Proceedings of Building Simulation 2011:
12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November.

THE USE OF NORMATIVE ENERGY CALCULATION BEYOND BUILDING PERFORMANCE RATING SYSTEMS

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ABSTRACT

Standardized building performance assessment is best expressed with a so-called normative calculation method, such as the CEN/ISO calculation standards. The normative calculation method has advantages of simplicity, transparency, robustness, and reproducibility. For systematic energy performance assessment at various scales, i.e., at the unit of analysis of one building up to a large-scale collection of buildings, the authors' group developed the Energy Performance Standard Calculation Toolkit (EPSCT). This toolkit calculates objective indicators of building energy performance using either the monthly or hourly calculation method as specified in the CEN/ISO standard for building energy calculation. The toolkit is the foundation for numerous single, medium-scale and large-scale building energy management applications. At the largest level, applications should be able to manage hundreds or thousands of buildings. The paper introduces two novel applications that have the normative calculation at their core: (1) network energy performance modeling and (2) agent-based building stock energy modeling.

INTRODUCTION

To achieve energy efficiency for buildings, the systematic evaluation of energy performance of each building is necessary. This should support decisions about individual building improvement as well as energy and environmental policy development. The European Union and its Energy Performance in Buildings Directive (EPBD) has focused on methodologies for calculating and rating the energy performance of new and existing buildings (European Commission 2002). This has brought the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO) together to develop international standards, such as ISO 13790:2008 (ISO 2008), for the calculation of building energy performance. This standard defines the calculation recipe according to a set of normative statements about functional building category, assumed usage scenario, system efficiency, etc. Through its simplicity and unified modeling assumption this approach forms the basis for assessing building energy performance in a standardized and transparent way (Hogeling and Van Dijk 2008). The calculation of energy performance is critical when setting energy efficiency targets for large sets of buildings, i.e. for policy development.

The main philosophy of the approach is based on two pillars:

1. All modeling assumptions are normative, i.e. there is no modeler's bias
2. All usage scenarios are normative, i.e. there is no need to "predict" the actual use of the building

The consequence of the first pillar is that the calculation method is specified as an algebra over a set of parameters, i.e., a set of algebraic equations where certain "model" parameters are derived from observable building design parameters whereas others are derived through empirical equations specified in the standard. The philosophy automatically leads to the rejection of dynamic simulation, as there is no simulation tool that would endorse a fully transparent calculation method that rules out modeler's bias. Obviously this raises the question how accurately the algebra approximates the actual energy use, and how well the (in many cases macro) parameters in the calculation reflect the actual physical behavior of the (micro) physics of the building. This is an interesting question but not always the most relevant question. After all, a standardized expression of performance does not need a prediction of actual energy consumption (or the best approximation of it), as it only needs to guarantee that the resulting energy performance coefficient (EPC):

$$EPC = \frac{Energy\ Calculated}{Energy\ Referenced}$$

is an objective measure for the energy performance. As the equation shows, the EPC is normalized by proper definition of a reference value, E_{ref} for every functionally equivalent building type. The correlation between the normative outcome and simulated energy consumption have indeed been studied and results thus far are enough proof to accept the approach as good enough to accept the calculated EPC as objective indicator of performance (Augenbroe and Park 2005).

As any normative method, this method also raises important fairness concerns for instance, when a building uses special energy saving measures or technologies that may not get the credit they deserve in the calculation method. Not surprisingly, all standardization bodies that mandate the use of the normative standard in their building code are facing this issue. In fact, manufacturers and designers line up to claim energy benefits that the calculation does not endorse. Some countries leave a “back door option” open, which is to allow using simulation in such cases. This obviously negates many of the benefits of the normative approach. A better way forward would be to continuously update the calculation to account better for certain design measures and technologies.

The second pillar in the philosophy is less contentious. Indeed, for normative energy labeling it should not matter how the building is used by the client as the rating is meant to label the building, not the combination of building and client. Understanding the difference is easy in the example of car ownership. Assume that person A has a fuel economic car and drives mostly alone, and about 20,000 mile per year. Person B has a gas guzzler, but always drives with his family of four and drives only 10,000 miles per year. Two interesting questions can be raised: (1) which car is more efficient; (2) which car is used more efficiently? We will not present any calculations to answer these questions, but it is obvious that the answers to both will have different answers. So it is essential that in rating methods, one takes a clear perspective on what is to be rated. In the case of buildings, our starting point is that the building should be rated, and that will also form the baseline of our application studies. It should be noted that the building simulation discipline often laments that their results are not confirmed by real data as they could not foresee how the building was actually going to be used. We argue, based on the above that such comparisons are futile as rating a design should *not* be dependent on the assumptions about the building’s use. This is indeed another good reason to use a normative rating method.

A building energy rating system therefore defines the energy performance under standard conditions. For a new building, the EPBD framework determines the energy rating based on the calculated energy use following the calculation procedure for a standard usage pattern and climatic condition (CEN 2008). The approach is designed to rate the buildings and not the occupant. Thus, the calculated building energy rating does not depend on actual conditions of occupant and behavior and weather (Pe ́rez-Lombard, Ortiz et al. 2009). It should be obvious the assumed standard usage profile does not matter much as it is normalized through the appropriate choice of E_{ref}.

It is worth noting that building energy performance quantification for existing buildings as well as new designs is identical. In both cases one would assume the design specifications.

The calculation method is validated through a number of rigorous validation efforts (Jokisalo and Kurnitski 2007; Kokogiannakis and Strachan 2007; Millet 2007; Siren and Hasan 2007; Burhenne and Jacob 2008; Kokogiannakis, Strachan et al. 2008; Orosa and Oliveira 2010; Ruiz-Pardo, Domı ́nguez et al. 2010).

Another factor getting increasing attention, and rightly so, is the role of uncertainties. Simulation creates a virtual model that reflects many modeling assumptions and simplifications (by the modeler and by the software developer) that introduce many uncertainties (de Wit and Augenbroe 2002; Moon and Augenbroe 2007; Hopfe 2009; Hu 2009). The mentioned studies have looked at the impact of these uncertainties on the calculated energy consumption and in general a large impact is found. An ongoing major study (Sun, Heo et al. 2011) as set out to quantify uncertainties at different scales and determine their relative impact on energy performance predictions. A major intended outcome of that study is to compare the confidence levels in energy performance outcomes obtained with the proposed normative method, compared to simulation based methods. Based on currently available work it is to be expected that normative models will produce a higher level of confidence, in spite of their deficiencies in not being able to represent all building and system features.

Combined with the fact that the normative calculation approach has advantages of easiness, transparency, robustness, and reproducibility (Van Dijk and Spiekman 2007), it provides the best way forward for energy performance rating.We will in fact argue that the approach has many additional application areas. The following section introduces the energy performance assessment tool EPSCT, a computer translation of the CEN/ISO standards. It is used for various energy performance research efforts described below.

EPSCT

EPSCT is an energy performance assessment toolkit has been developed for both the monthly and hourly normative calculation methods as defined in the ISO 13790 standard and supporting documents. The standard introduces a monthly quasi-steady-state and a simple hourly method for the calculation of the energy need for space heating and cooling for residential and non-residential buildings (Van Dijk, Spiekman et al. 2005). In addition to the thermal energy demand for heating and cooling, the total building consumption is determined as the sum of energy consumed for heating, ventilation, lighting, pumps, cooling, (de)humidifying and preparation of domestic hot water by the building systems. Supporting calculation standards are EN ISO 13789 for transmission and ventilation heat transfer, EN 15241, EN 15242 for ventilation for buildings, EN 15243 for cooling and ventilation systems, EN 15193 for lighting, EN 15316-3 series for domestic hot water, and EN 15316-4 series for heating systems.

This section describes the set-up of the calculations and details a number of extensions to this set-up.

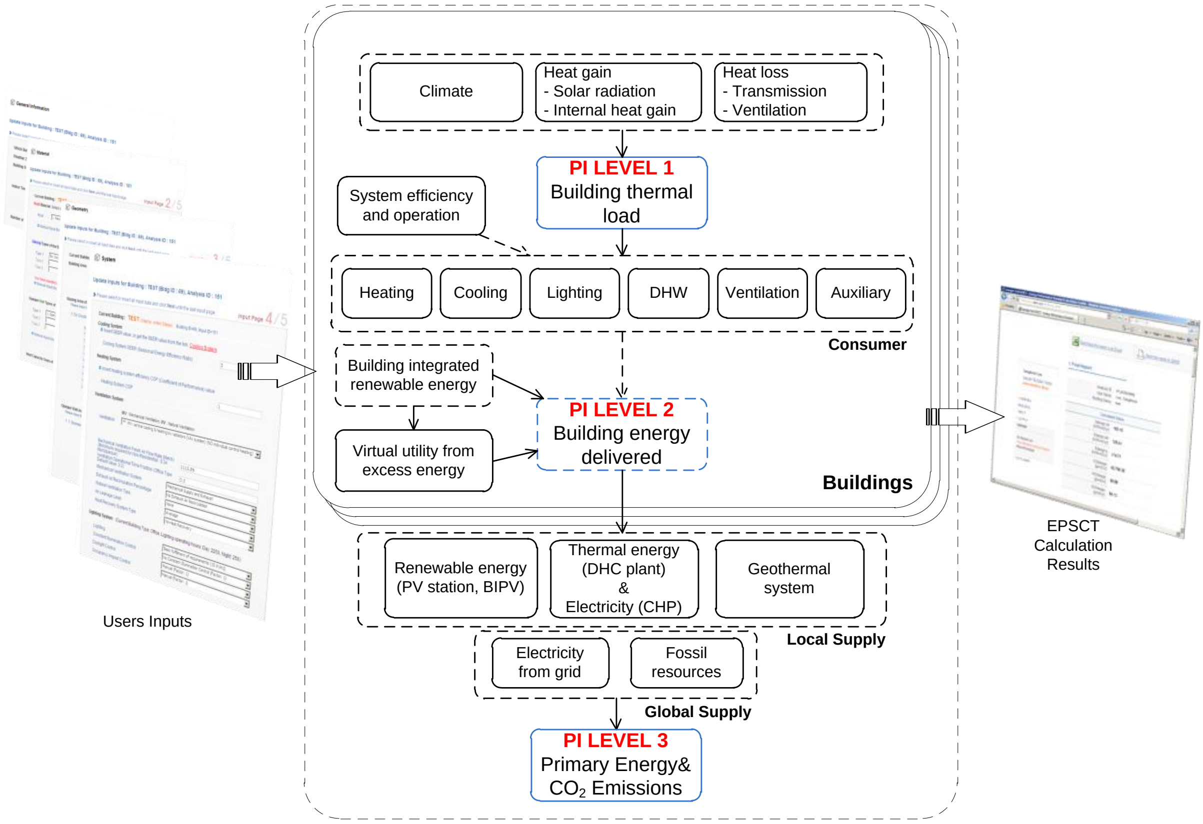


Figure 1 Schematic Diagram of EPSCT

Performance Assessment

Figure 1 depicts a schematic diagram of energy performance analysis using EPSCT. The calculation starts from level 1: *thermal energy needs* which take account of energy losses (transmission and ventilation), heat gains (solar, internal and system heat sources), and thermal inertia driven by building mass. The total thermal energy need is calculated and used to assess the energy efficiency performance of the architectural design (without any systems information). On level 2: *delivered energy,* the system energy consumption is determined by the systems that are designed to meet the thermal energy demand from the previous step. At this level, district heating and cooling plants can be part of the mix of local and distributed systems. Heating and cooling energy losses via water or air delivery, transmission losses and on-site renewable energy generation are taken into account at this level as well. The delivered energy is determined for each energy carrier. On level 3: *Primary energy and CO2 emissions* are calculated on the basis of the calculated delivered energy in the previous step. This step adds uses the specific details of the energy supply utilities and network, tracking the generation and emission efficiency of the local mix of utilities that the building consumes.

Added Feature: Internal Temperature Calculation

Room set-point temperatures play an important role in the transmission and ventilation heat transfer calculation. For the monthly calculation method, a fixed set-point temperature is used for a given calculation period when continuous heating and cooling are applied. With this approach, the empirical heating and cooling utilization factor as specified in the standard, takes consideration of dynamic effects that depend on the thermal inertia and the ratio of the heat gains to the heat losses. However, for intermittent heating and cooling with varying set points (night and weekend set-backs), the room temperature changes depend on external temperature, heat transfer, heat gain, and thermal inertia during the reduced set-point temperature or switch-off period for unoccupied periods. In such situations the room temperature will not be set to a fixed value but will be free-floating. This means that the cooling and heating based on average difference between inside and outside temperature cannot be determined unless we can approximate the internal temperature during these periods, as used in the ISO 13790 calculation method. Taking cooling as an example, Figure 2 illustrates the room temperature during normal system cooling operation in the occupied time and a switch-off period for the unoccupied time.

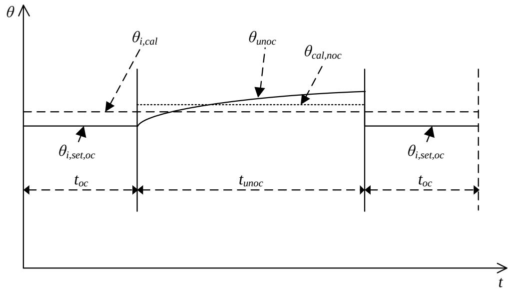


Figure 2 Internal Temperature Illustration in the Case of Intermittent Cooling

EPSCT calculates the free floating internal temperature, θ_{unoc} when the cooling system load is reduced or off during the unoccupied period. The unoccupied internal temperature θ_{unoc} is derived using the local heat balance equations with an approximation of the active local energy capacity for the considered room. It is assumed that the system delivers sufficient power to meet the internal set-point temperature when the occupied period starts hence room temperature is maintained at the desired set point. After θ_{unoc} is calculated, $\theta_{i,cal}$, the time average temperature for the calculation period is determined by averaging. In cases where a night time and weekend free-floating temperature, EPSCT uses $\theta_{i,cal}$ to calculate the cooling or heating need. A validation study was performed showing that the intermittent energy needs calculation using $\theta_{i,cal}$ as an internal set-point temperature improves transparency of the current ISO 13790 method and delivers a more adequate monthly heating and cooling energy need in case of user specified temperature setbacks.

APPLICATIONS USING NORMATIVE CALCULATION MODEL

For energy performance analysis on larger scale than one building unit, the normative calculation has a number of advantages over simulation. Apart from being objective and transparent, it is fast and lightweight and thereby enables scalability to hundreds or thousands of buildings. At that scale, use of dynamic simulation for every building would be very prohibitive in terms of computational effort.

We will show two applications (1) Network Energy Performance (NEP) Model and (2) Building Stock Energy Demand management, both of which were developed with EPSCT as the underlying engine.

Application 1: Network Energy Performance Modeling

So far, many tools have been developed to analyze energy performance of buildings at different levels of precision, stages of design, and scales of implementation. However, a systematic model for large-scale energy performance assessment that integrate buildings and energy producers incorporating the concept of building attached versus grid scale systems (virtual utility) has not yet been developed. Figure 3 shows a campus scale energy network with a variety of consumers and producers at different scales, with different connectivities to share and pool resources driven by real time information.

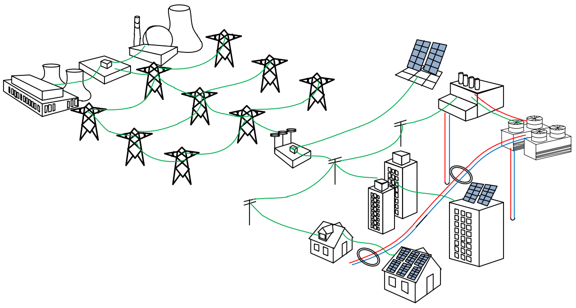


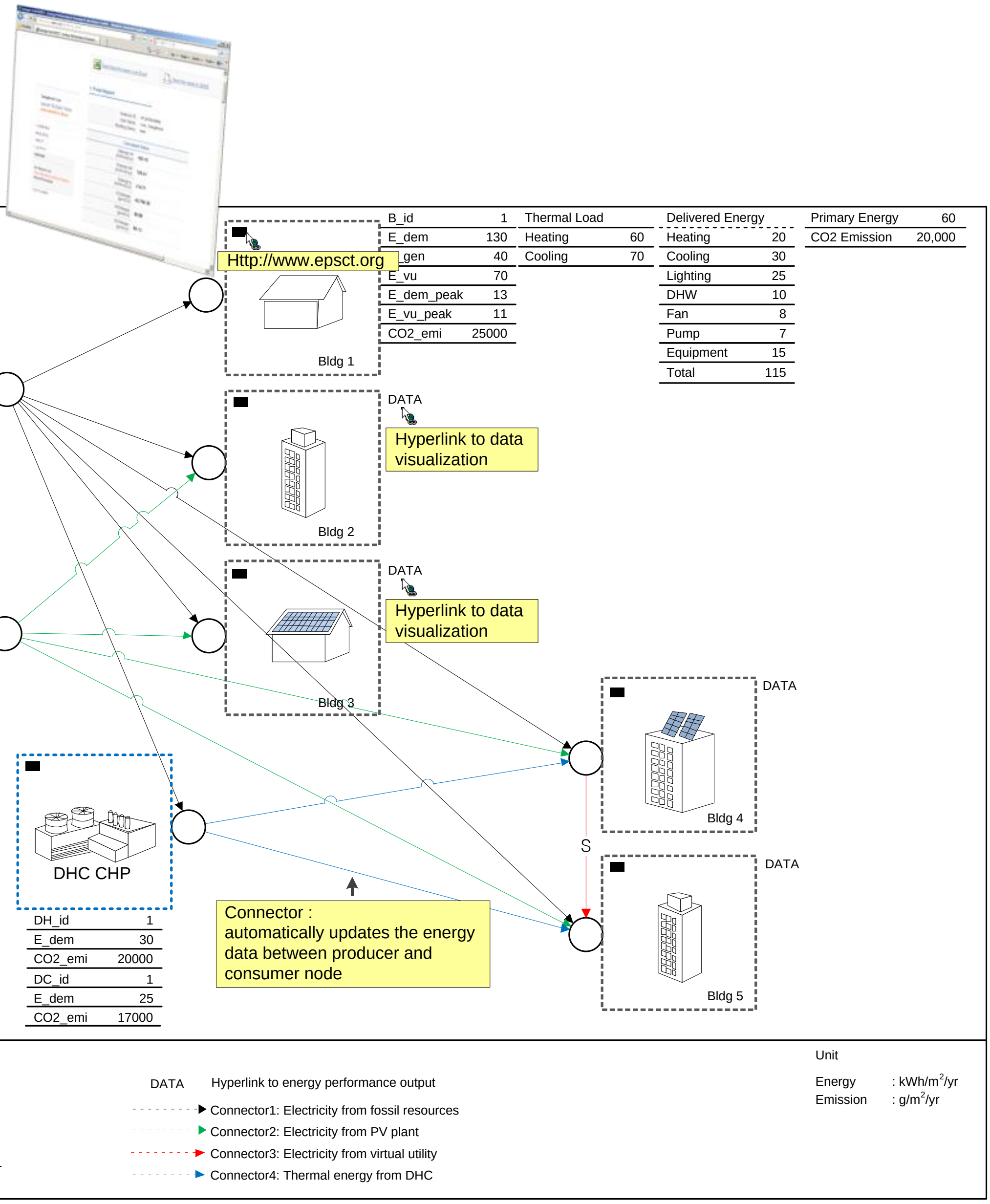
Figure 3 Representation of Energy Network

The Network Energy Performance (NEP) model systematically quantifies energy performance on a scale of campus or corporate portfolio, comprising energy consumption by single buildings or district systems and energy supply from various sources, attached to individual buildings or at grid scale level. Energy supply to buildings is delivered by conventional power plants, thermal energy from district heating and cooling plants, electricity from PV stations and/or combined heat power (CHP) systems, and as well as potential electricity from building integrated PV (BIPV) systems.

The NEP model consists of:

- The back end EPSCT module
- A front end network management tool (input)
- A set of energy performance dashboards (result presentation)

EPSCT is used to assess the energy performance of building related consumers and producers. A graphical interface allows users to manipulate the consumers and producers in the system modeling panel. The panel supports the modeling of a directed graph consisting of nodes and arcs. The nodes represent energy consumers and producers, and arcs represent ways in which they are connected. Arcs will come in different types, each type representing a particular way in which a supplier and consumer can be connected. Energy consumer nodes represent buildings at the highest level. At a lower level, a building node contains sub-nodes that represent the individual consumer systems (cooling, heating, pump, fan, and etc.) in a building. Producer nodes represent various electrical power and thermal energy supply systems, including power generation from fossil fuel power plants (this is typically an external node), renewable source systems and thermal energy distribution from district heating and cooling systems in conjunction with combined heat and power (CHP) plants. After a graph is constructed in the modeling panel and all properties of the system nodes used by EPSCT are provided, the calculation will run in the background and show all consumption, generation and energy flows that occur in the system in a given climate. The NEP model also analyses the total primary energy consumption and CO_2 emissions, while manipulating nodes and connections.



B_id	1
_gen	40
E_dem	130
E_vu	70
E_dem_peak	13
E_vu_peak	11
CO2_emi	25000

Thermal Load	
Heating	60
Cooling	70

Delivered Energy	
Heating	20
Cooling	30
Lighting	25
DHW	10
Fan	8
Pump	7
Equipment	15
Total	115

Primary Energy	60
CO2 Emission	20,000

PP_id	1
Ep	350
CO2_emi	77800

PVST_id	1
E_gen	60

DH_id	1
E_dem	30
CO2_emi	20000
DC_id	1
E_dem	25
CO2_emi	17000

Figure 4 Schematic Diagram of NEP Dashboard Application

Figure 4 represents a schematic diagram of the NEP modeling panel. Energy delivery of each building node is calculated considering building type, design features, type of occupants and installed systems. Global and local producers are added with their system specifications. Each node is hyperlinked to the EPSCT input page for assessment and potential modification. Once the energy performance of the node completes, a separate dashboard panel visualizes the EPSCT results for selected nodes. The results are harvested from the nodal dashboards to show aggregated total expected energy consumption and environmental impacts of the energy network. The calculation can be switched from monthly to hourly calculation in order to enable at a more detailed level, the analyses of peak energy demands for each consumer node which may be relevant to cost savings given the peak load based tariff schemes of the utility provider. The system automatically maintains the data in a graphical view when modifications are made for a network component. The NEP model supports systematic analysis to predict and minimize energy consumption and estimate environmental impacts which helps policy development at a given assessment scale.

The NEP approach proposes a lightweight tool that supports rapid decision making for energy efficient system design at building portfolio scale. There is no deep simulation required as the goal is to manage macro design decisions. The development does not target at this time the micro real time operational decisions, but it is obvious that the current development would be extensible to that level of decision making if appropriate nodal dynamics are added. A validation study is ongoing to determine whether the normative calculation for each node is accurate enough to support macro system level decision making. The current model is scalable to larger portfolios and systems and is flexible to explore different topologies by adding or taking away nodes through the user interface. The main distinguishing feature is the way that nodes and their connections can be managed in the graphical interface while the underlying representation will maintain the consistency to perform the calculations at any time. The energy performance quantification of buildings, energy supply, and energy generation systems will bring rich information for decision makers when they plan for energy saving and reducing GHG emissions.

Application 2: Building Stock Energy Modeling

Another application driven by normative energy calculation is for the quick large-scale energy demand estimation of the building stock. The efficient and rational implementation of building stock retrofit and demand response strategies requires the application of comprehensive building stock models that have the ability to (1) estimate the baseline energy demand profile of the existing building stock, (2) explore the technical and economic effects of different retrofit technologies over time with respect to building owner preferences, and (3) identify the interaction between building stocks and the power grid. Some of the current physics-based building stock models suffer from limitations that stem from problems regarding the computationally expensive modeling of a large number of buildings using dynamic simulations while others are not capable of specifying technical interventions applied to buildings due to their over-simplification of the physical and behavioral characteristics of buildings. To address these limitations, we aggregate similar individual buildings and assigning to them a representative model. This approach has been widely used by the building stock modeling research community (Natarajan and Levermore 2007; Sansregret and Millette 2009; Yamaguchi and Shimoda 2009; Zhao, Wang et al. 2010). We follow the same approach and introduce the agent-based modeling and simulation (ABMS) to this field for the modeling of various characteristics of buildings.

The proposed approach considers a cluster of buildings of the same type (use the same prototypical model) within the same region (use the same weather data) to be one block. This block is then defined as an *agent* interacting with others in the ABMS environment. Different agent adaptive actions, passive (e.g., performance degradation) or active (e.g., retrofit, DR), can be simulated by changing their input parameters of the prototypical models for the agents. The concept of aggregation and interaction is illustrated as Figure 5.

Figure 5 Conceptual Illustration of Building Aggregation

We place this approach in the context of the commercial building sector in the United States. Based on the 2003 Commercial Building Energy Consumption Survey (CBECS) developed by the U.S. Energy Information Agency (U.S. EIA 2006), we develop a building model base with 10 building types (i.e., large office, medium office, small office, warehouse, retail, strip mall, supermarket, hospital, hotel, and midrise apartments), 16 climate zones, and three vintage categories (New, Post 1980, and Pre 1980). Every instance in the model base has a uniform set of input modeling parameters for EPSCT quick energy calculation. Based on these prototypical models, a software was developed to automate the multi-agent simulation process and apply it to the contexts of large-scale demand response and energy retrofit of commercial buildings.

With the development of power system deregulation and smart metering technologies, price-based demand response becomes an alternative solution to improve power system efficiency and to reduce the investment in peak load generators. To model demand response behaviors of commercial buildings at the electricity transmission level, each building agent is defined to be capable of applying various demand response strategies at given real time electricity prices. Such strategies include (1) changing room set-points, (b) reducing lighting power intensity, and (c) reducing the equipment power intensity. Each building stock agent has identical thresholds and preferences of selecting these demand response strategies, given different real-time electricity prices, and therefore perform differently in the hourly EPSCT calculation. This model is used to simulate different types of commercial buildings as agents and to derive the hourly load profile of the entire building stock at the electric transmission level. By updating building operating parameters in this bottom-up model according to different occupant control strategies under real-time electricity pricing, the total electricity demand of the building stock can be estimated. This will, in turn, affect the electricity market (illustrated in Figure 6). Details of this application and two test cases are described by Zhao, Wang et al. (2010).

As results of the simulation, hourly load profiles of commercial building stocks and the corresponding hourly electricity prices are generated. These profiles can be used to evaluate regional utility reliability under different demand response scenarios. They can also estimate the energy and monetary savings of the building stock.

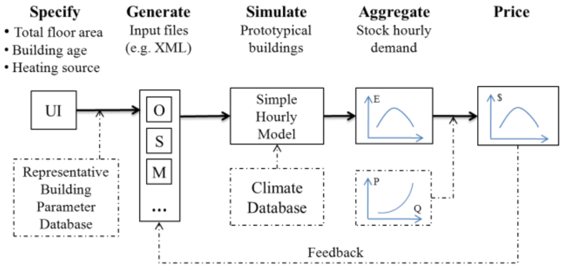


Figure 6 Building Stock Electricity Demand Modeling Using Hourly Normative Calculation [Adapted from (Zhao, Wang et al. 2010)]

In addition to the application of demand response within electricity transmission networks, achieving commercial building energy-efficiency targets is also an important target to pursue. To model large-scale building performance degradation and retrofit, each agent is defined to (1) degrade its performance annually and (2) adapt energy conservation measures (ECMs) when being triggered. The performance degradation of an agent is modeled by continuously updating three parameters of the building model annually: the energy use intensity of lighting fixtures, the seasonal energy efficiency ratio (SEER) of cooling systems, and the efficiency of heating systems.

The energy retrofit of an agent is a more comprehensive process. Martinez-Moyano, Zhao et al. (2011) reviewed existing energy efficiency programs offered by utility companies and proposed 13 ECMs for building stock agents to choose from, including insulation improvement, shading device installation, infiltration reduction, heat recovery system installation, cooling system tune-up, high-efficiency chiller installation, heating system tune-up, high-efficiency gas heater installation, auto-controlled pump system installation, LED/CFL lighting installation, day-lighting control sensor installation, occupancy sensor installation, and EnergyStar appliances installation. In this list, every ECM has an update function representatively which modifies the input parameters of the prototypical buildings in EPSCT in each iteration. Each building stock agent is capable of adopting ECMs every year following its identical decision-making scenario when its energy use intensity reaches a predefined threshold. EPSCT in its monthly mode then evaluates the annual energy consumption and environmental impacts of agents over time and generates aggregated outputs for decades. This process is illustrated as Figure 7. Martinez-Moyano, Zhao et al. (2011) present the prototype model and initial simulation results.

As results of the simulation, the annual energy consumption and CO_2 emissions of commercial buildings in a region is projected. Projections under different scenarios can be used to evaluate building energy standards, retrofit incentives, and sector-wide technology or performance.

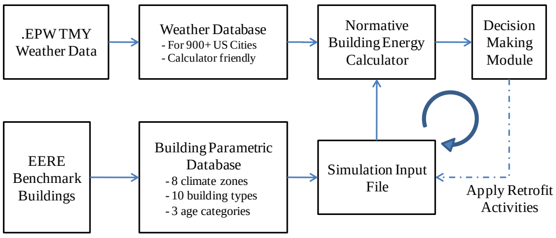


Figure 7 Building Stock Degradation and Retrofit Modeling Using Monthly Normative Calculation [Adapted from (Martinez-Moyano, Zhao et al. 2011)]

CONCLUSIONS

This paper explores novel applications for systematic energy performance assessment at a large-scale. Taking advantages of a normative calculation method, the authors' group developed the Energy Performance Standard Calculation Toolkit (EPSCT), which calculates objective indicators of building energy performance using both a monthly and hourly calculation method. EPSCT is used as the engine in applications such as a Network Energy Performance (NEP) model and a building stock energy model. The NEP model analyses total environmental impacts of buildings at the scale of campus or corporate portfolio considering a wide variety of energy supply systems to manage the energy distribution within the network. The NEP modeling panel and embedded dashboards is a lightweight, scalable tool supporting rapid decision making for the design of energy-efficient systems by evaluating different planning topologies. The building stock modeling application targets a larger number of buildings by developing a model base of different archetypes. It uses ABMS to simulation both the short-term reaction (demand response) and the long-term evolution (performance degradation and energy retrofit) of the commercial building stock. Both applications aim to support the decision making of planning and improving the overall performance of regions consisted of various types of buildings.

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