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HVAC Optimization of Energy Management: Case Study of an Office Building

Sadaf Zeeshan

Mechanical Engineering Department, University of Central Punjab, Lahore, Pakistan

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ABSRACT-- ***Pakistan has been in a state of severe energy crisis since 2006-2007. Not much progress has been done since 2008 to cater the required energy needs. This is a major hindrance in the economy, leading to prolonged hours of load shedding. According to Energy Experts Group constituted by Economic Advisory Council in 2009 in Pakistan, it is estimated that the energy demand for Pakistan by the end of 2030 will increase by 64%. Steps therefore need be taken not only to install new power plants but also to implement policies which are energy optimized. According to survey, more than 50 % of energy in Pakistan is used in buildings. From amongst the buildings, a major portion of energy is utilized in office buildings. Special incentives should be given to companies by the government whose buildings are energy optimized. Surveys and studies have shown that office buildings that have the HVAC (heating, ventilation and air conditioning) system optimized by energy conservation methods; have shown considerable amount of saving of electricity cost. A case study has been carried of an office building where the current electricity utilization is analyzed and optimization techniques are suggested. Further, calculations are done to show that if suggested methods are implemented for system optimization, energy saving of about 33.25% can be achieved. Pakistan is currently facing crippling effects by the hands of energy crisis. If similar energy saving can be done by other office buildings on a larger scale considerable contribution can be made for the country to emerge from one of the most dreadful energy crisis ever.***

Keywords- Office buildings, energy optimization, Pakistan, efficiency, energy conservation

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1. INTRODUCTION

Pakistan with its increasing energy consumption and depletion of resources, optimization of HVAC system of buildings has become a major need of today. A major part of this energy is utilized in office buildings. Giorgos et al. [5] suggested that according to a world survey, office buildings are declared as buildings with the maximum energy consumption. Joseph et al. [7] pointed that in a recent research conducted worldwide, use of energy in office buildings is about 70-300kwh/m2 per annum;10-20 times that of residential buildings. M.M.Rehman et al.[10] further pointed out that almost 42% of total annual energy consumption is associated with building sector. Out of this major part of energy is utilized by the HVAC system, lighting and office appliances. Santamouris et al.[11] carried out energy audits in 158 Greek buildings and found out that office buildings was the third largest category for maximum consumption of energy after hospital and hotel buildings. Luis et al. [9] pointed out that commercial analysis conducted for energy consumption and system optimization should commence with office building. He supported his argument by the fact that in Spain, office buildings report one third of commercial sector energy consumption.

Furthermore, Joseph et al.[7] suggested that factors like population growth, ever rising demand of services provided by buildings and increased level of human comfort along with increase of time spent in the building assure that in future this upward trend in energy demand will continue. Imran et al.[6] reported that studies have proved that in South Africa, almost 20% of all electricity energy consumption is utilized in commercial and office buildings. Shobhakar et al.[14] explained that it is because of the highly significant role in business, commercial and government activities that office buildings are very important part of mega structured cities. He also pointed out that in Tokyo, Japan although office buildings are less in quantity (3% of total buildings); however, the space occupied by them in area is quite large and significant (about 14% of total building floor area). Hence the consumption of energy and demand of cooling per unit floor area is far greater in office buildings.

A lot of research has been done trying to emphasize the importance of optimization of buildings. Athina et al.[2] suggested in a case study that the most effective energy conservation measures for office/commercial buildings is installation of building management system causing a saving of 20%. Ery et al.[4] achieved optimization by detecting and reducing over sizing by using a calculation for a roof top unit. C.A.Balaras et al.[3] suggested that four focus areas of energy conservation, for proper system sizing are space heating, space cooling, domestic hot water and artificial lighting. These include actions like insulation, solar control, energy efficient lighting, etc. Similarly, T.Maarkis et al.[15] focused on installing double glazing and reducing thermal bridges to achieve optimization. A.Dimoudi et al.[1] suggested combination of different energy saving measures (insulation of the support frame, increased thickness of wall insulation, air tightness improvement and increasing of shading) results in considerable energy saving without compromising on comfort.

It should be kept in mind that for existing buildings, optimization potential for each office building will be different depending on various factors. These factors are based on location, climate, building type, construction etc. Thus, it becomes necessary to have a detailed audit after collection and study of all relevant and suitable data. This will determine the best possible optimization method which saves maximum energy without compromising on comfort levels. Studying the trends of energy usage and consumption, it is only wise to start making system optimization policies and to have it strictly implemented. In Pakistan, optimization of existing buildings will not only conserve energy to play a role in solving the load shedding crisis but will also result in a notable reduction of the electricity bills. Hence, with increasing load shedding, limited resources and increasing bills, optimization of system in buildings seems a very reasonable solution.

2. METHODOLOGY

The first step involved the collection of all relevant building data. This included the architectural drawing, building location, climate, building construction and envelop, air flow rate, lighting, office equipment used, temperature and humidity in peak season, etc. Also, the electricity consumption through electricity bills for a whole year of 2010 from January to December was analyzed. According to the building structure and energy usage, the building was divided into 11 zones.

After load calculation of the building using software CoolPack based on CLTD/CLF (cooling load temperature difference/cooling load factor) method, a detailed investigation was then conducted for each zone, analyzing the prime areas consuming maximum energy where the potential for energy conservation existed. Based on the study of the energy conservation techniques possible for the existing office building, the following energy conservation methods were then evaluated. Through calculations, approximate percentage energy saving possible, when the suggested optimized methods are implemented, was found.

3. CASE STUDY

3.1 Building Description

A single story building is selected for this case study. The building is located in an Industrial area in Township, Lahore, Pakistan facing north. The latitude of the building is 31° 34'and the longitude is 74° 22'. The building is divided into 11 zones. It covers a total floor area of 27.5m×17.7m and floor height of 3m. The walls consist of heavy concrete with four inch insulation. The roof is non-suspended type made of heavy concrete covered with 4 inch insulation. Windows are single glazed with shading co-efficient of 0.8. A single reciprocating type chiller is used having a capacity of 740 KW. The lights consist of 40 W fluorescent lamps with light density of 25 W/m2. The office equipment that runs on electricity includes personal computers, laser printers and a photocopy machine. Occupation time of the building is from 8 am till 6 pm.

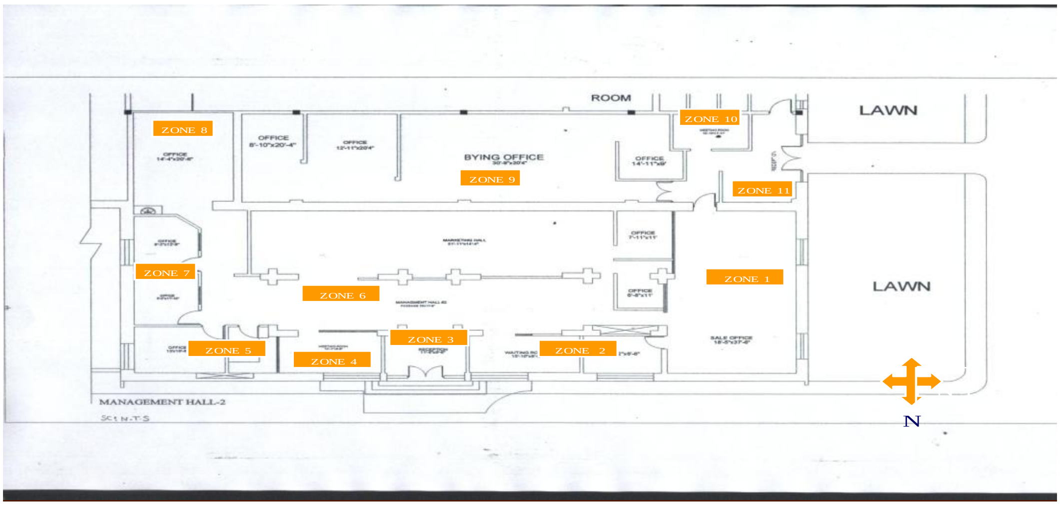


Figure 1: Case Study Building Layout

3.2 Load Calculation

The three basic methods used in load calculations are rule of thumb, CLTD/CLF (cooling load temperature difference/cooling load factor) method and load calculation software. The technique used for the case study building is a load calculation software (CoolPack).

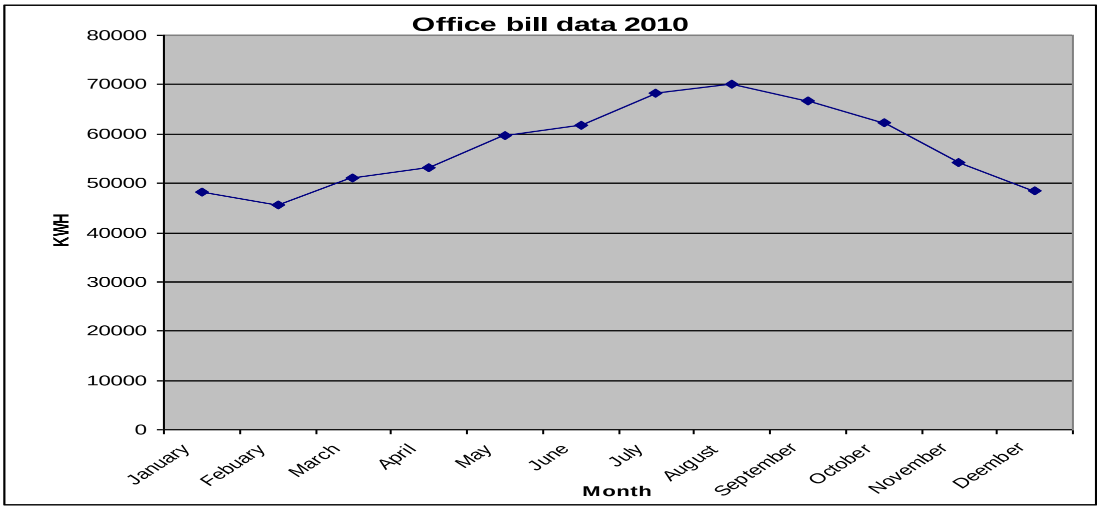
Table 1: Load Calculation Chart for maximum temperature (1700) for the month of August, 2010

SENSIBLE LOAD (W)												
	zone 1	zone 2	zone 3	zone 4	zone 5	zone 6	zone 7	zone 8	zone 9	zone 10	zone 11	TOTAL
Wall [N]	143.8	126	0	67.13	124.3	0	0	0	0	0	0	**461.2**
Wall [E]	273.83	0	0	0	0	0	0	0	0	0	138.6	**412.4**
Roof	2686.5	894	376.8	471.3	795.2	7072.5	929.1	1138	4237.5	339.84	1300.6	**20241.3**
Window	610.5	442	460.91	221	132.56	0	0	0	0	0	359.86	**2226.8**
Solar Glazing	4949	4070	4245.2	2035	1221	0	0	0	0	0	2917.23	**19437.4**
Air Exchange	966.96	321.75	135.6	170.1	286.2	2545.6	326.4	409.56	1488.6	409.56	456.9	**7517.2**
Lights	1611.5	536.25	226	283.5	477	4242.5	544	682.6	2481.1	119.4	761.5	**11965.3**
Equipment	1050	125	125	125	250	1050	400	275	900		125	**4425.0**
People	978.8	783	326.3	913.5	391.5	1435.5	326.25	261	1305	391.5	326.25	**7438.6**
TOTAL	**13271**	**7298**	**5895.81**	**4286.5**	**3677.8**	**16346.1**	**2525.8**	**2766.16**	**10412**	**1260.3**	**6385.94**	**74125.4**
LATENT LOAD (W)												
Air Exchange	1617	538	2268	284.4	478.6	4256.74	545.7	684.865	2489.3	718.7	764	**14645.3**
People	675	540	225	630	270	990	225	180	900	270	225	**5130.0**
TOTAL	**2292**	**1078**	**2493**	**914.4**	**748.6**	**5246.74**	**770.7**	**864.865**	**3389.3**	**988.7**	**989**	**19775.3**

Net Total: sensible load +Latent load=74,125.39+19,775.31=93900.7W

Table 2: Company Head Office Electricity Bill chart for 2010

Month	KWH
January	48174
February	45703
March	51068
April	53266
May	59743
June	61632
July	68262
August	70085
September	66672
October	62273
November	54072
December	48397



Maximum KWh for August=70085

No. of days in August=31

No. of hours=31×24=744 hours

Total Power (KW)=70085/744=94.2 KW

3.3 Load Calculation Analysis

After the load calculations it was speculated that the maximum energy was generated at the peak temperature of 1700 out of the time of 1600, 1700 and 1800. Therefore, all analysis is made for this peak temperature. The peak month for maximum heat generation is August which has been verified by the electricity bills of the company's office building. The load calculation done was an interesting eye-opener for making changes in optimization of the building. The calculations reveals that maximum amount of heat is generated through conduction by the roofs. It contributes to about 21.6% of the total amount of heat generated in the building. This is followed by the heat generated through the windows by solar glazing (solar energy transmission through glass), which is responsible for 20.7% of the total amount of heat generated in the building. The third largest heat generating component for sensible heat in the building are the lights. The lights contribute to 12.7% of the total heat generated in the building. From the above analysis, it is clear that in order to achieve noticeable results in the reducing heat generation of building, focus should be kept on these three prime areas: windows, roofs and lights. If noticeable reduction in energy in these areas can be achieved, great amount of energy conservation can be done. These along with other energy conservation techniques possible will help to optimize the building and hence cause energy saving with required comfort.

3.4 Energy Conservation Potential

To examine the energy conservation potential, various components generating heat are separately studied. Energy conservation methods for each component are carefully and practically reviewed. A careful study can reveal the problem areas which need to be fixed along with the need for any new improvise.

3.4.1 Windows

Keeping the focus areas in mind, we start with the component generating great amount of heat: the windows. By studying the building data, it was noticed that the building windows are single glazed (one layer of glass). These single glazed windows contribute to a U value of 6.12 W/m2. Instead of single glazed window if pane of glass can be doubled with a space between them and then sealed to form a single unit, it will increase the insulation of windows and hence reduce the value of U. The additional number of panes oppose the flow of heat. Thus, windows can be double glazed with the new value of U being 3.5 W/m2. Also, reflective coatings on window glass can help reduce the transmittance of solar radiation. Reflective coating consists of thin metallic coating that lowers the Solar Heat Gain Factor (SHGF) and hence less heat is transmitted and the glass provides a greater shading ability. SHGF is the factor determining the solar energy (infra rays) transmittance through the glass. A product with low Solar Heat Gain Factor rating is more effective in reducing cooling load during summers. Also a properly designed over hang or a shade will be able to block solar radiation through windows in summers while allowing solar radiation to enter through windows in winter. This slight modification in the building can thus be beneficial in both summers and winters.

3.4.2 Roof

Another area of major concern which generates a lot of heat in the building is the roof. Infact, in the case study building, the maximum amount of heat is generated through the roofs. The surface of roof is directly exposed to the sun and hence results in great amount of heat production, contributing to being the largest component generating maximum amount of energy. A number of things can be one to make the roof absorb less heat. Starting from a simple method, the roof can be painted with reflective paint which is now available by many good paint brands in Pakistan. A light coloured paint on the roof will also be beneficial in reflecting more radiation and absorbing less heat than standard roof. Study shows a good white coat provides the best result which is even better in reflecting heat that zinc-galvanized (silvery) coat .This is because it fails to emit infra red back to the sky.

Another method for reducing heat generation through roofs is to insulate the roof. This can be done by using an insulation sheet, or by using highly reflective tiles. The best solution which provides maximum reduction in roof heating is insulation. Reflective roof coatings are available which easily gel with roof walls to provide heavy insulation. Types of coatings used on roof are elastometric coating, acrylic coating, aluminum coating, polyurethane foam coating and synthetic rubber. Since the building used for case study is a single story building with a flat roof, use of high density foam insulation above the roof will be the best solution for minimizing heat generation through roofs. In Pakistan, Jumbolon Board (insulation board) has been introduced which provides high quality long term high insulation efficiency. It is available in the form of boards, sprays and rolls. It has very low thermal conductivity and is available in sizes from 20mm to 75mm thickness. Sprays can be applied on all types of existing surfaces and has little weight and can be more cost effective. However, insulation rolls provide the best thermal insulation. Method of installation of rolls simply involves sandwiching the insulation rolls between concrete roof and water proof sheet and cement followed by roof tiles. The use of roof insulation by this technique is now being used by many engineers in new building construction and housing schemes and highly satisfactory results have been confirmed by its consumers in Pakistan.

3.4.3 Lights

Lighting in the office building accounts for 12.7% of the total electrical energy. There are a variety of basic and inexpensive measures to improve efficiency of lights. These measures include use of energy efficient lamps and dimmer control ballast. For the case study building 40 W fluorescent lamps are used. As an energy conservation measure, light density of 15 W/m2 is considered. People should also be trained to switch on lights only when required. Addition to that reflective devices can also be used which help to brighten up the room. Also same luminosity is not required throughout the floor like in halls and passage way, dimmers should be used to conserve energy. In later stage, time switches and photocell sensors can also be used along with dimming devices.

4. Energy Conservation Evaluation

The above discussed energy conservation techniques will now be evaluated to see how much minimum energy can be saved by applying these in the case study building. The following parameters are evaluated:

1. Roof Insulation
2. Double Glazing
3. Shading and Reflective Coating
4. Light Saving

This is followed by the total energy saving after applying all of the above parameters together to observe the total percentage saving of the case study building.

Table 3: Revised load values generated by roof and lights for all zone after insulation

				revised roof load	**revised light load**
A (m^2)	**U** (W/m^2•K)	**CLTD** (K)	**ALD** (W/m^2)	**Q= U×A×(T2-T1)** (W)	**Q= A×ALD** (W)
64.46	0.35	36.7	15	827.98	966.9
21.45	0.35	36.7	15	275.52	321.75
9.04	0.35	36.7	15	116.12	135.6
7.885	0.35	36.7	15	101.28	170.1
19.08	0.35	36.7	15	245.08	286.2
169.7	0.35	36.7	15	2179.80	2545.5
21.76	0.35	36.7	15	279.51	326.4
27.30	0.35	36.7	15	350.72	409.56
99.24	0.35	36.7	15	1274.76	1488.63
7.96	0.35	36.7	15	102.23	119.39
30.46	0.35	36.7	15	391.26	456.9
				6144.2773	**7226.925**

Where,

A=surface area

U= overall heat transfer co-efficient

CLTD=cooling load temperature difference

ALD= average light density

Q=calculated load

Table 4: Percentage Power Saving by Roof Insulation

Percentage Saving by Roof Insulation	
	Total Power [KW]
Total load after roof insulation	79803.63
Total load before roof insulation	93900.7
Percentage Saving Steps:	
Subtract the above two total energy	14097.062
Divide the above with total energy before roof insulation	0.150
Multiply with 100 to get percentage saving by roof insulation	**15.01%**

Therefore, insulation of roof alone results in 15% power saving.

Table 5: Percentage Power Saving by Lights

Percentage Saving by Lights	
	Total Power [KW]
Total load after light saving	88872.09
Total load before light saving	93900.7
Percentage Saving Steps:	
Subtract the above two total load	11121.84
Divide the above with total load before light saving	0.1184
Multiply with 100 to get percentage saving by light saving	**11.84%**

The use of flourescents lamp of slightly lower average light density with reflective devices results in 11.84% of power saving.

Table 6: Revised load values generated by Shading and Reflective Coating for all zones

At peak temp(1700)							**revised window load**	**revised solar glazing load**
	A	**U**	**CLTD**	**SC**	**SHGF**	**CLF**	**Q= U×A×(T2-T1)**	**Q= A×SC×SHGF×CLF**
zone 1	14.25	3.5	7	0.3	678.3	0.8	349.1	2319.8
zone 2	10	3.5	7	0.3	678.3	0.8	245.0	1627.9
zone 3	10.431	3.5	7	0.3	678.3	0.8	255.6	1698.1
zone 4	5	3.5	7	0.3	678.3	0.8	122.5	814.0
zone 5	3	3.5	7	0.3	678.3	0.8	73.5	488.4
zone 6	0	3.5	7	0.3	678.3	0.8	0.0	0.0
zone 7	0	3.5	7	0.3	678.3	0.8	0.0	0.0
zone 8	0	3.5	7	0.3	678.3	0.8	0.0	0.0
zone 9	0	3.5	7	0.3	678.3	0.8	0.0	0.0
zone 10	0	3.5	7	0.3	678.3	0.8	0.0	0.0
zone 11	8.4	3.5	7	0.3	678.3	0.8	205.8	1367.5
Total								
							1251.4845	**8315.6**

Where,

A= surface area (m^2)

U= overall heat transfer co-efficient (W/m^2•K)

CLTD= cooling load temperature difference (K)

SC=shading co-efficient

SHGF=solar heat gain factor

CLF=cooling load factor

Q=calculated load (W)

The above table shows the revised load calculation for windows both by double glazing (using 2 panes of glass for windows) and by making shaded windows. Making a shaded window at a certain angle lowers SHGF of the window. Hence less solar radiance is transmitted resulting in power saving.

Table 7: Percentage Power Saving by Shading and Reflective Coating

Percentage Saving by Shading and Reflective Coating	
	Total Power [KW]
Total load after saving	82778.86
Total load before saving	93900.7
Percentage Saving Steps:	
Subtract the above two total load	11121.84
Divide the above with total load before saving	0.1184
Multiply with 100 to get percentage saving by shading and coating	**11.84%**

Applying shades above the windows results in 11.84% saving.

Table 8: Revised Power values generated by double glazing

Percentage Saving by Double Glazing	
	Total Power [KW]
Total load after window insulation	92925.37
Total load before window insulation	93900.7
Percentage Saving Steps:	
Subtract the above two total load	975.33
Divide the above with total load before window insulation	0.0104
Multiply with 100 to get percentage saving by window insulation	**1.04%**

Double glazing does not result in significant energy saving. It accounts for only 1.04% power saving.

Table 9: Percentage Total Power Saving

Total Percentage Saving	
	Total Energy [KW]
Total load after all techniques	62678
Total load before all techniques	93900.7
Percentage Saving Steps:	
Subtract the above two total load	31222.7
Divide the above with total load before all techniques	0.332
Multiply with 100 to get total percentage saving	**33.25%**

If all the above energy conservation techniques for roof, lights and windows are applied power saving of 33.25% is possible.

5. CONCLUSION

The following conclusions are obtained from the above calculations in the prior chapter:

- Application of urethane foam insulation allows maximum protection from energy approximately 15%. Although insulation application is an expensive method but because of its good conservation from energy it is expected to profit in the long run.
- Slight light density reduction is a good suggestion as it conserves a lot of energy. Maximum use of day light should be enhanced and unnecessary lights should be switched off. This method can help save energy about 11.8%.
- Use of shades and reflectors on windows also allows energy to be saved substantially approximately 11.84%. Making shades at the right angle and size can enable the building to benefit not only in summers but also in winters; allowing minimum heat in summers while allowing it in winters.
- Application of double glazing showed no considerable conservation in energy, only about 1.04%. This is due to window location in the building as well as size of the windows that cover the wall area. Double glazing is an expensive process and according to the calculations done, the result obtained is not favorable to proceed for this method.
- The application of the above discussed method can help reduce electricity bills by approximately 32.25%. This is a huge saving of energy as well of cost and assures less payback time for the methods opted.

6. RECOMMENDATIONS

- Use of urethane foam insulation on the entire roof.
- Use of reflectors on the window
- Building of shades above the windows of calculated angle and size
- Using of compact fluorescent light of density 15W/m2 with dimmers.
- Switching off of unnecessary lights especially during lunch break.

7. REFERENCES

[1] A. Dimoudi, P. Kostarela, “Energy monitoring and conservation potential in school buildings in the C’ climatic zone of Greece”, Renewable Energy vol. 34 pp. 289-298, 2009

[2] Athina G. Gaglia, Constantinos A. Balaras, Sevastianos Mirasgedis, Elena Georgopolou, Yiannis Sarafids, Dimitris P. Lalas, "Empirical assessment of the Hellenic non-residential building stock, energy consumption, emissions and potential energy saving", Energy and Management vol.48 pp. 1160-1175, 2007

[3] C.A.Balaras, K.Droutsa, A.AArgirioo, D.N.Asimokopoulos, "Potential for energy conservation in apartment buildings" , Energy and Buildings vol. 31 pp. 143-154, 2000

[4] Ery Djunaedy, Kevin Vanden Wymelenberg, Brad Acker, Harshana Thimmana, "Oversizing of HVAC system: signature and penalties", Energy and Buildings vol.43 pp. 468- 47, 2011

[5] Giorgos N. Spyropoulous, Comstantinos A. Balaras "Energy consumption and potential of energy in Hellenic office buildings used as bank branches – A case study" , Energy and Buildings vol. 43 pp. 770-778, 2011

[6] Imran Iqbal, Muhammad S.Al.Homoudi, "Parametric analysis of alternative energy conservation measures in an office building in hot and humid climate" , Building and Environment vol. 42 pp. 2166-2177,2007

[7] Joseph Iwaro, Abrahim Mwasha, "A review of building energy regulation and policy for energy conservation in developing countries", Energy Policy vol. 38 pp. 7744-7755, 2010

[8] Jung-Ho Huh, Michael J. Brandemuehl, "Optimization of air-conditioning system operating strategies for hot and humid climates", Energy and Buildings vol. 40 pp.1202-1213, 2008

[9] Luis Perez Lombard, Jose Ortiz, Christine Pout, "A review of building energy consumption information", Energy and Buildings vol. 40 pp.394-398, 2008

[10] M.M. Rahman, M.G. Rasul, M.M.K.Khan, "Energy conservation measures in an institutional building in sub-tropical climate in Australia", Applied Energy vol. 87 pp. 2994-3004, 2010

[11] M.Santamourious, C A Balaris, E. Dascalaki, A.Argirious, A.Gaglia, " Energy conservation and retrofitting potential in Hellenic hotels", Energy and Buildings vol. 24 pp. 65-75,1996

[12] Peter Simmonds, "The utilisation of optimal design and operation strategies in lowering the energy consumption in office buildings", Renewable Energy, vol.5 part 2, pp. 1193-1201, 1994

[13] Rima Fayaz and Behrouz M. Kari, "Comparison of energy conservation building codes of Iran, Turkey,Germany,China ISO 9164 and EN 832" , Applied Energy vol.86 pp. 1949-195, 2009

[14] Shobhakar Dhakal, Keisuke Hanaki, Ai Hiramatsu, "Heat discharge from an office building in Tokyo using DOE-2", Energy Conservation and Management vol. 45 pp. 1107-1118, 2004

[15] T.Maarkis, J.A. Paravantis, "Energy conservation in small enterprises", Energy and Buildings vol. 39 pp. 404-415, 2007