More than **bricks** and **mortar**

Dr Oliver Amft and colleagues – **Dr Paul Shrubsole** and **Dr Alexander Lazovik** – describe how the GreenerBuildings system uses cutting-edge ubiquitous technology and a bespoke processing framework to reduce the energy consumption of office buildings large and small



To begin, can you provide a background to GreenerBuildings by explaining the inspiration behind the project as well as your main vision?

OA: Buildings are typically designed once and used for several decades. However, occupant usage patterns change over time. With today's quickly changing business, office buildings need to be more adaptive in order to conserve energy and improve comfort, and hence productivity.

GreenerBuildings is based on the idea that the activity and behaviour of office workers are key inputs to advanced use-dependent control of buildings. We investigate distributed user behaviour inference using ubiquitous sensors and develop a processing framework to support dynamic control of appliances, lighting and heating/ventilation systems corresponding to sensed use patterns. The framework considers occupant preferences and incorporates existing building maintenance rules.

What role do you have in the project?

OA: Besides the overall project coordination and management, and interaction with consortium partners, my research group is responsible for activity recognition and inferring human behaviour in buildings using ubiquitous systems. Activity and behaviour inference is at the core of the GreenerBuildings' proposition to conserve energy and create comfortable office environments.

Can you describe the energy-aware framework developed by GreenerBuildings?

AL: Office buildings range from a few rooms to complex systems with hundreds of office, meeting and complementary rooms containing controllable equipment and appliances. All of these rooms are relevant to the behaviour inference and dynamic use-dependent control targeted by GreenerBuildings.

We have developed a service that incorporates components for ubiquitous low power sensing; sensor-based human activity recognition; optimisation goal control and composition; and device orchestration, to guarantee responsiveness, scalability and dependability. To save energy (without compromising user comfort) we apply logic- and artificial intelligence (AI) planning-based techniques, taking into account available context information, user activities, utility and cost of particular building services.

How would you define the key to effective energy management in buildings?

OA: There are three areas that contribute to office building energy management: materials and building construction; energy-efficient equipment; and intelligent control. ICT-based solutions as provided by GreenerBuildings can contribute to the latter two.

How will GreenerBuildings improve energy efficiency?

OA: GreenerBuildings focuses on intelligent automation using occupant activity patterns and behaviour information that was previously not considered or available due to lack of sensors and processing algorithms.

By deriving behaviour patterns at each desk and room, building services (such as equipment and appliances) can be controlled according to actual needs rather than assumed ones. Office desks and rooms have a recurring set of sensors, office appliances and installed equipment, such as presence detectors, desk and overhead lighting, computer screens and so on. Therefore, control based on occupant activities and behaviour can be replicated for every desk, room, floor, etc.

Nevertheless, control remains individual and dynamic through user input and sensor readings. This distributed concept of standard desk and room types enables the GreenerBuildings architecture to scale-up to large office buildings.

How can you dynamically adjust buildings to improve efficiency?

OA: It's often assumed that operational office buildings require a constant energy supply. However, usage is not constant and thus building services could be dynamically adjusted. We consider that optimal dynamic energy management depends on context information comprising dynamic space usage (eg. the people count presently occupying a building space), office activities (eg. actual use of computer screens) and environmental conditions (eg. natural desk lighting). In contrast, current office building adjustments often consider occupant motion only and building energy management systems operate based on fixed rules and weather conditions.

GreenerBuildings innovates by acquiring a holistic view of a building, each building space and individual desks. In particular, fine-grained information on usage and office activity enables us to optimally adjust building services for every second of operation.

In what ways is the GreenerBuildings system architecture evaluated?

PS: GreenerBuildings adopts the concept of living laboratories, in which technology and the framework are evaluated in real-world conditions. We consider both a quantification of energy saving and an evaluation of comfort that can be achieved through activity-aware building control. In the quantification of energy, we consider occupant presence and energy needs for lighting, heating-ventilation-air conditioning (HVAC) and office appliances.

In parallel, user experience is assessed through general and use-dependent questionnaires in combination with usage statistics of manual overrides. For example, we study how occupants rate the current living laboratory building at baseline and whilst using the living laboratory meeting room by specifically designed questionnaires.

Minimising energy waste is key. How will you go about doing this?

AL: Unlike traditional rule-based systems, we take into account energy consumption of available building devices and minimise consumption if there is no rule activated. From a basic rule, eg. ‘if there is someone in the room and if dark, turn on lights’, the system will infer that lights should be off when nobody is present. In the context of a whole building, with many activity-dependent interrelated rules, the energy saving potential is enormous.

We have developed several other composition modules, targeting possible aspects of building automation. For example, a scheduling component takes into account future energy prices by scheduling long-running operations (eg. heating) to optimise overall building maintenance costs. A computational fluid dynamics (CFD) component takes care of optimal heating/cooling to optimise user thermal comfort and minimise energy consumption.

In practical terms, how does the system work?

AL: GreenerBuildings uses principles of web service-based architectures. Web services can be used to build distributed applications by combining the functionalities of already existing software modules. The GreenerBuildings web services can be provided by different manufacturers and distributed across different computational units for robust operation. Since interoperability and scalability are key requirements for the GreenerBuildings framework to operate in large-scale office buildings, web services are thus an optimal choice.

Could the GreenerBuildings system be applied in older buildings?

GreenerBuildings is meant to retrofit existing buildings as well as to leverage facilities in new ones. We envision that the GreenerBuildings framework will interact with traditional building management systems by providing complementary user- and activity-aware control options.

Do you envisage energy management in buildings changing in the future?

PS: We believe building management systems will become more and more intellectual property-based and will interact much more with business ICT (enterprise) software systems. The GreenerBuildings framework is designed to fully exploit this technology convergence and will potentially impact the way in which comfort and energy services can be gracefully deployed to coexist with current and future building management systems.

Large-scale networks of intelligent collaborating devices are the primary means to realise the GreenerBuildings framework. Many such device networks already exist in modern or refurbished buildings and interlink presence sensors or thermostats. Thus, the GreenerBuildings framework can be readily applied in these buildings.

GreenerBuildings is a large, multidisciplinary project – what challenges has this collaborative aspect posed?

OA: To investigate new ideas, specific expertise from various disciplines must be combined. This is exactly the case for the EU Seventh Framework Programme (FP7)-funded GreenerBuildings project, where key know-how in human activity recognition and behaviour inference, web technology, artificial intelligence, embedded systems and user experience analysis, are combined with expertise in building automation, thermodynamic modelling and performing large-scale evaluations.

Will GreenerBuildings have an impact on society and the environment?

OA: We hope that the concepts and further versions of the GreenerBuildings framework will be operating in office buildings in the future to help optimise energy consumption. Any overall reduction of energy waste will help to reduce greenhouse gases.

What are the prospects for further research?

OA: The GreenerBuildings consortium is on track to achieve its targets for 2013. Of course, there is a host of ideas and scientific analyses that will remain for the future. The established GreenerBuildings living laboratories will be operational beyond 2013 to help evaluate new ideas and technical systems.

Through Horizon 2020, we seek options to pursue long-term technology studies of the GreenerBuildings solutions and follow-up innovations.

Green **offices**

As energy costs spiral and organisations look for ways to reduce them, researchers in The Netherlands are hoping that an intelligent building management system – which understands and learns from human behaviour – could be the answer

THE WORLD IS in the midst of an energy crisis, with spiralling oil prices now a reality rather than a threat. Global demand for energy continues to grow apace, with China and India requiring an ever greater share of the available resources. Coupled with the continued turmoil in oil-producing states affecting the supply of oil and natural gas, it is no wonder that the domestic cost of energy increases every year, outstripping the rate of inflation. This increase in costs is, in turn, putting an increasing strain on businesses of all sizes – particularly those with large office spaces.

Currently, most modern offices already have some sort of building energy management system (BEMS) in place which, through a series of pre-programmed rules, scenarios and parameters, aims to control conditions, limiting the amount of energy used. Such rules can include maintaining a constant temperature or switching off lights when no movement is detected for a certain amount of time.

Current BEMS systems do not consider office worker behaviour and thus have limited options to balance energy and comfort needs. In an effort to create new building adaptation solutions that support current BEMS, a European consortium came together for the project GreenerBuildings to develop a framework that, rather than following pre-defined rules triggered by individual sensors, is able to understand and learn from the world in which it operates. The GreenerBuildings team is working to create a 'breathing' building in which energy saving is part of its makeup.

WORLDWIDE CONCERN

Heating, lighting and the maintenance of buildings account for around 40 per cent of the world's energy consumption and are responsible for large amounts of CO_2 emissions. So-called 'green' buildings – those which are designed with energy-saving features and functions – are gaining popularity but, for organisations in older buildings or those without such technological advancements, access to efficient building management solutions is currently limited.

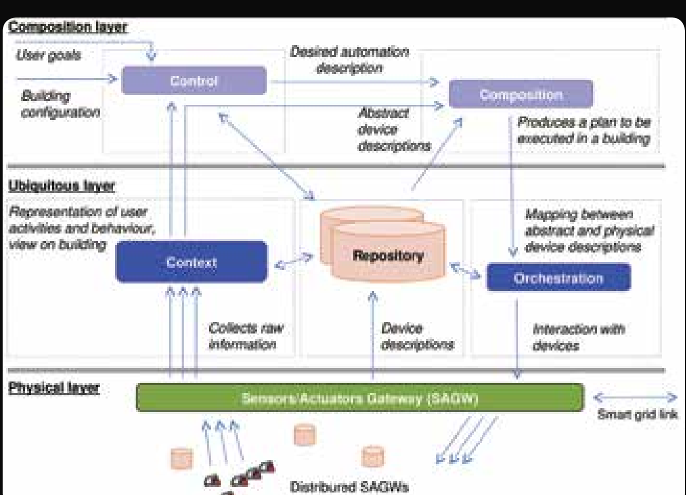

Illustration of the GreenerBuildings system architecture partitioned into physical, ubiquitous and composition layers. Each layer hosts components that interact through web service-based techniques. The architecture can be adjusted to fit new and refurbished buildings of various demands.

The GreenerBuildings project began in 2010 as a consortium of both academic and business organisations in Europe and beyond. The team, funded through an EU Seventh Framework Programme (FP7) award, is tackling the problem in a new and innovative way – marrying diverse features like human activity recognition, artificial intelligence, thermodynamic modelling and much more to create new solutions to this perennial problem.

CREATURE COMFORTS

Technological advancements have made sensors for light, heat and many other modalities now cost-effective to install in large numbers. The GreenerBuildings system relies upon such unobtrusive sensors to gather detailed information about human behaviour in the office environment. By processing sensor data, the system develops something the team describes as 'context awareness' – essentially, the ability to recognise, record and learn from patterns of human behaviour over a period of time, and thus manage the building's energy requirements.

Once implemented, the system is capable of managing various aspect of a building's energy usage, depending on available sensors and actuators. For example, there are sensors that can detect the levels of natural light and worker activity at an office desk and either increase or reduce the amount of artificial light according to work-related demands; continuously maintain the temperature and ventilation of rooms based on an understanding of how many people are present in the room; and switch off monitors the minute a human walks away from the screen.

A TAILORED APPROACH

GreenerBuildings works on three distinct levels: the physical layer, the ubiquitous layer and the service composition layer. The physical layer is concerned with the placing of sensors and actuators within the office environment. The ubiquitous layer manages sensor and actuator information flows, and infers human behaviour and context information. Finally, at the composition level, the system activates rules to control actuators based on the novel context information provided from the ubiquitous layer.

The system itself works remotely and, aside from the physical sensors and actuators required to provide information and control the building, is entirely virtual. The software is accessible from any networked computer and is programmed to manage a building in terms of individual units, or 'cells'. Each building is broken down by the system into these individually defined cells, with their own distinct properties. These could be rooms, a floor or a whole wing. The system monitors and learns about individual cells and manages their energy consumption according to momentary needs.

THE LIVING LABORATORY

Interoperability – the concept of many systems interacting and working together to fulfil a common goal – is key to the GreenerBuildings initiative, as is the robustness of the developed framework. To examine and refine the system in real-world conditions, a living laboratory at the Potentiaal building on the TU Eindhoven campus has been created. Fitted with sensors, actuators and a variety of technologically advanced equipment – the majority of which the team is confident will find their way to the next generation of office spaces – the researchers are able to explore how the system reacts to the unpredictable behaviour of its human occupants.

Perhaps more importantly given the aims of GreenerBuildings, the investigators are able to monitor and measure the energy efficiency and resulting savings. In the first round of results, the GreenerBuildings system has saved upwards of 50 per cent in computer screen energy costs – a significant saving which will have many organisations around the world keen to see where the project leads.

The living laboratory concept also enables the team to gather feedback from actual users, all of which can be incorporated into the system itself. Interestingly, this concept allows them to examine and document how the system – and the building's inhabitants – respond to differing energy management models. For example, parameters set to prioritise the comfort of inhabitants can be changed to make energy saving (and therefore cost) more important.

The system allows the researchers to test the balance between the two. In real life, reducing the temperature of an office by a few degrees could equate to huge savings, so the GreenerBuildings collaborators are keen to find the right balance. Once operational, each individual organisation can select the balance between economy and comfort through appropriate user interfaces.

GREEN FUTURE

The application of the concept and system in practice is surely of great interest to customers across the world, with its development already positively influenced by the involvement of partners like the Taiwanese Industrial Technology Research Institute (ITRI) and Philips Research. One of the most encouraging aspects in terms of commercial application is that the system and sensors can be cost-effectively retrofitted into older buildings.

By the time the project finishes in late 2013, it will be clear that GreenerBuildings is an innovation where all are winners – businesses will save money and workers will get a responsive and comfortable environment which is likely to improve productivity. The ultimate beneficiary though is the planet, with systems such as this saving its precious resources. In the future, we may all be working in a GreenerBuildings office.

The GreenerBuildings system relies upon unobtrusive sensors to gather detailed information about human behaviour in the office environment

GREENERBUILDINGS – AN UBIQUITOUS EMBEDDED SYSTEMS FRAMEWORK FOR ENERGY-AWARE BUILDINGS USING ACTIVITY AND CONTEXT KNOWLEDGE

OBJECTIVES

To investigate distributed user behaviour inference using ubiquitous sensors and develop a processing framework to support dynamic control of appliances, lighting and heating/ventilation systems corresponding to sensed use patterns in buildings.

PROJECT PARTNERS

Eindhoven University of Technology

University of Groningen

Sapienza Università di Roma

Consorzio Interuniversitario Nazionale per l'Informatica (CINI)

Fluid Solutions - alternative srl

Philips Research

Advantic Sistemas Y Servicios SL

Taiwanese Industrial Technology Research Institute (ITRI)

FUNDING

EU Seventh Framework Programme (FP7)

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DR OLIVER AMFT's research focuses on pattern recognition and machine learning applied to activity recognition and human behaviour inference from ubiquitous sensors. He is an assistant professor leading the ACTLab research group at TU Eindhoven and also a senior research advisor at ETH Zurich. Amft has co-authored more than 70 scientific papers on activity recognition and leads several national and European projects in this field.