INTEGRATED SMART INDOOR – OUTDOOR WEB BASED ENERGY MANAGEMENT SYSTEM FOR UNIVERSITY CAMPUSES

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Abstract

Universities' campuses can be viewed as small towns due to their size, users and mixed complex activities, enclosing numerous actions that occur in urban districts. Energy wastage in several building uses, such as teaching auditoriums, working areas (offices, laboratories, computer rooms etc.) or living areas (dormitories), can be encountered. Furthermore, since the University campuses comprise of buildings covered with artificial surfaces with undesirable thermal effects, along with the possible overheating by human energy release and absorption of solar radiation on dark surfaces of buildings, create an urban – kind climate. The energy and environmental impact of universities could be considerably reduced by applying organizational, technological and energy optimization measures. To design and operate a sustainable campus, it is essential to take into account – among other – the real time interaction between the indoor and outdoor environment, using sensors and metering equipment, local and global control algorithms and actuators to control heating, cooling, ventilation, lighting, shading and other types of systems. In the present work, existing Information & Communication Technology (ICT) is exploited to create a micro-grid by integrating sensors, actuators, control algorithms etc., aiming at minimizing energy consumption of buildings and activities within the Campus. On this basis, the research project Camp-IT is expected to create new frontiers for research and development in energy management by considering the single building aspect as part of a "district" approach, where real time interaction of indoor and outdoor spaces is monitored and controlled. The aim of the Camp-IT project is to review the techniques of building modelling incorporating outdoor spaces as well as the control algorithms for energy load prediction, in order to develop, test and validate an integrated and holistic indoor - outdoor Web based Energy management System for Campuses. Preliminary results indicate a potential reduction of annual energy consumption of approximately 30% due to reduction of energy waste.

As a result, this project will contribute to a future smart grid community by deploying and testing of a decision support tool and optimization method for a web based energy management system in real time conditions, taking into account indoor / outdoor environmental parameters and user preferences.

1 Development and validation of indoor and outdoor thermal models of the campus buildings

In order to implement the CampIT power management system, two buildings in the campus of the Technical University of Crete in Chania are selected and modelled.

Chania is a city on the eastern part of the island of Crete, the southernmost region of Greece. The climate in Chania is primarily Mediterranean, with mild winters and hot summers.

The University Campus (

Figure 1) is located approximately 6 km northeast of the city centre of Chania, 137 m above sea level. The campus area, confines five University departments, administrative buildings and student dormitories, with total area of 2,900 m^2.

The buildings (K1 & K2) selected for the Camp-IT project, house the Environmental Engineering Department facilities and services and both comprise the same type of materials and systems.

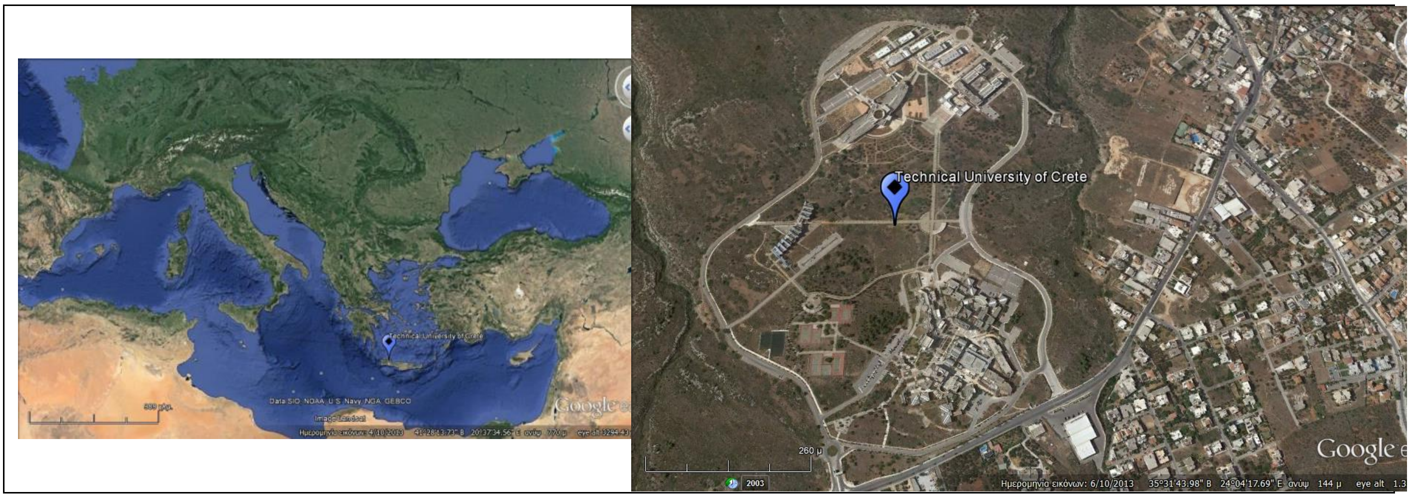


Figure 1. Technical University of Greece.

Table 1 summarizes the main characteristics of the selected buildings.

Table 1. Main characteristics of the selected buildings.

Characteristics of K1	
General Dimensions (m)	(Length/ Width/ Height): 86.40 / 15.20 / 12.00
Number of Floors	3
Facilities on Ground floor	14 laboratories, 3 offices, 2 mechanical rooms, elevators, stairs, WC
Facilities on 1st floor	17 offices, 1 meeting room, 2 mechanical rooms, elevators, stairs, WC
Facilities on 2nd floor	Laboratories & mechanical rooms
Characteristics of K2	
General Dimensions (m)	(Length/ Width/ Height): 48.00 / 15.20 / 11.00
Number of Floors	3
Facilities on Ground floor	5 computer rooms, 1 printer room, 1 office, 1 mechanical room, elevators, stairs, WC
Facilities on 1st floor	3 laboratories, 14 offices, elevators, stairs, WC
Facilities on 2nd floor	Mechanical rooms
Characteristics of Exterior spaces	
Exterior spaces	Soil, marble, stone, tiles (cotto), plants, trees

The building K1 is located at the northern end of the campus with its main façade facing north-west. The distance between K1 and K2 is approximately 16.20 m, with K2 sited to the south of K1. Each floor of K1 is divided in two wings, connected through an atrium. The structural materials of K1 and K2 are described in Table 2. (Technical Administration of TUC 2000).

Table 2. Structural materials of buildings K1 and K2.

Structural materials of K1 & K2	
Exterior walls	**Ground and first floors ceilings**
a) Double plasterboard (width:18mm each) b) Insulation: 5 cm rockwool, d=80kg/m^3 c) Cement board: 12 mm	a) Uncoated concrete: 2 cm b) Insulation: 5 cm rockwool, d=80kg/m^3 c) Ceramic tiles: 10 mm
Second floor ceilings	**Windows (104 windows in B1 & 68 windows in B2)**
a) Uncoated concrete: 2 cm b) Insulation: 10 cm c) Asphalt membrane: 10 mm	a) Double pane windows b) Aluminium frames c) Exterior lamellas
Floor top coating	
a) Ceramic tiles: 10 mm (in all spaces) b) Industrial flooring: 20 mm (Chemistry lab)	

Figure 2 and

Figure 3 depict the buildings under study, the exterior spaces around them and the topography of the area.

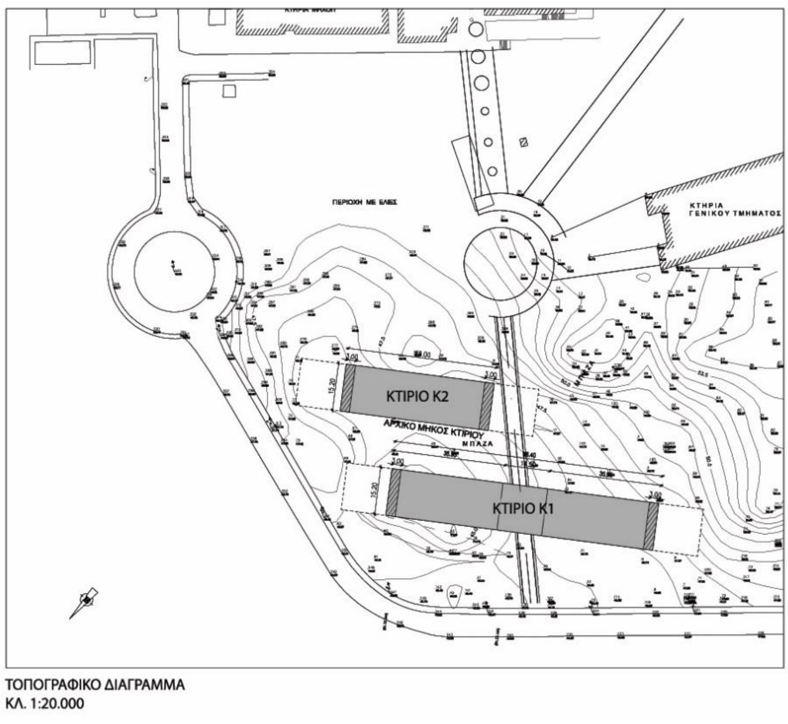


Figure 2. Topographic plan of campus buildings K1 and K2.

Figure 3. (a) east side of buildings K1 and K2, (b) south side of building K2, (c) the outside environment between K1 (left) and K2 (right), (d) external environment in the south (right) of K2

The two buildings K1 and K2 and one open space (bordering the chosen buildings) is used for the Camp-IT web-based energy management system development. In order to manage the application stage, this is done in three phases:
Phase 1: Implementation of control algorithms in buildings without additional hardware interventions. This phase provides energy data with the improved energy management system (EMS) implemented.
Phase 2: Installation of hardware and technologies in the buildings and surrounding public spaces.
Phase 3: Implementation of control algorithms in the buildings and possible off-line monitoring in public spaces. This phase provides energy data with hardware and new technologies in place.
At the present time, the Camp-IT project timeline is during the implementation of Phase 2, in which all the hardware technologies are installed in the buildings.

1.1 Outdoor modelling

The external environmental conditions (air temperature, solar radiation, wind speed, humidity, etc.), combined with the geometry of the built environment in urban and semi-urban regions, affects human activities and can lead to local increase in temperature.
The outdoor environmental conditions simulation enables the forecast of thermal discomfort phenomena and facilitates the prevention of possible harms or damages. External environmental conditions can be predicted by complex microscale or mesoscale computer

models (CFD, OpenFoam, MIST, ENVIMET, WW5, etc.). In this case, the three-dimensional microclimate model ENVI-met is used. (Bruse 2004)

The first step for performing the simulation involves the pre-processing, were the campus domain (

Figure 4) is described using a computational grid. Initial boundary conditions of the campus area are set, such as the roughness coefficient of the various building and soil surfaces, the size and coverage of vegetation, while the physical fluid properties are specified.

Figure 4. Campus Buildings and their surrounding environment.

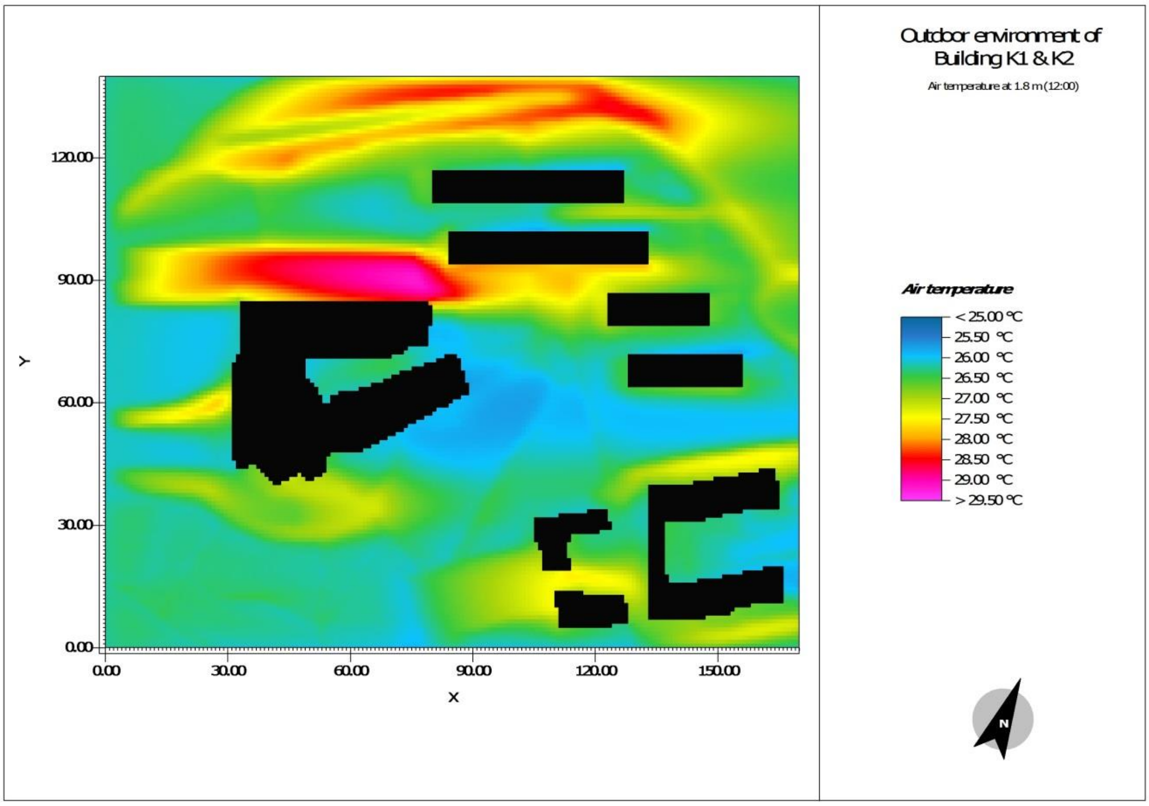


Figure 5. Spatial distribution of the air temperature at 12:00 at a height of 1.8m

Subsequently, the outdoor model is linked with the indoor energy model described below, in order to improve the accuracy of the indoor energy management system.

1.2 Indoor modelling

The ESP-r energy modelling tool is employed for the campus building simulation. ESP-r is a building simulation program which has been under development for more than 25 years. It is available at no cost under an Open Source license. ESP-r can simulate any element of the building envelope and the related electrical-mechanical equipment, for example rooms, stairways, doors, windows with different types of glass, internal-external or fixed or movable awnings, external or internal walls and the electrical-mechanical equipment. (William et al. 2014).

The following procedure is followed for a building simulation in ESP-r (

Figure 6):

1. Conversion of all drawings in digital format
2. Creation the 3D building model in SketchUp
3. Export of data (.geo, .cnn, .cfg) suitable for insertion into ESP-r.
4. Data import in ESP-r
5. Definition of the physical characteristics of materials, coverings as well as weather archive, internal gains from users, lighting and equipment, etc.
6. Validation (fine-tuning) of the ESPr model using measurements of outdoor and indoor temperature in representative spaces of different orientation, use etc.

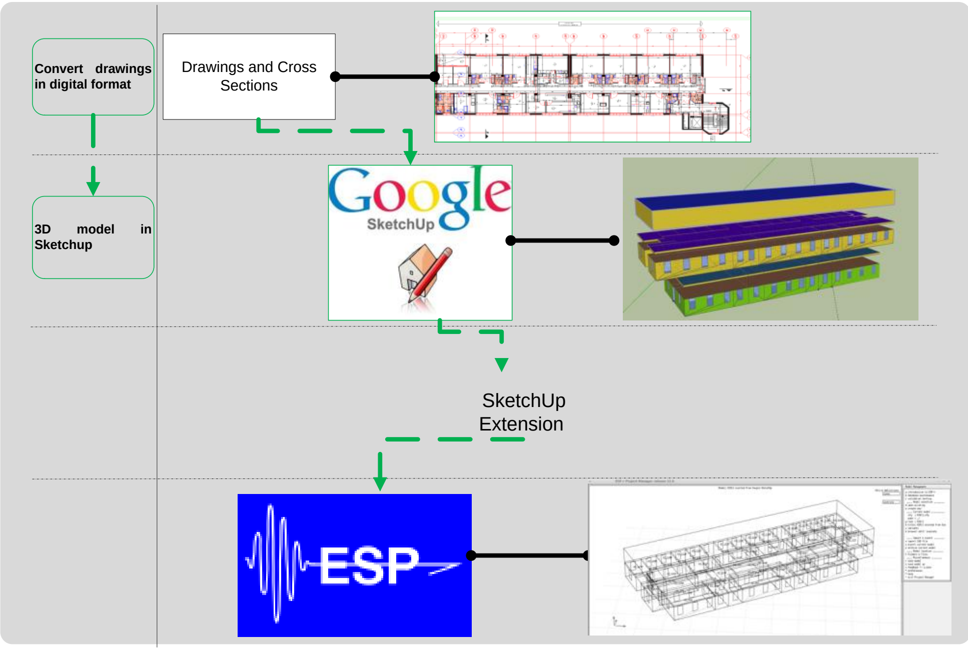
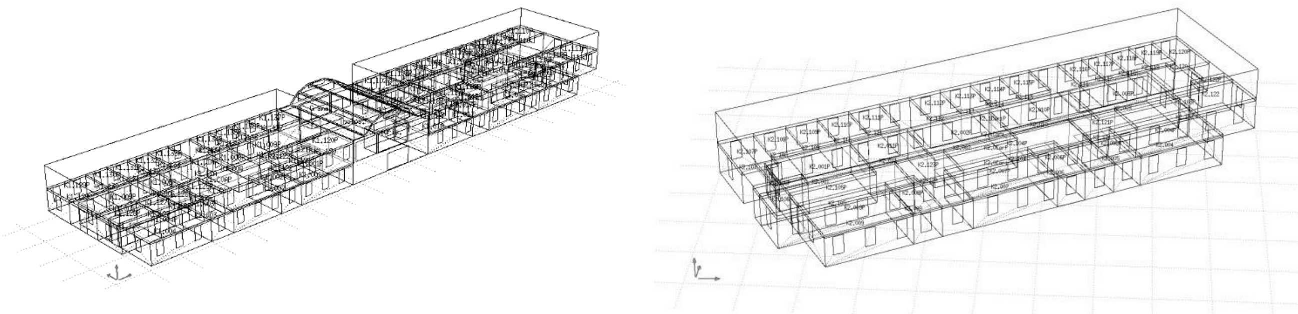


Figure 6. Schematic description of the development of geometry in ESP-r.



K1 building K2 building

Figure 7. K1 & K2 Building models in ESP-r.

2 Development of control and optimization algorithms

After the development of the indoor and outdoor thermal models, the control algorithms for the central air conditioning units and lighting systems of the building facilities of the School of Environmental Engineering were developed. The architecture of the optimization algorithms is depicted in
Figure 8. (Kolokotsa et al. 2009; Papantoniou et al. 2014)

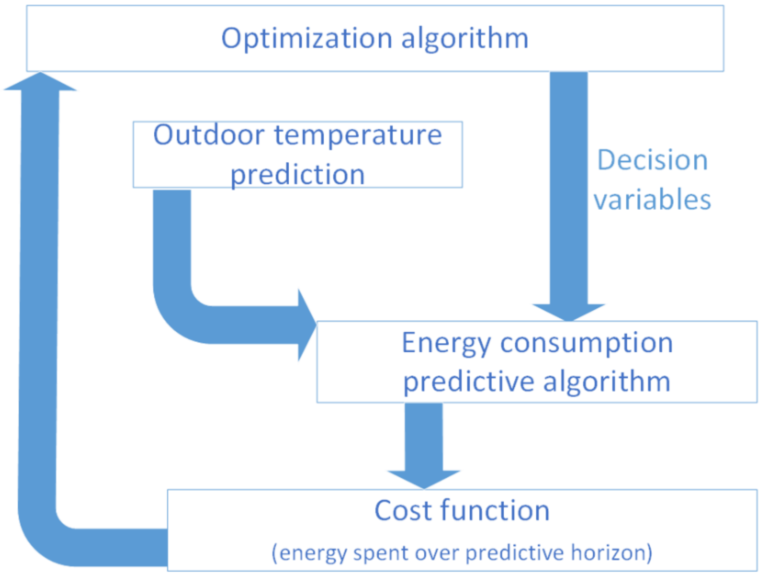


Figure 8. Architecture of optimization algorithms.

Control algorithms were developed based on fuzzy logic for the operation of the lighting devices. As a result, visual comfort is ensured when natural light is not enough, while energy is saved by automatically turning off the lights as appropriate. The developed algorithm controls the thermal comfort, expressed by the PMV index, which involves the comfort of building users and the air quality, measured in carbon dioxide concentration. The PMV index is calculated taking into account the temperature and humidity of the air, measured by suitable indoor sensors. The developed controller regulates the operation of the air conditioning and ventilation systems. The control algorithms run online on field-controllers, which monitor continuously the indoor conditions using the installed sensors.

In parallel, the predicted outdoor air temperature is combined with neural network algorithms for the calculation of the indoor air temperature, in order to develop an optimization process for the definition of the proper indoor air temperature set-point, which minimizes the energy cost of the HVAC systems operation in the next 8 – 12 hours. Thus, the running cost of the HVAC systems is further reduced, while maintaining the indoor comfort level. This process is executed offline and the calculated set-points are fed to the field-controllers. (Santamouris et al. 1999). In Figure 9, three different energy management scenarios are shown, depending on the selected control parameter (indoor temperature, air quality, energy consumption).

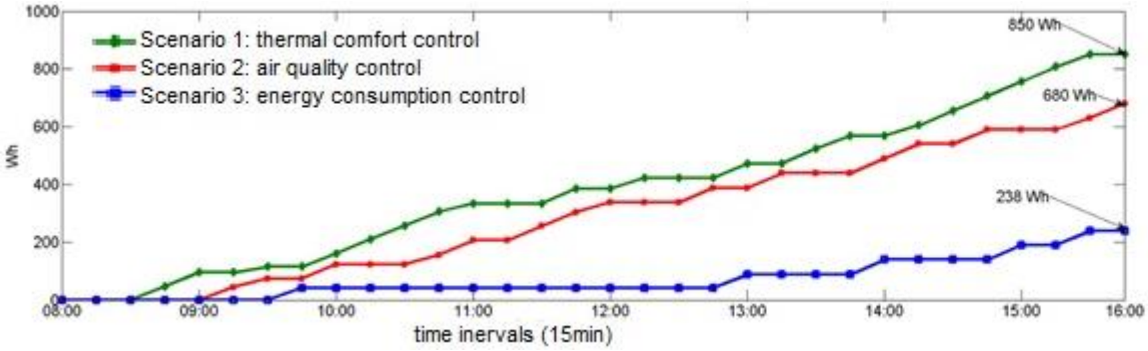


Figure 9. Energy management scenarios

3 Interconnection of indoor-outdoor thermal models and control algorithms for fine-tuning

The control algorithms, developed in the Matlab environment, need to share data with the thermal model developed in the ESP-r software. The communication between the two control algorithms is performed using the Building Control Virtual Test Bed (BCVTB) program. By means of the BCVTB, the above mentioned algorithms, developed in different software environments, exchange data in real time. The outdoor model calculates the environmental parameters, which form the weather file of the indoor ESP-r building model. This forecasting is used for the fine tuning of the energy management model.
Installation-Integration
The development of all models and control algorithms enabled the specification of the monitoring and control equipment, which is being installed in the buildings K1 and K2 of the Technical University Campus (Table 3). The project demonstration at the campus involves the actual installation of the developed technologies and instrumentation.

The equipment per building includes:

Table 3. Equipment installed in each building

11 Temperature-Humidity sensors	
11 Indoor CO_2 sensors	
11 Indoor CLC sensors (brightness level control)	
11 relays	
12 Motion Detection Sensors	
4 Multipurpose Management Appliances- Local controllers (MPM)	
35 opening / closing window detecting sensors	
11 opening / closing door detecting sensors	
1 Electrical energy meter	

The above equipment provides the input data for the control algorithms, which are executed in the local controllers (MPM).

The interconnection of the local controllers and the controlled devices is achieved by means of the StruxureWare platform, which supports data exchange between the MPM and the BMS of the building, Figure 10.

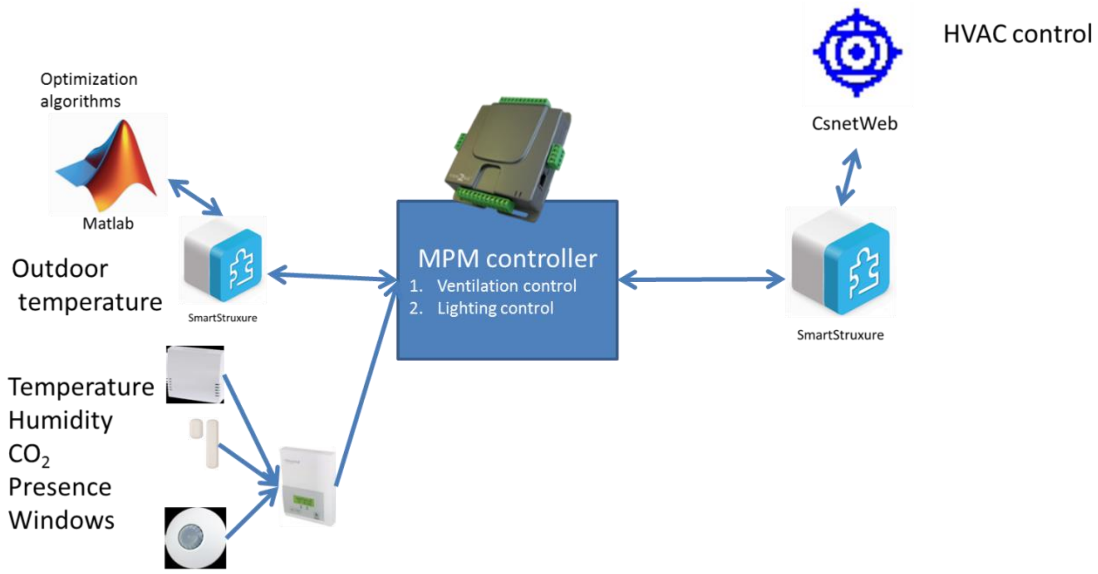


Figure 10. Interconnection of control algorithms local controllers and HVAC-lighting devices.

Furthermore, a user friendly dashboard has been created, integrated into the Camp-IT website (www.campit.gr), for visualization of the measurements and the energy consumption, as shown in

Figure 11. The temperature (^oC), the air quality (ppm CO_2), the relative humidity (%), the power demand (kW) and the presence and windows situation (open or closed) are illustrated in real time, for each building room.

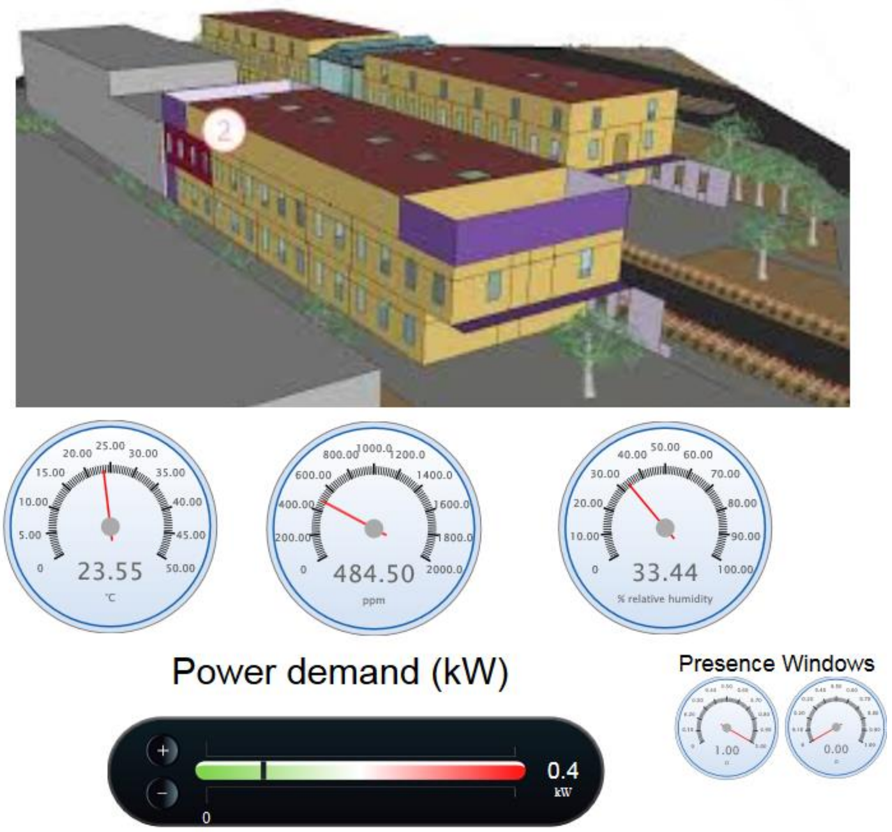


Figure 11. The Camp-IT Dashboard.

4 Results

At the present stage of the Camp-IT project, the equipment and hardware have been installed for the interconnection of the energy management system. The results, regarding the indoor/outdoor thermal models and the control algorithms of lighting and air conditioning, indicate energy savings up to 30%.

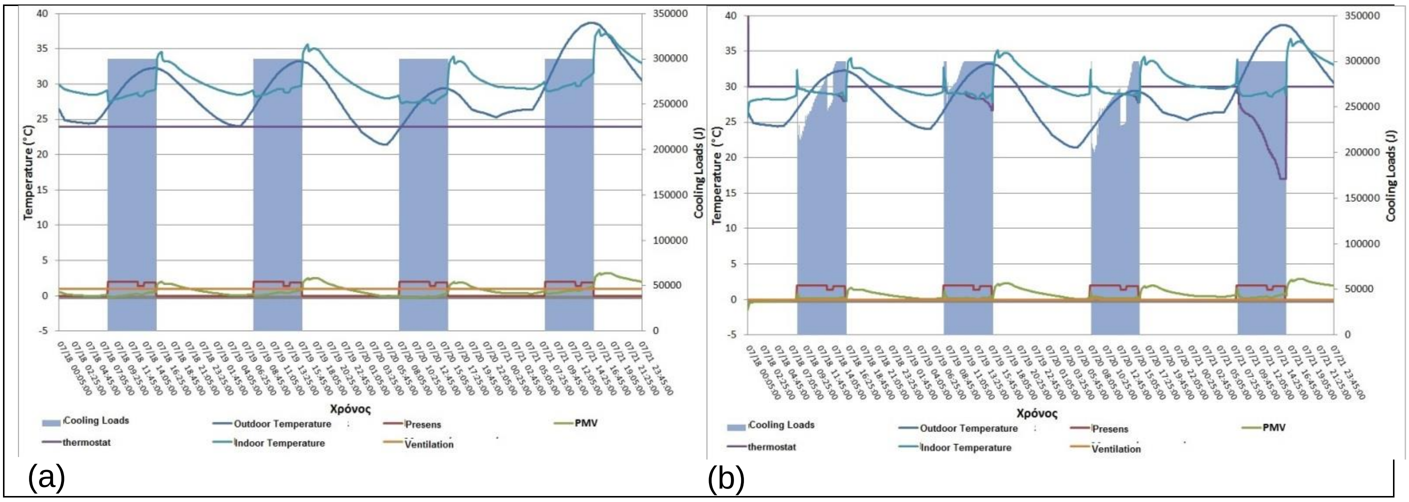


Figure 12. Cooling loads and indoor comfort in a building office with (a) the existing energy management system and (b) the proposed control algorithm during the warmest week of the year.

The control algorithms reduce the inclination of the buildings' energy signature as indicated at the Power Demand (y-axis) – Ambient Temperature (x-axis) diagram (Figure 13) (Belussi & Danza 2012).

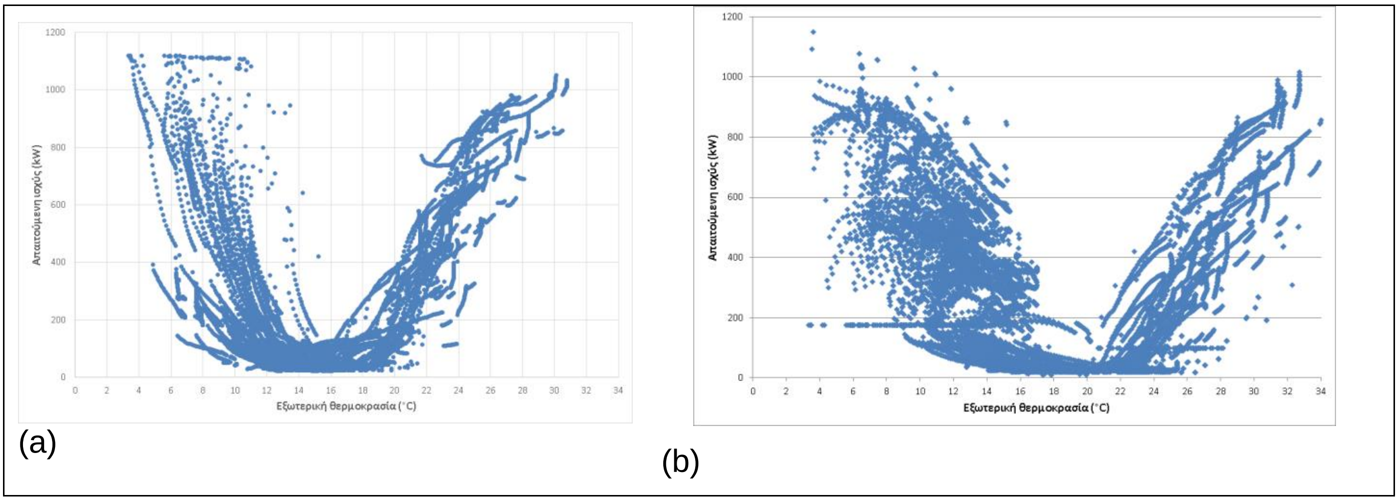


Figure 13. W-t diagramm before (a) and after (b) the controll algorithms.

5 Conclusions

Currently, the rest of the equipment is being installed and tested by the Ember research staff and Camp-IT partners.

After the completion of the installation, the verification in the campus sites will be performed, to ensure the proper functionality of the whole system, i.e. the data collection and processing software, the sensors, actuators & user-interfaces, as well as the interconnection, using smart metering, with the power substations. The necessary off-line testing will also take place within this task, mainly for the public spaces. According to the validated model energy savings of up to 30% can be achieved. Nevertheless, this project constitutes part of TUC's Strategic Sustainable Development Plan, aiming at measurable results and promoting the University to become an "open lab" for research and technology in sustainable development.

6 References

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