Development and application of smart control and management algorithms in hospitals

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EMBER

Energy Management in the Built Environment
Research Unit

Contents

- Energy consumption in Hospitals
- Green@Hospital project
- Hospital of Chania: “Saint George Hospital”
  - Energy saving potential, the Fan coil (paediatric department)
  - Energy saving potential, artificial lights (paediatric department)

Scope of research

Development and application of smart control and management algorithms in buildings towards nearly zero energy buildings

- Energy saving in existing buildings towards ZEB
- Implementation and evaluation of BOC algorithms in different systems using Internet based techniques.

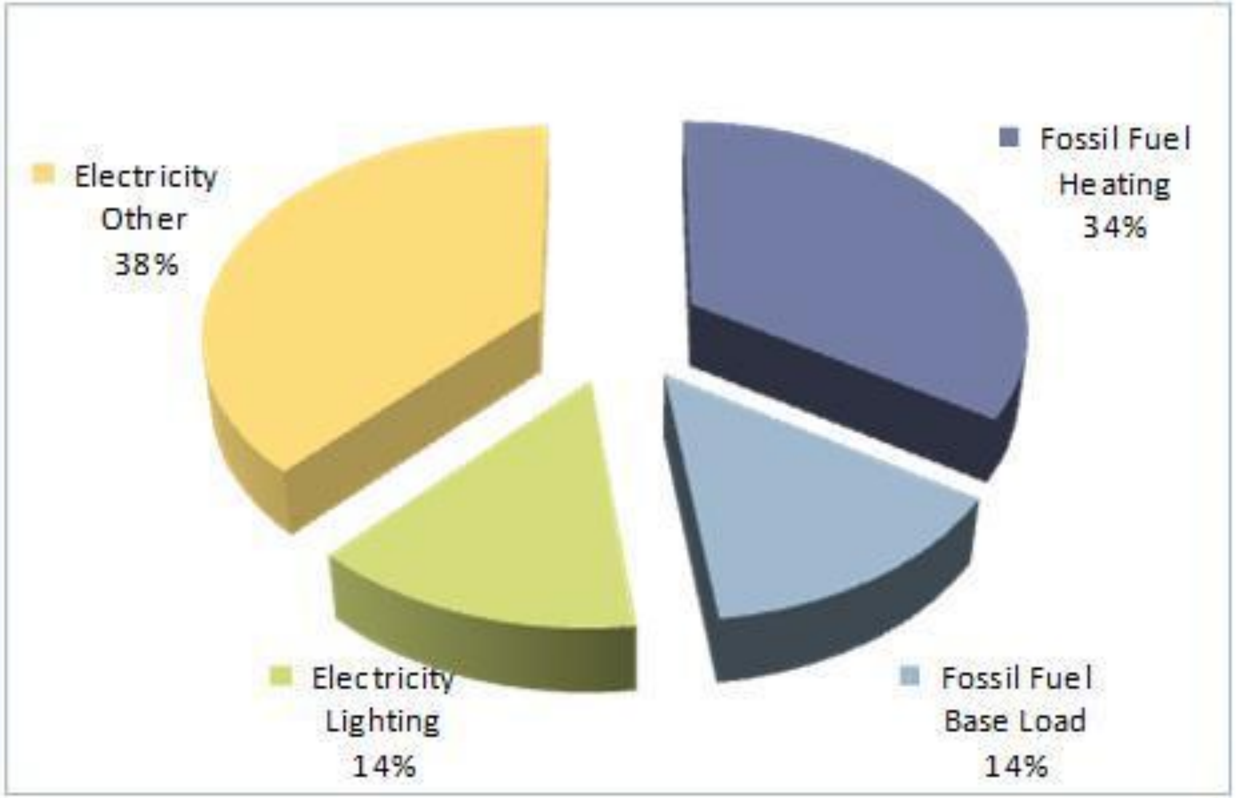
Energy consumption in Hospitals

SCENARIO

- Hospitals are large energy consumers because of:
  - 24/7 operability
  - medical imaging equipment
  - special requirements for clean air and disease control
- Energy consumption per square meter in hospitals is much higher than in many other types of buildings.
- A typical hospital building is designed for long term use and, in practice, is often utilised for longer periods than its builders ever intended.
- High interest proved by the high number of documents produced by public organizations and private companies.

Energy consumption in Hospitals

HOSPITAL ENERGY CONSUMPTION BREAKDOWN



Source: **white paper on Healthcare by TAC – Schneider Electrics**

Green@Hospital project

OBJECTIVE

Green@Hospital acts on ICT devices and infrastructures converting them **from energy intensive systems to drivers for energy efficiency.**

The expected result is a **15% consumption reduction in the involved areas** operating on:

- heating and cooling generation
- lighting
- ventilation
- data center

The main output of the project is a **Web-based Energy Management and Control System (Web-EMCS) which integrates model based energy saving algorithms.**

A Maintenance Energy Service, specifically developed and integrated in the Web-EMCS, helps to maintain optimal energy efficiency after initial efforts.

Pilot Hospitals (Green@Hospital project)

Hospital Virgen de las Nieves of Servicio Andaluz de Salud

Area:134.000 m^2

Beds: 915

Selected solution sets

- HVAC Emergency room
- HVAC Surgery room
- Chillers of data center

Hospital de Mollet

Area:27.000 m^2

Beds: 160

Selected solution sets

- Surgery room HVAC
- Heating & cooling plant

Azienda Ospedaliero Universitaria – Ospedali Riuniti di Ancona

Area:100.000 m^2

Beds: 756

Selected solution sets

- Artificial lights
- Chillers of data center

Hospital of Chania

Area:50.000 m^2

Beds: 450

Selected solution sets

- Artificial lights
- Fan coils

Case study Hospital of Chania: “Saint George Hospital”

Work performed:

- Outdoor air temperature prediction
- Building and optimization control algorithm for HVAC
- Control algorithm for artificial lights

Methodology followed

Control algorithms

Development phase

Input

Local controller

Output

Test phase

Local controller

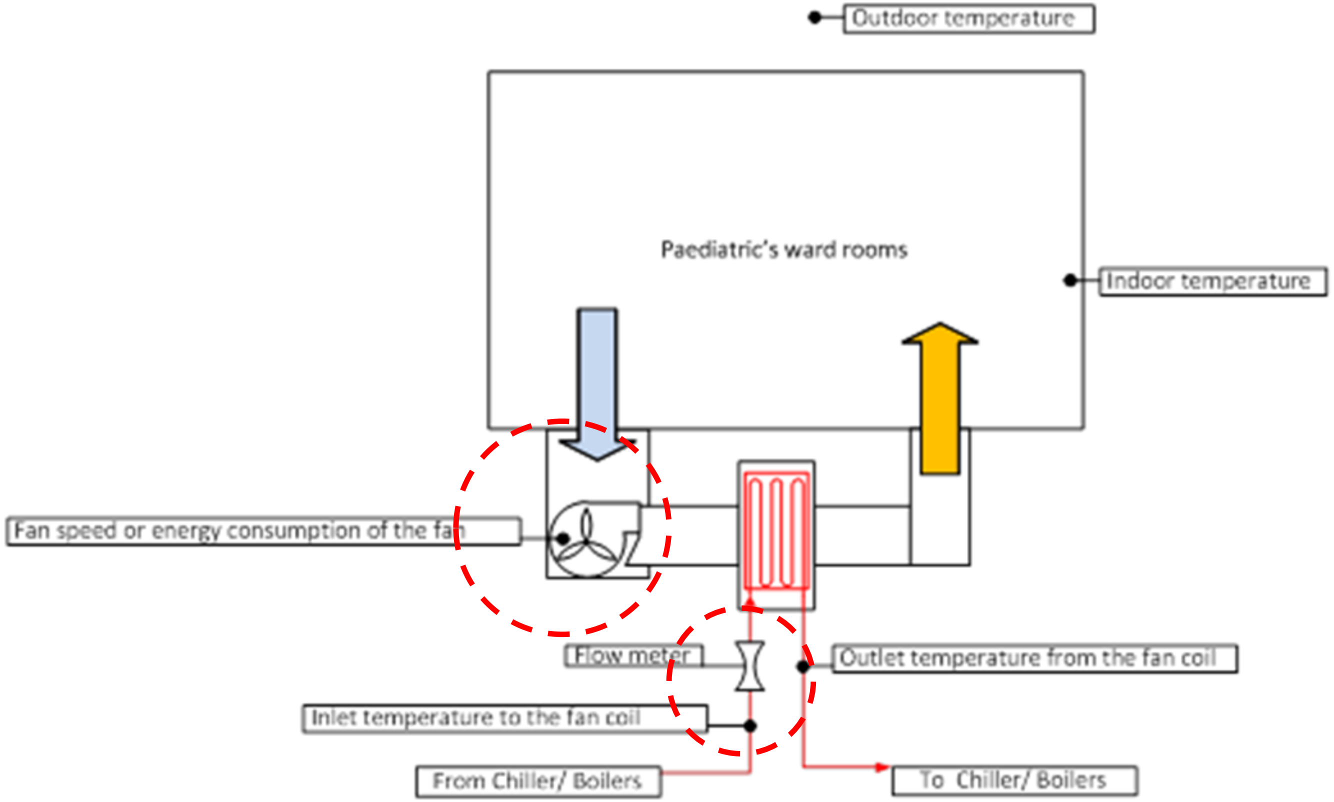
TrnSyS/ Radiance model

Controller

The controller is giving a new command every **15 min**.

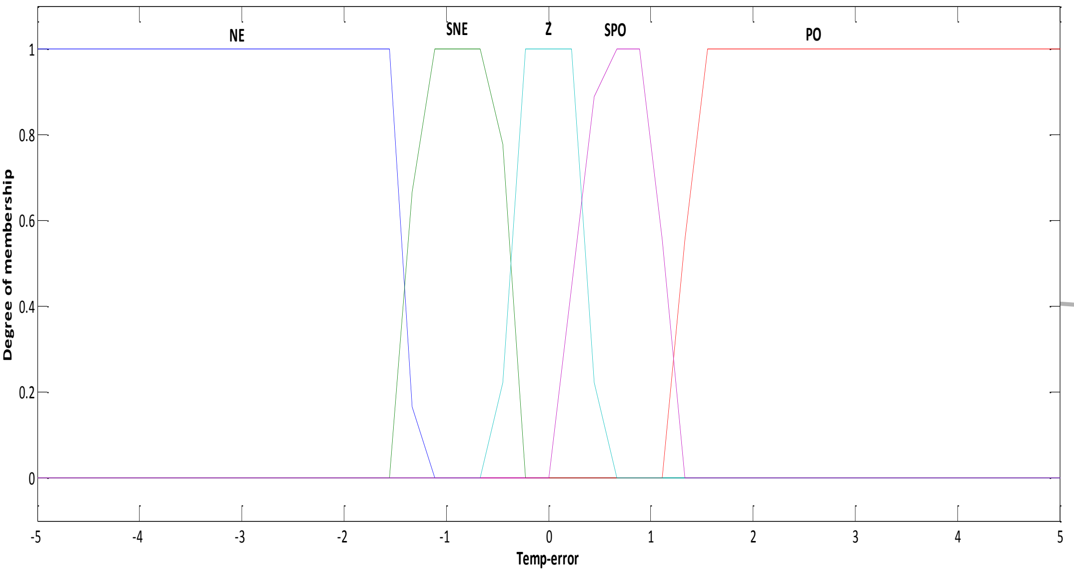
In SGH the controller is changing the state of:

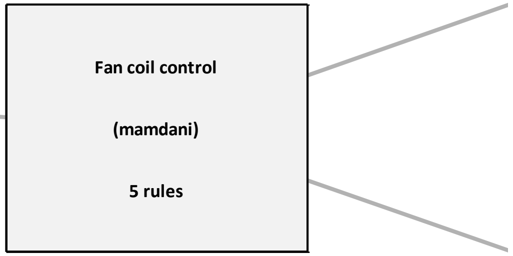
- **Fan coil's fan speed**
- **Fan coil's valve**



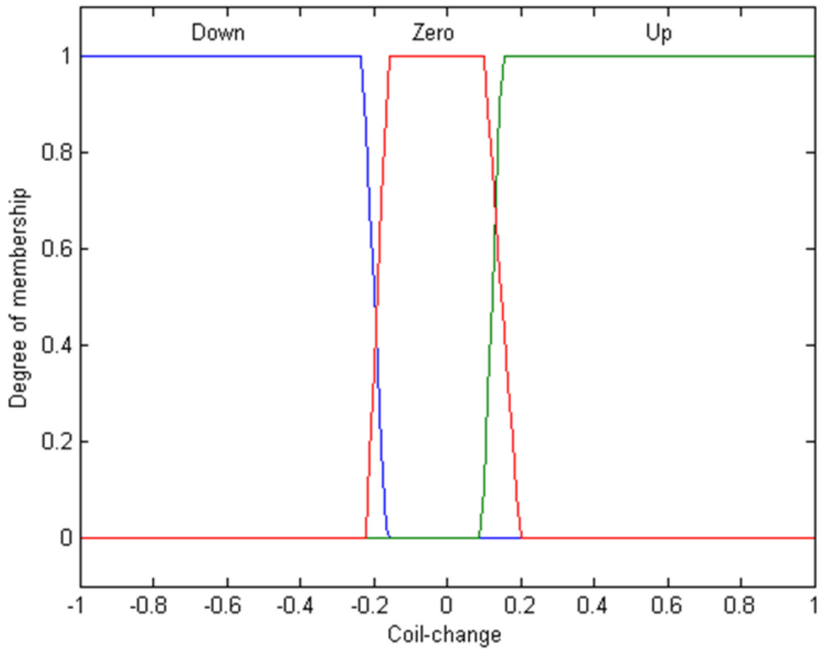
Controller

Input

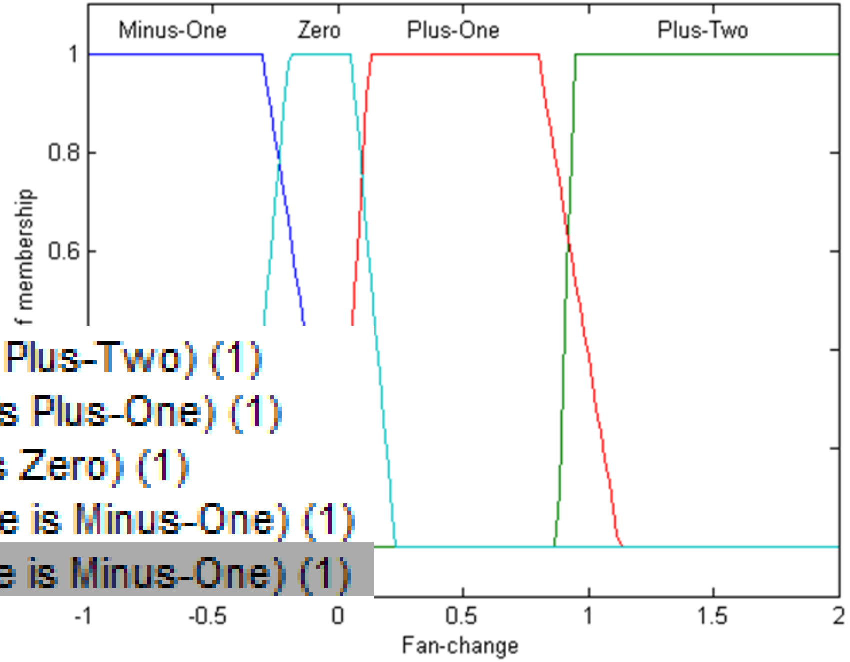




System Fan coil control: 1 inputs, 2 outputs, 5 rules



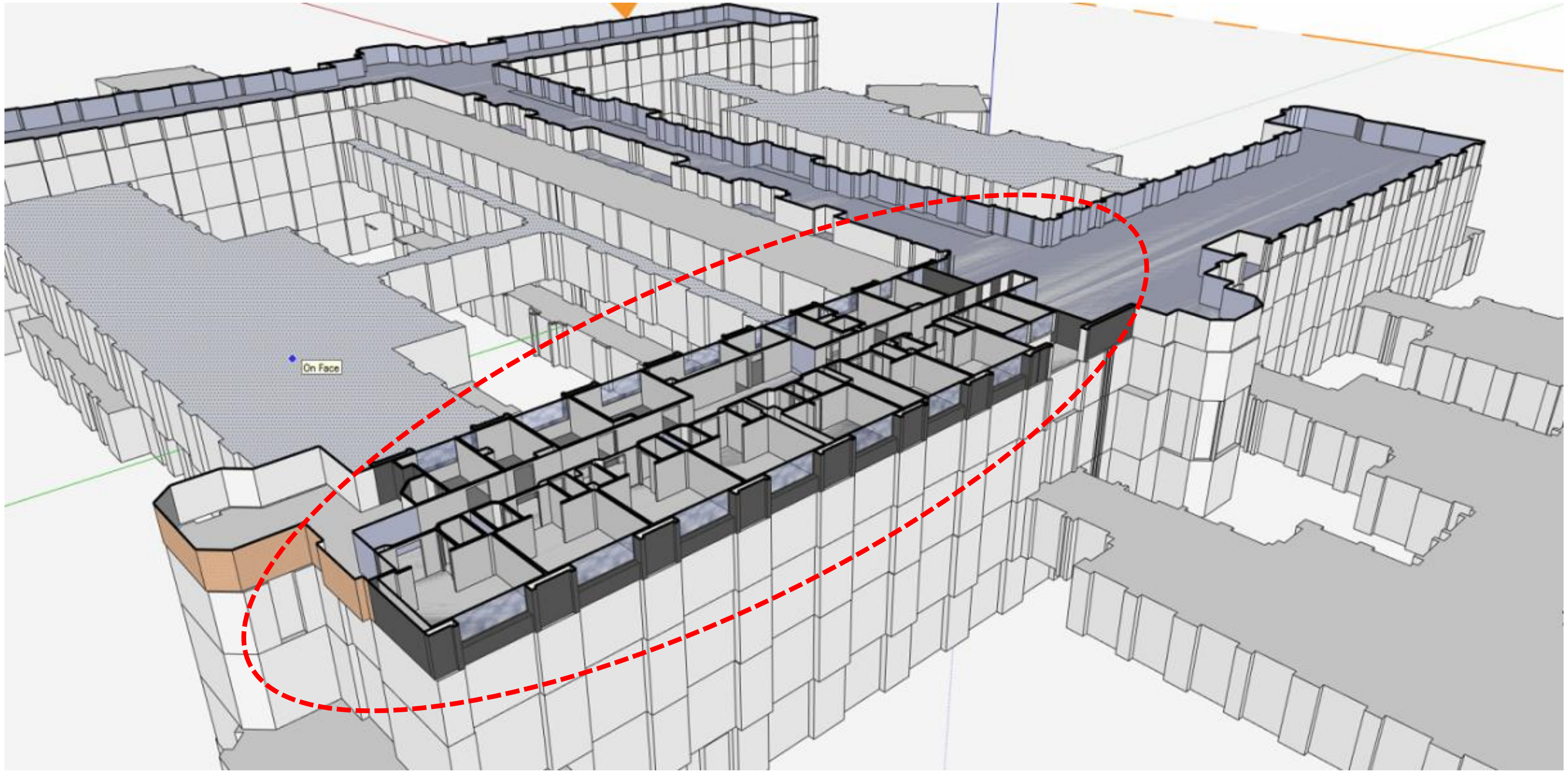
Output



Rules

If (Temp-error is NE) then (Coil-change is Up)(Fan-change is Plus-Two) (1)
If (Temp-error is SNE) then (Coil-change is Up)(Fan-change is Plus-One) (1)
If (Temp-error is Z) then (Coil-change is Zero)(Fan-change is Zero) (1)
If (Temp-error is SPO) then (Coil-change is Zero)(Fan-change is Minus-One) (1)
If (Temp-error is PO) then (Coil-change is Down)(Fan-change is Minus-One) (1)

Hospital of Chania: “Pediatric department”

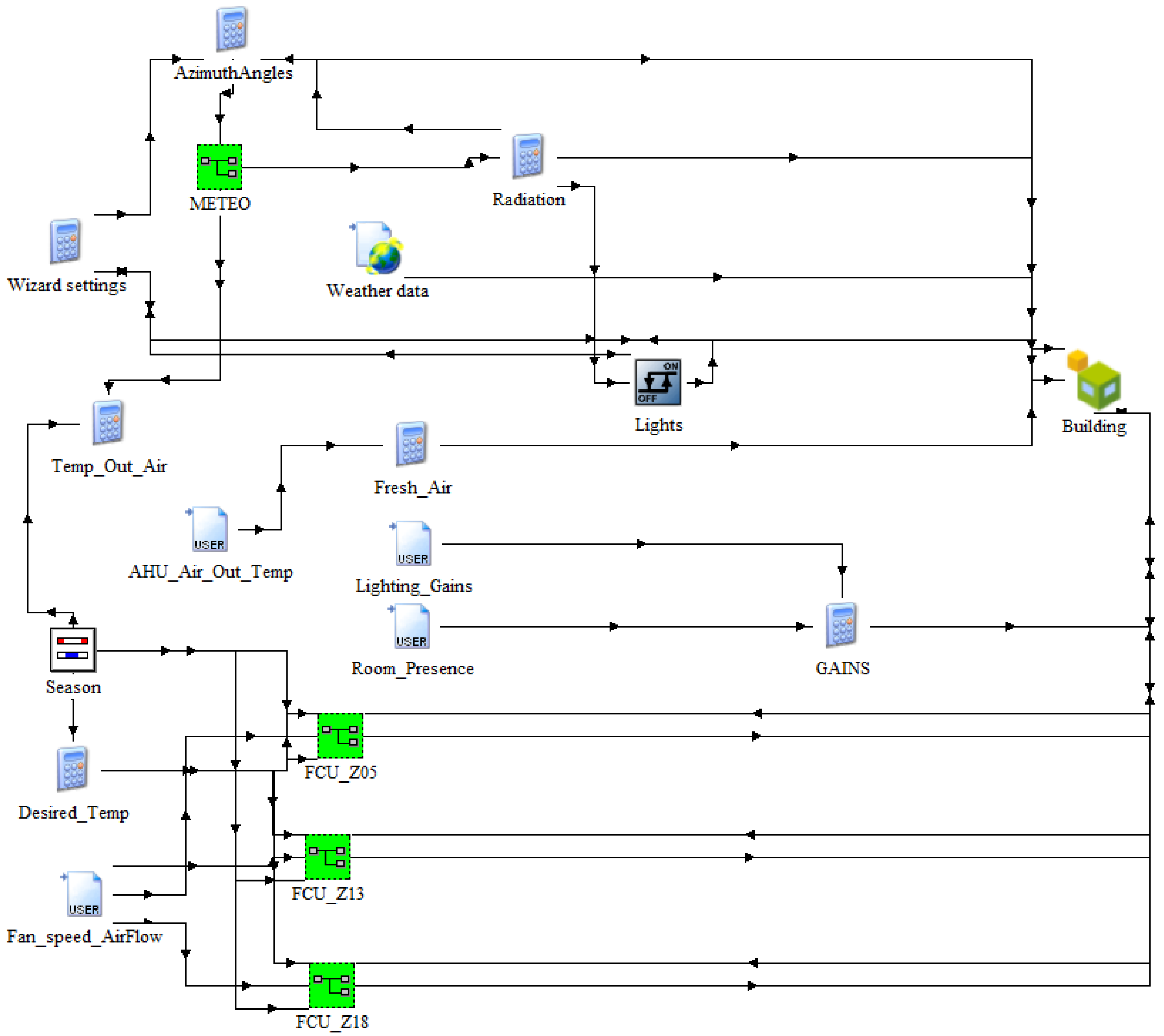


Pediatric department of Saint George Hospital

Development of dynamic thermal model for fan coil operation

Thermal dynamic model

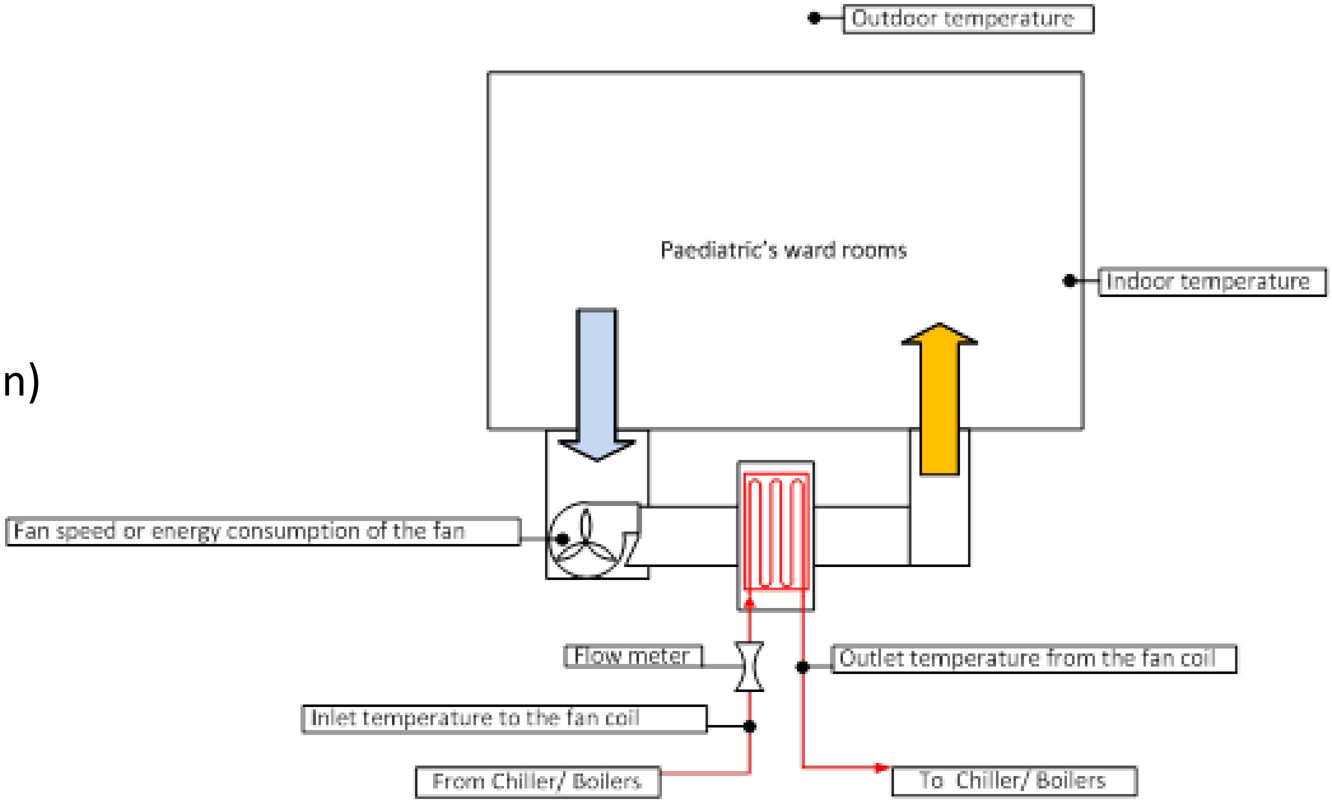
- Simulation software: **TrnSyS version 17**
- Geometry: **Hospital's floor plans, section & views**
- Fan coil specs: **Datasheet**
- Internal gains information: **Collected from hospital**
- Outdoor conditions: **Meteonorm weather file**



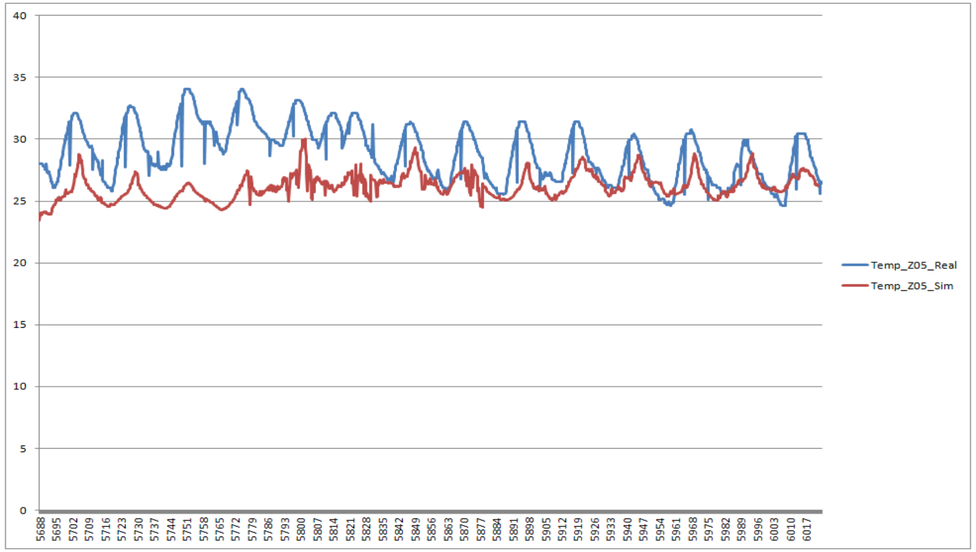
Measurements collection

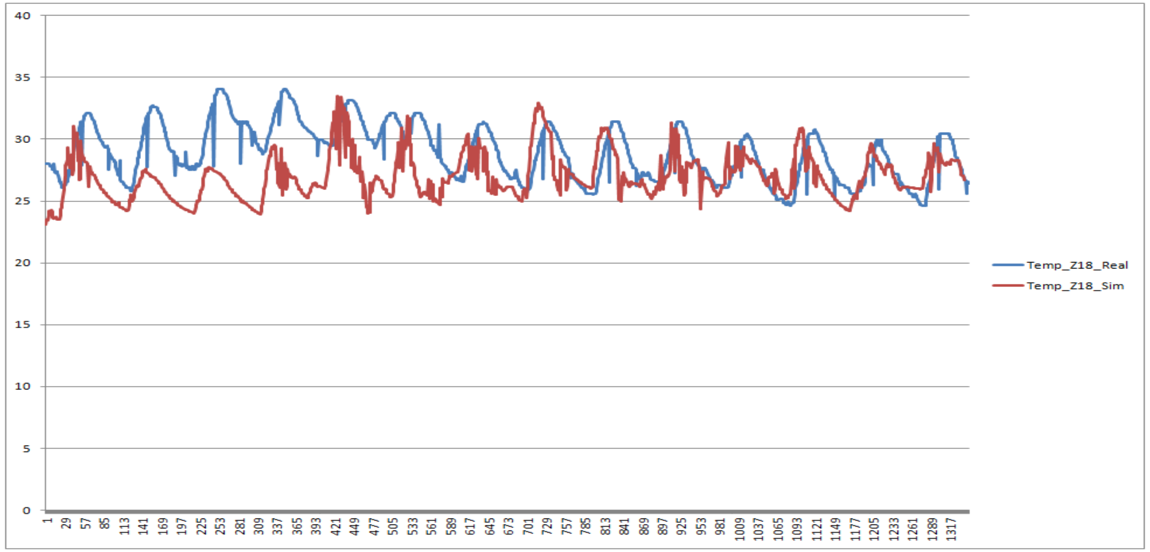
Data available from 26/08/2013 to 08/09/2013

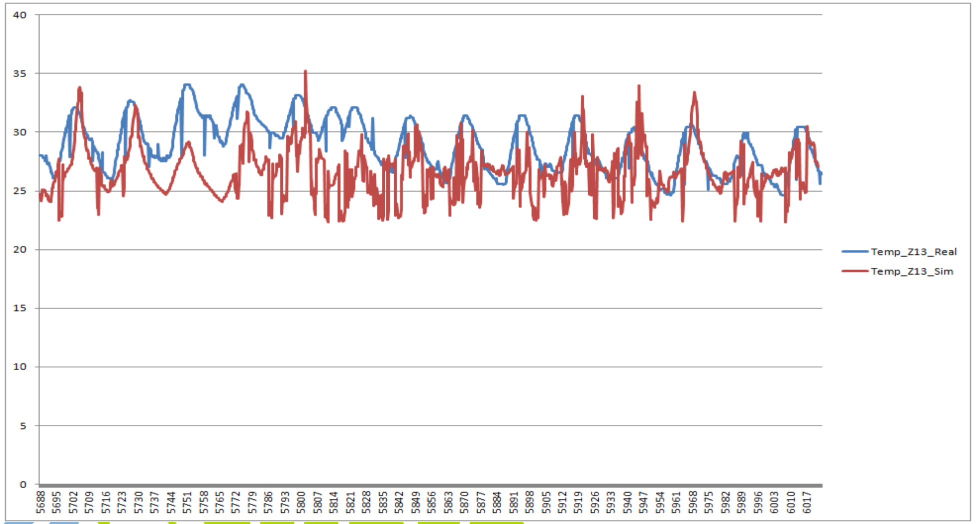
- Indoor air temperature
- Fan coil energy consumption (thermal & electrical)
- Artificial lights operation
- Windows position
- Outdoor conditions (temperature, humidity, radiation)



Development of dynamic thermal model for fan coil operation – Model validation



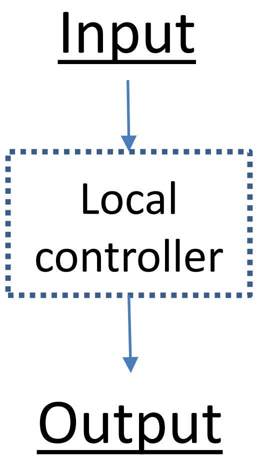




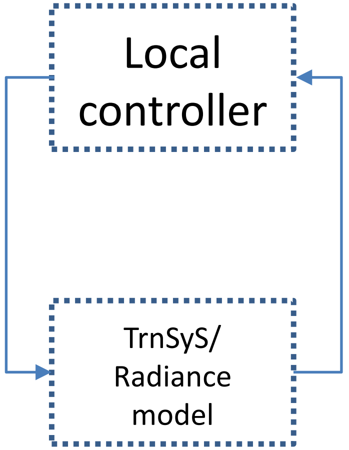
Methodology followed

Control algorithms

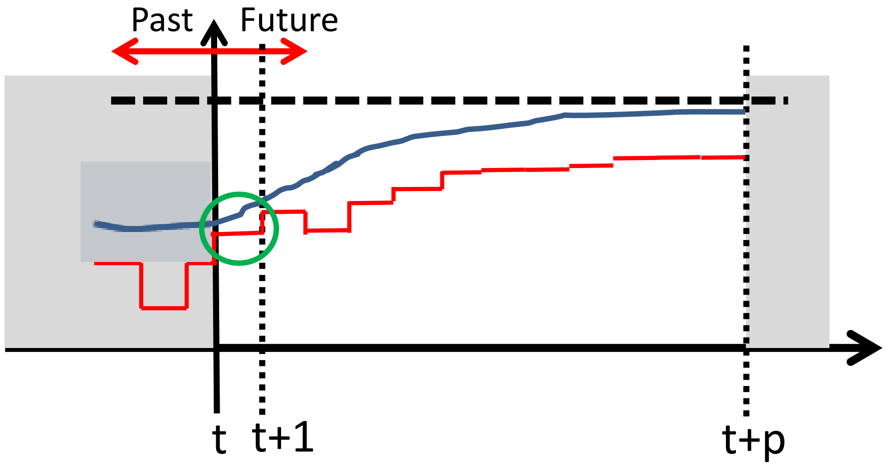
Development phase



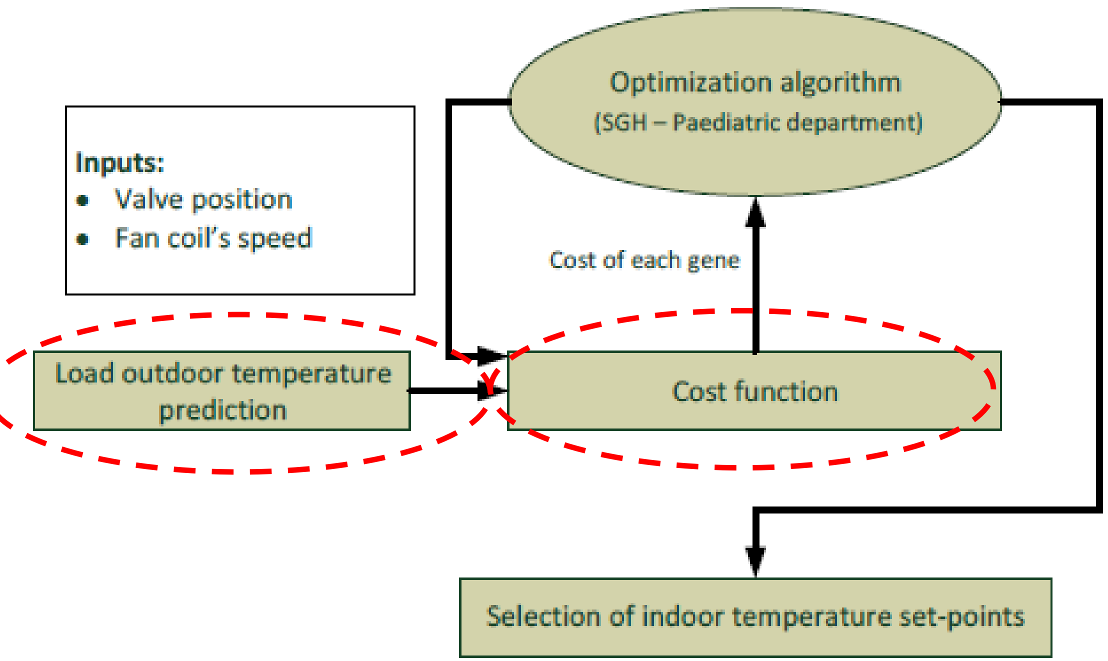
Test phase



Optimization algorithms



Optimization process

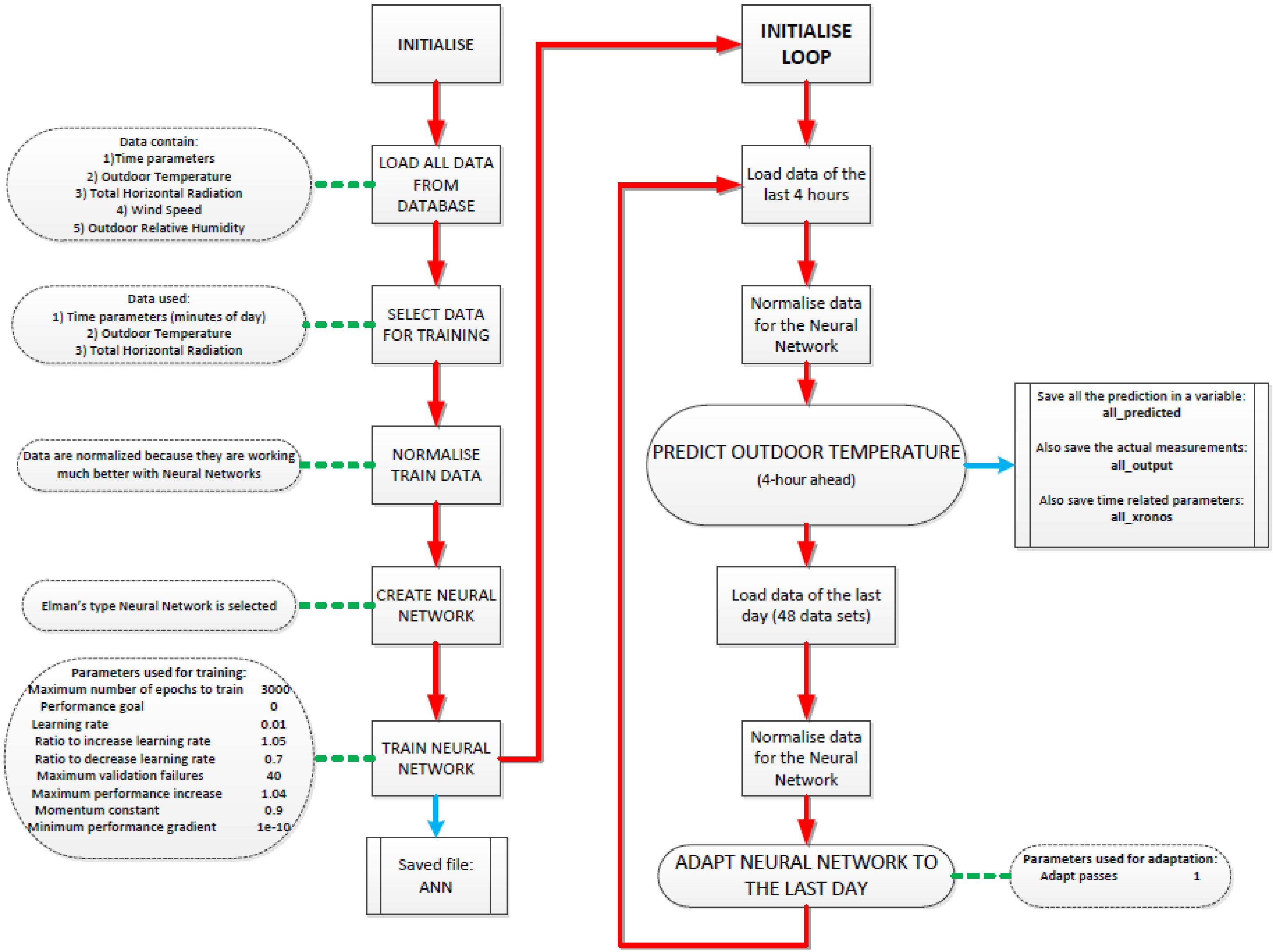


$$min\left(\sum_{1}^{32} Cost\ of\ operating\ the\ fan\ coil + Error\ of\ temperature\right)$$

so that

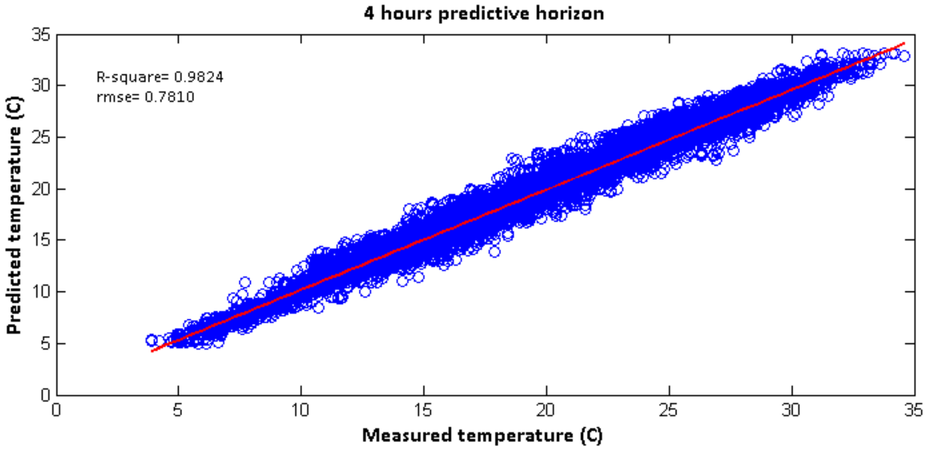
- fan of the fan coil is operating only when fan coil valve is open
- when fan coil operates, windows must be closed

Outdoor air temperature prediction - Strategy

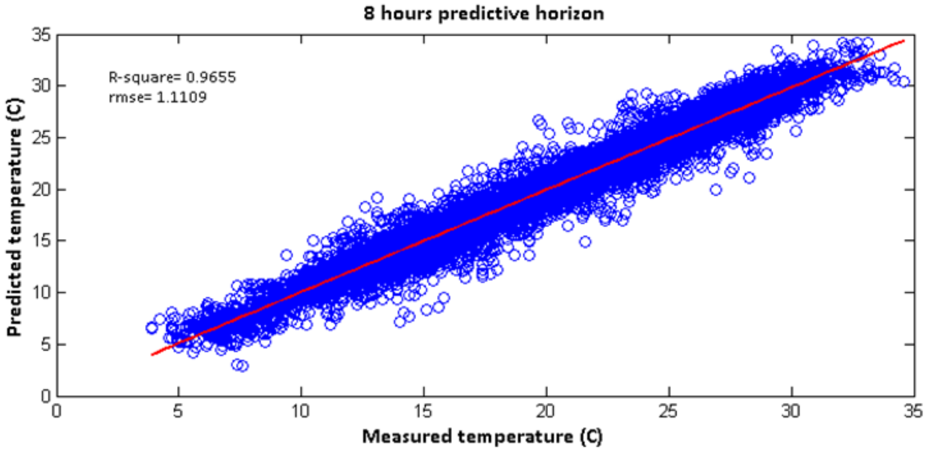


Outdoor air temperature prediction – Results

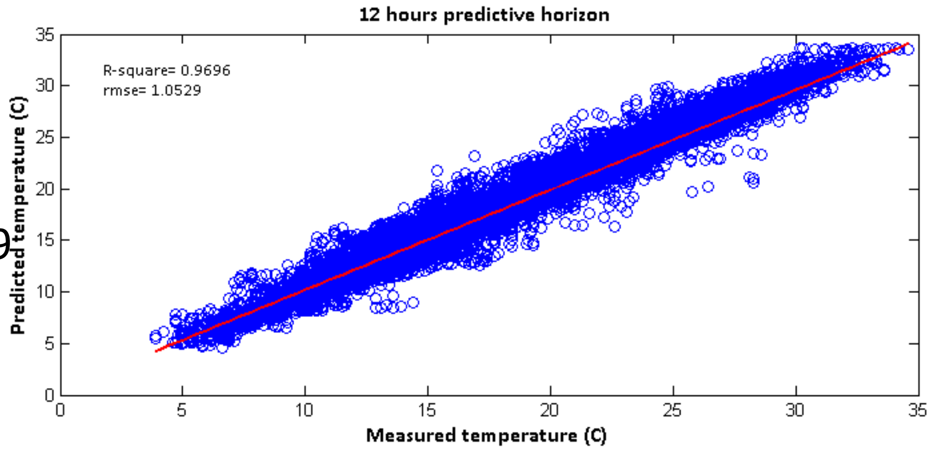
R^2=0.982
rmse=0.781



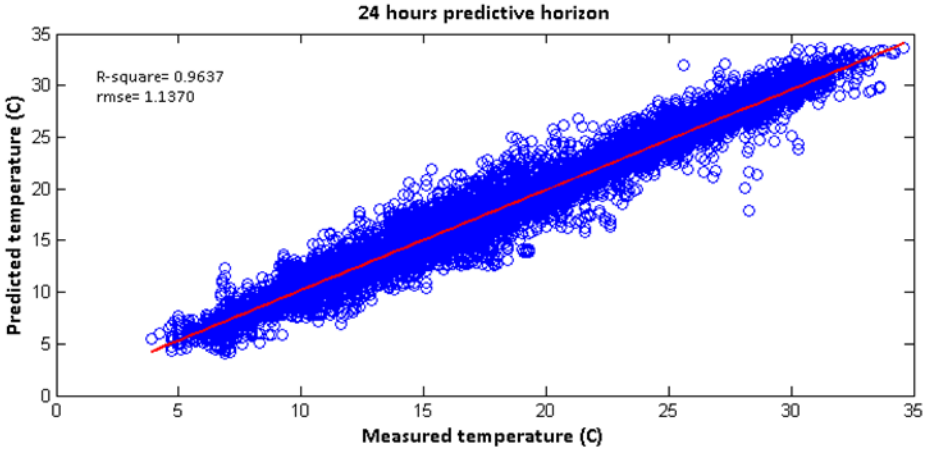
R^2=0.9655
rmse=1.1109



R^2=0.9696
rmse=1.0529



R^2=0.9637
rmse=1.1370



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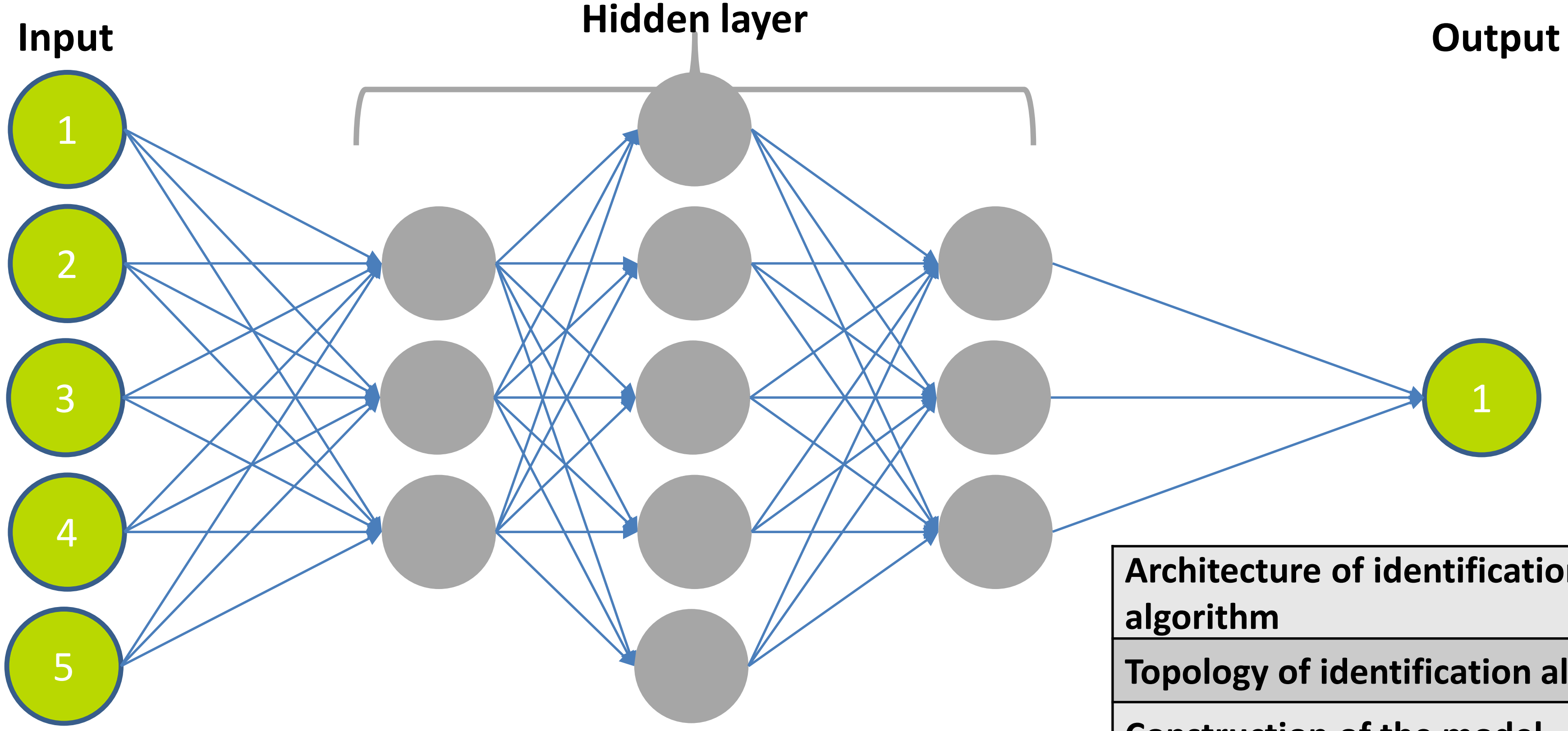
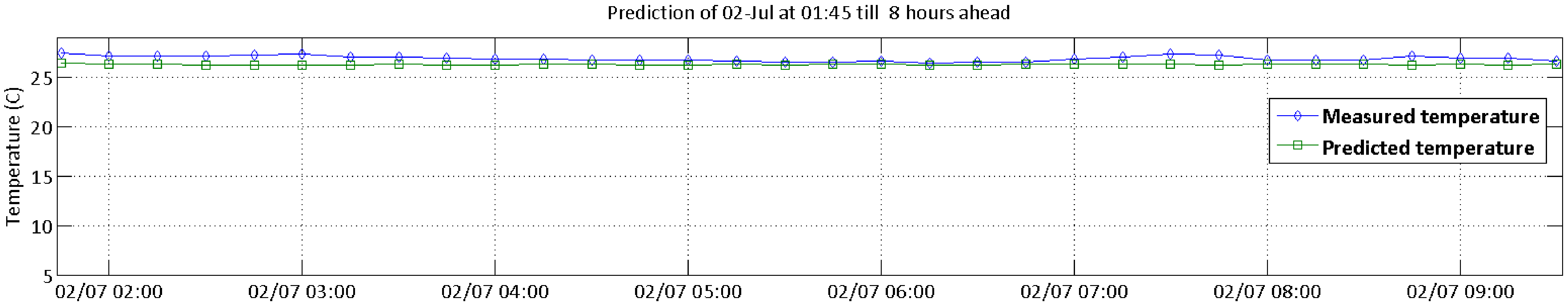
Identification algorithm



Architecture of identification algorithm	**Artificial Neural Network**
Topology of identification algorithm	Elman Neural Network
Construction of the model	Grey box
Performance function/ indicator	“Mean square error”
Size of initial train data set	1000
Number of epochs	3000
Number of maximum fails	3000
Predictive horizon	1 step (15 min)

Indentification algorithms - Results

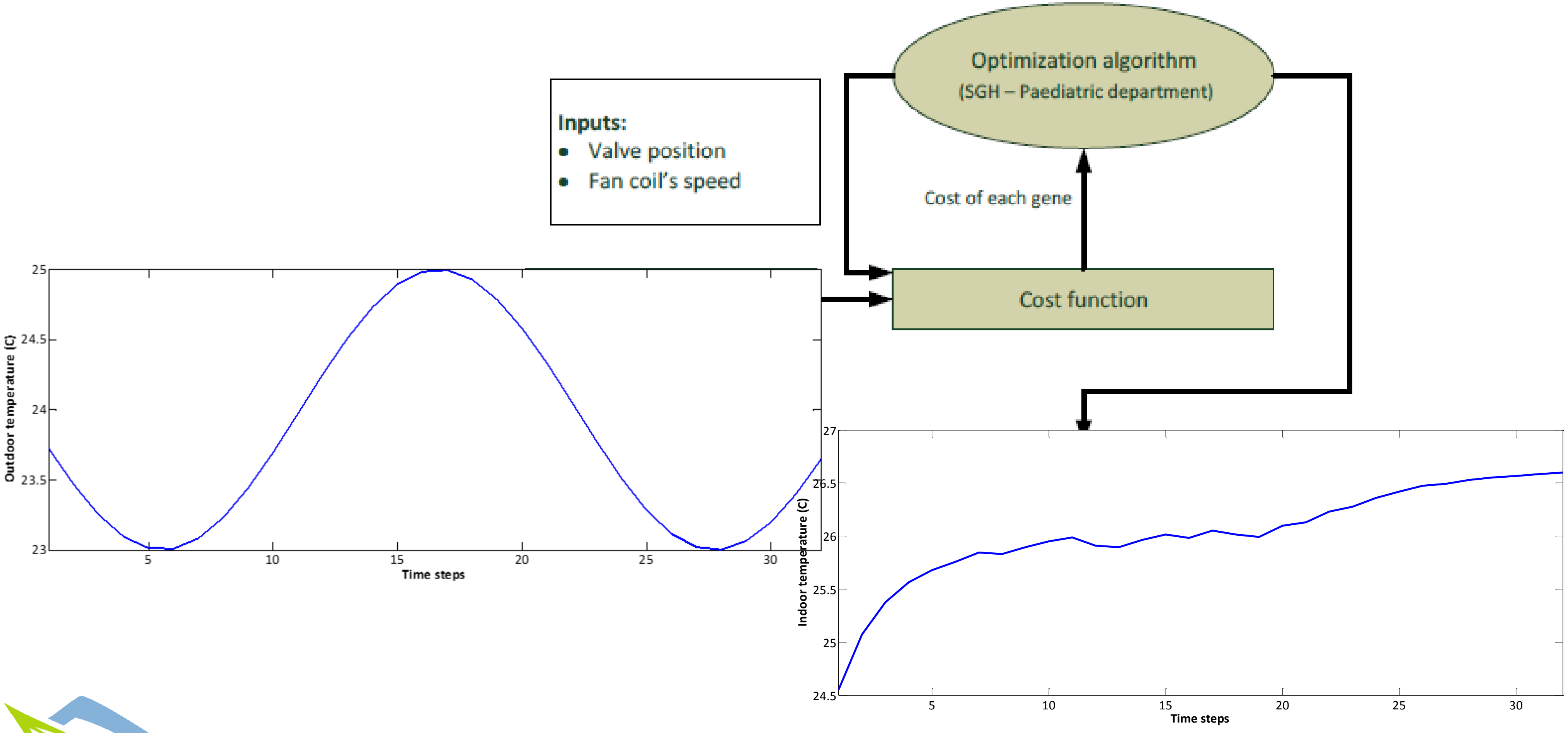


- Statistical comparison between measured temperature and predicted:

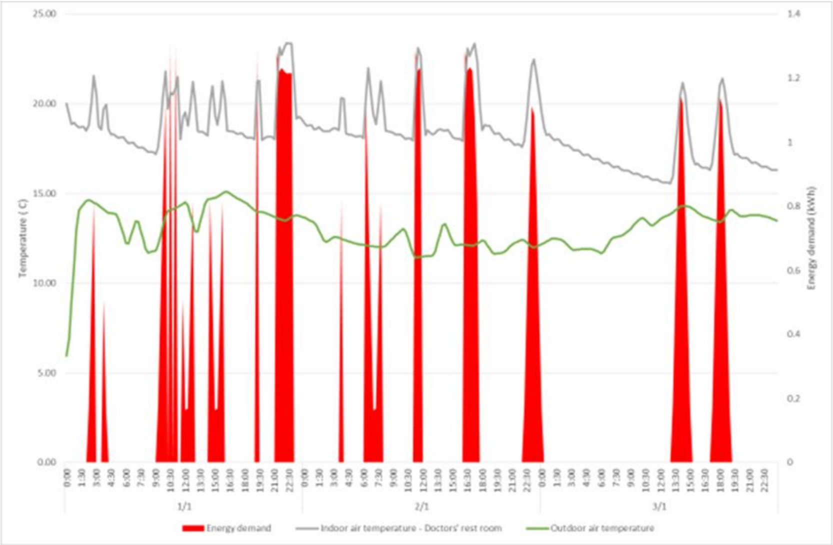
  0.15 < R-square < 0.81

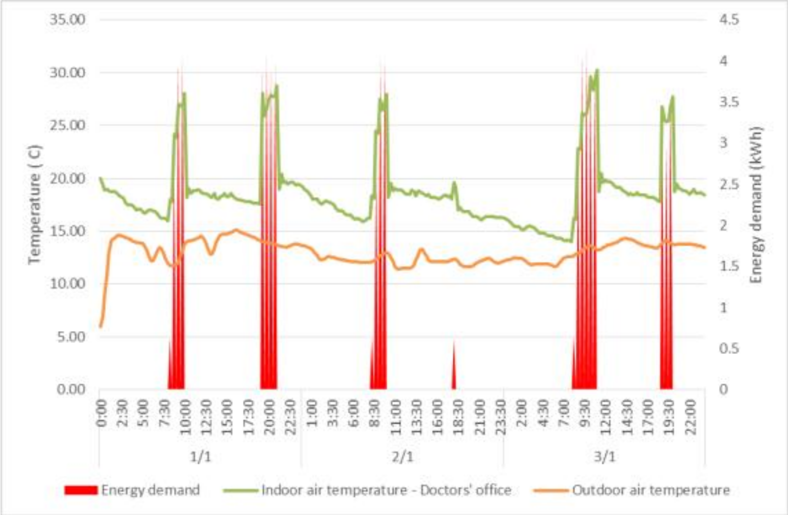
  Root mean square error < 0.6 C

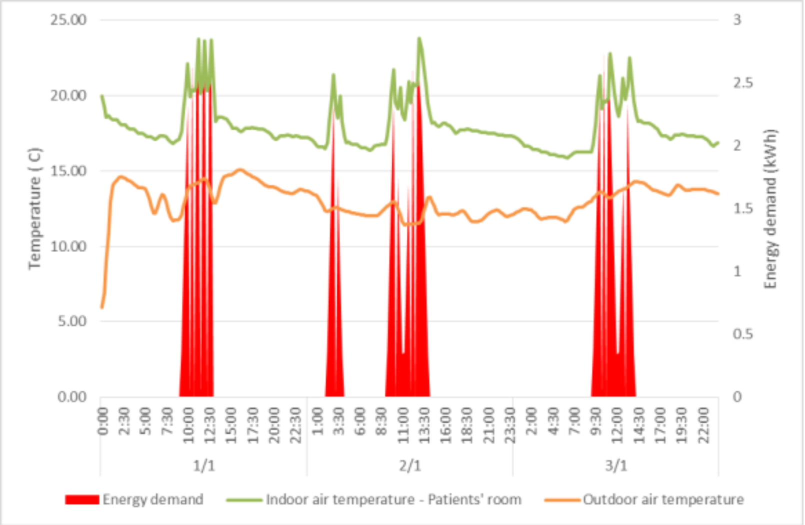
Optimization algorithm - Results

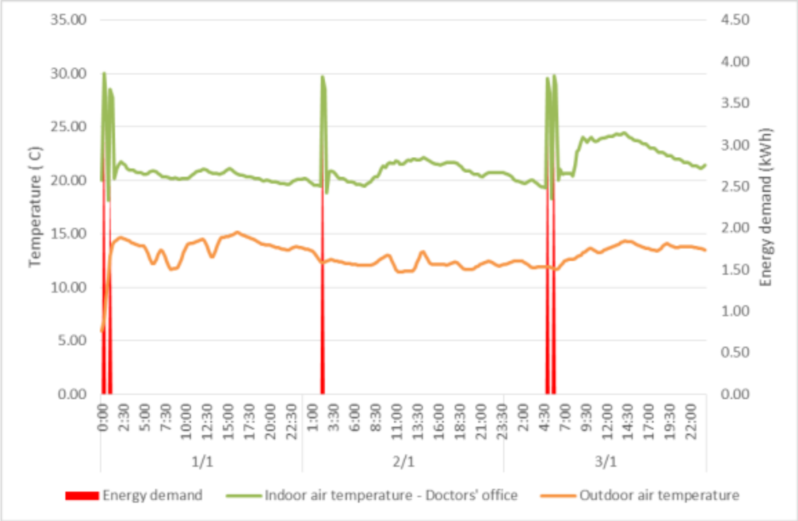


The building optimization and control algorithm - Results









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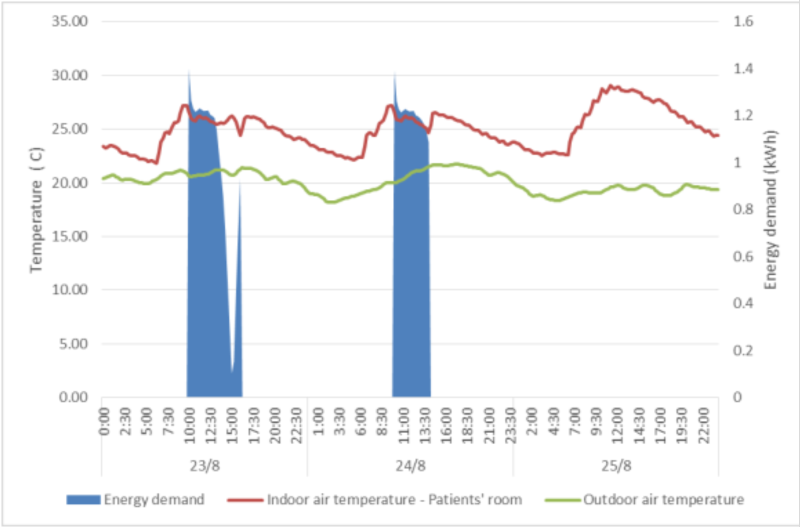

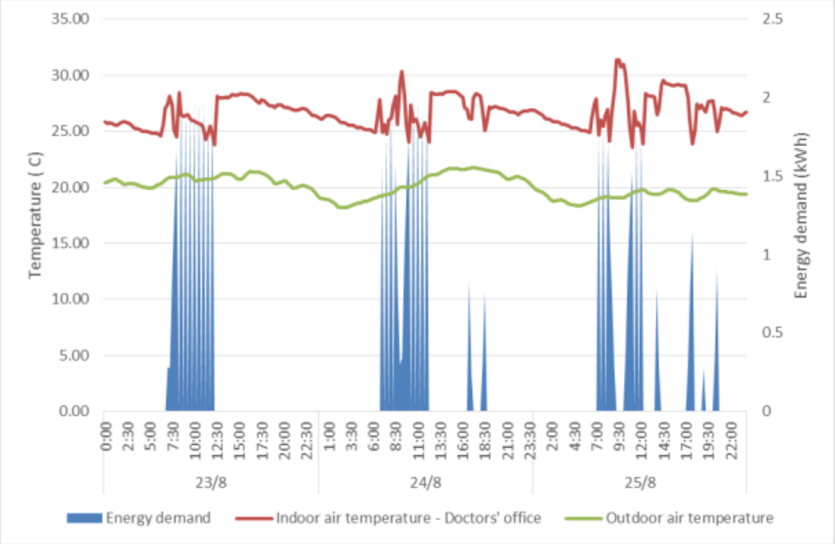

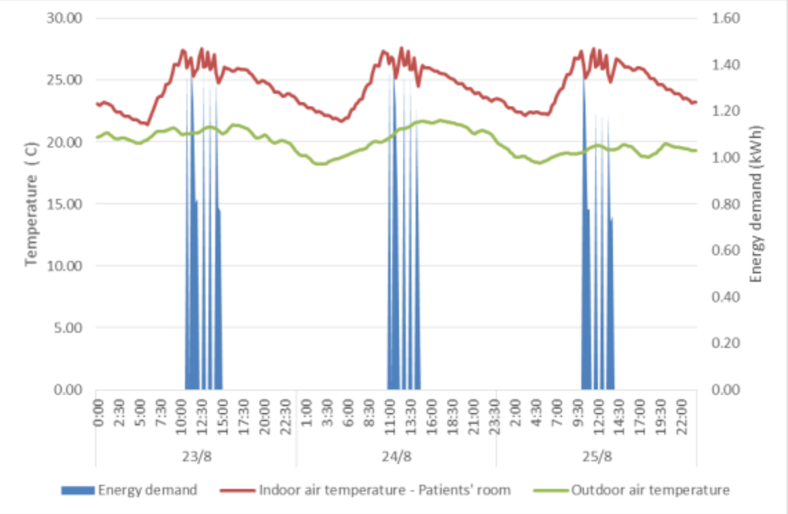

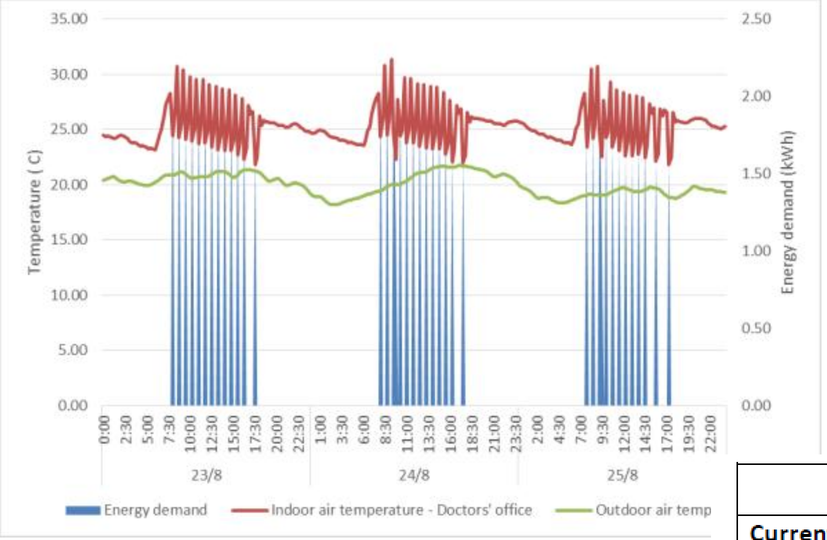

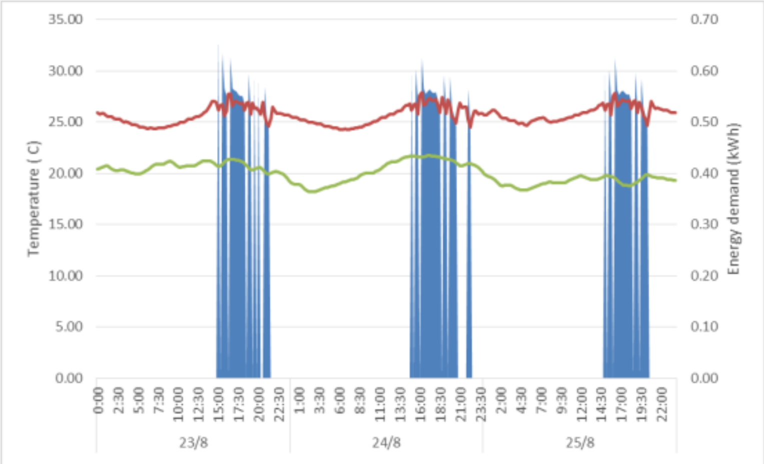

	Heating (kWh)	Cooling (kWh)	Total (kWh)
Current condition	4494.05	961.46	5455.5
Matlab BOC	1428.1	2073.28	3501.4
% Energy saving	68.22 %	-115.6 %	36 %

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Methodology followed

Control algorithms

Development phase

Input

Local controller

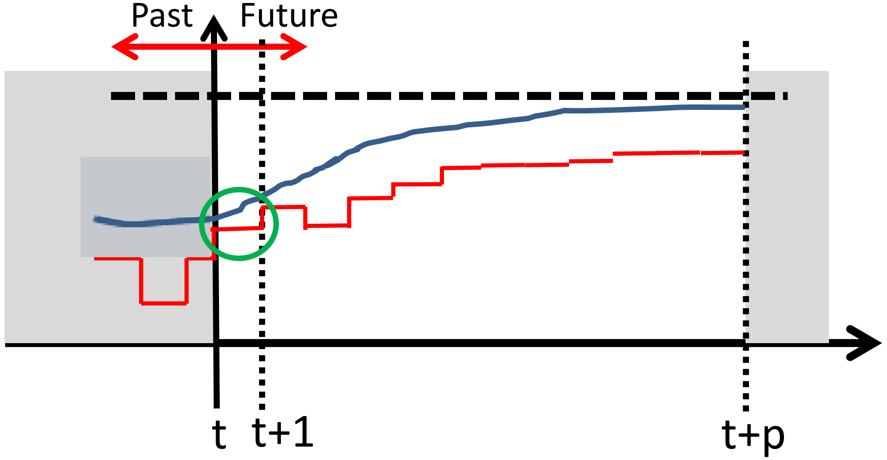
Output

Test phase

Local controller

TrnSySS/ Radiance model

Optimization algorithms



Implementation phase

Local controller/ Optimization

Green@Hospital

web-based enerGy management system foR the optimisation of the EnErgy coNsumption in Hospitals

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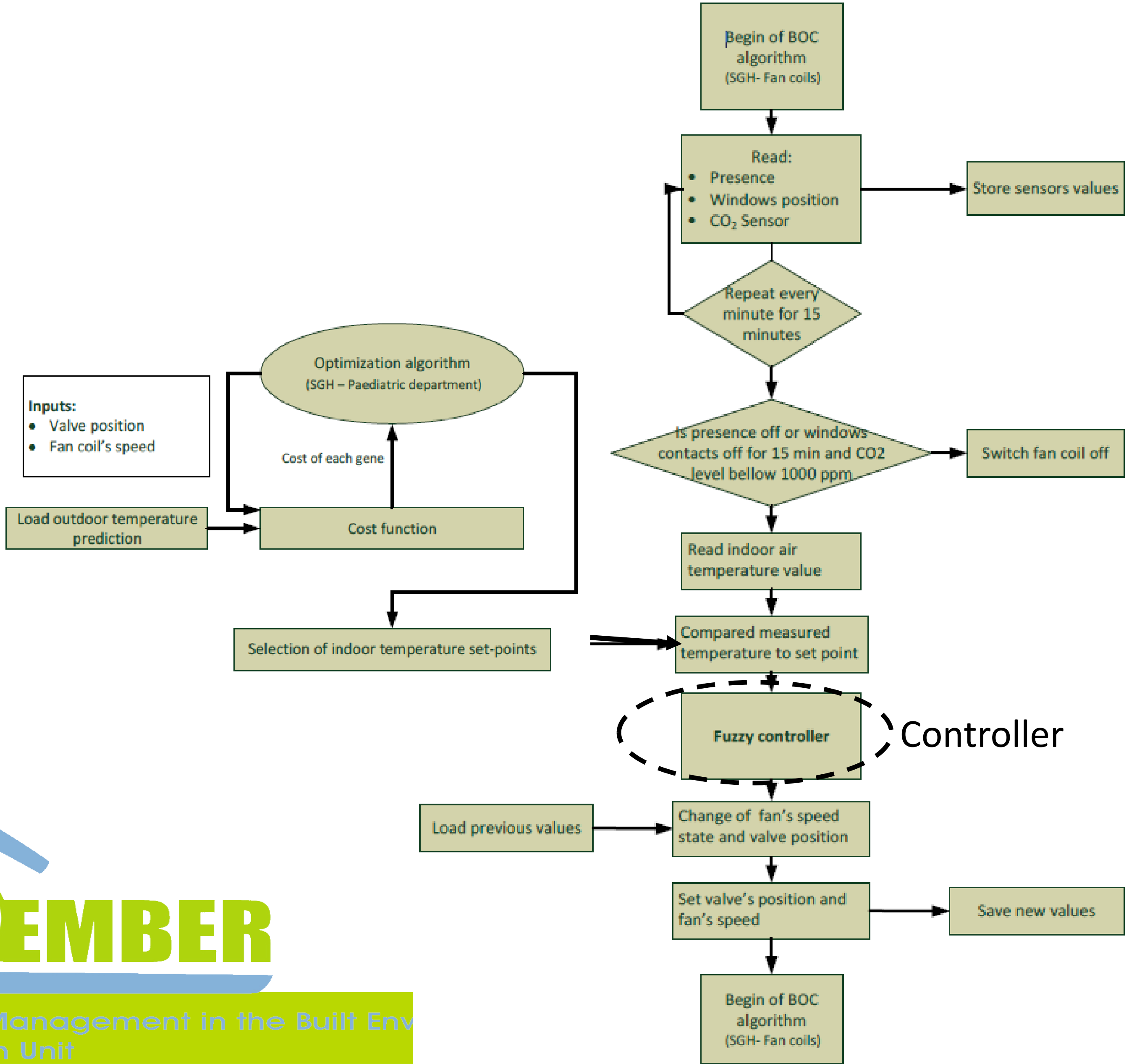
The building optimization and control algorithm - Strategy



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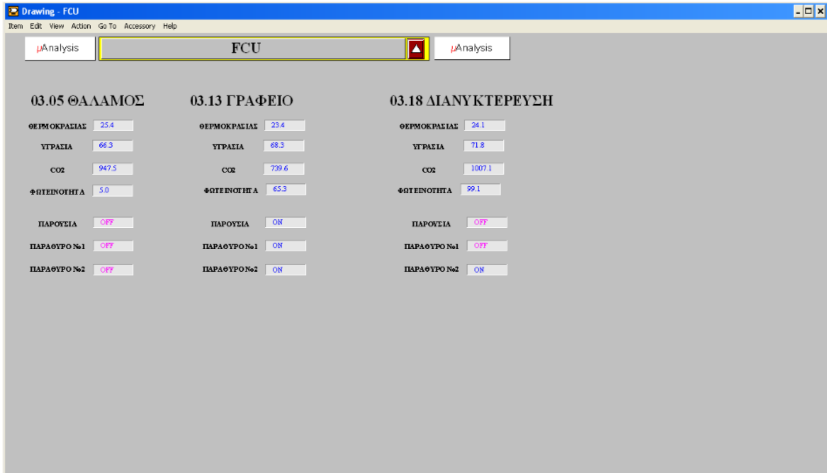
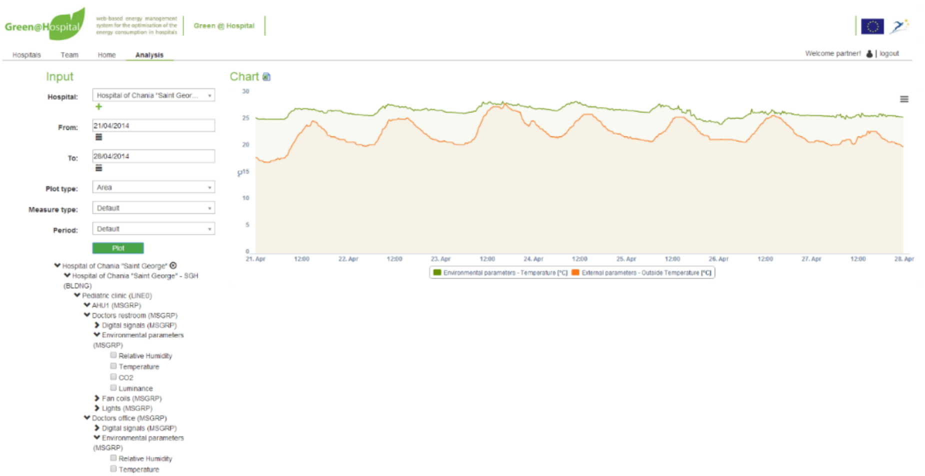
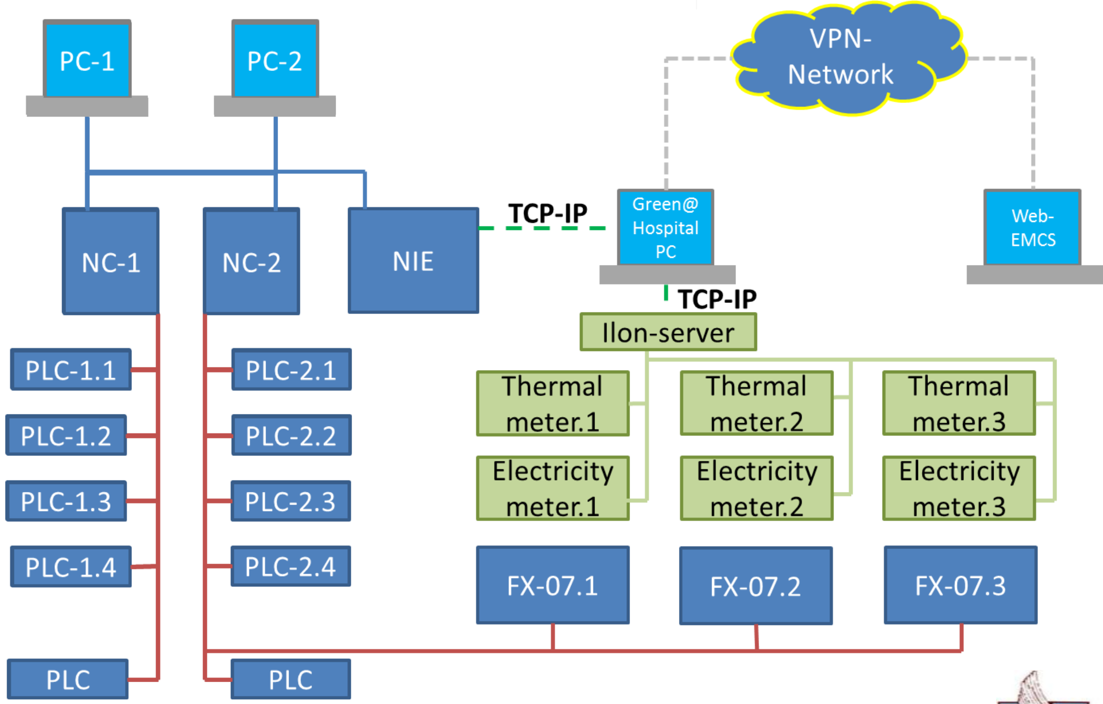
Development of a Web-EMCS







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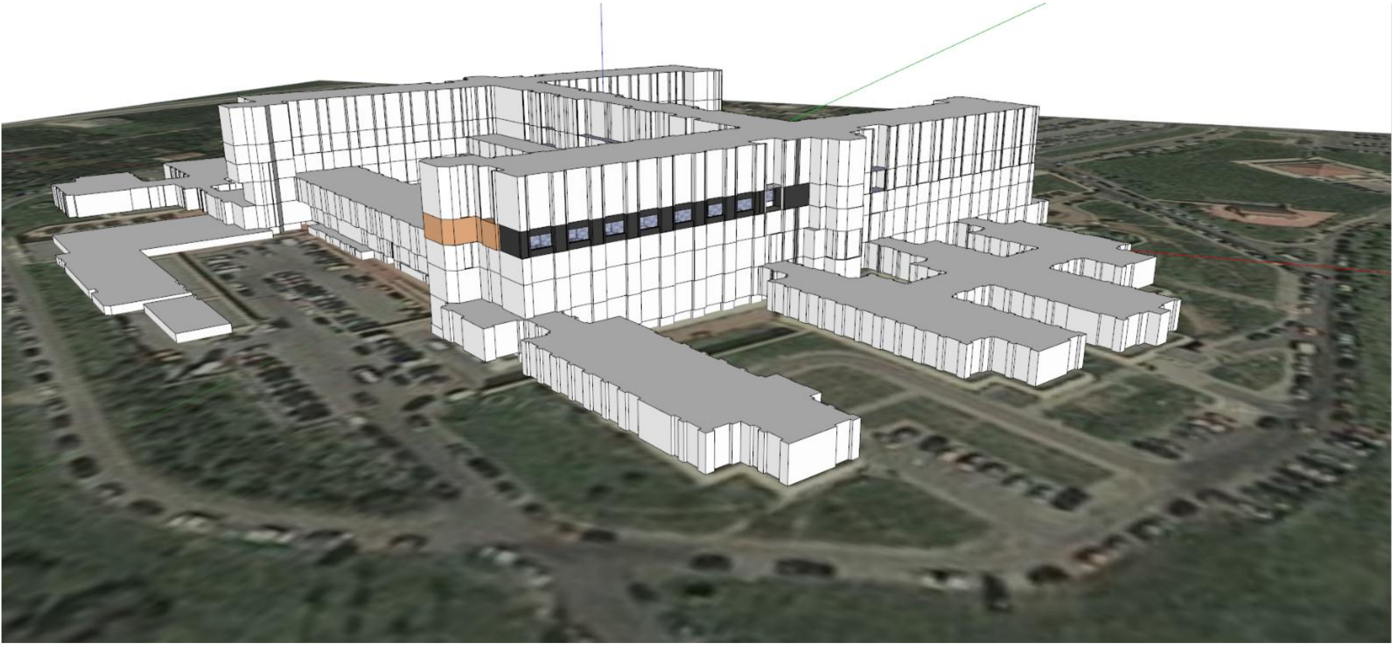
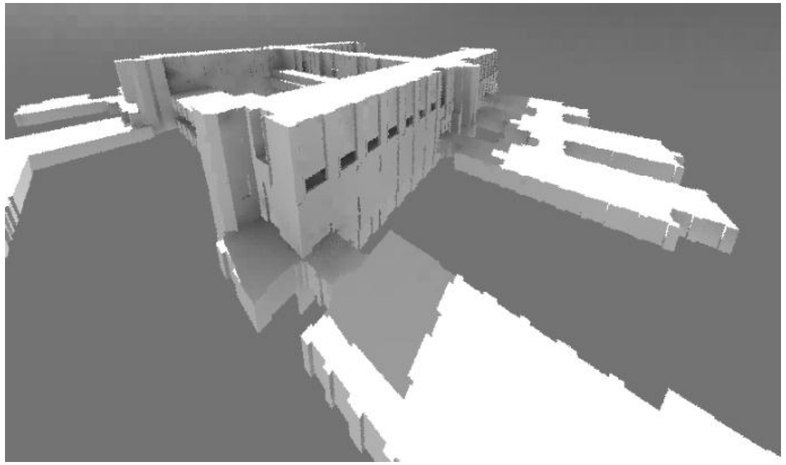
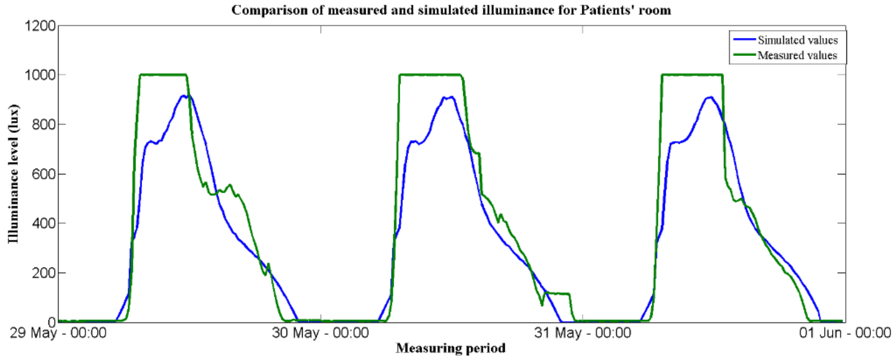
Artificial lights - Model development and validation

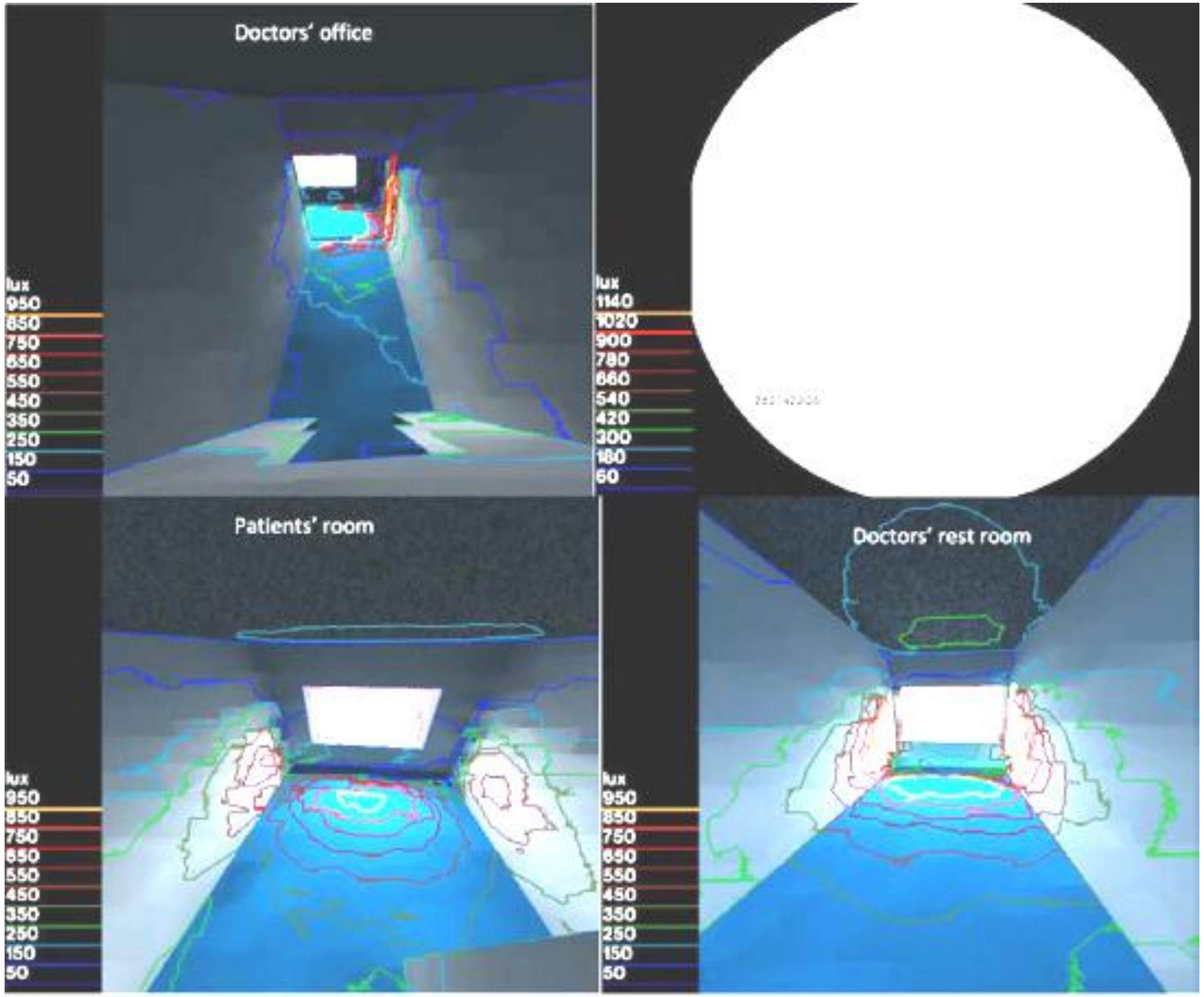




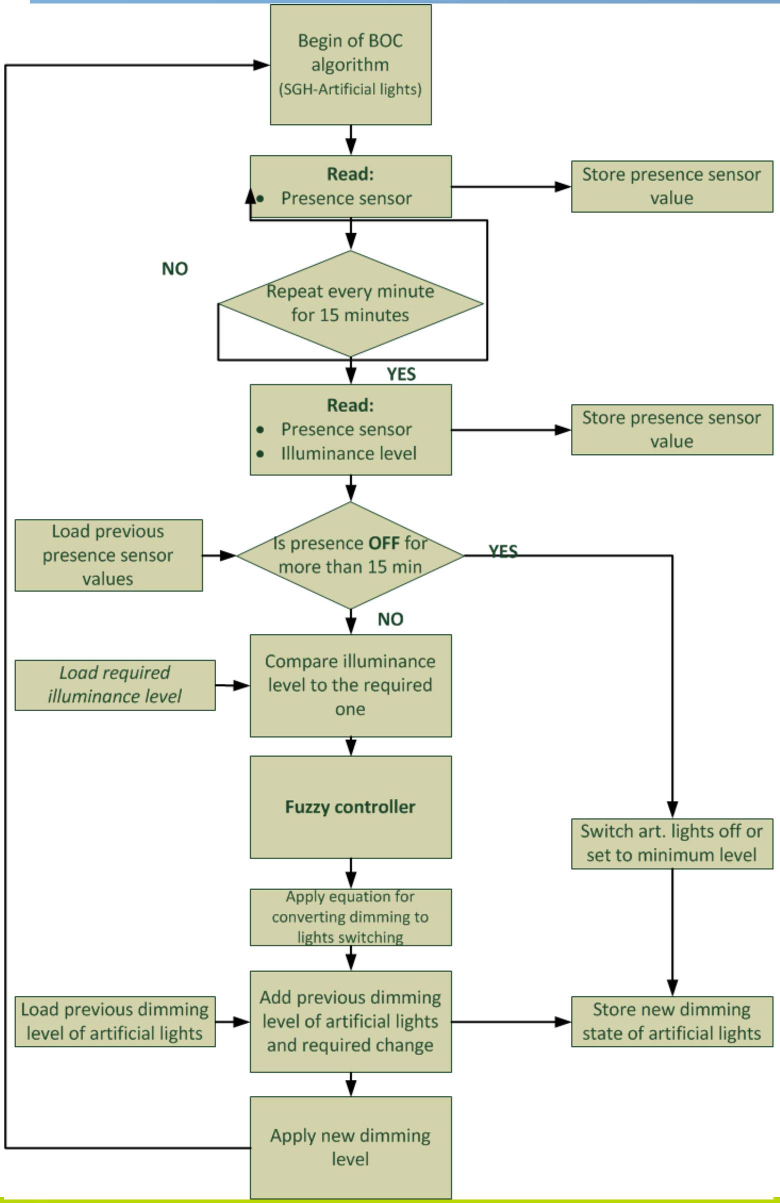


Dept	Room	R^2	rmse
Ped	Patient's room	0.9095	119.5 lux
	Doctor's room	0.7762	163.9 lux
	Doctors' rest room	0.2949	122.6 lux

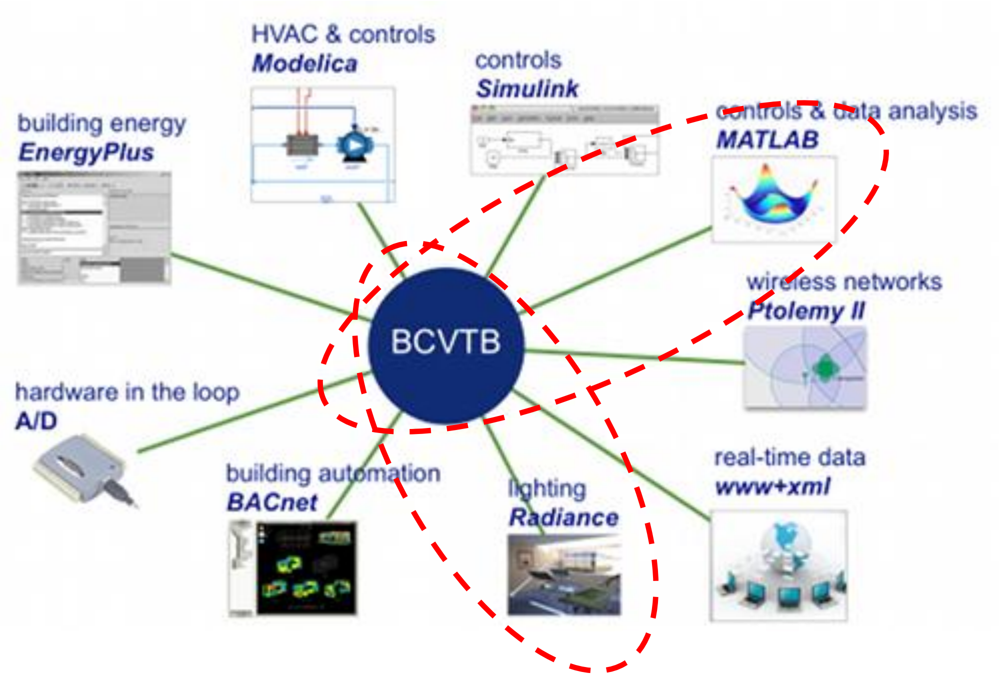
Artificial lights – Model output



Development of the BOC algorithm

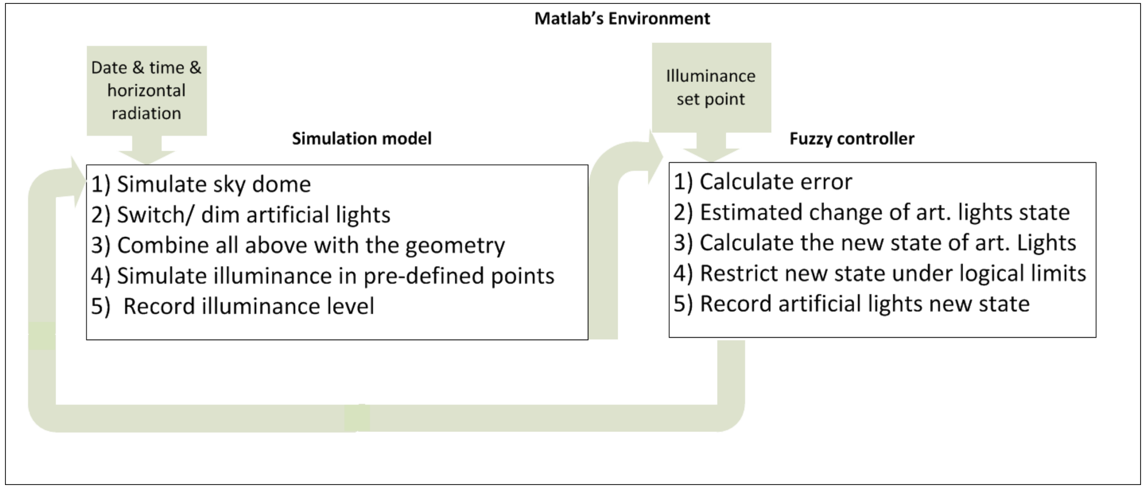


Connection between Matlab and Radiance



Current approach

Radiance currently connects with BCVTB only in Linux environment



Our proposal

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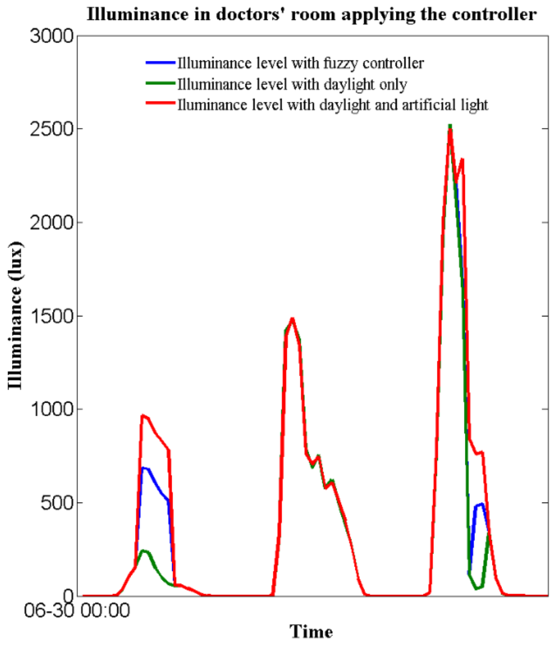
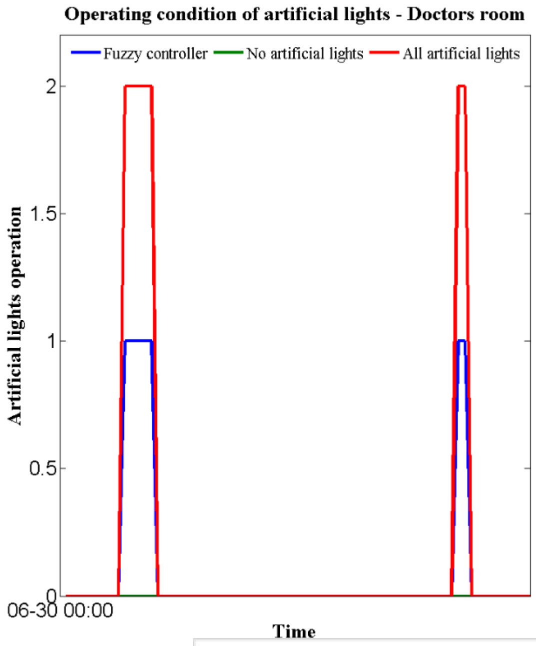
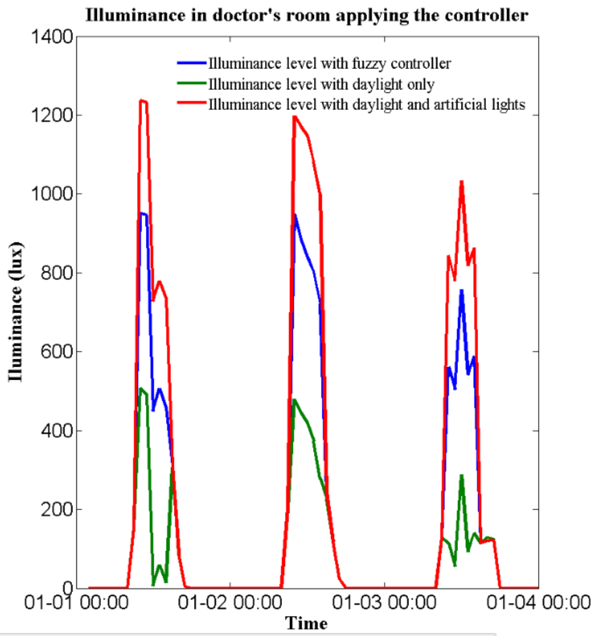
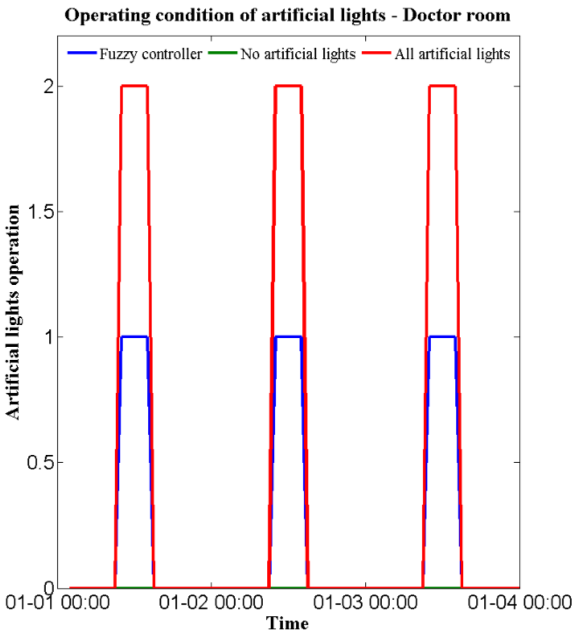
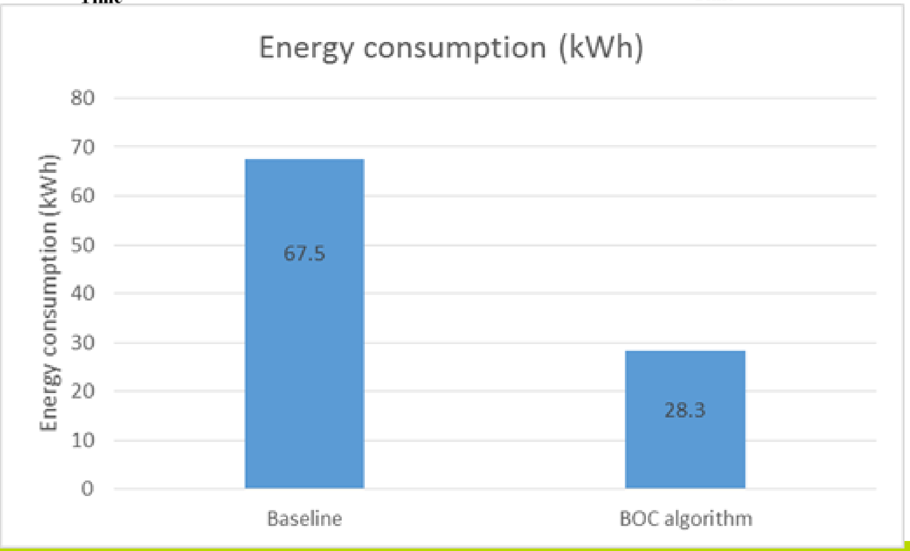
Energy saving potential – Saint George Hospital











Energy saving potential:
58 %

Preliminary conclusions

- ✓ Energy saving (> 15%) can be achieved using ICT in hospitals
- ✓ Control and optimization algorithms contribute to the energy performance of the systems
- ✓ Further improvements can be accomplished by fine-tuning the BOC algorithms

Publications

Journals

- **Sotiris Papantoniou**, Denia Kolokotsa, Kostas Kalaitzakis, Davide Nardi Cesarini, Eduard Cubi and Cristina Cristalli, "Adaptive lighting controllers using smart sensors", International Journal of Sustainable Energy
- Kolokotsa, D., Tsoutsos, T., & **Papantoniou, S.** (2012). Energy conservation techniques for hospital buildings. Advances in Building Energy Research, 6(1), 159–172.
- Mandalaki, M., **Papantoniou, S.**, & Tsoutsos, T. (2014). Assessment of energy production from photovoltaic modules integrated in typical shading devices. Sustainable Cities and Society, 10, 222–231.

Conferences

- Foutrakis, P., **Papantoniou**, S., Kalaitzakis, K., & Kolokotsa, D. (2013). DEVELOPMENT OF A SMART SENSOR FOR CONTROLLING ARTIFICIAL LIGHTS AND VENETIAN BLINDS. In 34th AIVC Conference (pp. 1300 – 1309).
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- **Papantoniou, S.**, Kolokotsa, D., & Pouliezos, A. (2012). Neuro-fuzzy model based predictive algorihm for environmental management of buildings. Chania: 3rd International Conference on Industrial and Hazardous Waste Management.

Acknowledgements

Green@Hospital

web-based energy management system for the optimisation of the energy consumption in hospitals

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Thank you
Questions?

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