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Contributed Paper

Intelligent Agents Enabling Negotiated Control of Pervasive Environments

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ABSTRACT

One of the important goals of the intelligent buildings especially in commercial applications is not only to minimize the energy consumption but also to enhance the occupant's comfort. However, most of current development in the intelligent buildings focuses on an implementation of the automatic building control systems that can support energy efficiency approach. The consideration of occupants' preferences is not adequate. To improve occupant's wellbeing and energy efficiency in intelligent environments, we develop four types of agent combined together to form a multi-agent system to control the intelligent buildings. Users' preferential conflicts are discussed. Furthermore, a negotiation mechanism for conflict resolution, has been proposed in order to reach an agreement, and has been represented in syntax directed translation schemes for future implementation and testing.

Keywords: conflict resolution, intelligent buildings, multi-agent systems (MAS), negotiation strategy, syntax directed translation schemes (SDTS).

1. INTRODUCTION

As reported by the department of trade and industry, UK [1], overall energy consumption in the UK has increased by 10% between 1990 and 2001. For a domestic sector, energy consumption has increased by 19% since 1990. In 2000, most of domestic energy consumption is for space heating (58% of the total energy consumption). Besides, other major areas of energy consumption in the domestic sector are for heating water (24%), for lighting and appliances (13%) and for cooking (5%). For a service sector divided into a public administration and a private commercial, energy in the private commercial is used by 61% of all service sector energy consumption. Consequently, the idea of the intelligent buildings has proposed. The concept of integration between an intelligent architecture and the building systems leads to a new modern building called an intelligent building. To develop the intelligent buildings, novel building control systems are proposed not only to provide optimum comfort that enables the occupants to attain satisfaction but also in order to improve energy efficiency. As showed in [2-4] one of the important factors affecting the overall performance of business is productivity. Therefore, workplace environment parameters, such as humidity, indoor temperature and lighting have significant relationships with workers' satisfaction and performance. As a result, the environment parameters of the workplaces should be adjusted to make the workers feel comfortable. Because the workplaces' environment parameters may affect the overall morale of the workers, the comfortable workplaces lead to a workforce that is not only healthy and happy but also more productive.

Furthermore, a project [5] has shown that dynamic online control in intelligent workplaces could reduce energy consumption up to 20%. The project proposed a new comfort control technology by integration between a building occupant and a workplace building leads to new possibilities to further reduce energy consumption, and also offers an individual control to the building occupant.

One of advanced technologies for building control is intelligent agent systems. As presented by most of previous research in intelligent building, a multi-agent system is applied to implement the building control system. The multi-agent system provides a practical application which can minimize not only energy consumption but also the building occupants' discomfort. The following section of the paper begins by reviewing related work in area of intelligent buildings and agent technology. In section 3, we explain what pervasive informatics is, and how we apply pervasive informatics to the intelligent buildings. Representing an architecture overview of building control systems, agents in multi-agent systems, conflict scenarios and solutions is presented in section 4 respectively. In section 5, how we develop our propose system is illustrated. Applying SDTS for negotiation representation is described in section 6. The final section provides a conclusion.

2. RELATED WORK

During the last few years, the interest in smart environments has increased and many projects are being conduced. The smart environments are living spaces(such as homes, offices, hospital, etc.) where constitute an important subset of smart ubiquitous computing environments[6]. An intelligent building is one of smart environments where is equipped with a huge amount of sensors and actuators for instance temperature, moisture or radiation sensors. These sensors generate an immense amount of data which require to be processed in near real-time in order to take decisions right on time. There are many perspectives of intelligent building' s definition mentioned by the following part. Furthermore, the examples of the agent-based control system in intelligent buildings are described.

2.1 Intelligent Buildings

There is no standard definition of an intelligent building (IB) because the intelligent building concept is a relatively new idea, and the IB industry is not yet fully developed. The IB concept can be understood in various ways depending on the purposes within the research, education and construction industry. One of the definitions cited in [7] is proposed by the European Intelligent Building Group: *"An intelligent building creates an environment that allows organizations to achieve their business objectives and maximizes the effectiveness of its occupants, while at the same time allowing efficient management of resources with minimum life-time costs."* Based on the above definition, the concept of intelligent building concerns with the relationship between building providers, developers, and occupants in terms of economy and stakeholders 'requirements and interests.

Furthermore, the similar perspective of the intelligent buildings is proposed by Clements-Croome [8]. The author has mentioned that the building environment affects the wellbeing and comfort of human in the workplace, and in turn it influences human's productivity, morale and satisfaction. Consequently, design of the intelligent buildings requires both attention of environmental factors that affect occupants' perception, comfort, and productivity and the capability in controlling of basic infrastructures of building such as network access, lighting control, fresh air and temperature control. Therefore, environment control and basic infrastructure control are combined together to set as a part of building service system.

The Continental Automated Buildings Association (CABA) states that *"The intelligent buildings is where technological buildings systems, communications and controls are integrated to create facility that is safer and more productive for its occupants and more operationally efficient for its owners"* [9]. This is further illustrated Figure1.

In summary, many disciplines such as information and communication technology, construction engineering, business management and so on are integrated together to create a building that provides the building stakeholders including the owner, operator and occupant with an environment which is flexible, effective, comfortable and secure.

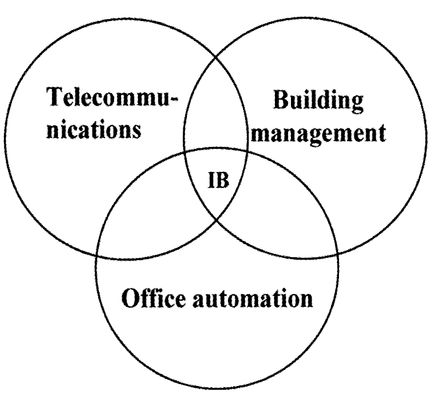


Figure1. CABA's definition of IB.

2.2 Agents and Multi-Agent Systems

As noted by Wooldridge and Jennings [10], agent is hardware or software that is continually processes the input it gets from its environment to determine the output that it should send back to the system. Furthermore, the agent must be flexible by four properties: autonomy, social ability, reactivity, and pro-activeness. Following this definition, an agent has three key factors as follows[11]:

- Autonomy. This refers to the principle that agents can operate on their own without the need for human guidance. Agents have individual internal states and goals then they act in such a manner as to meet theirs goals on behalf of theirs user. A key element of agents autonomy is their proactiveness, for example their ability to 'take the initiative' rather than acting simply in response to their environment.

-Cooperation with other agents is paramount. In order to cooperate, agents need to possess a social ability, for example the ability to interact with other agents and possibly humans via some communication language.

-Learning as agents react and/or interact with their external environment makes agent systems to be truly 'smart' because a key attribute of any intelligent being is its ability to learn. The learning may also take the form of increased performance over time.

Multi-agent systems (MAS) can be employed to solve the problems which are complex, difficult, or impossible for an individual agent to solve. The concept of MAS focuses on system in which the intelligent agents interact with each other to achieve their own individual goal rather than to solve a common problem. MAS are suitable for the domains involving interaction between different people/organizations with different goals and proprietary information. Due to the lack of centralized control, the agents in MAS have to solve the problem of the relationship between each agent's behaviour and goals, and those of the global system or MAS community. Therefore, negotiation often plays a central role in agent cooperation [12].

As proposed by D'Inverno and Luck [13], a multi-agent system is one that contains a collection of two or more agents. In addition, the system has to contain at least one autonomous agent. However, the system can consist of more than one autonomous agent. Furthermore, there must be some interaction between the agents of the system in order to satisfy the goal of one agent by the other. By conclusion, MAS is any system that composes with: 1) two or more agent; 2) at least one autonomous agent; and 3) at least one relationship between two agents where one satisfies the goal of the other.

2.3 Applying Intelligent Agents to Intelligent Building Control

The intelligent agents and Multi-Agent Systems (MAS) are widely used because of their ability to manage complex tasks and systems, in autonomous and intelligent ways. Agents are popular computational technologies contributing to diverse domains such as computer games, computer mediated collaboration, education and training, electronic commerce, information retrieval, pervasive and ubiquitous computing, robotics, service-oriented computing, social simulation, and user interfaces. Besides growing communication abilities, agents can collaborate efficiently with others, support human interaction, and even collaborate with humans.

Nowadays many new areas of research and applications emerge using agents and MAS to perform a variety of complex tasks. One of these areas is applying to control an intelligent building. An intelligent building can be managed and controlled via multi-agent approach to keep balancing between energy saving and the needs, comfort, and preferences of occupants. The research attempt on multi-agent control system has increased rapidly during the last many years. There are the examples of the previous research.

Brooks [14] builds the intelligent room project at the MIT AI lab. Its main focus is on the interaction between the users and the system, in particular on how to integrate different sensor modalities, such as vision, gestures, and speech. The project is implemented for two scenarios. The first one is the disaster relief scenario and the last is an interactive space scenario for virtual tour of the MIT Artificial Intelligent Laboratory. The software to control the room is divided into three conceptual levels. The lowest levels are perceptual systems that provide real-time descriptions of event what is happening in the room. The next level provides a uniform agent-based interface to everything installed in the room such as devices drivers, vision code, speech understanding systems, and off the shelf software (e.g. Netscape, the X windows system) so that the agent interfaces eliminate any network problems occurring from different parts of the system and from the different characteristic time frames from interactions with underlying software. The top levels are application layers that prepare particular functionality for each room. The upper two levels of the controlling software of this project are implemented in the special agent language, SodaBot, specially developed for the project. For the second level, the agents act as the wrappers. They wrap the sub systems of this level via SodaBot language so this method conceals details of all implementation from the higher level application agents.

The research presented in [15-20] is part of the ISES (Information/Society/Energy/System) project. It has main goal both to increase energy saving realized by automatic control of lighting and temperature and customer preference realized by automatic control of lighting and temperature that are set according to occupants' comfort. A multi-agent system approach is used to control an intelligent building. There are four categories of agents in the MAS presented in this research. Personal Comfort (PC) agents which each records personal preference and try to increase occupant's satisfaction. Room agents, which each represents and controls a particular room to maximize energy saving and to make occupant well being in the same time. Environmental Parameter (EP)agents, each of them monitors and controls the environmental parameters in a particular room. Because of the capable of EP agents to access both sensor and actuator devices, they can read and changing the parameter to achieve and keep the value parameter decided by Room agent. Badge System Agent (BSA) keeps location's track of each person in the building and maintains a data base of PC agents. However, the personal preferences are predefined and are static because they are not adjusted according to behavior or feedback of occupants. Besides, limitation of badge system, it can detect the present occupant in a room but it cannot distinguish between actuations from different occupants so this is one of system constraints that happens when an irrelevant person who is not a room's owner enters to the room, the environmental conditions are not be changed according to current occupant. It means that this research lacks the capability of learning and predicting about occupants' behavior. Nevertheless, the ability is added to another research [16] for enhancing the system.

Another research [21] presents multi-agent system approach for intelligent building control. The multi-agent system is implemented in terms of an unsupervised online real-time learning algorithm that constructs a fuzzy rule-base, derived from very sparse data in a changing environment. Each agent in multi-agent system of this research responses to a particular task and offers this task as service to other agents. Collaboration among agents is mediated by asynchronous messages. The MAS of this research composes of three layers. The agents in lowest layer interact directly to the intelligent building's device bus. The middle layer consists of both the DistributionAgent providing inter-agent communication and StructureAgent managing structure information. The top layer is allocated for intelligent learning agents. There are different instances of ControlAgent, and are responsible for controlling the effectors. Because this research emphasizes using a multi-agent control system for decision making of a small sub region of the whole state space, learning algorithm of this research is completely unsupervised. All feedback is acquired by observing the inhabitants' behaviors without intruding them so it make the multi-agent system lack of the capability to differentiate between effectors and preferences from different inhabitants, and thus the preferences that are learned are coupled with only the room that the inhabitants are in.

3. PERVASIVE INFORMATICS FOR INTELLIGENT ENVIRONMENTS

A building is a typical example of a built environment where modern technology can be used to enhance the communication and interaction between the occupants and the environment. Much study can be found on how effective use of information and technology improves the function of the built environment and makes the environment intelligent.

3.1 Pervasive Informatics

Pervasive informatics [22] is an emerging discipline to focus on the effect of information in enhancing the interaction and communication between occupants and the environment. The value of a built environment such as a building is far beyond its physical protection for its occupants, but often more importantly it offers a comprehensive service including occupants' comfort and well-being, and meeting the social and cultural needs. Much of the value is achieved not only through physical artifact but through the proper provision and utilization of information. In the physical dimension, a building provides services of accommodating people with a specified capacity. Physiological comfort affected by appropriate HVAC, lighting and factors is essential. However, the quality of the service in a building is also affected by the occupants interact with the environment through the use of sensory information such as audio and visual information. The occupant constantly perceives signs, images and signals from his sensors which he then makes sense and coverts to something called "information". In other words, he is immersed in a pervasive environment of information, especially in an intelligent building where information technology is employed to enhance the human communication with the environment.

Pervasive informatics recognizes the powerful effect of information in people's perception of the quality of service in an intelligent building. A building normally contains many defined spaces, each for a set of predominant functions or purposes. Appropriate layout and decoration are supposed to support the manifestation of the intended functions and purposes. Appropriate technologies are deployed to make it more convenient or more elaborate towards the intended themes of the space; hence the quality of services is enhanced. The spaces are designed following the right thematic structure (i.e. syntax) to inform the user about the meant functions (i.e. the meaning or semantics). Therefore the spaces and, further, the buildings are complex signs that are intended for the users to "read", to "consume" and to enjoy. Pervasive informatics offers a systematic way of interpreting, understanding and utilizing spaces and built environments from the perspective of human communication and interaction with the buildings [23].

3.2 Applying Pervasive Informatics to the Intelligent Buildings: Using MASBO as Case Study

Understanding the role of information and interaction in an intelligent built environment, the MASBO project [24] treats a building as a complex sign and aims to provide effective mechanisms to enable the users to interact better with the intelligent building. Viewing a complex sign of an intelligent building, MASBO (multi-agent system for building control) examines the spaces in a building from the syntactical level by identifying the structural patterns and the semantic level identifying the patterns of functions and purposes of spaces. These two aspects can be studied using semiotics [25], a well-established discipline for studying signs and sign systems in human communication. By adopting organizational semiotics [26], a specific branch of semiotics, MASBO also investigates how an intelligent building can best deliver the satisfaction and the total value as the quality of service. This ultimate impact on the building user is called the pragmatic effect, or pragmatics. The relationship of these three aspects can be summarized in Figure2, which highlights their interdependencies if a maximum value is expected from a built environment.

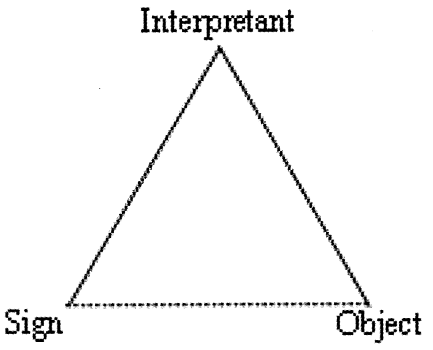


Figure2. A semiotic perspective.

According to [27], the analysis based on the three distinct fields of semiotics, known as syntactics, semantics and pragmatics shows relevant issues that have to be addressed in the design of an intelligent pervasive space:

- *Syntax/building structure and space layout,* there are requirements on the topology, layout, frontage, and interior and exterior decoration.

-*Semantics/building functions and purposes,* the space configuration, layout, frontage and decoration affect on the usability must make senses to the user and satisfy the user's requirements. The space provides and environment for the user to have appropriate 'affordances'. The users and the space will establish a mutual dependency. A well-designed space may promote a friendly interaction between the environment and the user; although a complete inverse is also possible.

-*Pragmatics/effect and quality of services,* each part of the building will transmit silent messages. For example, an elegant appearance of the space may cast an image of importance of the occupant. Paying attention to the details inside the building and incorporating ornaments appropriate to the intended effects may enhance the business performance.

The agents in MASBO capture social and business rules (or norms) from the three aspects: syntactics, semantics and pragmatics. The norms held in each agent represent the expectations of each relevant stakeholder when the agents exercise their functions in support the automatic control of the buildings. Further extensions have been introduced in the work reported in this paper.

4. SYSTEM ARCHITECTURE AND DESIGN

Figure3 shows an overall architecture of the proposed system. The agents-based building control system (ABBC) of intelligent building obtains input by a means of collecting input such as sensors via wireless sensor

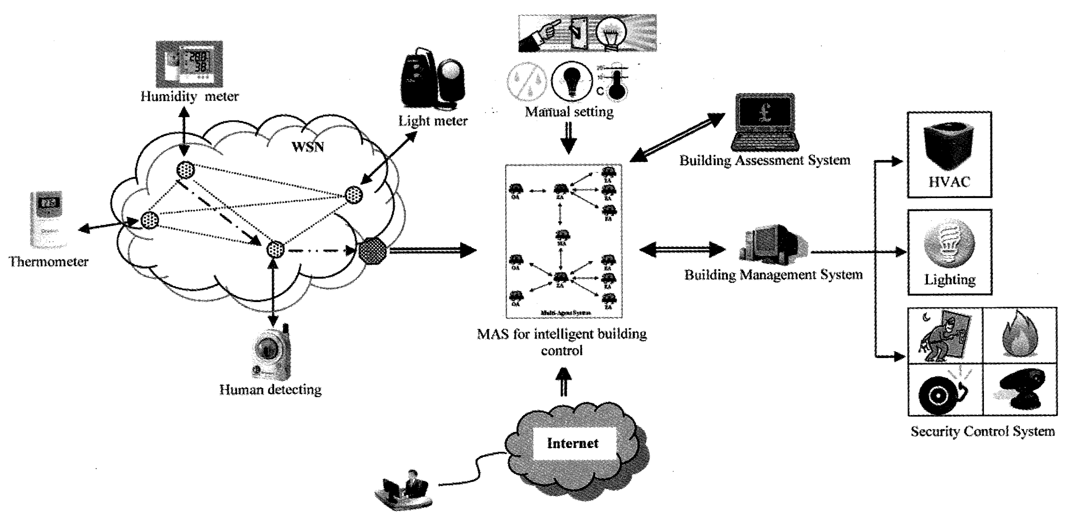


Figure3. Architecture of ABBC (based on [24]).

network (WSN) for real-time data, or manually entered data by users (occupants). Outputs of the system are generated in the form of commands to the building management system (BMS) according to decisions such as increase/decrease temperature, turn on the light, change light intensity etc. When the BMS receives the command from the system, it will activate the relating actuators approximately. For the further detail of our system architecture and design, we describe in this section.

4.1 Architecture of the Building

4.1.1 Zone Layout: Applying IRC Office as Case Study

IRC office is set as our test-bed for experiment. The office area is divided into zones which are defined as the smallest logical unit in the physical structure building controlled by a set of sensor and actuator. According to IRC zone layout shown by Figure4, if Office Room 5's temperature is part of a cooling system that covers two rooms(Office Room5 and Office Room6) then the smallest logical unit is a zone where composes with the two physical rooms. Therefore, the zone can be a single room, a multi room, or an open area, and may be occupied by a single occupant or multi occupant. IRC zone is categorized into two main types: a private zone and a public zone. Typically, the private zone such as office room is occupied by one person whereas there are at least two persons appear in the public zone simultaneously. However, it is possible that more than one occupant appear in the private zone, while the public zone is occupied by one occupant. Therefore, this is one of the challenges to set the optimal environmental zone.

In a case of an individual occupant, environment conditions of the zone are set based on his/her preferences. However, if the multi occupants are present in the zone where the occupants share an open area such as a conference room, negotiation session between the occupants is used to find out the joint preference that make all occupants comfort. Although, the system have to adjust the environment conditions, for example temperature, light, noise, air flow, humidity, etc., according to the occupants' preferences but this setting must process under conditions of energy saving that are issued by a building owner or government. In generally, the owner associates with setting building policies that are regulations, associated legislation, and overall goals to operate BMS. These policies are recorded via GUI into a policy base in terms of rule sets.

4.1.2 Zone Control Panel

The zone is controlled by a client application with runs on the occupant's personal computer. The client application is called a zone control panel. The occupant need to logon to the intelligent building control system server to access the zone information and update personal profile.

The client application interacts with the zone's environmental devices through the server. Each instant of the application registered with a zone and associated with an occupant. Only the occupant of the zone can log in to the application and operate it. The panel fetches the zone's environmental parameters from the server and sends occupant's preferences to the occupant's personal agent that runs on the server and the preferences will be processed during the agents' interaction.

When the user logged on, the zone control panel shows the current environmental information (parameters) of the zone, i.e. temperature, relative humidity (in percentage), lighting level and air quality.

The panel also shows a user control area

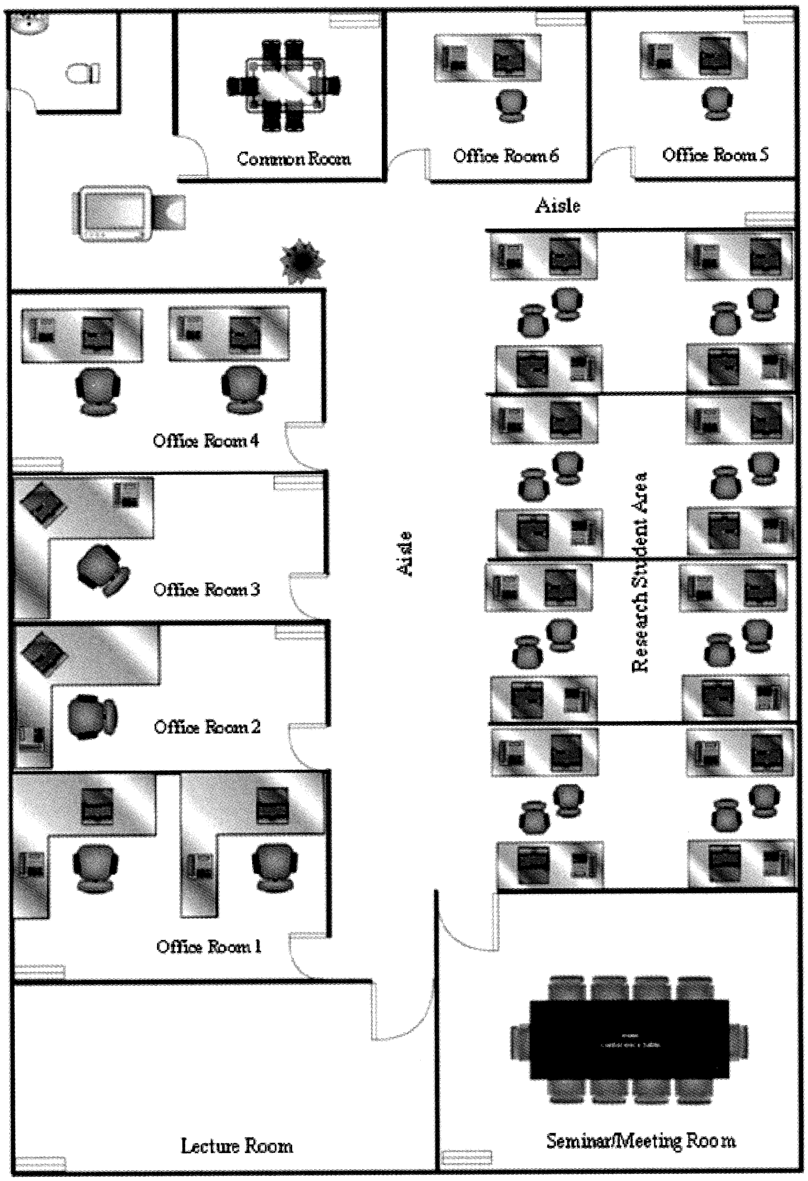


Figure 4. IRC zone layout.

that enables the user to update his/her preferences to adjust the zone environmental parameters. The user can only adjust the parameters within the boundaries defined by building regulations, e.g. the lowest temperature allowed in the zone is 19°C, so the user is not permitted to set the zone temperature lower than 19°C. However, in a shared zone, the user cannot control the zone's environment directly through this panel. The preferences user uploaded to the server are for the agent negotiation. Figure4 shows the control panel for one of the staff in the IRC office.

Users with different priorities have different permissions to access the control panel. The software engineers have the highest priority to access each occupant's control panel' s network setting when deploying the intelligent building control system and the facility managers also have the priority to configure the application for the occupant during anytime in the building operation. According to specific project, the priority to change the relative humidity may be open to the occupant. In our IRC case, the relative humidity can only be changed by the Director of the centre and the facility manager of the building. So in Figure5, the humidity setting is not usable.

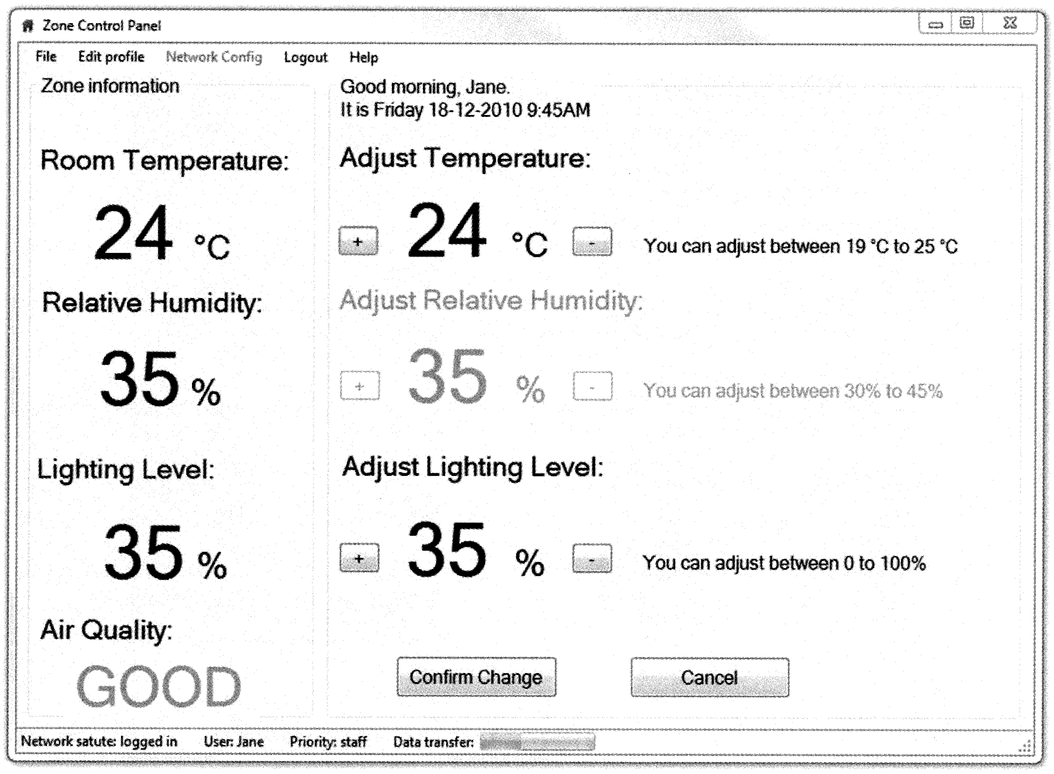


Figure5. The zone control panel of ABBC.

4.2 Architecture of ABBC

The building control system is designed as cooperative MAS that provide a practical application. Agents of the system are specialized agents that are each pursuing their own goals. These agents need to cooperate with others in order to reach such goals because they cannot achieve their goal by the individual agent. E-EDA (extended-epistemic-deontic-axiologic)agent model is applied to knowledge representation and reasoning mechanism of the agents in the agents-based building control system. The further detail of E-EDA architecture is described by the following section.

4.2.1 Extended-EDA Agent

The E-EDA model has been inspired by the EDA model that has been contributed by combination between norms and corresponding attitudes for supporting the organizational semiotics approach [28]. The original EDA model has been proposed for normative reasoning in business domain, and most agents are referred to human-agent. However, the agents in our research domain are both human-representing agents such as occupant agents and artefact-representing agents such as zone agents then the traditional EDA model has been adjusted to support our research domain.

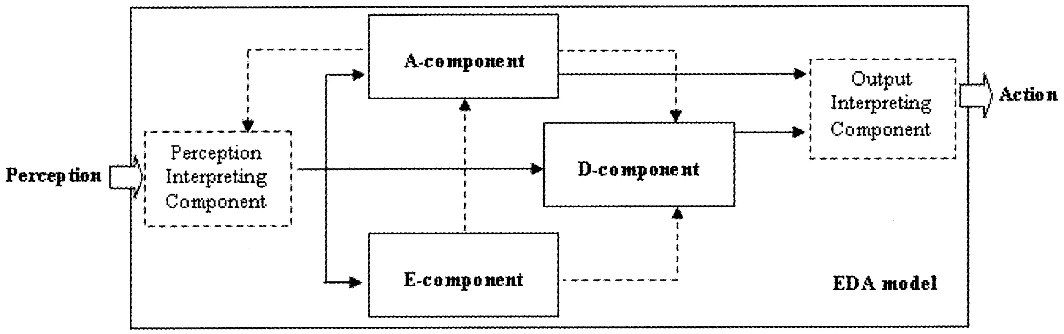


Figure 6. EDA model.

The concept of EDA model has been contributed by combination between norms and corresponding attitudes. As shown by Figure6, the main components of the model are epistemic component (E-component), deontic component (D-component), and axiologic component (A-component). Furthermore, two external components are included: a perception interface obtaining and interpreting external events from the environment, and an action interface sending the output actions to the environment. The EDA model has its own beliefs represented in E-component that contains current beliefs or facts about the world. This component represents the existing knowledge and beliefs the agent attained from the building regulations, policies, building devices' capability, occupants' profile and preferences and historical process log as a service repository in the form of belief statements and cognitive norms. The obligations, rights and behaviours of agent are set in D-component where a set of plans is declared in terms of the interesting behaviours of agent. component hold a set of behavioural norms that guide the agent's action. Intelligent building control requires the comprehensive knowledge that specifies what actions are needed in certain situation. This knowledge can be extracted from building rules and regulation, for example, the operation guidelines for the facility managers in form of goals and actions embedded with behavioural norms. A-component is an evaluating component for assigning a preference relationship among the available plans in D-component providing a dynamically value-setting method for each agent in order to assign the importance of norms. The constituted obligations are assessed through axiology then the committed intentions are established. For example, the building has two goals: one is to reduce the running cost and the other one is to enhance the occupants' wellbeing. If there is an important meeting takes place, the building may decide to close one of the goals: reducing the running cost temporarily to ensure the wellbeing of the meeting attendees. EDA architecture has been adopted for implementing the MASBO (multi-agent system for building control) which has been conducted by cooperating between Informatics Research Centre and the Co-ordinated Management of Intelligent

Pervasive Spaces [27].

The preliminary architecture of the E-EDA model has been illustrated by Duangsuwan and Liu [29] where the normative processes have been described namely: norm identification, norm adoption, goal generation, and preference evaluation. In this paper, we focus on deontic component (D-component) where we elaborate such processes. Figure7 represents architecture of E-EDA model. The generic architecture of E-EDA model remains the three main components of the original EDA model. However, the specific architecture is included to a particular component of the original model in order to enhance the agent capability to take into account the existence of social norms in its decisions. The E-EDA architecture expresses the specific sub-components for norm processing in the D-component which manages about norms and the interaction between norms, goals, and plans. In addition, the normative meta-interpreter called action command generator is represented as an external component in order to translation normative actions into general commands understood by the building management system (BMS). Although, D-component of E-EDA model is divided into three sub-components: *norm management*, *goal management*, and *plan management* but in this paper we only explain norm management in depth detail to depict how norms relate to our proposed model.

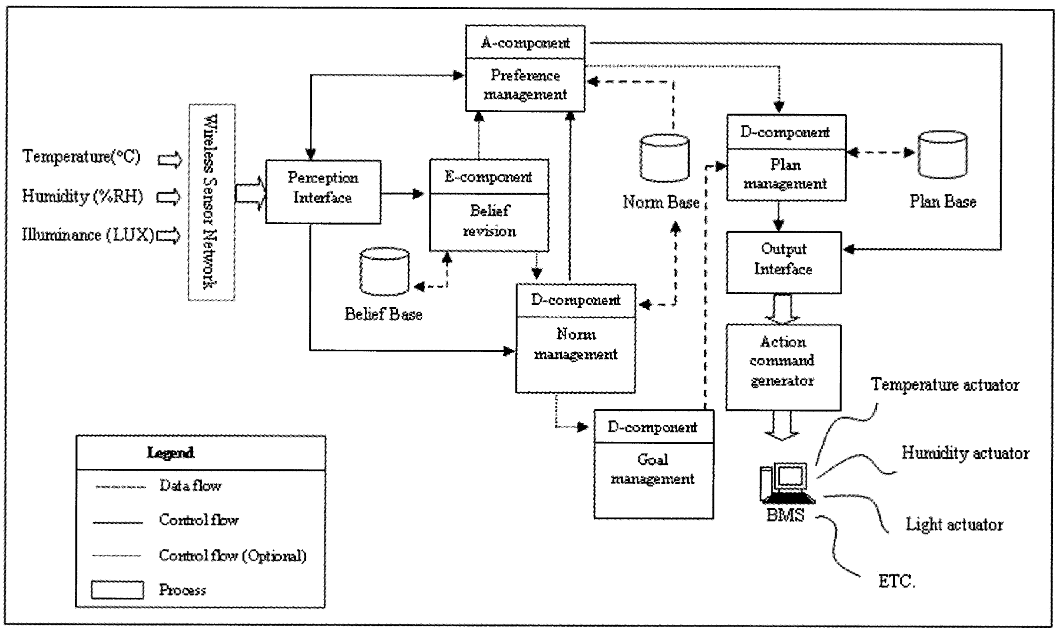


Figure 7. Extended-EDA agent model applying to ABBC.

The norm management is categorized into two sub-components: norm representation and norm deliberation illustrated by Figure8. Norm representation provides the processes which facilitate the creation, maintenance, and use of norm base. To represent norm, we adopt [30] to represent norms in declarative form :

Whenever some trigger condition occur (C)

If human-agent is (R),

Then intelligent-agent/acting agent is deontic operator (N)

To achieve some state of affairs or to perform some actions (A)

Where N is a set of norm types which can be an obligation, permission or prohibition, C is a trigger condition(s) making norm active, R is a role identifier for a norm addressee (agent), and A is the activity specification that can be either an achievement of a state of affairs or a performance of an action.

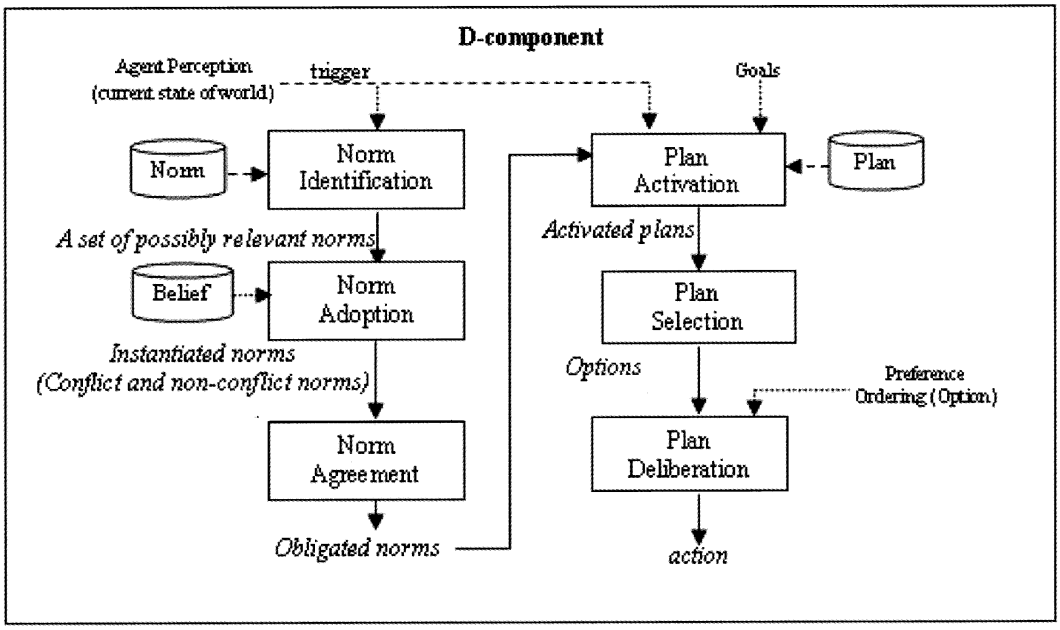


Figure 8. Normative reasoning model in D-component of E-EDA agent model.

Norm deliberation directly performing about norms composes of following internal processes:

a) *Norm identification* is responsible for retrieving relevant norms from the norm base which stores all norms involving to intelligent building control such as building policies, regulation of organization, level of socialization, and so on. The agents may access to certain norms which can be represented as a model of norm. We propose the components of the model which are described by definition2. In extended-EDA model, it is assumed that the norm repertoire is represented as a set of pre-specified building regulations and prepared by BMS.

c) *Norm agreement* determines which norms the agents must to comply with. When agent decides to comply with the norms, there are two possible options: 1) the normative goals of those norms must be added as a part of agent's goals, or 2) the normative goals may affect the agent's goals then it is important to consider the impact of norms on the current goals of agent. By this process, the instantiated norms from the previous process are classified into a set of non-conflict instantiated norms and a set of conflict instantiated norms. Both of norms might influence the agent goals. The non-conflict norm means it does not contest with one of agent's goals, while another conflicts with any agent's goals if the norm is accomplished. To make decision whether or not to fulfill norms, agent must be able to determine how such norms influence the consistency of its current goals. Therefore, the following problems must be addressed:

- What effects does the fulfillment of norms have on the agent's current goals? (i.e.

the benefits of execution or rewards expected)

- What effects does the violation of norms have on the agent's current goals? (i.e. the costs of violation or possible sanctions to be induced)

4.2.2 Agents for ABBC

By applying agent technology, the participants in the intelligent buildings have been represented in terms of agents. There are the different agents, representing rooms or floors of the building, the building occupants, the building services, and so on. Such agents can interact with each other in order to get the best conditions for their representative for example; an occupant agent representing a particular occupant has a goal to achieve the occupant's comfort. The following types of agent are used in the building control system:

Occupant agent (OA) carries out a set of operations on behalf of a particular person who lives or works in an intelligent building. The agent presents some characters of a particular person, monitors and adapts to the person's activities, learns the person's styles and preferences. The goal of OA is to manage user's preferences by learning these preferences from observing occupants' behaviours. OA can reside on the various tools for example; a personal computer, a badge, a mobile phone, Radio Frequency Identification technology and so on.

Zone agent (ZA) corresponds to and controls a particular zone in the building. The agent determines the parameter setting of the zone's environments to minimize energy consumption but preserves the comfort conditions of the occupants. A zone is defined as a region of a building structure and a zone can be a single room, a group of rooms, an open area, a common area, a meeting room etc. However, each region is represented by only one ZA. In addition, many sensors are embedded in each zone such as the temperature sensors, the lighting sensors, the blind sensors etc. As a result, ZA observes the environment via these sensors, and set the environment parameters according to the occupant's preferences.

Manager agent (MA) directly interfaces to BMS by sending the final decision for governing the location's environment to BMS. Furthermore, the agent responses to the preference-priority among agents in the multi-occupant scenario. This agent starts and stops the new agents in the MAS.

Environmental control agent (EA) monitors and controls different environmental parameters in each zone such as temperature, humidity, lighting etc. These environment parameters correspond to the physical objects which sense and response to environment changes in a particular zone. For example, a temperature agent can read the temperature sensor and control the actuators in a zone.

Figure9 depicts the internal architecture of agent via UML class diagram. Agents of the system have been designed in terms of classes which represent their interrelationships, the operations and attributes of the classes. The agents inherit from E-EDA agent class which is abstract so that objects are not created directly from it, and it captures the similarities among the particular agents. Furthermore, other objects relating to the agents such as user, room, sensor, and actuator are represented by classes.

5. IMPLEMENTATION

The intelligent building control system includes the software part and the hardware part. On the software part, we have the server application (a multi-agent system) and the client application (zone control panel).

The system is developed with Microsoft Visual Studio and C# language. It is based on the .Net platform. The database used by the

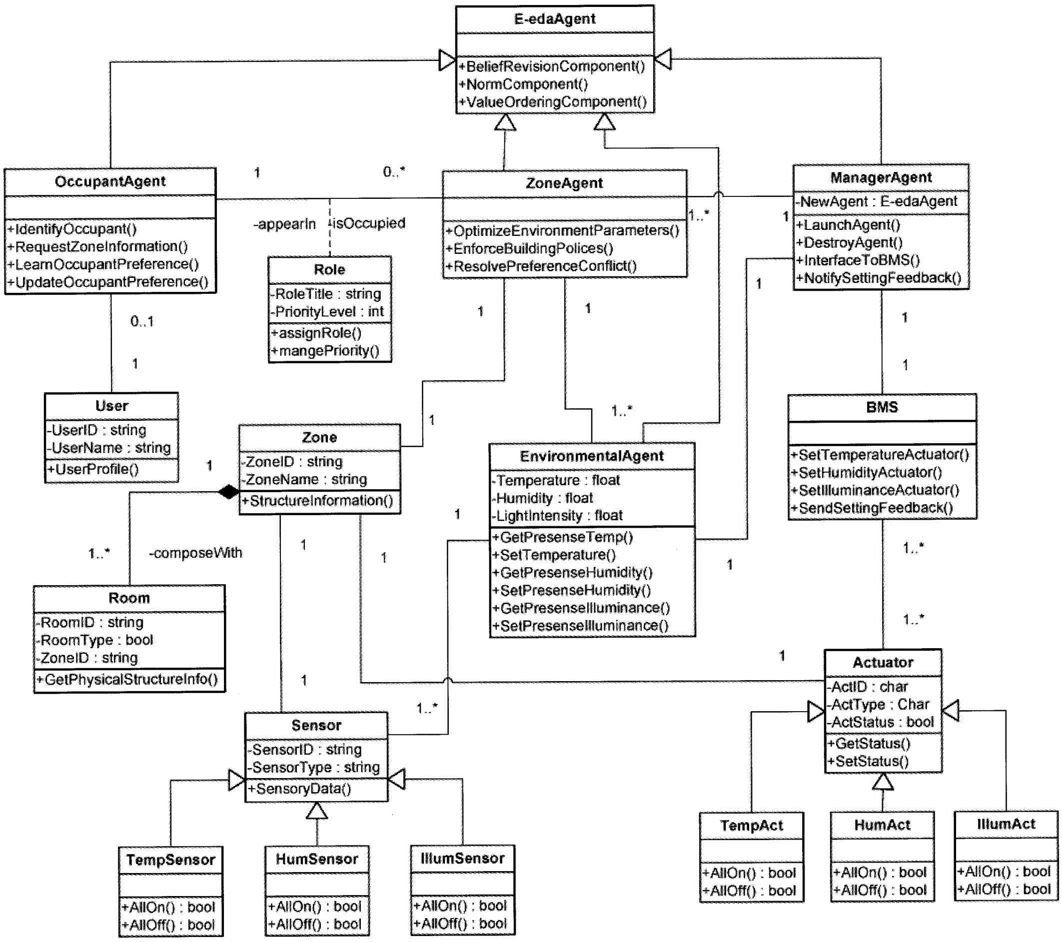


Figure 9. UML class diagram of the implementation for ABBC.

system is Microsoft SQL server. The system runs on Microsoft Windows Servers. To adopt the Microsoft solutions, the system developers are able to develop the system rapidly and with a high programming quality.

Through experiments, the system can handle more than 5,000 intelligent agents and more than 3,000 devices in the building. The agents can also be distributed on different servers. This means the system is scalable and it has a great potential in handling large projects.

The software includes a server application that monitors and controls the entire site and a client application for occupants to monitor and control their own zones. As we have discussed the zone control panel earlier in this paper, the focus will be put on the server application. Figure 10 shows the interface of the server application.

On the left side of the interface, the general information about the site is displayed. The user can also apply some over all control to the building, e.g. change the ventilation setting or change the norm set used by the system. For the ease-of-use reason, the norm set in the application is represented as rule set.

The building plan is in the middle. User can view zone information and control the zones by clicking the zone labels on the building plan.

A zone list is on the right hand side. User can view the general zone information from the list, i.e. the zone name, the zone type, the zone occupancy, the location of the zone and the zone owner.

If a zone is selected from list or from the building plan, the zone information is displayed under the zone list. User can manually control the zone by ticking the manual control box.

The occupants and the norm set can be managed in the menu.

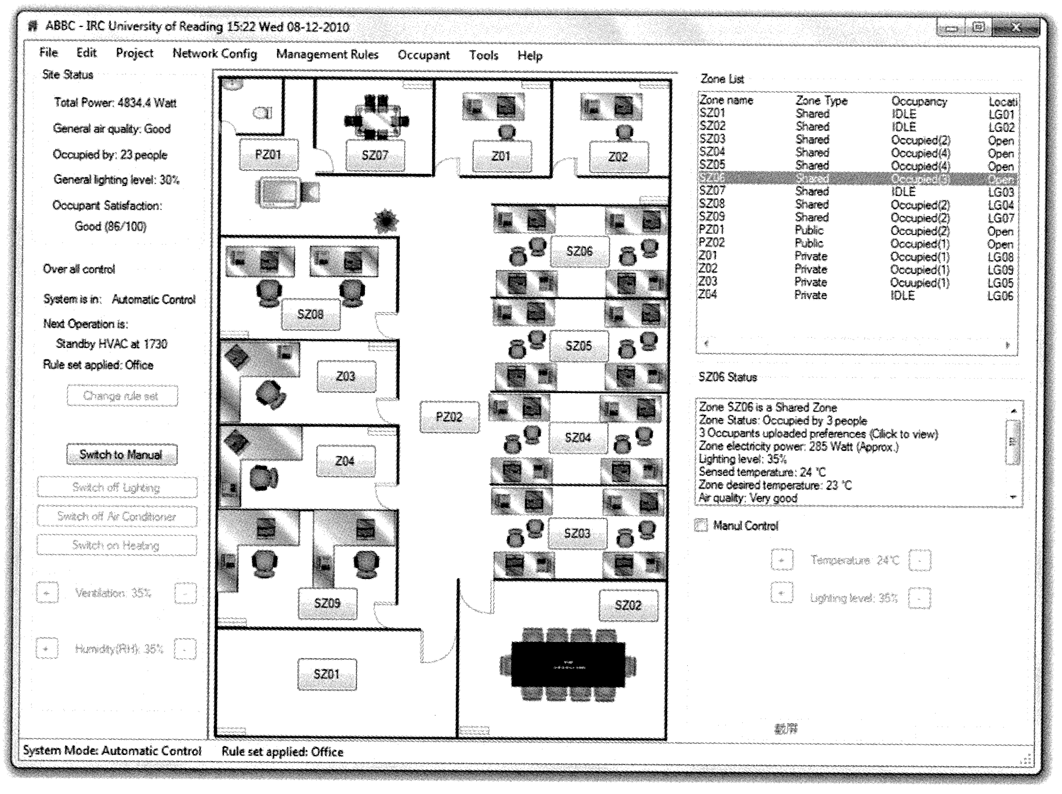


Figure 10. The Agent-Based Building Control System.

On the hardware side, the system communicates with devices through driver applications. A driver application is a software interface independent from the system that understands the devices' communication protocol and converts the messages between the software and devices. A driver application is associated with the devices that use the same communication protocol. It identifies different devices by their communication addresses. The driver applications make the system communicates to universal devices. The system developers develop new driver application based on a template to enable a new type of device join in the system.

The software talks to the devices via TCP/IP connection and serial ports. It also supports Zigbee wireless devices, RS 485 bus devices and other type of devices by applying hardware converters.

The system can also be attached to existing BMS systems. In this case, the system fetches the building information from the BMS's data based instead of fetching data from device via driver applications. It sends commands to the devices via the BMS through an interface.

6. Illustration: Using Agents-Based System for Negotiated Environment Control

Negotiation is a key form of interaction that enables a group of agents to arrive at a mutual agreement regarding some belief, goal or plan. Particularly because the agents are autonomous and, in some cases, are self-motivated, then the agents must influence others to convince them to act in certain ways[31].

6.1 Negotiation in Mas

Many negotiation techniques for MAS have been proposed. We summarize some techniques described by [12] as follow.

Contract-based negotiation called contract net protocol is a simple negotiation mechanism among co-operative agents in a distributed problem solver environment. An agent who has some work to subcontract broadcasts an offer, and waits for other agents to send bids. When the agent retains the best offer, the contracts are allocated to one or more contractors who process their subtask. This approach is simple and efficient but it fails to capture many intuitive and important aspects of the negotiation process such as lacking of counter-proposing, lacking of modification of the service agreement parameters, and so on. However, various improvements and extensions to the contract net protocol have been proposed by [32, 33].

Market-based negotiation is a technique that classifies agents as producers and consumers of goods and services. In some situation, a consumer agent wants to obtain goods but it has a limitation of budget. Thus, it will make offers base on the current price of goods and its own preferences. In order to make the offers for goods or services, the consumer agent has an internal utility functions, and its goal to increase utility. A producer agent aims to maximize its profits. Given a set of prices by the producer agent, the trading process involves a sequence of offers in which each consumer states how much of each resource it wants to purchase. If the demand differs from the supply then price will have to be adjusted by the producers. One of the drawbacks of this technique using prices as a primary controlling mechanism is the convergence process may be slow because of a large number of offers. However, a new approach which focuses on resources rather than prices has been propose by many researchers such as [34-36].

Game theory-based negotiation has been developed based on a particular matching between game theory and agent-based system. Game theory assumes that the players are rational then Game theory is relevant to the study of automated negotiation because the participants in such negotiations can reasonably be assumed to be self interested. However, applying game theory to analyzing human negotiation regularly faces two main problems: 1) human beings do not always act rationally, and 2) human beings frequently do not have consistent preferences over alternatives. By contrast, agents which are pre-programmed for their behaviours, make concrete the notion of strategy which plays a central role in game theory. The agent adopts rules of behaviour before starting to play a game. Such rules control agent's responses while it is playing the game. Besides rationality, there are other basic assumptions of game theory for negotiation such as utility maximization, complete knowledge, isolated negotiation, and so on. Although game theory provides a theoretical basis for MAS negotiation mechanism, it is not a perfect solution because problems in real world situation, such as complete information assumption; in flexibility and inadequacy, limit to the application of game theory in MAS. As a result, many researchers have attempted to incorporate other negotiation mechanisms such as bargaining theoretic approach with game theory.

Psychology-based negotiation is presented as a cyclic negotiation model which is based on Gulliver's (1979) eight phases of negotiation process. The general strategy of this approach is that negotiation begins with an/the agent(s) making a proposal. Next, the agents evaluate and check the proposal against their preferences, and criticize it by listing any of their preferences violated by the proposal. The agents then update their knowledge about the other agent's preferences and the negotiation cycle resumes with a new proposal in the light of this newly learned information. Conflicts between the agents are handled in a concurrent conflict resolution cycle.

Argument-based negotiation emphasizes on how the agents can justify their negotiation stance, and how they persuade one another to change their decision. The agents may use *arguments* to try to change their opponents view, and to make their own proposal more attractive by providing additional meta-level information in its support. The nature and types of arguments are varied, but include threats, rewards and appeals. Whatever its precise form, the role of the supporting argument is either to modify the recipient's region of acceptability or its rating function over this region. In so doing, arguments have the potential to increase the likelihood and/or the speed of agreements being reached; for example, if agents prefer arguments that are more likely to lead to an agreement, it is possible to prove that argumentation leads to quicker agreement. In the former case, by persuading agents to accept deals that they may previously have rejected. In the latter case, by convincing agents to accept their opponent's position on a given issue (and to cease negotiating over it).

In addition, other approaches have been developed to address different aspects of negotiation. AI-based negotiation adopts several AI approaches; such as case-based reasoning, negotiation search, knowledge-based approach; to develop agent negotiation mechanisms. Plan-based negotiation is based on co-operation protocols and strategies for resolving conflicts among the plans of a group of agents.

6.2 Conflict Scenario and Resolution

According to [6] there are several points of view on agent cooperation which depend on the attitude of agents that they decide to work together (e.g. cooperation as an intentional posture), or whether one places oneself in the position of an observer (e.g. cooperation from the observer's point of view), etc. Conflict resolution is one point of agent cooperation which is applied to resolve the situations where agents' interests may be contradictory. Such situations generally happen when two agents simultaneously desire something for which any sharing reduces what one of the agents could have obtained if the other had not been present. For example when two people want to use the same facsimile at the same time, they are in conflict situation. Therefore, the conflict situations lead to the interactions between agents in order to achieve a way out of conflict. Two techniques, arbitration and negotiation, are used by MAS to resolve conflicts. These techniques are the means to avoid and reduce disagreements between the particular agents.

Arbitration is based on rules of behaviour which act as constraints. For example, in human being societies the behaviour is governed and restricted by laws and regulations. The punishments are prepared when the human do not obligate the regulations.

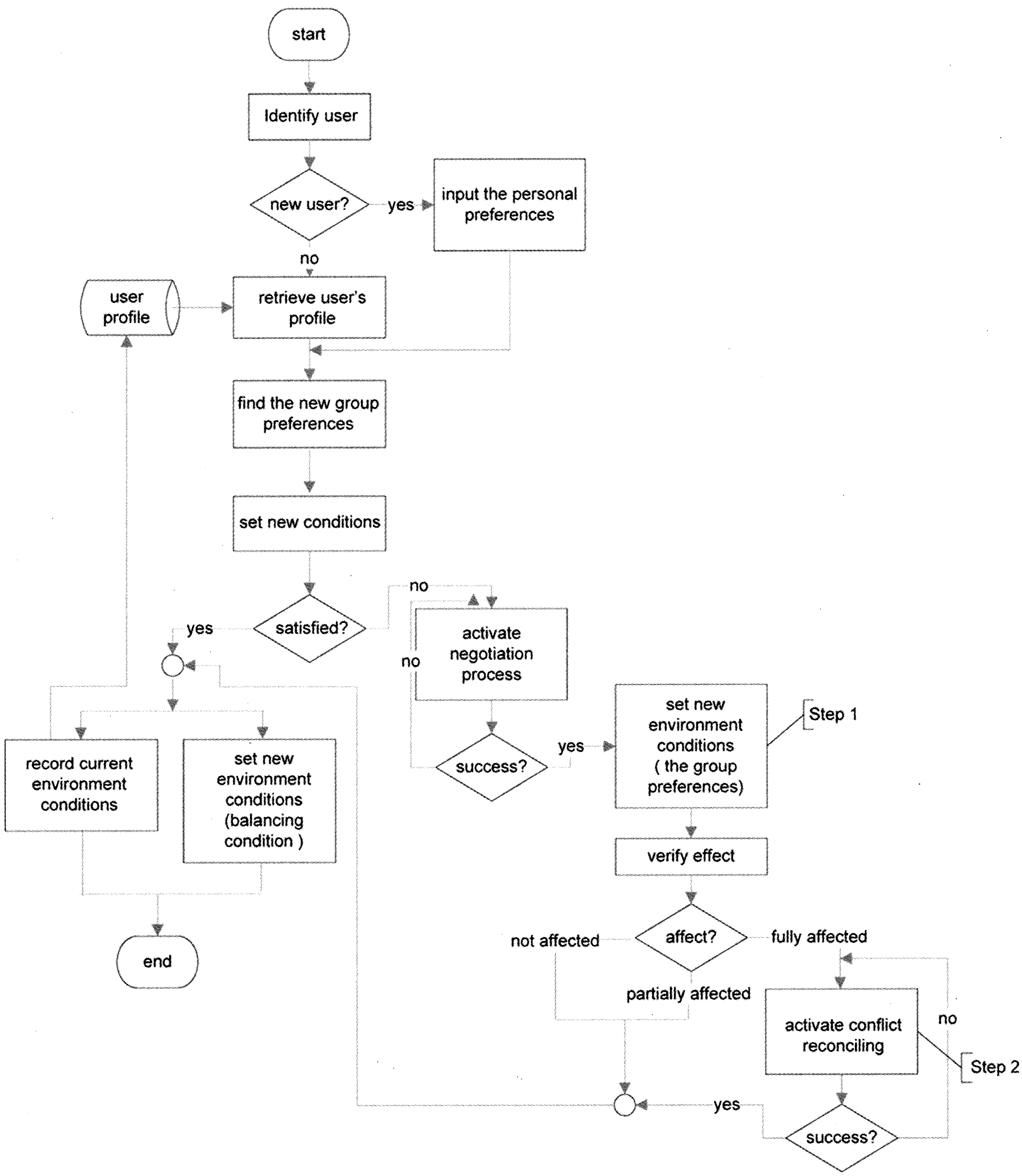


Figure 11. The processes of conflict resolution in the multi-occupant scenario.

In MAS, as appeared in many studies [7, 8], negotiation process has been applied to resolve the conflict. According to [9], negotiation is a process which leads to a joint decision of two or more agents in order to achieve an individual goal or objective. The agents first communicate their positions, which might conflict, and then try to move towards agreement by making concessions or searching for alternatives.

The certain situation called *a multi-occupant scenario* is taken consideration in our research in order to demonstrate how the control system adjusts the environment parameters of zone when it is occupied by a group of person. The multi-occupant situation represents at least two occupants appear in a same zone at the same time. Such situation, the conflict among occupants may occur due to the different preferences of occupants. Therefore, the processes of conflict resolution have been proposed through the flowchart in Figure11. To reconcile the preferential difference conflict, argument-based negotiation is employed to find the certain preferences among the occupants that make most of them satisfy under energy saving regulations. However, the negotiation will be activated when one of the occupants request to change the current conditions otherwise we assume that the occupants prefer the current conditions that is adjusted automatically by a building control system. The negotiation is divided into two steps:

Step1: negotiation among the occupants through the occupant agents in order to find the group preferences.

Step2: negotiation between an occupant agent and a zone agent representing an associated area occupied by the occupant.

Due to limitation of the pages, we do not go through in depth detail of the steps for negotiation. However, the preliminary design of negotiation mechanism presented in [37] is described.

Negotiation ability is added as part of general function of the occupant agents so that negotiation can be carried out directly among the occupant agents without deploying a mediator agent for an improved efficiency. The negotiation among the occupant agents is processed under rules as follow. In addition, the rules are represented as a graphic scenario through attributed-SDTS that is presented in section 6.3.

- An agent negotiating initiator called a persuader is an occupant agent representing an occupant who needs to change the zone's environments set at that time.

- The persuader is responsible for broadcasting the first proposal.

- Each agent called a compromiser that receives a proposal accepts/rejects it by sending the message back to the initiator. If all compromisers accept the proposal, the persuader announces the proposal as a consensus in terms of a group preference. In contrast, if at least one compromiser rejects the proposal, the new initiator is the agent which rejected the proposal.

- The new initiator relaxes it's constrain then it broadcasts the new proposal in next round of negotiation and the process repeats from point 3.

-Even though the negotiation is requested to change the current environments of a zone, the new desired environmental conditions are still based on both occupants' preferences and energy saving considerations.

6.3 Negotiation Representation Via Attribute SDTS

The SDTS proposed by [38] is device for translation elements attached to each production/rule. Whenever a production/rule is used in the derivation of an input sentence, the associated translation element generates a part of the output sentence. The formal representation of SDTS is presented in terms of a 5-tuple T.

$$T = (N, X, Y, R, S)$$

Where N is a finite set of non-terminal symbols; X is a finite input alphabet; Y is a finite output alphabet; S ÎN is the start symbol; and R is a finite set of productions/rules of the form:

$$P = A \rightarrow aB,\ bB \quad \text{or} \quad A \rightarrow a,\ b$$

Where $a \in X$; $b \in Y$; $A, B \in N$ then the SDTS can be represent as a graph shown in Figure12:

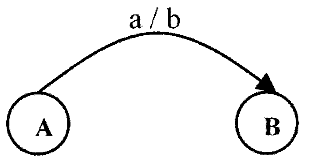


Figure12. Transition graph representing the rule $A \rightarrow a, b$ [39].

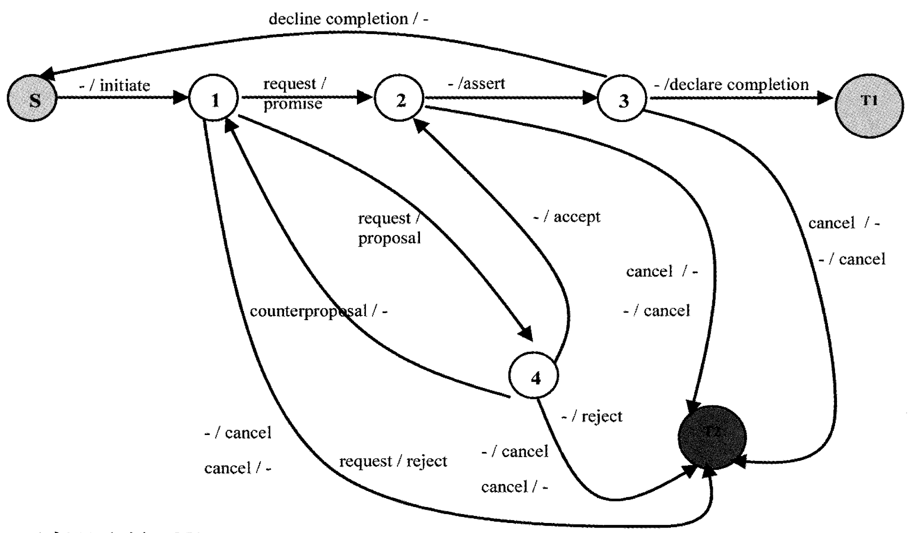
Notational shorthand which is used for representing the m productions is denoted as:

A → B1 | B2 | . . . | Bm

However, using only SDTS concept cannot represent the conversation among agent which occurs in negotiation process so that attributed-SDTS [39] is used as tool to demonstrate the conversation. By using apply attributed-SDTA to negotiation mechanism described in section2.2; graph and syntactic rules of SDTS representing negotiation protocol are illustrated accordingly. Illustrated by Figure13, node T1 and T2 represent the terminal nodes for successful and unsuccessful transactions, respectively.

7. CONCLUSION

We have illustrated a conceptual framework of the intelligent building control system using the multi-agent systems approach. The agents of the system represent particular participants who involve in the intelligent buildings such as an occupant, a room, a zone of the buildings. Such agents try to reach its goal; for example, an occupant agent has to maximize occupant comfort but zone agent tries to maximize the energy efficiency. However, the common goal, optimizing between occupant's comfort and energy consumption, has to be fulfilled.



S→N1, initiateN1

N1→requestN2, promiseN2 | requestN4, proposalN4 | requestT2, rejectT2 | ϕT2, cancelT2 | cancelT2, ϕT2

N2→ϕN3, assertlN3 | ϕT2, cancelT2 | cancelT2, ϕT2

N3→ϕT1,declare_completionT1|decline_completioS,ϕS | ϕT2, cancelT2 | cancelT2, ϕT2

N4→ϕN1, proposalN1 | ϕN2, acceptN2 | ϕT2, rejectT2 | ϕT2, cancelT2 | cancelT2, ϕT2

Figure 13. Graph and syntactic rules of SDTS representing negotiation of agents.

Therefore, we have employed a negotiation mechanism to give opportunity for the occupants to offer their preferences to others in order to find out the optimal preferences that make the occupants feel comfort as much as possible. Furthermore, a particular agent of the proposed multi-agent system is modelled under an extended-EDA architecture enhanced capability to support normative decision making. Different from the other systems, we have added norm concept that promotes an increased flexibility towards the policies and the preferences of occupants in the building. Therefore, the system gives a good support for extensions and adaptations in the building's policies that optimize the energy consumption, and also make the building's occupants feel comfort as much as possible.

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