Framework for fast prototyping of energy-saving controllers

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***Abstract*—Due to the high costs of live research, performance simulation has become a widely accepted method of assessment for the quality of proposed solutions in the field of energy saving. Additionally, being able to simulate the behavior of the future occupants of a residential building, as well as weather forecasts, can be very useful since it can support both design-time and run-time decisions leading to reduced energy consumption through, e.g., the design of model predictive controllers that incorporate user behavior and weather predictions. In this work, we provide a framework for fast prototyping of energy saving controllers in residential buildings. In fact, we are interested in how to deal with many aspects of the process so that these controllers can implement alternative strategies for energy saving.**

***Keywords*-model predictive control; energy consumption; energy saving**

I. Introduction

Today, many different criteria must be balanced in order to provide high quality, comfortable buildings that also optimize energy costs and reduce environmental impact. Due to the high costs of live research, performance simulations have become a widely accepted method of assessment for the quality of energy and environmental impact strategies. These simulations are often carried out by some kind of simulation software that allow users to model building heating, cooling, lighting, ventilation, and other energy flows inside a building [8]. However, these simulators are often complex and difficult to configure, for this reason appropriate tools leading to make these configuration tasks are needed more intuitive.

In this work, we aim to develop a software tool (framework or wrapper) that can hide the complexity of simulators. To do that, we have chosen to use the software EnergyPlus (from the US Department of Energy) for testing our energy saving strategies. The rationale behind this choice is that from a preliminary study we realized that this simulation software includes many innovative simulation capabilities that other simulators do not consider. These simulation capabilities include time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, air flow for multiple zones, thermal comfort, water use, natural ventilation, and photovoltaic systems. The problem is that this software is a stand-alone computer program without a user friendly graphical interface, and this is precisely where our work comes in. We have integrated EnergyPlus with an environment to allow researchers and practitioners to carry out simulations in a comfortable, fast and precise way.

Our workbench has been specifically developed around this popular simulator allowing exploiting its most important characteristics. These characteristics include an easy (but not fast) prototyping of the houses that are going to host the energy saving controllers (including building materials, constructions, windows, blinds, doors, and so on), the housing systems are going to be controlled as well as the energy saving controllers that are going to be tested. The software we are describing here is designed so that user can choose among a number of predefined houses, system and controllers types to be defined parametrically without the need for complex layouts. This allows us to replicate a real environment in a few minutes (without such an environment some hours, and even days would be needed).

Therefore, the major functionality that our framework for fast prototyping of energy saving controllers includes:

1) Easy comparison of design alternatives (regarding houses, housing systems or controllers)
2) Optimization of the design of a house, system or controller at any stage
3) Modeling of even complex buildings in a very fast manner
4) Simplification of Energy Plus thermal simulations
5) Simplification of the analysis, design and testing of energy saving controllers

Additionally, our framework is able to manage simulations and give users access to the output files through a graphical interface. In fact, our framework enables browsing, plotting, and comparing EnergyPlus output data, especially time series.

The rest of this paper is structured in the following way: Section 2 presents related work on energy saving strategies in residential buildings. Section 3 describes the architecture of our software solution for the rapid development of energy saving controllers. In Section 4, we explain how to configure the system for simulating realistic scenarios. In Section 5, we report how to execute the system to evaluate the benefit of the energy saving controllers. Finally, Section 6 presents concluding remarks and future work.

II. Related work

According the literature, there are two major approaches for addressing the problem of saving energy in modern buildings. The first approach depends highly on human intervention since it proposes manual control purely based on consumption feedback from the utility companies, domestic systems, and so on. On the other hand, the second approach tries to automatically supervising the buildings and limiting their energy usage by means of energy-saving controllers.

One of the most popular strategies to control energy usage includes model predictive controllers [7]. Controllers of this kind work with models concerning the habits of the home occupants and future weather predictions. The goal is to improve existing energy-saving strategies. This hypothesis is supported by many works such as: Wood & Newbotough [13] achieved a good percentage of reduction in energy consumption of occupants by changing their behavior. Hoes et al. [4] show that electrical energy consumption in buildings is not only linked to their operational and space utilization characteristics, but also to the behavior of their occupants. Yu et al. [14] tried to identify the impacts of occupant behavior on building energy consumption. The results obtained give hints to prioritize efforts when modifying user behavior in order to reduce costs. Rijal et al. [12] proposed a model which was designed to include the interaction of an average user of an office space with good results. Bourgeois [1] found that a realistic treatment of the control of lighting device can result in significant reductions in energy use. Ouyang and Hokao [11] investigated energy-saving potential by improving user behavior in houses, results obtained showed that effective promotion of energy-conscious behavior could reduce energy consumption. Finally, some works demonstrated that low energy strategies, such as natural ventilation, shading to control solar heat gains, day lighting, and so on, need the interactions from users [5].

III. System Architecture

Our framework comprises a number of modules which work together to provide in-depth analysis of energy use, consumption and commitment for any kind of modeled building, using any kind of housing systems and operating with any kind of energy saving controller. It is important to remark that every module integrates with other modules, so it is possible to run a simulation containing only a number of selected modules.

A. Overview

The overall goal of our framework is that different kinds of users such as design researchers, practitioners or students could have an user interface which could be easy to understand and use. In this way, it is possible to get up to speed in a fraction of the time required for other software so it possible to complete projects/simulations on time and on budget.

B. Reference Model of Typical Residential Building

Our aim is not to start from scratch when modeling a residential building. For this reason we offer a number of predefined houses that can be easily configured. Figure 1 shows the different templates that can be edited. To reduce complexity behind configuring the reference house, we initially predefine five different reference house types. These reference house types differ from each other in the number of enclosed floors.

The configuration of the house also allows us to define the following characteristics:

1) Data entry and storage for all environmental calculations including activity, constructions, glazing, lighting, HVAC, renewable, cost, etc.
2) Templates provide a quick way to load commonly used data sets into model.
3) Building geometry is described by placing blocks with options to stretch and scale blocks using simple tools.
4) Walls, floors, roofs, partitions window constructions are all represented.
5) Blocks are easily partitioned up into zones (see Section C).
6) Once the building design is definitely established and the details of the facade layout are clear, individual windows, panels, doors, and in general, any kind of surface can be chosen by the designer.

C. Building Geometry: Zones

It is also important to define the geometry regarding the different zones of the residential house. To do that, we are starting with an empty floor that can be segmented into a number of different zones. Each zone has to be assigned with a purpose. In this version of the framework we have decided that each house type of a residential building consists of seven zones, each zone represents a separate room:

1) LIVING ZONE
2) SANITARY ZONE
3) SLEEPING ZONE
4) CHILDREN ZONE
5) CORRIDOR ZONE
6) BASEMENT ZONE
7) TECHNICAL ROOM ZONE

The first five proposed zones are assigned to the ground floor and/or first floor of a concrete house type. If a house type also consists of a basement then the basement is represented by a separate zone called basement zone. The basement zone represents a single zone and covers the whole basement. Further, we assume that the basement has installed no HVAC systems. The technical room zone can be underground or outside and contains the equipment concerning the HVAC systems.

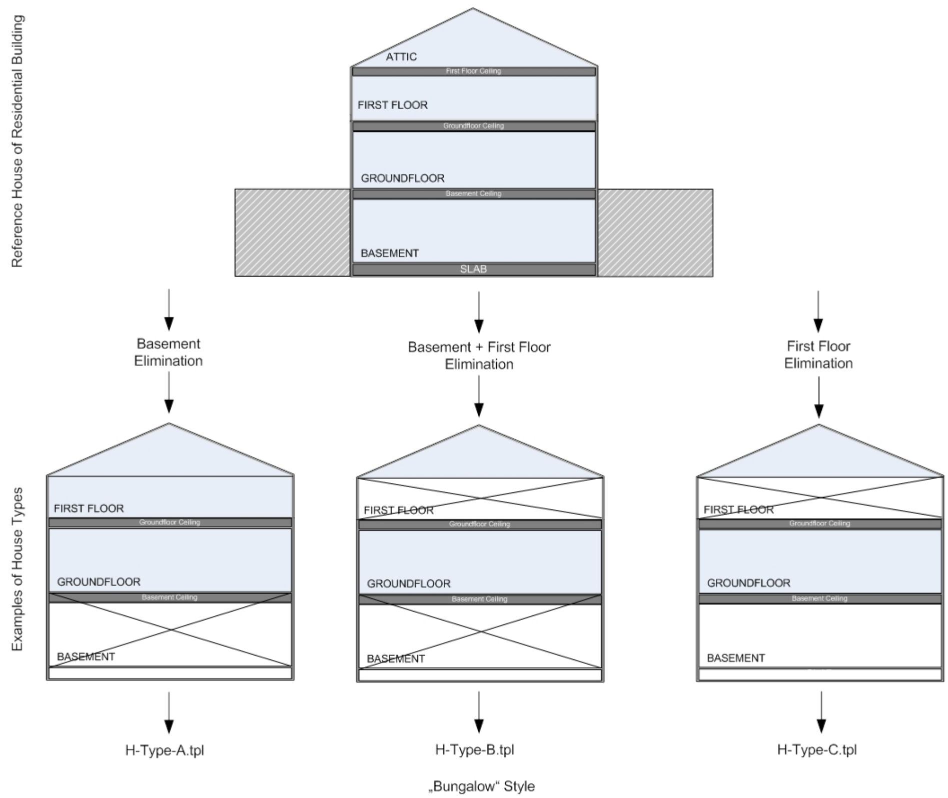

Figure 1. Different house models that our solution proposes

D. Building Geometry: Fenestration

It is also possible to have different windows included in a specific zone. As a starting point, there are two windows predefined for each sky-direction. Hence, there are 8 windows in total and each window is referenced by a constant value.

E. Building Material

It is important for us to allow the user to specify default materials for each type of surface and subsurface (walls, windows, floors, etc.) in a building. We offer the following characteristics between the multiple choices for the definition of building material for reference residential buildings components:

- Roof material
- Exterior wall
- Interior wall
- Ceiling thickness
- Floor thickness

F. HVAC Systems

Our workbench allows us to access the advanced HVAC modeling capability of EnergyPlus through a graphical environment. A wide range of predefined housing systems can be loaded, pre-connected and all systems can be customized either at the placement stage or afterwards after placement. Table 1 shows a possible configuration.

Zone	Radiator Heating	Floor Heating	Wall Heating
Living Zone			x
Sanitary Zone		x	
Sleeping Zone		x	
Children Zone		x	
Corridor Zone	x		

Table I
POSSIBLE CONFIGURATION OF THE HEATING SYSTEM

G. Configuration Steps

Each simulation requires an appropriate configuration. Figure 2 shows the logic behind the configuration of our workbench.

IV. CONFIGURATION OF BUILDING GEOMETRY

Proportional scaling facilitates an increase/decrease of a predefined building size by a constant increase/decrease value. Scaling up or down the size of a building causes an adjustment of several building objects and HVAC objects. Adjustment of building objects relates to the proportional increase/decrease of zones with respect to the global scaling factor.

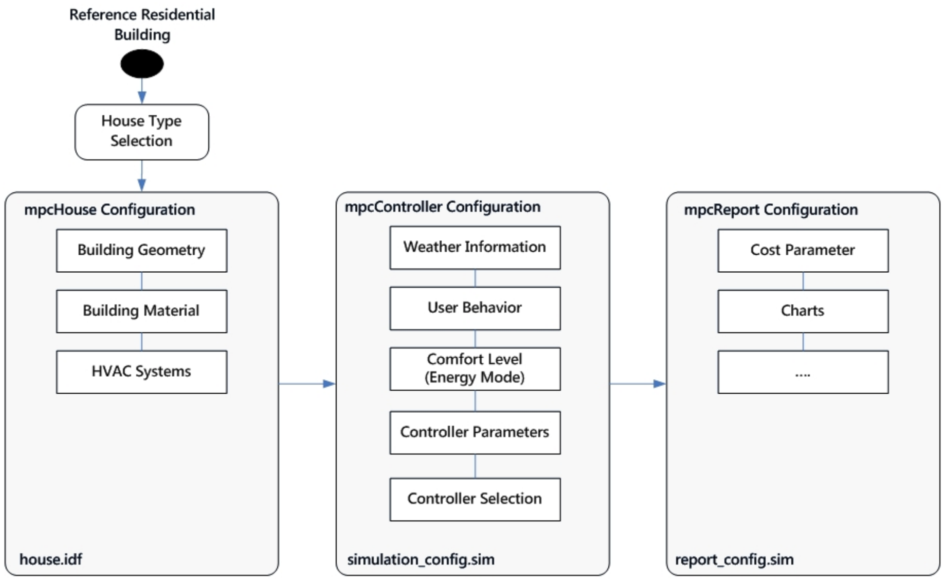

Figure 2. Configuration of the framework

A. Proportional Scaling: Room/Zone Adjustments

By default, our templates defines a building size of 10 x 8 m such that basement and ground floor size is given by 80 m^2. The ground floor size is partitioned into fives zones, each of which is assigned a local scaling factor. The scaling factor represents the proportion to which the size of the zone is increased/decreased with respect to the global increase/decrease value.

B. Proportional Scaling: Fenestration Adjustments

By default, each exterior wall has assigned two windows with a predefined size and material properties. Our framework enables to increase/decrease the size of each window by a constant value or by a newly defined window height and length.

Some situations may require to remove a predefined window from an outside wall. In this case, it suffices to configure the respective window with a height and length of zero. This achieves the same effect like removing the respective window object from the IDF file.

V. Simulation

Once we have defined all the parameters including internal gains from lighting, equipment, and occupants; heating, cooling, and ventilation systems; schedules of occupants, equipment, and lighting. Energy models will output building energy use predictions in typical end-use categories: heating, cooling, lighting, fan, plug, process. In addition to energy units, our framework includes utility rates input, and can predict energy costs.

A. Functionality

- EnergyPlus is integrated with our system to provide advanced dynamic thermal simulation at different timesteps.
- Provide environmental performance data such as energy consumption, CO^2 emissions, room comfort at annual, monthly, daily, hourly, and sub-hourly intervals.
- Report solar gains on different surfaces.
- Access an extensive range of results for buildings and systems.
- Assess performance and temperature distribution.
- Export surface temperatures and airflow rates.
- Size heating and cooling systems.

Figure 3 shows a screenshot of our software solution for fast prototyping of energy saving controllers.

B. Reporting

Finally, our framework allows reporting too. The reporting functionality includes:

- Measures can be used to create custom reports in HTML format
- Allows users to quickly visualize and summarize data for different audiences
- Reports can be simple or highly interactive

VI. Conclusions

We have described our system to estimate how different energy saving controllers can influence building energy use and operating costs. Our goal is to shed more light in a very interesting topic which can help researchers and practitioners to build energy saving controllers which are not only interested in traditional aspects like outdoor and indoor

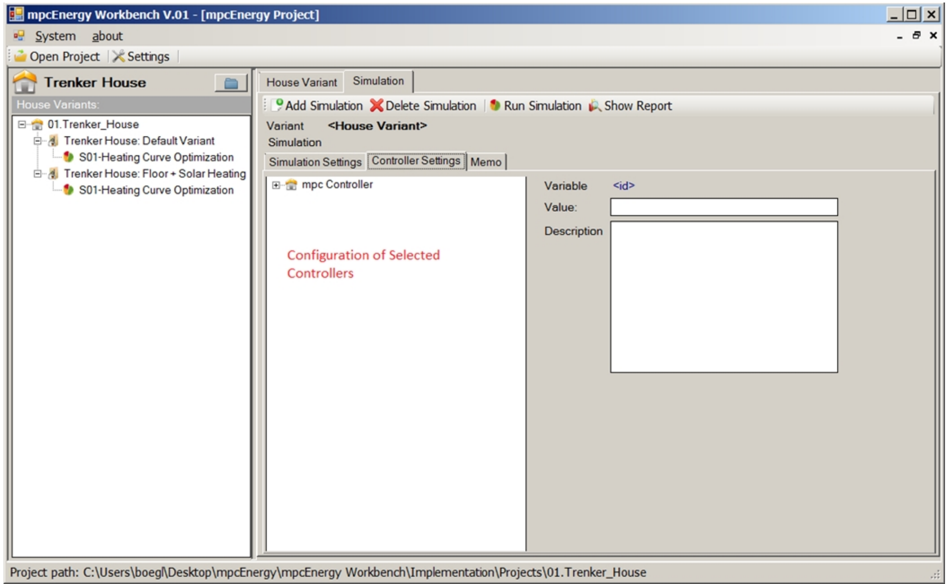

Figure 3. Screenshot of our software solution

data like weather forecasts, seasonal statistics, humidity indicators, and so on, but in the behavior of the occupants who live or work in a given house or office. Properly used, our system can help optimize the building design and allow the end users to prioritize investment in the controllers and strategies that will have the greatest effect on the buildings energy use.

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