The EnTrak System: Supporting Energy Action Planning via the Internet

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Abstract

Recent energy policy is designed to foster better energy efficiency and assist with the deployment of clean energy systems, especially those derived from renewable energy sources. To attain the envisaged targets will require action at all levels and effective collaboration between disparate groups (e.g. policy makers, developers, local authorities, energy managers, building designers, consumers etc) impacting on energy and environment. To support such actions and collaborations, an Internet-enabled energy information system called 'EnTrak' was developed. The aim was to provide decision-makers with information on energy demands, supplies and impacts by sector, time, fuel type and so on, in support of energy action plan formulation and enactment. This paper describes the system structure and capabilities of the EnTrak system.

Keywords: Sustainable energy, Internet-based information system, decision support

1. Introduction

Energy actions may be devised to encourage public organisations and companies to form partnerships to tackle the common problems associated with reducing energy use and gaseous emissions. A Community Energy Management (CEM) approach combines planning concepts, including complete communities and green cities, with energy management concepts such as energy cascading (e.g. recycling energy network, transformation etc), demand-side management and integrated resource planning (Jaccard et al 1997). An urban energy management scheme adopted to promote energy efficient practices within urban developments shows the significance of the partnership between public authorities and the private sector (Energy Efficiency Office 1995).

Developers and planners are likely to pay attention to the energy efficient plans defined by the energy and environment policy. Building designers often have to undertake an appraisal of the design options for new-build or refurbishment to improve the performance to a level that meets the target of the energy action. From the viewpoint of citizen involvement in energy actions, it is necessary to change the energy consumption behaviour of consumers. It is generally known that increasing consumer's energy awareness leads to reduced consumption (Wilhite and Ling 1995). Therefore, it is significant to support decision-makers at all levels in a coherent way to achieve effective aims in energy action. Various types of decision-makers (e.g. policy makers, developers, local authorities, energy managers, home occupiers etc) impacting on energy and environment issues require support to inform their decisions at different levels.

To tackle the situation efficiently, a collaborative system is needed in which data sharing and communication can be carried out. The distributed resources such as databases must be connected within an integrated network so that the partners can share these resources. In terms of the number of users and the growing bandwidth, the Internet infrastructure is expanding, and destined to become a ubiquitous communications medium. To construct the envisaged information sharing system between energy partnerships, a prototype Energy Environment Information System (EEIS) was suggested on the basis of the Internet infrastructure. The partners might contribute to, and draw from, an Energy and Environment Information System (EEIS) established to facilitate information sharing. They may then exploit remote databases or applications together with local information to support their decision-making via the EEIS.

Taking into account of the availability of Information Technology, the prototype of the EEIS has been implemented in a software package called 'EnTrak' focusing on developments in the following areas:

- o a data model and management system that accommodates extensive and multi-scale energy/environment data;
- o a user support system and analysis model

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that enables strategic and tactical decision making in a coherent manner; and

- on-line system connectivity with third party applications covering integrated energy modelling and internet-based monitoring and remote control system.

The following sections describe the data model, analysis capabilities and system connectivity of EnTak, which is an open source program available in public domain (ESRU 2004).

2. Architecture of EnTrak

The network based software technologies, such as Java, offers suitable tools to support the sharing of information and ideas among a scattered audience, and can be readily equipped with an information security system. The middleware of database interfaces, such as JDBC, allows EnTrak to manage distributed information resources. In addition, future energy service providers, who may wish to exploit advanced communication technology such as electronic gateway device may require an interface to construct two-way digital communication networks (OSGi 2004). On the basis of current information technologies, the architecture of the EnTrak system has been conceived as illustrated in Figure 2. The communication and connectivity between the components is established through system interfaces and operated via the Internet-based client-server arrangement.

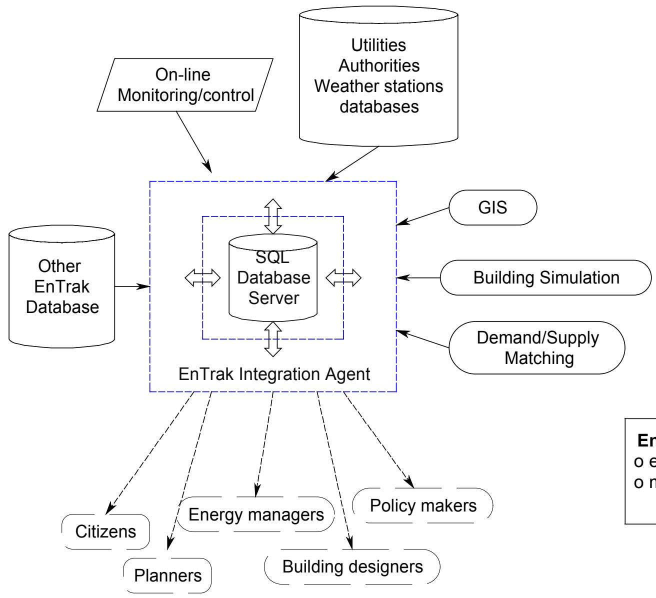

Figure 1 Architecture of EnTrak.

Data within database management systems possessed by other organisations could be collected using database connection protocols (i.e. JDBC), which contribute to large-scale energy/environment partnerships by increasing the potential for large-scale data management and connectivity to existing DBMSs. The data transmission between EnTrak and electronic data sources, such as on-line monitoring devices embedded within buildings (or energy systems), may be enabled through electronic gateway systems. The combination of electronic gateway and EnTrak could increase end-users involvement in energy actions to reduce their energy consumption and sustain comfort.

Meanwhile, user interfaces, at the front-end of server-side components such as databases and analysis tools are implemented within Web-clients or an application package to handle various user requirements. A central database can be shared by different user groups (e.g. citizens, energy managers, planners, policy makers, building designers etc) while central administration makes resource maintenance easier and securer. This multi-user interface system manages user authentication policy depending on the user level and supports multi-type users by providing different data aspect models according to the user type.

3. Data Model

The information dealt with in EnTrak is associated with energy action planning to reduce energy demand, increase the energy efficiency and alleviate environmental impact (i.e. low CO_2 emissions). The data model of the EnTrak system has been designed on the basis of the relationship between an entity, energy/environmental factors and associated events. The term of 'entity' is here a demand/supply system corresponding to the subject of energy/environment management. An entity may therefore represent a demand or supply system, which could be a building, a wind farm, a photovoltaic panel, a vehicle and so on. The information on an entity includes property type, ownership, energy systems data, constructional characteristics and geographic location.

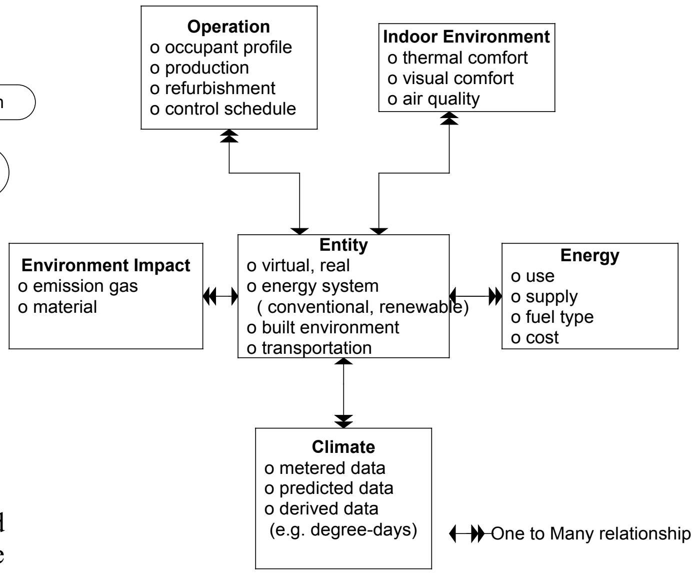

Figure 2 EnTrak Data model.

As illustrated in Figure 2, an entity, whether it could be real or virtual, has a relationship with several energy/environment events. An entity may have many metering points with different fuel types (e.g. gas, electricity, oil etc) being recorded at different frequencies. The energy information associated with the entity may contain consumption/supply data, fuel type and cost. The environment information is related to weather factors affecting the energy demand/supply of the entity, indoor climate and the gaseous emissions caused by energy consumption. Other relevant information could be extensive, including land-use, population, finance and operation. The EnTrak data model has been implemented as a SQL compliant database (Kim 2004).

4 User supporting system

While the data dealt with in EnTrak is large in terms of the potential scale and diversity, the entities of interest must be defined prior to a specific analysis. Information processing in the EnTrak is based on data comprised of static descriptors (e.g. entity type, location etc) and dynamic data (e.g. energy use, weather parameters and operational aspects). Sometimes it is necessary to track down the data domain from group level to individual in pursuit of identifying the causes of the problems discovered from higher-level analysis. It is, however, not trivial for users to understand the database and manipulate the data due to the complexity of the data with large volume and different frequencies.

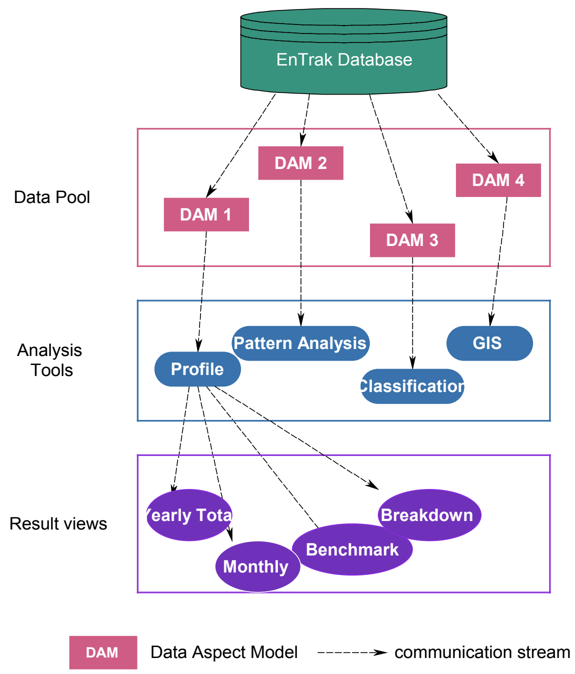

Figure 3 Portable data aspect models supporting multi-scales analysis model.

To support users to extract useful information from a data reservoir, a flexible analysis model, comprising 3 tiers (data pool, analysis tool and result view), was designed to increase portability of data aspect models and analysis components to meet the different demands from decision-makers operating at different levels (Figure 3). A data aspect model is defined by associating a scope of entities of interest with dynamic data. It will be virtually created and positioned in a buffer area (i.e. data pool tier) to be utilised by the corresponding analysis tool. This portable data handling mechanism makes it easy to manage various user requirements at different levels. It can be implemented in a coherent manner to undertake different analyses (e.g. multi-scales profiles from daily statistics to yearly statistics, comparisons of energy consumption/gas emissions over different periods). In practice, the data aspect model is facilitated by making SQL scripts when retrieving the data from the EnTrak database.

To enhance user interactivity with the EnTrak database, a scope map interface system has been developed, which offers a visual tool for users to handle scopes. Users can move from one scope of interest to another via image maps. A map model consists of scope information and a corresponding image map that has been selected to represent the scope (e.g. a regional map, a street map or a building plan).

5. Analysis Capability

In terms of analysis capabilities, EnTrak provides integrated analysis support:

- to manage large property sets as well as individual entities and to deal with a high diversity of entity types;
- to classify properties by design parameters and/or fuel consumption; and
- to predict or assess the energy performance of buildings under different conditions and to explore the savings potential of alternative design or control intervention.

As well as quantitative analysis methodologies, exploratory analysis was also adopted to support strategic energy action planning.

As a new approach to managing a large volume of energy/environment data, the 3D data visualisation model was developed on the basis of Benedikt's data spaces model (Benedikt 1991). It is aimed at:

- identifying the energy pattern within a scope of entities, which are clustered into several sub-groups according to entity types;
- discovering the problematic entities in each group as entities drifting away from the predominant pattern; and
- perceiving the energy patterns of each group and diagnose questionable phenomena.

The pattern-based assessment of energy actions will give decision makers a good insight into the overall energy performance and the effectiveness of energy strategies.

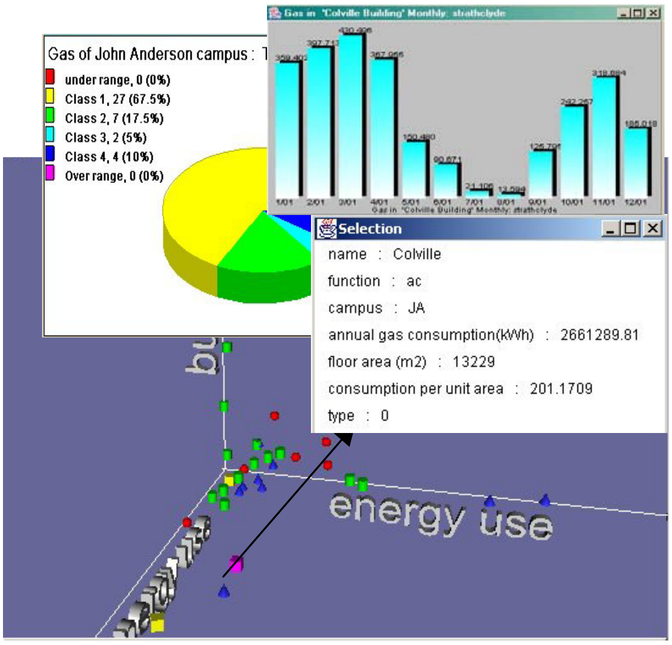

Figure 4 Integrated analysis support by EnTrak in coherent manner.

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Combining these quantitative and qualitative analysis techniques, integrated energy reports are supported by EnTrak in coherent manner. For example, as illustrated in Figure 4, while the energy classification of a scope, the energy pattern of the scope is also found in the 3D data visualisation model from which a problematic entity can be traced back. Strategic decision-makers identify problematic phenomena by looking at the patterns before they focus on a group of data to find possible causes. High-level managers will require such information to assess overall performance and respond to questions relating to sustainability. The information is likely to have long-term based and aggregated data. The report is dedicated for setting energy policy for the next year. To fulfil the policy, high-level decision-makers will consider both technical (e.g. system refurbishment) and non-technical measures (e.g. motivation, marketing etc). Taking technical approaches to improve energy efficiency, they would identify specific problems quantifying the phenomena for tactical purposes using dedicated statistical analysis techniques.

Eventually, the analysis capabilities in EnTrak can be applied strategically, to establish broad policy, and tactically, to investigate particular design and operational changes. They allow users to make use of scenario-based planning, energy appraisals, environmental impact assessments, renewable opportunity identification and so on.

6. Interoperatible system connectivity

A number of modelling techniques, including detailed building simulation, renewable energy systems modelling, statistical models and GIS models, are often involved in decision-making for energy planning (Clarke et al 1997, Fragniere et al 1999, Sorensen et al 1999, Jones et al 2001). In practice, such modelling techniques cannot be effective unless decision-makers possess the necessary expertise and access to reliable input data. It is possible to integrate distributed information resources within EnTrak in order to set up a collaborative decision-support system.

Combining GIS spatial data and EnTrak energy/environment data enables more effective sustainability appreciation and intervention. While coupling with GIS allows the automatic interrogation of spatial data in support of strategic decision-making involving a broad geographic area, the energy simulation package can support data generation for future options appraisal or virtual metering.

Meanwhile, in order to make interactive operation with monitoring/control systems, EnTrak operates electronic data transmission between devices and servers (e.g. database, data transaction etc). As Clarke et al (2004) presented, integrating monitoring/control systems and simulation packages in an on-line information system will bring new capability to energy demand/supply management by allowing real-time operation based on high quality data and sophisticated modelling techniques. Establishing the electronic communication, EnTrak not only obtains real data supply channels but also controls circumstances in a comprehensive way.

Consequently, the system connectivity within EnTrak will permit the following capabilities.

- The integration of virtual and real data in real-time by combining such entities in a consistent model.
- High resolution and high quality data: large volume energy/environment data may be monitored at high frequency through electronic data channels with no human intervention.
- Concurrency of strategic, tactical and operational decision-making. By sharing monitoring and control channels with various decision-makers in real time, problems may be rapidly detected and rectified.

Ultimately, coupling with modelling packages and Internet-based electronic communication systems will enable a deepening of the quality of the information available in estate performance and options for change.

7 Application: GIS-based urban energy planning

To evaluate the impact of energy actions and help in the planning of new energy strategies from a city viewpoint, a GIS-based urban energy model was used for the identification of energy demand profiles and prediction of the impact of scenarios concerning the adoption of renewable energy sources. In constructing the urban energy model, extensive data are required (e.g. land use, building types, ownership etc), and the capabilities of the model depends on the resolution of the data available. This case study considers how high resolution data may be established, and demonstrates the outcomes of the GIS-based urban energy model.

Figure 5 illustrates the data connectivity and procedure for the GIS-based energy map model. The process model is based on the portable data aspect model described in Figure 3. The data connectivity is constructed with a data aspect model, a GIS model and map views. Firstly, to create the data aspect model, the entity data and energy-environment data are defined by selecting data from the EnTrak database and registering these data as a data source in the data pooling tier. The entity data and the energy/environment data are then joined into a virtual table of the data aspect model. This virtual table is then used as an entity attribute containing the geographic position data such as x y co-ordinate data or post code.

The GIS model is defined by linking the entity attribution to geographic features implemented in a spatial data model (e.g. coverage, grid). A GIS map model consists of several layers of the attribution and the spatial data models. Accordingly, the map view manager of the GIS application organises various map views using the entity attribution and the spatial data model.

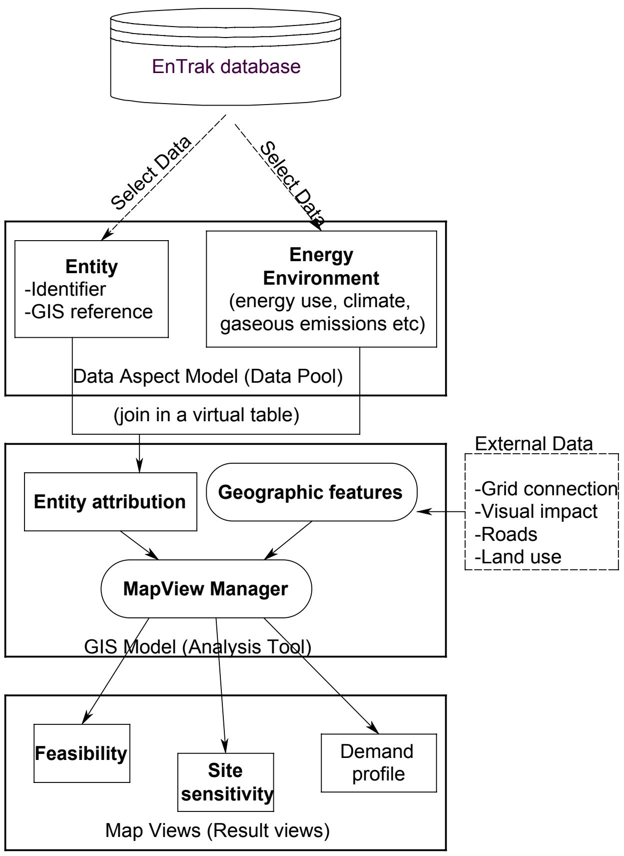

Figure 5 The data connectivity and procedure of GIS-based energy data views.

The data on properties in an urban area in Glasgow city, were extracted from the City Council's corporate database where the information is held for use in connection with tax and electoral registers. Most of the buildings in the urban area are either commercial or domestic properties. There are 7,311 properties, mostly domestic, classified into 18 architectural house types. Most of these data contain geographical co-ordinates, address, property type, ownership, letting type, house size etc (see Figure 6).

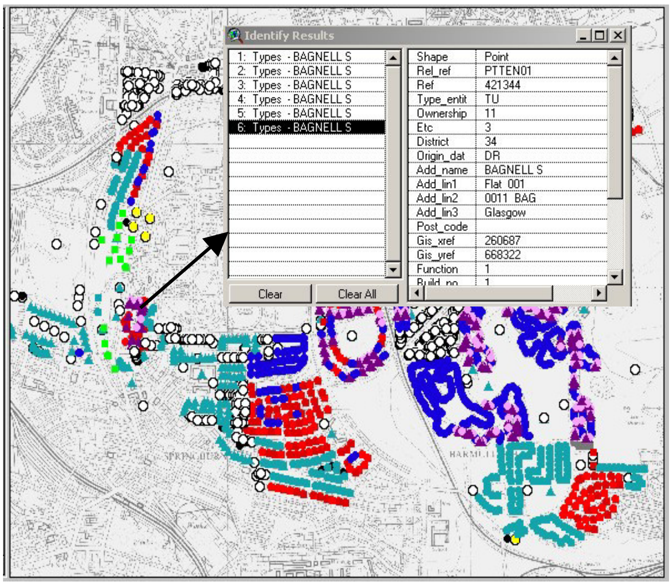

Figure 6 Distribution of properties according to property type.

In terms of energy data, it is hardly to collect real energy data for all properties due to data confidentiality constraints. The local Council has no right of access to data for individual properties in the private sector and only a small part of the estate (less than 1%) is owned by the Council. To overcome the problem, a scrambling mechanism was adopted (Evans 2000). The utility companies supplied electricity consumption for groups of properties (typically 10), but scrambled to prevent the data being associated with a specific household. Through the scrambling algorithm, it was able to create virtual data assigned to each property. This technique permitted adequate database resolution while overcoming issues of data confidentiality.

The energy map views created by the GIS application linked to the EnTrak database display the distribution of The properties in the area were classified on the basis of their annual total electricity consumption. The result is displayed on the energy map view of Figure 6. The per-apartment, normalised energy consumption was then calculated to assist with the detection of problematic properties. 'Poor' or 'bad' properties, so-called high energy spots, are then readily recognised on the map view.

The feasibility of Combined Heat and Power (CHP) was now assessed street-by-street on the basis of the distribution of the heat-to-power ratio. Figure 7 shows the feasibility classified into 5 levels: excellent, good, fair, poor and bad.

Figure 6 Classification according to normalised energy use.

Figure 7 the feasibility of CHP.

While the identification of energy demand profiles at the street level is significant for sustainable development, the reliability of the result from such analyses depends greatly on the data accuracy. Unfortunately, the availability of real data is inevitably limited unless all properties are monitored: and the collected data made widely available. At present, it is impractical to collect energy data for all properties. Conventional monitoring and targeting tools have failed to overcome this barrier. The Internet-enabled approach of data collection represents one possible solution because such a massive monitoring operation can be implemented with low cost. The following section will describe the possibility of the Internet-based data collection cooperated with the EnTrak system.

On other hand, virtual prototypes are still useful for scenario-based urban energy planning, which will require that algorithms for virtual data are reinforced and agreed by the industry. The reliability of the virtual prototype approach may be improved by adopting building modelling. A detailed simulation program can be used to create typical building types in a local area. For instance, house types may be classified into detached, semi-detached, mid-terrace, multi-storey apartments and so on and endowed with representative constructional attributes. In addition, statistical information based on real but limited data can be used to refine the prototype models by associating it with non-building elements (e.g. occupancy) and providing calibration data to refine and prove models before use. The predicted energy data attached to the prototype models is both realistic and dynamic. Once a reliable database has been established, comprising real and virtual entities, the impact of new energy efficiency strategies (e.g. adoption of renewable energy system such as photovoltaic pannels) may be studied by simply replacing the prototypes.

Although planning procedure requires various considerations and extensive information, high level decision-makers such as policy makers and energy managers can be provided with appropriate decision-support on demand by combining in-house information resource (e.g. virtual/real entities, energy data) and external information (e.g. landscape, road, environmental policy etc) via The EnTrak system. As the internal (e.g. energy management database) and external (e.g. Planning Department's database) resources are integrated via the Internet, update of information in external resource (e.g. new roads, change of policy) can be easily accommodated an input to the planning process. This gives decision-makers significant advantage in handling strategic approaches as well as routine-based energy management.

The outcomes of the EnTrak analysis facilities can lead decision-makers to identify problematic entities that can then be investigated in more detail before deciding on remedial action. Once such action has been implemented, the impact becomes immediately known due to the real-time nature of the decision-support tool.

8 Application: on-line energy service

The architecture of a prospective on-line energy service system was constructed by combining the monitoring/control devices, the OSGi compliant e-service system (Gatespace 2004) and the EnTrak system as illustrated in Figure 8. A gateway-based monitoring/control system comprises a residential gateway system, called 'e-box', sensing/actuating devices with a base station to monitor energy/environment data (e.g. temperature, humidity, movement, CO, power etc), and to impose actuations (e.g. switches). The role of the e-box is here to serve as a bridge between monitoring/control devices and the e-service system located remotely over the Internet. The data communication between the e-box and the e-server centre was implemented through the secured SMTP on the basis of the OSGi platform. The e-service centre controls all communication with the distributed e-boxes. It receives data from the e-boxes and passes it to the EnTrak database server, which makes them retrievable to supply data aspect models for front-end energy service providers.

efficient control actions (e.g. issuing alert messages);

Once the on-line energy service is built, it may be used to more effectively engage citizens in energy and environment issues. By increasing the awareness and motivation for energy saving, for example, it is possible to involve citizens in local energy actions.

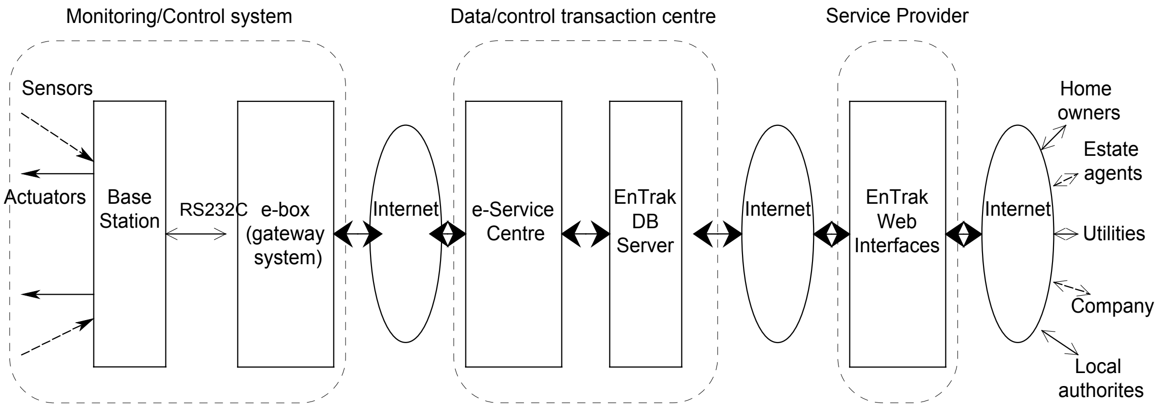

Figure 8 Infrastructure for on-line energy service.

The energy service providers offer different products according to the requirements of end-users who may be utilities (e.g. automatic meter reading, demand/supply control), home-owners (e.g. remote home appliance control, health and safety), local authorities (e.g. large scale data management, sophisticate analysis commissioning), or companies (e.g. gas trading information). To implement their own service, the Web service systems request data aspect models from the EnTrak database server using the SQL database connectivity. The service provider possesses functionalities that enable it to:

- offer analysis tools (e.g. modelling programs, GIS maps etc) with properly aggregated data;
- broadcast the relevant information to subscribing users; and
- provide end-users with interfaces for monitoring and control.

Based on this network infrastructure, the full-scale operation was achieved by deploying a number of e-box monitoring/control devices in the field. This field deployment was undertaken as part of an EC project, ‘On-line Energy Service for Smart Homes’ (EnerBuild RTD 2004). The field test was initiated to investigate the ability to handle large-scale monitoring/control issues:

- robustness in long term operation;
- performance affected by network traffic congestion;
- database capacity in manipulating high frequency monitoring data ; and
- interactivity with proper response time for

By supporting comparisons with benchmark data formed from similar property types, a competitive element may be introduced that has been observed elsewhere to drive down consumption. Comparative analysis such as classification, performance ranking etc, within the same category (i.e. similar type houses, same area), may indicate poor/good performers. This does not mean that the data should be open to the public. Benchmark tests can be conducted to locate the best performing properties. The outcome does not need to be identified thus preserving confidentiality. Limited data access by authorised personnel could be permitted by new legislation. Alternatively, a market mechanism might be introduced that gives customers an energy discount in return for sharing their energy data.

By integrating an e-service system within EnTrak, new types of on-line energy services are realisable with the following benefits.

- High quality and high resolution energy/environment data can be collected via secured communication streams.
- An aggregated information can be provided in real-time, which can be used to control an entity (e.g. demand control according to collective load trends).
- Monitored data (e.g. micro-climate data from a local weather station) may be broadcast to all clients in the service network in real-time.
- The interactive demand/supply management will be possible in a micro-grid where the monitoring/control systems are installed, and appropriate control algorithms (e.g. switching supply channels according to demand profile) are deployed.

Delivering information based on up-to-date energy data is the prerequisite of future 'energy alert' actions. Significantly, poor performance can often be identified by just observing real data in real-time and comparing trends to acceptable benchmark data or historical trends. Experienced personnel can then be dispatched to investigate problems and devise plausible solutions without delay. The EnTrak system has demonstrated the potential of such an information management system to deliver essential data in real-time and allow users to observe property performance in support of their decision-making.

8. Conclusion

The requirements of EnTrak are that it can integrate data from a variety of sources and distribute information via the world-wide web. The EnTrak system is equipped with a consistent analysis system corresponding to various decision-making levels, from large-scale exploratory analysis to specified analysis. The applicability of EnTrak was tested using real data collected at different scales and being employed in the field study of on-line energy service. The outcomes from these analyses demonstrate the potential for global support for decision-making at all levels.

Using EnTrak, it is envisaged that a collaborative system for sustainability between citizens, organisations, professional groupings and utilities can be established on a real-time basis. Such a system will enable a global analysis based on aggregated data derived from the on-line integration of distributed databases and allowing two-way information flow between decision makers and with the entities being managed (e.g. remote control of demand). Most importantly, such an on-line collaborative system can be implemented at low cost by utilising the rapidly growing Internet infrastructure.

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