An Intelligent System for Energy Efficiency in a Complex of Buildings

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***Abstract*—Energy efficiency has nowadays become one of the most challenging task for both academic and commercial organizations, and this has boosted research on novel fields, such as Ambient Intelligence. In this paper we address the issue of timely and ubiquitous monitoring of building complexes in order to optimize their energy consumption, and present an intelligent system addressed to the typical end user, i.e. the administrator, or responsible operator, of the complex. A three-level architecture has been designed for detecting the presence of the building inhabitants user and understanding their preferences with respect to the environmental conditions in order to optimize the overall energy efficiency of the buildings. Wireless Sensor and Actuator Networks (WSAN) are used to remotely monitor and control the environment according to the decisions made by a centralized reasoner. A case study derived from an actual implementation of the system regarding the management of a university building is also described.**

I. Introduction

In recent years, mainly due to a greater sensitivity to the different types of pollution and, more recently, to the Global Financial Crisis, the issue of *energy efficiency* has caught the interest of many researchers with different backgrounds ranging from nanotechnology to computer science. This work addresses the scenario of smart solutions for energy efficiency in a complex of buildings by means of intelligent tools for monitoring and automatic control of *power consumption* in everyday life.

Commercial building automation systems usually provide a fixed set of well-known, useful, controls (e.g., lighting or heating), and a variety of home entertainment solutions (e.g., automatic adjustment of audio/video devices). The main limitation of such systems is the lack of flexibility to dynamic situations. In fact, most of the commercial systems are heavily dependent on choices made at design time, so that structural or logical modifications in the monitored environment often require a reengineering process of the whole system. For this reason, dynamic, intelligent, systems are preferable.

Ambient Intelligence (AmI) is a new paradigm in Artificial Intelligence that focuses on the role of the end user. AmI techniques can be applied to efficiently understanding dynamic environments, from a single home to an entire district, and make decisions according to some high-level constraints, e.g. user preferences. In traditional building automation systems, the user interacts with the system, while in Ambient Intelligence scenarios the user preferences are fully integrated into the system. In this respect, the fundamental requirement of any AmI system is the presence of pervasive devices, e.g., sensor nodes, which are essential to ensure context-aware reasoning in order to act upon the environment, modify its state, and react to user-driven stimuli.

Today's advances in technology allow for cheap and unintrusive sensors that may be easily distributed in the environment in order to sense relevant measurements. In particular, Wireless Sensor Networks (WSNs) are one of the most interesting and investigated approaches for reliable [1] remote sensing. WSNs are typically made of hundreds of small and cheap devices, each containing a microprocessor, memory and radio unit. Such nodes communicate with each other and are equipped with a number of expansion boards in order to measure the data of interest (e.g., temperature, humidity, light intensity, noise level, acceleration, GPS) in real, unconstrained, scenarios.

Even if WSNs easily allow for low-level ambient sensing, basic nodes are not sufficient to perceive high-level features such as *who* is in a room or *what* this person is doing there (e.g. reading, talking, using their workstations, and so on); for this purpose, a combination of low-level and high-level sensors is needed. The work [2] describes an approach based on Bayesian Networks for merging data coming from heterogeneous sensors, in order to improve the detection of the user presence.

Wireless Sensor and Actuator Networks (WSANs) extend the functionalities of traditional WSNs by adding control devices, i.e., actuators. Such networks do not only passively monitor the environment, but represent the tool by means of which the system interacts with the surrounding world. WSANs are the active part of the system and allow to modify the environment according to the observed data, high-level goals (i.e., energy efficiency) and user preferences.

Traditional systems use an AmI approach for the efficient management of an individual building, or in many cases, for a few rooms.

The challenge addressed in the proposed work is the realization of an intelligent system for timely and ubiquitous observations of a *complex* of buildings. The end user of such a system is the administrator of the complex, who needs a unique tool for efficiently managing the whole structure.

For example, an intelligent system for energy efficiency in

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building complexes is needed as part of future *smart grids* [3], [4], i.e., electrical grids that address the problem of energy efficiency and sustainability of electricity services, and can be effectively used by private citizens as well as by public organizations.

The paper is organized as follows: some related works are presented in Section II, while the proposed system architecture is described in Section III. A case study implemented at the University of Palermo will be shown and discussed in Section IV. Conclusions will follow in Section V.

II. Related Work

Many architectural solutions, showing different degrees of complexity both with respect to the adopted technology and to the overall architectural structure, have been proposed in literature for Ambient Intelligence systems. The adequacy of each solution needs to be evaluated in relation to the goals of the AmI system.

Simple architectures and cheap technologies are adequate mainly when the adopted energy saving strategy is to develop a full users' awareness about energy consumption. Providing simple feedbacks can valuably influence the users behavior since, in general, users do not have consciousness of their energy footprint and of the potential influence of their day-to-day behavior impacting energy consumption [5]. Such strategy has been adopted in several projects, such as Google PowerMeter [6], Berkeley Energy Dashboard [7], the AlertMe tool [8] and the Cambridge Sensor Kit (CSK) for Energy [9], [10]. The main part of this type of architecture uses a single point of measurements for energy consumption, so that the resulting architecture is very simple. An exception is the beAware project [11], [12] adopting a WSN-based architecture for providing users information about the energy consumption of each appliance. Although feedbacks represent the first step for users obtaining some reduction in energy waste, their effectiveness is limited.

With respect to this simple energy saving strategy a little improvement can be achieved by enhancing the energy monitoring system with a set of smart interfaces that allow users to easily interact with the actuators [13]. Nevertheless, in our opinion, this choice is not sufficient to ensure a steady level of energy saving [14], especially in an office environment [10].

The best choice in order to obtain a more relevant and stable energy saving is to adopt a totally automated Building Management System (BMS). Such a system has to be able to monitor energy consumption, to sense environment conditions, and to modify these conditions through the actuators deployed into the environment, such as the HVAC (Heating, Ventilation and Air Conditioning) and lighting devices, in order to get the ambient conditions to the desired state.

A number of general-purpose BMS architectures have been proposed, however, considering the ever increasing relevance of energy saving in the context of building automation, the number of energy-aware BMS architectures is correspondingly rising.

GreenBuilding [15] is a BMS architecture, based on WSNs, supporting moderately heterogenous hardware. Two different architectural schemes are proposed: the former, with homogeneous technology, but more costly, and the latter with a greater degree of heterogeneity, but cheaper. Both schemes assume the presence of: a system for monitoring the energy consumption of electrical appliances and the environmental state; a control system, able to tune or even switch off altogether the energy flow to devices. Sensory data are collected into a central server that carries on the various policies for energy saving and actuator control. Some other solutions [16] use the same infrastructure for both sensor and control devices.

Separating sensors and actuators may be convenient in terms of costs, since wireless sensors for energy monitoring are still quite expensive to date, but such a solution requires an additional effort for technology integration, since actuators cannot be directly combined with a WSN. Moreover, several works in literature on pervasive and distributed systems state the need for a multi-layer architecture allowing to cope with heterogeneity at a sufficient degree of abstraction [17], [18], [19].

The DOMOSEC architecture [20] aims at integrating several communication technologies through an IP-based platform; the main goal is to avoid a tight dependence on a specific technology. The separation between the application layer and the physical one is the driving idea of many works presented in literature, such as [21], [22].

Moreover, some works aims to achieve greater separation and independence through a hierarchical architecture. A hierarchical architecture with gateways interconnecting different technologies is proposed in [23], [24], in the context of the AIM project [25]; the main goal is the establishment of a bridge between home communication and power distribution networks in order to control the energy consumption of household appliances.

To the best of our knowledge, works proposed in literature principally focus on a single intelligent building, interacting with the external world not more than for communicating with the end user or with external servers. A notable exception is the work proposed in [26] whose goal is to provide insight on how power is consumed in a complex of buildings. However, it lacks a view of the building as part of a community, where buildings cooperate in order to achieve common goals such as energy saving and users wellness. Our approach differs from other works because it deals with a complex of buildings in which a common and shared energy saving strategy can be adopted. Moreover, buildings complexes are able to share aggregated information with each other, in order to develop a distributed basis for comparing the efficiency of the energy saving policy adopted by each one.

III. System Architecture

Our system focuses on *sensing* the presence of the user and understanding their preferences in order to optimize the energy efficiency of the building. However, in such a dynamic scenario, sensory data is likely to be biased by environmental

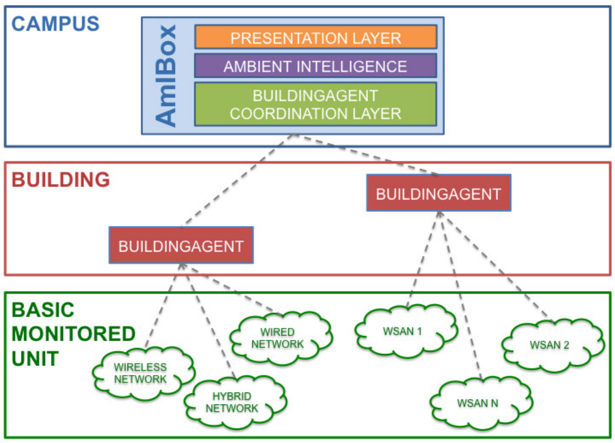

Fig. 1. System Architecture.

noise and by the imperfect nature of sensor devices, so it is necessary to adopt an approach able to cope with uncertainty. Our architecture is thus designed to make use of intelligent modules that allow to meet this requirement, and also to manage information fusion in a dynamic scenario.

The remote, sensor infrastructure acts as the termination of a centralized reasoner, where sensed data are processed in order to extract higher-level information and produce the necessary actions to adapt the environment to the user requirements. A set of actuators finally takes care of putting the planned modifications to the environment state into practice.

The system architecture has been designed to guarantee the scalability of the proposed solution with respect to the number of buildings to be monitored and the number of different devices to be used. In order to efficiently organize the system modules, each corresponding to a different logical task, we chose a three-tier architecture as a model. The lowest level, the *physical layer*, consists of sensor and actuator devices; the *middleware layer* defines a set of AmI components that can be composed to implement intelligent AmI functionalities; the *application layer* allows for applying the monitoring and controlling rules with respect of energy constraints.

In the following, a more detailed description of three architecture levels is given.

Sensing Layer
: it is the lowest level and consists of small and cheap sensors and actuators. The capacity of such devices is usually improved by means of expansion modules containing more sensors (e.g., barometers, thermometers, hygrometers, accelerometers, instruments to measure noise and light levels, RFId readers).

Middleware Layer
: it provides a standard interface between physical sensors and AmI algorithms. The middleware layer implements the methods for monitoring and controlling an indoor environment in order to adapt the observed area to the user's preferences. Any decision made by the middleware layer for a particular area (e.g., the user office) must always take into account the energy efficiency constraints of the whole building. The intelligent core of such layer consists of data fusion algorithms used for modeling collected data and user profiling approaches that enable to implicitly understand the user preferences. Moreover, artificial intelligence techniques are used to drive high-level reasoning that allows for handling the uncertainty of measured data.

Application Layer
: it implements some ad-hoc functionalities according to a specific scenario (i.e., system installation) and includes the presentation layer (i.e., user interfaces).

The deployment of our architecture in a medium-sized building complex is shown in Fig. 2. Building premises constitute the basic monitored units of our system, where the distributed sensor and actuator networks are installed. These networks are heterogeneous both in terms of the adopted technology and of the performed monitoring/actuating tasks; some collectors are asked for low-level tasks (e.g., data gathering) and for providing a first abstraction of devices capabilities. Several basic monitored units are coordinated by a *BuildingAgent*, responsible of performing reactive control and further data aggregation. In small buildings, there will be a single BuildingAgent for each building, but in order to ensure system scalability, in medium or large buildings there could be a number of these distributed devices. The high-level AmI functionalities are provided by a centralized entity, called *AmiBox*, responsible for coordinating the BuildingAgent networks, for performing intelligent reasoning and for choosing the adopted energy saving strategy.

In our vision, the individual building is part of a community coordinated by a central orchestra leader, the AmIBox, which ensures coherence of the adopted energy saving strategy. Moreover, the AmIBox is able to communicate with other AmIBoxes, thus allowing the development of a real smart city

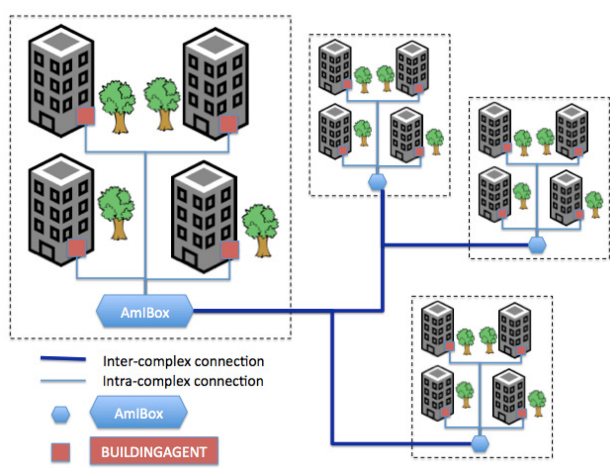

Fig. 2. Communication between AmIBoxes.

(see Fig. 2). This communication does not involve information about current power consumption and about users profiles, in order to guarantee privacy and security of building inhabitants. Only statistical aggregated information are transmitted to other AmIBoxes and communication are protected by the adoption of a distributed reputation management protocol. The knowledge about the behavior and efficiency of other AmIBoxes is used as basis for comparison in order to make the adaptive learning of the energy saving strategy more convenient for the specific building complex.

IV. Case Study

The proposed architecture aims for timely and ubiquitous observations of a complex of buildings considering three different scenarios: Campus University, Housing Complex, Manufacturing Facility.

In this work we focus on the first application scenario consisting in the management of an office environment, namely a university building, in order to fulfill constraints deriving both from the specific user preferences and from considerations on the overall energy consumption.

The system will reason on such facts as "air quality", "lighting conditions", "room occupancy level", but each fact refers to a physical measurement captured by the physical layer. Since the system must be able to learn the user preferences, ad-hoc sensors for capturing the interaction between users and actuators are needed. For example, if the user modifies the temperature setting of the heating system then we can suppose that they consider such value inadequate; if the user is working in its office without interacting with the actuators we can assume that they like the current conditions. An intelligent system should address such requirements.

Some possible examples of reasoning are: if the user has not been in the office for a short time, then turn off the light; if the user has not been in the office for a long time then turn off both light and heating system; if the user is working in the office then control the actuator (e.g., lights, curtains, rolling shutters) in order to optimize the energy efficiency.

The construction of a real prototype of the monitoring and controlling system has been started at the University of Palermo, and we are currently designing the monitoring system for the third floor of one of the buildings of our Department; in the next months the prototype will be extended to other floors and then to separate buildings. The plan of one office, giving an example of the adopted solutions, is showed in Fig. 3.

The devices labelled as A and B are used as a first-level, rough, control of the users presence. In our prototype, RFId readers (**A**) are installed close to the main entrance and to each office door, while RFId tags are embedded into ID badges for the department personnel. Readings from each tag are collected via their coupled nodes, and forwarded by the WSN to the intelligent core, that will process them and will reason about the presence of a particular user. The status of the electric lock (**B**) allows for checking whether the user is in the office or not; moreover the electric lock is the actuator used by

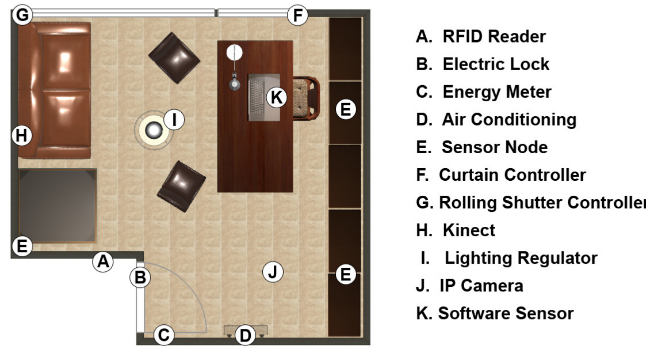

Fig. 3. Monitored office.

the system for granting access to private areas of the building. Such low-level reasoning about users' position is imprecise and requires the integration with other sensory information, such as those collected by specialized software demons acting as virtual *software sensors* (**K**) and used to detect the users' activities on their workstations.

The sensing infrastructure is realized by means of a Wireless Sensor and Actuator Network, whose nodes (**E**) are able to measure temperature, relative humidity, ambient light exposure and noise level. Sensor nodes can be located close to several points of interest, e.g., door, window, user's desk; moreover, nodes equipped with outdoor sensors can also be installed on the building facade, close to the office windows, in order to monitor outdoor temperature, relative humidity, and light exposure. Actuators are able to change the state of the environment by acting on some measures of interest. The air-conditioning system (**D**), the curtain and rolling shutter controllers (**F, G**), and the lighting regulator (**I**) address this task by modifying the office temperature and lighting conditions. Both temperature and light management are fundamental for the energy efficiency of the office, but in order to achieve better results a more accurate analysis of the power consumption is required. For this reason, we used energy monitoring units for each device (e.g, air-conditioner, lights, PCs) and an energy meter (**C**) for the overall monitoring of each office.

The users' interaction with actuators is also captured via ad-hoc sensor monitors. For instance, if the user manually triggers any of the provided actuators (e.g. the air conditioning, the motorized electric curtains, or the lighting systems) via the remote controls or traditional switches, specialized sensors capture the relative IR or electric signals so that the system may use them as implicit feedback.

The main contribution for detecting user's presence is given by video sensors integrated with wireless sensor nodes. Video sensors (**J**) can be used to perceive high-level features such as who is in the office [27], while the Microsoft Kinect sensor (**H**) is responsible for detecting the presence of the user and recognizing some gestures that activate predefined actions (e.g., open the door, turn on/off the light).

The monitoring infrastructure is based on the IRIS Mote produced by Crossbow, equipped with a number of sensors (i.e., temperature, humidity, light intensity, noise level, CO2). The IRIS is a 2.4 GHz Mote module designed specifically for deeply embedded sensor networks. Other ad-hoc sensors and actuators (e.g., curtain reader and controller) can be connected with the WSAN by means of standard protocols (e.g., ZigBee, EIA RS-485). For testing purposes, we selected a miniature fanless PC (i.e., fit-PC2i [28]) with Intel Atom Z530 1.6GHz CPU) as BuildingAgent, while the AmiBox functionalities will be implemented on a traditional server.

V. Conclusion

In this paper we presented the intelligent system under development in our University. Our approach is based on a new paradigm in Artificial Intelligence, i.e., Ambient Intelligence (AmI), that focuses on the role of the end user. In fact, AmI techniques can be applied to efficiently understand dynamic environments and make decisions according to some high level constraints, i.e., user preferences. In order to ensure context-aware reasoning, the presence of pervasive devices, e.g., sensor nodes, is required. Wireless Sensor and Actuator Networks (WSAN) is the technology we adopted to modify the environment and react to user- driven stimuli.

Compared to traditional AmI systems, we chose a scenario with multiple buildings to be monitored, i.e., a complex of buildings. The system architecture has been designed to guarantee the scalability of the proposed solution according to the number of buildings to be monitored and the number of different devices to be used. In order to efficiently organize the system modules, each corresponding to a different logical task, we chose as model a three-tier architecture. The proposed architecture aims for realtime and ubiquitous observations of building complexes in order to optimize the overall energy consumption. At present, we are finalizing a real prototype of the monitoring and controlling system at the University of Palermo. A description of a test scenario consisting in the management of an office environment, namely a university building, in order to fulfill constraints deriving both from the specific user preferences and from considerations on the overall energy consumption has been provided.

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References

[1] D. Messina, M. Ortolani, and G. Lo Re, "Achieving robustness through caching and retransmissions in ieee 802.15.4-based wsns," in *Computer Communications and Networks, 2007. ICCCN 2007. Proceedings of 16th International Conference on*, aug. 2007, pp. 1117 –1122.

[2] A. De Paola, M. La Cascia, G. Lo Re, M. Morana, and M. Ortolani, "User Detection through Multi-Sensor Fusion in an AmI Scenario," *in Proc. of the 15th International Conference on Information Fusion*, 2012.

[3] A. Ipakchi and F. Albuyeh, "Grid of the future," *Power and Energy Magazine, IEEE*, vol. 7, no. 2, pp. 52 –62, march-april 2009.

[4] S. Massoud Amin and B. Wollenberg, "Toward a smart grid: power delivery for the 21st century," *Power and Energy Magazine, IEEE*, vol. 3, no. 5, pp. 34 – 41, sept.-oct. 2005.

[5] S. Darby, "The effectiveness of Feedback on energy Consumption," *A Review for DEFRA of the Literature on Metering, Billing and direct Displays, April*, 2006.

[6] http://www.google.com/powermeter/about/.

[7] http://us.pulseenergy.com/UniCalBerkeley/dashboard.

[8] http://www.alertme.com/.

[9] http://www.cambridgesensorkit.org/.

[10] S. Taherian, M. Pias, G. Coulouris, and J. Crowcroft, "Profiling energy use in households and office spaces," in *Proceedings of the 1st International Conference on Energy-Efficient Computing and Networking*. ACM, 2010, pp. 21–30.

[11] http://www.energyawareness.eu/.

[12] C. Björkskog, G. Jacucci, L. Gamberini, T. Nieminen, T. Mikkola, C. Torstensson, and M. Bertoncini, "Energylife: pervasive energy awareness for households," in *Proceedings of the 12th ACM international conference adjunct papers on Ubiquitous computing*. ACM, 2010, pp. 361–362.

[13] A. Krioukov, S. Dawson-Haggerty, L. Lee, O. Rehmane, and D. Culler, "A living laboratory study in personalized automated lighting controls," in *3rd ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings*, 2011, pp. 1–6.

[14] X. Jiang, M. Van Ly, J. Taneja, P. Dutta, and D. Culler, "Experiences with a high-fidelity wireless building energy auditing network," in *Proceedings of the 7th ACM Conference on Embedded Networked Sensor Systems*. ACM, 2009, pp. 113–126.

[15] F. Corucci, G. Anastasi, and F. Marcelloni, "A WSN-based Testbed for Energy Efficiency in Buildings," in *Proceedings of the 16th IEEE Symposium on Computers and Communications (ISCC'11)*. IEEE, 2011, pp. 990–993.

[16] Y. Wen and A. Agogino, "Wireless networked lighting systems for optimizing energy savings and user satisfaction," in *Wireless Hive Networks Conference, 2008. WHNC 2008. IEEE*. IEEE, 2008, pp. 1–7.

[17] L. Yeh, Y. Wang, and Y. Tseng, "ipower: an energy conservation system for intelligent buildings by wireless sensor networks," *International Journal of Sensor Networks*, vol. 5, no. 1, pp. 1–10, 2009.

[18] A. De Paola, S. Gaglio, G. Lo Re, and M. Ortolani, "Sensor9k: A testbed for designing and experimenting with WSN-based ambient intelligence applications," *Pervasive and Mobile Computing. Elsevier*, vol. 8, no. 3, pp. 448–466, 2012.

[19] A. De Paola, S. Fiduccia, S. Gaglio, L. Gatani, G. Lo Re, A. Pizzitola, M. Ortolani, P. Storniolo, and A. Urso, "Rule based reasoning for network management," in *Proceedings of the Seventh International Workshop on Computer Architecture for Machine Perception (CAMP 2005)*. IEEE, 2005, pp. 25–30.

[20] M. Zamora-Izquierdo, J. Santa *et al.*, "Integral and networked home automation solution towards indoor ambient intelligence," *Pervasive Computing, IEEE*, vol. 9, no. 4, pp. 66–77, 2010.

[21] J.-Y. Son, J.-H. Park, K.-D. Moon, and Y.-H. Lee, "Resource-aware smart home management system by constructing resource relation graph," *IEEE Transactions on Consumer Electronics*, vol. 57, no. 3, pp. 1112–1119, 2011.

[22] G. Chong, L. Zhihao, and Y. Yifeng, "The research and implement of smart home system based on internet of things," in *Electronics, Communications and Control (ICECC), 2011 International Conference on*. IEEE, 2011, pp. 2944–2947.

[23] A. Capone, M. Barros, H. Hrasnica, and S. Tompros, "A New Architecture for Reduction of Energy Consumption of Home Appliances," in *TOWARDS eENVIRONMENT, European conference of the Czech Presidency of the Council of the EU*, 2009, pp. 1–8.

[24] A. Barbato, L. Borsani, and A. Capone, "A wireless sensor network based system for reducing home energy consumption," in *Sensor Mesh and Ad Hoc Communications and Networks (SECON), 2010 7th Annual IEEE Communications Society Conference on*, 2010, pp. 21–25.

[25] The AIM Consortium, "AIM - A novel architecture for modelling, virtualising and managing the energy consumption of household appliances," http://www.ict-aim.eu/, 2008.

[26] G. Bellala, M. Marwah, M. Arlitt, G. Lyon, and C. Bash, "Towards an understanding of campus-scale power consumption," in *3rd ACM Workshop On Embedded Sensing Systems For Energy-Efficiency In Buildings*, 2011, pp. 1–6.

[27] E. Ardizzone, M. La Cascia, and M. Morana, "Face processing on low-power devices," in *Embedded and Multimedia Computing, 2009. EM-Com 2009. 4th International Conference on*, dec. 2009, pp. 1 –6.

[28] http://www.fit-pc.com/.