MODELING FOR BUILDING ENERGY PERFORMANCE IMPROVEMENT IN ACCORDANCE WITH THE LOCAL CLIMATIC SETTINGS: A CASE OF A GENERALIZABLE BUILDING DESIGN OF INTERMEDIATE HEALTH CARE FACILITIES IN THAILAND

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ABSTRACT

This study aims to conduct an Integrated Building Design process (IBD), collaborating a Building Information Modeling (BIM) application with a Building Energy Simulation tool (BES) to perform energy analysis, and improving the building energy performance of a Generalizable Building Design (GBD), an universal application on health care facilities design in Thailand, to state recommendations and guidelines of the BIM-BES integration for architects. A baseline model is created using a BIM system, exported by means of gbXML into a BES tool. An additional two types of modifications are performed to test the improvement of energy performance. The simulation results show that a slight variation of building orientations could alter the extent of energy consumption. Building materials constituting the envelope show their significant role on performance improvement (6.39 – 6.55 %). An integration of high performance measures could minimize energy consumption as much as 12.62 – 12.84%. Finally, the research addresses some limitations of the BIM-BES integration workflow.

INTRODUCTION

Thailand has limited domestic fuel production and reserves, and the country still remains dependent on imports of energy sources (58% in 2008) to meet growing domestic demand for the fuel (EPPO, 2009).

Building energy sector consumption accounts for 27% of the national gross. The health care facilities subsector, 65% of the national total number of inpatient beds are government's (DEDE, 2009), is one of the largest amount of energy consumption on construction and operation.

The Design and Construction Division (DCD) is a government organization in the management and administration of government health care facility buildings design and construction in Thailand. The DCD was established 50 years ago, more than 12,000 health care facility building designs have been administrated.

Thailand Public Health Care has been classified in 4 levels by population responsibility and distance between districts and provinces. There are total 781 government's Secondary Level hospitals which 200 of them are Intermediate Secondary (2.2 Level) Health Care Facilities that designated to serve more than 20 millions of Thai people.

The Generalizable Building Designs

Most of the 2.2 Level Health Care Facilities have been designed under the DCD's **Generalizable Building Designs** (**GBDs**), from the concept of "One Size Fits All" for universal application on health care facilities design which are in the GBD criteria of its type, functions, size and work load capacity, for the sake of time and resources minimization during new building design processes, aimed for being constructed in rural areas all over Thailand. Necessarily, GBDs should be simple and easy to build by any local contractors which most of them are low-tech, using inexpensive, easy to deliver materials even in the remote areas. There are more than 500 of GBDs that still being used and provided from the DCD to be included in nearly all of the construction project delivery packages for primary and secondary level health care facilities. The overall gross floor area of GBD buildings ranged from 40 square meters to thousands square meters, some of the GBDs have been used to build more than 5,000 buildings.

The GBD, however, has been established without critical consideration on the location, orientation, and configuration of the site planning to minimize energy consumption (Somboonwit, 2009). Most DCD architects, on the other hand, have limited knowledge on building energy performance; yet depend much upon their experiences and intuition during the design process.

Integrated Building Design Process

Since Thailand Public Sector Reform (PSR) was initiated in 2003. Due to one of the PSR goals, improving the public service performance with less cost, number of the DCD workforce has been reduced constantly but their duties, by contrast, have never been diminished. All personnel must have performed their task adaptively to complete the overwhelming load of works and sought for new ways of working and alternative tools superseding the conventional ones, 2D CAD and error-prone paper-based modes of communication (Eastman et al., 2008). A substantial choice of tool has been **Building Information Modeling** (**BIM**); BIM is an emerging tool / methodology / process of virtual design and construction which creates and uses the coordinated, consistent, computable information of the 3D models of the project components interconnect with the holistic information with the project's planning, construction, operation, and decommissioning (Krygiel and Nies, 2008; Kymmell, 2008). A BIM model serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward (Smith and Edgar, 2008).

From the time BIM was introduced to DCD architects and engineers, a number of DCD studies and design projects have included BIM into their tools. Noragrai (2007) and Phasurawanich et al. (2009) conducted studies of using BIM for development of Generalizable Building Designs. Somboonwit (2009) studied of the measurement and improvement of energy performance of a health facility building information model. Perceiving a lot of benefits of BIM and its distinguished abilities (i.e., Visualization, Parametric Modeling, and Integrated Building Design (IBD) support) through those pilot implementations, BIM has shown a lot of promise to succeed 2D CAD for DCD officers.

However, migrating to BIM is a great investment for a small government organization such the DCD, the results must be appreciable. To achieve the BIM's greatest productivity benefit, DCD architects have attempted to utilize it in multidisciplinary collaboration, with the software integration which the goal is to obtain high performance building designs during the early phase of design processes.

This study aims to conduct the data integration of an **Integrated Building Design process** (**IBD**), a process design in which multiple disciplines and seemingly unrelated aspects of design and a range of simultion tools are integrated in a manner that permits synergistic benefits to be realized (U.S. Department of Energy, 2001; Treldal, 2008), collaborating the BIM with the **Building Energy Simulation** tool (**BES**) to perform energy analysis, and improving the building energy performance of the case study building to state the recommendations and guidelines of the BIM-BES integration in Generalizable Building Design (GBD) process for DCD architects.

METHODOLOGY

Tools selection

The Autodesk Revit Architecture software is utilized for the BIM application, and the Autodesk Ecotect Analysis to perform energy analysis. Autodesk Revit Architecture is a BIM software developed by Autodesk, Inc., and Autodesk Ecotect Analysis is an environmental analysis tool with highly graphical interface that allows designers to simulate building performance from the earliest stages of conceptual design (Wikipedia, 2010; Krygiel and Nies, 2008).

A surpassing capability of BIM is inter-transferring of the building geometry and embedded information from the model with other applications to retain the consistency of data and eliminates the need to replicate data input that has already been generated, thus a considerable amount of modeling time can be reduced. The Green Building XML schema (gbXML), a schema developed to transfer energy consumption characteristics of buildings and information needed for preliminary energy analysis that usable by many BES applications currently available on the market (Eastman et al., 2007; Krygiel and Nies, 2008), is employed for data transfer in the BIM-BES integration.

Weather data

The location to simulate the building energy performance of the case study building is Bangkok, Thailand. Its global coordinates are 13°N 100°30′E. Bangkok lies about two meters above sea level and it has a tropical wet and dry climate, the annual temperature mean value is 27.83 ^{o}C and high temperature mean daily value is 32.73 ^{o}C (World Climate, 2011). Figure 1 shows daily averages, the range of average maximum and minimum temperatures are shown as a graded red scale along with direct and diffuse solar radiation, and relative humidity weather data for Bangkok, generated from the weather data for EnergyPlus that derived from the Typical Meteorological Year (TMY2) weather format (EERE, 2010).

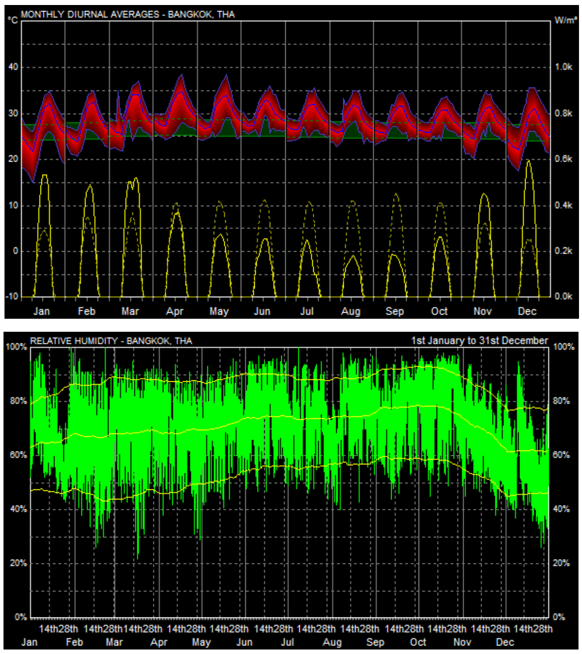

Figure 1 Daily average and relative humidity weather data for Bangkok generated from Weather Tool: Ecotect Analysis

Case study building

The DCD's GBD number 10404 is chosen as case study, a typical Emergency Medicine building for the Intermediate Secondary Level health facilities (up to 200 patients per day). Figure 2 shows the floor plan of the case study building, it is a small single storey building consists of 557 m^2 functional area used for Emergency Medicine Services; ambulance and ambulatory entrances, waiting area, patients cleaning room, administrative area, , main storage, ambulance equipments storage, sterilization, staff toilet, patient toilet, janitor room, and the principle function of the building; *the treatment hall* consists of reception desk, resuscitation area, acute treatment area, observation area, nurse workstations and pharmacy service.

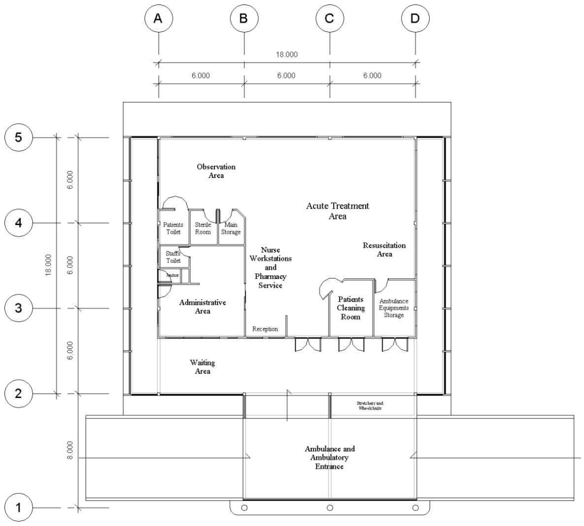

Figure 2 The case study building floor plan

Its physical characteristics are those of typical budget controlled government's health facility buildings; the structural constructions are in situ reinforced concrete, the exterior opaque walls are plastered brick walls, the glazing for windows is clear float 6 mm glass, and the roofs are asbestos cement sheets. Table 1 shows the U values of the case study building's components.

Table 1
U Values of the Case Study building components

Component	U Value (W/m-K)	Solar Absorption
100 mm Plastered Brick Wall	3.19	0.5
100 mm Concrete Wall	4.04	0.5
100 mm Concrete Floor	4.04	0.7
100 mm Concrete Slab Roof	4.04	0.7
100 mm Concrete Floor Ceramic Tile	3.78	0.7
Sloping Roof	2.79	0.7
6 mm Single Clear Glazing Window	5.62	SHGC 0.73
10 mm Gypsum Plaster Board Ceiling	4.68	-

The floor-to-ceiling height of all interior spaces is 3.45 m, and above them is the space under the roof, which has no natural ventilation by its design. The building has no specified building orientation at the first place; it will be determined whenever the construction project delivery packages provided form the DCD.

Thermal zones

The case study building divided into three types of zones: air-conditioned thermal zones, natural ventilation thermal zones, and non-thermal zone, which are

- Air-conditioned thermal zone: treatment hall, patients cleaning room, and administrative area.
- Natural ventilation thermal zone: main storage, ambulance equipments storage, sterilization, staff toilet, patient toilet, janitor room, and attic.
- Non-thermal zone comprises ambulance and ambulatory entrances, waiting area, and corridors.

HVAC

This building is located in a very hot and humid area; almost half of the building's area served by three cooling systems, no heating needed.

The treatment hall and *the patient cleaning room* are the same systems: the FCU is ceiling concealed w/return plenum and filter, ducted type, direct drive and the CDU is air-cooled type. For *the administrative area*: FCU is ceiling suspended, exposed type, direct drive and the CDU is Air Cooled type. All of the systems efficiency is 95%.

Simulation data

The internal gains of the case study building consist of occupancy, medical equipments, office equipments, and lighting. According to the case study building's purpose of usage, the building has an occupancy schedule for 24 hours everyday. The occupancy density fluctuates, depending on the activities and areas, the full occupancy may occur in the case of group accidents, but they are seldom. Due to the simulation engine, latent gains are not yet included in the internal thermal calculations (Autodesk Ecotect Analysis, 2010), only the sensible gains taken into account. ***Air infiltration*** specifies the amount of air leakage within the zone in air changes per hour, values range from *1.0 ach for air-conditioned thermal zones* and *50 ach for natural ventilation thermal zones*. In addition, ***wind sensitivity*** specifies the sensitivity of the zones to external wind speed, is set for *a suburban terrain and* *reasonably protected at 0.25 ach*. Table 2 shows the summary data in each of the thermal zones.

Table 2
Summary data for energy simulation

Thermal Zone	Descriptions
Treatment hall	• *Air-conditioned thermal zone* • Area 177.00 m^2 • Volume 590.07 m^3 • Lighting Level: 500 lux • Sensible Gain: 117 W/m^2 • Number of people: 10 • Activity: 100W • Clothing: 1.0 clo
Patients cleaning room	• *Air-conditioned thermal zone* • Area 12.00 m^2 • Volume 36.93 m^3 • Lighting Level: 500 lux • Sensible Gain: 117 W/m^2 • Number of people: 3 • Activity: 100W • Clothing: 1.0 clo
Administrative area	• *Air-conditioned thermal zone* • Area 34.00 m^2 • Volume 110.67 m^3 • Lighting Level: 300 lux • Sensible Gain: 109 W/m^2 • Number of people: 5 • Activity: 70W • Clothing: 1.0 clo
Main storage	• *Natural ventilation thermal zone* • Area 5.00 m^2 • Volume 16.32 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Ambulance equipments storage	• *Natural ventilation thermal zone* • Area 12.00 m^2 • Volume 38.11 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Sterilization	• *Natural ventilation thermal zone* • Area 5.00 m^2 • Volume 16.52 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Staff toilet	• *Natural ventilation thermal zone* • Area 3.00 m^2 • Volume 7.96 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Patient toilet	• *Natural ventilation thermal zone* • Area 5.00 m^2 • Volume 14.69 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Janitor room	• *Natural ventilation thermal zone* • Area 2.00 m^2 • Volume 6.12 m^3 • Lighting Level: 300 lux • Sensible Gain: 80 W/m^2 • Number of people: 1 • Activity: 70W • Clothing: 1.0 clo
Attic	• *Natural ventilation thermal zone* • Area 329.00 m^2 • Volume 589.28 m^3

USING BIM FOR ENERGY ANALYSIS

Baseline model development

To create the baseline information model, all the building components of the case study building specifications must be translated into the BIM's terms; the Revit Elements. Revit Architecture classifies elements by categories, families, and types. A category is a group of elements that utilized to model or document a building design and families are classes of element in a category. A family groups elements with a common set of parameters, identical use, and similar graphical representation (Autodesk, 2010). Use system families to build the baseline model, system families are the predefined set of families. Avoid using a generic model template or in-place families to create building model components; they are untranslatable into the building energy model (Somboonwit, 2009; Integrated Environmental Solutions, 2009).

There are limitations of practical BIM workflow for integration with the BES workflow because many BIM elements do not support information exchange identifying the thermal performance characteristics needed for energy analysis. Moreover, practical modeling procedures usually go into excessive detail and they are fallible in information transfer, e.g., using Structural or In Place Families build a model, model spaces enclosed within spaces, etc., these limitations causing a specific BIM workflow for energy performance analysis is a requisite.

It is important to simplify the baseline model to the necessary details to reduce energy simulation time .In this study, ***the Room-Based Modeling***, the concept of modeling and defining each Room as its own thermal zone (Integrated Environmental Solutions, 2009) has been used to model and define rooms within the baseline model. Because the case study building is a small building and its design has been finalized, this concept of modeling allows for a more accurate building performance analysis than Zone-Based Modeling.

The Room Bounding Elements: Walls, Floors, Roofs and Ceilings, surround and define room elements, must have proper joint of their geometry. Room Bounding instance parameter must be specified correctly. In addition, avoid modeling the Room Bounding Elements overlap into other zones; otherwise, they will be broken into multiple surfaces. These issues cause misplacement of model elements and may cause miscalculation in the simulation process. Orient the main / ambulance and ambulatory entrances of the baseline model to the true south.

There are several settings more within the BIM, before exporting the energy model. Defining the project information: location and building type; is fundamental because it is an important factor in energy use. Room element must be created and defined correctly, each room needs to be bound by a wall, floor, or roof (Krygiel et. al., 2010) and each area within the baseline model that will be affected by the mechanical system will need to have a room element added to it. Verify that the upper and lower boundary of rooms and room height is set correctly. Compute Room Volumes determines the volumes of the spaces by choosing to calculate the rooms from At Wall Center. Because it is a sloped vertical perimeter of a thermal zone, the computation height adjusted to 0.00 m to achieve accurate room areas and volumes computation is necessary.

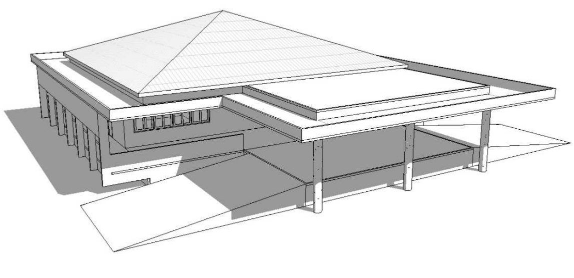

Figure 3 A South-Southwest perspective of the baseline model

Arrange the Room Tags on each room elements, a room tag is an annotation element that added in the baseline model to display values for related parameters, and to identify and retain the consistency of the thermal zone names exporting to the BES program. Figure 3 shows a perspective view of the simplified case study building: the baseline model.

Exporting to gbXML

Examine the Rooms and Analytical Surfaces in Export gbXML – Setting dialog box. Figure 4 shows the Export gbXML window, colors displayed in the model describe Surface Elements; dark blue as roofs, purple as floors/slabs, light purple as ceilings, green as exterior walls, light green as interior walls, light blue as windows, and pink as doors. Export the Baseline model gbXML by setting the parameter: Export Complexity to Complex with Mullions and Shading Surfaces. If any incorrect surfaces are identified, the exporting process must be aborted, there is no edit mode in this process. Examining for errors with those room elements thoroughly, ensure the gbXML is free from any warnings before completing the export.

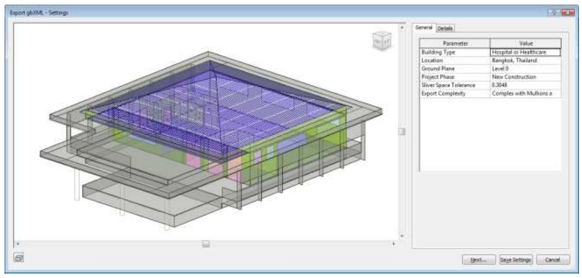

Figure 4 Export gbXML - Setting Window

Baseline model BIM-BES integration

Some of the building materials energy properties in the BES program's library are different from the obligatory standard used in Thailand. Before importing the gbXML file of the baseline model for energy analysis, create the Ecotect Analysis's materials library of Thailand's code-compliant material properties by using the Element Properties Dialog of the Ecotect Analysis. Adding the materials into the library and calculating the U-Values of the new materials.

Then assign the properly additional materials from the Element Library to the components of the energy model, using Material Assignments Panel. Figure 5 shows a perspective of the baseline energy model.

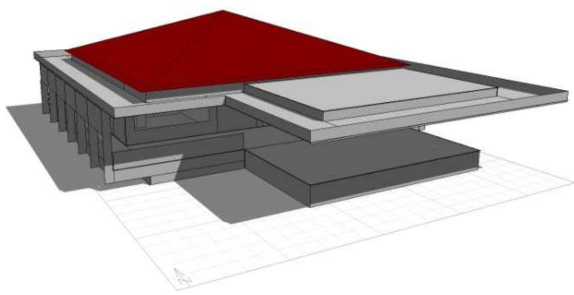

Figure 5 A perspective of the baseline building energy model

Assigning each zone properties using internal gains, infiltration rate, occupancy, and HVAC data described earlier. Convert climate and weather data in an EnergyPlus format (EPW) of Bangkok, Thailand with Weather Tool to the Ecotect format (WEA), and applied as contextual information in the simulation process. Set the orientation of the baseline energy model facing south; true north-based azimuth (AZI) of 180°, the 0° orientation. Energy simulating of the baseline orientation is done against seven types of geographic directions counterclockwise (CCW): 45° (AZI = 135°), 90° (AZI = 90°), 135° (AZI = 45°), 180° (AZI = 0°), 225° (AZI = 315°), 270° (AZI = 270°), and 315° (AZI = 225°) as shown in Figure 6, to compare the differentiation of energy performance among directions.

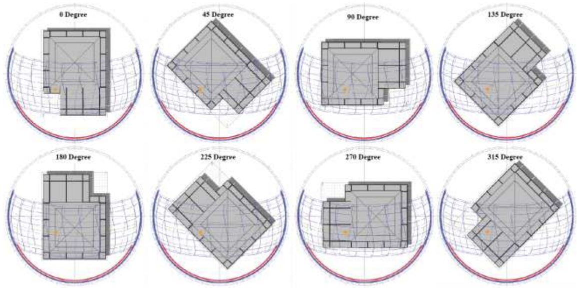

Figure 6 Counterclockwise rotations of baseline model orientations

Modification models

An additional two types of modifications are performed to test the improvement of energy performance. Both of the modifications are simple and easy to build, using common domestic building materials and construction techniques.

Modification model 1: Model 1

The Model 1 replaces the envelope components of the baseline model with higher performance materials while the original building structure is retained. There is a replacement of four building elements; improves the performance of solar absorption properties of the walls, roof slabs, and sloping roof using solar reflective ceramic coating as a thermal barrier, the ceramic particulate reflects solar radiation, it reduces *the solar absorption coefficient* from 0.5 of walls and 0.7 of concrete slabs and asbestos cement sheets roofing to 0.3. To improve *the glazing performance*, using low-e double glazing window to replace the clear single glazing, *the U-value* has a reduction to 2.71 W/m^2-k and reduces *SHGC* to 0.44. Using reinforced aluminium foil and 100 mm of the fiberglass blanket insulation for the sloping roof, the U-value of the roof can be reduced to 0.30. Furthermore, the additional fiberglass quilt insulation for the ceiling, the improved insulated gypsum plasterboard ceiling reduces the U-value to 0.37.

Accomplishing to create the model 1 by adding the substitute materials in the Element Library and using them replace the elements in the energy model of the baseline model, in this step, there is unnecessary to develop a new model in the BIM system. All settings for the energy simulation uses the input data is identical to the baseline model and performing the Model 1 energy performance simulation against seven orientations in the similar way of the baseline model.

Modification model 2: Model 2

The Model 2 has the equivalent properties of the replaced building elements to the Model 1: solar absorption properties improvement of the building envelopes, using low-e double glazing window, adding reflective foil insulation and blanket insulation to the sloping roof, and installing the additional insulation for the ceiling. Figure 7 shows a perspective rendering of Model 2 that the form of roof has an alteration, from the square pyramid roof with horizontal concrete slab roof to a combined hip roof while its covering area is unchanged.

Figure 7 A perspective rendering of Model 2

Improving the performance by uplifting of roof structure to allow better ventilation through the roof air pocket, it is an effective way to reduce both the conduction and convection heat transfer from roof to the ceiling. To protect the roof air pocket from birds and insects, the horizontal louvers with nylon nest have been applied over the voids. Light shelves design is also added to minimize needs of artificial lighting during daytime as shown in Figure 8.

The main concept of this study is the integration of systems; thus avoid any geometry editing in the BES application. Therefore, a development of the Model 2 in the BIM system and a reprocess of BIM-BES integration are necessary. Once again, the simulation settings and input data have been used to perform the energy performance simulation of model 2 and the other seven orientations as well.

Figure 8 A perspective view of Model 2 shows the light shelves

RESULTS AND DISCUSSION

Energy performances of all the three models: the baseline model, Model 1 and Model 2 are compared by means of energy consumption on monthly and annual cooling loads (Watt-hour: Wh).

Energy performance of the baseline model

Figure 9 depicts the monthly results energy consumption that are served as a basis for further comparison, and it shows the highest energy consumption period on cooling loads are the three month of April, May, and June.

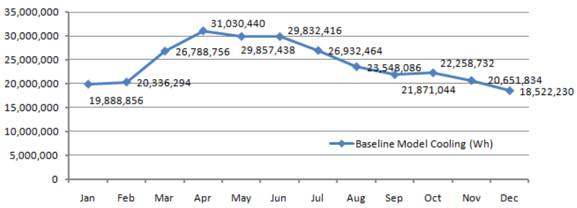

Figure 9 Monthly energy consumption comparison of the baseline model

Figure 10 shows the best orientation for placing the baseline model is the 0°orientation and the worst one is the 270°orientation. Findings reveal that that even the same building placed in different ways of orientation causes different building energy performances, even though slightly variant (0.051 % - 0.455%). It can be seen clearly that the baseline model at the 0°orientation is positioned by its narrow and most shadowed side facing south. On the other hand, the 270°orientation places the baseline model's longest side to the south itself.

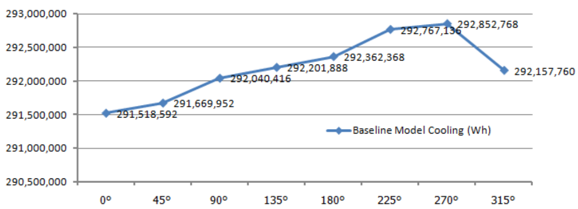

Figure 10 Annual energy consumption comparison of baseline model against other seven orientations

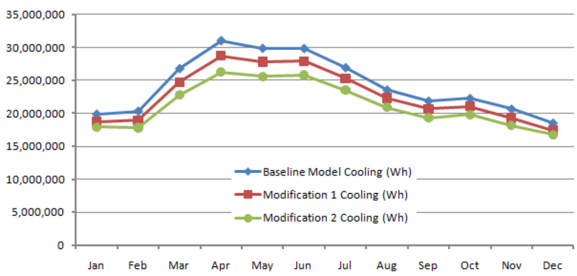

Figure 11 Monthly energy consumption comparison of all models, the 0° orientation

A comparison of results

Figure 11 presents the monthly energy consumption on cooling loads which all models, at the 0° orientation, have been simulated and compared, the results show in harmonious way to the seasons of Thailand all of three models.

Figure 12 shows the differences between the results of all models compare to the orientations are very small. The baseline model and both of modification models are single storey building, heat that flows into the thermal zones that causes the largest amount of cooling loads is from solar radiation through the roof and all models are efficiently shaded by their architectural design and therefore, having a good control of the direct solar gains, the cooling load remains almost the same while rotating the building in the different orientation angles.

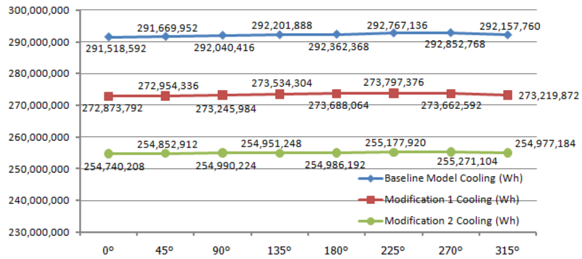

Figure 12 Annual energy consumption comparison of all models against other seven orientations

Conspicuously, Figure 13 shows the modification Model 1 that constitutes of high performance envelope materials shows its significant role on energy performance improvement, 6.39 – 6.55 % of energy consumption can be reduced from the baseline model.

An integration of three modification measures in Model 2 is the largest reduction of energy usage could minimize energy consumption as much as 12.62 – 12.84%, and up to 37,589,216 Wh per year.

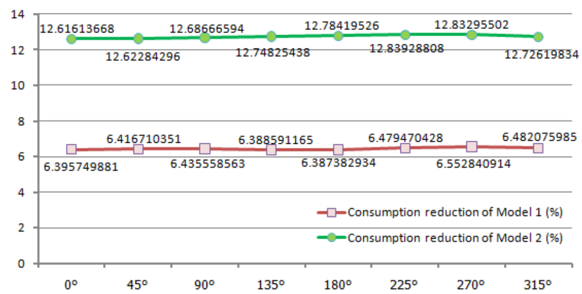

Figure 13 The percentage of annual energy consumption reduction compares to baseline model

CONCLUSION

The expected outcome of this study is the perceiving of the DCD architects and engineers in an Integrated Building Design process (IBD) that helping them to use the process to become an integrated practice to achieve improvements in the built environment. All of elements of this study, e.g., the software and procedures have been accustomed to the future trend of working for architects and building designers in Thailand, which aiming to be widely used in the professional practice. A study on BIM-BES integration workflow of the case study building, an example of a small single storey Generalizable Building Design (GBD), is a pilot experiment that has potential; it is fundamental and encouraging the upcoming implementation of the IBD workflows for much larger DCD's building design and construction, to make better, more energy efficient, sustainable buildings. Finding recommendations for the usage of the GBD on the impacts of building orientations, high performance building materials and passive cooling on building energy consumption may suggest the DCD personnel who will intend to use the GBD and the similar types of buildings to have some supportive information for more efficient construction in the future.

Finally, the practical BIM workflow and the research tools have limitations, using some common-use model templates and common modeling procedures cause mistranslated building model in the energy model. In order to take advantage of the capability to integrate BIM and BES between the platforms, the BIM model needs to be developed with a specific workflow; it causes excessive time spent modeling the building twice. Fully integrated approach: workflows, tools, and, modeling and transferring standards will maximize the ability of the IBD – a crucial strategy for making buildings more sustainable in the future.

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