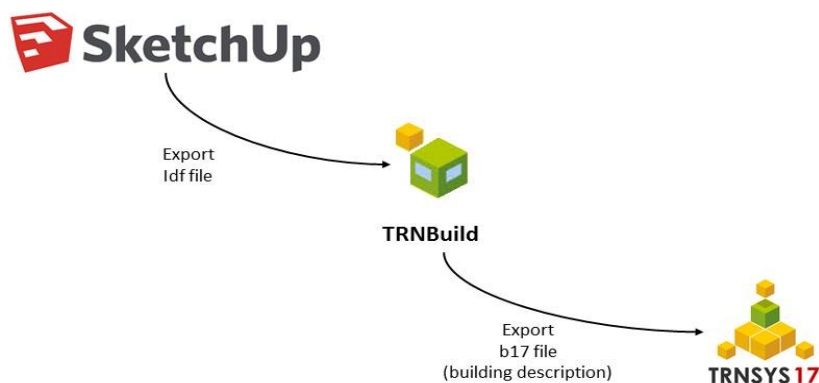
Fig. 24: 3D description for TRNSYS

CSTB is developing an intermediate tool which is able to read an IFC file in order to prepare an input data file for TRNSYS. Today, the geometry description is a 2D description but a 3D description is the next objective.

Weather data

The weather data file is a readable text file.

Material Data

The material properties for wall layers are described with the three following readable text files:

- **Prglay.lib**: Grouped by "material family", contains the material layer name and the conductivity, the capacity and the density of material.
- **Prgwlay.lib**: Grouped by wall type, contains each layers with the thickness and material properties are given.
- **Prgwall.lib:** list layers name for each wall.

In addition, the user can create his own wall composition and store it in a file called usr_wall.lib and his own material layer properties in the file usr_layer.lib.

- **PrgWin.lib**: thermal properties for window.

These files could be used:

- To add some thermal properties for each material layer found in the IFC file (wall composition is then given by the IFC - name and thickness for each material layer).
- To create and associate a user wall composition to the IfcWall (wall composition in then created by the user by associating material layer from the Prglay.lib and thickness).

HVAC equipment

For each component, parameters are described in an HTML file (**proformat file**). Equipment's parameters could be thus exposed into the interface of the intermediate tool by reading these "proformat" files but a template file is needed (see below).

Simulation input file

Either to simulate the behavior of the building envelope, or the behavior of MEP equipment, a template file is mandatory because it contains the connections between all the "black boxes" that we can see in the diagram below:
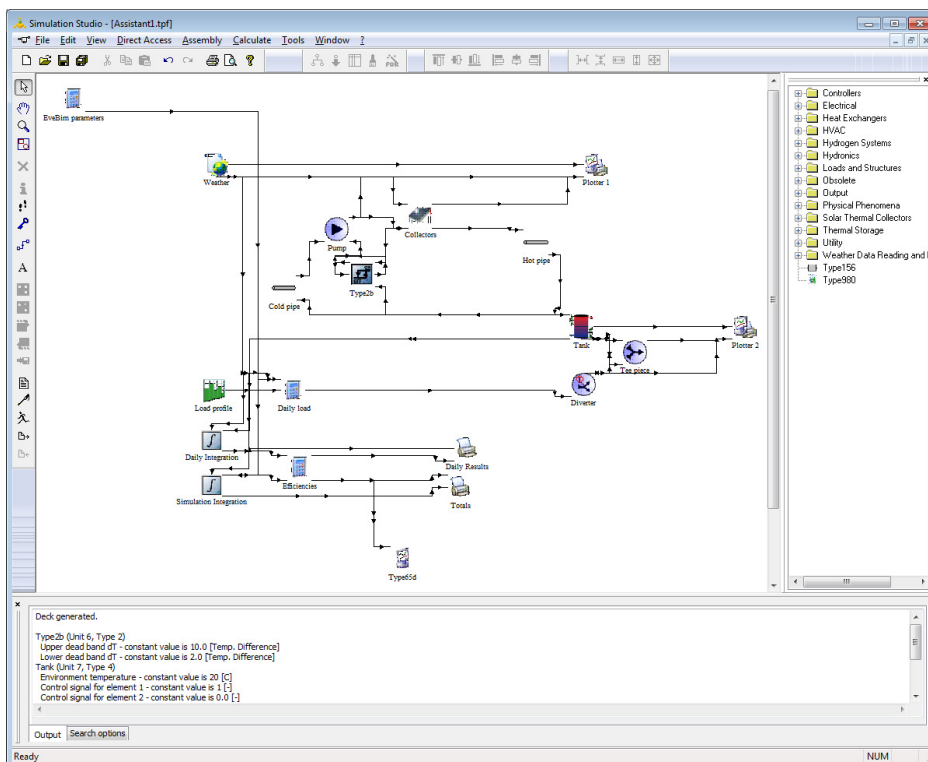

Fig. 25: simulation Studio environment for TRNSYS simulation

Each box corresponds to a mathematical model that describes the equipment's behavior. A complete system is thus constituted by the "cabling" of a certain number of boxes. Let us indicate that some of them have no "physical" existence but is rather "numerical" objects (addition of signals for example). These objects are not transferable to a BIM format and therefore justify the creation in advance of a template file as a *.dck file for TRNSYS.

Simulation of equipment in TRNSYS would therefore be done by creating a template that the engineer will then complete using the intermediate tool with building data retrieved from the BIM.

Output

The results are generally given by hourly step in a text file.

There are approximately 200 types of output regarding the behavior of the building (all data related to temperature, Heat and cooling needs, hygrometry / comfort …).

Main Locks

The main locks are:

- The presence and the geometrically coherent definition of all the spatial boundaries of a space (or a thermal zone).
- Transform a 3D solid description (from IFC format) of the space into a 3D surface description [TRANS-IFC2IDF-2007] using a dedicated intermediate tool to redefine space boundaries as solution example given by Bazjanac [SB-2010].

  In an IFC file, spaces are separated from each other by walls or slabs with a thickness. In a 3D surface model such as we can generate with Sketchup, walls and slabs don't have any thickness and the thermal zones are in contact with each other.

  If we wish to verify the input 3D model for TRNSYS by using Sketchup, it is thus necessary to be able to transform the 3D solid geometry of the space into a 3D surface as presented in the picture below:
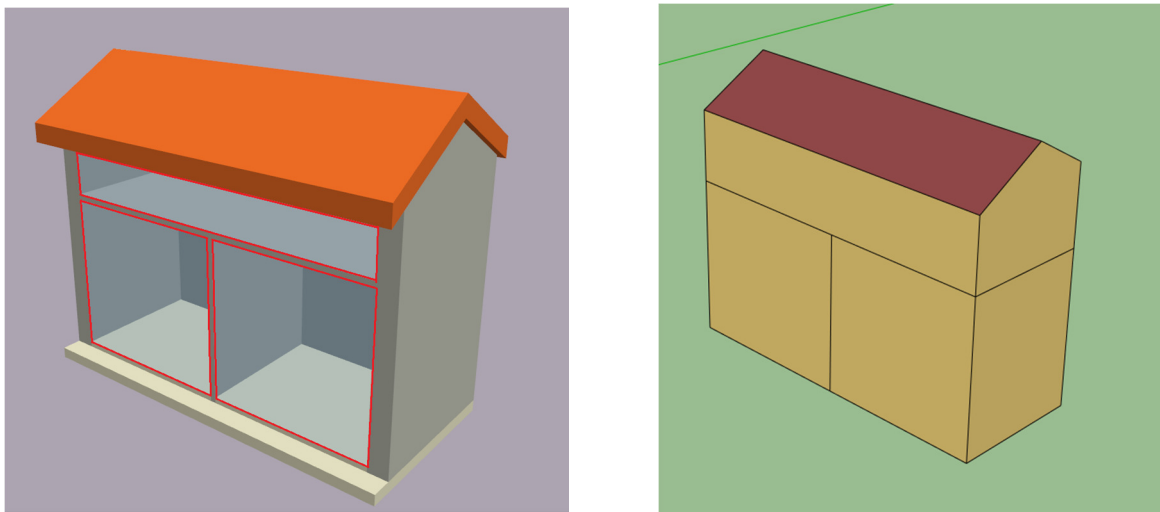

Fig. 26: difference of zone definition between IFC file and Google Sketchup

- Consideration of equipment.

Software specifications

- Develop a mechanism for associating either the thermal properties (conductivity, specific heat capacity, density from the Prglay.lib file) to an IFC material (referred into material layers in the walls, slabs or door), or a wall composition (described in prgwlay.lib and prgwall.lib files) to a wall in the IFC file.
- Develop a mechanism for grouping spaces into thermal zones.
- Transform a 3D solid description of the space into a 3D surface model.
- Develop functions to verify that the data required for the simulation have been filled.
- Save data provided by the engineer in the IFC format (with associated external files if necessary).

5.3.2   VABI-ELEMENTS

VABI-Elements [VABI] is an energy simulating program usable in different design stages. The output is a 3D visualization or detailed energy calculation report. Typical calculations are like heating and cooling design calculation, evaluating thermal comfort conditions and computed energy demand. VABI-Elements has a user friendly interface and allows the user to have a fast development in the BIM-flow. It has a strong position with connection to (Dutch) legislation.

Building geometry definition

The geometry can be imported from an IFC file. If necessary, the IFC file can be corrected, or enriched (to add missing space for example). To realize these corrections, Revit is used to edit the 3D model (it could be done with any other CAD tool possessing an IFC export):
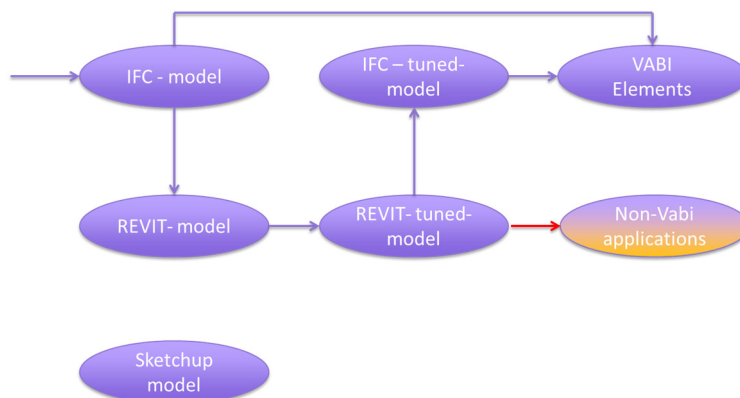

Fig. 27: context IFC/Revit with VABI

As for Trnsys (and many other simulation tools), it is necessary to define "spaces or rooms" in IFC. On the following picture, we can see that not all relevant information is yet retrieved from IFC to supply VABI:
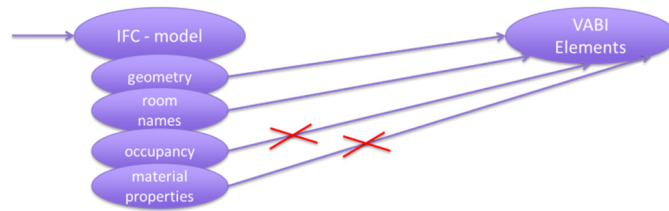
Fig. 28: data exchanged from IFC to VABI

The 3D solid geometry description from IFC is transformed into a 3D surface description:
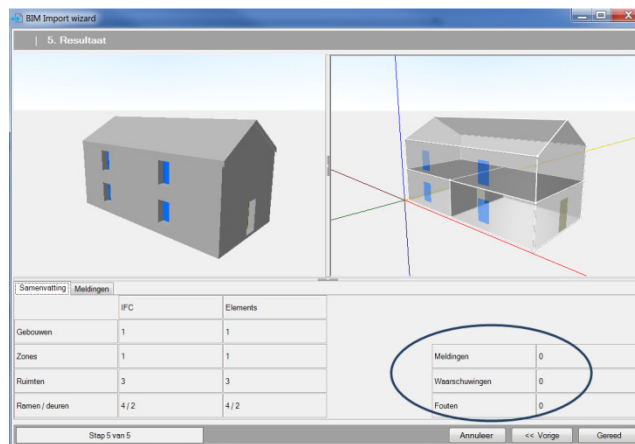
Fig. 29: geometry imported in VABI-Elements

With possible corrections directly into VABI:
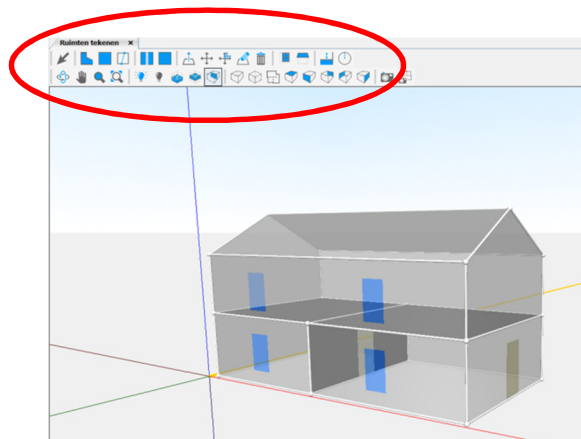
Fig. 30: functionalities to correct geometry with VABI-Elements

Material Data

The material data is not retrieved from the IFC. As the imported geometric model is a 3D surface model, it means that walls separating the different zones do not have any thickness; it is then possible to assign material layers and an overall thickness directly in VABI from an embedded material file (readable text file).
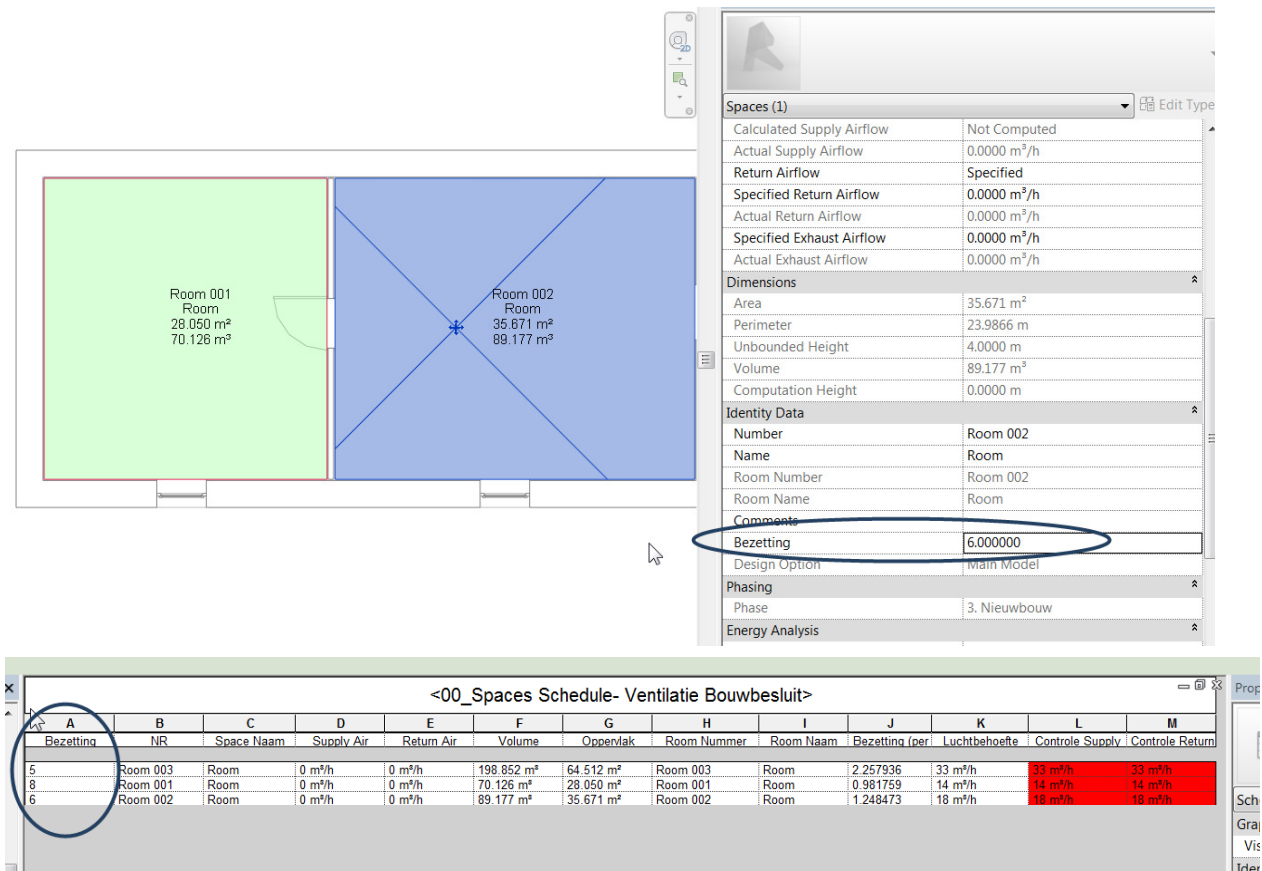
Fig. 31: adding information in Revit

HVAC equipment

The description of HVAC equipment is fairly simple in VABI. For example, it does not allow to simulate a power plant.

Simulation input file

The preparation of the simulation uses a template corresponding to the available choices (see figure below) when opening a project:
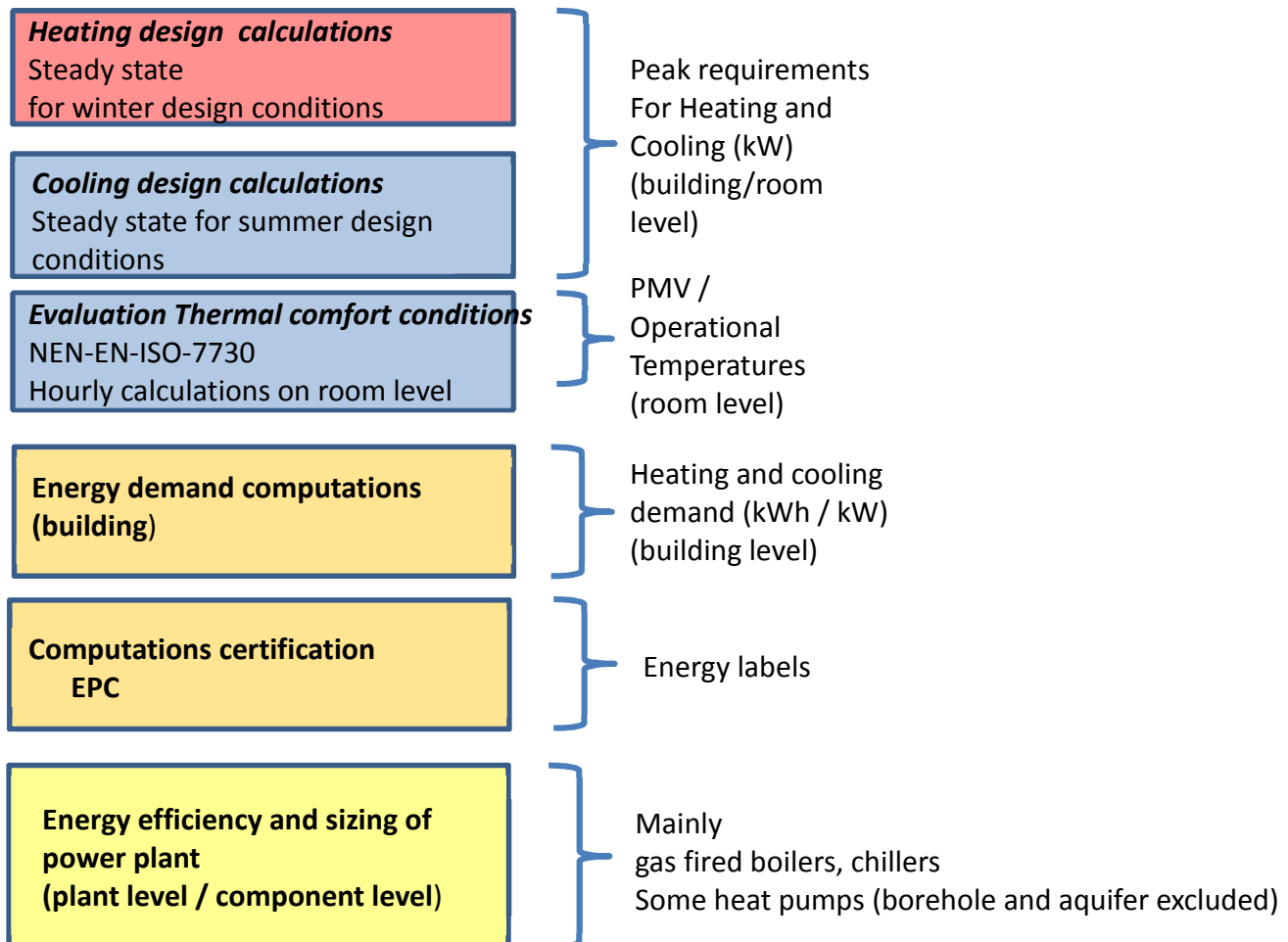
Fig. 32: VABI-Elements as design tool

The contents of the input file are accessible in VABI.

Output

The results are generally given by hourly, daily, monthly or annual steps in a text file.

Examples of results:

- Indoor temperature, heating and cooling needs, hygrometry / comfort, DHW,
- Heating design calculations (in Dutch: warmteverliesberekeningen)
- Cooling design calculations (in Dutch: koellastberekeningen)
- Thermal comfort evaluation on room level (in Dutch: temperatuuroverschrijdingsberekeningen)
- Certification tools (Energy Performance Coefficient according to Dutch legislation).

Workflow in the software VABI Elements

- **Project definition**

What kind of computations to perform and variants definition (glazing percentage, orientation, etc.).
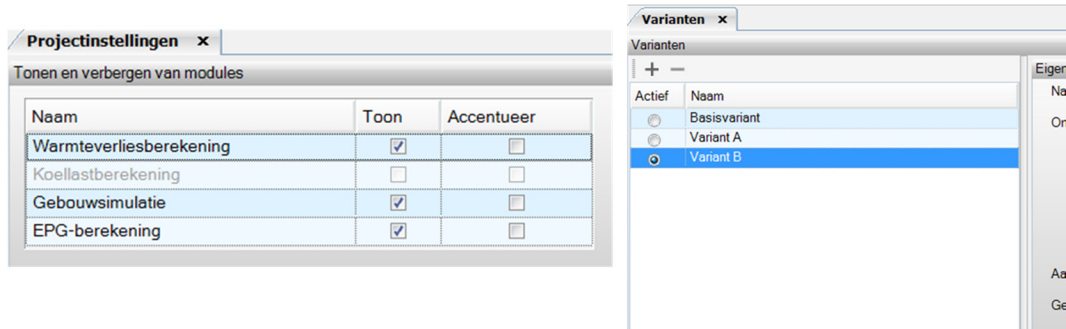
Fig. 33: Project definition with VABI-Elements

- **Adding schedules and material properties**
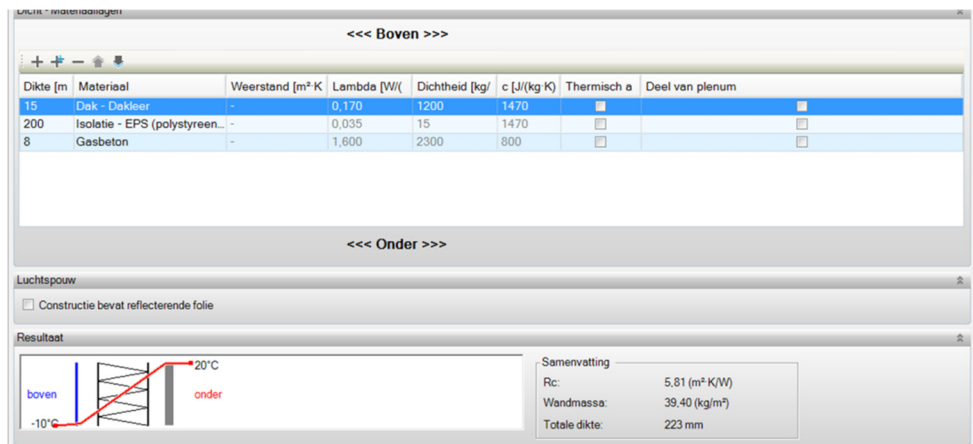
Fig. 34: adding material properties with VABI-Elements

- **Coupling schedules and properties**

  Templates   Library   occupancy schedules,

                                                        ventilation schedules etc.
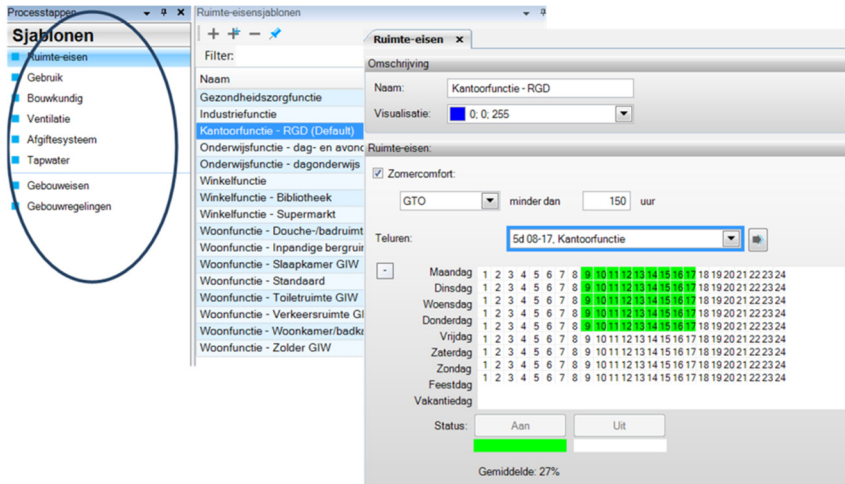
Fig. 35: coupling properties and schedules with VABI-Elements

- **Fine-tuning of geometry**
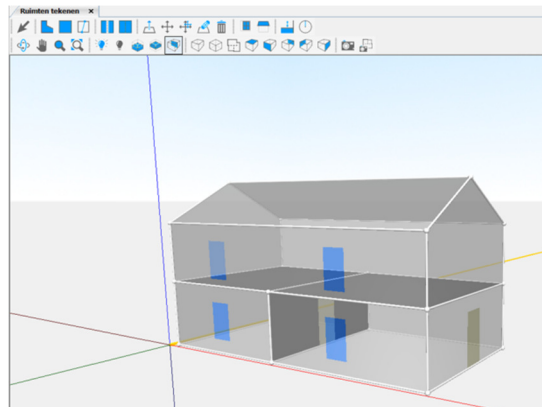
Fig. 36: tuning geometry with VABI-Elements

- **Coupling schedules and properties to rooms/spaces**

Concept of templates opens perspective for energy profiles as defined in STREAMER

Fig. 37: coupling schedules and properties with VABI-Elements

- Results heating design calculation
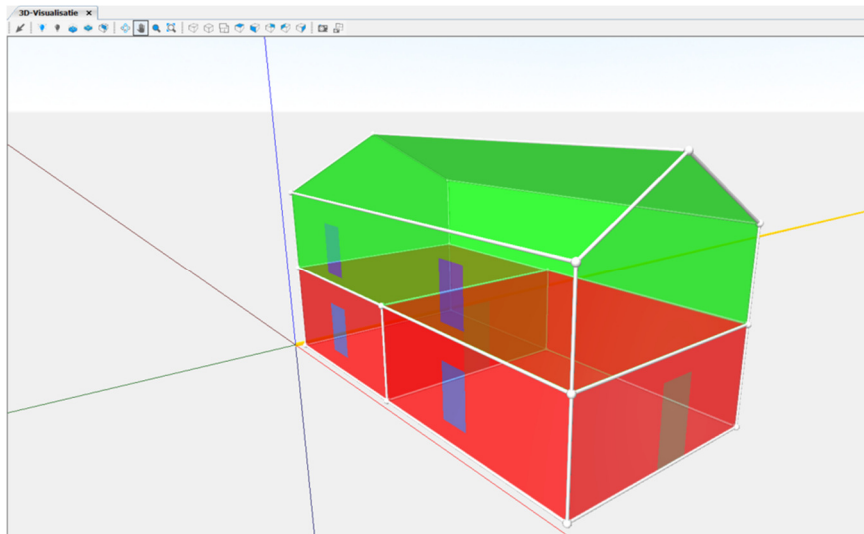
Fig. 38: 3D results with VABI-Elements

Further developments / Software specifications

- Retrieve more information from IFC, for example glazing percentage, etc.
- Save data provided by the engineer in the IFC format (with associated external files if necessary).
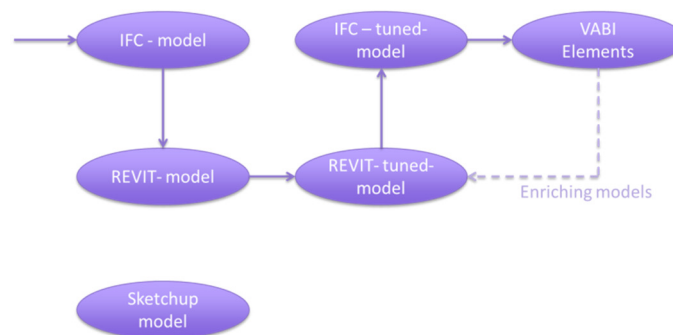
Fig. 39: enrich model from VABI

5.3.3   IES-VE

IES-VE [IESVE] is a robust and flexible simulation tool that offers a complete package of modelling solutions via a series of software modules. It features a graphical interface for modelling or import/export of building geometry, simulation modules for thermal, daylighting and energy studies, standard or custom HVAC equipment selection and renewable technologies. The software is typically used for analysis and system sizing, either via steady state analysis or dynamic modelling, whereby dynamic studies can be performed to assess complex natural ventilation, energy consumption or daylight linking of lighting. Results from modelling are clear, concise and easily transferred to other software packages.

Strengths

IES-VE is a complete package with good user interface, designed to simulate all aspects of a building's design and HVAC systems. As the software is modular the user can either opt for simplified modelling (which allows for quick and accurate model development), or detailed analysis (by adding on further modules to enhance the overall accuracy of the simulation). The software is well established and there are a great number of user guides and support from the forums. Finally the software has good links with gbXML, and is developing IFC support.

Weaknesses

The source code is unavailable as it is a commercial piece of software, therefore it can be hard to understand certain aspects of calculations happening in the background. Geometry import (particularly gbXML) is not perfect and therefore it is often preferable to produce a simplified model outside of the import process.

Building geometry definition:

Building geometry is easily created within the software via the GUI, producing full 3D geometry from 2D floor plans. However geometry can be imported from BIM packages via gbXML as well. Furthermore there is a standalone plug-in for Trimble Sketchup, that allows for complex geometry to be imported into IES:VE, which is particularly useful for modelling complex shading and geometry. IFC support is being worked on.
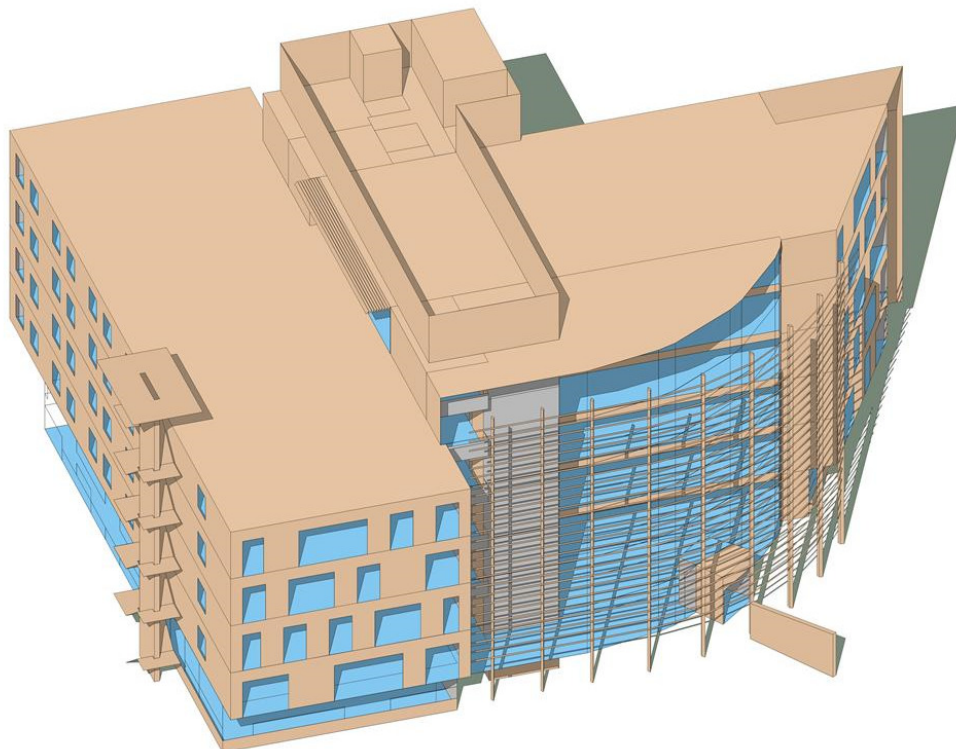
Fig. 40: Example Complex Geometry Imported From Sketchup

Weather Data

Weather files are contained in .fwt format for UK building regulations compliance, however the software will also accept .epw weather files.

Material Data

Material data is either selected from the existing database of constructions, created manually, or can be imported from gbXML data. This can be exported as a text file to be used elsewhere.

An advantage of the IES:VE is its intelligence in identifying from the building geometry which surfaces represent walls, roofs, floors etc. which therefore allows for the model to be constructed faster and eliminate potential errors.
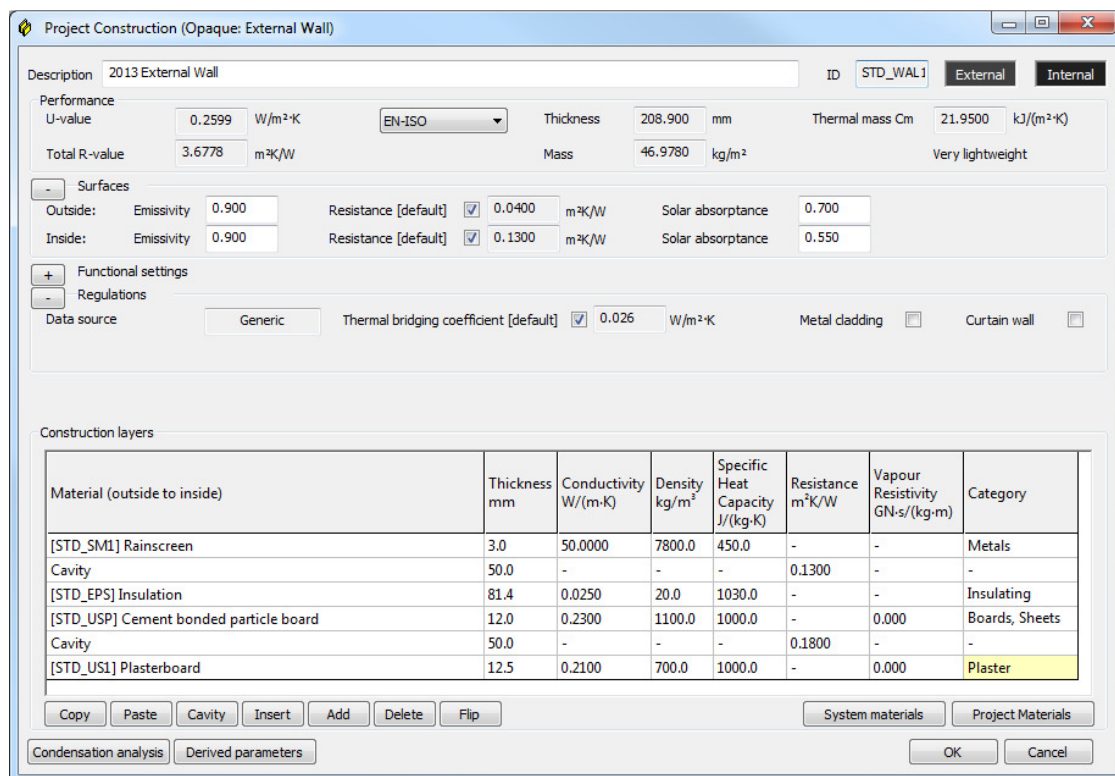
Fig. 41: Material Data for External Wall Construction from IES:VE

HVAC equipment

HVAC equipment details can be entered in two ways. The first is relatively simple, allowing simple characteristics of the system to be identified (e.g. boiler/chiller efficiencies). The second allows for construction of complex interacting HVAC systems (such as the relationship within an AHU and FCU based system).

- This approach is another benefit of IES:VE as it is not necessary to complete the more complex HVAC system when it is not required.
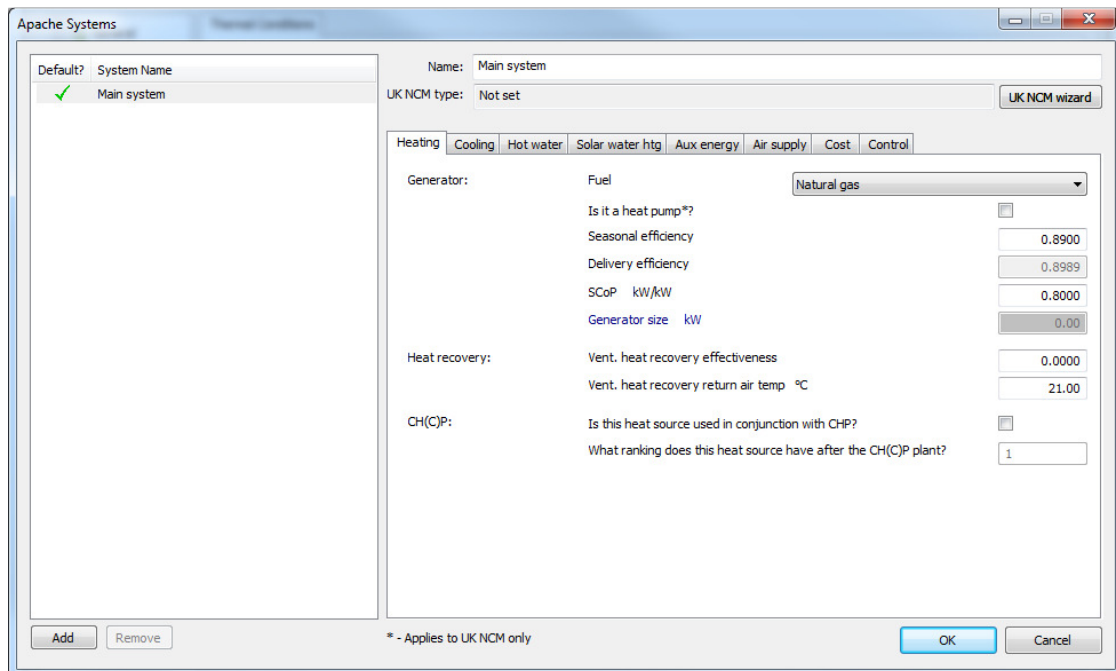
Fig. 42: IES:VE Simple HVAC Data
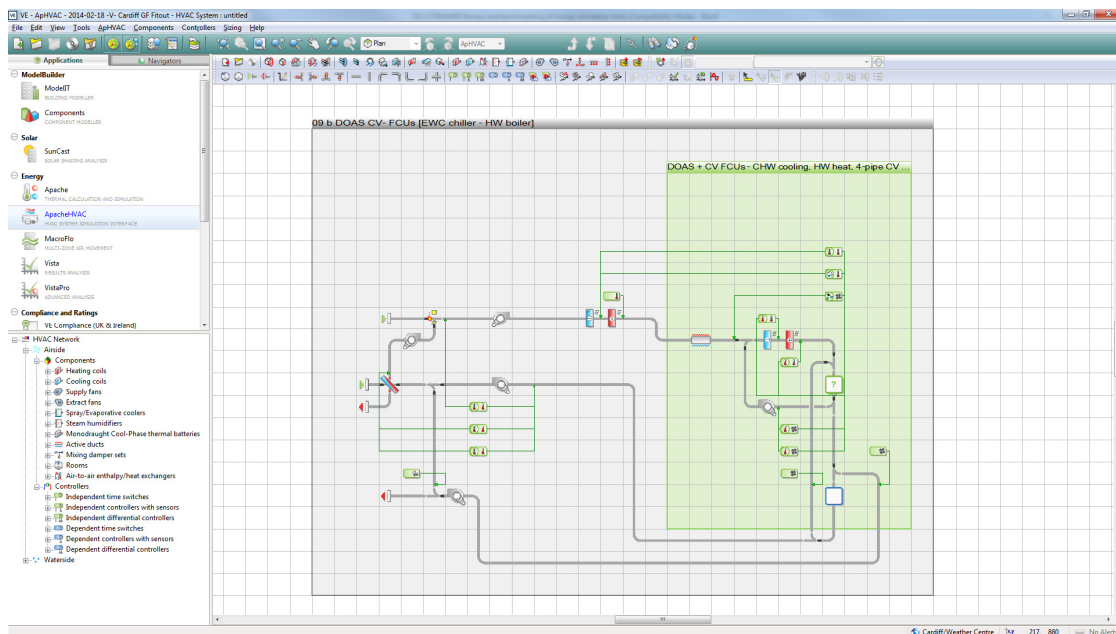
Fig. 43 Complex HVAC System

Simulation

When performing a simulation, layers of complexity can either be added or subtracted from the model depending upon the type of analysis being performed and depending on the user licences available. Examples include:

- Suncast support for accurate shading simulation based on building location and adjacent buildings
- MacroFlo to simulate complex airflows within the building (for natural ventilation scenarios)
- ApacheHVAC support for complex HVAC simulation
- Radiance to account for lighting/daylighting simulation

Various simulation parameters can also be set, such as a variable timestep, reporting interval and preconditioning period of the model. Furthermore there is support for batch simulation.
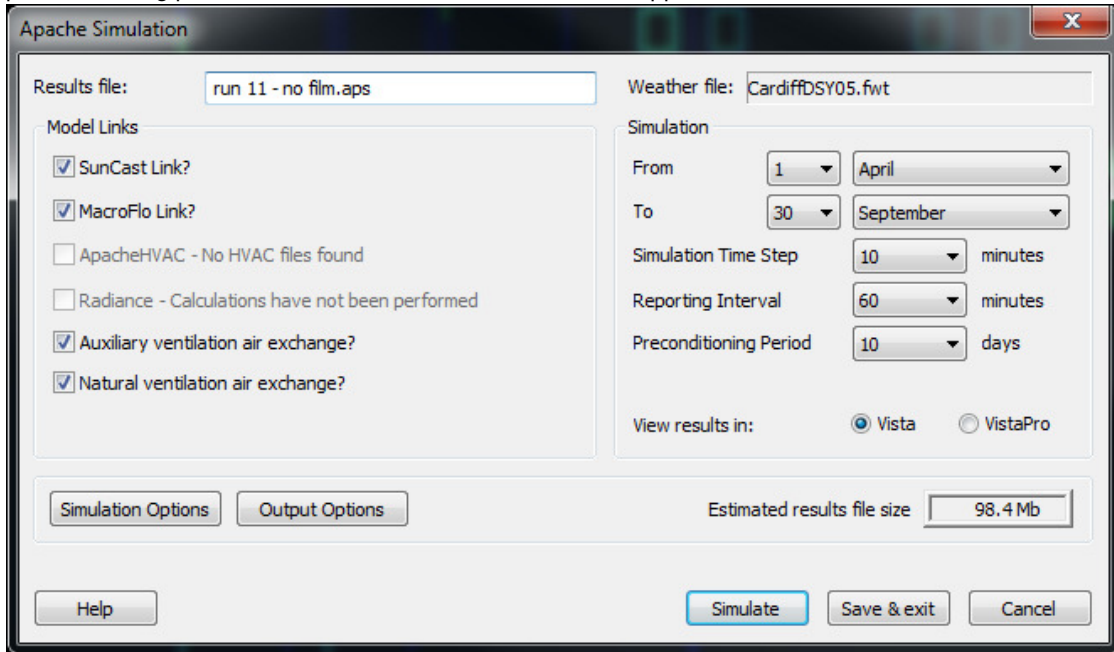
Fig. 44: IES:VE Simulation Selection

Output

Results can be produced at either 6, 10, 30, or 60 minute intervals, although typically 60 minutes are acceptable.

Outputs range from building level data such as loads or energy consumption, down to room level such as temperature or internal gain. Furthermore environmental data is included such as solar gains and inner/outer surface temperatures which can also form the basis for CFD analysis.
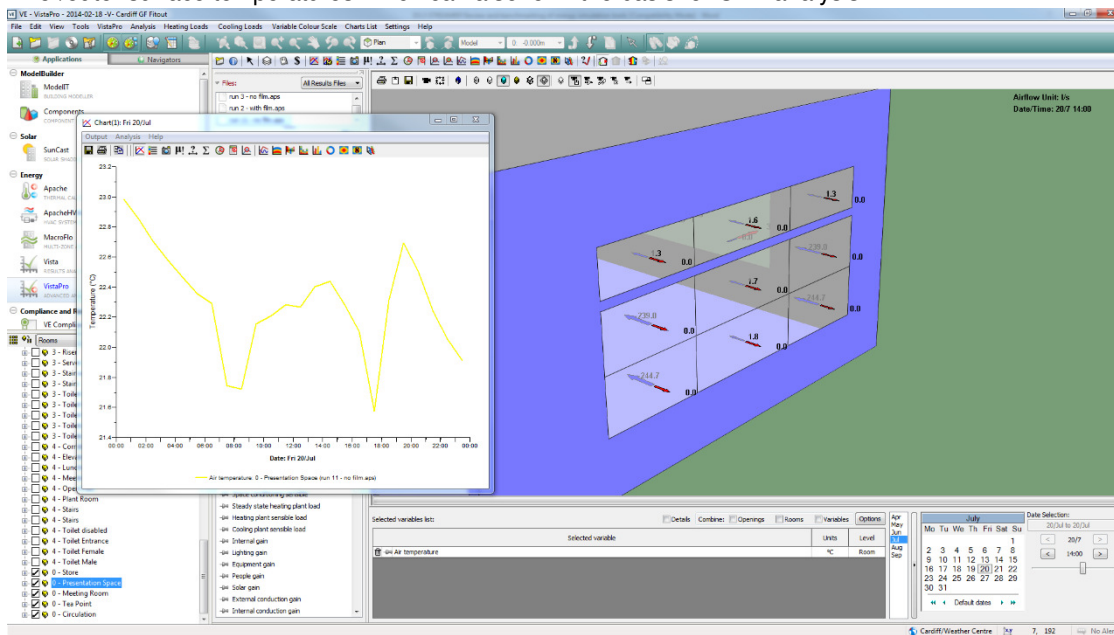
Fig. 45: IES:VE Results - Air Temperature & Airflow Through Windows

Range of use

IES:VE can be used throughout the design process from concept to detail to operational design.

The main challenges in creating a successful simulation particularly with relevant to BIM processes are:

- BIM functionality is currently only possible with gbXML format data, and this has been optimized by the software developers to work more efficiently from certain software (e.g. Revit in particular). This means gbXML is supported, but when using an alternative source its compatibility is not guaranteed.

- The geometry translation is challenging in general, either via gbXML import (which is often not perfect) and requires 'healing', or via manual creation (hence relying on the user skills, plus interpretation of the architectural model/drawings).

- The BIM process is currently only one way – i.e. export of geometric information from a BIM package. It is currently not possible to reference other variables. Similarly to get simulation information back into the BIM model, it requires heavy modification of data (e.g. using Excel-link with Revit) which leaves possibilities for errors.

- In theory a perfect export would be to have the geometric information, building fabric parameters, room variables (e.g. people, lighting, equipment), and HVAC information so that the model could utilize these in running a model.

- Knowledge of the limitations of the software. Whilst the software is very advanced, due to its closed nature (not open source) it can be difficult in transferring real world HVAC data into the simulation.

- Some software modules have not been developed for a significant time, and therefore can cause the simulation process (when running a model) to take time to complete a run.

Software Specifications

- Develop geometry either in IES:VE software, or import from gbXML
    - 'Heal' as necessary to ensure a working model – 'healing' can be done via automated software processes in-built into IES:VE to fix common issues, however it is common to have to delete and redraw geometric zones as it is impossible to heal perfectly.
    - The software programmers have been aiming to improve this process, but it acknowledged that perfect geometry sharing between packages is unlikely – and that user involvement will be required to develop the model manually.
- Modify and refine constructions
    - This involves the creation/refinement of the building fabric constructions
    - Limited information is pulled through from the BIM model – and again this is something that the software programmers are hoping to improve upon as the information is (or can be) contained within the BIM model.
- Create/refine the HVAC systems
    - This step represents the creation of HVAC systems
    - Currently no information is pulled from the BIM model, and again this would be advantageous

- HVAC system selection could be on a 'sliding scale' of accuracy (i.e. simple information for early models, then detailed for the final design/build)
  - Much of this process is based upon manually interpreting manufacturers data – unfortunately it appears that it will stay this way as manufacturers are keen to hold onto performance data due to its commercial sensitivity.
- Add additional analysis as necessary (e.g. solar shading, natural ventilation, daylight linking)
  - IES:VE is very scalable in this regard, which enhances the accuracy of the simulation (e.g. there is limited requirement for having natural ventilation simulated when a building is fully air conditioned)
- Run simulation for desired period
- Analyse results either within software or export to other packages

Currently the biggest issue facing IES:VE is the successful import of geometric data. This process has been improving over time, but it is acknowledged that often the best zoning of a building is done by hand rather than importing from a BIM model. Currently the BIM import process is limited to geometry only, but there would be a significant advantage to setting up the majority of components within the BIM environment and exporting to IES:VE to simply run the required simulation. Unfortunately as the software has sections which are quite old and underdeveloped, plus it is a closed source commercial package, it is appears unlikely that we will see jumps in the quality of BIM data appearing within IES:VE.

5.3.4 UNIFE/EFAF-MC4HVAC

This tool consists in a step-by-step procedure that derives from a combination of two tools, the first developed by EFAF (the Laboratory of Energy of the Department of Architecture of the University of Ferrara) over a standard Excel platform, the second, is commercial energy software: HVAC MC4 [MC4].

The tool allows a full simulation of even composite structures and facilities such as hospital pavilions, permitting a final cross-check verification of the results and a general validation of the building thermal model as well.

The HVAC-software tool has a graphical interface, the EFAF tool, instead, uses excel sheets. Both EFAF and MC4 have simulation engines, and specific libraries of building components.
Given the same input data:
- building envelope material (transmittances) and geometry data,
- description of homogeneous plant thermal zones in terms of their position, surface and volume,
- weather data,

One can run the energy simulations in parallel with the two tools, yielding the highest thermal instantaneous demand [power] and/or the thermal requirements on a certain timespan basis [energy] as a result.

The comparison of the two results allows a first direct cross validation of the reliability of the building digital model. At this step, the official figure between each pair of values can be chosen in accordance to two alternative procedures.

In the first case, each figure is determined through a simple arithmetical average of the values pair. However, when the gross consumptions of the facility, in terms of fuels, are available, or when the reading of the power meters are provided, a third control-number for each pair can be determined through a top down procedure that, departing from the real primary energy demand, yields the correspondent thermal value considering the average efficiency of the plant. A human operator shall then scrutinize the initial double results, choosing among them the value that best approximates the third control-number.

This last process, when feasible, allows a keen verification of the reliability of the building digital model, built on the two platforms EFAF and MC4. Thermal requirements are calculated in accordance to a quasi-steady state model, simulating that the outdoor temperature varies on an hourly basis, whereas the indoor one fluctuates around a design temperature set on the typical end use that take places into a certain thermal zone. The results are then compliant to the EN ISO 13790 and EN 15603 norms.

The EFAF tool has a specific sheet to run the final step: given the input of the thermal data computed in the previous step, and setting the efficiency of each transformation process that take places in the energy supply chain, it is in fact possible to determine the required primary energy (or instantaneous power) data.

Hence, the final step of the procedure leads to the calculation of the primary energy requirements of each selected part of the building in a given timespan, both for verification of historical data of the facility, or for testing the effectiveness of a certain design option in terms of energy savings.

The first situation, for instance, is ideal to verify if and when there have been wastes and/or inefficiency in the energy management of the pavilions (e.g. a mismatch between the expected primary requirements from the models and the values read from the bills is, in fact, a first immediate feedback that demonstrates the existence of wastes). In the second case it is immediate to test if an intervention is desirable or not, thanks to the building 3D model.

Strengths

The step by step approach allows several cross check controls during the whole process. Past research experiences on hospitals have demonstrated that the building digital models, resulting from such a procedure, are very solid and that the findings of the simulations well match with the historical primary energy figures, when available.

Once the building model has been set, the tool is extremely flexible for modelling and testing the effectiveness of a variety of energy good practices even of a certain complexity. This is possible simply modifying or adding components in the tools library. The users have the possibility to create himself his

own components and plants. The procedure interacts with Autocad in its MC4 part and is built on standard an Excel platform in the EFAF section.

Weaknesses

- The process is very complex.
- It is not easy to make the two tools interact and sometimes the pairs of figures resulting from simulations show considerable gaps that require the necessity of the determination of the third control number through the bill assessment previously described, but these data are not always available.
- The computations are very time consuming.
- The interfaces of the process are not well structured.

Fig. 46: MC4 environment (hospital of Comacchio – Ferrara)

Building geometry definition

The EFAF tool describes each room of the examined building through tables. MC4, instead allow a full description of the facility in 2D (DXF plans floor by floor).Having added the heights manually a 3D representation is possible to assist the designer providing him a general view of the envelope.

In both cases the user has to input the area (m²) of the exchange surfaces between the different spaces (or homogeneous thermal zones), the elevation of each floors and the surface (and the position, thickness and in terms of its orientation) of each element of the envelope (opaque and transparent).

BECQUEREL ELECTRIC SRL is considering how to implement the procedure increasing the interoperability between the two main platforms in the management of building databases, ad example thanks to IFC files.

Weather data

Weather data are provided in an Excel sheet in the EFAF tool, whereas they are automatically imported by MC4 software once the site location has been defined. These data consist in the outdoor temperature of the 'typical day' of each month of the year, determined over a statistic basic (historical data recorded by official weather stations) in a certain location. They are of fundamental importance permitting to run the simulations in quasi steady state conditions, i.e. considering that the outdoor temperature varies in accordance to statistical recorded data on the typical days, month by month.

TEMPERATURE ESTERNE ORARIE MEDIE (VALORI CNR)

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
GENNAIO	-2,1	-2,7	-3,3	-3,8	-4,1	-4.2	-4	-3,4	-2,3	-0,8	1.0	3.1	5.0	6.4	7.4	7.8	7.4	6.6	5.2	3.7	2.1	0.8	-0,4	-1,4
FEBBRAIO	-0,6	-1,2	-1,8	-2,2	-2,6	-2.7	-2,5	-1,9	-0,8	0.8	2.6	4.6	6.5	8.0	8.9	9.3	8.9	8.1	6.8	5.2	3.6	2.3	1.1	0.2
MARZO	4.0	3.4	2.8	2.4	2.0	1.9	2.1	2.7	3.8	5.4	7.2	9.2	11.1	12.6	13.5	13.9	13.5	12.7	11.4	9.8	8.2	6.9	5.7	4.8
APRILE	9.0	8.4	7.8	7.3	6.9	6.8	7.0	7.6	8.7	10.3	12.1	14.1	16.0	17.5	18.4	18.8	18.4	17.6	16.3	14.7	13.2	11.8	10.6	9.7
MAGGIO	13.9	13.3	12.7	12.2	11.9	11.7	12.0	12.6	13.7	15.2	17.0	19.1	21.0	22.4	23.4	23.7	23.4	22.5	21.2	19.7	18.1	16.8	15.6	14.6
GIUGNO	18.2	17.6	17.0	16.5	16.2	16.0	16.3	16.9	18.0	19.5	21.3	23.4	25.3	26.7	27.7	28.0	27.7	26.8	25.5	24.0	22.4	21.1	19.9	18.9
LUGLIO	22.2	21.6	21.0	20.5	20.1	20.0	20.2	20.8	21.9	23.5	25.3	27.3	29.2	30.7	31.6	32.0	31.6	30.8	29.5	27.9	26.4	25.0	23.8	22.9
AGOSTO	21.3	20.7	20.1	19.6	19.2	19.1	19.4	20.0	21.0	22.6	24.4	26.4	28.4	29.8	30.8	31.1	30.8	29.9	28.6	27.0	25.5	24.2	23.0	22.0
SETTEMBRE	17.9	17.3	16.7	16.2	15.9	15.7	16.0	16.6	17.7	19.2	21.0	23.1	25.0	26.4	27.4	27.7	27.4	26.5	25.2	23.7	22.1	20.8	19.6	18.6
OTTOBRE	11.8	11.2	10.6	10.1	9.7	9.6	9.8	10.4	11.5	13.1	14.9	16.9	18.8	20.3	21.2	21.6	21.2	20.4	19.1	17.5	16.0	14.6	13.4	12.5
NOVEMBRE	5.1	4.5	3.9	3.4	3.1	2.9	3.2	3.8	4.9	6.4	8.2	10.3	12.2	13.6	14.6	14.9	14.6	13.7	12.4	10.9	9.3	8.0	6.8	5.8
DICEMBRE	-0,4	-1	-1,6	-2,1	-2,4	-2.5	-2,3	-1,7	-0,6	0.9	2.7	4.8	6.7	8.1	9.1	9.5	9.1	8.3	6.9	5.4	3.8	2.5	1.3	0.3

Fig. 47: outdoor hourly air temperature provided by weather official data, month by month (EFAF tool)

Material Data

The material properties for walls/windows layers need to be defined in both the tools.

In particular:

- In the excel EFAF tool, one has to input all the necessary main data: thickness, thermal conductivity (associated to the specific material through official laboratory abacus), permeability (as before), tilt angle (e.g. vertical, horizontal, sloping), azimuth angle (orientation with respect to the south direction), solar factor/light transmittance/other glazing parameters in case of transparent items. The software automatically yields the U value for each element of the envelope (opaque or transparent does not matter). In addition, Glaser test is run to verify the absence of vapour condensation within the wall layers.

- In the MC4 software, the material data are automatically imported from IFC databases once the operator select their typology. However, there is still the necessity to define the geometrical and spatial data such as thickness of each layers, tilt and azimuth angles, etc. Again, the output is U-Values for all the elements and Glaser tests as well.
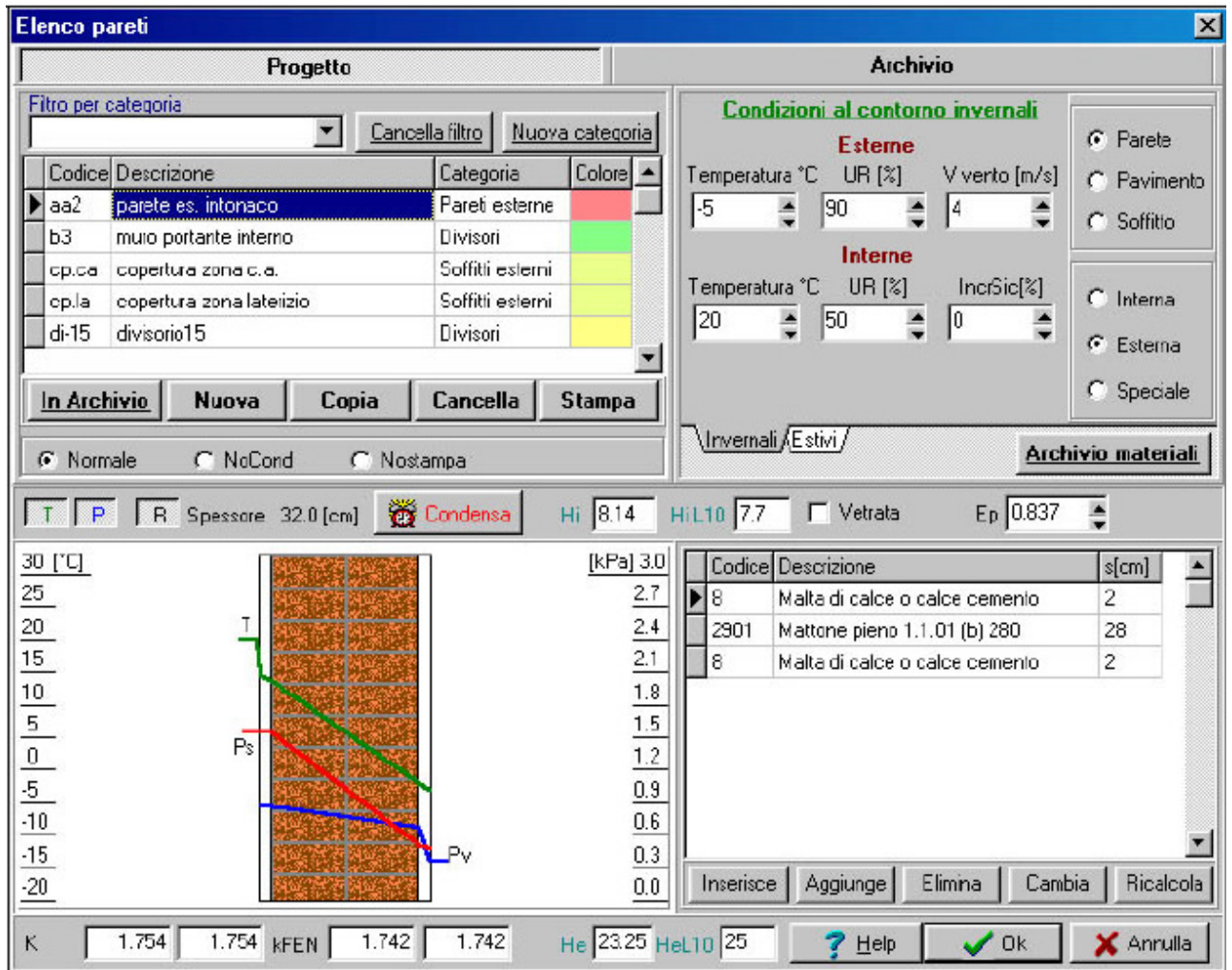
Fig. 48: windows where to input material data (opaque case), automatically calculating U-value for each element of the envelope (MC4 tool)

HVAC equipment

HVAC systems and, in general, all the appliances, need to be input manually in a specific database of excel EFAF tool, with specific reference to their efficiencies and characteristic specifications data (i.e. nominal power, etc).

In MC4 there is the possibility of defining the plant characteristics (e.g. location, typology, setting options) and software automatically assigns the efficiency to the specific process (e.g. distribution efficiency in relation to where the ducts are located in the walls, thermal output efficiency in relation to the kind of distribution systems and terminals, etc).

	POTENZA	TEMPO AL GIORNO IN FUNZIONE	CONSUMO GIORNALIERO SINGOLO IMPIANTO	GIORNI A SETTIMANA	TIPOLOGIA DI FABBISOGNI ELETTRICI
AUTOCLAVE PER ACQUA SANITARIA	>10 KW	24 ore	240 KWh	7	costante durante l'anno
COMPRESSORE ARIA	5-10 KW	10 ore	50-100 KWh	5	costante durante l'anno
COMPRESSORE PER IL VUOTO	5 KW			5	costante durante l'anno
MACCHINA RADIOLOGICA	standard:30-40 KW t.a.c.:100 KW	5 minuti	10 KWh	7	costante durante l'anno
ASCENSORE	>10 KW	16 ore	160 KWh	7	costante durante l'anno
POMPA DI CIRCOLAZIONE FLUIDO TERMOVETTORE	1-10 KW	24 ore	100-240 KWh	7	costante durante l'anno
CELLE FRIGORIFERE	5 KW	24 ore	120 KWh	7	costante durante l'anno
FRIGORIFERO	1 KW			7	costante durante l'anno
CARRELLO SCALDVIVANDE	3-4 KW	4-5 ore	15-20 KWh	7	costante durante l'anno
FORNELLINO ELETTRICO	2 KW			7	costante durante l'anno
VENTILATORE U.T.A.	1-3 KW	24 ore	20 KWh	7	prevalentemente costante durante l'anno

Fig. 49: plants data (Excel table on EFAF tool)

Simulation input file

The input files that are necessary for simulations are related to building geometry, materials, plants and they are normally listed in specific databases. Unfortunately, so far, there are not any connections/digital interfaces that allow importing these data and automatically running the calculations through the two tools of the procedure.

MC4 allows importing data from AutoCAD files when available.

Output

The results are given by hourly steps in a text file (quasi steady state model).

The output is the result of two steps:

- At the end of the first phases (i.e. the ones using both MC4 and EFAF) thermal requirements and/or thermal demand are provided.
- Then at the end of the second phase, the procedure gives the energy requirements in terms of primary energy over a certain period (e.g. typical day, month season, and year). The figures are displayed in tables.

It is possible to calculate the energy requirements for the whole building, or for a part of it such as Department, Floor, or just for a Thermal zone.

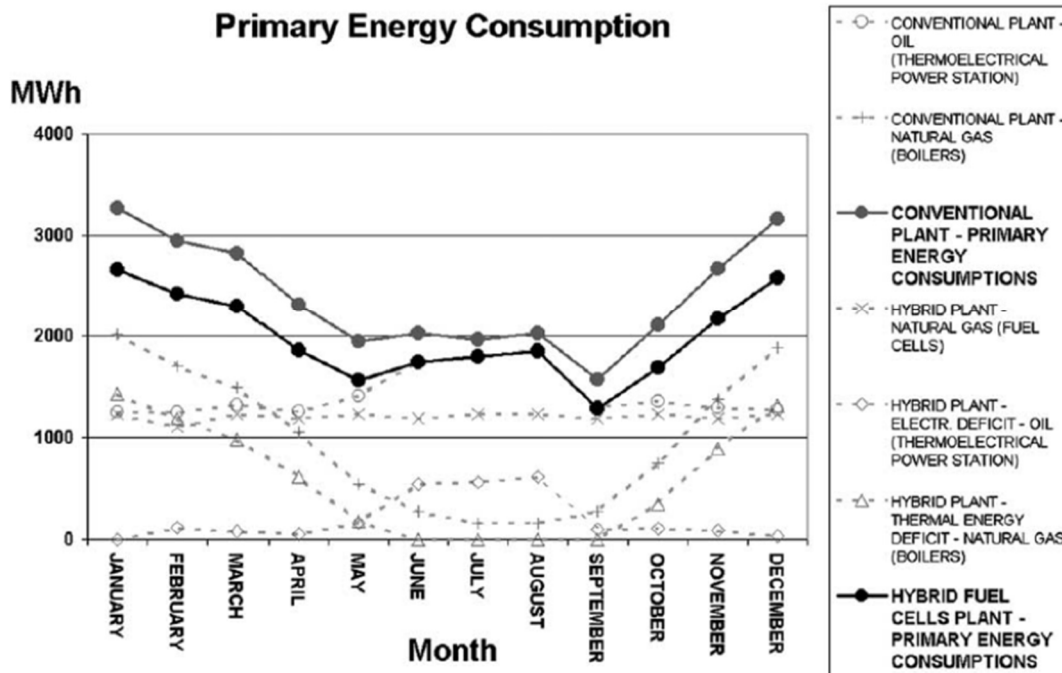*G. Bizzarri, G.L. Morini / Applied Thermal Engineering 24 (2004) 383–400*

Fig. 50: primary energy consumption output

Range of use

Even though the procedure is rather complex, the range of use of the findings is rather flexible since the high reliability of the energy building model. This model results from the implementation of the digital sample, representing the investigated building through the cross-check.

The comparison between the findings of the energy analyses and of the data resulting from the bills reading for instance, is ideal to verify if and when there has been wastes and/or inefficiency in the energy management of the pavilions (e.g. a mismatch is, in fact, a first immediate feedback that demonstrates the existence of wastes).

The keen detail of the building 3D digital model is hence ideal to test and evaluate every energy saving policy being ideal for the design phase as well helping the designer, from the beginning of his work, to choose the best interventions given a certain amount of financial resources.

Main Locks

The main locks are:

- The presence and the geometrically coherent definition of all the spatial boundaries of a space (or a thermal zone).
- Approximations deriving from the transformation of the building 3 D geometrical data and the digital 3 D model built by the MC4 software. Junctions connecting vertical and horizontal elements in particular are not well represented sometimes.
- Representation of plants and appliances.
- Consideration of equipment.

Software specifications

- Develop a mechanism for associating either the thermal properties (conductivity, specific heat capacity, density from the Prglay.lib file) to an IFC material (referred into material layers in the walls, slabs or door), either a wall composition (described in prgwlay.lib and prgwall.lib files) to a wall in the IFC file.

- Transform a 3D solid description of the space into a 3D surface model (MC4 section).

- Develop automatic functions to verify which is the value to be chosen in each pair resulting from the first phase simulation (the ones that yield the thermal requirements).

- Develop automatic functions to determine the primary energy requirements demand when thermal demand and plants efficiencies are specified.

- Save data provided by the engineer in the IFC format (with associated external files if necessary)

5.3.5   ENERGYPLUS

EnergyPlus is a building energy simulation program developed by the U.S. Department of Energy (DoE) [ENERGY+]. It is a whole building energy simulation program to model energy and water use in buildings. It allows to model heating, cooling, lighting, ventilation, other energy flows, and water use inside a building. This simulation can be used for analysis and sizing, multi-zone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes.

EnergyPlus runs mainly from command line, but a GUI front-end for invocation and specification of calling parameters is also provided. A GUI for other activities related to the tool (e.g. building modeling, etc.) does not come with the tool, but third-party GUIs are available [ENERGY+].

When run from command line, input files (building project and weather file to be used) are looked for in the current (working) directory where it is invoked. Tools for building projects editing are available, but allowing only to modify the sections of the building project file (an input text file, as explain in the following); a GUI-based editing tool is not natively available. EnergyPlus relies on external viewers (e.g. Revit or DDS-CAD Viewer) for showing building projects in a graphical way.

EnergyPlus runs on different platforms, namely Windows, Macintosh, and Linux. Free add-ons and other third-party software products are available for use with this tool.

EnergyPlus offers the following features:

- **Sub-hourly, user-definable time steps** for the interaction between the thermal zones and the environment; variable time steps for interactions between the thermal zones and the HVAC systems (automatically varied to ensure solution stability)

- **ASCII text based weather, input, and output files** that include hourly or sub-hourly environmental conditions, and standard and user definable reports, respectively

- **Integrated, simultaneous solution** where the building response and the primary and secondary systems are tightly coupled (iteration performed when necessary)

- **Heat balance based solution** technique for building thermal loads that allows for simultaneous calculation of radiant and convective effects at both in the interior and exterior surface during each time step
- **Transient heat conduction** through building elements such as walls, roofs, floors, etc. using conduction transfer functions
- **Improved ground heat transfer modeling** through links to three-dimensional finite difference ground models and simplified analytical techniques
- **Combined heat and mass transfer** model that accounts for moisture adsorption/desorption either as a layer-by-layer integration into the conduction transfer functions or as an effective moisture penetration depth model (EMPD)
- **Thermal comfort models** based on activity, inside dry bulb, humidity, etc.
- **Anisotropic sky model** for improved calculation of diffuse solar on tilted surfaces
- **Advanced fenestration calculations** including controllable window blinds, electrochromic glazings, layer-by-layer heat balances that allow proper assignment of solar energy absorbed by window panes, and a performance library for numerous commercially available windows
- **Daylighting controls** including interior illuminance calculations, glare simulation and control, luminaire controls, and the effect of reduced artificial lighting on heating and cooling
- **Atmospheric pollution calculations** that predict CO_2, SO_x, NO_x, CO, particulate matter, and hydrocarbon production for both on site and remote energy conversion

Strengths

EnergyPlus includes many innovative simulation capabilities: time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems.

Weaknesses

Given the current BIM trends and expected evolution of the domain, one of the main drawbacks of EnergyPlus is that it does not allow to import or treat IFC files directly. A conversion tool is needed to obtain the IDF input file related to a project.

Building geometry definition

EnergyPlus models the concepts of Zone (thermal zones), mainly seen as containers of the building elements, which are mainly classified as BuildingSurface (opaque surfaces such as wall) and FenestrationSurface (such as a wall with an opening, like a door or a window). Building elements are defined by their coordinates in the reference system of the model, and the can be assigned to a Zone. Other building-specific concepts, such as floor or storey for example, are not explicitly defined as first-level objects of the model. This feature stems from the structure of the IDF file format, input of the tool.

Weather data

Weather data files are readable text files in the EPW file format, a format widely used for weather data storage.

Material Data

Each material used for any object reported in the building project file is defined in the same project file in dedicated sections, along with some of their physical properties (those needed by EnergyPlus for performing the energy simulation).

HVAC equipment

EnergyPlus provides the definition for a set of types of equipment (e.g. Pump, Solar collector plate, water heater, etc.), which can be specifically defined through the settings of parameters' values. These elements can be connected together with Branch and Loop elements, which are a first-level object type of the IDF format for model definition and represent branches and loop in defined circuit of the HVAC system.

Through the Schedule object it is also possible to define a regular schedule (time slots of a day) of use of the defined HVAC elements.

Input and output files are only text-based files, in different format according to the information provided.

Simulation input file

Input file is a file in the IDF format containing the specification of building geometric and HVAC specifications. IDF format is the same format used by other simulation tools (e.g. TRNSYS), although some sections can be tool-specific.

It is not possible to import models directly from another format (e.g. IFC or others). Conversion can be done but through ad-hoc solutions. For example, a Java library has been implemented at CEA to allow the execution of simulations with EnergyPlus starting from IFC 2x3 files. Such library performs an arbitrary IFC-to-IDF conversion (given that no references or standards exist for such conversion). A C++ porting of the same library has been recently done, focusing on latest version of IFC, IFCv4.

Output

Output of Energyplus consists in a set of files. All data relevant to the simulations variables such as temperature, Heat and cooling needs, hygrometry / comfort, DHW are provided as a csv output file. Output variables set is customizable in the IDF file, according to user needs, and has to be defined in the IDF file in order to be included with their value in the output csv. Other EnergyPlus-specific files (e.g. for checking nodes connections, etc.) or geometric files (e.g. DWX or VRML files) are generated as output starting from the IDF model.

Main Locks

The main locks are:

- The presence and the geometrically coherent definition of all the spatial boundaries of a space (or a thermal zone).

- Transform a 3D solid description (from IFC format) of the space into a 3D surface description

- Indeed, in a file IFC, spaces are separated from each other by walls or slabs thickness. In a 3D surface model such as we can generate with Sketchup, walls and slabs don't have any thickness and the thermal zones are in contact with each other.

- If we wish to verify the input 3D model for TRNSYS by using Sketchup, it is thus necessary to be able to transform the 3D solid geometry of the space into a 3D surface as presented in the picture below

- Consideration of equipment.

Software specifications

- Develop a mechanism for associating the thermal properties (conductivity, specific heat capacity, density, from an external data source) to an IFC material (referred into material layers in the walls, slabs or door) to a wall in the IFC file.

- Develop functions to verify that the data required for the simulation have been filled.

5.3.6   MC IMPIANTI11300

MC Impianti 11300 [IMPIANTI] is an energy simulation tool which is highly user-friendly and very frequently used in Italy for its simplicity and effectiveness. It has a simple ribbon interface for commands, a simulation engine, and a library of components, climate data and a range for various building models to standard HVAC equipment and renewable energy. Simulations are used for analysis of the thermal and energetic building performance, with also energy performance.

Strengths

User friendly interface;

- extremely flexible for modelling and calculation;
- users can creates themselves components not in the standard library;
- results are easy to read with a subdivision of various HVAC systems;
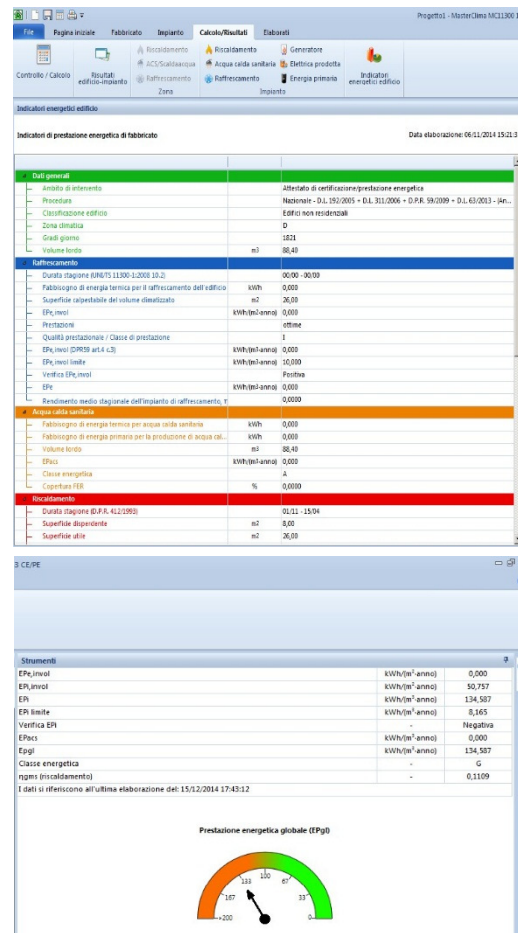- is compatible with the XML format for importing and exporting data.

Fig. 51: MC Impianti environment

Weaknesses

- No 3D geometry input
- Is not compatible with several simulation software tools.
- The design of every component, and relative material, must be implemented separately each time.

Building geometry definition

Under investigation.

Weather data

There is the possibility of implementing a text file (human editable).

Material Data

The possibility to extract some material properties from an IFC file is under investigation. Material properties remain editable in a text file.

HVAC equipment

Described in a text file.

Simulation input file

There is no specific template to build a simulation file. The format is human readable.

Output

Full requirements of a certain building (thermal, cooling needs, etc), temperature, hygrometry / comfort. Since the software is compliant to all the European Directives (European Directive , and has been approved by CTI[9], its results can be used to certify the energy class of a certain building according to the Italian norm.

5.3.7 OPENSTUDIO

The Legacy OpenStudio Plug-in [OPENSTUDIO] for SketchUp makes it easy to create and edit the building geometry in your EnergyPlus input files. This free plug-in also allows user to launch EnergyPlus simulations and view the results without leaving the SketchUp 3D drawing program. OpenStudio is a cross-platform (Windows, Mac, and Linux) collection of software tools to support whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance.

The graphical applications include the Trimble SketchUp Plug-in, RunManager, and ResultsViewer. RunManager manages simulations and workflows and gives users access to the output files through a graphical interface. ResultsViewer enables browsing, plotting, and comparing EnergyPlus output data, especially time series.

Building geometry definition

Openstudio works directly with the internal 3D geometry description from Sketchup without using a standard format, but gbXML files could also be imported. The following gbXML element types are imported to the OpenStudio Model:

- Construction
- Material
- ScheduleDay
- ScheduleWeek
- Schedule
- Campus
- Building
- Space
- Surface
- SubSurface

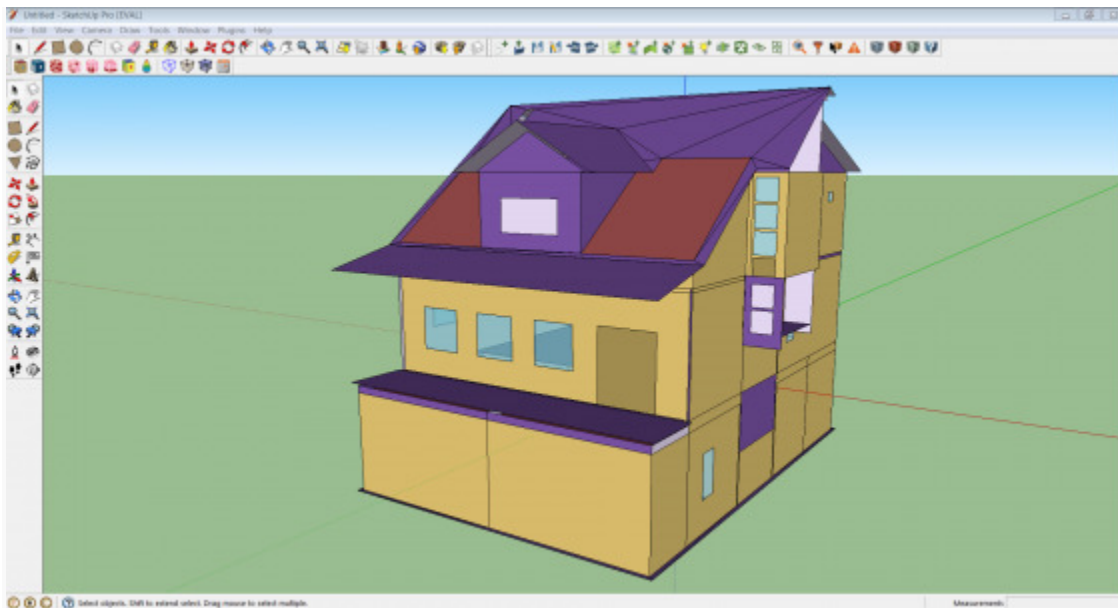
[9] Comitato Termotecnico Italiano

Fig. 52: Screenshot of Import gbXML Model result

Additional data

- To assign schedules, add loads, add HVAC systems, and more, the user must open the model in the OpenStudio application. It could be done directly from the SketchUp Plug-in.

  A Schedule Set is a collection of schedules for building activities or elements. It can be applied to an entire building, a story, a space type, or an individual space.

  The following figure shows the schedule sub-tab where the user can create and edit his own schedule, or use schedule from Library.
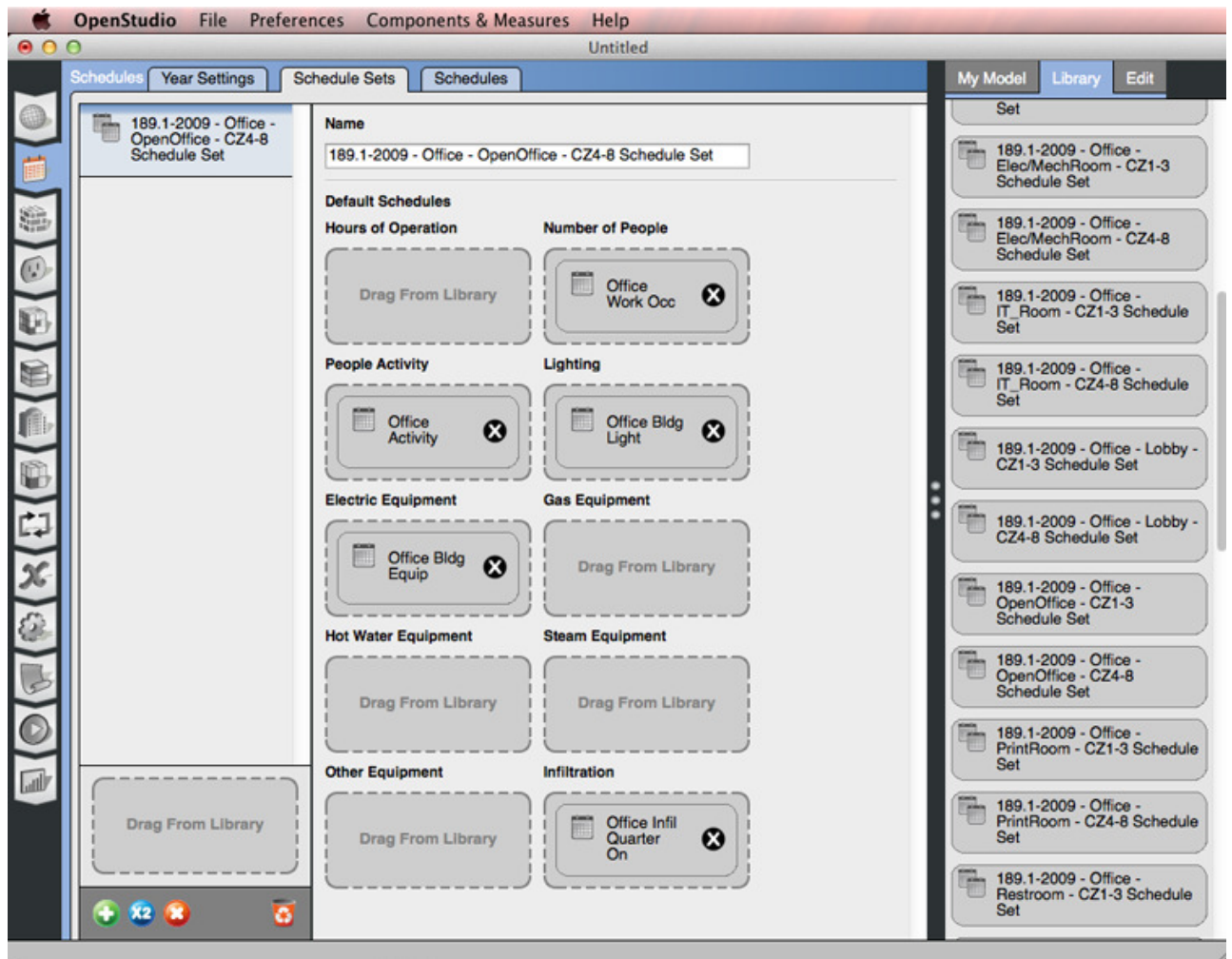
Fig. 53: Create and edit schedule sets.

- Constructions are made of one or more layers of materials. The Materials sub-tab lets the user inspect and edit those materials. There are various classes of material objects.

Different types of material will have different data fields availabl
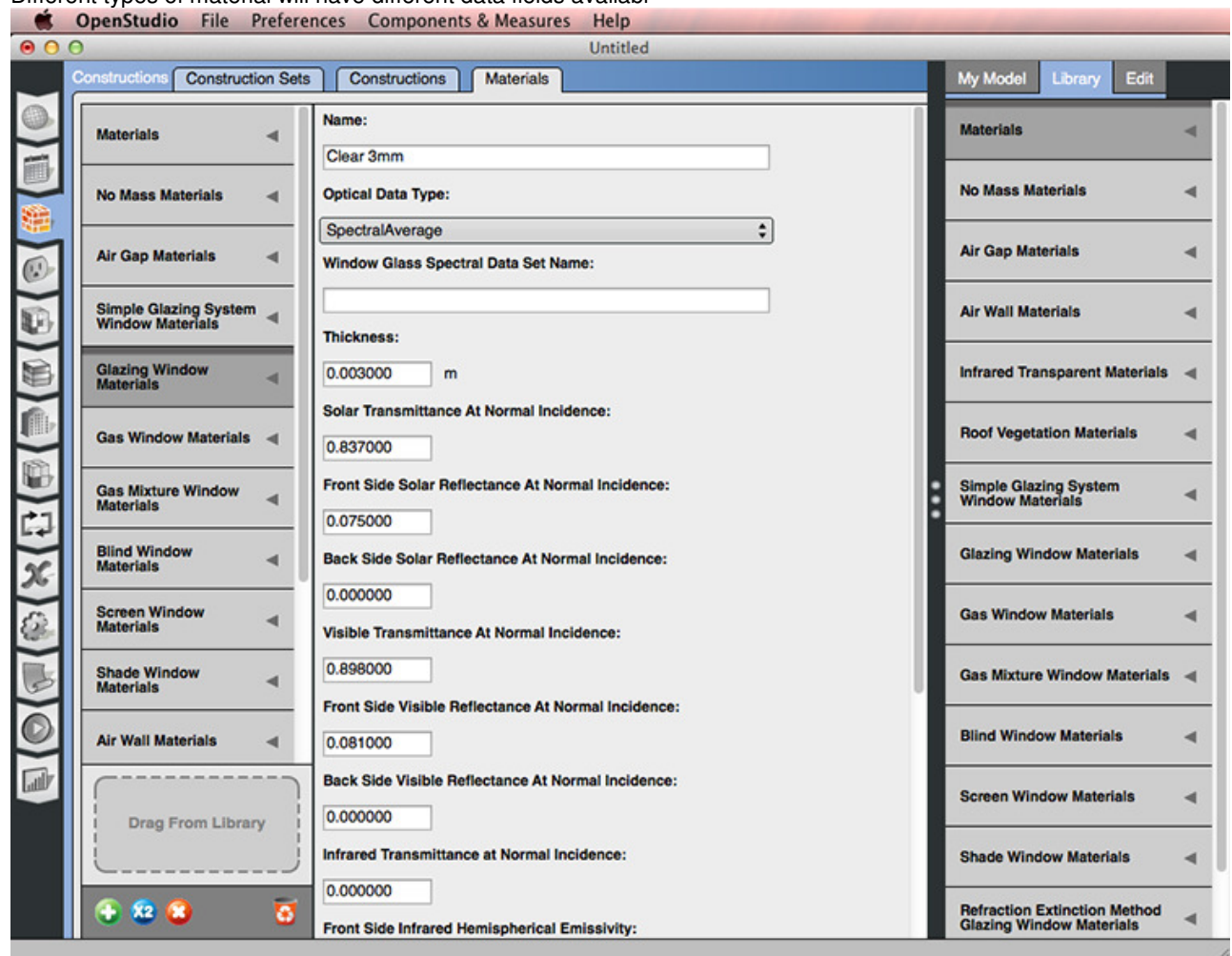

Fig. 54: Edit and create materials on this tab.

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- Weather files can be downloaded from the EnergyPlus site. Weather data is available for over 2
  000 locations in a file format that can be read by EnergyPlus but the user can also download its
  desired weather data.

- The HVAC Systems tab is used to create, inspect, and edit air and plant loops. OpenStudio names HVAC systems and components to match EnergyPlus. So if you are familiar with EnergyPlus you will be able to recognize components names.
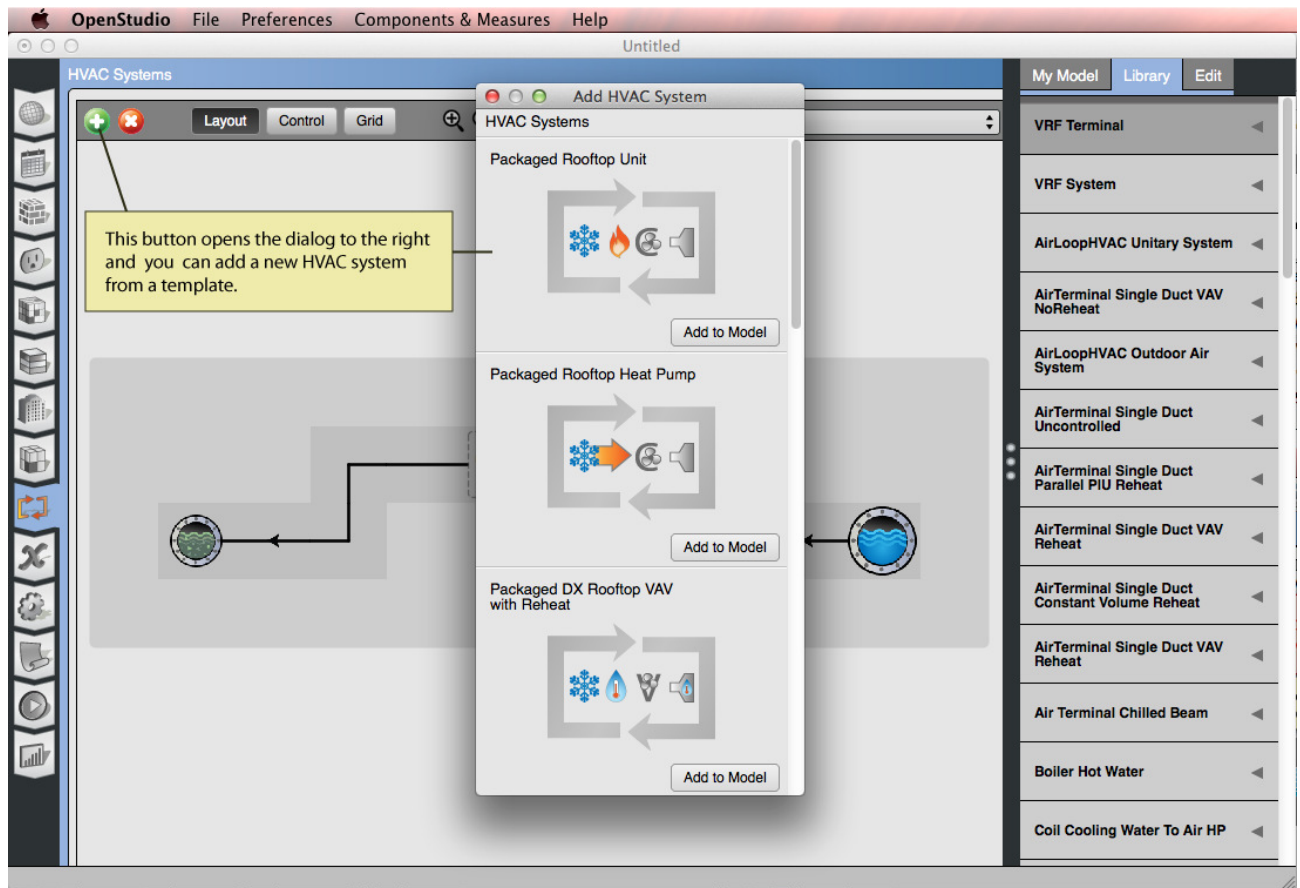

Fig. 55: Add an HVAC system to your model.

Output

The user can select which kind of outputs variable he wants by using toggle button in the graphical interface:
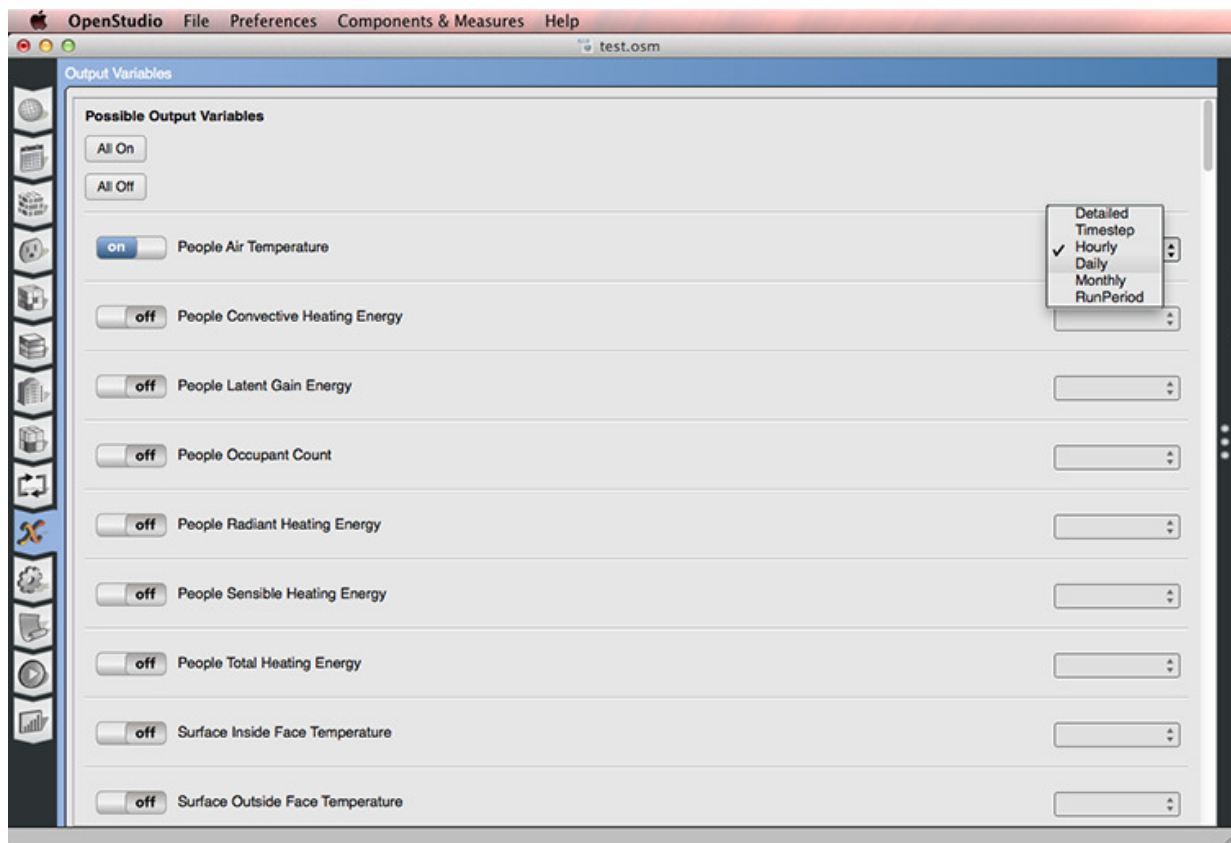
Fig. 56: Screenshot of selecting output variables.

Standard OpenStudio results are provided with your run. If you add in utility bills you can also view a calibration report.

You can also use measures to add additional reports. You can also write your own measures to create custom reports. Add reporting measures on the OpenStudio Measures or Scripts tab.
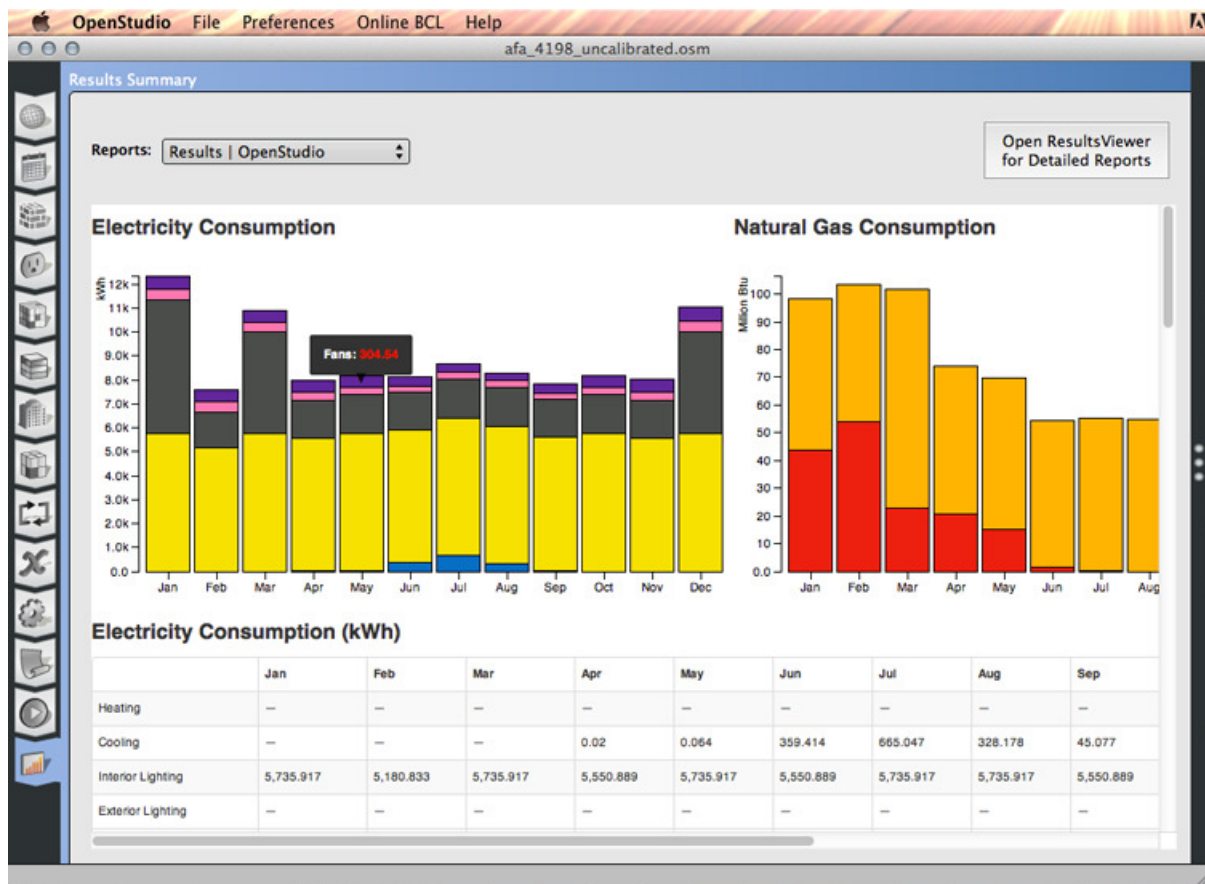
Fig. 57: This screenshot shows and example of the standard OpenStudio results.

5.3.8   SEFAIRA

The product comes in 2 applications [SEFAIRA]:

- Sefaira Architecture: provides performance analysis where you need it: inside the 3D modeling environment (plugin for Revit and Sketchup). Sefaira interprets models on the fly, delivering results while you design, even in the early stages of the process. It allows engineer to optimize key design parameters such as shading, orientation, glazing ratios.

- Sefaira Systems: uses the industry-standard EnergyPlus engine and expert-designed HVAC templates to deliver accurate results. Sefaira Systems allow you to download EnergyPlus-input files for validation or further analysis.

Plugin for Revit adds some properties and parameters which are then editable in Revit and further used by Sefaira during the real-time analysis.
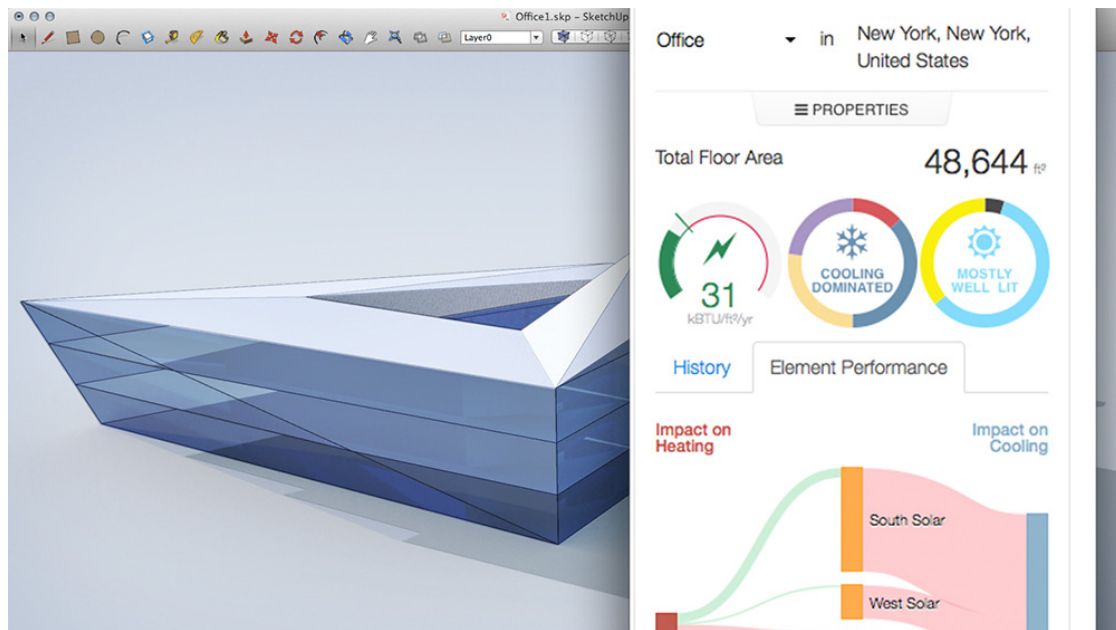
Fig.58: First estimation at early stages with Sefaira Architecture

Building geometry definition

As we have a full integration process, Sefaira works directly with the internal 3D geometry description from Revit or Sketchup without using a standard format.

Simulation input file

Templates of common system types eliminate the need to spend substantial time setting up individual HVAC system models.

Weather and material data

The only input that user has to specify are:

- The location of the project
- The space use
- The baseline which sets values for the envelope's characteristics (wall insulation, glazing U-Factor …) and heating/cooling efficiency.

Output

Sefaira proposes real-time analysis and real-time daylight visualization. Compare massing options, envelope properties and HVAC design choices in a single interface, making it easy to assemble the data you need.
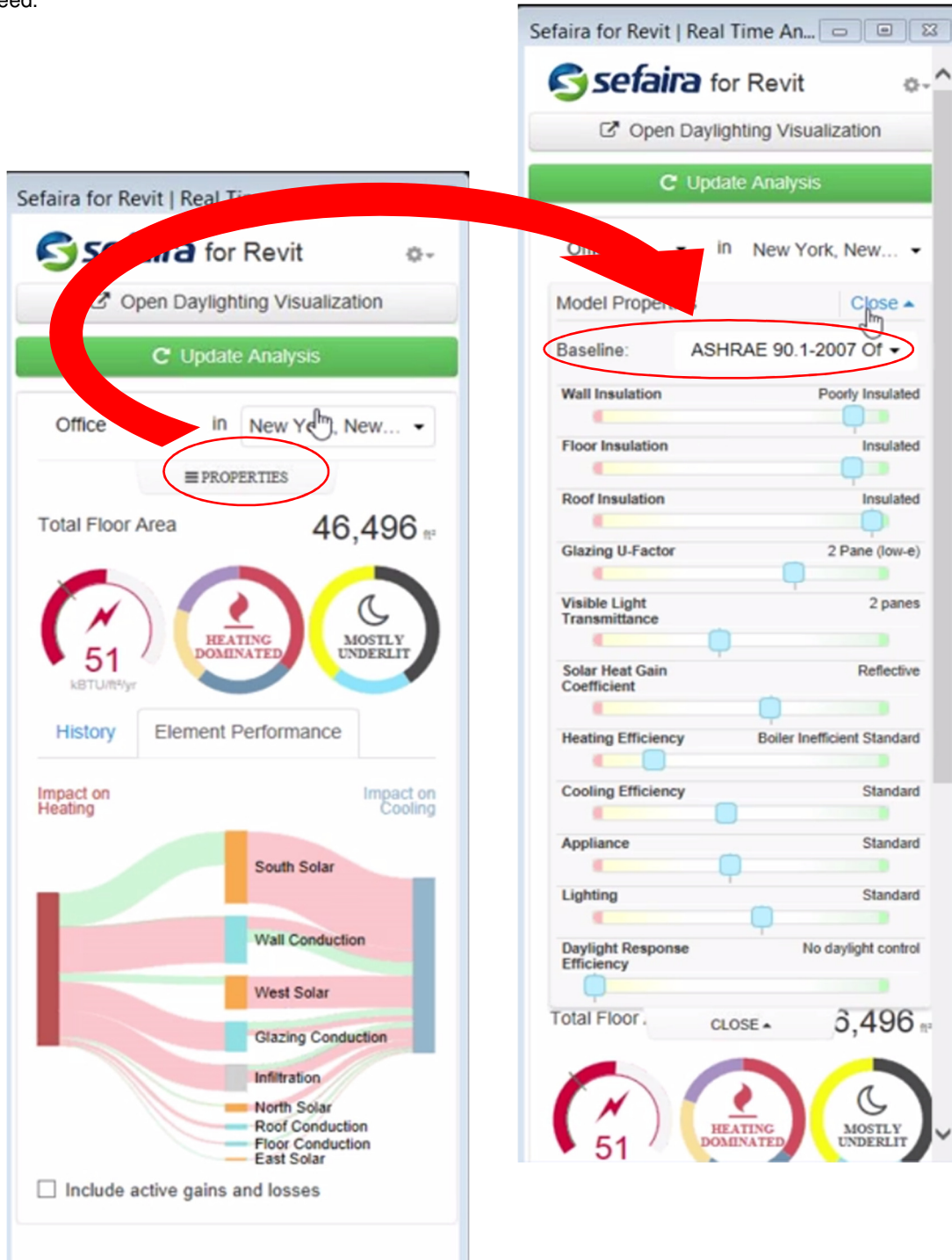

Fig. 59: Real-time analysis panel

The estimation is presented under the shape of a dashboard to 3 dials:

- The first one represents the Energy metrics.
- The second one presents where the energy is used to the breakdown: heating, cooling, appliances and lighting
- The last one represents the daylight metrics.

Then an Element Performance presents impacts on heating and cooling of the each element (wall conduction, infiltration …).
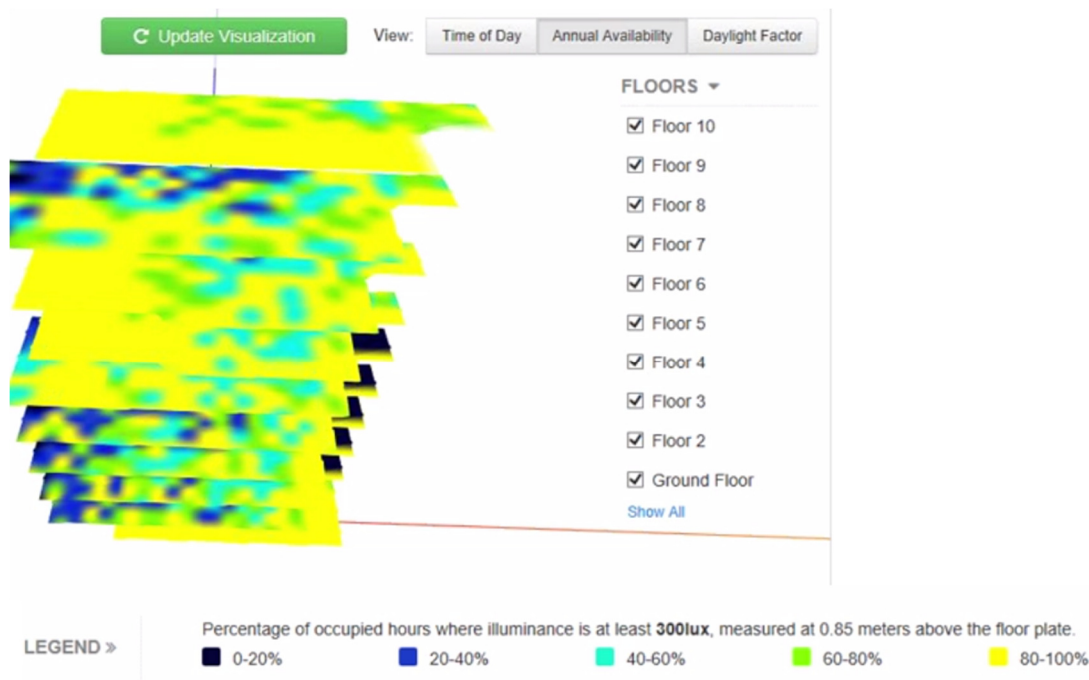
Fig. 60: Daylight visualization

5.3.9   RIUSKA

RIUSKA [RIUSKA] is an efficient and versatile comfort and energy simulation application. It uses a building's information model (BIM) to calculate the thermal conditions of a building and its spaces in different loading and weather conditions.

The RIUSKA application can be used, e.g., for the following tasks:

- To ensure compliance with the objectives
- Temperatures of premises in summer and winter
- Comparison of indoor climate quality levels
- Comparison of architectural solutions (windows, window protection, façade solutions)
- Comparison and dimensioning of systems
- Analysis of problematic spaces
- Energy consumption of buildings and building systems
- Projected consumption of maintenance

The application takes into account structures, massiveness, local weather, thermal loads, usage hours and so forth. It performs hourly calculations on, for example, annual energy consumption, temperatures in various spaces and their constancy as well as heating and cooling needs.

RIUSKA is based on many years of development at Granlund and the core of the tool, the internationally acclaimed DOE 2.1E simulation program. RIUSKA has been developed in collaboration with the developer of the DOE program, Lawrence Berkeley National Laboratory (LBNL).

Building geometry definition

RIUSKA can use information models in the IFC format (import/export).

Material Data

Construction types for the outer walls, inner walls, baseplate, roof, intermediate floors/ceilings, windows and doors of the as build situation are assigned with the construction library of RIUSKA.

HVAC equipment

Parameters for the ventilation equipment, heat recovery and time schedules are set for every ventilation zone.

Output

Spatial max/min temperatures.

Sized spatial air flow, cooling and heating needs.

Energy consumption of heating, cooling and electricity.

5.3.10 IDA ICE

IDA ICE [IDAICE] is an innovative and trusted whole-year detailed and dynamic multi-zone simulation application for study of thermal indoor climate as well as the energy consumption of the entire building. The physical models of IDA ICE reflect the latest research and best models available, and the computed results compare well with measured data. While serving a global market, IDA ICE is adapted to local languages and requirements (climate data, standards, special systems, special reports, product and material data).

Building geometry definition

IDA ICE imports all common 2D and 3D CAD files. The BIM Import extension allows you to import 3D CAD buildings directly into IDA ICE, using the open and neutral IFC (Industry Foundation Classes) format. The IFC format, which is commonly used for BIM (Building Information Modelling) models, includes geometry (walls, roofs, walls, windows and doors), spaces (in order to create zones), and sets of properties (for walls, windows and materials).

The default language in IDA ICE is English, and it includes over 2 000 worldwide locations and over 3 000 climate files. Make it easier and more efficient to use IDA ICE for projects in selected regions by

adding a localization package (Finnish, French, German, Swedish and Swiss localizations are possible for the moment). Besides a translated user interface and regional locations and climate files, some localization packages also support regional building regulations and include tailored reports.

Fig. 61: IFC import in IDA ICE

Material Data

The IDA ICE user interface is designed to make it easy to build and simulate both simple and advanced cases, while still offering the advanced user full flexibility. You can refine your model in steps, while always providing both 3D graphical and tabular feedback. You work in a single program and may jump back and forth between tasks.

Fig. 62: Table of material properties for each surface

Simulation input file

Equation based modeling, using the Modelica-like Neutral Model Format (NMF), makes it straight-forward to quickly expand the software with new modelling capabilities, either by our in-house development team or by the experienced user. The newly created component models can also easily be shared with other IDA ICE users.

In the advance level, the user can visualize all equipment models in the form of diagram which describes the HVAC network.
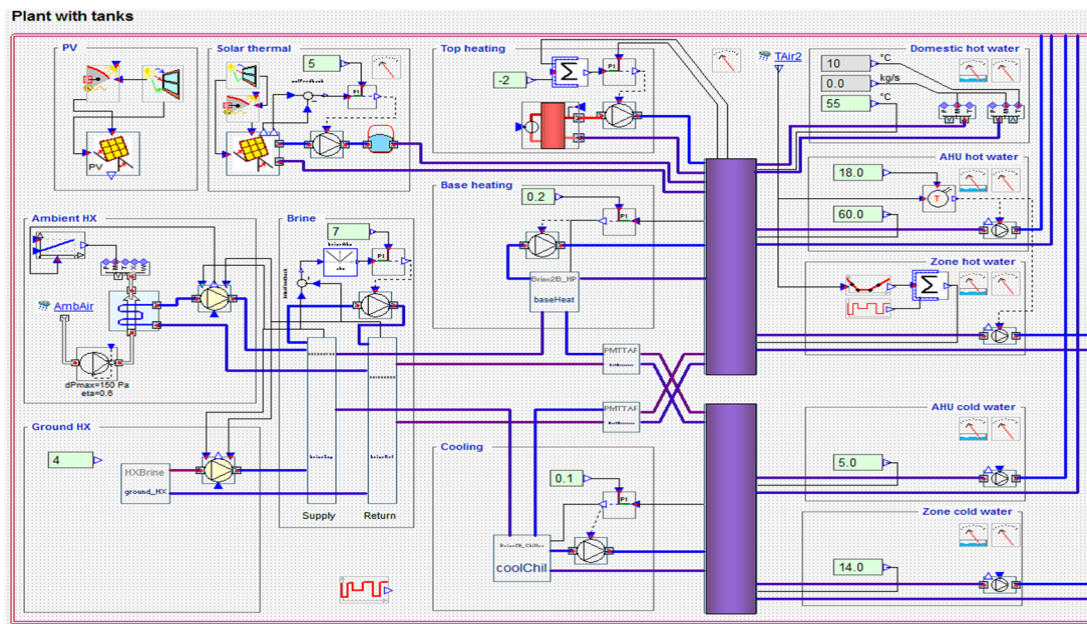
Fig. 63: HVAC equipment diagram

Output

IDA ICE is not a black box, which means that the user is not expected to trust the "secret model". Every underlying equation can be browsed, and every variable can be logged. For a single zone, this means that about a thousand temperatures, heat fluxes, CO_2 levels, control signals and other variables can be inspected by the critical user.

IDA ICE keeps track on model changes and automatically reruns all cases that depend on a change. The differences are stored and results are effectively compared.

The user is able to save its results into an IFC file. They are placed in a custom property set named Pset_SpaceThermalDesign attached to each IfcSpace.

5.3.11 ArchiWIZARD
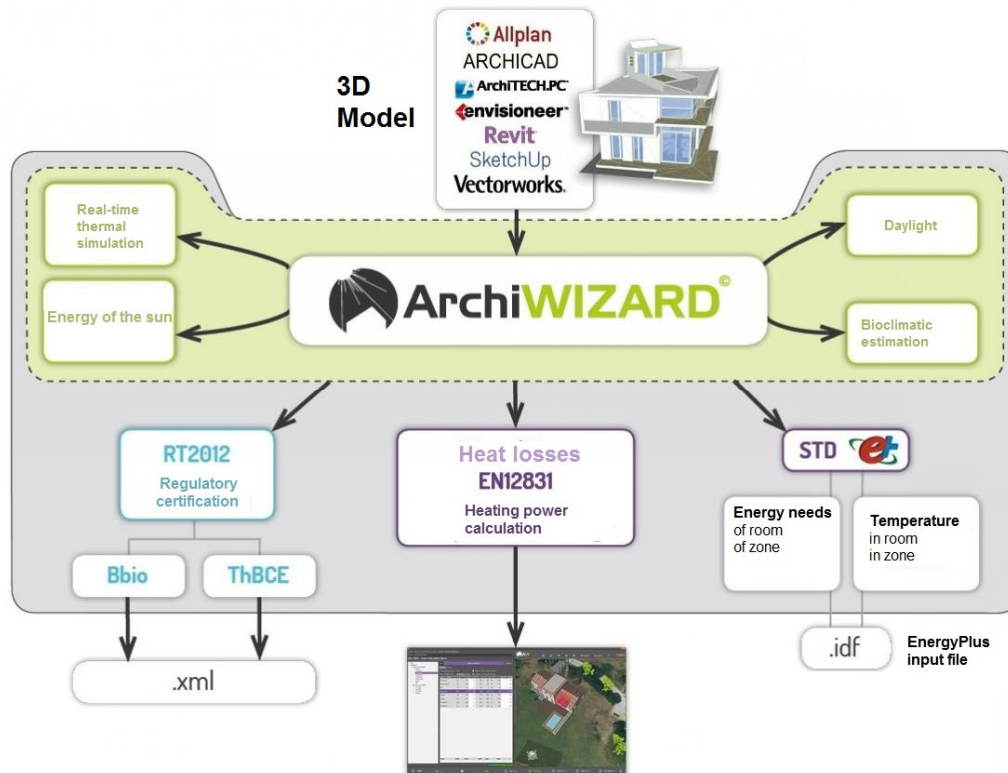
Fig. 64: ArchiWIZARD workflow

ArchiWIZARD [ARCHIWIZARD] is real-time 3D thermal simulation software, on the digital model (BIM), in direct connection with CAD software:

ArchiWIZARD is prescribed thermal calculation software which also informs about the relevance and performance of architectural and technical choices for:

- lighting comfort
- thermal
- bioclimatic quality

Building geometry definition

ArchiWIZARD works with Sketchup file and also with proprietary data structure of CAD tools by using dedicated plugins.

Weather and Material Data

ArchiWIZARD has a large library of material properties which in particular assess the energy performance of existing buildings based on their year of construction. It uses METEONORM for weather data.

5.3.12 Revit and ArchiCAD

We will note also that Revit and ArchiCAD have their own energy calculation engine that allows an estimate of energy consumption. These calculations use directly the materials properties and equipment parameters (simplified models) that are managed by the proprietary data structure of each two tools.
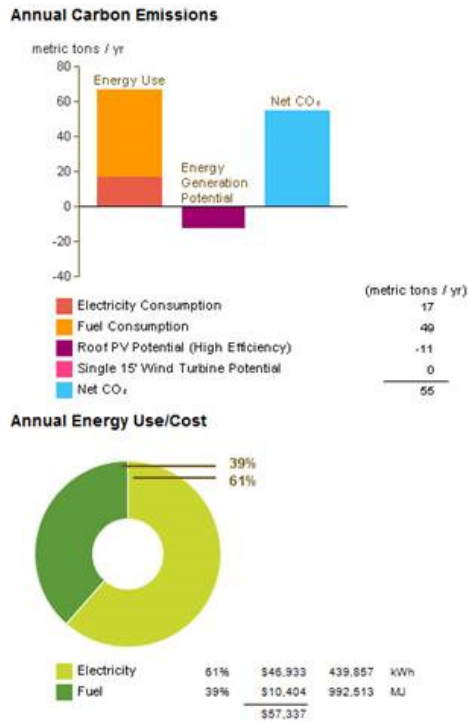
Fig. 65: Example of result with Revit
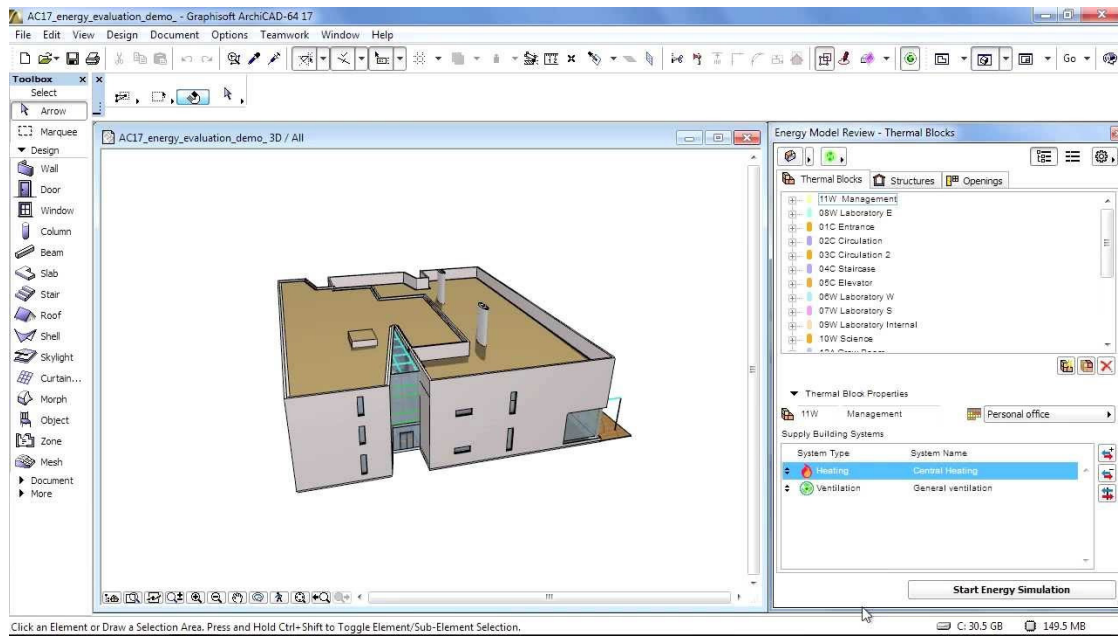
Fig. 66: Example of Energetic Estimation with ArchiCAD

5.4 Summary table

Early design phase

	Google Sketchup Sefaira ENERGYPLUS	Google Sketchup Openstudio ENERGYPLUS	Google Sketchup ArchiWIZARD with ENERGYPLUS
Building geometry			
Import IFC		**x[10]**	
Import gbXML		**x**	
Import DXF/DWG			
Other	**Sketchup**	**Sketchup**	**Sketchup**
Thermal Zoning			
Possibility to define your own zoning	**x**	**x**	**x**
Need space definition	**x**	**x**	
Need storey structuration			
Weather data			
Accessible via API or text file	**text**	**text**	**text**
Material data			
What kind of data recoverable from IFC or gbXML	**U-value defined in Sefaira**		
Accessible via API or text file	**text**	**text**	**via software**
HVAC systems			

---

[10] is under development

LOD for systems	**detailed**	**detailed**	**detailed**
Accessible via API or text file	**text**	**text**	**via software**
Simulation input file			
Need template file to take MEP systems into account	**yes**	**yes**	
Accessible via API or text file	**text**	**text**	**via software**
Output			
Accessible via API or text file	**text**	**text**	**text**
Export into IFC			

Relevant for Streamer

Compared to existing tools, and specifically with regard to early design stage (OpenStudio or Sefaira both operate on the basis of proprietary formats Sketchup or Revit), an objective of the Streamer project is to develop an operational workflow of decision support[11] based on the IFC format by integrating an optimization process[12] (multi-thread analysis) of the rooms distribution per storey.

---

[11] see the "Architecture for interoperability" picture in the deliverable D3.5 - semantic interface of the simulation tools based on the semantic design configurator
[12] It is an objective of the early design configurator

Design phase

	eveBIM-TRNSYS[13]	VABI	IES-VE	UNIFE/EFAF MC4HVAC	MC Impianti 11300	Intermediate[14] tool with ENERGYPLUS	Revit Sefaira ENERGYPLUS	RIUSKA	IDA-ICE	ArchiWIZARD ENERGYPLUS	Revit ArchiCAD
Building geometry											
Import IFC	x	x	x[15]			x		x	x		
Import gbXML			x								
Import DXF/DWG		x		x							
Other							**Revit**			**Revit/Sketchup**	**Proprietary format**
Thermal Zoning											
Possibility to define your own zoning	x	x	x	x	x	x	x		x	x	x
Need space definition	x	x				x	x	x	x		x
Need storey structuration			x	x	x				x		x
Weather data											
Accessible via	**text**	**via**	**text**	**text**	**via**	**text**	**text**			**text**	

---

[13] eveBIM-Trnsys is an intermediate tool, developed by CSTB, which makes possible the relation between IFC model and Trnsys input file

[14] Intermediate tool developed by CEA which makes possible the relation between IFC model and ENERGYPLUS input file

[15] is under development

API or text file		software			software						
Material data											
What kind of data recoverable from IFC or gbXML	**U-value conductivity density capacity**		**U-value**			**U-value**	**U-value defined in Sefaira**	**U-value**	**U-value**		
Accessible via API or text file	**text**	**text**	**text**	**text**	**text**	**text**	**text**	**via software**		**via software**	
HVAC systems											
LOD for systems	**detailed**	**simple**	**detailed**	**simple**		**detailed**	**detailed**	**simple**	**detailed**	**detailed**	**Idealized**
Accessible via API or text file	**text**	**Text**	**via software**	**text**	**text**	**text**	**Text**			**via software**	
Simulation input file											
Need template file to take MEP systems into account	**yes**	**yes**	**yes**	**yes**	**no**	**yes**	**yes**		**yes**		
Accessible via API or text file	**text**		**via software**		**text**	**text**	**text**			**via software**	
Output											
Accessible via API or text file	**text**	**Text**	**via software**	**text**		**text**	**text**		**text**	**text**	
Export into IFC									**x**		

Relevant for Streamer (design phase)

We will attempt to homogenize the use of the BIM workflow around IFC format from existing tools which don't have necessary the same degree of maturity.

6. **CONCLUSIONS AND RECOMMENDATIONS**

Regarding this objective to bring together the BIM and the simulation worlds, we assumed that the engineers would continue to use the software they use for their performance and quality rather than change for software they have not yet mastered. So, the proposed approach aims to foster a "smooth" transition to integrate the practices of engineers into a BIM workflow rather than imposing a particular tool.

It is for that reason that we have pre-selected simulation tools planned to be used in the WP7 (demonstration and validation). These tools are:

- TRNSYS
- VABI
- IES-VE
- ENERGYPLUS
- UNIFE/EFAF - MC4HVAC
- MC Impianti 11300

As we are talking about commercial software (for most of them), the need for an intermediate tools has been identified. These tools would be designed to transfer data from a BIM format to the simulation tool using standard by:

- checking / controlling data (including geometric data)
- assigning properties from external data sources BIM (material properties, use and occupation of the areas, equipment parameters)

And potentially, to propose to enrich the BIM by saving the choices of thermal engineer (material properties ...).

Concerning BIM formats, we focused our attention on the two main open standards IFC and gbXML which are the best suited considering their use for energy estimate. The IFC has a few more advantages in its ability to include the entire life cycle as well as other themes (acoustic, structure …).

For each of these simulation tools, we have identified suggested improvement to be developed in the D3.4 (simulation tool of the energy performance for newly and retrofitted buildings). In order to control these developments, test cases (IFC file) will be generated and proposed to different users. These files will contain some information useful for simulation tools (the appendix 2 gives some examples of necessary data):

- At the walls level: U-value
- At material level: conductivity, capacity, density
- Different configuration of spatial boundaries [SB-2010]

References

[STREAMER-D6.5] Streamer D6.5 - Advance Mapping Structures and Standards – 2015

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[Bentley2011] Utilizing gbXML with AECOsim Building Designer and speedikon Building Performance Analysis using Bentley Products - A Bentley White Paper - Igor Sokolov, John Crosby, October 2011

[Connection-BIM-Models2014] An approach to enhancing the connection between BIM models and building energy simulation – HVAC systems in the loop - Sylvain Robert & Davide Mazza (CEA), Bruno Hilaire & Paul Sette & Benoît Vinot (CSTB) (2014) - ECPPM

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[BIMtoBEM2013] Transforming BIM to BEM: Generation of Building Geometry for the NASA Ames Sustainability Base BIM, James T. O'Donnell, Tobias Maile, Cody Rose, Nataša Mrazović, Elmer Morrissey, Cynthia Regnier, Kristen Parrish and Vladimir Bazjanac - January 2013

[Concept Design BIM 2010] Generic AEC/FM BIM View Specification – Concept Design BIM 2010

[TRANS-IFC2IDF-2007] Transformation from IFC data of design results to IDF data for analysis of building's energy consumption - Ma Zhiliang, Zeng Tonghua, Wei Zhenhua, Feng Yan - 2007

[ENERGY+] EnergyPlus Graphical User Interfaces,
http://apps1.eere.energy.gov/buildings/energyplus/ep_interfaces.cfm

[SBT] https://gaia.lbl.gov/interoperability/SBT

[TRNSYS] www.**trnsys**.com

[VABI] http://www.vabi.nl/Producten/Vabi-Elements

[IESVE] http://www.iesve.com/

[MC4] http://www.mc4software.com/

[IMPIANTI] http://www.masterclima.info/page/Software-MC11300.aspx

[ENERGY+] http://apps1.eere.energy.gov/buildings/energyplus/

[SEFAIRA] http://sefaira.com/

[RISUKA] http://www.granlund.fi/en/software/riuska/

[IDAICE] http://www.equa.se/en/ida-ice

[ARCHIWIZARD] http://www.archiwizard.fr/fr/

[OPENSTUDIO] https://www.openstudio.net/downloads

APPENDIX 1 – List of software

Modelling tools (Drawing)	BIM format import/export	Modelling tools (Energy)	BIM format import/export
Autodesk Revit	Import/export IFC Export gbXML	**IES Thermal model Input Data**	Import Revit file Import gbXML Import sketchup
Trimble Sketch up Pro	Now IFC native	**TAS**	Import gbXML Import IDF
Bentley Microstation	To be determined	**Oasys BEANS**	To be determined
Autodesk Revit MEP	Import/export IFC Export gbXML	**Autodesk Revit (Energy function)**	Import IFC
Graphisoft ArchiCAD	Import/export IFC	**ArchiCAD (Energy function)**	Import IFC
DDS-CAD	Import/export IFC	**Energy Plus**	Import IDF
CYPECAD	Import/export IFC	**Trnsys**	CSTB developed a user friendly to import IFC
Nemetschek AllPlan	Import/export IFC	**CYPECAD**	Import IFC
BriefBuilder		**MC 11300 (Masterclima)**	To be determined
OADIS		**Thermo (Namirial-Microsoftware)**	Import/Export gbXML ?
		Termus (ACCA software)	To be determined
		VABI	Import IFC

	HESMOS[16]	See if framework prototype is available?
	RIUSKA	Import IFC
	MonaVisa (Monitoring)	To be determined
	IDEAS	To be determined
	Archiwizard	Import Sketchup Import IFC (soon)
	ClimaWin	Import IFC Import gbXML
	Energy Calculation Component (Pim vd Helm)	
	Sefaira (Energy+ solver)	Import BIM from Revit or Sketchup via dedicated plugin

In-house developments	Interface import	Developed by
IfcExplorer / FZKViewer	IFC, gbXML, CityGML	KIT
IfcCheckingTool	IFC	KIT
eveBIM-Viewer	IFC	CSTB
Urban Strategy	?	TNO

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[16] HESMOS - ICT Platform for Holistic Energy Efficiency Simulation and Lifecycle Management of Public Use Facilities

eveCity	CityGML	CSTB
BIMserver	?	?
BIMreqCap	?	?
EUREKA	?	?
SACS	?	?

APPENDIX 2 – Necessary data for simulation

During the construction process, there are some important milestones where the architect, the contractor and/or the technical engineer need to have an energy estimation to consolidate choices. Of course, available data and expected results are different for each of these steps.

We have identified below three of these steps:

Stage 1: Conceptual design

Needed Data (IFC or gbXML format) :

- Data relating to the project environment (open street map, city GML,…) : geographic location, network, infrastructures, surrounding buildings.
- Weather data (solar radiation)
- Footprint and building geometry (Only one zone)
- Performance of building envelope (default U-value for walls)
- Wall and slab surfaces
- Percentage of glazed and associated performance; consideration of solar masks (through an adjustment coefficient)
- Internal gain (Simple scenarios of uses)

Output :

- Annual load or load on heating season

Kind of tool :

- Regulatory tools
- Excel Macro excel / equations
- …

Remark:
Considering the poor quantity of information at this stage, it would be preferable to talk about energy estimation rather than energy simulation.

Stage 2: ~ Preliminary design

Needed Data (IFC or gbXML format) :

- geographic location
  - Longitude-latitude
  - Weather file
- Envelope's geometry and performance
- Multi zone with different use by zone : storeys organization with several zones for each storey
- Thermal inertia of building
  - Conductivity, specific heat capacity and density for each material layer and openings (external door and window)
- Windows location in each wall
- Solar mask
- Internal gain (scenarios of uses by zone)
- Set point temperature by zone
- Idealized system (or equipment): perfect thermal generation, perfect regulation.

Output :

- Hourly temperature profile by zone

Kind of tool :

- Dynamic simulation tool (TRNSYS, EnergyPlus, …)

Stage 3: ~ Detailed design

Needed Data (IFC or gbXML format) :

- geographic location
  - o Longitude-latitude
  - o Weather file
- Multi zone with different use by zone : storeys organization with several zones for each storey, thermal characteristics for partition walls
- Performances de l'enveloppe (découpage en couches), et des vitrages
- Thermal inertia of building
  - o Conductivity, specific heat capacity and density for each material layer and openings (external door and window)
- Windows location in each wall
- Detailed solar mask
- Use scenarios by zone

Needed data (in the simulation tool native format) :

- System models
- Connection of systems (between them and with zones)
- Regulating characteristics

Output :

- Hourly temperature profile by zone
- Detailed energy consumption
- Dynamical profiles for the way systems work

Kind of tool :

- Dynamic simulation tool (TRNSYS, EnergyPlus,…)

APPENDIX 3 – IFC for energy simulation

The objective of this document is to describe the structure and the information which the IFC model can contain, so that it can be exploited at best by the energy performances simulation tools.

The ISO-IFC is an exchange format, designed to allow the various partners of a construction project to exchange the technical information by minimizing the risks of errors and seize them again.

Usually, the initial file IFC is produced by the software of architectural CAD (new project) or the surveyor expert (collecting existing dimensions with the aim of rehabilitation or of an asset management). The quality of the IFC is thus very dependent on the tool used for this seizure, in particular on the degree of maturity of the interface of export IFC of the tool.

IFC structure

The IFC[17] is an open standard of technical and graphic exchange in the sector of the Construction. The IFC does not claim to model all of the views[18] of a building, and this model of exchange reduces the semantic reality of the elements of a job at the level of the data of technical software.

The building is then represented as an organization of components. These entities are called objects IFC and possess three types of associated information: a class, properties[19] and relations.

Which kind of data for Energy performance simulation

Units
Stored on IfcProject.

Orientation
The orientation relative to the geographic North is stored in IfcProject.

Geography referencing
Stored on IfcSite.

Room (or space)
The IfcSpace entity is a fundamental element in the description of a building, because it translates the notion of room. IfcSpace represents a basic link for the simulation, especially for thermal studies where it can be assimilated to a thermal zone. A good practice is divided into 2 stages:

• construction of the principle according a IfcSpace by room,

• group these IfcSpace in IfcZone, comparable to thermal zones.

The relationship object "IfcRelSpaceBoundary" allows then to retrieve all the spatial boundaries of a given IfcSpace and thus identify IfcSpace or IfcZone adjacent to this space.

---

[17] Initially acronym for Industry Foundation Classes (or Information For Construction)

[18] The only real common point of the professionals who are going to exchange the data of the project with their specific software, it is that all belong to the world of the construction. During an operation of construction, all work on a unique building, even if each "views" this construction of a different eye (we says according to different "views").

[19] Also call attributes

The following property set definitions specific to the IfcSpace could be interesting for energy performance calculations:

Pset_SpaceThermalDesign :

Name	Property Type	Data Type	Definition
CoolingDesignAirflow	IfcPropertySingleValue	IfcVolumetricFlowRateMeasure	The air flowrate required during the peak cooling conditions.
HeatingDesignAirflow	IfcPropertySingleValue	IfcVolumetricFlowRateMeasure	The air flowrate required during the peak heating conditions, but could also be determined by minimum ventilation requirement or minimum air change requirements.
TotalSensibleHeatGain	IfcPropertySingleValue	IfcPowerMeasure /	The total sensible heat or energy gained by the space during the peak cooling conditions.
TotalHeatGain	IfcPropertySingleValue	IfcPowerMeasure /	The total amount of heat or energy gained by the space at the time of the space's peak cooling conditions.
TotalHeatLoss	IfcPropertySingleValue	IfcPowerMeasure /	The total amount of heat or energy lost by the space at the time of the space's peak heating conditions.
CoolingDryBulb	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Inside dry bulb temperature for cooling design
CoolingRelativeHumidity	IfcPropertySingleValue	IfcPositiveRatioMeasure	Inside relative humidity for cooling design.
HeatingDryBulb	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Inside dry bulb temperature for heating design
HeatingRelativeHumidity	IfcPropertySingleValue	IfcPositiveRatioMeasure	Inside relative humidity for heating design.
VentilationAirFlowrate	IfcPropertySingleValue	IfcVolumetricFlowRateMeasure	Ventilation outside air requirement for the space.
ExhaustAirFlowrate	IfcPropertySingleValue	IfcVolumetricFlowRateMeasure	Design exhaust air flow rate for the space.
CeilingRAPlenum	IfcPropertySingleValue	IfcBoolean • Default Value: Falsch	Ceiling plenum used for return air or not.
BoundaryAreaHeatLoss	IfcPropertySingleValue	IfcHeatFluxDensityMeasure	Heat loss per unit area for the boundary object. This is a design input value for use in the absence of calculated load data.

Pset_SpaceThermalRequirements :

Name	Property Type	Data Type	Definition
SpaceTemperatureMax	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Maximal temperature of the space or zone, that is required from user/designer view point. If no summer or winter space temperature

			requirements are given, it applies all year, otherwise for the intermediate period.
SpaceTemperatureMin	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Minimal temperature of the space or zone, that is required from user/designer view point. If no summer or winter space temperature requirements are given, it applies all year, otherwise for the intermediate period.
SpaceTemperatureSummerMax	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Maximal temperature of the space or zone for the hot (summer) period, that is required from user/designer view point.
SpaceTemperatureSummerMin	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Minimal temperature of the space or zone for the hot (summer) period, that is required from user/designer view point.
SpaceTemperatureWinterMax	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Maximal temperature of the space or zone for the cold (winter) period, that is required from user/designer view point.
SpaceTemperatureWinterMin	IfcPropertySingleValue	IfcThermodynamicTemperatureMeasure	Minimal temperature of the space or zone for the cold (winter) period, that is required from user/designer view point.
SpaceHumidity	IfcPropertySingleValue	IfcRatioMeasure	Humidity of the space or zone that is required from user/designer view point. If no summer or winter space humidity requirements are given, it applies all year, otherwise for the intermediate period.
SpaceHumiditySummer	IfcPropertySingleValue	IfcRatioMeasure	Humidity of the space or zone for the hot (summer) period, that is required from user/designer view point.
SpaceHumidityWinter	IfcPropertySingleValue	IfcRatioMeasure	Humidity of the space or zone for the cold (winter) period that is required from user/designer view point.
DiscontinuedHeating	IfcPropertySingleValue	IfcBoolean • Default Value: FALSE	Indication whether discontinued heating is required/desirable from user/designer view point.
NaturalVentilation	IfcPropertySingleValue	IfcBoolean • Default Value: TRUE	Indication whether the space is required to have natural ventilation or mechanical ventilation.
NaturalVentilationRate	IfcPropertySingleValue	IfcCountMeasure	Indication of the requirement of a particular

Name	Property Type	Data Type	Definition
			natural air ventilation rate, given in air changes per hour.
MechanicalVentilationRate	IfcPropertySingleValue	IfcCountMeasure	Indication of the requirement of a particular mechanical air ventilation rate, given in air changes per hour.
AirConditioning	IfcPropertySingleValue	IfcBoolean • Default Value: FALSE	Indication whether this space requires air conditioning provided.
AirConditioningCentral	IfcPropertySingleValue	IfcBoolean • Default Value: FALSE	Indication whether the space requires a central air conditioning provided or not. It should only be given, if the property "AirConditioning" is set to TRUE.

Pset_SpaceOccupancyRequirements

Name	Property Type	Data Type	Definition
OccupancyType	IfcPropertySingleValue	IfcLabel	Occupancy type for this object. It is defined according to the presiding national building code.
OccupancyNumber	IfcPropertySingleValue	IfcCountMeasure	Number of people required for the activity assigned to this space.
OccupancyNumberPeak	IfcPropertySingleValue	IfcCountMeasure	Maximal number of people required for the activity assigned to this space in peak time.
OccupancyTimePerDay	IfcPropertySingleValue	IfcTimeMeasure	The amount of time during the day that the activity is required within this space.
AreaPerOccupant	IfcPropertySingleValue	IfcAreaMeasure	Design occupancy loading for this type of usage assigned to this space.
MinimumHeadroom	IfcPropertySingleValue	IfcLengthMeasure	Headroom required for the activity assigned to this space.
IsOutlookDesirable	IfcPropertySingleValue	IfcBoolean	An indication of whether the outlook is desirable or not

Data for construction element

- IfcWall and IfcSlab :

With regard to the walls (walls, floor or ceiling), it will be possible to describe them as multilayer elements (incorporating the elements of structure: insulation ...).

With regard to the properties of a IfcWall or IfcSlab, we find the definition of common set of properties. Thus, for the walls, we find Pset_WallCommon which is common a property set for all wall occurrences. This propery set contains different properties but there is one interesting for thermal simulation: the Thermal Transmittance coefficient (U-Value).

This is the total thermal transmittance coefficient through the wall (including all material's layer), usually measured in Watts/m² Kelvin.

We also find the "IsExternal" property that could give information about thermal conditions.

IfcWall

Name	Property Type	Data Type	Definition
ThermalTransmittance	IfcPropertySingleValue	IfcThermalTransmittanceMeasure	Thermal transmittance coefficient (U-Value) of a material. Here the total thermal transmittance coefficient through the wall (including all materials).
IsExternal	IfcPropertySingleValue	IfcBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the outside of the building.

IfcSlab

Name	Property Type	Data Type	Definition
ThermalTransmittance	IfcPropertySingleValue	IfcThermalTransmittanceMeasure	Thermal transmittance coefficient (U-Value) of a material. Here the total thermal transmittance coefficient through the slab (including all materials).
IsExternal	IfcPropertySingleValue	IfcBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the outside of the building
PitchAngle	IfcPropertySingleValue	IfcPlaneAngleMeasure	Angle of the slab to the horizontal when used as a component for the roof (specified as 0 degrees or not asserted for cases where the slab is not used as a roof component).

Data for opening elements (IfcDoor et IfcWindow)

We found the same information for IfcDoor et IfcWindow through Pset_DoorCommon or Pset_WindowCommon.

IfcWindow

Name	Property Type	Data Type	Definition
IsExternal	IfcPropertySingleValue	IfcBoolean	Indication whether the element is designed for use in the exterior (TRUE) or not (FALSE). If (TRUE) it is an external element and faces the outside of the building.
ThermalTransmittance	IfcPropertySingleValue	IfcThermalTransmittanceMeasure	Thermal transmittance coefficient (U-Value) of a material. It applies to the total door construction.

We have also a set of specific property (Pset_DoorWindowGlazingType) for the properties of glazing:

Name	Property Type	Data Type	Definition
GlassLayers	IfcPropertySingleValue	IfcCountMeasure	Number of glass layers within the frame. E.g. "2" for double glazing.
GlassThickness1	IfcPropertySingleValue	IfcPositiveLengthMeasure	Thickness of the first (inner) glass layer.
GlassThickness2	IfcPropertySingleValue	IfcPositiveLengthMeasure	Thickness of the second (intermediate or outer) glass layer.
GlassThickness3	IfcPropertySingleValue	IfcPositiveLengthMeasure / LENGTHUNIT	Thickness of the third (outer) glass layer.
FillGas	IfcPropertySingleValue	IfcLabel	Name of the gas by which the gap between two glass layers is filled. It is given for information purposes only.
GlassColor	IfcPropertySingleValue	IfcLabel	Color (tint) selection for this glazing. It is given for information purposes only.
IsTempered	IfcPropertySingleValue	IfcBoolean	Indication whether the glass is tempered (TRUE) or not (FALSE) .
IsLaminated	IfcPropertySingleValue	IfcBoolean	Indication whether the glass is layered with other materials (TRUE) or not (FALSE).
IsCoated	IfcPropertySingleValue	IfcBoolean	Indication whether the glass is coated with a material (TRUE) or not (FALSE).
IsWired	IfcPropertySingleValue	IfcBoolean	Indication whether the glass includes a contained wire mesh to prevent break-in (TRUE) or not (FALSE)
Translucency	IfcPropertySingleValue	IfcPositiveRatioMeasure	Fraction of the visible light that passes the glazing at normal incidence. It is a value without unit.
Reflectivity	IfcPropertySingleValue	IfcPositiveRatioMeasure	Fraction of the visible light that is reflected by the glazing at normal incidence. It is a value without unit.
BeamRadiationTransmittance	IfcPropertySingleValue	IfcPositiveRatioMeasure	Direct solar radiation transmittance that passes the glazing at normal incidence. It is a value without unit, often referred to as (Tsol).
SolarHeatGainTransmittance	IfcPropertySingleValue	IfcPositiveRatioMeasure	Total solar heat transmittance that passes the glazing at normal incidence. It is a value without unit, often referred to as (SHGC):.
ThermalTransmittanceSummer	IfcPropertySingleValue	IfcThermalTransmittanceMeasure	Thermal transmittance coefficient (U-Value) of a material. Summer thermal transmittance coefficient of the glazing only, often referred to as (U-value)
ThermalTransmittanceWinter	IfcPropertySingleValue	IfcThermalTransmittanceMeasure	Thermal transmittance coefficient (U-Value) of a material. Winter thermal transmittance coefficient of the glazing only, often referred to as (U-value)

IfcThermalMaterialProperties

The IFC standard makes it possible to define sets of material properties with "physical point of view". Regarding the thermal IfcThermalMaterialProperties class is a container with the following thermal material properties:

- SpecificHeatCapacity. Usually measured in [J/kg K].

- BoilingPoint. Usually measured in Kelvin.

- FreezingPoint. Usually measured in Kelvin.

- Thermal conductivity. Usually in [W/m K].

If it is possible to define multilayer walls describing the layers thickness and the name of the associated material, however it is impossible to assign physical properties to these materials directly from existing CAD tools.

It is therefore necessary to have an additional tool to add / modify these physical properties of the materials of construction elements.

Systems and equipments

Among the various areas covered by IFC in their 2x3 version, we are particularly interested in the remainder of this document to those dealing with energy engineering such as heating, air conditioning, electrical systems, and control systems.

System

IFC defines the notion of system as an entity grouping (thus inheriting IfcGroup) several elements (IfcElement), and providing a given service or part of a building. For example, in the case of a distribution system (electrical, heating, etc...), all elements must be (or derived from objects) from IfcDistributionElement.

Several IfcSystem instances can be defined in a building, each with a different function. IfcRelServicesBuildings objects defines the relationship between a system and sites, buildings, floors or IfcSpace concerned. A system can be connected to several spatial structures defining a plurality of instances IfcRelServicesBuildings.

Distribution

The elements involved in the distribution system (heating, cooling, ventilation, electrical, etc.) derive from IfcDistributionElement. Control elements (IfcDistributionControlElement). We distinguish systems (eg to maintain comfort conditions in the building) and the elements involved in the distribution of energy, air, etc. (IfcDistributionFlowElement) such as piping, wiring or terminal equipment.

Connection of network elements

The entity IfcPort describes a possibility of connection of an element with other elements. The derived entity IfcDistributionPort specializes this connection for components distribution.

The entity IfcRelConnectsPortToElement defines the relationship between an element (IfcElement) and a connection point of this element (IfcPort). To define a connecting link between 2 elements, the use of IfcRelConnectsPorts will establish the link between a connection point of each of the two elements.

APPENDIX 4 – gbXML FOR ENERGY SIMULATION

Building

Attribute Name	gbXML object
Usage	Building

Geographical location	gbXML:Campus:
	• Location
	    o Longitude
	    o Latitude
	    o Elevation

Orientation	gbXML:Campus • Location o CADModelAzimuth
Weather data file	gbXML:Campus: • designHeatWeathIdRef • designCoolWeathIdRef

Zone (grouping of room spaces)

Attribute Name	gbXML object (ver 5.12)
Occupancy	Space • PeopleNumber
Usage	Space • SpaceType
Ground area	Space • Area
Volume	Space • Volume
Temperature	Space • Temperature

Ventilation	Space/Zone
	• AirLoopId
	    o AirLoopEquipment
	        ▪ RatedFlow
	        ▪ …

Air conditioning	Space/Zone

	• HydronicLoopId
	o HydronicLoopEquipment
	▪ RatedFlow
	…
Adjacency	Space/Zone • SpaceBoundary

Opaque walls (wall, slab, roof, door)

Attribute Name	gbXML object
Type	gbXML:Campus • Surface o SurfaceType
Internal or External	gbXML:Campus • Surface o SurfaceType

Azimuth	gbXML:Campus
	• Surface
	     o RectangularGeometry
	         ▪ Azimuth

Slope	gbXML:Campus
	• Surface
	     o RectangularGeometry
	         • Tilt

Surface	gbXML:Campus
	• Surface
	     o RectangularGeometry
	         ▪ Height and Width

U-value	gbXML:Campus
	• Surface
	     o Construction
	         ▪ U-value

Material layer properties	gbXML:Material • SpecificHeat • Conductivity • R-value • Density
Solar factor	gbXML:Campus • Surface o exposedToSun

Window

Attribute Name	gbXML object

Type	gbXML:Campus
	   • Surface
	       o Opening
	          ▪ windowType

Azimuth	gbXML:Campus
	   • Surface
	       o Opening
	          ▪ RectangularGeometry
	             • Azimuth

Slope	gbXML:Campus
	   • Surface
	       o Opening
	          ▪ RectangularGeometry
	             • Tilt

Surface	gbXML:Campus
	   • Surface
	       o Opening
	          ▪ RectangularGeometry
	             • Height and Width

U-value	Campus
	   • Surface
	       o Opening
	          ▪ U-value

Solar factor	gbXML::WindowType • Transmittance
Light transmittance	gbXML::WindowType • ShadingCoef

Shading

Attribute Name	gbXML object
Dimensions	-

Thermal Inertia

Attribute Name	gbXML object
Type	-

| Exchange area | - |

Permeability

Attribute Name	gbXML object
Flow rate	-

Thermal losses

Attribute Name	gbXML object
Spatial location	Buidlig • Space
Parameters	-