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# Smart systems for energy consumption management in green buildings and its economic evaluation in Iran

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**ABSTRACT:**

The combination of physical world with computer capabilities would develop a new world which is able to think with a computer mind. In this research, we will investigate smart systems and review a number of cases which have utilized them. This paper attempts to answer the following questions: “Are smart systems able to manage energy consumption?”, “Given the considerable cost of smart systems, can one propose a cheaper alternative with the same efficiency at least for residential buildings?”, and “Which building groups best suit smart systems? The results of this study confirmed that the use of smart systems is cost effective for general, industrial and office buildings thanks to return on investment. With regard to residential buildings, however, one can minimize the waste of energy without suffering the costs of purchase and maintenance of smart systems, by using climatic design solutions such as selection of optimal building direction, optimization of ducts, adoption of efficient building design, and the utilization of appropriate attachments.

**Keywords:**

Smart control system, Green building, Energy, Residential architecture.

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## INTRODUCTION

The design of office buildings is under change and transformation. Until a few decades ago, employees used to be paid no attention when designing office buildings, particularly in Anglo-Saxon countries. The constructors of office buildings sought high profit and low risk, with their buildings meeting only the simple office needs and offering a fixed and steady work process. Today, a major question is whether or not such office buildings are able to meet the new organizational needs without undergoing fundamental changes (Fakhri *et al*., 2016).

The design of office buildings has undergone a simplistic approach adopted by designers, constructors and employers who paid no attention to various aspects of the building and gave a series of predefined answers to problems. In fact, there was not any multipurpose building and the new organizational needs were not met by the architecture belonging to the traditions of global spaces in the age of modernism. Likewise, the constructors and financial institutions which financed these projects hardly accept the fact that different parts of the market had varied needs and expectations (Same).

The idea of smart building is the best solution for optimal use of technology and electronics (Yazici *et al*., 2017). This is particularly important for office buildings, because the transformed nature of office works demands the use of electronic management methods and development of modern buildings with the ability to utilize the most recent technologies. Today, office buildings are responsible for providing more efficient services to their residents so as to help them adapt to new conditions. To do so, they have to develop into smart buildings by using different technologies (Cirigliano *et al*., 2016).

Smart building management systems are able to control the environment, lighting system, elevators, and so on. In a recently developed technology called Building Management System (BMS), the sensors have been combined with a monitoring, maintenance and control system whereby promoting its power and efficiency. The advantage of BMS lies in the reduction of building control, which may result in the reduced repair and the increased lifetime of furniture. By using BMS, a small expert group is able to maintain a large building or several small buildings from a far distance. The proper selection of BMS, whether for a new building or for an existing one, requires a consultation team consisting of construction engineers and architects as well as making the necessary investment for the project (Habash *et al*., 2014).

In this article, we reviewed smart systems and a number of cases which have used them. This article aims to answer the following questions: “Are smart systems able to manage energy consumption?”, “Given the considerable cost of smart systems, can one propose a cheaper alternative with the same efficiency at least for residential buildings?”, and “Which building groups best suit smart systems?”

### Smart building

Generally, smart building is one equipped with a powerful communication structure which is able to react to varied situations in a continuous manner, enabling the residents to use the existing resources more efficiently and enhancing their security and comfort. A major advantage of smart buildings is that they can reduce energy consumption. In developed countries, smart building is defined as a building which provides a dynamic and cost effective environment by integrating four elements: systems, structure, services, and management (Habash *et al*., 2014). Therefore, smart building is a dynamic and cost effective building which is developed through integration of four parts as follows:

1. HVAC (Heating, Ventilation and Air-Conditioning)
2. Fire Safety
3. Security
4. Lighting Management and Energy

### Building management system

Building Management System (BMS) refers to a set of hardware and software installed for integrated monitoring and operation of important and vital parts of the building. The duty of building management system is to monitor different parts of the building in a continuous manner and give the necessary commands so that different parts are kept in optimal conditions, unwanted consumptions are reduced, and a comfortable and safe environment is developed. BMS enables to enhance the efficiency of existing equipment and facilities of the building and promote the level of services by using the most recent technologies. As with other control systems, BMS consists of three parts viz., sensor, controllers and Actuators (Addington and Schodek, 2004)

**Sensors**

Sensors are responsible for assessing the environmental parameters and sending the necessary information to the system. They act as the nerves of the building and identify certain situations. The information produced by sensors include the internal and external temperatures, heating or cooling fluid temperature, light, humidity, amount of gases in the air, presence or absence of individuals, and any other information which may be vital to optimal operation of the system.

**Controllers**

Controllers receive the information from the sensors, process the information using their internal software or network software, and send the necessary commands to actuators.

**Actuators**

Actuators receive the commands from the controllers and react to them accordingly. Actuators may be electrical valves, adjustable openings for the passage of air, electrical current relays, and so on. The above said three parts are interconnected through a communicative mechanism which is composed of two major parts:

1. Communicative media such as wire, optical fiber, and radio waves
2. Communicative protocol such as LonWorks and BacNet (Kicanovic, 2016)

**Smart system equipment**

**A) Remote control**

It is possible to get the image of internal space of the building by means of telephone or internet and control all systems in the building.

**B) Lighting control**

According to the statistics provided by Fuel Consumption Optimization Organization, over 40% of electrical energy received by buildings is consumed by lighting devices. Despite such a great consumption, lighting devices fail to provide residents with the sufficient light. Smart lighting system enables to control electrical energy consumption and provide sufficient light. The logic of this control is defined by the intensity of needed light in proportion to each space. An advantage of implementing smart system in buildings is the ability to define a new logic for each situation only by making necessary changes in planning, without any need to physical change (e.g. change of wiring) (Ritter, 2007). Different modes of lighting can be defined for each situation, such as normal mode, guest mode, night mode, and travel mode for residential buildings and session mode, lecture mode, film mode, study mode, and computer mode for office buildings. Other advantages of smart lighting systems include time-based planning, light control by automatic voltage reducers, remote control of keys, light control according to intensity of environmental light, prevention of energy waste, and prevention of unwanted consumptions.

**C) Controlling the temperature (Huang and Mao, 2017)**

In smart systems, temperature is accurately measured and the desired temperature is adjusted by control valves according to the defined logic. In order to prevent the waste of energy, the control valve can be automatically closed when windows are opened. There are several air makers in the building, each covering a specific area. A duty of air conditioner is to monitor the air injected to different areas of the building. Also, some areas are directly fed by air conditioner. Another duty of air maker is to produce fresh air for the internal spaces of the building, which is done by a mixer and demands the balance between fresh air dampers and the returned air. To do so, BMS collects the temperature, humidity, and CO1 information and makes the best balance between input and output dampers, which results in optimal use of the returned air.

**D) Security control**

This section manages all signals related to security systems and adjusts risk signals.

**E) Simulation of presence of residents**

When the residents are absent, windows are opened and closed in a normal manner and the lighting and sound systems are turned on and off as if the residents are present in the building, so that thieves do not become aware of their absence.

**F) Status of locks**

When the doors and windows are closed, all contacts are checked and, in case of incomplete closure, alarms start to signal.

G**) Prevention of disruption (Salvo, 2016)**

If doors or windows are opened by force, the security system is activated and the presence of unauthorized individuals is detected by motion sensors. If residents are present in the place and feel there is a risk, they can activate the entire security system by pressing one button.

**H) Sunshade and curtain system**

Sunshades and curtains can be controlled according a predefined logic for each situation. All curtains and sunshades can be used to change the light of rooms automatically, via remote control or manually. The relevant control function can act in a fully automatic manner based on the defined time, the amount of lighting, or wind direction. For example, all windows can be planned to be closed at 6:00 o'clock. If the light falls down a specified limit, or if windows remain open during the day, or if a severe wind starts to blow, the windows will be closed to prevent the possible damages.

**I) Alarm systems**

Alarm system can be activated along with lighting system. The soundless alarms will inform neighbors, emergency services center, or local police by phone.

**J) Fire safety**

Smoke detection sensors are adjusted with electrical systems of the building. In effect, different systems of the building are interconnected like a chain in order to protect the building against probable risks. In addition, security measures are taken in the right time when the damages have not yet led to building destruction (Kicanovic, 2016).

**K) Technical alarms**

Smart buildings are able to manage technical messages. The residents are immediately informed of the damages to water systems or electric circuits and subsequent problems are prevented.

**Making buildings smart**

In addition to the foregoing specifications, some other features are also involved in the classification of smart systems. The proposed classification of smart systems is based on three features (Ashkani, 2011). 1)Smart system with the capability to change internal specifications: smart systems are able to change the shape, color and links; 2) Smart system with the capability to exchange energy: smart systems are able to emit light, produces electricity, and saves energy; 3) Smart system with the capability to change and exchange internal materials: the most important point in the classification of smart systems is the attention paid to sustainable development, which is the major concern of the present century (Hamernik *et al*., 2012.)

**Smart transformation system**

Certain materials are able to change their form and dimensions. These changes depend on the type of distribution and arrangement of their internal compounds. Many systems with such capability are now available, with the most popular ones being thermostrictive, piezoelectric electroactive, and chemostrictive systems which have drawn much attention in the field of architecture (Eley, 2016).

**Smart reactive changes of temperature**

This type of smart system is a subdivision of smart transformation system and is able to react to ambient temperature changes. Where temperature changes are inactive, smart system continuously adjusts its internal temperature with the ambient temperature via its external layer. Where the impacts are active, smart system creates some kind of active heating by using the electrical field. The reactive temperature system covers various types of materials, but only a limited number of them are used in the architecture (Cardei *et al*., 2016).

Thermal Expansion Material (TEM) is an example of reactive temperature system which has a thermal expansion coefficient. Thermometers were the first systems to be made by this material. However, this system is most widely used in thermostats, construction services, green houses, and façades of buildings (for energy control and management). It is also used in ventilation systems of building rooms. While TEM has been used as a part of thermostats during the recent decades, its application in automatic ventilation system of buildings is limited to the recent years. In the following project, the reactive temperature system has been combined with architectural and construction techniques (Alvisi and Franchini, 2016).

**Gathering hall project**

In 2004, an architectural competition was held in the former camp of Hinzert, Germany, for design and construction of gathering hall. The architect's idea for designing this structure was the circular form used in the former structure. This idea was used as the basic element of building design. The design included four circles, each covering the other circles, which produced the shape of a broken cone altogether. Two external circles belonged to library and conference hall and the glass cylinder crossing the circles had three floors which housed the gallery rooms. The open area between the circles acted as the gathering place (Tiago *et al*., 2015). The walls of gathering hall have a circular structure with frameless glass façade which has a metal cover in its external part. The façade has a movable and dynamic form and can lead varied amounts of sunlight into the building. This façade is divided into two panels which are able to rotate around an axis in different angles. The rotation angles depend on the angle of sunlight. A thin layer of solar cells enables TEM to automatically control the amount of sunlight coming to the building. In order to restrict the impacts of thermal energy and to ensure that sunlight is the only controlling stimulus, some other elements have been added to the system. At the same time, the sheets located at the corners of façade move towards the external part where a highest amount of sunlight exists and solar cells and collectors located in the roof complete the energy-centered idea of the project (Atkins, 2004).

**Smart color change**

This system, as its name implies, is able to change its visual features in response to one or more external stimuli in a restorable manner. Depending on the type of external stimulus, this system has various types. A few types of this system are used for architectural applications, including photochromic, thermochromic, and electrochromic, which are briefly explained in the following paragraphs (Akın and Pedgley, 2016).

**Photochromic**

Photochromic (PC) is being widely used by architects. This system is able to change its color in reaction to ultraviolet ray, light, infrared ray, and electromagnetic ray. At present, PC is available in the form of photochromic pigments, photochromic glasses, and photochromic plastics and polymers (Tarfiei, 2015). Among the first projects which used PC system is the entrance of Munich Modern Arts Museum designed by two German architects in 1992. Since then-on, this system has been widely used in architectural projects and building façades. In the beginning, this system was used for its beauty feature because it created a color spectrum in response to light. But researchers conducted broad studies about this system in order to utilize it for other applications such as reduction of energy consumption or change of temperature. Electro-chromic system is also used in the architecture of electro-optical glasses. This system is able to change its transparency when exposed to sunlight. The biggest electro-optical cover in the world belongs to a building in Tokyo which was constructed in 2004.

**Central office of Shanel company**

This project was executed in Tokyo in 2006 and is unique in its kind. It consists of 10 buildings including shopping center, concert hall, and restaurant. The most interesting part of this project is its façade which is able to take various forms during the day thanks to its special design. This façade consists of several functional layers. The external layer has a gray glass connected to iron frames and a rhombus-shaped structure which augment the beauty of building. The next layer is an empty space in which the electro-optical system is located. The internal layer is made of glass with two security layers in both sides, which is crossed by a horizontal aluminum rail on which two rows of lamps have been mounted. The electro -optical glass and the entire façade are transparent during the day, producing an incredible vision from inside the building. When it gets dark, the glass turns opaque and the façade creates a vision like a cinema screen. In this mode, the images can be seen as clearly as in a cinema screen.

**Smart light emitter**

This system consists of special molecules which are able to produce light when simulated by certain kinds of energy such as electrical fields. This phenomenon is a temporary mode which occurs in reaction to the impact of certain energies. In this phenomenon, some part of the energy absorbed by molecules is emitted in the form of visible electromagnetic ray. This system is most widely used in architecture, photolomins system, and electro-lumins system (Kolarevic and Klinger, 2013).

**Habitat hotel in Spain**

This tree-shaped hotel, built in 2007 in Barcelona, utilizes smart light emitter, LED, and solar cells. A forest with artificial leaves forms the external layer of this hotel. The façade of this hotel consists of the popular glass covered by a metal network with a large amount of artificial electronic leaves. The leaves consist of solar cells, each with a diameter of 25 cm. During the day, the electrical energy generated by solar cells is temporarily stored in a reservoir and is sent to LEDs by a processor in night. Then, the LEDs emit the energy in the form of a seven-color light. Therefore, solar energy constitutes the entire energy needed for lighting system of this large structure. Moreover, the amount of light and color varies depending on the situation (Salvo, 2016).

**Smart energy storage**

These systems are able to store energy in a visible or invisible form (e.g. light, heat, hydrogen, and electricity) (Shaikh, 2012). While these systems can store energy in various forms, smart heat storage system has drawn much more attention. This system is able to store energy in the form of heat and is widely used in architecture. Among the most widely used systems the suitable one is which, used to adjust the temperature. NASA is the first organization to use this system in 1960 for space projects.

**Table 1. Saving percentage after optimization (Iranian Ministry of Energy, 2011)**

| S. No. | Project location | Annual saving percentage | Annual saving (cubic meter) | Pollutants (Kg/year) | Equivalent crude oil barrel (per year) |
|---|---|---|---|---|---|
| 1 | Education organization of district 10 of Tehran (new machine room) | 8.72% | 40523 | 85098 | 247 |
| 2 | Education organization of district 10 of Tehran (old machine room) | 7407% | 42729 | 89731 | 260 |
| 3 | Municipality of district 10 of Tehran | 20.15% | 32307 | 67845 | 197 |
| 4 | Shahrak-e Gharb Residential Complex | 21.18% | 9699 | 20368 | 59 |

**Table 2. Amount of saving after optimization (in Iranian Rial) (Iranian Ministry of Energy, 2011)**

| S. No | Project location | Savings (Iranian rial) | Environmental and social costs | Total (Iranian rial) |
|---|---|---|---|---|
| 1 | Education Organization of District 10 of Tehran (new machine room) | 12.976.360 | 43.910.568 | 56.877.928 |
| 2 | Education Organization of District 10 of Tehran (old machine room) | 13.673.280 | 46.301.196 | 59.974.476 |
| 3 | Municipality of District 10 of Tehran | 10.338.240 | 35.008.020 | 45.346.260 |
| 4 | Shahrak-e Gharb Residential Complex | 3.103.680 | 10.509.888 | 13.613.568 |
| 5 | Total | 40.082.560 | 137.322.564 | 177.405.124 |

**Residential complex in Switzerland**

This project used smart thermal energy storage system isolated by hydrate salt.

**Smart exchange of internal materials**

This system has restorable compounds which can release materials in gas, liquid or solid form by different physical and chemical processes. When exposed to gas, steam, water, or even water-containing solutions, this system adds them to its own volume. Thanks to this property, this system can be used in external or internal views of buildings. The most popular type of this system is one which automatically cleans itself and destroys air pollutants on the building surfaces (Ashkani, 2011). This material has unique properties and is able to change into a severely active material when exposed to ultraviolet ray. The chemical reaction of this material prevents the bacteria and dirt from sticking to the walls, causing them to be easily washed off by rainfall. The self-cleaning feature is one of the most important applications of this system in urban design which can greatly contribute to the cleanness of large cities and reduction of air pollution (Loonen *et al*., 2013).

**Residential-commercial complex in Austria:**

This complex uses a smart system with the capability to change and exchange internal materials and self-cleaning feature.

**Smart software for energy calculation**

So far, more than 395 software programs have been introduced for the simulation of energy consumption. These software programs are used for different purposes including the assessment of energy efficiency, recyclable energies, and other aspects of sustainability. Some of the existing simulators utilize a shared computational engine. For example, Energy Plus (Kutz, 2002) computational engine is used in many simulation tools such as Builder Design which has recently been introduced to the market. Comparison of simulators is not an easy job and demands the collaboration of a large number of experts during a relatively long time (Crawley *et al*., 2000).

In 2005, the general capabilities of 20 popular

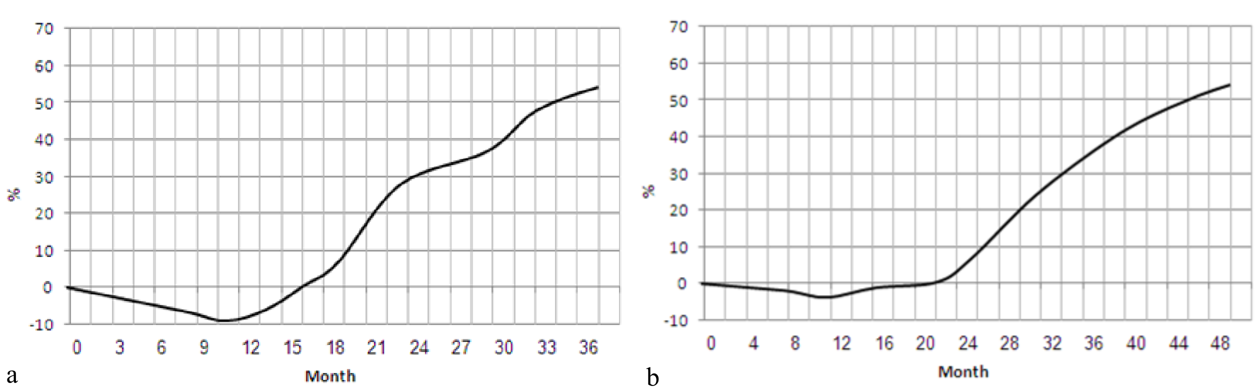


**Figure 1. Percentage of saving; a) three years; b) four years (Hamernik *et al*., 2012)**

**Table 3. Eight climatic parts of the country in terms of energy need (Iranian National Standards Organization, 2011)**

| Row | Climate type | Mean of maximum temperature in summer (C°) | Mean of relative humidity in summer (%) | Mean of maximum temperature in winter (C°) | Mean of relative humidity in winter (%) | City |
|---|---|---|---|---|---|---|
| 1 | Very cold | 30-25 | 55-45 | 5-10 | 75-65 | Sarab |
| 2 | Cold | 40-35 | 40-25 | 5-10 | 75-65 | Tabriz |
| 3 | Temperate and rainy | 30-25 | More than 60 | 0-5 | More than 60 | Rasht |
| 4 | Semi-temperate and rainy | 35-30 | More than 50 | 0-5 | More than 60 | Moghan |
| 5 | Semi-arid | 40-35 | 45-20 | 0-5 | 60-40 | Tehran |
| 6 | Hot and dry | 45-35 | 20-15 | 0-5 | 50-35 | Zahedan |
| 7 | Very hot and dry | 50-45 | 30-2 | 5-10 | 70-60 | Ahvaz |
| 8 | Very hot and humid | 40-35 | More than 60 | 10-20 | More than 60 | Bandar Abbas |

software programs were simulated through the collaboration of Strathclyde University of Scotland, Wisconsin University of the US, and Energy Department of the US (Sadeghi *et al*., 2011; National Research Council. 2004). In 2006, these three institutions presented a new report in the 9th international annual conference of building simulation, which completed the previous report. At the end of this report, the results have been summarized in a table, which is one of the best resources in this field despite its drawbacks. Considering the broad range of energy simulators and based on the results of the aforementioned research, we can enumerate the popular simulators as follows: DOE-2.1E, BLAST SUNREL, BSim, IDA ICE, Energy-10, TRN SYS, PowerDomus, Energy Express, Ener-Win, eQUEST, ECOTECT, DeST, Tas, HEED, HAP, EnergyPlus, ESP-r, IES, TRACE (Robles, 2010).

**Economic computation of smart building system in Iran**

Energy consumption in buildings constitutes more than 40% of annual energy production in Iran, which is equal to 30% of oil sale income. Energy consumption optimization process may be executed in buildings by conducting feasibility studies, auditing energy consumption in the buildings being designed, and applying national construction regulations. The cost of this system may also be considerably decreased by executing modern systems and the cost imposed by implementation of this system may be compensated by the saved energy within a short time (Park *et al*., 2014).

Furthermore, the high rate of energy intensity (the amount of consumed energy per one million Dollars of gross domestic production) indicates the weakness of energy management systems in Iran, particularly in residential houses. For example, energy intensity is 88.6 in Japan, 109.6 in Asia (without China), and 110.4 in OECD countries. In Iran, energy intensity is 248 which indicates the low efficiency of energy consumption in the country and the need for development of energy management systems in different sectors (Iranian Ministry of Energy, 2011).

Among other advantages of energy control and management systems is the reduction of energy consumption, reduction of energy costs, promotion of quality, reduction of maintenance and repair costs, improvement of comfort, positive environmental impacts (the reduced

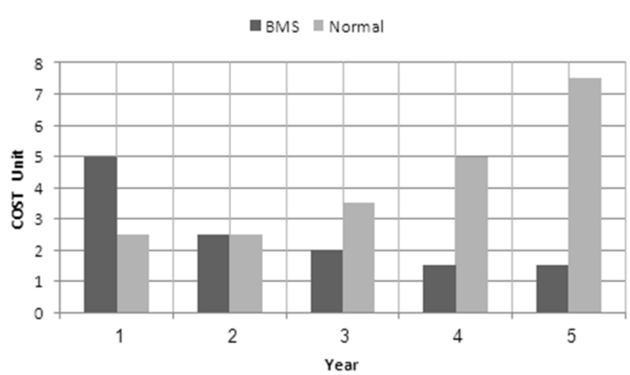


**Figure 2. Comparison of normal and BMS systems in terms of cost during five years (Tarfiei, 2015)**

emission of greenhouse gases), and enhancement of building security. Tables 1 and 2 contain the scientific results obtained from installation of smart control system in a number of buildings with various types.

In Tables 1 and 2, each 164.2 cubic meters of natural gas is equivalent to one crude oil barrel.

- The weight of pollutants is calculated based on 2.1 kg of pollutant per cubic meter of natural gas.
- The mount of saving (in Iranian rial) is calculated based on the global gas price (320 rials per cubic meter)
- Environmental and social costs are calculated based on 516 rials for each cubic meter of gas.

According to the report of State Fuel Consumption Optimization company, the use of smart machine room system can save energy by 40% in office and educational buildings and 15% in residential buildings. Another example of energy saving is the reduction of electrical energy consumed by lighting systems. In this connection, Iran Green Building Association has reported 65% energy saving in lighting section.

The foregoing is the results of a comprehensive energy management program which ideally may produce 15-25% annual profit depending on the amount of its flexibility. Generally, 3-6% saving can be achieved in the buildings with very high consumption and 3-4% saving is achievable in multi-purpose institutions. The following diagrams illustrate the cost rate based on installation time (Iranian Ministry of Energy, 2011).

Figure 1 illustrates the cost rate for three-year and four-year periods. As you can see, there is a negative value in the first nine months which continues until the 15th month, from which the ascending trend starts. The same is true in the four-year diagram. While it seems in the beginning that BMS increases the costs during installation and execution process, a more accurate look reveals that the costs are fully restored after 3-5 years and energy consumption and current expenses will be saved (Figure 2) (Atkins *et al*., 2004). The most important question asked by architectural engineers is "Is construction of a smart building economically justifiable?" The reality is that the cost increases by approximately 30% if a building is constructed by smart method.

Table 3 represents the eight climatic parts of the country in terms of energy need. Given the return on investment, the use of smart control systems is cost effective for general, industrial and office buildings. With regard to residential buildings, however, one can minimize energy consumption without suffering the costs of purchase and maintenance of smart systems, by using climatic design solutions such as selection of optimal building direction, optimization of openers, adoption of efficient building design, and the utilization of proper attachments.

## CONCLUSION

Smart building management system is able to control lighting system, fire safety, communications, and energy consumption. This control is continuous and can be applied from a far distance. Given the reduction of operation costs such as water, electricity and gas, smart building management system would be a cost effective system in the long term and an appropriate pattern for optimization of energy consumption in buildings and is ecologically valuable. The unnecessary loss of energy due to the over use or improper use would be controlled by smart systems.

In addition to smart management systems, certain solutions may be used in designing phase including the proper use of natural light, proper adjustment of sunlight, and selection of proper building direction. The utilization of smart systems would have the advantage of investment return in the long term. In Iran, for example, the statistics showed that the use of smart systems has resulted in 82% reduction in lighting energy and 20% reduction in heating and cooling systems, which is a valuable benefit for building owners.

As a conclusion, the use of smart control systems would be cost effective for general, industrial and office buildings given the return on investment. With regard to residential buildings, however, one can minimize energy consumption without suffering the costs of purchase and maintenance of smart systems, by using climatic design solutions such as selection of optimal building direction, optimization of openers, adoption of efficient building design, and the utilization of proper attachments.

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