Improving Energy Efficiency and Risk Management in EU Public Buildings

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Why Energy Efficiency in Buildings?

National and regional authorities worldwide have passed legislation in order to mitigate climate change. For example, the "20-20-20" targets of the European Commission include a 20% improvement in energy efficiency by 2020 relative to 1990 levels (EU, 2008; EU, 2009). One pathway for this objective to be achieved is via improved operational and retrofitting practices in existing buildings. Since the building sector is responsible for nearly 40% of the energy consumed in the EU (EU, 2011), sectoral improvements could make a substantial impact overall.

Contemporaneously, electricity-sector deregulation in most industrialised countries aims to improve economic efficiency by providing more transparent price signals to producers and consumers (Wilson, 2002). Indeed, unlike the hierarchical, vertically integrated paradigm, the deregulated one facilitates more decentralised decision making. On the one hand, this creates incentives for building managers to respond to market conditions by adjusting their set points in the short term (taking into account weather forecasts and occupancy levels) or by retrofitting in the long term; yet, on the other hand, they will have to guard against volatile energy prices and to trade off both investment and operational decisions over time. In effect, consumers need better decision support for potentially conflicting objectives, e.g., lowering energy costs, managing risk, and improving energy efficiency.

From the perspective of public building managers in the EU, an optimisation approach based on modelling energy flows may enhance decision making. In particular, our preliminary results based on data from test sites in Austria and Spain (as part of the EU FP7 EnRiMa project) indicate how dynamic zone temperatures for heating via conventional radiators and heating/cooling via HVAC systems reduce energy consumption by 10%. This is possible by responding to external conditions and internal loads while taking into account the thermodynamics of the heating/cooling system and the building's physics. Longer-term savings from retrofitting may also be possible and are being investigated.

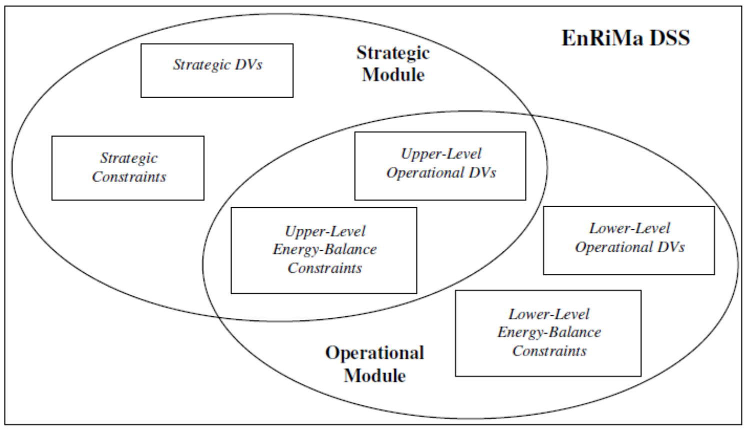

Figure 1. EnRiMa DSS Schema

A Dual-Level Approach

The EnRiMa decision support system (DSS) considers short-term (operational) and long-term (strategic) problems in distinct, but linked, modules (Figure 1). The former assumes that building equipment and shells are fixed, and the building manager must meet various energy demands over time by procuring energy from diverse sources, e.g., energy markets or on-site production. This leads to upper-level operational decision variables (DVs) and energy-balance constraints. It is also the approach used in most optimisation-based treatments, e.g., King and Morgan (2007) or Marnay et al. (2008), which essentially adapt large-scale models, e.g., Hobbs (1995), to the building level.

We extend this approach by focusing on energy services (instead of demands) for a building's occupants. For example, while it may be natural to think of demand for lighting or other electricity-only end-uses, heating or cooling services are more natural to cast in terms of comfort, i.e., a desirable temperature or range. Unlike traditional optimisation methods for building energy management, which estimate heating and cooling demands exogenously, we assume that these demands arise endogenously based on the building manager's desirable temperature range, thermodynamics of conventional radiators or the HVAC system (e.g., how heated water or air affects the zone temperature), building physics (e.g., how the shell retains heat over time), solar gains, external temperatures, and internal loads (e.g., number of occupants and level of activity). These lower-level

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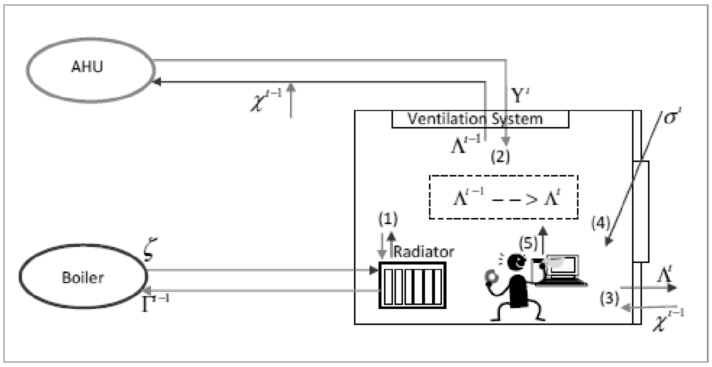

Figure 2. Lower-Level Operational Model

energy-balance constraints also lead to lower-level DVs, i.e., flow rates of air or water and use of natural ventilation, which not only vary with current conditions but also anticipate future ones in order to allow for pre-heating in the winter (Figure 2). Such lower-level energy-balance constraints together with the lower-level DVs may be run independently or in conjunction with the upper-level energy-balance constraints and operational DVs to constitute the operational module that minimises the cost or the level of energy consumption. Finally, our approach is in contrast to how traditional building energy management systems operate, i.e., by adjusting air or water flow in heating and cooling systems in response to pre-determined triggers, viz., large deviations in the zone temperature from the set-point temperature.

In the long term, both the building envelope and the installed equipment may be replaced, which is handled by the strategic module. Its novelty compared to existing investment models at the building level, e.g., King and Morgan (2007) or Marnay et al. (2008), is in addressing uncertainty in both energy prices and technology performance. Indeed, volatile energy prices and technological change may expose building managers to risk and deter energy-efficiency investments. Thus, the strategic module provides a way to make such long-term decisions under uncertainty while also allowing for financial contracting to hedge against risk. In contrast to the operational module, the strategic one abstracts from the details of equipment thermodynamics and instead captures operational effects through upper-level energy-balance constraints.

Preliminary Results

The lower-level operational module is run for two EU public buildings: Centro de Adultos La Arboleya (in Siero, Asturias, Spain), which belongs to Fundación Asturiana de Atención y Protección a Personas con Discapacidades y/o Dependencias (FASAD), and Fachhochschul Studiengänge Burgenland's Pinkafeld campus (in Pinkafeld, Burgenland, Austria). Both sites currently buy all of their energy (electricity and natural gas for FASAD and electricity and district heating for Pinkafeld) at regulated tariffs from local utilities. Thus, in the short term, there is no price uncertainty facing these consumers. Nevertheless, they face a challenge in reducing energy consumption given their existing building configurations. We focus on the case for Pinkafeld as the findings are qualitatively similar for both sites.

Assuming that the building manager's desired zone temperature range during a typical winter day for Pinkafeld is 19-22°C during peak hours (and 16-17°C during off-peak hours), we capture the extent of energy savings from using dynamic temperature set points for the radiators and HVAC system. We run the lower-level operational module under three cases: fixed-mean temperature (FMT), fixed-lower temperature (FLT), and optimisation within desired zone temperature ranges (OFP). The FMT case mimics existing building operations in which the zone temperature is maintained at the target level (in this case, the mean of the ranges given). FLT provides a more conservative way to run the heating system, i.e., by targeting the lower limit of the desirable range. By contrast, OFP is a true optimisation that determines hourly zone temperatures and, thus, the desired set points for the heating system throughout the day in a cost-minimising manner. In a similar spirit, a dynamic approach that trades off cost and comfort for an HVAC system only is taken in Liang et al. (2012).

The OFP case results in daily energy consumption of 632.79 kWh, which is a 10% reduction from the FMT case. When the rigid temperature requirement is set to the lower limit, the total energy consumption is 638.78 kWh, which is 1% higher than in the optimised case with less user comfort. Hence, the optimisation approach proposed here may support building operators in trading off energy costs and user comfort (Table 1).

Case	Space Heat Demand (kWh)	HVAC Electricity Demand (kWh_e)	Cost (€)
FMT	696.11	5.77	56.74
FLT	631.07	7.77	51.83
OFP	629.15	3.64	51.05

Table 1
Summary of Resutls

Figure 3 indicates how the zone temperatures change during the day relative to the external temperatures in the FMT case. Note that the estimated and required temperatures are coincident because of the lack of flexibility. Due to high solar gains in the middle of the day and the rigid temperature requirement, the HVAC system needs to be operated, which creates relatively high electricity consumption in comparison to the OFP case. The pattern is similar for the FLT case (Figure 4)), and there is again no difference between the estimated and required temperatures. By contrast, the OFP case allows the zone temperatures to drift within the acceptable range, thereby taking advantage of the solar gains and reducing the need for the HVAC system (Figure 5). For example, between 6 AM and 8 AM, the cumulative space heat demands are 154.31 kWh and 155.04 kWh for the OFP and FLT cases, respectively, as the flexibility to ramp up the radiator gradually in the former case reduces energy consumption. Similarly, between 6 PM and 7 PM, the flexibility over the radiator's operations means that the space heat demand is 42.19 kWh in the OFP case as opposed to 43.39 kWh in the FLT one. Thus, total space heat demand is reduced by approximately 1.92 kWh.

Surprisingly, even with a lower fixed temperature setting as in Figure 4, the energy and cost savings are not as high as with an optimisation within a temperature range. In effect, the flexibility of the building's conventional heating and HVAC systems to respond to environmental (and, potentially, market) conditions is valuable from both economic and energy-efficiency perspectives. This is encouraging for managers of public buildings and policymakers alike: with the right kind of decision support, energy savings of up to 10% are possible simply from better operations without any changes to the existing building or equipment.

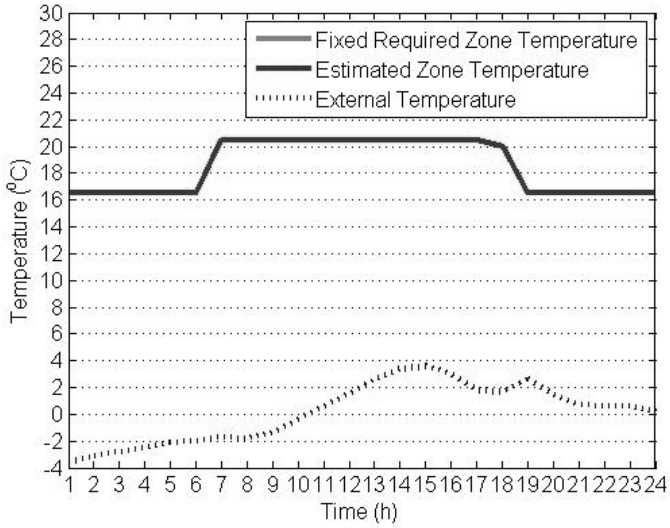

Figure 3. Mean-Temperature Operations

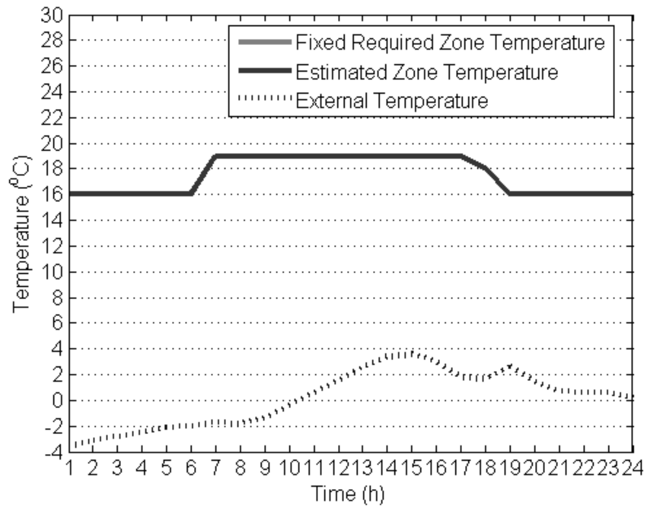

Figure 4. Lower-Temperature Operations

Next Steps

The EU's "20-20-20" targets will require not only improvements in supply-side technologies but also reductions in energy consumption. Market-based incentives for consumers, e.g., real-time pricing, along with better decision support may deliver such savings without sacrificing comfort. The EnRiMa operational module illustrates how optimisation may be combined with lower-level details about building physics and equipment thermodynamics to enable set points for conventional radiators and HVAC systems to respond to anticipated environmental conditions. We find that 10% savings in energy consumption are possible even with flat tariffs relative to static temperature set points. Additional policy insights about the benefits of real-time pricing could be obtained by running such a module under stochastic prices.

For future work, validation of the energy-balance equations at a laboratory facility will prepare the DSS for implementation at the two test sites. Ultimately, the objective of the EnRiMa project is not only to demonstrate that energy savings are possible at the building level but also to integrate the DSS with the buildings' ICT systems in order to verify via audits the extent of the savings. Indeed, in order for this research to contribute to the "20-20-20" targets, a business model based on services provided by a DSS will have to be developed. Quantifiable savings at real buildings of public use could, thus, be the first tangible step in this direction.

At a strategic level, the DSS could also provide insights about equipment retrofits while taking uncertainty in prices and demand into account. Higher investment costs

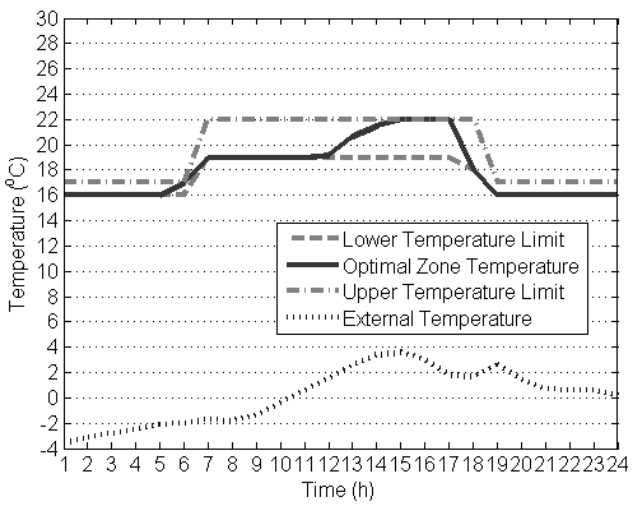

Figure 5. Optimal Operations

for more efficient technologies may deter building managers from purchasing such equipment if they cannot evaluate their operations adequately. The strategic module would enable building managers to assess the trade-off between the costs of investing in equipment and the costs of running it efficiently. Moreover, an optimisation-based DSS would help building managers to find a customised portfolio of diverse technologies and measures complementing each other during day-to-day operations. Taking into account uncertainty, the strategic module of the DSS will ensure that such a portfolio of technologies and equipment is not adapted to optimal conditions but will perform well (if not optimally) in a variety of situations. Finally, similar to the operational module, the strategic module could be used for policy analysis, e.g., in setting CO_2 prices or building codes, to obtain long-term efficiency improvements.

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