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An approach to estimate the life-cycle cost of energy efficiency improvement of room air conditioners

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Abstract

This paper presents an approach to calculate life-cycle cost analysis of energy efficiency improvement of room air conditioners. The least efficient model from a survey in the market is selected for sample calculation. The method includes the selection of a set of design options that increase efficiency, life cycle cost (*LCC*) analysis and payback period. *LCC* is analyzed as a function of seven design options and five variables, namely discount rate, fuel price, appliance lifetime, incremental cost and potential efficiency improvement. The study found that, certain level of efficiency improvement can be achieved, if manufacturers willing to adopt more efficient design options with a little additional investment for the product. Furthermore, the method can be used for other appliances without any major modification.

Keywords: Life cycle cost; Engineering/Economics analysis; Energy efficiency ratio; Room air conditioner; Cost benefit; Energy efficiency standard

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Nomenclature

BEC	Baseline energy consumption (Wh)
ES	Energy Savings (Wh)
EER	Energy Efficiency Ratio, (Btu/Wh)
DEC	Energy consumption of new design option (Wh)
LCC	Life cycle cost, (RM$)
N	Life time of the appliance, (year)
OC	Annual operating cost, (RM$)
OH	Operating hour
PAY	Payback period, (year)
PC	Purchase Cost, (RM$)
PF	Price of fuel or electricity (RM$)
PI	Power input (Watt)
PWF	Present worth factor
r	Discount rate, (%)
t	Time (year)

1. Introduction

Energy efficiency standards and labels for household appliances are presently formulated in many countries. The program is usually set based on input and advice from industry, R&D organization and university expert on the importance of appliance energy efficiency (EE) improvement in the market. Experiences in the US proved that the manufacturers have to be motivated to adopt advanced technologies in order to meet tough new energy efficiency standards established by the US Department of Energy.

There are two categories of design options for calculating energy efficiency improvement. The first is a set of design that reflects existing and emerging technological options that are available in the market. The second consists of design options that will require additional research and development. However, only selected existing proven technology improvement and their cost impact that are potential to be implemented for the product are considered in this study.

The design options are usually used to calculate potential energy savings in correlation with energy efficiency improvement and to determine *LCC* for that particular savings value. Design options indicate technical feasibility of achieving the optimum level of efficiency. This has been used for setting energy conservation standard in the US [1]. The methodology for calculating life cycle cost analysis presented in this paper can be used for other appliances and applications without major modification. Literature on energy efficiency standards and labels are widely available. However, very limited articles discussed the method to calculate life-cycle cost analysis of potential energy efficiency improvement. Energy efficiency is defined as the percentage of energy generated by a heat source that is converted into usable heat [2, 3].

In this study, a room air conditioner has been selected as a case study and the methodology for calculating energy efficiency improvement is presented. Further energy efficiency improvement is determined based on information provided by manufacturers, survey data, and the technical committee for performance of household and electrical appliance of Malaysia.

2. Survey data

Survey data inputs for calculation are necessary in order to use this method. These data include baseline model, electricity price, discount rate, operation hour, potential design option improvement etc. The design options are the changes to the design of the baseline model that will improve the energy efficiency of the product. The baseline model selected is the least efficient model in the market based on survey data of 324 models of room air conditioners in Malaysia. The potential improved design options are determined based on available technology in the market, input from manufacturers and available literatures. Some of the design options are already included in the existing products and others are being developed. The estimated room air conditioner efficiency gains with potential improved design option are given by Ref. [4]. The list of potential energy efficiency improvement based on design option are shown in Table 1, and baseline input data are presented in Table 2 [5-9].

Table 1. Potential design options for energy efficiency improvement

No	Type of Design Options
1a	Increase in frontal coil area (15%)
1b	Increase in frontal coil area (30%)
1c	Increase in frontal coil area (45%)
2a	Additional refrigerant tube (1 extra row)
2b	Additional refrigerant tube (2 extra rows)
3a	Increased fin density (10%)
3b	Increased fin density (20%)
4	Add sub cooler to condenser coil
5	Improved fin design
6	Improved tube design
7a	Use high efficiency fan motor
7b	Use electronically commutated motor
8a	Improved compressor efficiency (5%)
8b	Improved compressor efficiency (10%)
8c	Improved compressor efficiency (15%)
9	Use of refrigerant R-410a
10	Use variable speed compressors
11	Use electronic expansion valves
12	Use advance controls

3. Methodology

The life-cycle cost and the engineering/economic analysis have carried out to analyze potential efficiency improvement of new design options that are already adopted by existing models in the market or some other combinations of design that are more efficient. The steps for conducting this analysis include (i) identification of the manufacturing process of the product, (ii) selection of baseline units, (iii) selection of design options, (iv) efficiency improvement of each design option, (v) efficiency improvements of combined design options, (vi) cost for each design option (vii) cost-efficiency curves, and (viii) energy savings potential [2, 10]. Each step will be discussed in the following sections.

Table 2. The baseline input data

Description	Value
Electricity price	RM 0.235/kWh
Discount rate	7%
Appliance lifespan	12 years
Baseline energy consumption	7830 kWh/year
Cooling capacity	22700 (Btu/h)
Baseline *EER*	7.32
Energy Efficiency Standards *EER*	10.00
Appliance lifespan	12 (years)
Average operation hour	2525 (h/year)

Note: 1US $ ≈RM3.20

3. 1. Manufacturing process of the product

Before conducting energy efficiency improvement, the process assembly of appliance is identified to understand the manufacturing process of the appliance in order to calculate its potential efficiency improvement. This part is necessary to identify the component of the product which can be improved by the manufacturer since some of components of the appliance are produced and supplied by vendors or by other manufacturers.

3. 2. Selection of baseline units

The baseline unit of appliance serves to provide basic design features for this analysis. For products without any standards, a baseline models are the ones that has efficiency equal to the minimum or the average of the existing models in the market. Selecting the least efficient model as the baseline is recommended since this permits analysis at all possible levels of efficiency, starting from the least efficient model [2, 11]. Therefore, the least efficient model from the market is selected as a baseline for this analysis.

3. 3. Selection of design options

Design options are the changes to the design of the baseline model that would increase its energy efficiency. The potential design options selected depend on the substitution of more efficient components to the baseline product. The data of potential design improvement is collected from manufacturers of the baseline unit which is least efficient model.

3. 4. Efficiency improvement of each design option

Efficiency improvement of each design option is determined by calculating potential improvement of components substitution to the baseline models for improving energy performance. The design options are usually selected based on inputs from manufacturer of the baseline models and other possible improvements available in the market or from references.

3. 5. Efficiency improvements of combination design options

The combination of design options is the cumulative changes to the design that improve energy efficiency of the baseline model. Calculations are conducted for various components substitution to the baseline product in accordance with the inputs from manufacturers of the baseline models and other available improvement from the market or from other references. For combination of design options, energy savings, and efficiency improvement are determined through cumulative improvement of each design option.

3. 6. Cost estimation for each design option

The increase of cost for each design option is the cost of producing products with the improved design options. The expected cost of manufacturing each additional design option is obtained from manufacturer. When manufacturer costs are unavailable, the costs are estimated based on retail price, or from the designs option that already exists in market.

3. 7. Life-cycle cost

A life cycle cost (*LCC*) analysis calculates the cost of a system or product over its entire life span. For this study *LCC* is used to calculate the cost of energy efficiency improvement of the appliance based on each design option, and combination of design options of the product. The *LCC* is the sum of investment cost and the annual operating cost discounted over the lifetime of the product. *LCC* is calculated by the following equation [12]:

$$LCC = PC + \sum_{1}^{N} \frac{OC_t}{(1-r)^t} \tag{1}$$

If operating expenses are constant over time, the *LCC* is simplified to the following equations:

$$\mathrm{LCC} = \mathrm{PC} + (\mathrm{PWF})(\mathrm{OC}) \tag{2}$$

3. 8. Operating cost

To calculate *LCC*, the operating cost for the baseline unit should be identified. The operating cost (*OC*) of appliance is a function of the annual energy use and electricity price. Annual energy use is determined by multiplying the electrical power input, the annual hours of operation and price of fuel or electricity which is given by the following equation:

$$OC = PI \times OH \times PF \tag{3}$$

3. 9. Present worth factor

Present worth factor (PWF) is the value by which future cash flow to be received in order to obtain the current present value. The present worth factor can be calculated by the following equation:

$$PWF = \sum_{1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^N}\right] \quad (4)$$

3. 10. Payback period

The payback period (*PAY*) measures the amount of time needed to recover the additional investment (increment cost) on efficiency improvement through lower operating costs. *PAY* is found by solving the following equation:

$$\Delta PC + \sum_{1}^{PAY} \Delta OC_t = 0 \quad (5)$$

In general, *PAY* is found by interpolating between the two years when the above expression changes sign. If the *OC* is constant, the equation has the following solution:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad (6)$$

The *PAY* is the ratio of the incremental cost (from the baseline to the more efficient product) to the decrease in annual operating cost. If *PAY* is greater than the lifetime of the product, it means that the increased purchase price is not recovered in reduced operating cost.

3. 11. Energy savings

The unit energy savings associated with each design option is the baseline energy consumption minus the energy consumption of the appliance with each or cumulative design options that is related to efficiency improvement of the product. It can be expressed using the following mathematical equation:

$$ES = BEC - DEC \quad (7)$$

4. Results and discussion

Most of appliance manufacturers rely on a combination of automated and manual processes in the manufacturing flow. For room air conditioners, the cabinets and heat exchangers are usually produced in-house. Other components such as compressor, fan motor, fans and controller are supplied by vendors. The room air conditioner manufacturing flow diagram is presented in Fig. 1 [1].

The operating cost of room air conditioner is a function of the annual energy use and electricity price. Annual energy use is determined by multiplying the electrical input with the annual hours of operation of compressor (note that the compressor operation is usually in on/off mode) and accessories (fans etc) which can be calculated by the following equation:

$$OC = \frac{CC \times OH \times PF}{EER \times 1000} \quad (8)$$

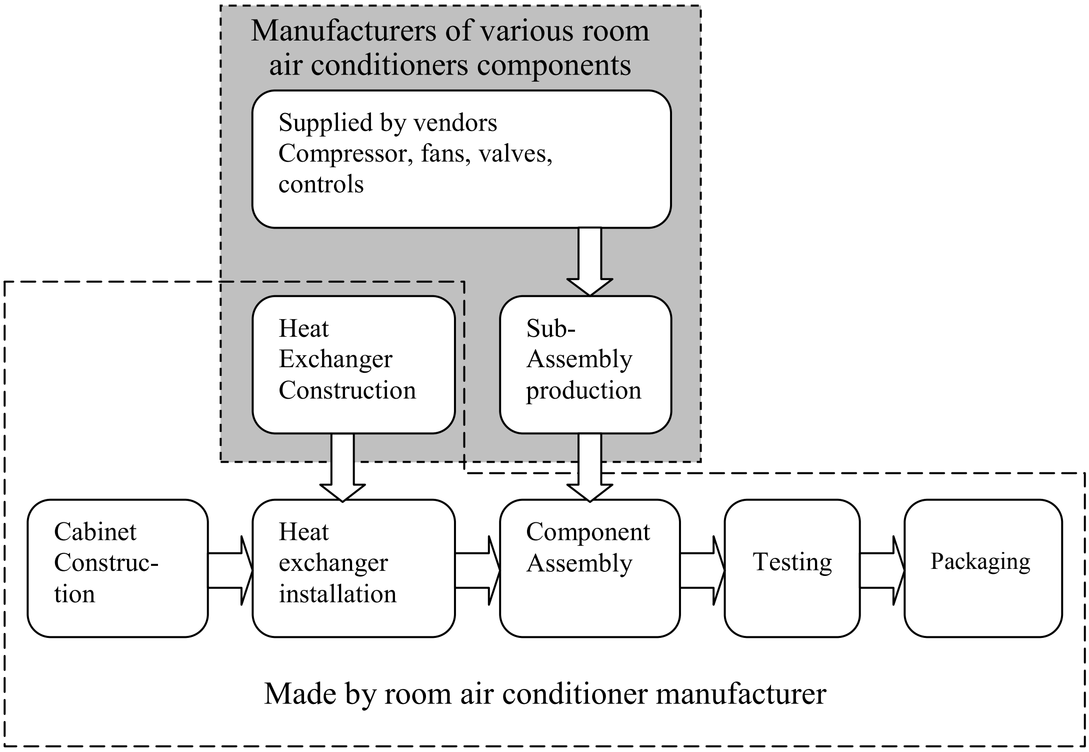

Fig. 1. Manufacturing flow diagram of room air conditioners.

The energy savings associated with each design options is the baseline energy consumption minus the energy consumption of the appliance with each design option that is related to *EER* improvement of the product. The mathematical expression of the ES can be written as follows:

$$ES = BEC - \left[\frac{CC \times OH}{EER \times 1000} \right] \tag{9}$$

The other data required for this analysis are, potential efficiency improvement and its additional cost. Room air conditioner uses *EER* or *COP* to calculate its performance and in this study, *EER* has been selected. Some of the data are collected from manufacturers and some others are estimated based on a baseline unit and the result has been presented in Table 2.

From the analysis of the data presented in Table 1 it is observed that significant *EER* improvement can be achieved by room air conditioners if manufacturers are willing to adopt more efficient design options. The calculation shows that, even the least efficient models in the market can reach the minimum energy efficiency standards proposed by US Department of Energy which is at *EER* 10.00. This can be achieved by having improved fin design, tube design and addition of extra rows of refrigerant tube (design options 1 to 3), while the incremental cost is only about ± 8.6%. The analysis shows that the investment is quite low

Table 3. Selected Design options, potential *EER* improvement and additional cost

Design Options	Technological Improvements	Increase in *EER* (%)	Increase in Price (%)
0	Baseline design	0	0.0
5	0+Improved fin design	11	0.4
6	1+Improve tube design	8	0.8
2b	2+Add of refrigerant tube (2 extra rows)	16	7.4
10	3+Use variable speed compressors	12	9.7
1b	4+Increase in frontal coil area (30%)	8	9.6
8c	5+Improve compressor efficiency (15%)	8	11.5
9	6+Use of R-410A	5	20.6

comparing to *EER* improvement. However, in the future, the use of refrigerant R-410a as a replacement for ozone depleting refrigerant should be considered as the main priority due to environmental consciousness in some countries. The impact of design changes on room air conditioner price and *EER* are presented in Fig. 2

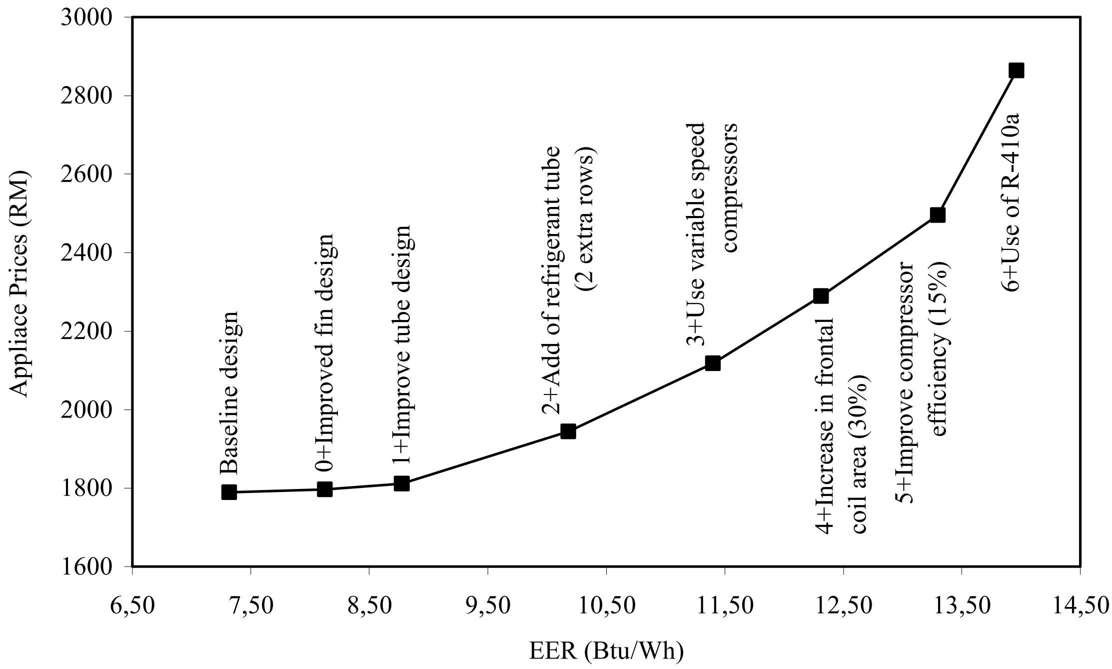

Fig. 2. Impact of design options changes on appliance price and *EER*.

The calculation results of cumulative payback period, life cycle cost and potential energy savings for typical room air conditioner is tabulated in Table 4 and presented in Fig. 3.

Fig. 3 shows that the potential *EER* improvement for room air conditioner can reach a maximum, which is at 13.96 if all seven design options are adopted. However, the additional cost for the least four design options is quite high, which is about 50% of the baseline cost.

Table 4. Life-cycle cost and payback periods

No	Design options	EER Imp.	Price Imp. (RM)	OC (RM)	LCC (RM)	PAY (Year)	ES (kWh)
0	Baseline design	7.32	1790	1840	16405	0.00	776
1	0+Improved fin design	8.13	1797	1658	14964	0.04	1298
2	1+Improved tube design	8.78	1811	1535	14003	0.07	2199
3	2+Add of refrigerant tube (2 extra rows)	10.18	1944	1323	12454	0.30	2802
4	3+Use variable speed compressors	11.40	2118	1181	11502	0.50	3175
5	4+Increase in frontal coil area (30%)	12.31	2289	1094	10978	0.67	3520
6	5+Improve compressor efficiency (15%)	13.30	2495	1013	10541	0.85	3725
7	6+Use of refrigerant R-410a	13.96	2864	965	10526	1.23	7830

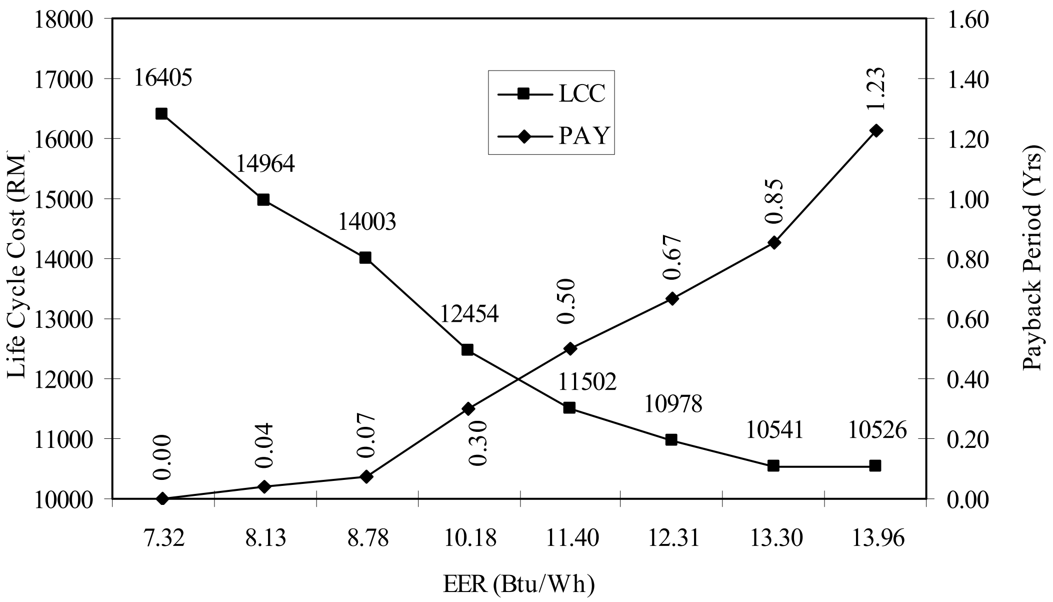

Fig. 3. Payback period and life cycle cost.

5. Conclusions

In this paper a methodology for calculating life-cycle cost of energy efficiency improvement is presented. This method is very useful as a reference to calculate potential energy efficiency improvement of the product which is correlated with its investment cost. For the case of room air conditioner it can be concluded that a significant improvement could be achieved if manufacturers in this country are willing to adopt more efficient design options. The calculation found that even the least efficient model in the market can still reach double digit *EER* by improving fin design, tube design and addition of extra rows of refrigerant tube (design options 1 to 3). The study also found that the investments are quite low comparing to energy efficiency improvement. Through this design option improvement, hopefully the product can pass the tough energy efficiency standard set by developed countries. Finally, as the world largest exporter of room air conditioners, Malaysia should be one of the front-runner for more efficient room air conditioners and therefore, manufacturer should be encouraged to adopt cost-effective of more efficient design options. Finally, it is expected that this piece of work gives an idea of how to calculate life-cycle cost of energy efficiency improvement of the product by adopting more efficient design option to improve the product toward more energy efficient and environmental friendly to capture the market. Even though the paper only investigates room air conditioner as a case study, the method is also applicable for other appliances without any major modification [13-24].

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References

[1] Lawrence Berkeley National Laboratory. Technical support document for energy conservation standards for room air conditioners. Energy and Environment Division, Technology and Market Assessment Group, Berkeley, 1997.
[2] Demirbas A. Concept of energy conversion in engineering education. Energy Educ Sci Technol Part B 2009:1:183-197.
[3] Saidur R. Energy, economics and environmental analysis for chillers in office buildings. Energy Educ Sci Technol Part A 2010:25:1-16.
[4] Adnot J. Energy efficiency of room air conditioners. Study for the Directorate-General for Energy (DGXVII) of the Commission of the European Communities, France, 1999.
[5] Appliance Efficiency. Hungry cooling: room air conditioners. Appliance Efficiency Newsletter of IDEA, the International Network for Domestic Energy- Efficient Appliances, 1999; 3(3):6-10.
[6] Mahlia TMI. Energy efficiency standards and labels of room air conditioners in Malaysia. PhD Dissertation, University of Malaya, Kuala Lumpur, Malaysia, 2002.
[7] Masjuki HH, Mahlia TMI, Choudhury IA. Energy Convers Mgmt 2001;42:439–450.
[8] Mahlia TMI, Masjuki HH, Choudhury IA. Energy Convers Mgmt 2001;42:1673-1685.
[9] Technical committee for Performance of Household and Electrical Appliance Meeting, SIRIM Berhad, Shah Alam, Malaysia, 2002.
[10] Karamustafaoglu.Active learning strategies in physics teaching. Energy Educ Sci Technol Part B 2009:1:27-50.
[11] Turiel I, Chan T, McMahon JE. Theory and methodology of appliance standards. Energy Buildings 1997;26:35–44.
[12] Economic Planning Unit. Study on energy policy analysis and planning to the year 2020. Prime Minister Department, Kuala Lumpur, Malaysia, 1996.
[13] Demirbas A. Energy concept and energy education. Energy Educ Sci Technol Part B 2009;1:85-101.
[14] Ulusarslan D, Gemici Z, Teke I. Currency of district cooling systems and alternative energy sources. Energy Educ Sci Technol Part A 2009;23:31-53.
[15] Bolukbasi A, Comakli K, Sahin S. Domestic energy savings: Investigation of optimum insulation thicknesses for the external wall of rural houses in Turkey. Energy Educ Sci Technol Part A 2009;24:25-37.
[16] Ucar A. The environmental impact of optimum insulation thickness for external walls and flat roofs of building in Turkey's different degree-day regions. Energy Educ Sci Technol Part A 2009;24:49-69.
[17] Cerci Y. Experimental investigation of capacitor effects on performance parameters planning for household refrigerator and energy systems. Energy Educ Sci Technol Part A 2009;24:15-24.

[18] Gungor C, Kaya D. Experimental investigation of the effect of absorber pre-cooler to the performance of the absorption cooling system. Energy Educ Sci Technol Part A 2009;24:71-83.
[19] Sanjay Kumar T, Mittal V, Thakur NS, Kumar A. Performance evaluation of a smooth flat plate solar air heater. Energy Educ Sci Technol Part A 2009;23:105-117.
[20] Bugutekin A, Yilmaz M, Kentli A, Isikan MO. A mathematical model for condensation of bubbles injected through an orifice into subcooled water. Energy Educ Sci Technol Part A 2010;24:151-171.
[21] Akpinar EK, Akpinar S. Modelling of weather characteristics and wind power density in Elazig-Turkey. Energy Educ Sci Technol Part A 2010;25:45-57.
[22] Ozbalta TG, Ozbalta N. Theoretical and experimental analysis of the solar energy gain of transparent insulated external wall in climatic conditions of Izmir. Energy Educ Sci Technol Part A 2010;25:69-86.
[23] Gaffer HE, El-Khatib EM, Fahmy HM, Gouda MA. Enhancing functional and dyeing properties of viscose fabric. Energy Educ Sci Technol Part A 2010;25:105-115.
[24] Kecebas A, Kayveci M. Effect on optimum insulation thickness, cost and saving of storage design temperature in cold storage in Turkey. Energy Educ Sci Technol Part A 2010;25:117-127.