RAS-Funded Project on Creation of Educational Material

1. Title of Proposal

Case Study of Modeling and Control in Energy-Efficient Buildings

2. Names and Affiliations of corresponding proposer & group members

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3. Names of TC or EC

Technical committee on Smart Buildings

4. Executive Summary of the Proposal

This proposal intends to develop an online resource center to host several case studies of modeling and control in energy-efficient buildings. This will create educational material for researchers to learn some popular simulation software in the field, and to test control and optimization methodologies on some real test beds. Such hands-on experience will greatly help the users to enter the field.

We will create case studies for learning the simulation software, EnergyPlus. Many efforts have been directed into the field of building design optimization concerning building energy performance. In this field, the whole building energy simulation program EnergyPlus has been extensively used and validated, facilitating related engineering and researches. In this

project we will provide materials helping beginners to gain a primary experience on how to use EnergyPlus to estimate buildings energy consumptions, to design energy-efficient buildings, and to evaluate the effectiveness of HVAC systems control laws.

Based on our previous research, we will publish two case studies of EnergyPlus applications through a webpage. One is the design of a building envelope for a single-zone welding shop. The other is the investigation of the value of a traditional north-light roof in lowering building energy consumptions. In the first case study, two EnergyPlus-based tools will be presented: one performing building energy estimation for user-specified envelope configuration, and one performing envelope optimization for the welding shop. In the second case study, three tools will be presented. The first helps to show that choosing a north-light roof is not always good for different locations and climate zones. The other two help respectively to estimate the building energy for user-specified roof configuration and location, and to find an optimized roof shape for a user-specified location where the north-light has better energy performance than the flat.

The above two cases will educate the user how EnergyPlus can be used for building energy consumption estimation and energy-efficient building design in a quantitative way.

Lastly, we propose to integrate basic control methods in EnergyPlus, and allow the users to modify their parameters (e.g., thresholds, gains, etc.). This will help students and researchers understand how much control laws can affect the energy consumptions, and how much important is to have good control laws in comparison to a good building design.

For testing the control methods in energy-efficient buildings, we will leverage existing platforms. The user will be able to download real data that is collected in real buildings, and to test their control methodologies in these testbeds (after online approval of access request).

5. Way of Distribution (webpage, books, etc.)

We will publish our case study through a dedicated **webpage**. Visitors can access and use these materials worldwide.

6. Scope (purpose, area of technical fields, target zone of education, ...)

These materials are suitable to the beginners who want to use EnergyPlus to understand building energy issues. The audience may include college, undergraduate and graduate students who are interested in using EnergyPlus.

EnergyPlus is a very powerful and popular software in the building research area. However, it is very complicated and difficult for beginners because it has to be configured with many parameters and modules before running it. This is even more difficult for college students. In this proposal, we aim to use some case studies pre-developed in EnergyPlus, and provide to the users some ready-configured models of buildings and associated HVAC control laws. We will provide some simplified configuration modules, and enable users to customize their own models in an easy way. This will encourage the beginners to use EnergyPlus more in their projects or studies, and to become interested in the building technologies science.

7. Goal (contents, courses, materials, cost, ...)

We will present two case study models, published through a dedicated website, to demonstrate the application of EnergyPlus in building energy estimation and energy efficient building design. The case studies are related to building envelope / HVAC control laws design and are based on our research, reported in [1-3]. We will develop the corresponding tools and publish them on webpage. With these tools, the visitors can customize and run the EnergyPlus in an easier way.

Case study 1

The first case study is to design the building envelope for a single-zone welding shop. The activities of the machines and the workers within the shop are known, acting as the building's internal loads dissipating heat, moisture, contamination, etc. To maintain the inner environmental occupant comfort levels, energy is needed to condition the temperature, humidity and air quality, etc. The case study attempts to control some parameters of the building envelope to achieve low energy consumption.

Three features related to the building envelope are chosen to be controlled to obtain high energy efficiency, including building orientation, shape coefficient (the ratio between the external skin surfaces and the inner volume of the building) and window-to-wall ratio (Fig. 1). These three features are known as key features that have significant impacts on building energy. Other features such as the layers and materials of the envelope surfaces (walls, ground, roof and doors) and window glazing properties, which may also have impacts on building energy, are assumed to be given (see [1] for details). This corresponds to the scenario of determining the building envelope layout with building construction materials having been selected.

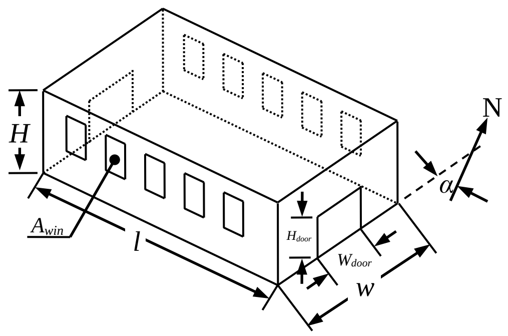

Fig. 1. With the given features, the three features to be controlled could be represented by four variables: building azimuth α, building length l and width w, and the number of windows in pairs n (see [#] for details).

This envelope design model is actually an optimization problem model, and building energy estimation based on EnergyPlus is the basis of the optimization. To present the case study, we will publish on the website two related tools. One is an *EnergyPlus-integrated building* *energy estimation tool*. The tool receives the input of values of the four design variables, calls EnergyPlus to estimate the shop's annual building energy consumption and then presents the results. The user can set different values for the four variables and see how the features impact the building energy. The user can also change the location of the building to check the dependence of the building's energy performance on the geographical location.

The other tool is for *building envelope optimization*, which is based on the function of the energy estimation tool. By this tool the user can obtain optimized sets of envelope design variables for buildings at different locations, and may gain a general idea of which building envelope configuration can achieve the highest energy efficiency at different locations.

Case study 2

The second case study investigates the value of a traditional north-light roof (Fig. 2) in lowering building energy consumptions. Architects are paying more attention to a building's environmental performance in addition to their structural performance. The shape of a building structure may impact the building's energy performance in different ways and an architect should comprehensively estimate the impact in order to achieve low energy consumption. The north-light roof structure is a good demonstration for this. The structure is usual applied to increase the plant's reliance on natural light and thus to lower artificial lighting levels. However, this comes with an increased air volume, and this may potentially increase the heating and cooling loads requirements, leading eventually to higher HVAC energy demands. Moreover, there is also the consideration that heat losses through the north-lights increase.,.

In this case study, all the parameters of the building are known but the roof shape related parameters (see [2] for details).

(a) (b)

Fig. 2. (a) Exterior view of a convex north-light roof system over the former Production Hall, Ammunition Factory, Beijing, China (1950s). (b) Interior view of same hall, rehabilitated in 2008 as the Pace Art Gallery, shows optimal use of diffuse north light to provide adequate lighting levels for previous bench work activities and currently display art work.

We present three tools in this case study. One tool helps to *show the north-light roof is not always good for locations of different climate zones*. Three typical roof types are given with determined configurations: convex north-light, concave north-light, and flat. The user could estimate their energy performance for different locations to see which roof type has highest energy efficiency and which has lowest.

The other two tools help respectively to *estimate the building energy for user specified roof* *configuration and location*, and to *find an optimized north-light roof shape for a certain user-specified location* where the north-light structure has better energy performance than the flat structure. These two tools' functions are similar to the two tools in case study 1, only with the controlled variables changed to the roof shape related variables (Fig. 3).

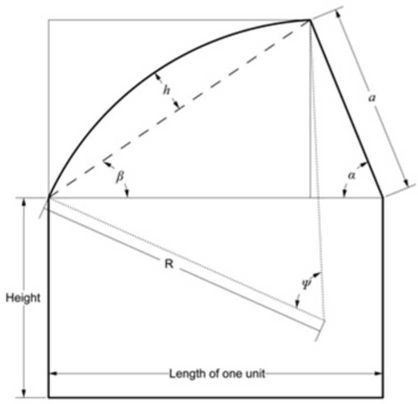

Fig. 3. Design Parameters of the north-light roof shape: (α, a, h), where α is the angle between the horizontal and the flat side of the roof, a is the absolute inclined height of the pitch of the roof and h is the absolute height of the arc relative to the chord. (see [2] for details).

The website will also provide necessary guides for users to run the tools and to understand the results.

For testing the control methods in energy-efficient buildings, we will leverage existing platforms. The user will be able to download real data that is collected in real buildings, and to test their control methodologies in these testbeds (after online approval of access request). One existing platform developed by the group members is http://hvac.ee.kth.se/. Tutorial materials for using this testbed, and examples of control methodologies will be developed for educating researchers in the field to better utilize this testbed.

Case study 3

Multiple-Chiller Plant Simulation Platform

This case is to design a decoupled multiple-chiller plant that consists of a primary chilled water production loop and a secondary chilled water distribution system. Fig.1 illustrates the structure of a typical multiple-chiller plant. Chillers are arranged in parallel and each chiller is coupled with a constant-speed pump. When a chiller is staged on, the coupled pump will be switched on accordingly to maintain a constant water flow rate through the chiller. Two temperature sensors (one for chilled water supply and one for chilled water return) and one flow meter are installed at the head pipes for supervising the operating condition and generating signal for sequencing controller when using the total cooling load based sequencing control strategy. Normally, the chilled water supply temperature is controlled to a set point, say 7 ^{o}C, and the return temperature is determined by load demand. When the load is higher, the return temperature is higher.

The chilled water supply will be sent to chilled water distribution system, including a secondary pump and air-handling units (AHU). The secondary water pump circulates the chilled water to the AHUs and the flow rate is determined by the demand from AHUs. The AHUs are used to condition supply air to a desired temperature and humidity, which will then be sent to indoor space for thermal comfort.

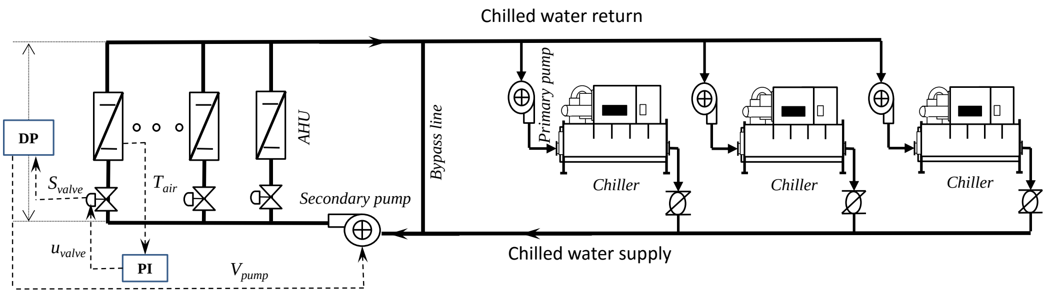

Fig. 4 Multiple-chiller plant

A simulation platform will be constructed for a typical multiple-chiller plant. Figure 5 shows the basic functional blocks and main connects among them. The platform will be open for editing and users can configure the platform according to their requirement. Currently, this platform can be used for

- Energy performance evaluation of multiple-chiller plant
- Components (AHUs, pumps, valves) performance evaluation
- Chiller sequencing control
- Chilled water supply temperature optimization

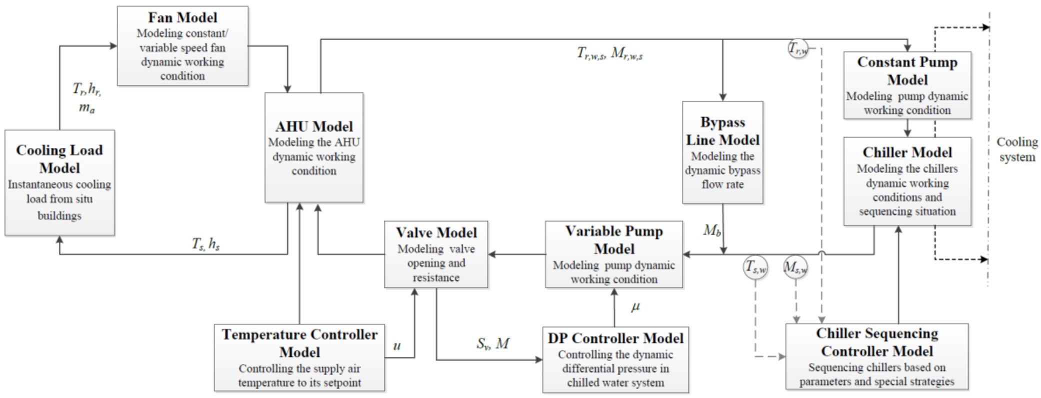

Fig. 5 Simulation platform (TRNSYS)

8. References

[1] Liu H, Zhao QC, Huang NJ and Zhao X, "A Simulation Based Tool for Energy Efficient Building Design for a Class of Manufacturing Plants," IEEE Transactions on Automation Sciences and Engineering, 10(1):117-123, 2013.

[2] Adriaenssens S, Liu H, Wahed M, Zhao QC, "Evaluation and Optimization of a Traditional

North-Light Roof on Industrial Plant Energy Consumption", Energies, 6:1944-1960, 2013.
[3] Parisio A, Molinari M, Varagnolo D, Johansson KH, "A Scenario-based Predictive Control Approach to Building HVAC Management Systems". IEEE Conference on Automation Science and Engineering, 2013.