Selection of Energy Conservation Measures in Building Design Phases Considering Level of Details

Mina Choi, Gahee Kim, and Sean Hay Kim

***Abstract*—Building energy simulation plays an important role in the design process by predicting building performance. Yet practitioner designers often feel frustrated during preparing simulations, if they are not sure of design variables of an Energy Conservation Measures (ECMs) requiring accurate information about building and systems. To help practitioners, this paper provides a guideline to select ECMs, evaluation simulation tools, and detailed inputs for modeling of ECM at each building design phase as a format of Level of Detail (LOD).**

***Index Terms*—Energy conservation measure, level of detail, energy simulation, building modeling guideline.**

I. Background and Objective

A global warming caused by an increasing use of fossil fuels begins to cause a serious environmental problem. Buildings take up to 30% of national energy consumption as in lighting, electrical equipment, heating ventilating and air conditioning (HVAC) system, and refrigeration systems. To effectively and efficiently regulate building energy use, it is important to select appropriate Energy Conservation Measures (ECMs) in building design process, rather than to add some actions after construction. In a design stage, building energy simulation is a useful tool to analyze the energy performance of a building model containing ECMs. Most energy simulations, however, require an expert level of system knowledge as well as simulation knowledge. It is, thus, hard for practitioners to actively employ building energy simulations during design process.

II. Research Process

The aim of this study is to suggest a guideline that improves a use of energy simulations in each design phase. This study proposes what simulations are appropriate to capture features of ECMs and when Level of Detail (LOD) of each ECM starts being discussed and confirmed in the design process. Fig. 1 briefly elaborates how this study has proceeded.

First, we have examined major tasks at each design phase and formulated a basic framework of the design process based on interviews with design engineers. Next, we have explored literature and selected ECMs available in the market and then classified them into passive measures applied to a building and Mechanical Electronic and Plumbing (MEP) measures. In the third step, LOD of each ECM has been factorized and then analyzed in which design phase the LOD can be decided. Lastly major simulation tools that have a sufficient capability of evaluating ECMs in each design stage in terms of algorithm and usability have been investigated. The final artifact of this study is well described in Table I. Readers can find a useful information concerning a choice of ECMs, evaluation tools, and information availability of the ECM at each design phase.

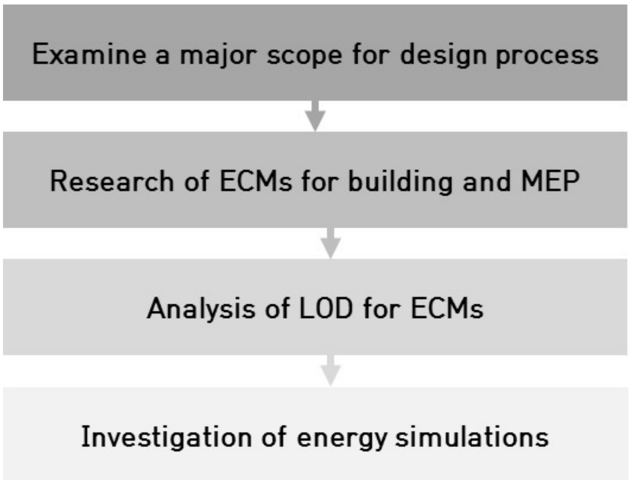

Fig. 1. Process of the research.

III. Building Design Phases

The building design process can be divided into phases in Table II. Also, it elaborates primary tasks of each design stage in order to identify when LOD starts to be discussed and confirmed.

IV. Energy Conservation Measure (ECM)

Factors affecting energy consumption of a building can be divided into architecture, MEP, and controls as shown in Fig. 2. Architectural design can be classified into mass and layout plan, building envelope and materials. MEP design can be classified into heat source, air conditioning system, lighting system, renewable energy system, equipment. Controls mean an operation method of buildings and equipment such as scheduled ventilation and night purge that means ventilating. Most ECMs in this paper were selected based on [1]-[7].

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The authors are with School of Architecture, Seoul National University of Science and Technology, Seoul, South Korea (e-mail: chmina94@naver.com, rkgml9408@naver.com, seanhay.kim@seoultech.ac.kr).

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TABLE I: LEVEL OF DETAIL (LOD) FOR PRIMARY ECMs OF BUILDINGS AND SIMULATION TOOLS TO EVALUATE ECMS

ECM	Simulation	Object	Sub-Object	LOD	PS	SD	D D	CD	Cons/ Occp.
Shading and daylighting optimized by surroundings	EnergyPlus, eQUEST, TRNSYS	Mass	G&T	Placement, Area, Volume, Floor, Height, Orientation	□				■
		Site	Microclimate	Shade by surroundings, Reflection by surroundings, Solar radiation modulated by surroundings, Ground reflectance modulated by surroundings, Air temperature elevation by urban heat island effect	□				■
Building mass minimizing envelope area and taking advantage of solar gain and heat loss	EnergyPlus, eQUEST	Mass	G&T	Placement, Area, Volume, Floor, Height, Orientation	□				■
Landscaping per orientation considering seasonal solar gain and shading	EnergyPlus, eQUEST	Site	Microclimate	Shade by surroundings, Reflection by surroundings, Solar radiation modulated by surroundings, Ground reflectance modulated by surroundings, Air temperature elevation by urban heat island effect	□				■
		Landscape	Tree	Type, Orientation			□		■

ECM	Simulation	Object	Sub-Object	LOD	PS	SD	D D	CD	Cons/ Ocup
Envelope finish considering solar absorption and reflectance	EnergyPlus, eQUEST, TRNSYS	Roof	G&T	Placement, Area	□				■
			Exterior finish	Color, Reflectance			□		■
		Window/ Curtain wall/ Sky light	G&T	Placement, Area	□				■
			Glazing	SHGC, VT		□			■
			Frame/ Mullion	Glass-Frame ratio		□			■
			Shade	Exterior horizontal/vertical shade		□			■
Cool roof	EnergyPlus, eQUEST, TRNSYS	Roof	G&T	Placement, Area	□				■
			Exterior finish	Color, Reflectance			□		■
Glazing considering solar gain and shading	EnergyPlus, eQUEST, TRNSYS	Window/ Curtain wall/ Sky light	Glazing	U-value, SHGC, VT		□			■
			Frame/ Mullion	U-value, Glass-Frame ratio, Air tightness		□			■
			Shade	Exterior horizontal/vertical shade		□			■
Electrochromic Glazing	EnergyPlus, eQUEST	Window/ Curtain wall/ Sky light	Glazing	SHGC, VT		□			■
Air-tight envelope to reduce infiltration	EnergyPlus, eQUEST, TRNSYS	Exterior wall	Construction	Air tightness		□			■
		Door	Vestibule	Placement, Volume		□			■
		Window/ Curtain wall/ Sky light	Frame/ Mullion	Air tightness		□			■
Double skin facade/air flow window	EnergyPlus, TRNSYS	Window/ Curtain wall/ Sky light	Glazing	U-value, SHGC, VT		□			■
		Exterior wall	Frame/ Mullion	U-value, Glass-Frame ratio, Air tightness		□			■
Green roof	EnergyPlus, TRNSYS *not yet commercial	Roof	Construction	R-value, Heat capacity		□			■
			Insulation	Insulation, R-value		□			■
		Landscape	Tree, Grass	Type, Orientation		□			■
Green wall	TRNSYS	Exterior wall	Construction	R-value, Heat capacity		□			■
			Insulation	R-value		□			■
		Landscape	Grass	Type, Orientation		□			■
Light shelf	EnergyPlus, Equest	Window/ Sky light	G&T	Placement, Area	□				■
			Glazing	U-value, SHGC, VT		□			■
Sky light	EnergyPlus, eQUEST, TRNSYS		Frame/ Mullion	U-value, Glass-Frame ratio, Air tightness		□			■
Light duct	EnergyPlus		Shade	Exterior horizontal/ vertical shade		□			■

			Blind/Curtain	Indoor blind				□	■
Trombe wall	EnergyPlus, eQUEST,TRNSYS	Mass	G&T	Placement, Area, Orientation	□				■
		Exterior wall	Construction	R-value, Heat capacity		□			■
		Window/ Curtain wall/ Sky light	Glazing	U-value, SHGC		□			■
EVB (Exterior Venetian Blinds)	EnergyPlus, eQUEST,TRNSYS	Window/ Curtain wall/ Sky light	Shade	Exterior horizontal/ vertical shade		□			■
PCM (Phase Change Material) applied in wall and ceiling	EnergyPlus, TRNSYS	Exterior wall	Construction	R-value, Heat capacity, Air tightness		□			■
			Insulation	R-value		□			■
		Ceiling	Construction	Color, Heat capacity		□			■

ECM	Simulation	Object	Sub-Object	LOD	PS	SD	DD	CD	Cons/ Ocup
High efficiency plant	EnergyPlus, eQUEST, TRNSYS	Heat exchanger for district heating		Placement, Capacity			□		■
				Efficiency, Heat source type	□				■
		Water/Steam boliler		Placement, Heating capacity			□		■
				Fuel type, Tube type, Efficiency				□	■
High efficiency refrigerator	EnergyPlus, eQUEST, TRNSYS	Vapor compression chiller		Placement, Capacity			□		■
				COP, Compression refrigeration type, Compressor type, IPLV, Performance curve, Compressor control			□		■
		Absorption chiller		Placement, Cooling capacity, Hot water capacity			□		■
				Heat source connection Fuel for direct fire External heat source, Cooling COP, Heating COP, IPLV, Performance curve				□	■
		Ice storage		Placement, Heat capacity			□		■
				Volume, Ice making type, Insulation, Refrigerant type				□	■
		CHW storage		Placement, Heat capacity			□		■
				Volume, Insulation				□	■
Variable speed compressor, condenser, pump, fan	EnergyPlus, eQUEST, TRNSYS	Heat pump/ Variable Refrigerant Flow (VRF)	Compressor	Speed control				□	■
			Fan	Flow control				□	■
		Vapor compression chiller		Compression refrigerator type, Compressor type, Compressor control				□	■
Absorption chiller-heater	EnergyPlus, eQUEST, TRNSYS	Absorption chiller		Placement, Cooling capacity, Hot water capacity			□		■
				Heat source connection Fuel for direct fire External heat source, Cooling COP, Heating COP, IPLV, Performance curve				□	■
District heating and cooling	EnergyPlus, eQUEST, TRNSYS	Heat exchanger		Placement, Capacity			□		■
				Efficiency				□	■
				Heat source type	□				■
Optimal on/off for plants	EnergyPlus, eQUEST, TRNSYS	Water/Steam boiler		HW reset, On-demand control				□	■
On-demand operation for plants				On-demand control				□	■
Outside air and load reset for CHW, CW, HW	EnergyPlus, eQUEST, TRNSYS	CHW, CW, HW Pump		Placement			□		■
				Efficiency, Performance curve (Flow rate, Head) Flow control, Power				□	■
		CHW, CW, HW Pipe		Placement, Diameter, Length			□		■
				U-value, Inlet outlet water delta t, Pressure drop per unit length, Pressure drop by fitting, Pressure drop by plant, Pressure drop by equipment/device, Pressure drop by control and balancing				□	■

				valve					
Optimized HVAC zoning	EnergyPlus, eQUEST, TRNSYS	AHU		Placement, Volume, Cooling capacity, Heating capacity, Configuration, Dimension			□		■
		Heat pump/ Variable Refrigerant Flow (VRF)		Placement, Heating capacity, Cooling capacity, length, Configuration			□		■

ECM	Simulation	Object	Sub-Object	LOD	PS	SD	DD	CD	Cons/ Ocup
Optimized HVAC zoning	EnergyPlus, eQUEST, TRNSYS	Dedicated Outdoor Air System (DOAS)		Placement, Volume, Air flow rate, Cooling capacity, Heating capacity			□		■
		FCU		Placement, Cooling capacity, Heating capacity, Air flow rate, HW flow rate, CHW flow rate			□		■
		Chilled beam	Diffuser	Placement, Actuation type Induction ratio, Cooling capacity, Heating capacity, Air flow rate HW flow rate, CHW flow rate Indoor unit control			□		■
		Underfloor Air Distribution System, Displacement ventilation systems	Diffuser	Placement, Actuation type Return air type			□		■
			Supply fan	Revolving type, Power, Efficiency, Performance curve (Flow rate, Pressure), Flow volume control, Flow control			□		■
		Zone		Placement, Area, Volume			□		■
		Mass		Placement, Area, Volume, Height, Orientation			□		■
Heat/Enthalpy Recovery Ventilation	EnergyPlus, eQUEST, TRNSYS	AHU	Heat/enthalpy recovery	Type, Flow rate, Heating heat recovery rate, Cooling heat recovery rate				□	■
		ERV unit		Placement			□		■
				Type, Flow rate, Heating heat recovery rate, Cooling heat recovery rate				□	■
Desiccant and evaporate cooling	EnergyPlus, eQUEST, TRNSYS	DOAS	Desiccant Cooling	Desiccant type				□	■
			Evaporative Cooling	Method, Flow rate, Cooling performance curve				□	■
Night purge control	EnergyPlus	AHU		Night purge				□	■
		DOAS	Economizer	OA control OA damper airtightness					
Demand Controlled Ventilation(DCV)	EnergyPlus, eQUEST, TRNSYS	AHU DOAS	Economizer	OA control OA damper airtightness				□	■
Duty cycle control	EnergyPlus, eQUEST, TRNSYS	AHU		Duty cycle control				□	■
Optimal on/off control for AHU				Optimal on/off control				□	■
Outside air temperature and load reset	EnergyPlus, eQUEST, TRNSYS	Boiler		HW reset				□	■
		Cooling tower		Optimum CW temperature control				□	■
Garage Carbon Monoxide control	TRNSYS	AHU		CO control for garage				□	■
High efficiency water heater	EnergyPlus, eQUEST, TRNSYS	Water heater		Placement, Hot water capacity			□		■
				Fuel type, Efficiency, Water storage				□	■
Insulated pipe	EnergyPlus, eQUEST, TRNSYS	CHW, CW, HW, DHW pipe		U-value				□	■
Water saving closet and tab	EnergyPlus, Equest *only water heating	Closet, Tab		Placement, Volume, Heat				□	■
				Boiling method Insulation				□	■
Daylight sensor	EnergyPlus, eQUEST, TRNSYS	Ambient light		Light schedule, Daylight control, LED deeming control, Exterior light automatic on/off, Grouping control				□	■
Deeming and on/off control	EnergyPlus, eQUEST, TRNSYS	Ambient light		Light schedule, LED deeming control, Exterior light automatic on/off, Grouping control				□	■

ECM	Simulation	Object	Sub-Object	LOD	PS	SD	DD	CD	Cons/ Ocup
Lighting schedule per space	EnergyPlus, eQUEST, TRNSYS	Ambient light		Light schedule				□	■
Photovoltaic exterior light	EnergyPlus, eQUEST, TRNSYS	Ext. light		Placement, Wattage, On-site PV attached				□	■
		Photovoltaic	Solar panel	Placement, Area, Azimuth, Angle, Seasonal shade				□	■
				Module type, Tracking mode Generation capacity, Generation efficiency Nominal operation cell temperature, Temperature coefficient, Loss coefficient				□	■
			Inverter	Placement, Capacity				□	■
				Efficiency				□	■
Parasitic load control	EnergyPlus, eQUEST, TRNSYS	Static capacitor		Placement, Voltage, Wattage, Current				□	■
Sequence control, group and schedule management of elevator/escalator	EnergyPlus, eQUEST, TRNSYS	Elevator/ Escalator		Placement, Number			□		■
				Control				□	■
Solar water and space heating	EnergyPlus, TRNSYS	Solar panel		Placement, Area, Azimuth, Altitude, Seasonal shade		□			■
				Type			□		■
				Capacity, Efficiency, Absorptivity			□		■
		Hot water tank		Placement, Volume, Heat capacity			□		■
				Insulation				□	■
		Primary pump		Placement, Power			□		■
				Efficiency, Performance curve (Flow rate, Head)			□		■
				Flow control				□	■
		Heat exchanger		Placement, Capacity, Efficiency			□		■
Solar air heater	EnergyPlus, TRNSYS	Solar panel		Placement, Area, Azimuth, Altitude, Seasonal shade		□			■
				Type			□		■
				Capacity, Efficiency, Absorptivity, Flow volume			□		■
		Supply fan		Placement, Power			□		■
				Revolving type			□		■
				Efficiency, Performance curve (Flow rate, Pressure)				□	■
				Flow volume control (CAV, VAV)				□	■
				Variable flow control (RPM, Outlet/Inlet damper, Inlet vane, Variable pitch				□	■
Geothermal heat pump	EnergyPlus, eQUEST, TRNSYS	Heat pump		Placement		□			■
				Cooling capacity, Heating capacity, Cooling COP, Heating COP			□		■
				Compressor control				□	■
		Ground heat exchanger		Placement, Land area, Length, Number, Pipe diameter, Distance between pipes		□			■
				Type		□			■
				Capacity, Grouting conductivity			□		■
		Primary and Secondary pump		Placement, Power			□		■
				Efficiency, Performance curve (Flow rate, Head)			□		■
				Flow control				□	■
		Expansion tank		Placement, Volume, Heat capacity			□		■

TABLE II: PHASES OF THE BUILDING DESIGN PROCESS

Phase	Detailed tasks
Pre-Schematic Design (PS)	Outline space plan, Check Building code, Field study, Analysis of existing building, User analysis
Schematic Design (SD)	Rough estimation, Planning of building and MEP, Examine approval process
Design Development (DD)	Approval, Drawing layer
Construction Document (CD)	Embody drawing, Create construction document, Estimating detailed construction expenses
Construction/ Post occupancy (Cons/Ocup)	Bidding, Construction, Operation

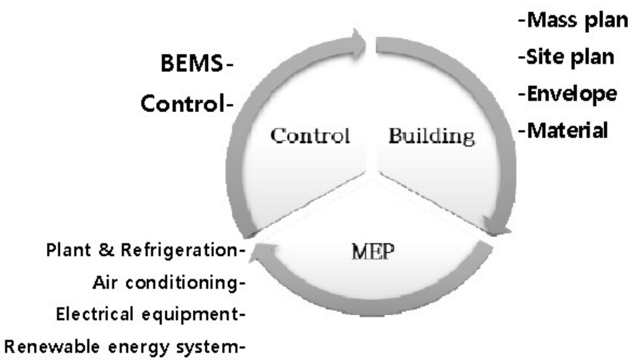

Fig. 2. Building energy consumption factors.

V. LEVEL OF DETAIL (LOD) OF AN ECM

First, we have investigated the design phases at which design elements and attributes of architectural and MEP objects are determined according to the building design process in Table III.

TABLE III: PRIMARY DESIGN ENTITIES DETERMINED IN EACH DESIGN PHASE

Design phase	Architecture	MEP
Pre-Schematic Design (PS)	Mass plan, Standards for design	Placement, Type and area of Geothermal heat exchange
Schematic Design (SD)	Building size, Zoning, Shape, Material	Schedule, Block planning of Renewable system
Design Development (DD)	Detailed Property	Placement, Type, Capacity, Efficiency, Control
Construction Document (CD)	Fixed	Fixed

In the pre-schematic design phase, layout and mass planning (such as location, orientation, height and area of a building) are mainly discussed with a feasibility study and then confirmed in the schematic design phase. Design criteria and conditions are already fixed (such as the surrounding terrain and climate of the building) before the design process begins. For MEP, it is very little to be determined at this stage because no specific design values are available yet. Since a ground heat exchanger is, however, installed in the site, the position and area of the geothermal system need to be considered together within the building layout.

In the schematic design stage, an overall shape, structure and materials of a building (such as envelopes, story height, stairs) are determined. In the MEP, user schedule, lighting and ventilation can be captured considering the use and size of the building. In addition, properties such as location and area are discussed for design entities located outside the building such as solar panels or underground heat exchangers.

In the design development stage, as most design values related to the building is determined, properties of MEP are started to be determined. At the beginning of this phase, placement, type and capacity of the equipment are settled down and properties related to the building controls are determined in the latter part of this stage.

In the construction document phase, most properties are determined and there can be necessary design changes. In Table I, the design phase at which each ECM is discussed is marked by □, and the design phase at which it is confirmed is indicated by ■.

VI. SIMULATION PROGRAMS FOR EVALUATING BUILDING ENERGY PERFORMANCE

Building energy simulation has been developed since 1970, and a use of simulation tools has been highly encouraged for green building designs. However, contrary to the advocacy group who goes for a new technology of building simulation, the pragmatist groups such as design engineers are somehow reluctant to understand unfamiliar simulations.

Therefore, in this paper, we have tried to propose a guideline of simulation use in order to encourage the simulation practitioners in easily evaluating the building energy performance. We have investigated a functionality of DOE-2.1, ECOTECT, EnergyPlus, eQUEST, ESP-r, HAP, IDA ICE, IES <VE>, Tas, TRACE and TRNSYS to determine what simulation tools best capture ECMs at each design stage. But only EnergyPlus, eQUEST and TRNSYS are marked in Table I, because they are mostly used simulations in Korea.

VII. CONCLUSION

To encourage energy simulations in building design, this paper proposes a guideline concerning what simulation is appropriate for each ECM to practitioner designers who are lack of the expertise in energy simulation. We hope to convince the people who have a sense of discomfort with unfamiliar simulations, such that various applications of building energy simulation can be tried out in the design phase. We also expect a convergence between architectural designers who is lack of the expertise of equipment, and MEP designers who is lack of the expertise of architecture. Therefore a systematic and integrated design can be implemented from the initial planning phase to the operation and maintenance phase.

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Mina Choi will receive a B.S degree in engineering in February 2017 from the School of Architecture of Seoul National University of Science and Technology, Seoul, South Korea.

Gahee Kim will receive a B.S degree in engineering in February 2017 from the School of Architecture of Seoul National University of Science and Technology, Seoul, South Korea.

Sean Hay Kim received a Ph.D. from the Georgia Tech. Before joining the Seoul National University of Science and Technology, she worked for Siemens and Autodesk in the U.S.