Recent Developments in City Scale Modelling, Monitoring and Performance Information Delivery

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Abstract. This paper corresponds to a presentation delivered at the *SmarT-ABCD'15* workshop on *Smart Technologies and Applications in Buildings, Cities and Districts* organised within the framework of the 11th International Conference on Artificial Intelligence Applications and Innovations. It reports outcomes from recent research that established a means to deliver, rapidly and at low cost, energy-related apps corresponding to discrete issues such as inappropriate HVAC system regulation, occupant discomfort avoidance, energy use reporting, upgrade quality assurance and the like.

Keywords: pervasive sensing, data processing, energy services, building performance simulation, benchmarking

1 Introduction

Many technologies and systems are routinely mooted as potential solutions for low energy/carbon cities. Examples include innovative insulation products, advanced glazing, context-aware smart control, combined heat and power plant, heat pumps, solar thermal/electric systems, fuel cells, urban wind power, low energy lighting, smart grids and biomass/district heating. Given the complexity of the problem domain, it is unlikely that fiscal measures alone will bring about solutions comprising effective blends of such technologies. This notion gives rise to two aphorisms.

1. If a proposal is not simulated at the design stage then it is unlikely to deliver the required performance when built.
2. If post occupancy performance is not routinely monitored then the present gap between operational performance and design intent will persist.

These issues may best be addressed by a data-centric approach whereby estate simulation and monitoring is routinely applied; a means to blend the virtual and real outcome data established; and transformation techniques applied to this blend to yield information that may be acted upon by interested stakeholders, including designers, planners, property managers and citizens. Ensuring such a whole-systems approach to the design, commissioning and operation of single or groups of buildings is the intent of the recently launched *Hit2Gap* project [1] as funded under the European Commission's Horizon 2020 R&D programme.

2 Data-centric Approach

Figure 1 summarises the data-centric approach to performance assessment when applied at the city scale. Data is collected from a variety of estate monitoring devices – such as utility meters, weather stations and pervasively deployed environmental sensors – and used to quantify the multi-variate performance of the estate being addressed. These performance data are then delivered to a range of stakeholders in user-specific format, e.g. as spatial maps depicting low carbon technology deployment opportunity at the city level or as timely advisories to building operators. To support action planning, scenario simulations are undertaken to quantify the likely outcome of proposed interventions, such as existing building upgrades, the introduction of demand management/response, or the introduction of a disruptive technology such as electric vehicles.

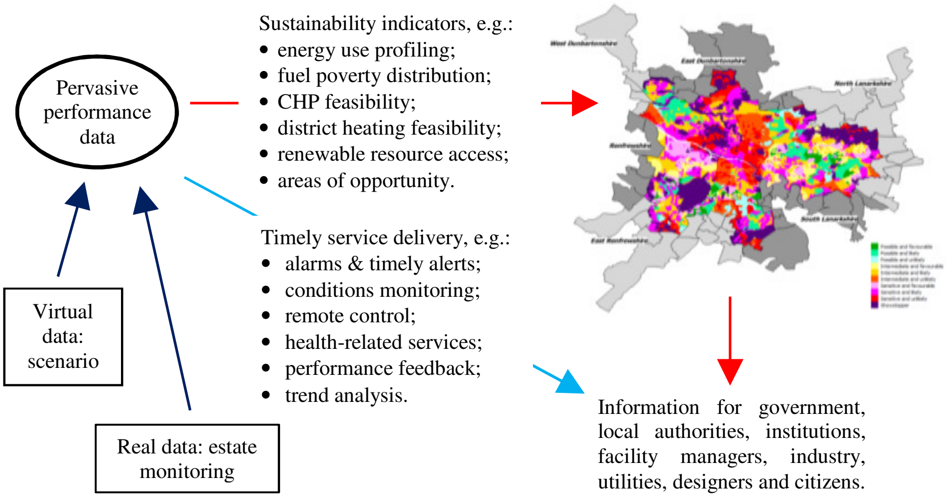

Fig. 1. A data-centred approach to future city management.

As depicted in Figure 2, a significant feature of the simulation approach [2] is its ability to generate disaggregated demand profiles at high resolution (per property, technical system or connected estate for example) for building stock models generated automatically on the basis of rules derived from stock survey [3].

The significant point is that the approach respects the underlying thermodynamic complexity, links energy use considerations to wider issues such as comfort, air quality, emissions *etc*., enables life cycle assessment, and accommodates uncertainty – all while providing an integrated view of the overall, multi-variate performance as depicted in Figure 3. Within the present work, the ESP-r system has been modified to these ends and made compatible with the EnTrak data management system [4].

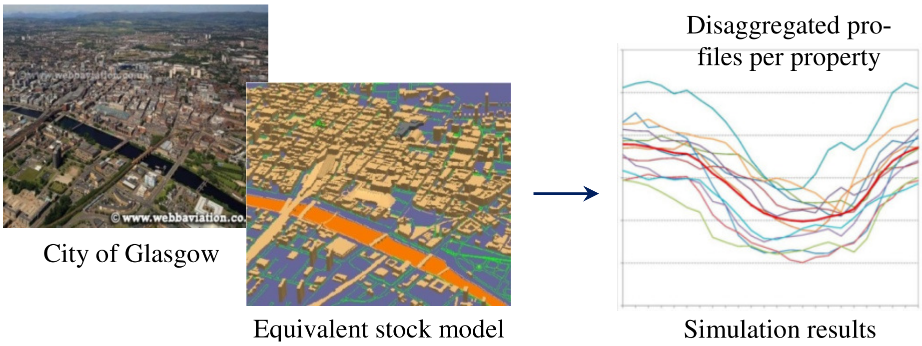

Fig. 2. Disaggregated load profiles generated from a building stock model.

This notion of a virtual reality approach to building performance assessment is encapsulated in the future vision statement as published by the International Building Performance Simulation Association [5] and portends a future wherein proposals may be pre-tested under conditions that emulate the likely future reality.

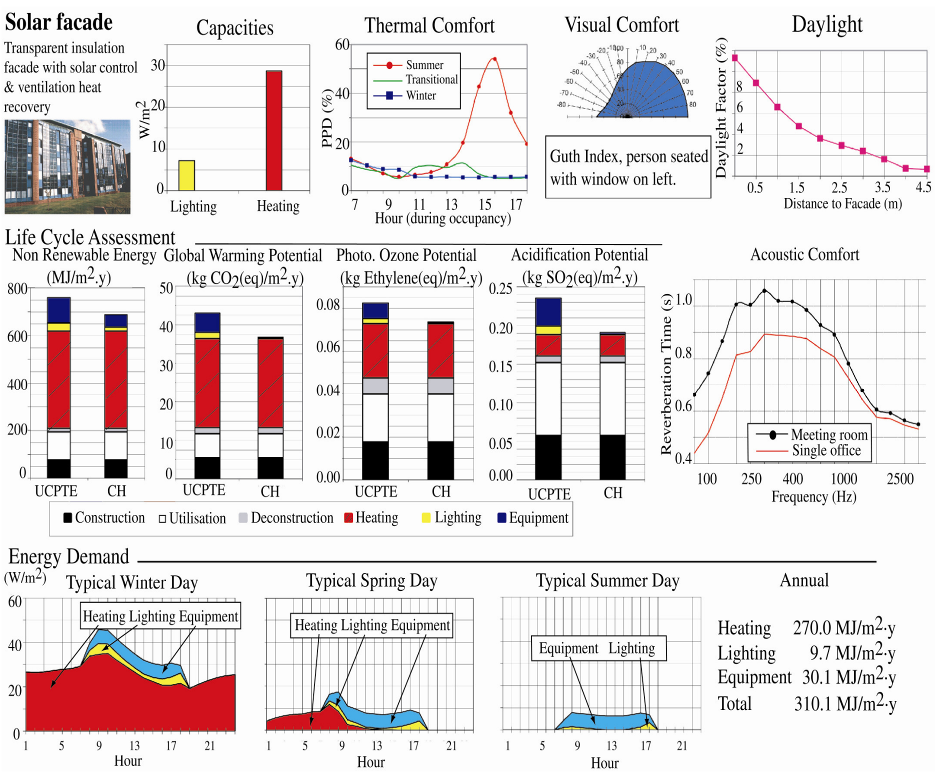

Fig. 3. An integrated view of performance resulting from multi-domain building performance simulation.

3 Estate Monitoring

While it may be expected that building energy management systems are able to provide a portion of the required estate performance information, it is unlikely that the required dataset will be complete in several important respects. Because the focus will be on HVAC system state measurement and control, issues such as occupancy presence and behaviour, the spatial distribution of indoor conditions, disaggregation of load profiles, and local weather will typically be omitted. It is for these reasons that the BuildAX monitoring system, as depicted in Figure 4, was developed within a project funded by the UK Science and Engineering Research Council (project EP/I000739/1) [6].

Fig. 4. A BuildAX logger/router/server (left) and multi-sensor environmental monitor.

The environmental monitor integrates sensors for temperature, relative humidity, movement, illuminance, contact (e.g. door/window opening), and battery state. These data are broadcast to the logger/router wirelessly at 2.4 GHz from whence they may be collected by remote agents as described below. The technology is open and has an established supplied chain. The logger/router encapsulates a Web server that enables immediate display of the monitored data as depicted in Figure 5 for the case of a deployment of 6 monitors at locations throughout an office as shown.

Fig. 5. BuildAX data superimposed on a plan view alongside a graph of the environment state data.

4 Energy Service Definition

Whether the collected data are real or virtual, they must be transformed to useful information. This requires the imposition of data processing rules that depend on the service being enacted. This transformation is performed by the EnTrak system [7] via a three stage process as follows.

As shown in Figure 6, the first stage involves the formal definition of the entities being monitored – here buildings on the Strathclyde University campus. In another application an entity might be a utility meter, a vehicle, a plant component *etc*., or any heterogeneous mix of such objects.

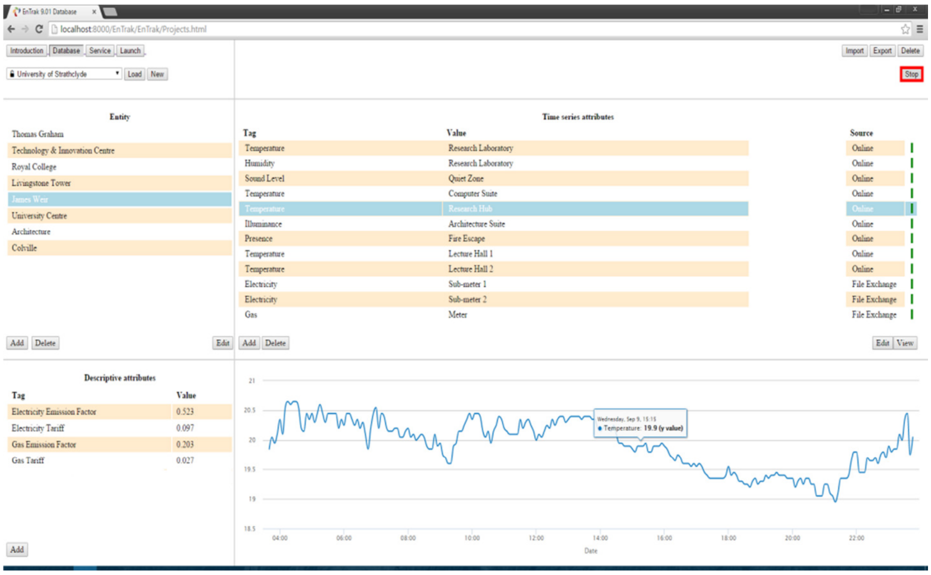

Fig. 6. Data schema definition in EnTrak.

Entities are defined in terms of descriptive and time series attributes, where each attribute is a tuple comprising a tag/value pair. Typically, attribution is restricted to only those data required to enact the targeted service, i.e. EnTrak should not be considered as a general building database system. Each time series attribute has an associate data location definition, such as collection by file exchange with a remote server or by the direct querying of monitoring devices deployed in the field, e.g. a BuildAX logger/router. The required fetch frequency is then specified per attribute and a test connection made; at some later time, usually after completion of stage 2, the overall data monitoring scheme is commenced with all data stored in a mySQL database.

In the second stage, services are established by associating actions with all or part of the data schema as required. For example, in the upper part of Figure 7 an operational Energy Performance Certificate (EPC) has been defined by applying a set of actions to electricity and gas meter readings, while in the lower portion a high temperature alert is defined by range checking all dynamic attributes with tag ‘Temperature’ and value ‘Lecture Hall’.

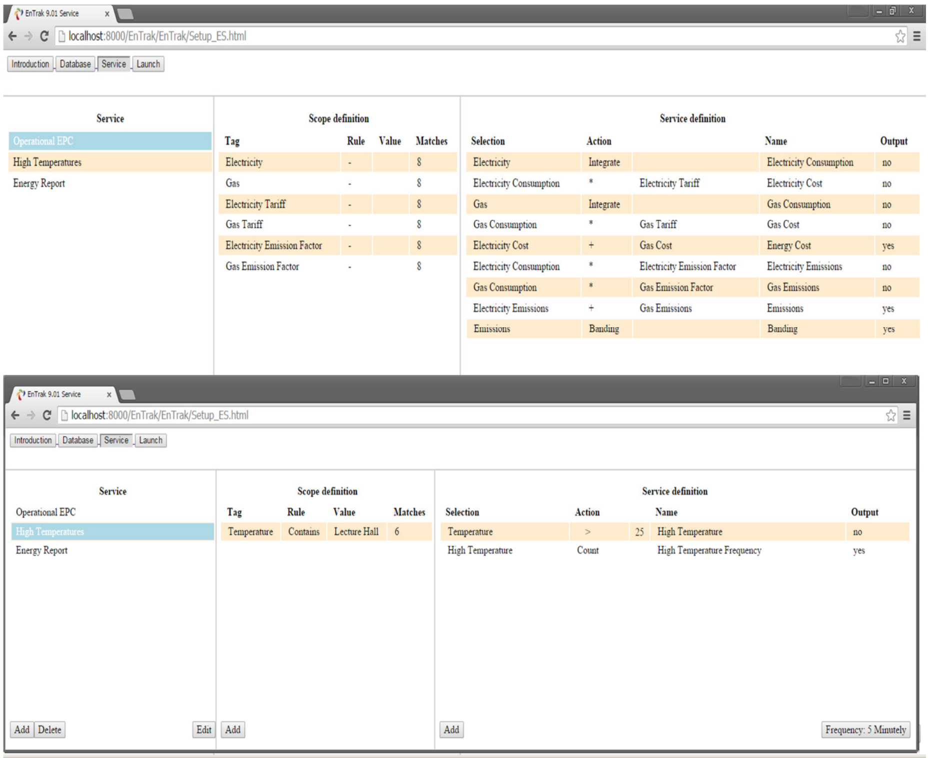

Fig. 7. Defining a service in terms of data processing rules applied to entity attributes.

In the third stage, individual services are started and run at the required frequency (e.g. monthly for the EPC service, 5 minutely for the temperature alert service). This results in the repetitive application of the stage rules to the incoming monitored data until the service is stopped. As shown in Figure 8, the final outcome is delivered as an xml file in order to support alternative delivery formats, styles and devices. In the example shown here, the final delivery platform is a smart phone app developed by a company, who are partnering the university in trial deployments of EnTrak.

To support 'what-if' studies, it is possible to replace the incoming data from field monitoring with prediction time series emanating from simulation, or to mix real and virtual data. In relation to the first service defined in Figure 7, one service may then deliver an operational EPC based on actual performance, while another service delivers a virtual EPC corresponding to some post-upgrade scenario. The difference then quantifies the potential to inform the upgrade decision-making process.

The EnTrak system, including its BuildAX and ESP-r components, has been applied to 75 homes as part of the Innovate UK Future Cities Demonstrator project [8]. Based on the monitoring of energy use, indoor conditions and weather parameters, and stock simulation to generate benchmarks, a service was established to assure the quality of insulation upgrades applied to hard-to-heat homes. Figure 9 depicts the service outcome as delivered to the housing department of Glasgow City Council.

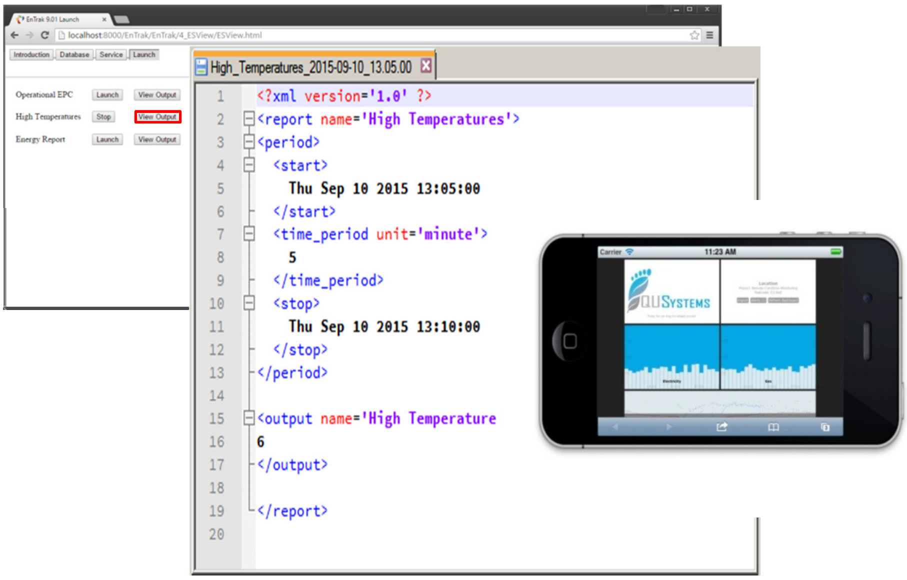

Fig. 8. A service outcome example.

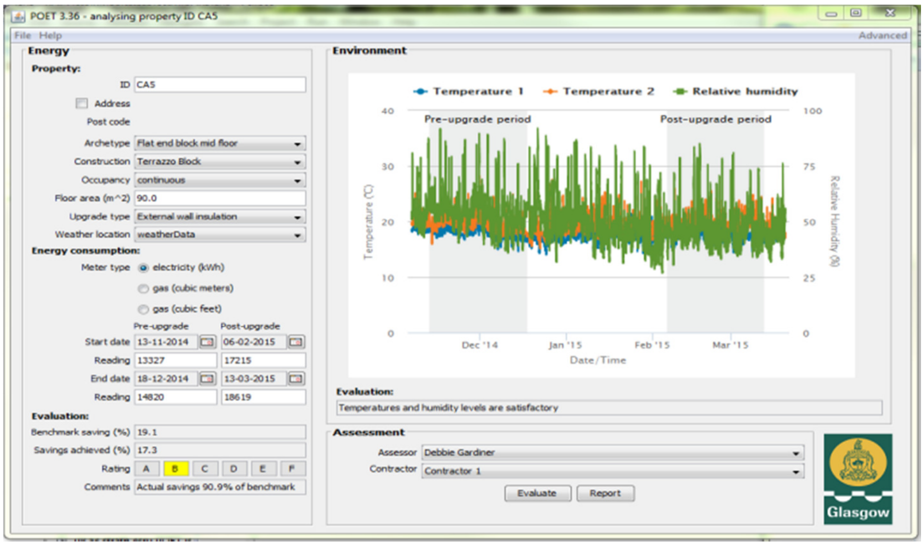

Fig. 9. A housing upgrade quality assurance service as delivered to Glasgow City Council.

Other deployments include 15 commercial buildings undertaken as part of the EPSRC's digital transformation programme targeting digitally mediated occupant negotiation in facilities management; large building stock performance reporting in support of energy action planning and policy formulation; scenario appraisal for future network resilience assessment and active network control in smart grids; and online assessment of novel building designs and systems as deployed within the BRE Innovation Park network.

5 Conclusions

This paper corresponds to a presentation on the EnTrak/BuildAX/ESP-r technologies delivered at the SmarTABCD'15 workshop on Smart Technologies and Applications in Buildings, Cities and Districts delivered at the AIAI'15 conference. The approach, as described, portends a future where the building energy management and performance reporting process is atomised into discrete services, with timely outcomes delivered to a range of stakeholders. The integration of estate monitoring and building performance simulation will allow the data analytics being applied to monitored data to be underpinned by a model of the process that delivers information on the ideal performance target. One goal of the Hit2Gap project is to evolve low cost, open hardware and highly functional simulation tools for performance monitoring, options assessment and new information delivery.

6 Acknowledgements

I am indebted to my ESRU colleagues, who have made crucial inputs to the ESP-r, EnTrak and BuildAX projects, and to colleagues at the University of Newcastle's Culture Lab, who fabricated the BuildAX devices within the above-mentioned EPSRC project.

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