Better building efficiency

Dr Alexandre Nassiopoulos explains how his project is working to reduce the environmental and economic impact of heating and ventilation in buildings by predicting weather conditions and the behaviour of inhabitants.

Could you offer a brief history detailing the motivations behind your project Prediction and Intelligent Control using Simulation and Numerical Optimisation (PRECCISION)? What are the main aims and objectives?

PRECCISION was imagined and set up due to the observation that new or retrofitted buildings do not often meet the energy performances that they are expected to. The more the design aims for high performance, the more the interactions and coupling effects between the building, its environment and the conditions of use are important. PRECCISION aims to provide tools that will improve the energy management of buildings in order to maximise the thermal comfort they provide while minimising consumption.

Your project is a collaboration with several academic and industrial partners. How were they chosen and what expertise have they brought to the research?

The partners were chosen based on their scientific excellence in order to gather within the consortium all the technical skills that are necessary for the project. The consortium brings together building physics specialists (MINES ParisTech, University of Bordeaux, CEA-INES, IFSTTAR), a company specialised in multiphysics systems modelling (Siemens PLM); two teams that develop simulation and optimisation tools for thermal and electric systems (Grenoble INP); the start-up Vesta-System, which specialises in software solutions for energy system optimisation; and the company Delta Dore, which produces hardware solutions for building energy management.

Why is it difficult to design energy management systems that take into account the interactions you cite?

The interactions between the various building components (envelope, heating, ventilation and air conditioning (HVAC) systems, etc) and their environment cannot be intuitively assessed. In the project, we try to actively maximise a building's efficiency by continuously monitoring the various energy transfers and computing an optimal strategy based on predicted weather forecasts.

One needs sensors deployed in the field to monitor energy transfers, but the number of sensors one can deploy in a building is limited. One also needs to know the building's characteristics (e.g., material properties). Not only are these rarely known, but a building's state is also always changing due to weather variations and unpredictable occupants' behaviour. It is therefore necessary to use a numerical model in order to complete the information gathered by a very limited number of sensors and to obtain what is called a calibrated simulation model (i.e., a model that is able to accurately predict actual thermal behaviour under some given conditions). Last but not least, optimal strategies have to be calculated quickly on a small computer.

Can you explain this method in more detail?

The whole methodology is based on both hardware and software. First, some sensors are deployed in the building to provide temperature and energy consumption measurements. At regular intervals, these data are collected on a home- or web-based server that also collects weather forecasts for the next 24 hours. The server then tries various control strategies for the HVAC systems and other controllable devices (e.g., automated solar blinds) and computes the building's thermal behaviour for the next 24 hours for each of these strategies. The strategy that gives the maximum thermal comfort for the minimum consumption is chosen. Finally, the server sends back to the building the commands required to prescribe this optimal strategy.

In what way is your energy management system self-learning?

Computation of the various control strategies is based upon a numerical model that predicts thermal behaviour under some given weather and use conditions. The accuracy of this numerical model depends on the knowledge of building characteristics, which is extremely poor in general. Before computing optimal control strategies, the system passes through a configuration period in which it uses data from sensors in order to determine these unknown building characteristics.

Two years into the three-year project, how close are you to reaching a conclusion?

The main theoretical aspects of the work have been studied. The first tests on real buildings were launched at the end of 2014. The third year will be mainly devoted to analysing experimental results and on the refinement of the various tools that were developed.
PRECCISION
heating and cooling

The French-led PRECCISION project aims to harness the power of numerical modelling to make heating and cooling systems in buildings smarter and more efficient.

AS A GAUGE of the importance of buildings to the European economy and citizen’s wellbeing, the construction sector is the largest single activity and biggest employer in Europe, and buildings consume a staggering 40 per cent of total EU energy and generate 36 per cent of greenhouse gases. Recognising these facts, the EU, through its series of Framework Programmes for Research and Technological Development, and individual Member States have long funded projects that aim to improve the efficiency of both new and old buildings.

One collaborative project – Prediction and Intelligent Control using Simulation and Numerical Optimisation (PRECCISION) – is exploring new solutions to the energy efficiency challenge by focusing on energy management systems in high-performance buildings. The objective is to define optimal building management strategies that ensure the best thermal comfort to occupants without deteriorating the actual performance of the building. To achieve this, constant adaptation based on advanced numerical modelling to changing use, environmental conditions and even variables such as energy price or CO₂ emissions associated with energy use, allows a prediction of a building’s future state and therefore the intelligent control of its current ecosystem.

ACADEMIA MEETS INDUSTRY
The three-year, €2.5 million PRECCISION project began in January 2013 as a joint academic and industrial venture partially funded by the French National Research Agency (ANR). In order to accomplish their ambitious goal of predictive control, project partners looked to design optimal control techniques to actively maximise building efficiency through smart heating, ventilation and air-conditioning (HVAC) systems. To achieve this, the team has developed a model of the controlled system and an optimisation process based on a cost function. Taking three experimental buildings as case studies, the researchers created predictive command laws whereby future conditions can be anticipated and thus energy output minimised and thermal comfort maximised.

Ultimately, the model will be used as part of a building management system (BMS) on new builds and significantly renovated or retrofitted buildings. BMSs use data about the current state of a building to control how the systems within the building act. There are several methods that can be implemented in a BMS, including proportional-integral-derivative (PID) controllers and model predictive control (MPC). In PID, an error value is calculated between what the desired point and actual point are and then the controller achieves the desired point by acting directly on the system’s command. For instance, in a simple standard thermostat, the actual temperature is below the desired temperature, so the radiator is turned on (the variable is manipulated) and the room warms. In MPC, a numerical model of the system and a prediction of its future states are known prior to any changes of variable. Then a model predicts how the system will evolve and computes the best command law acting not only on one unique system, but on all building systems simultaneously: the building’s global behaviour is taken into account. Hence MPC actively optimises efficiency over time instead of simply reacting to current conditions. MPCs are desirable because they are more efficient, but they are harder to implement because they require an accurate model and predictions of what will be asked of the system over time.

MODELS OF EFFICIENCY
PRECCISION participants have developed various MPC strategies that take into account how comfortable the temperature is for inhabitants as well as power consumption, while predicting future energy needs. To achieve accuracy in their model, the team has implemented a calibration phase where key parameters of the specific building are identified; for instance, the walls, floors and how they transfer heat have all been characterised for the case studies and inputted into the algorithm. This so-called calibration phase is crucial because the model quality depends upon the building’s characteristics, such as its insulation level, whether it has an unheated attic and the properties of the materials from which it is built. For instance, cement floors act as heat sinks while hardwood or carpeted floors tend to remain warmer. The size and shape of the building’s rooms will also have a large impact on how effective a heater will be, and will greatly affect energy consumption. Additionally, the HVAC system has a great impact, particularly how and where vents and intakes are located.
INTERNATIONAL INNOVATION

INTELLIGENCE

PRECCISION

OBJECTIVE
To develop hardware and software components including modelling tools based on building physics, model reduction techniques, identification and inverse modelling methods and optimisation algorithms.

PARTNERS
French institute of science and technology for transport, development and networks (IFSTTAR)
MINES ParisTech Engineering School
National Solar Energy Institute (CEA-INES)
Grenoble Institute of Technology (Grenoble INP)
University of Bordeaux
Delta Dore
Vesta System
Siemens – LMS
FUNDING
French National Research Agency (ANR)
Project partners’ individual investment

CONTACT
Dr Alex Nassiopoulos
Project Coordinator
IFSTTAR - Nantes
Route de Bouaye
CS4 44344 Bouguenais Cedex
France
T +33 240 845 919
E alexandre.nassiopoulos@ifsttar.fr
www.preccision.org

ALEX NASSIPOULOS holds a PhD from the Ecole nationale des ponts et chaussées (ENPC). He steers research activities in the fields of numerical modelling, system identification, optimal control and inverse heat transfer. His recent work concerns the development of state-parameter identification methods for the assessment, monitoring and management optimisation of buildings’ energy performance. He is the main author of the building model identification toolbox ReTroFit and of two international patents on on-site characterisation of building thermal properties.

CASE STUDIES

Passive house: INCA experimental buildings at INES

The passive house INCA is an experimental building located on the campus of INES – one of the project’s partners – in Chambéry, France. The unoccupied house is equipped with hundreds of sensors and a sophisticated monitoring system in order to provide experimental data for research in building energy performance. The algorithms developed in PRECCISION were implemented for this house and will be tried out for one year.

Offices and classrooms: PREDIS experimental platform

The PREDIS/MHI platform, located in G2E Lab (Grenoble INP), is part of a real building and composed of two rooms: an office and a classroom. PREDIS is a centre of innovation and training on distributed energy, and a demonstration tool for intelligent energy management close to real networks. It connects different modes of decentralised energy production to different uses through an expert supervision system. Platform MHI is representative of a tertiary low-energy building. This platform is highly instrumented and all energy flows are measured using different sensor technologies. Numerous parameters can be monitored; for example, the flow of people into and out of the classroom is deduced from the CO₂ quantity and fan speed, in correlation with the classroom schedule.

Real-world buildings

A retrofitted house will be chosen for the final case study, which is due to start in 2015, to see how well the PRECCISION system performs in a real-world building. The final candidate has not yet been defined. The house will be equipped with sensors manufactured by Delta Dore, the supervision front-end developed by Vesta-System, and the entire control software chain jointly developed by the PRECCISION team.

The implementation of the project’s results in real buildings relies on an excellent software front-end developed by one of the partners – Vesta-System: “The front-end provides an intuitive interface helping managers and users to install the sensors, configure the algorithms and monitor the system’s behaviour,” explains Dr Alexandre Nassiopoulos, coordinator of PRECCISION. Having this means consortium members have been able to focus on the development of core hardware and software tools that are needed in the various system parts. The data harvesting in the buildings is enabled by high-performance innovative wireless sensors developed by Delta Dore, also a project partner.

REAL-WORLD SCENARIOS

Although it began with a simple theoretical two-room case study, the project has progressed to real-world scenarios, with Nassiopoulos and colleagues choosing established test platforms for other projects with which members of the consortium were involved. This has allowed knowledge sharing between projects and a better understanding of the buildings. Additionally, these platforms are already fitted with a large number of sensors, such as smart meters, which allow real-time reporting of data.

The progression to inhabited urban and suburban buildings will allow for feedback regarding the thermal comfort of inhabitants while the PRECCISION MPC algorithms control the buildings’ temperatures. Looking ahead, when PRECCISION is available for wider scale implementation, it will be possible to configure the system for the bespoke requirements of building managers and inhabitants, and it may be possible for users to be able to view and act upon the predictive data provided by the system.

The innovative MPC algorithms, with real-time updates and predictive capabilities, developed by the PRECCISION team represent a sea-change in how buildings could be managed, and may form an integral part of an energy-efficient future in Europe and beyond. Designed primarily for new builds or buildings that have undergone significant renovation or retrofitting, demand for such systems will only rise as Europe slowly pulls itself out of the economic doldrums and into recovery.

The INCA building in Chambéry equipped with the optimal management system.

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