Ontology-based Temporal Context Reasoning Approach For Saving Energy in Smart Building

1st Houssem Eddine Degha[1], 2nd Fatima Zohra Laallam[1],3rd Bachir Said[1]

[1]*Lab.Laboratoire de l'Intelligence Artificielle et des Technologies de l'Information*

Faculte´ des nouvelles technologies de l'information et de la communication

Universite´ Kasdi Merbah Ouargla Ouargla,30000, Algerie´

degha.houssem@univ-ouargla.dz, laallam.fatima zohra@univ-ouargla.dz, said.bachir@univ-ouargla.dz

Abstract—The majority of intelligent approaches supporting advanced energy-saving policies require a learning phase. Preliminary and necessary knowledge is acquired to allow the smart building management system to provide efficient energy saving services. But all those approaches are non-temporal. Decisions results from energy saving artificial intelligent algorithms run out at the smart building without examining the effects that may result from the implementation of these decisions. The series implementation of those services can lead to deficient energysaving policy, even if those decisions save some wasted energy in current situations. In this paper, we present a new approach for saving energy in smart buildings based on temporal context called TempCSESB (temporal context for Saving energy in the smart building). TempCSESB uses a new technique to enhance the effectiveness of energy-saving decisions. Before applying those decisions in the real smart building, the proposed method uses temporal context to test provided services in temporal phase. This temporal context model contains a full description of the current state of the smart building to simulate the building situations in a temporal context. The proposed approach allows knowing the effect of the services before applying them to the real smart building.

Index Terms—Energy Efficiency; Smart Building; Temporal Context; Context-awareness; Ontology; SWRL rules; proteg´ e´ 5

I. Introduction

In recent years, energy-saving becomes an important research area because of the increase in energy cost and concerns about the environment. Business and residential building account for a significant fraction of the overall world energy consumption of about 20%. Today technology produces many appliances that automate our tasks and offer many services. There are many systems provide solutions to make our life more comfortable and secure. Various methods and techniques explore technology and artificial intelligence approaches to delivering solutions for saving energy in the building. The most straightforward approach to energy efficiency in the building is increasing users awareness about energy consumption. This method is based on providing appropriate feedback to users about energy consumption to raise their awareness and encourage eco-friendly behaviors. User awareness is supported in many commercial systems in order to valuably influence the user behaviors to reduce cost by providing feedback using the measures of energy consumption [1]. Several products support user awareness such as Microsoft Hohm [2], which is an online web application that allows consumers to analyze their energy consumption and provide energy-saving recommendations. This product was delivered by Microsoft in 2009. Berkeley Energy Dashboard is another user awareness supported product application [3], it tracks the effects of inhabitants' efforts for saving energy in the building, for example, turning the light off at night or activating energy saving mode on the computer. This method enables us to see clearly the cumulative impact of inhabitant behaviors in the building. However, there are many other proposed solutions to increase the user's energy consumption awareness as AlertMe [4], E2Home [5]. User awareness approach is quite limited. It is not based on intelligent algorithms. And it does not have any direct effect in the environment that brings about decisions to be applied in a smart building through actuators and appliances. Reducing standby power consumption mode is another simple method for saving energy in the building. This method is based on reducing energy waste of standby mode. Once the standby mode detected, the device can switch off. There are numerous works dealing with this issue like [6], [7]. Reducing energy in standby is also a limited way because it is based only on appliances in standby mode. However, the biggest energy waste comes from the running appliances in waste contexts. Activity scheduling [16] is an approach based on determining the optimal schedule of human activity regarding appliances that consume higher energy or energy-hungry tasks that do not require user interaction like a dishwasher or washing machine. This method reduces the cost of electricity by planning this activity or tasks when the energy fares are cheaper or the green energy production is available like solar energy. This approach can be applied just if energy fares vary over time or the building has a renewable energy source and production change over time. In [8], the author proposes a building management system that enables users to specify the exact time period when a certain task must be executed by an appliance. There are several other works using this approach like [9]–[11]. Adaptive control is an approach based on the immediate reaction of smart building devices in real-time For example when the room is empty the light goes off or controlling the Heating, ventilation, and air conditioning (HVAC) to save energy. This approach is the most important feature in building energy management system (BEMS). But this method should follow the right policies to avoid negative effects on inhabitants' comfort. This approach needs to be supported by artificial intelligence techniques to detect users' presence activity [12]–[15], learning users' preferences to satisfy their need taking into account only their actual requirements. The energy saving approaches can be divided into 2 groups: reaction-based approaches and long-term planning based approaches [16].

Reducing standby power consumption and adaptive control techniques can be seen as reaction-based approaches. Those approaches are based on surveillance smart building and it's the environment and make immediate reaction based on intelligent algorithms to changing environmental parameters by controlling appliances, for example switching device on/off or update its parameter values. Energy consumption awareness and activity scheduling approach can be considered as a long-term planning approach because the result of that approach appears later. The problem in these two main approaches is the difficulty to ensure the interaction based methods to lead the smart building to the best energy saving policy and get the best energy saving resulting in future. The other problem of intelligent techniques for planning is missing the immediate interaction and high cost for planning especially in the context of complex scenarios which require planning over time.

In our opinion, the solution to provide the best energy saving policies in the following direction to identify a trade-off between a reactive approach and long-term planning approaches (figure 1). To benefit from the advantage of both strategies and addressing avoidable environmental fluctuations, and the variations in user behavior. The other lack in both approaches is applying the result of those intelligent techniques directly in the smart building. This method could not avoid the mistake of bad decisions if they implemented directly in an intelligent building. To solve those problems, We propose a new approach called TempCSESB (Temporal context for saving energy in the smart building).

The rest of this paper is structured as follows: Section II we will present the definition of context concept. then we display our TempCSESB approach and its models in section III. In section IV we explain the TempCSESB working mechanism. Finally, we conclude with Conclusion and the planned future work for this project.

II. Concepts Definition

A. Context definition

There are many types of research provide definitions of context, Abowd and Mynatt [18] identified five minimum necessary information to understand contexts are W's (who, what, where, when, why). Dey [20] define context as: ' Context is any information that can be used to characterize the "situation of an entity". An entity is a "person", "place", or

"object" that is considered relevant to the interaction between

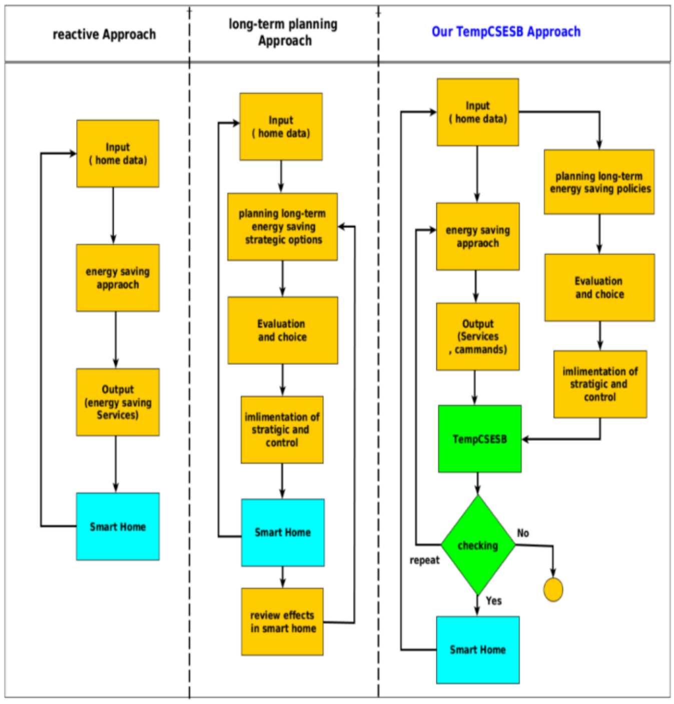


Fig. 1. Comparison of TempCSESB with other saving energy approaches.

a "user and an application", "including the user and applications" themselves". Sanchez [21] explained the distinction between 'data row' and 'context information', data row (sensor data) is is unprocessed and retrieved directly from the data sources like sensors. And context information is generated by processing data row. There are many concepts related to context definition, we will present some of the most important concepts in following subsections.

1) context levels: the context level is divided into two levels: the primary context and secondary context. The primary context is a piece of information collected without using existing contexts and without performing any kind of process (sensor data fusion operation). The secondary context is any information that can be computed using the primary context.

2) Context types and Categorization Schemes : There are many kinds of context types and each type is used to characterize an entity. Perera and Arkady [22] have presented the most '24' context types used in literature. They have identified User, Computing (system), Physical (Environment), Social, Networking, Things, Sensor, Who (identity), Where (Location), When (Time), What (Activity), Why, Sensed, Static, Profiled , Derived, Operational, Objective, External (Physical), Internal (Logical), Low-Level (Observable) and Hight-Level (Non-Observable). There are two broader categories of context: operational and conceptual. The operational context categorization is based on how data were acquired, modeled and treated. The conceptual context categorization is based on the meaning and conceptual relationships between the contexts.

3) Context Model and context Attribute: Henrichsen [23] defines context model and attribute as fellow: the context model identifies a concrete subset of the context that is realistically attainable from sensors, applications, and users and able to be exploited in the execution of the task. The context model that is employed by a given context-aware application is usually explicitly specified by the application developer but may evolve over time [23]. A context attribute is an element of the context model describing the context. A context attribute has an identifier, a type, and a value.

4) Context life cycle: The context lifecycle shows how data moves from phase to phase in software systems. There are many types of research provide there own context life cycle. In following list 1-7 belong, we present some context lifecycle examples. The right arrow denotes data transfer from one phase to another. Three dots (...) reconnecting to the first phase when completing the cycle.

1) Information Lifecycle Management (ILM) [24]: *creation and receipt → distribution → use → Maintenance → Disposition → ...*
2) Hayden's Data Lifecycle [25]: *collection → Relevance → classification → handling and storage → transmission and transportation → manipulate → conversion and alteration → release → backup → retention destruction → ...*
3) Intelligence Cycle [26]: *collection → Processing → analysis→ publication → Feedback → ...*
4) Ferscha et al. Lifecycle [27]: *sensing → transformation→ representation → rule base → Actuation → ...*
5) WCXMS Lifecycle [28]: *context sensing → context transmission → context acquisition → context classification → context handling → context dissemination → context usage → context deletion → Context request → context maintenance → context disposition → ...*
6) In addition to the life cycles, Bernardos et al. [29] identified three phases in a typical context management system: *context acquisition → information processing → reasoning → decision ...*
7) Charith Perera, Student Member [22] , After reviewing the above life cycles, we derived an appropriate (i.e. minimum number of phases but includes all essential) context life cycle as depicted in Figure 6 : *Context Acquisition → Context moduleing → Context Reasoning → Context ...*

III. The TempCSESB technique

As we know each event happen in the smart building, have an effect on smart building and its environment. And each event can be a condition to start one or more events. The provided services of saving energy techniques are considered as the events. And those services may lead to producing effects on the environment. these effects sometimes lead to bad energy saving policy. We propose a new approach called TempCSESB (Temporal Context for Saving Energy in Smart Building). TempCSESB uses a temporal context to ensure the efficiency of energy saving techniques by providing the

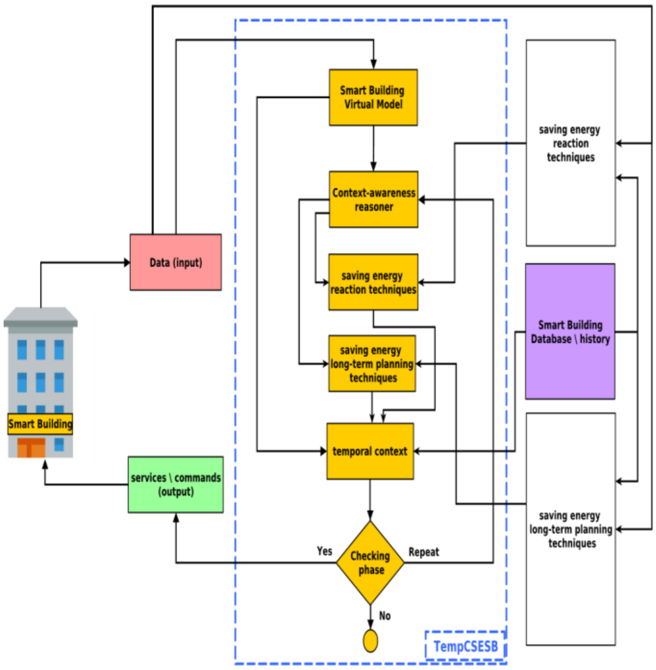


Fig. 2. Temporal context for saving energy in smart building (TempCSESB) architecture.

ability to coordinate between reaction and long-term planning approaches. The provided services energy saving techniques from both approaches will be implemented in the virtual temporal context of the smart building that simulates the current real-time state of the smart building.

This temporal context will produce events and effects may happen in the smart building after applying the decisions of energy saving services. This strategy ensures the effectiveness of services. iI the execution of energy saving services is not adequate with the context of the smart building or it produces bad occurs later, those services will not be applied in real smart building and the process will be stoped in the temporal context. Else if those services are good and lead to good energy saving policy and adequate with smart building context. TempCSESB contains five main modules are: smart building virtual model, context-awareness reasoner, saving energy techniques(reaction and long-term approaches), a temporal context of the smart building, and checking model to validate the reasoning face. Fig.2 presents the general architecture of TempCSESB.

A. Ontology based smart building modeling

The first step toward developing the TempCSESB system is modeling the smart building and its environment. Ontology is one of the most famous and powerful tools to provide a structural framework for organizing smart building information. The objective of our Onto-SB (Smart Building ontology) [30] is to give a conceptualization for smart building domain. It can be used for several ends. Members of the community of the domain can communicate and share knowledge between them. It can also be used to develop an intelligent system for a

Fig. 3. Onto-SB in Proteg´ e´ 5.

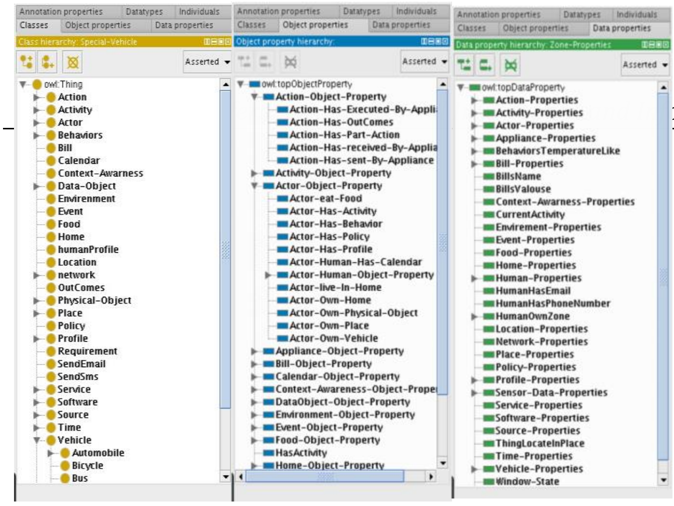
different purpose: security, saving energy, health-surveillance and so on. To conceptualize our ontology, we have used a combination of the top-down and bottom-up approaches. First, we have defined the more used concepts in the smart building and its environment like human, Appliance, service, network, place, time and more. Then we had generalized and specialized them appropriately. After this step, we have added for each concept its properties. Then we have created logical relationships between those concepts. Finally, we have got our ontology that we call Onto-SB ”Ontology for Smart Building.” It contains several concepts such as Building, Profile, environment, policy, appliance, service, energy source, context-awareness, time, etc [30]. Onto-SB contains 209 class, 98 relations, and more than 225 property. To have a machinereadable ontology, we use the Proteg´ e´ 5 ontology editor [17]. This editor allows representing the ontology into different languages like OWL and RDF. Onto-SB classes, properties, and relations are shown in Fig.3.

B. context-awarness reasoning

The context-awareness reasoning is an important part of TempCSESB system that translates building data into context awareness and provides adequate information. This information is so valuable, it helps to understand the environment and context inside smart building easier. This module executes SWRL to complete missed contextual information, and deduce new information using existing contextual information. for example, detecting the activities carried on by the user, like watching-TV activity. The rule down bellow presents the activity detection rule of watching-Tv in the Living Room.

Place(?x) ˆ LivingRoom(?x) ˆ Lights(?y) ˆ Devices_State(?y, ?stat1) ˆ swrlb:equal(? stat1, "on") ˆ
DeviseLocateIn(?x,?y) ˆ Tv(?z) ˆ Devices_State (?z, ?stat2) ˆ swrlb:equal(?stat2, "on") ˆ

turn it off. Reducing standby is another technique base to detect the standby mode in appliances and turn them off. This approach can be a more sophisticated approach consists of taking into account information related to the user presence, or in learning their behavior and activities. Another type of techniques is long-term planning approaches



including activity scheduling and other planning approaches to organizing human activities in order to minimize the energy consumption based on some condition. This model is responsible to coordinate between many types of algorithms to make the reaction based approaches adequate with long-term planning policies for saving energy.

D. temporal context model

Temporal context model, it is an important model in TempCSESB system. The temporal context represents the current smart building in the virtual model and then implement the energy saving services provided by energy saving techniques in the virtual temporal context. Then the model will produce the events and results affected by those services. This model will apply some other rules to simulate the behaviors of the real smart building after applying

DeviseLocateIn(?x,?z) ˆ MovingSensor(?k) ˆ Devices State(?k ?stat3) ˆ swrlb:equal(?stat3, " true ") ˆ DeviseLocateIn(?x,?k) ˆ LocateIn(?x,?h) ˆ Human(?h) -> CurrentActivity(" Watching - Tv ")

C. Energy saving approaches

There are two main approaches to saving energy in the smart building. Reaction approaches represent the method who apply energy saving decision directly after treating the current smart building state to eliminate wast energy contexts. Our approach uses a hybrid of both approaches. There are many techniques to effect in environment throw changing the appliance start or turn them off/on. Like the activity recognition approach when the technique able to detect the activity carried out in the smart building then can detect the unneeded devices to services. This method will provide the ability to test the services in temporal virtual phase before applying them in the real smart building. This method ensures the efficiency of energy saving services and ensures the good saving energy policies in the future.

E. checking phase the checking phase is the last step in TempCSESB. This phase will filer the energy saving services before applying them in the real smart building. If the result of temporal context are adequate with saving energy policy of smart building and it satisfies the inhabitance needs, do not affect in the comfort and reducing the energy consumption, they will pass to execution phase to be applied in the real smart building. Else if not they will be stoped in the end phase of ask to repeat the progress of TempCSESB system again to check those services again.

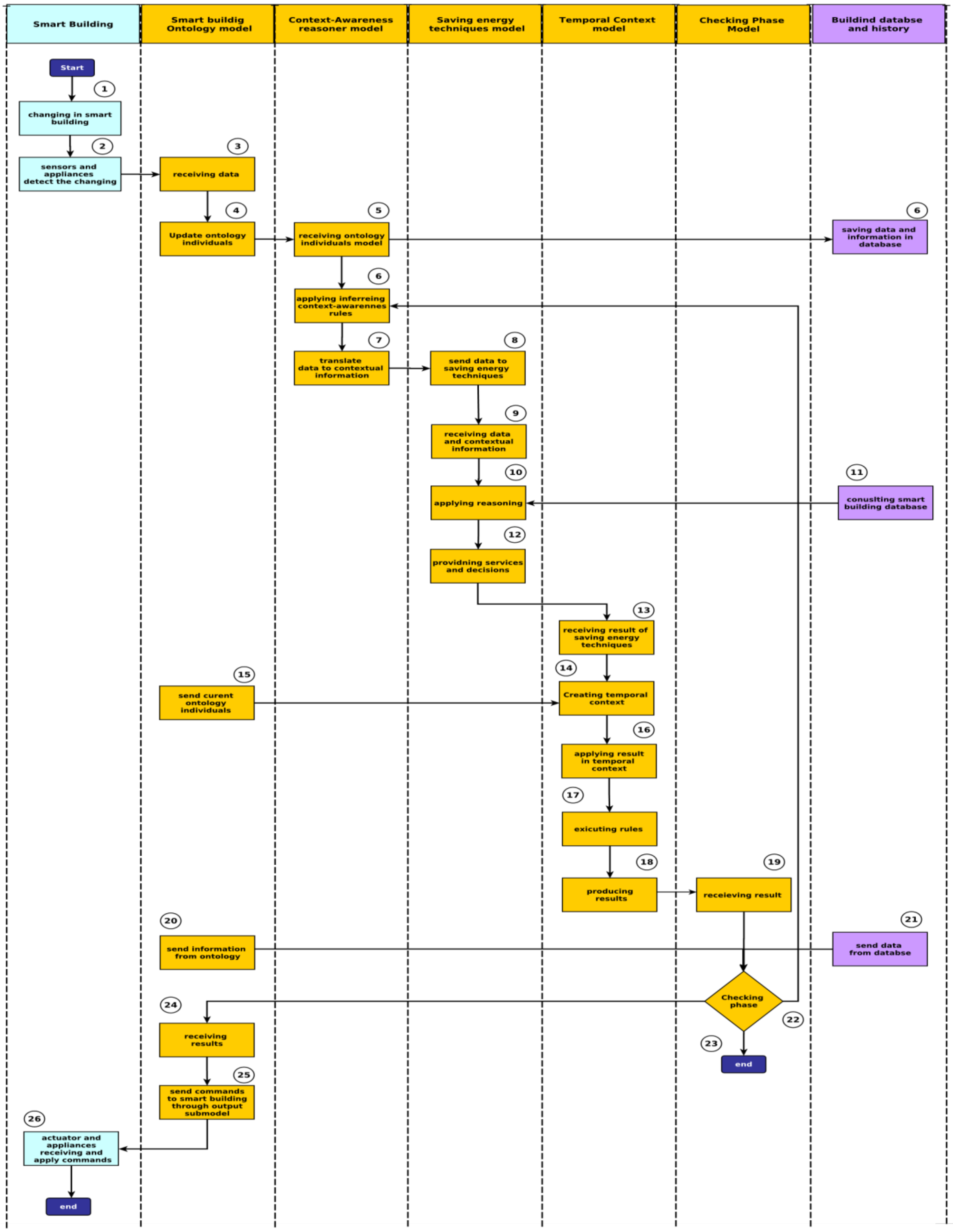


Fig. 4. TempCSESB working mechanism.

IV. TEMPCSESB WORKING MECHANISM

in this section, we present the TempCSESB working mechanism. There is 26 step to satisfy the TempCSESB goals. The process starts in step 1 when smart building appliances stat or environment parameters change. In step 2 the sensors detect changing and send data to smart building ontology model (step 3). In step 4 the smart building ontology will be updated with new reviewed data from the old step. In step 5 the smart building ontology individuals sent to contextawareness reasoning model to use this basic data to deducing new knowledge to understanding better, based on the available context's data using inferring rules (step 6,7). In step 6 also the context-awareness reasoning model sends information to smart building databased to be saved. in step 8 after completing the understanding of the smart building. The contextual information sent to energy saving techniques model. This model will teat this current building state and database information using the hybrid technique from both 2 approaches and provide services and decisions to eliminate the wast energy contexts and satisfy inhabitants needs (step 9,10,11,12). The (13-18) step in the most important step in our mechanism. The services/decisions provided by energy saving techniques pass to temporal context to apply it in the virtual model that simulates the real smart building state to test the effect may be happening after applying those services/decision in the real smart building. The saving energy technique produces result and pass to checking phase through step 19. The checking phase model checks if decision/services are adequate with smart building for saving energy and respect with energy saving policies of the smart building. If not the model decide if this process ends in step 23 or resent it to step 6 to reprocess it again. if the checking phase is positive will pass to step 24. This is the final step when the appliances and actuators in smart building receive the command to fix the environment parameters and satisfy users needs we present the TempCSESB working mechanism in figure 5.

V. Conclusion

This article is the first step towards developing the temporal context for saving energy in smart building (TempCSESB) system. In this paper, we present the TempCSESB system architecture and the TempCSESB working mechanism. TempCSESB contains from five main models: smart building virtual model, context-awareness reasoner model, saving energy techniques model, temporal context model and checking phase model. Those models work together in order to ensure the best energy saving policy in the smart building. This is a new hybrid technique using reaction based approach and long-term planning approach for saving energy in the smart building. The advantage of TempCSESB is the ability to avoid the mistakes may happen by energy saving services and maximize the inhabitance comfort and lead to the best energy saving policy. In our future work, we will develop the TempCSESB based on the distributed multi-agent system to make TempCSESB faster and did not affect the building energy management systems.

References

[1] X. Jiang, M. Van Ly, J. Taneja, P. Dutta, and D. Culler, "Experiences with a high-fidelity wireless building energy auditing network," Proc. 7th ACM Conf. Embed. Networked Sens. Syst. SenSys 09, p. 113, 2009.

[2] "Microsoft Hohm," 2011. [Online]. Available: http://www.microsoft.com/environment/. [Accessed: 30-Dec-2017].

[3] "Pulse Energy Inc," Berkeley Energy Dashboard, 2013. [Online]. Available: https://us.pulseenergy.com/UniCalBerkeley/dashboard. [Accessed: 30-Dec-2017].

[4] "AlertMe," 2013. [Online]. Available: http://www.alertme.com/. [Accessed: 30-Dec-2017].

[5] G. Ghidini and S. K. Das, "Improving home energy efficiency with E2Home: A Web-based application for integrated electricity consumption and contextual information visualization," 2012 IEEE Third Int. Conf. Smart Grid Commun., pp. 471–475, 2012.

[6] I. E. Agency, "Cool Appliance - Policy Strategies for Energy Efficient Homes," IEA Publ. Paris, Fr., 2003.

[7] X. J. X. Jiang, S. Dawson-Haggerty, P. Dutta, and D. Culler, "Design and implementation of a high-fidelity AC metering network," 2009 Int. Conf. Inf. Process. Sens. Networks, pp. 253–264, 2009.

[8] F. Corucci, G. Anastasi, and F. Marcelloni, "A WSN-based testbed for energy efficiency in buildings," Proc. - IEEE Symp. Comput. Commun., pp. 990–993, 2011.

[9] A.-G. Paetz, E. Dutschke,¨ and W. Fichtner, "Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions," J. Consum. Policy, vol. 35, no. 1, pp. 23–41, 2012.

[10] A.-G. Paetz, E. Dutschke,¨ and W. Fichtner, "Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions," J. Consum. Policy, vol. 35, no. 1, pp. 23–41, 2012.

[11] M. C. Bozchalui, S. A. Hashmi, H. Hassen, C. A. Canizares,˜ and K. Bhattacharya, "Optimal operation of residential energy hubs in smart grids," IEEE Trans. Smart Grid, vol. 3, no. 4, pp. 1755–1766, 2012.

[12] Y. Agarwal, B. Balaji, R. Gupta, J. Lyles, M. Wei, and T. Weng, "Occupancy-driven energy management for smart building automation," Proc. 2nd ACM Work. Embed. Sens. Syst. energy-efficiency Build., pp. 1–6, 2010.

[13] F. I. Vazquez and W. Kastner, "Clustering methods for occupancy prediction in smart home control," Proc. - ISIE 2011 2011 IEEE Int. Symp. Ind. Electron., pp. 1321–1328, 2011.

[14] A. De Paola, S. Gaglio, G. Lo Re, and M. Ortolani, "Sensor 9k: A testbed for designing and experimenting with WSN-based ambient intelligence applications," Pervasive Mob. Comput., vol. 8, no. 3, pp. 448–466, 2012.

[15] M. Milenkovic and O. Amft, "An opportunistic activity-sensing approach to save energy in office buildings," Proc. fourth Int. Conf. Futur. energy Syst. - e-Energy '13, p. 247, 2013.

[16] A. De Paola, M. Ortolani, G. Lo Re, G. Anastasi, and S. K. Das, "Intelligent Management Systems for Energy Efficiency in Buildings," ACM Comput. Surv., vol. 47, no. 1, pp. 1–38, 2014.

[17] "protege," 2017. [Online]. Available: https://protege.stanford.edu/products.php. [Accessed: 30-Dec-2017].

[18] G. D. Abowd and E. D. Mynatt, "Charting past, present, and future research in ubiquitous computing," ACM Trans. Comput.Hum. Interact., vol. 7, pp. 29–58, March 2000. [Online]. Available: http://doi.acm.org/10.1145/344949.344988

[19] S. Ahn and D. Kim, "Proactive context-aware sensor networks," in Wireless Sensor Networks, ser. Lecture Notes in Computer Science, K. Rmer, H. Karl, and F. Mattern, Eds. Springer Berlin / Heidelberg, 2006, vol.
3868, pp. 38–53. [Online]. Available: http://dx.doi.org/10.1007/11669463

[20] G. D. Abowd, A. K. Dey, P. J. Brown, N. Davies, M. Smith, and P. Steggles, "Towards a better understanding of context and context-awareness," in Proceedings of the 1st international symposium on Handheld and Ubiquitous Computing, ser. HUC '99. London, UK: Springer-Verlag, 1999, pp. 304–307. [Online]. Available: http://dl.acm.org/citation.cfm?id=647985.743843

[21] L. Sanchez, J. Lanza, R. Olsen, M. Bauer, and M. Girod-Genet, "A generic context management framework for personal networking environments," in Mobile and Ubiquitous Systems - Workshops, 2006. 3rd Annual International Conference on, july 2006, pp. 1 –8. [Online]. Available: http://dx.doi.org/10.1109/MOBIQW.2006.361743

[22] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Context Aware Computing for The Internet of Things: A Survey," vol. X, no. X, pp. 1–41, 2013.

[23] K. Henricksen, "A framework for context-aware pervasive computing applications," Computer Science, School of Information Technology and Electrical Engineering, The University of Queensland, Septem- ber 2003, http://henricksen.id.au/publications/phd-thesis.pdf [Accessed on:2012-0105]

[24] M. Peterson and E. Pierre, "Snias vision for information life cycle management (ilm)," in Storage Networking World. Computer World, 2004.

[25] E. Hayden, "Data lifecycle management model shows risks and integrated data flow," in Information Security Magazine, July 2008.

[26] A. N. Shulsky and G. J. Schmitt, Silent Warfare: Understanding the World of Intelligence, 3rd ed. Potomac Books Inc, May 2002.

[27] A. Ferscha, S. Vogl, and W. Beer, "Context sensing, aggregation, representation and exploitation in wireless networks," Scalable Computing: Practice and Experience, vol. 6, no. 2, p. 7181, 2005. [Online]. Available: http://www.scpe.org/index.php/scpe/article/view/327/17

[28] G. Hynes, V. Reynolds, and M. Hauswirth, "A context lifecycle for web-based context management services," in Smart Sensing and Context, ser. Lecture Notes in Computer Science, P. Barnaghi, K. Moessner, M. Presser, and S. Meissner, Eds. Springer Berlin / Heidelberg, 2009, vol. 5741, pp. 51–65. [Online]. Available: http://dx.doi.org/10.1007/978-3642-04471-7 5

[29] A. Bernardos, P. Tarrio, and J. Casar, "A data fusion framework for context-aware mobile services," in Multisensor Fusion and Integration for Intelligent Systems, 2008. MFI 2008. IEEE International Conference on, aug. 2008, pp. 606 –613. [Online]. Available: http://dx.doi.org/10.1109/MFI.2008.4648011

[30] H. E. Degha, F. Z. Laallam, B. Said, and D. Saba, Onto-SB: Human Profile Ontology for Energy Efficiency in Smart Building.