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Building thermal energy modeling with loss minimization

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ABSTRACT

The thermal losses in buildings are significant energy sinks. The Energy Semantic Network (ESN) is a new method for finding these losses at the design stage, as well as for the existing structures. The research purpose of ESN is to take into consideration the governing factors of building thermal performance (i.e. the insulation materials, the dimensions, the loads, and the schedules of people interactions), associate these factors with any building of choice, and to subject the model to range of dynamical changes, that will help to make the decisions for improving the building thermal performance. The current work is only an early stage on ESN, the end goal of ESN is to evaluate the thermal energy conservation technologies with respect to the dynamical thermal changes, and track the dominant sinks resulting from these changes. Currently, the energy conservation technologies present an opportunity for reducing the utility use, and, thereby, the savings in capital for long term performance. The thermal energy conservation problems are unique to every building, due to the storage and the supply of the energy in response to the seasonal demands, structure, and the nature of the building utilization (the involvement of people). With the current simulation software, such as Energy Plus, there exists a convenient way of simulating the annual building performance, without the tediousness of monitoring the physical building. However, in that case, any particular spontaneous effects may not be completely accounted. The ESN structure is intended to make up for the spontaneous effects, and be accountable for possible spikes in the energy use that may occur throughout the year. Such spikes in energy consumption do not have to be singular, because it is possible to assign an array of situations where energy losses occur and track them to the specific location. The use of ESN for tracking the energy losses can lead to a solution for preventing similar spikes in the future by isolating the most significant sink. The enclosed research on the ESN method includes the foundations of ESN, the case study of a hypothetical hotel located in Ontario, and a detailed Simulink representation of ESN.

1. Introduction

Thermal network simulation for energy conservation in a building is, generally, a heat transfer problem aimed at minimizing the energy dissipation from the building and preserving a comfortable thermal conditions. The three modes of heat

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transfer conduction, convection, and radiation, as well as the mass transfer are of primary relevance in thermal network analysis. However, buildings are largely affected by the human interaction, which requires consideration for comfort. The metrics for the typical human metabolism functions are available for use [1]. It is possible to weight all the heat transfer parameters, properties of materials, human metrics, and building dimensions to end up with a model which will allow to pin-point the areas of energy loss. If all of the weighted factors have assigned qualitative and quantitative properties derived from their corresponding normalized property matrices, then the problem becomes more affinitive to solution via the formal method procedure [2].

The current thermal environment simulation software, aim to ease the method of evaluating the energy performance of the buildings and their corresponding systems (DOE-2.1E, Energy Plus, ESP-r, TRNSYS, ECOTECT) [3]. Nonetheless, significant amount of time is consumed for building the models, verifying them via simulation and data collection, and the weighting procedure that leads to an energy conserving solution. This time can be shortened if the building simulation software is able to evaluate multitude of scenarios relevant to the building in a semantic manner; that is, by the application of dynamic changes within the thermal network representation of a building. The analysis from the Energy Semantic Network (ESN) will, ideally, result in only few key options that are the best in terms of energy conservation. Energy Semantic Network takes into account the events occurring within a structure that are independent of one another but affect the structure performance on a large scale. The erratic behavior of people and their interactions with the components of the building (the energy sources and sinks) creates irregularities that are usually linearized in the programs like Energy Plus, and the detailed information is lost without the benefit of applying it to possible control methodologies.

The use of ESN by the means of applying the energy loss protection layers (ELP) aims at finding the areas in the building where major thermal energy losses occur and preventing them through the application of ELP. The ESN and ELP system for evaluating building thermal energy performance is intended for existing as well as hypothetical buildings, and the use of this system is intended for making economically feasible and environmentally benign decisions.

The identification of the key performance indicators (KPIs) for the intelligent buildings is a primary step to creating time effective ESN models. The primary indicators of energy generators and the dissipating sinks in a building are universal to most of the simulation programs. Some researchers identify only several KPIs as significant representations of energy performance of the buildings [3], whereas others identify a multitude sub-KPIs related to a single KPI such as comfort [4]. Nonetheless, it is apparent that many of the present day KPIs point to a goal of achieving a net zero energy building [5–8], and whether it is possible to achieve this goal by retrofit [9]. Also, it is more convenient to have only several KPIs as the primary indicators (such as economy, environment, reliability, and quality) [3] and then have sub-categories of KPIs for specific cases relevant to particular building configurations. Covering every single KPI is not always feasible, especially in the case of large structures. Once the KPIs are identified the next step is to automate the evaluation procedure for the building thermal network in order to achieve only the most relevant scenarios for energy conservation.

The automation of solution generation procedure was achieved via the genetic algorithm procedures [10], the multi-agent systems [11], the fuzzy-logic functions [7], the lumped systems [12], and the neural networks [13]. Moreover, the simulation tools combined with the data acquisition systems are an efficient strategy for reducing both the modeling time and the time required to make an improvement to the original system, despite being quite expensive. The rapid data acquisition and a rapid response system can complement the thermal network simulations by following the control parameters of the simulation system [14]. This complementary system may provide an insight into the energy dissipation modes that may not be apparent in either the simulation or the data acquisition (ie. The flow of people in and out the building leads to leaving the doors open and letting the conditioned air out of the building systems). However, the ESN and the energy loss protection layers (ELP) aim to replace such approach by taking a set of data from either an existing building, or a building under design, to model the performance over a set time span with pre-determined spikes and transient signals to account for the uncertainties in the realistic settings. The ESN and ELP system for evaluating building thermal energy performance is intended for making economically feasible and environmentally benign decisions, which in the long run will lead to the design of building specific mechanisms.

2. Building thermal modeling

Nomenclature

k	conduction coefficient (W/(m °C))
A	area of the conducting element (m^2)
L	thickness of element (m)
h	transfer coefficient (W/(m^2 °C))
ρ	density (kg/m^3)
$V_{element}$	volume of the element (m^3)
Δt	change in time (s)
C	specific heat of the element (J/(kg °C))
ΔT	change in temperature (°C)