A GLOBAL MODEL BASED ENERGY MANAGEMENT SYSTEM APPLIED TO THE CANOPEA BUILDING

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ABSTRACT

This paper deals with the global model based anticipative energy management system adapted for the CANOPEA building prototype proposed by the team Rhône-Alpes for the Solar Decathlon Europe contest. It presents a practical application of theoretical studies originally developed in Grenoble Research labs (G-SCOP, G2Elab and LIG) and improved by the Vesta-System company. The different configurations of the building system including the envelope with the HVAC system, a battery and domestic appliances are presented: shutters, water storage, a temperature phase shifter, an air/air heat pump, an water/water heat pump, hybrid panels, The system, able to adapt to many different contexts to harvest the maximum energy, is so complex that it is difficult for a human to define the best configuration according to weather context and occupant activities. The proposed energy management system embeds a CANOPEA model connected to actual measurements, forecasts, realtime energy costs and occupant demands collected thanks to an Android tablet. It is able to support decision regarding the day ahead best CANOPEA configurations with a one-hour resolution.

INTRODUCTION

A Rhône-Alpes team (sol), led by the *Ecole Nationale Suprieure d'Architecture de Grenoble*, has designed and constructed a building prototype, named CANOPEA, for the Solar Decathlon Europe 2012 contest (sde). The Grenoble Institute of Technology, with a partnership with Vesta-System and UXP companies, has been in charge of designing an energy management system that was actually used as an action adviser. This paper depicted the solution that has been designed and used during the contest won by the CANOPEA prototype. The implemented building energy management system (BEMS) is an application of theoretical researches summarized in (Ha et al., 2012).

A home automation system basically consists of household appliances linked via a communication network allowing interactions for control purposes (Palensky and Posta, 1997). Thanks to this network, a load management mechanism can be carried out by *distributed control* (Wacks, 1993). Energy management allows inhabitants to set up the best building configuration in order to reduce energy expenses but also to adjust power consumption according to expected comfort and energy price variation. When price is rising, it is possible to decide to delay some services, to modify the envelope configuration (blinds, shutters,...), to reduce some set points or to modify the state of HVAC appliances. Occupants can manage it on their own but an energy management system provide a helpful support, especially when issues become complex, to better exploit the system flexibilities but also the occupant tolerances regarding comfort. It helps to reach dominant (according to Pareto's definition) compromise between energy cost and comfort. A global solution for the household load management problem has been proposed in (Ha et al., 2006). Some authors considered in particular the management of local production means and storage systems (Henze and Dodier, 2003; Foggia, 2009; Eynard, 2010). Energy load management has been conceptualized in (Ha et al., 2006). A dynamic programming approach has been proposed (Riffoneau, 2010). Other researchers used a multi-agent approach (Penya, 2003; Negenborn, 2007; **?**). But, a general approach of the energy management in dwellings yields new issues:

- solving energy management problems where uncertainties are predominant. A three layer architecture has been proposed in (Duy Ha et al., 2006; Ha et al., 2008b). Uncertainties can also be taken into account during the optimization step (Ha et al., 2008a).
- solving large dimension optimization problems. It has been tackled using a mixed integer linear programming approach that can manage thousands of binary and continuous variables. Ways of transforming an energy management problem into a MILP, which is a regular problem, have been shown in (Ha et al., 2009, 2010).
- solving singular problems. Multi-agent approaches have been used to manage services that can only be modeled by nonlinear equations in (Abras et al., 2006, 2007, 2010; Elmahaiawy et al., 2010).
- generating dynamically the energy management problems to solve them because each dwelling is unique and evolving. Dynamic optimization problem generation has been studied (Warkozek et al., 2009). Software architecture and solving process have been depicted (Ploix et al., 2010).

The CANOPEA energy management problem is firstly stated before detailing how the implemented BEMS has been customized. The system architecture is then discussed and example of results are presented. The paper finishes with the Android tablet application that has been designed to support interaction with occupants of the CANOPEA building.

PROBLEM STATEMENT

Figure 1 is a picture of the finalized CANOPEA building project in Madrid. The building system with its flexibilities can be decomposed into 4 parts.

Figure 1: The CANOPEA prototype in Madrid during the contest

The HVAC system

The different parts of the HVAC system are illustrated in figure 2. It is composed of an water/water and a main air/air heat pump manufactured by the Nilan company: warm or cool air can be pulsed into the living area but also warm or cool water can circulate into a radiant ceiling made of earth panels. The main air/air heat pump can produce domestic hot water using a electric resistance but the air/water heat pump can also support the domestic water heating process. This part is modeled by the Building Energy Management System (BEMS) but it is automatically managed by the Nilan system. A thermal storage tank with phase change material can store and restore heat to the earth panels thanks to a reversible water circuit with electric circulators. The air flow that feeds the air/air heat pump can come directly from outside or from a temperature phase shifter developed by the University of Geneva. It is made of fans and of materials with an important inertia and, providing that the fans are running, it provides a 12 hours shift of the outdoor temperature at the output that can be connected to the air/air heat pump to increase its efficiency. The water/water heat pump gets heat from hybrid solar panels located on the roof or from a air/water heat exchanger located outside of the building that emulates a district warm water loop.

The heat provided by the heat pumps and the configurations of the HVAC systems can be adjusted. $16(2 \times 8)$ authorized configurations have been considered. The number of configurations is doubled because in each configuration, the main air/air heat pump can be fed up directly by outdoor air or by the 12 hour shifted air provided by the temperature phase shifter.

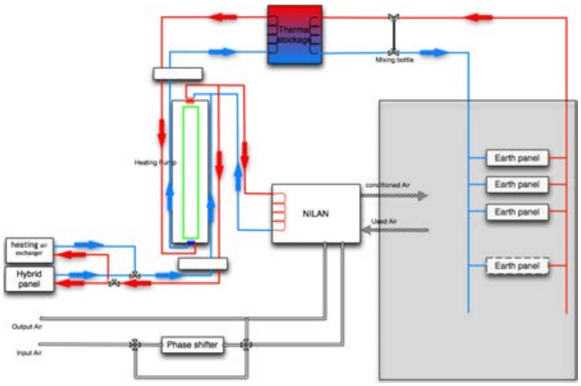

Figure 2: An example of configuration of the HVAC system

The configurations are:

configuration 1.1 and 2.1 The water is circulating in the earth panels but there is no exchange with the thermal storage tanks. The water/water heat pump is off. The air/air heat pump is on and pulses conditioned air into the first floor of CANOPEA (which is the only temperature controlled zone).

configuration 1.2 and 2.2 Same configuration than before except that the warm water coming out from the earth panels is injected to the top of the storage tank while cool water is taken at the bottom to be injected into the earth panels.

configuration 1.3 and 2.3 Same as x.2 except that the exchange with the storage tank is reverted. Warm water is collected from storage tank and introduced into the water circuit of ceiling.

configuration 1.4 and 2.4 Both heat pumps are on. Conditioned air is pulsed into CANOPEA. Hot water is taken for the top of the storage tank and is injected into the earth panels. The water/water heat pump is fed up with hot water taken from hybrid solar panel but also from water/air heat exchanger. The water/water heat pump supports the production of domestic hot water carried out by the main air/air heat pump. It also injects hot water into the heat storage tank.

configuration 1.5 and 2.5 Same than x.4 but without supporting the production of domestic hot water.

configuration 1.6 and 2.6 Same than x.4 except that directions of water circulations are reverted. Hot water is coming out from earth panel and injected to the thermal storage tank. Cool water is collected from the hybrid solar panels but also from the air/water heat exchanger and it is used by the water/water heat pump that feeds up the storage tank with cool water and supports the heating of domestic hot water.

configuration 1.7 and 2.7 Same than x.6 except that air/water heat exchanger is not used.

configuration 1.8 and 2.8 Same than x.6 except that hybrid solar panels are not used.

The envelope

The envelope is composed of two levels. Only the temperature of the ground level is controlled. Figure 3 illustrates an envelope configuration. The moving parts of the envelope are: external blinds made of fabric that can be opened and closed, shutters with three positions (opened, intermediate and closed) and windows. Moving parts are managed independently on each one of the four sides of the building. The upper floor is not managed by the BEMS. The solar radiation has been modeled according to (Duffie and Beckman, 2006), assuming there is no cloud into the sky, where solar protections have been taken into account. A local pyrometer is used to take into account nebulosity and to predict the average quantity of solar power and light coming inside the building. All the moving parts can be managed independently but windows cannot be opened when shutters are closed.

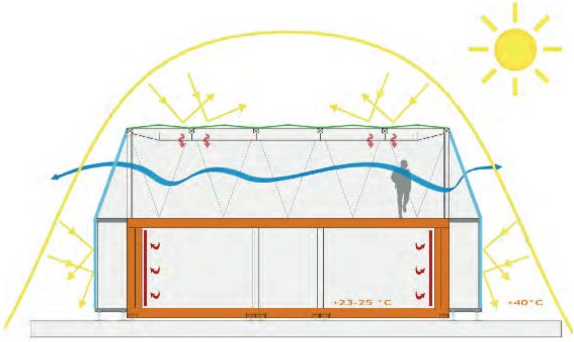

Figure 3: An example of configuration of the envelope

The electric system and appliances

In addition to the hybrid solar panel, the CANOPEA building is covered by photovoltaic panels on the roof. There are decomposed into two strings that can be disconnected in case of islanding in order to avoid overproduction. All these panels supplies the building with electricity as well as with power coming from the grid. A battery is also present in order to improve the coincidence between the consumption and the local production, which is an important criterion for the contest. In addition to the HVAC system, other common appliances are also present: washing machine, TV, computer,... Common appliances are not managed individually but given quantity of power consumed over given time periods. There are scheduled in order to determine the best moment to used electric appliances.

The occupants

Occupants are taken into account by the BEMS. Firstly, occupation is introduced into a calendar, which is used to determine metabolic heat. Calendar also contains the sleeping time when people are expected to remain below a given level of illumination. Occupant preferences are also modeled. The expectation regarding temperature, CO2 concentration, level of illumination are represented.

Overal problem

The overall problem to be solved consists in adjusting all the degrees of freedom previously mentioned, including set-points, starting times, configurations and occupant comfort tolerances, in order to get best (dominant) compromised between cost and an estimation of the overall comfort of occupants.

A GLOBAL MODEL BASED BEMS

In (Ha et al., 2012), it has been shown how to model building systems in a large mixed integer linear problem (MILP) that can be solved. Nevertheless, for CANOPEA, the problem was so complex that it was not possible to model the whole building with a Java Application Programming Interface as it was done before. Moreover, CANOPEA mixes different kinds of energy vectors: hot/cool water, electricity and hot/cool air.

To face this complexity, a multi-applicative modeling language has been developed in order to translate models into simulation problems for debugging purpose or into optimization problems to generate energy management strategies.

A multi-applicative modeling language

In building energy management, different kinds of problems may occur:

- parameter estimation problems i.e. nonlinear optimization problems, to adjust model parameters according to measurements
- simulation problems, to debug and solve occupant requests looking like ”what will be the consequences of this action”
- mixed integer linear optimization problems, to compute anticipative energy strategies
- constraint satisfaction problem, to perform fault diagnosis analysis

However, what can be expected is a unique formalism to describe models. Thus, providing some transformations, different kinds of problems previously mentioned could be solved. To make it possible, the modeling language has to satisfy the following properties:

1. language has to be natural for designers i.e. as closed as possible to mathematical formulation
2. because the designer intention is not assumed,
   (a) input and output variables are not a priori known i.e. the language must be a-causal
   (b) parameters and variables are not a priori distinguished (consider for instance parameter estimation)
   (c) language has to be declarative i.e. capable to state variables and constraints (equality or inequality)

3. language has to be consistent with existing languages, especially close to the a-causal MODELICA language.

Listing 1 MILP representation of an air/air heat pump

```
int i;
variable(”compressorOffsetPower: [0..1000]”);
variable(”ventilationPower: [0..1000]”);
for(i=0;i<nPeriods;i++) {
 variable(”electricPower[{i}] in electricPower : [0..{compressorPower}]”);
 variable(”injectedPower[{i}] in injectedPower: [−55e8..55e8]”);
 variable(”hotSourceEnergy[{i}] in hotSourceEnergy:[−55e8..55e8]”);
 variable(”coldSourceEnergy[{i}] in coldSourceEnergy: [−55e8..55e8]”);
 variable(”cop[{i}] in cop :[1..6]”);
 variable(”compressorPower[{i}] in compressorPower :[0..{compressorPower}]”);
 variable(”hotSourceInTemp[{i}] in heatSourceInputTemperature: [0..6e6]”);
 variable(”hotSourceOutTemp[{i}] in hotSourceOutTemp: [0..6e6]”);
 variable(”coldSourceInTemp[{i}] in coldSourceInTemp: [0..6e6]”);
 variable(”coldSourceOutTemp[{i}] in coldSourceOutTemp: [0..6e6]”);
 variable(”outdoorAirInTemp[{i}] in outdoorAirInTemp: [0..600]”);
 variable(”outdoorAirOutTemp[{i}] in outdoorAirOutTemp: [0..600]”);
 variable(”indoorAirInTemp[{i}] in indoorAirInTemp: [0..600]”);
 variable(”indoorAirOutTemp[{i}] in indoorAirOutTemp: [0..600]”);
 variable(”modeOff[{i}] in modeOff : {0..1}”);
 variable(”ventilMode[{i}] in ventilMode : {0..1}”);
 variable(”heatMode[{i}] in heatMode : {0..1}”);
 variable(”coolMode[{i}] in coolMode : {0..1}”);
 constraint(”mode[{i}] in mode: modeOff[{i}] + ventilMode[{i}]”+
   ”+ heatMode[{i}] + coolMode[{i}] == 1”);
//define connections for hot and cold sources (or zones)
 constraint(”modeOff1[{i}] in modeOff1: hotSourceOutTemp[{i}] == ”+
  ”{airCapa∗externalAirFlow}∗indoorAirOutTemp[{i}]∗heatMode[{i}] ”+
  ”+ {airCapa∗externalAirFlow}∗outdoorAirOutTemp[{i}]∗coolMode[{i}]”);
 constraint(”mode1[{i}] in mode: hotSourceOutTemp[{i}]”+
  ”{ == airCapa∗externalAirFlow}∗indoorAirOutTemp[{i}]∗heatMode[{i}] ”+
  ”+ {airCapa∗externalAirFlow}∗outdoorAirOutTemp[{i}]∗coolMode[{i}]”);
 constraint(”mode2[{i}] in mode: hotSourceInTemp[{i}]”+
  ” == {airCapa∗externalAirFlow}∗indoorAirInTemp[{i}]∗heatMode[{i}] ”+
  ”+ {airCapa∗externalAirFlow}∗outdoorAirInTemp[{i}]∗coolMode[{i}]”);
 constraint(”mode3[{i}] in mode: coldSourceOutTemp[{i}]”+
  ” == {airCapa∗externalAirFlow}∗outdoorAirOutTemp[{i}]∗heatMode[{i}] ”+
  ”+ {airCapa∗externalAirFlow}∗indoorAirOutTemp[{i}]∗coolMode[{i}]”);
 constraint(”mode4[{i}] in mode: coldSourceInTemp[{i}]”+
  ” == {airCapa∗externalAirFlow}∗outdoorAirInTemp[{i}]∗heatMode[{i}] ”+
  ”+ {airCapa∗externalAirFlow}∗indoorAirInTemp[{i}]∗coolMode[{i}]”);
//energetic models
 constraint(”pac1[{i}] in pac: coldSourceEnergy[{i}]==”+
  ”coldSourceOutTemp[{i}] − coldSourceInTemp[{i}]”);
 constraint(”pac2[{i}] in pac: hotSourceEnergy[{i}]==”+
  ”hotSourceOutTemp[{i}] − hotSourceInTemp[{i}]”);
 constraint(”pac3[{i}] in pac: electricPower[{i}]==”+
  ”coldSourceEnergy[{i}] + hotSourceEnergy[{i}]”);
 constraint(”pac4[{i}] in pac: hotSourceEnergy[{i}]==”+
  ”cop[{i}]∗heatMode[{i}]∗electricPower[{i}]+”+
  ”cop[{i}]∗coolMode[{i}]∗electricPower[{i}]”);
 constraint(”pac5[{i}] in pac: electricPower[{i}]==”+
  ”compressorPower[{i}] − compressorPower[{i}]∗modeOff[{i}] ” +
  ”+ heatMode[{i}]∗compressorOffsetPower”+
  ”+ coolMode[{i}]∗compressorOffsetPower”+
  ”+ ventilMode[{i}]∗ventilationPower”);
//define connections for hot and cold sources (or zones)
 constraint(”forceSortie4[{i}] in forceSortie4: ”+
  ”outdoorAirOutTemp[{i}]∗ventilMode[{i}]”+
  ” == indoorAirInTemp[{i}]∗ventilMode[{i}]”);
 constraint(”forceSortie5[{i}] in forceSortie5: ”+
  ”indoorAirOutTemp[{i}]∗ventilMode[{i}]”+
  ” == outdoorAirInTemp[{i}]∗ventilMode[{i}]”);
 constraint(”forceSortie8[{i}] in forceSortie8: ”+
  ”indoorAirOutTemp[{i}]∗modeOff[{i}] == ”+
  ”indoorAirInTemp[{i}]∗modeOff[{i}]”);
 constraint(”forceSortie9[{i}] in forceSortie9: ”+
  ”outdoorAirOutTemp[{i}]∗modeOff[{i}] == ”+
  ”outdoorAirInTemp[{i}]∗modeOff[{i}]”);
 constraint(”injectedPower[{i}] in injectedPower :” +
  ” {airCapa∗internalAirFlow}∗indoorAirOutTemp[{i}] ” +
 ”− {airCapa∗internalAirFlow}∗indoorAirInTemp[{i}]==injectedPower[{i}]”);
}
```

Example 1 is a prototype of language that illustrates how a heat pump can be modeled without a priori intention. Each variable is defined by a label and by a value domain, which can be an continuous interval or a set of integers. Each variable may belong to a *variable set* in order to facilitate the display by gathering variables. For instance, in example 1, all the variables *electricPowers* related to given time periods are gathered into the variable set *electricPower*. Constraints between variables are named and may also be gathered into *constraint sets*. A constraint is an a-causal relation between some variables. Parameters are not defined explicitly: they correspond to variables whose value domain is restricted to a single value a posteriori according to the usage of the model. For instance, the coefficient of performance (COP) can be transformed into a parameter by restriction to a single value to generate energy management strategies, it can also be modeled by an integer variable to model different values of COP or remains a continuous interval for parameter estimation purpose.

Regarding CANOPEA, models have been used for simulation with a debug purpose but also for MILP optimization for energy management purpose. For these two purposes, the same CPLEX MILP solver have been used. Therefore, model has to become linear but products like *outdoorAirOutTemp[i]*ventilMode[i]* are not. Nevertheless, some linearization patterns, given in (Ha et al., 2012), are automatically used to linearized these kinds of nonlinearities. The following linearization patterns are automatically applied recursively:

- product of n binary variables
- semi-continuous product of a binary variable and a continuous one
- logical implication or equivalence
- minimum or maximum
- linearization of nonlinear function by a stepwise function
- linearization of ordinary differential equations

A composition mechanism

Setting up a model for CANOPEA is not easy to manage because there is a huge quantity of components in the system. To set up such a system, the validation has been done step by step in modeling each component independently such as in figure 4. Then components can be built step by step starting by restricting some variables as inputs to generate simulations. Once the simulation is meaningful, some variables are relaxed in order to yield optimization problems. Then a larger composition is done by adding new components. A composition is obtained by instantiating model components, restricting parameter variables, by connecting variables between components using equality constraints. Depending on the problem to be solved, a criterion to be optimized may be added.

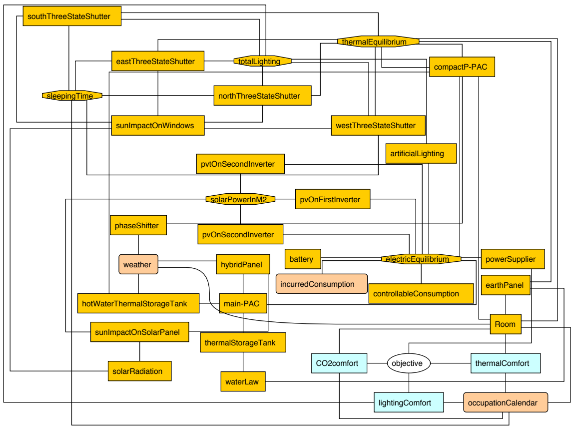

Figure 4: Structural representation of the CANOPEA model used for energy management

For the CANOPEA project, the Vesta-System company have modified the language proposed in program 1 in order to become closer to the MODELICA language, getting inspired by the SML language proposed by researchers from G2Elab.

SYSTEM ARCHITECTURE

The architecture of the energy management system used for CANOPEA is presented in this section. A networks of more than one hundred of sensors and actuators, measuring comforts, physical variables in the HVAC system and consumption of electric appliances, modifying artificial lighting, the behavior of the HVAC system have been set up by the IUT 1 GEII of Grenoble. In addition, some recent prototypes of sensors based on the Zigbee Green Power protocol have been provided by Schneider Electric. A part of the Home Abstraction Layer developed within the REACTIVHOME ANR project (REACTIVHOME) has been used to provide an open access to the different technologies of sensors but also to implement a new paradigm of low level control based on interconnected *datasources*, *controllers*, *requestbuffers* and *drivers*. This architecture handles data fission, for instance to transform a operational mode to a set of controls, and data fusion for instance to estimate occupant activities for a set of heterogeneous real sensors. The supervisor that contains CANOPEA models used to compute anticipative energy strategies maximizing energy efficiency is connected to the Home Abstraction Layer and the tablet interacts with occupants to collect their demands and to provide advices in return. The MILP solver with its optimization problem generator has been deployed in a datacenter far from the place of the contest in order to reduce its energetic impact. Locally, a supervisor with an interface, named Home Abstraction Layer, has been installed. It is connected to the solver located in datacentre, to the sensors and actuators of CANOPEA thanks to the Home Abstraction Layer, to a weather forecasting system and to a tablet application used as HMI.

The Home Abstraction Layer

Usually, in a building, different technologies of sensors are available with their own communication protocols. In order to homogenize the access to the different sensors and actuators, a global Restful webservice has been developed. It represents sensors and actuators in a meaningful hierarchical structure of resources, corresponding to thermal zone, appliances and systems, whatever the communication technologies and the protocols are. Two kinds of elements are available:

- the resources, which are hierarchically organized and that can be addressed thanks to an URL, may correspond to room, appliances, sensors, actuators,...
- the connectors, which can be registered to one or several resources in order to publish or collect data from an external HMI or alternatively by the supervisor of the BEMS. Connectors are possibly *datasources*, *controllers*, *requestbuffers* or *drivers*.

But the Home Abstraction Layer is much more than a presentation web interface. First of all, it is an interface easy to adapt to practical situations. Indeed, as shown in figure 5, it contains a set of drivers able to use different kinds of communication protocols. These *drivers* can be connected to different *datasources*, which publish data, and to *controllers* that collect control requests to be sent to actuators. In addition, *requestbuffers* can be used to collect occupant service demands. The energy manager can then collect the requests and, according to an energy management strategy, forwards or not a demand to a *controller*. These different connectors can be combined using a registration mechanism. For example, *controllers* and *datasources* can be combined with a embedded low level algorithms such as when CANOPEA is islanded, i.e. no longer connected to the grid, if the electric power produced by the photovoltaic panels is higher than the consumption, including consumption of the battery possibly in charge, disconnect one photovoltaic panel string then, if not sufficient, disconnect the second one. The 16 modes of the HVAC are managed in this way: a *controller* gets the operating mode and it uses *drivers* to transform the mode into low level controls sent to appliances: it corresponds to data fission and in this context, the controller is named *virtual controller*. Another mechanism is also possible for data fusion. Using a *virtual datasource* registered with other *datasources*, different sensor data can be combined to generate a new data standing for a virtual sensor such as for example the occupation of CANOPEA computed using CO2 concentration, consumption of electric appliances and actions of light switches.

The different connectors can be accessed via the resource URLs there are registered to. The following commands are available for each resource:

description , returns all the connectors registered with the *resource* and all the hierarchically descendant resources

data (+ datasource name) , returns the last data available in specified *datasource* or from all the registered datasources if not specified, using XML format

history (+ datasource name) (+ time period) , returns all the data corresponding to the specified *datasource(s)* for the given time period

register/unregister/collect + datasource name , makes it possible to register to a *datasource*. It creates a kind of mailbox with the IP address of the requester where all the data going through the *datasource* are recorded. The *collect* performative makes it possible to get all the data stored into the mailbox

control + controller name , collects control requests and sends a control to a *driver* or sends controls to other *controllers* if it is a *virtual controller*

request + requestbuffer name , records occupant requests than can be collected by a BEMS that may decide when to send the effective control to a *controller*.

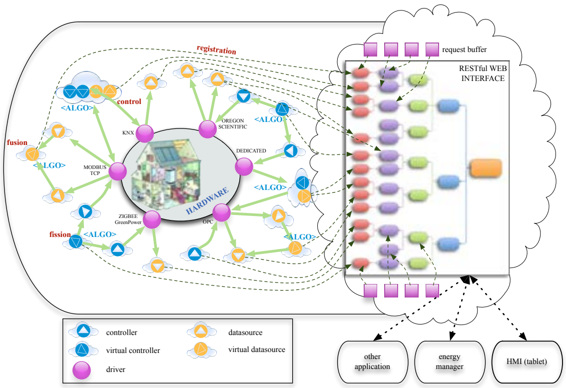

Figure 5: The Web RESTful interface between the energy manager and CANOPEA's sensors and actuators

Interaction with occupants

BEMS may behave in 2 complementary ways: it may manage some appliances for occupants or inform them about the actions that would be interesting to do. The G-homeTech/Vesta-Energy BEMS used for CANOPEA is able to manage both. However for the contest, it has been decided to use only the advise mode to limit the risk of weird controls i.e. occupants were in the control loop. Therefore, a human machine interface (HMI) is required. An Android application has been developed for a tablet. The graphic user interface is illustrated in figure 6.

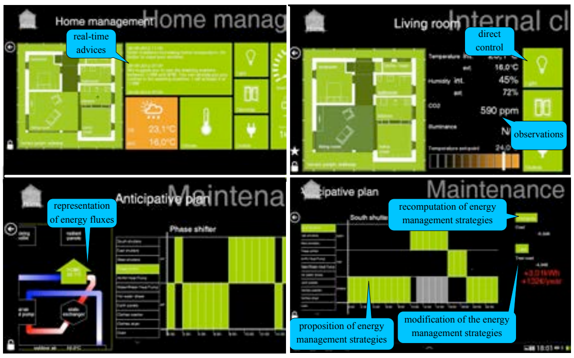

Figure 6: Different screenshots of the tablet application

In the left-hand top corner, the main welcome screen appears. It contains a finger sensitive representation of the first floor of CANOPEA with general information about consumption and weather. Each room can be selected to get access to related detailed controls and data. The presence of the BEMS appears in the middle thanks to real-time advices that are updated each hour. It tells occupants what they should do according to the best anticipative energy strategy computed thanks to the numerical model of CANOPEA.

In the top right-hand corner, the screen appearing when selecting a room from the main display can be seen. It points out that direct control are always possible and that occupants are free to follow or not the advices provided by the BEMS.

In the bottom left-hand corner, one can see a representation of the estimated energy flows computed by the BEMS but also the energy management strategies related to controllable appliances and components like south shutters, usage or not of the phase shifter, temperature set-point for both heat pump, recommended usage of clothe washer,...

The bottom right hand corner shows how the occupants can interact with the BEMS. They may use their fingers to modify the proposed energy management strategy. Then, two options are possible. Pressing the test button will compute the impact of the modification in kWh but also in euros by multiplying by 365 days in order to increase the impact on occupants. Another option is to press the compute button. In this case, it will consider the modification as constraints and the BEMS will recompute a new energy management strategy (which takes about one to two minutes).

EXAMPLE OF RESULTS

The HMI presents advices regarding energy management strategies in different ways. This section focuses on the core results computed by the G-homeTech/VestaEnergy BEMS. It illustrates how the computed global model based anticipative energy management strategies looks like and what it is considered to compute these strategies.

Figure 7 points out the computed best positions for the shutters. It is computed for the next 24 hours. Positions may be changed each hour.

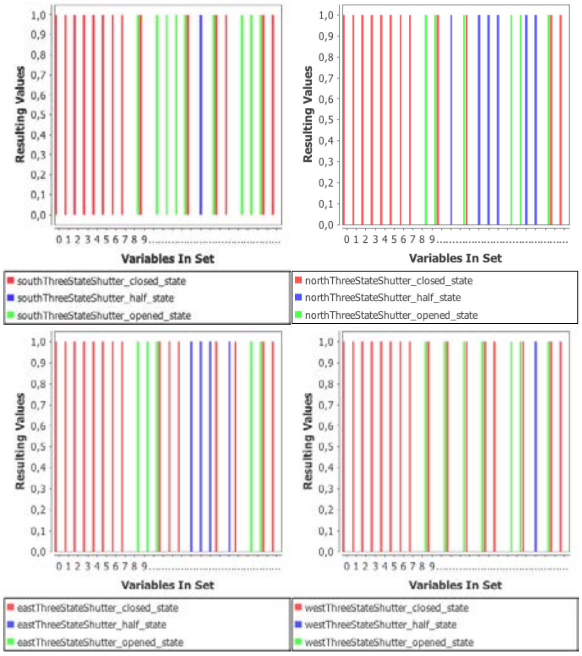

Figure 7: Example of generated energy management strategy

Figure 8 contains many different data. In the left-hand top corner, curves point out that the thermal solar gains through windows rely on complex models that take into account the direction of each window but also solar protection. Remaining curves point out that occupancy is taken into account but also storage tank and battery. It illustrates the concept of global management by contrast by local controls.

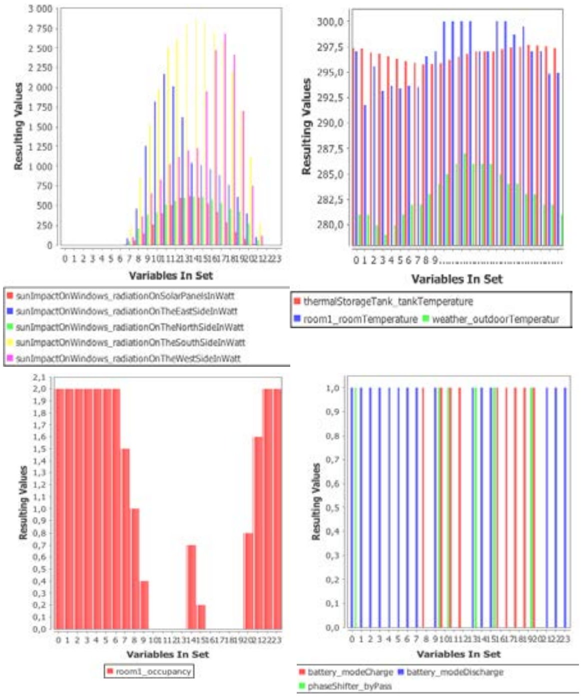

Figure 8: Example of generated energy management strategy

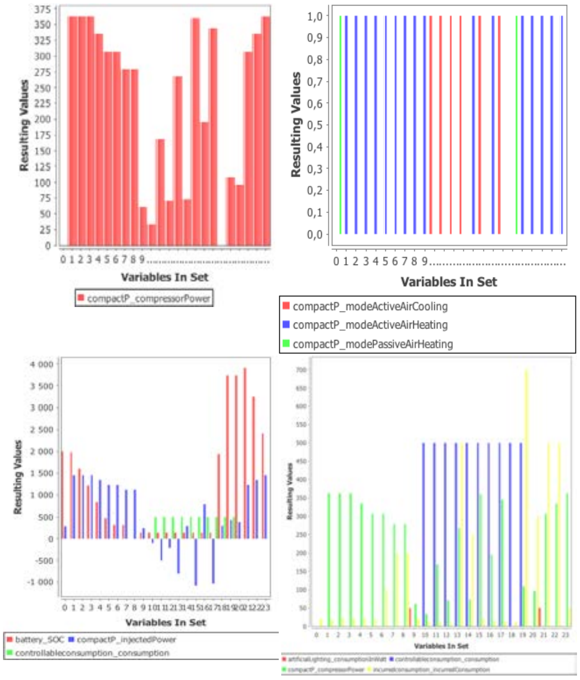

Figure 9: Example of generated energy management strategy

Figure 9 illustrates others variables related to heat pumps, lightings but also incurred predicted consumption and a controllable consumption modeled by a shiftable period of constant consumption. This latter model makes it possible to advice occupants about the best period to consume energy.

CONCLUSION

The adaptation of G-homeTech/Vesta-Energy building energy manager to the CANOPEA prototype led to new developments because of the complexity of the system. The Java native API was not comfortable enough to set up the BEMS. A new language has been designed to improve the model readability and the capability of designer to debug the overall CANOPEA model. A composition mechanism has been proposed in order to debug step by step the numerical representation of CANOPEA. It also led to the concept of multi-application language because for debugging, simulation of subsystems before optimization is an essential path for such complex systems.

An operational architecture has also been proposed for the energy management of CANOPEA. It includes a Home Abstraction Layer, which is a front-end for the building system that can be easily adapted. Indeed, it required only 24 hours to adapt it to CANOPEA although lots of collapses of the power supply. This abstraction interface make it easier to adapt a BEMS to a specific building with its heterogeneous sensor and actuator systems. For the Solar Decathlon Europe 2012 contest, for which CANOPEA got the pole position, the BEMS was able to compute energy management strategies and to propose advices to occupants.

Some improvements regarding the multi-application modeling language are under study. Indeed, the language proposed for CANOPEA is certainly able to handle simulation and computation of global energy management strategies but it is actually not able to handle parameter estimation problem, which leads to nonlinear optimization problems. New principles are under development: they rely on formal symbolic manipulations of constraints. It will increase the capability of model transformations.

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REFERENCES

http://www.sdeurope.org.

http://www.solardecathlon.fr.

Abras, S., Ploix, S., and Pesty, S. 2010. *Housing, Housing Costs and Mortgages: Trends, Impact and Prediction*, chapter Managing Power in a Smart Home Using Multi-Agent Systems. Number ISBN 978-1-60741-813-9 in Housing Issues, Laws and Programs. Nova Publishers.

Abras, S., Ploix, S., Pesty, S., and Jacomino, M. 2006. *Informatics in Control, Automation and Robotics III*, volume 15 of *Lecture Notes in Electrical Engineering*, chapter A multi-agent home automation system for power management. Springer Berlin Heidelberg.

Abras, S., Ploix, S., Pesty, S., and Jacomino, M. 2007. *Artificial intelligence and innovations : from theory to applications*, volume 247, chapter A multi-agent design for a home automation system dedicated to power management, pages 233–242. Springer eBooks collection, isbn 0387741615, 9780387741611, edition.

Duffie, J. A. and Beckman, W. A. 2006. *Solar engineering of thermal processes*. John Wiley and Sons, third edition edition.

Duy Ha, L., Ploix, S., Zamaï, E., and Jacomino, M. 2006. A home automation system to improve household energy control. In *The 12th IFAC Symposium INCOM2006*.

Elmahaiawy, A. M., Elfishawy, N., and El-Dien, M. N. 2010. Anticipation the consumed electrical power in smart home using evolutionary algorithms. In *MCIT 2010 conference*.

Eynard, J. 2010. *Gestion optimale de l'énergie dans un procédé multi-source pour le chauffage de bâtiments*. PhD thesis, l'Université de Perpignan Via Domitia.

Foggia, G. 2009. *Pilotage Optimal de Système Multi-sources pour le Bâtiment*. PhD thesis, Grenoble Institute of Technology (INPG).

Ha, L. D., Joumaa, H., Ploix, S., and Jacomino, M. 2012. An optimal approach for electrical management problem in dwelings. *Energy and Buildings*, 45:1–14.

Ha, L. D., Le Minh, H., and Ploix, S. 2008a. An approach for home load energy management problem in uncertain context. In *IEEE International Conference on Industrial Engineering and Engineering Management*, Singapor.

Ha, L. D., Ploix, S., Jacomino, M., and Le Minh, H. 2010. *Energy Management*, chapter A mixed integer programming formulation of the home energy management problem. ISBN 978-953-307-065-0. INTECH.

Ha, L. D., Ploix, S., Wurtz, F., Perichon, P., and Merten, J. 2009. Energy management system for a photovoltaic grid-connected building. In *24th EU PVSEC and 4th World Conference on Photovoltaic Energy Conversion*, Hamburg, Germany.

Ha, L. D., Ploix, S., Zamaï, E., and Jacomino, M. 2006. Tabu search for the optimization of household energy consumption. In *The 2006 IEEE International Conference on Information Reuse and Intergration IEEE IRI 2006*, Waikoloa Hawaii, USA.

Ha, L. D., Ploix, S., Zamaï, E., and Jacomino, M. 2008b. Realtimes dynamic optimization for demand-side load management. *International Journal of Management Science and Engineering Management*, 3(4).

Henze, G. P. and Dodier, R. H. 2003. Adaptive optimal control of a grid-independent photovoltaic system. *Transactions of the ASME*, 125:34–42.

Negenborn, R. R. 2007. *Multi-agent model predictive control with applications to power networks*. PhD thesis, Technische Universiteit Delft, Delft, Netherlands.

Palensky, P. and Posta, R. 1997. Demand side management in private home using lonworks. In *Proceedings of the IEEE International Workshop on Factory Communication Systems*.

Penya, Y. 2003. Last generation applied artificial intelligence for energy management in building automation. In *The 5th International Conference on Fieldbus Systems and their Applications*, Aveiro, Portugal.

Ploix, S., Duy Long, H., Abras, S., Jacomino, M., Wurtz, D., and Bacha, S. 2010. patent us/eu 61/326,542: Environment and method for managing services in a living place.

REACTIVHOME. https://reactivhome.rd.francetelecom.com.

Riffoneau, Y. 2010. *Gestion des flux énergétiques dans un système photovoltaïque avec stockage connecté au réseau.* PhD thesis, Grenoble Institute of Technology (INPG).

Wacks, K. 1993. The impact of home automation on power electronics. In *Applied Power Electronics Conference and Exposition*, pages 3–9.

Warkozek, G., Jacomino, M., Ploix, S., and Wurtz, F. 2009. Generic formulation of optimization problems for energy management: solving difficulties, practical and mathematical analysis. In *Proceedings of the 8th International Symposium on Electric and Magnetic Fields (EMF2009)*, Mondovi, Italy.