HI-SMART

HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #7

CHAPTER 1: FUNDAMENTALS OF BUILDING ENERGY SIMULATION

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7.1.1 PRINCIPLES OF BES

BES is a computational modelling and simulation tool which basically works with simplified descriptions of complex systems and process. Main role is in the optimization of the building system during the different phases, from pre-design through commissioning to operation. It covers a wide variety of aspects (Fig. 7.1.1.) and has a potential to reduce the environmental impact of the building environment, to improve indoor quality and productivity, as well as to facilitate future innovation and technological progress in construction. Moreover, it plays an important role in the development of new or renovated high-performance sustainable buildings and their components.

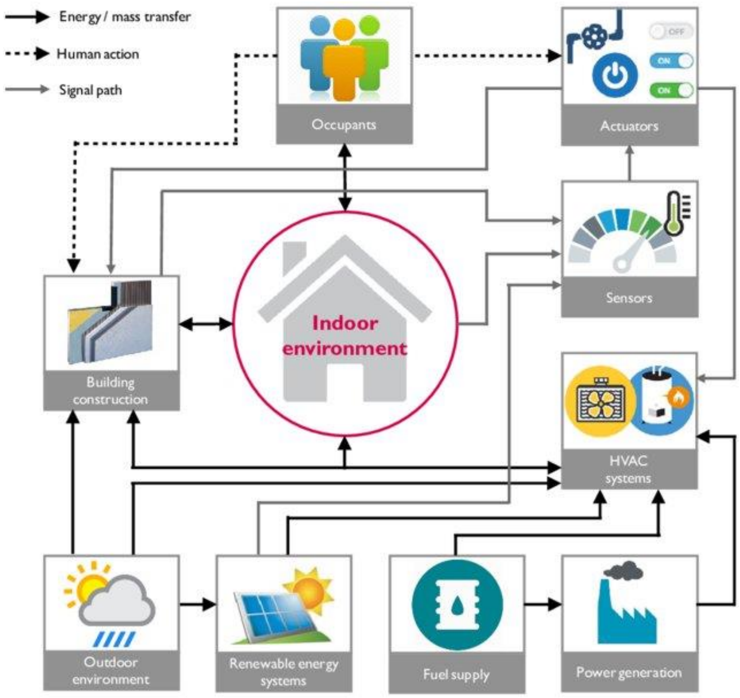

Figure 7.1.1 - Dynamic interactions of sub-systems in buildings. Source: Hensen and Lamberts (2019)

A building is a very complex system (from physical point of view), which is influenced by a wide range of parameters. For clear understanding of the simulation approach, it is useful to visualise such a system as an electrical network of time dependent resistances and capacitances subjected to time dependent potential differences. Constructional elements (room contents, glazing systems, plant components, renewable energy devices etc.) may be treated as network 'nodes' and characterised by capacitance, with the inter-node connections characterised by conductance. The flow paths encountered within and out with building and which interact, in a dynamic manner, to determinate interior comfort and building energy demands (Fig. 7.1.2) (Clarke, 2001).

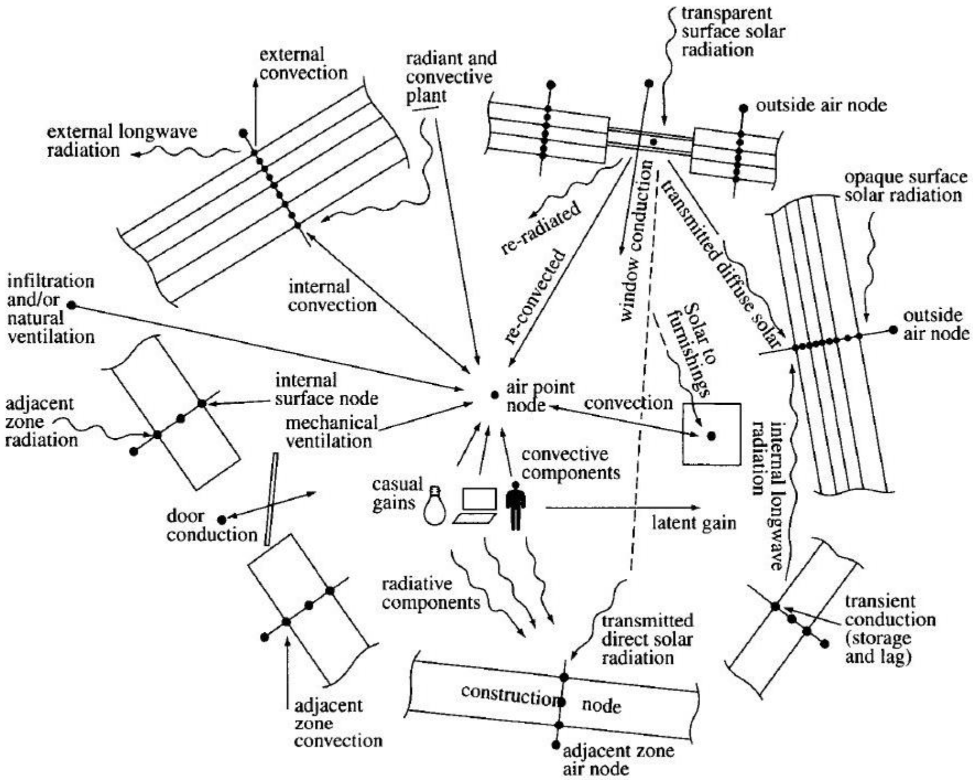

Figure 7.1.2. – Building energy flowpaths. Source: Clarke (2001)

A simulation model is an abstraction of the real building which allows to consider the influences on high level of detail and to analyze key performance indicators without expensive measurements. The user should work with the considerable amount of input data according to the required level of detail and modelling approaches. Various types of inputs data can be entered in accordance with categories (Tab. 7.1.1). The amount of required detail determines the model resolution and should be driven by the objective of the simulation study, although it should be emphasized that not all tools provide predictions for all domains.

Table 7.1.1. Types of input data required from user. Source: Beausoleil-Morrison (2021)

Category	Input
Geometry	Building plan and elevation Internal space layout Window sizes, locations, and shades Shading by neighbouring buildings and objects
Materials	Properties of structural and insulating materials Radiative properties of glazings
HVAC	Energy conversation and distribution systems Ventilation systems

	Component and supervisory controls
Airflow	Window and other intentional openings Cracks, holes, and defects in air barrier Airflow paths between internal spaces
Internal gains	Electrical appliances and lighting Moisture sources, such as cooking and plants
Occupants	Occupant density and schedule Activities that generate heat and moisture Control of appliances and lighting Interactions with windows and thermostats
Weather	Solar radiation Air temperature and humidity Wind speed and direction Sky conditions Ground snow cover Microclimates effects

Generally, BES is often used to research novel energy conversion and storage systems for buildings at many stages of their life cycle. It is helpful for establishing the shape, size, and layout of a building (pre-design and schematic design phases), as well as for detail design of the building envelope, HVAC, and lighting systems. Additionally, is often used post-design to demonstrate compliance with building or energy regulations, or as a requirement of energy labelling programmes. Although less common, it can also be used to assist BES tools and users during building commissioning and to improve building operations (building controls, fault detection). Table 7.1.2. provides a partial listing of BES applications.

BES applications leverage its ability to answer questions that cannot be easily answered by other means. Major use cases include the following [energy.gov]:

- **Architectural Design**: Architects use BES to design energy-efficient buildings, specifically to inform quantitative trade-offs between up-front construction costs and operational energy costs. In many cases, BES can reduce both energy costs and up-front construction costs.
- **HVAC Design and Operation**: Commercial building HVAC systems can be large and complex. BES helps mechanical engineers design HVAC systems that meet building thermal loads efficiently. It also helps design and test control strategies for these systems.
- **Building Performance Rating**: BES can be used to assess the inherent performance of a building while controlling for specific use and operation. Inherent performance rating is the basis for processes like code compliance, green certification, and financial incentives.
- **Building Stock Analysis:** BES analysis on prototype models supports the development of energy codes and standards and helps organizations like utilities and local governments plan large scale energy-efficiency programs.

Table 7.1.2. Applications of BES. Source: Beausoleil-Morrison (2021)

Category	Prediction
Thermal	Predicting energy consumption Estimating peak heating and cooling loads Sizing HVAC equipment Assessing building form and fabric Examining external shading Determining overheating risks Comparing HVAC systems Assessing natural and hybrid ventilation Exploring novel energy systems
Indoor environment	Ventilation effectiveness Airflow distribution Indoor air quality Daylighting Lighting quality Thermal comfort
Operations	Fault detection Model predictive control Comparing control options
Other	Occupant behaviour and movement Coupled heat, air, and moisture transfer Acoustics Fire propagation Building evacuation External airflow

The BES community does not have clear criteria to classify and evaluate the facilities offered by tools. There are not yet uniform definitions of tool requirements and specifications based on formal consultations with users, practitioners and tool developers. Additionally, there is no clear methodology to compare BES tools. Five selection criteria were proposed for assessing and definition of tool specifications and criteria for developers, practitioners, and tool users Fig. 7.1.3. (Attia et al., 2011). BES software cannot cover all physical domains in detail. An integrated BES environment based on an advanced multizone building performance simulation system which is run-time coupled to external software packages is continuously developed Fig. 7.1.4 (Malkawi and Augenbroe, 2004).

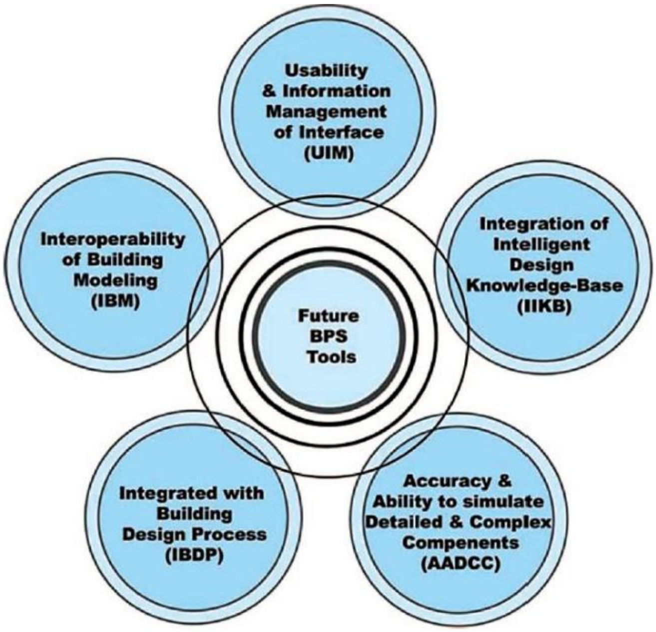

Figure 7.1.3. – The five selection criteria. Source: Attia et al. (2011)

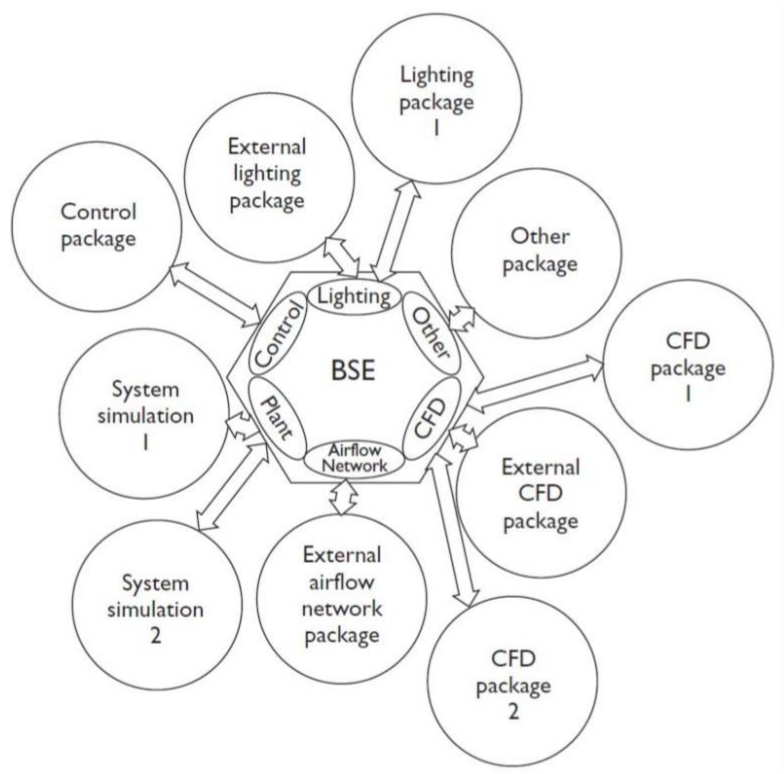

Figure 7.1.4. – The integrated BES environment. Source: Malkawi and Augenbroe (2004)

7.1.2 BES SOFTWARE

Nowadays, there is a variety of energy modelling applications (DesignBuilder, IDA-ICE, EnergyPlus, TRNSYS, eQUEST, Autodesk Green Building Studio, Ecotect etc.) available with different levels of complexity and responses to different presumed design parameters and operating conditions. There is a growing number of BPS software available on the market that are updated and listed here (buildingenergysoftwaretools.com). Different simulation tools require different levels of input details. More complex a software is, the more user experience is needed. The choice of which software should be used depends on the personal preference and the aim of the research. The nature of available BES tools and modelling approaches is fairly diverse, ranging from basic heat transfer physics to complicated material science, from simple living schedules to sophisticated human behaviours, from typical meteorological data to global warming impacts (Wang and Zhai, 2016). Nevertheless, they have a general structure of data flow (Fig. 7.1.5) (Al Ka'bi, 2020). BES programs require basically three main steps in the process of simulation:

- detailed input related to building geometry, building orientation, building location (weather data), building materials, systems.
- specification of activity and hours of building operation (the personal activities, existing equipment, comfort parameters, different kind of schedules, etc.).
- running the simulation, checking errors and results.

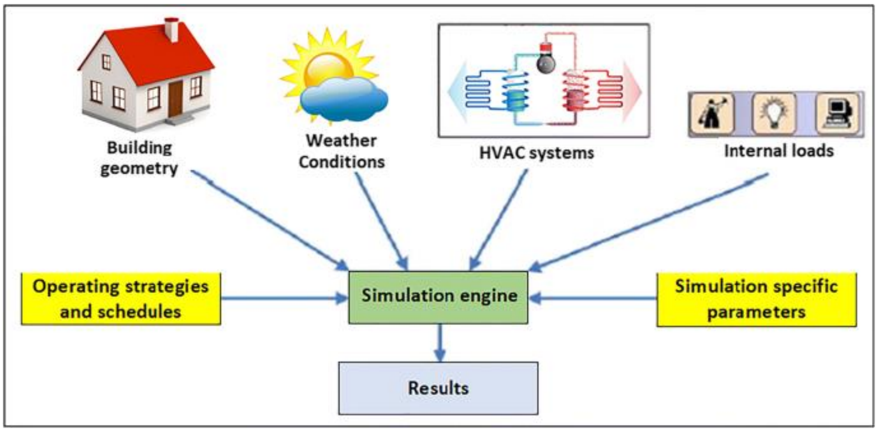

Figure 7.1.5. - General data flow of energy simulation applications. Source: Al Ka'bi, (2020).

The programs use weather data and calculate the heating and cooling requirements, daylight conditions and the annual or certain period energy usage. This is a good tool for companying multiple building or system alternatives. All facilities must be designed to meet capital budgets but must also be designed with future operating costs in mind. Energy efficiency will be achieved through a fully engineered system with properly selected equipment and controls systems. Energy modelling is also required by several countries and must be performed properly so building permits can be received in a timely manner (michaudcooley.com). Special category in simulation approach is applying principles of validation, verification and calibration, which are used to assure the quality of BES. Simulation programs use different methods and models to determine the simulation results. In general, there are many ways to group building simulation approaches and tools, which all have their own merits. They may represent a small part of the building, such as a one-dimensional section through a wall, or a complex combination of geometry, materials and systems representing a full building. One common way of classifying building simulation models is by their temporal dimension and distinguishing between stationary, semi-dynamic and transient models (P. de Wilde, 2018). Many of the widely used BPS tools adopt response factor techniques to solve the differential equations governing the heat and mass transfer through opaque building elements or use finite difference or finite volume methods for modelling transient conduction. BES tools have various capabilities and characteristics with respect to performance prediction of advanced building systems (Tab. 7.1.3) (R.C.G.M. Loonen et al., 2017).

Table 7.1.3. Characteristics of whole building energy simulation tools. Source: Beausoleil-Morrison (2021)

	Conduction solution method	User Interface	Source code access and modification	Control simulation capabilities	Physical domain integration
EnergyPlus v8.3	Conduction transfer function, Finite difference	IDF editor, DesignBuilder, Comfen, OpenStudio, Simergy, Sefaira, DIVA, AECOsim	X	Presets, Time-scheduled, Energy Management System (EMS)	Thermal, visual, airflow
ESP-r	Finite volume	Graphic and text mode	X	Presets, time-scheduled	Thermal, airflow
IDA ICE v4.7	Finite difference	Standard and advanced level	X	Presets, time-scheduled	Thermal, visual, airflow
IES v2015	Finite difference	IES VE, SketchUp and Revit plug-ins		Presets, time-scheduled, formula profile (APpro)	Thermal, visual, airflow
TRNSYS v17.1	Conduction transfer function	TRNBuild, SketchUp plug-in	X	Presets, time-scheduled, user-defined equations in Simulation Studio, W-editor (Type 79)	Thermal, airflow

Before simulation process, it is worth to consider the “ten reasons why not to simulate” (J. Banks and R.R. Gibson, 1997), which can be summarized as:

1. The problem can be solved using “common sense analysis”;
2. The problem can be solved analytically (using a closed form);
3. It’s easier to change or perform direct experiments on the real thing;
4. The cost of the simulation exceeds possible savings;
5. There aren’t proper resources available for the project;
6. There isn’t enough time for the model results to be useful;
7. There is no data – not even estimates;
8. The model can’t be verified or validated;
9. Project expectations can’t be met;

10. System behaviour is too complex, or can't be defined.

7.1.3 ENERGYPLUS

The U.S. Department of Energy (DOE) has supported research, development, and deployment of BES and has itself been an active user of BES since the 1970s. DOE develops two significant BES software packages (energy.gov).

- **EnergyPlus** is an engine capable of modelling low-energy building designs and HVAC systems, in addition to more conventional buildings.
- **OpenStudio** is a software development kit that reduces the effort of EnergyPlus-based application development. It also includes a graphical application.

The EnergyPlus is a modular, structured code based on the most popular features and capabilities of the two existing and well-functioning programs (BLAST and DOE-2). The OpenStudio software development kit (SDK) is behind an already large and growing number of public and private sector applications and services (Fig. 7.1.6).

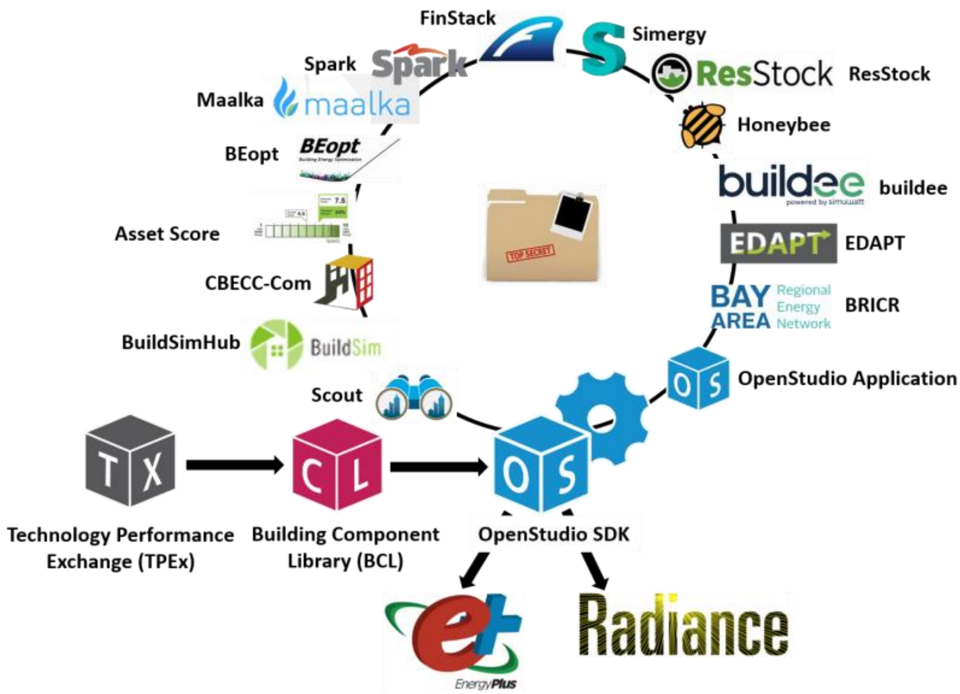

Figure 7.1.6. - The OpenStudio software development kit (SDK). Source: energy.gov.

EnergyPlus is one of the well-known BPS tools. It is a whole building energy simulation program to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings. Some of the notable features and capabilities of EnergyPlus include (energyplus.net):

- **Integrated, simultaneous solution** of thermal zone conditions and HVAC system response that does not assume that the HVAC system can meet zone loads and can simulate un-conditioned and under-conditioned spaces.
- **Heat balance-based solution** of radiant and convective effects that produce surface temperatures thermal comfort and condensation calculations.
- **Sub-hourly, user-definable time steps** for interaction between thermal zones and the environment; with automatically varied time steps for interactions between thermal zones and HVAC systems. These allow EnergyPlus to model systems with fast dynamics while also trading off simulation speed for precision.
- **Combined heat and mass transfer** model that accounts for air movement between zones.
- **Advanced fenestration models** including controllable window blinds, electrochromic glazings, and layer-by-layer heat balances that calculate solar energy absorbed by window panes.
- **Illuminance and glare calculations** for reporting visual comfort and driving lighting controls.
- **Component-based HVAC** that supports both standard and novel system configurations.
- **A large number of built-in HVAC and lighting control strategies** and an extensible runtime scripting system for user-defined control.
- **Functional Mockup Interface** import and export for co-simulation with other engines.
- **Standard summary and detailed output reports** as well as user definable reports with selectable time-resolution from annual to sub-hourly, all with energy source multipliers.

Energy Plus was explicitly designed as a simulation engine and does not exist a visual interface that allow users to see and concept the building. In this case third-party software tools, i.e., Design Builder, OpenStudion need to be used. The simulation of a building is divided into two stages (J. Sousa, 2012):

- Construction of the building.
- Introduction of data, such as environmental aspects, effects of shading, cooling system, internal gains, etc.

The overall program structure of EnergyPlus has three basic components: a simulation manager, a heat and mass balance simulation module, and a building systems simulation module (Fig. 7.1.7). The integrated solution manager of EnergyPlus manages the surface and air heat balance modules and acts as an interface between the heat balance and the building systems simulation manager (Fig. 7.1.8).

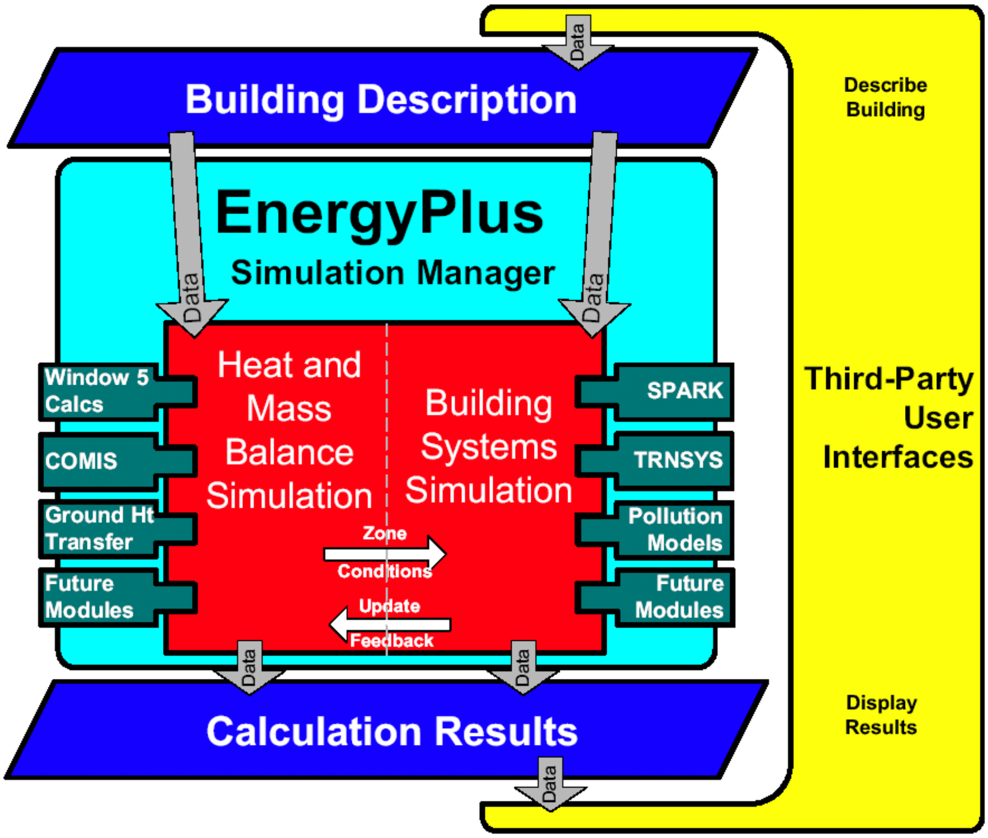

Figure 7.1.7. – EnergyPlus structure. Source: Crawley et al. (2004).

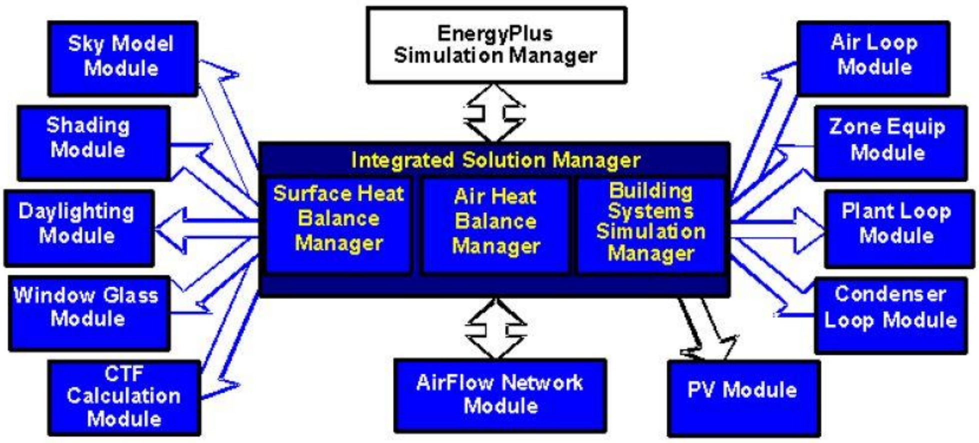

Figure 7.1.8. – Integrated simulation manager. Source: EnergyPlus Engineering Reference (2020).

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