The 2019 World Congress on
Advances in Structural Engineering and Mechanics (ASEM19)
Jeju Island, Korea, September 17 - 21, 2019

Optimization of Sustainable residential building in Kuwait

Ilham S. Al-Shemmeri*[1]

[1] *Executive Department, Ministry of Public Works, Kuwait*

Abstract. Reducing energy consumption in existing and new buildings in an economical fashion, while preserving health, productive, and good indoor air quality (IAQ) is the main concern for a country such as Kuwait. In summer, Kuwait reports having months with daily maximum temperatures averaging above 46 ºC, it's well beyond the hottest weather ever experienced in many other countries. Kuwait is facing an increase in energy consumption and the country is struggling to increase the electricity generating capacity in order to meet the high demand. The main objective of this work is to optimize building envelopes, windows and fenestration systems and energy efficiency ratio (EER) in order to decrease energy consumption. Another aim is to come up with optimum design for a residential building in Kuwait. The optimization technique uses Kuwait energy code as a basis, the multi-objective function is to minimize energy consumption and the cost of building materials. This approach is suitable for determination of optimum energy saving parameters in the residential building.

Energy consumption of a Kuwaiti house was modeled with an energy simulation software. Two base cases were optimized further by varying the parameters of Kuwait code. Case 1 involved maximum occupancy and peak load. Case 2 involved minimum occupancy and peak load. Payback periods analysis for exterior wall insulation, roof insulation, window glazing, shade window and requirements of EER devices were conducted to determine the effect of cost. Moreover, it shows that energy saving techniques should produce a return on investment within five years in order to achieve widespread adoption. The most effective parameter was the EER, with an increase in Kuwait code value of 17.5% in Case 1 and 15% in Case 2. Finally, the data was optimized with the payback calculations as a necessary optimality condition, and resulted in five optimized values for each base case. The peak load was determined with the optimized values for each base case and resulted in saving 20.8% of the cost for Case 1 and 15.4% for Case 2.

Key words: Optimization, Residential building, Energy consumption.

1. Introduction

[1)] Eng: Ilham Al-Shemmeri, E-mail: engilhamsaleh@hotmail.com

Energy consumption per capita in Kuwait is among the highest in the world. This is caused by a high standard of living, harsh summer climatic conditions, which necessitate cooling, highly subsidized energy costs, and rapid economic growth. Kuwait's climate is classified as dry, hot, with long summers, and short winters. As the relative humidity increases, the temperature sometimes exceeds 50 ºC in the shade. Climate data is one of the most important variables used to calculate building energy consumption and is well defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards, which categorizes countries into zones based on climate and thermal criteria related to cool and hot days. According to climate classification of ASHRAE standard, Kuwait is classified as zone 1b (hot and dry). Kuwait is an oil-rich country located in the Middle East, Western Asia. This small country lies at the far northwestern corner of the Arabian Gulf. Kuwait's production of oil and natural gas reached three million barrels of oil per day in 2015 and is currently working to boost production capacity to about four million barrels of oil per day by 2020 (KOC, Kuwait Oil Company, 2015).

Kuwait's increasing population and the response to it is a main contributor to the problems of energy consumption. Kuwait's population has grown from approximately 1,906,000 people in 2000 to 3,000,000 in 2010. The population for 2013 was 3,820,000 and the expected population for 2018 was 4,246,540 [Kuwait Central Statistical Bureau, 2018]. This continuous increase in population, with an average growth rate of 3.3%, contributes highly to the energy consumption in the country. Other factors contribute to this problem of increasing energy consumption as well. One is the significant amount of waste and over-consumption of energy, which adds to the insufficiency of the energy supply.

The consumption of electrical energy per capita was 13,530 KWh during 2013 [MEW Statistical Yearbook, 2014]. In summer, air conditioning systems consume nearly 70% of the peak load demand and 45% of the annual energy consumption [Kuwait Code MEW R-6-2014] as they are the biggest silent energy users in residential buildings. The seasonal demand variation closely follows the climatic cycle, with a summer peak load of 12,060 MW for July alone in 2013 [MEW Statistical Yearbook, 2014]. The total yearly electrical consumption in Kuwait by the end of 2013 was 60,982 M. KWh. The residential (private) sector consumed 41% of the total yearly electrical consumption, representing a high percentage of the total yearly electrical consumption. Energy consumption and carbon dioxide emissions worldwide are increasing at alarming rates. Both low-rise buildings and high-rise buildings are the major users of energy consuming 40-50% of primary energy. Building usage results in approximately 40% of CO_2 emissions.

The building envelope is the parts of a building that shapes the primary thermal barrier between interior and exterior. These parts greatly influence the energy consumption of a building. In this study, the five parameters of U-Wall, U-Roof, U-Window, SHGC, and EER will be focused onto determine the annual energy consumption of a residential building in Kuwait. Thickness of the walls and roof layers will be studied to see their effect on energy consumption. Windows and fenestration systems of a building play an important role in energy saving, therefore [Sun et al., 2014], these will be studied. The other significant parameter used to determine the energy conservation on a building is the EER, which has significant bearing on sustainable energy development. In this research, optimization is described as to how to quantify and implement energy performance solutions in residential buildings in Kuwait. This in turn will help to determine where and to what degree of the total annual energy (KWh) is wasted.

2. Literature Review

Energy conservation presents many opportunities for research and the optimization of the energy consumption of a building has emerged as a major challenge. A number of studies have recently carried out and optimized the most effective parameters of a building on energy saving along with recommendations. A study presented three strategies to improve HVAC system performance for a commercial building located in a hot and dry climate. A significant reduction in energy consumption from 25.3% to 44.2% was achieved [Vakiloroayaa et al., 2014]. Ascionea et al., (2013) studied varying the HVAC systems in Mediterranean climates to achieve energy saving in the building. To analyze the same issue, another important research by Al-Qabandi (2013) presented a parametric study for energy consumption in residential buildings in Kuwait, varying the overall heat transfer coefficients for the walls, roof and windows plus the solar heat gain coefficient of the fenestration with respect to MEW R-6 (Kuwait Code) and ASHRAE 90.2. The results show the effect of the building envelope, glazing and fenestration system on reducing energy consumption by 12%, while the effect of the lighting loads on energy savings was 4%. Turning off the HVAC system in a residential building when residents are away and when rooms are unoccupied could be saved more than 20% of energy consumption (Kanagaraj & Sharmila, 2015).

3. Experimental Designs

The building used in the case study is a residential house located in Kuwait that has a floor surface of 4,305.6 ft^2. The building contains an approximate total of 14,262.2ft^2 on three floors and a basement. It is a semi-detached single-family dwelling consisting of a basement, ground floor, first floor, and second floor. The ground floor and the basement each are 4,305.6 ft^2. The first and second floors each have 2,825.5ft^2. The equipment load is 0.62 w/ft^2 for the basement and the three floors. In addition, the overhead lighting for all the floors is 0.93 w/ft^2. The building was completed in compliance to Kuwait Code requirements. The air conditioning system consists of split DX fan coil units and CAV air system.

4. Test Producer

Two base cases are; Case 1 involved maximum plug load and occupancy and Case 2 involved minimum plug load and occupancy. A comparison will be made between the increase and decrease of each of these five parameters on the two scenarios presented using the Kuwait Code requirements. Based on this, the cost rate (flat price) is assumed to be $0.14 /KWh for the consumer. Moreover, the emissions analysis is set a constant CO_2 factor of 1.41 lb/KWh throughout this study. The main purpose of this work, 1) What is the energy consumption of the same coded residential building in relation to the number of occupants and the plug load?; and 2) What is the optimum energy saving potential of the residential building of each of the five parameters when increased or decreased for the two base cases? In addition, how does the influence of the building orientation, starting with the north angle at zero degrees and rotating progressively 45º (e.g. 0º, 45º, 90º, 135º, 180º, 225º, 270º and 315º), impact the parameters in each base case scenario?. A multi-objective function with inequality constraints, the inequality constrains are: parameters values < +20% of Kuwait code value and parameters values > –20% of Kuwait code value with an increment of 2.5%. The data was optimized with the payback calculations as a necessary optimality condition.

5. Theoretical Conserations

Modeling energy consumption will utilize Hourly Analysis Program 4.7 (HAP) energy simulation software, and optimizing the results will use MAT LAB. The optimization parameters include those of building envelopes, windows, fenestration, and HVAC parameters (i.e. overall heat transfer coefficients, windows SHGC, building orientation, EER, and unit cost).

6. Results

Table 1: Shows the optimized parameter values of base Case 1 and their effect on the annual energy consumption plus its payback periods.

Parameter	Optimized Value	Parameter Percentage to Kuwait Code	*AEC (KWh)	Reduction Percentages on AEC	North Angle	Payback Periods (Year)
U-Wall	0.08	–20%	300,134	0.5344%	0º& 180º	1.8
U-Roof	0.056	–20%	300,486	0.4203%	0º& 180º	1.1
U-Window	0.557	–5%	301,385	0.1238%	0º& 180º	4.8
SHGC	0.237	–17.5%	297,263	0.9840%	0º& 180º	4.8
EER	8.225	+17.5%	288,134	4.615%	0º& 180º	4.75

Table 2: Shows the optimized parameter values of base Case 2 and their effect on the annual energy consumption plus its payback periods.

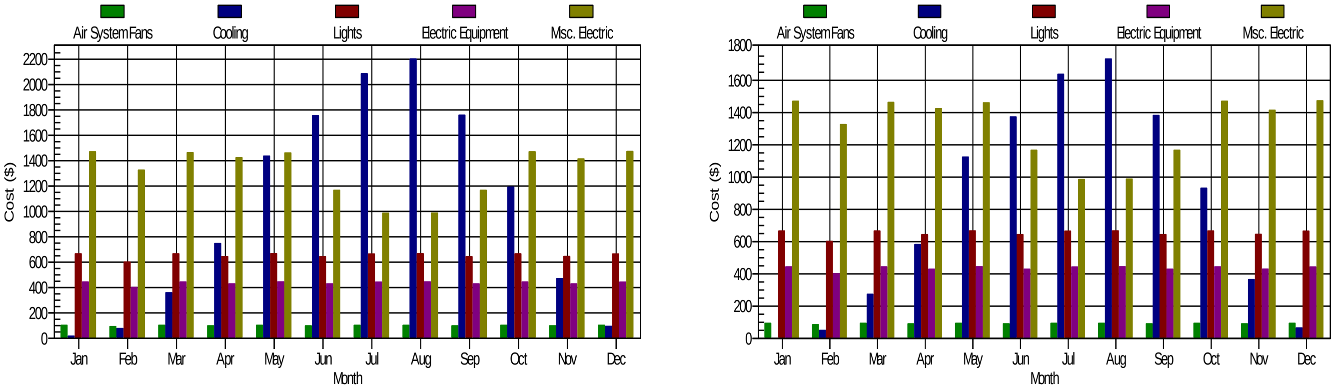
Parameter	Optimized Value	Parameter Percentage to Kuwait Code	*AEC (KWh)	Reduction Percentages on AEC	North Angle	Payback Periods (Year)
U-Wall	0.08	–20%	259,390	0.6045%	0^o& 180^o	1.9
U-Roof	0.056	–20%	259,723	0.4755%	0^o& 180^o	1.1
U-Window	0.572	–2.5%	260,824	0.0514%	0^o& 180^o	2.7
SHGC	0.244	–15%	256,923	0.9653%	0^o& 180^o	4.5
EER	8.05	+15%	249,296	4.560%	0^o& 180^o	4

*AEC: Annual Energy Consumption (KWh).
** The Annual Energy Consumption when using Kuwait Code parameters is 300,188 (KWh).

Table 3: Monthly peak load cost by end use in ($) for the two base cases and their optimum solution within a year.

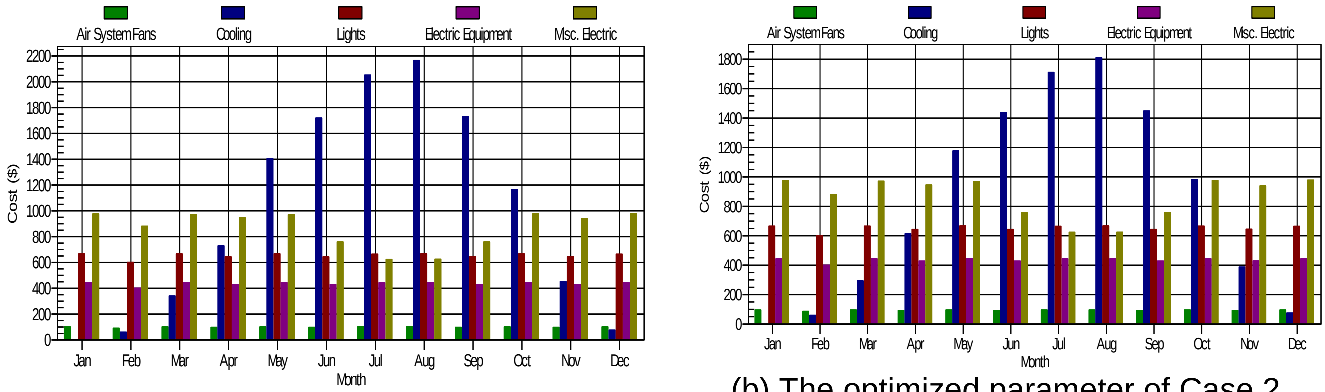
Month	Base Case 1 HVAC Total ($)	Optimum Case 1 HVAC Total ($)	Base Case 2 HVAC Total ($)	Optimum Case 2 HVAC Total ($)
January	116	96	104	101
February	164	133	138	145
March	456	366	429	389
April	841	672	814	706
May	1,533	1,217	1,487	1,273
June	1,851	1,463	1,796	1,529
July	2,184	1,730	2,134	1,806
August	2,302	1,825	2,246	1,906
September	1,853	1,472	1,809	1,541
October	1,288	1,024	1,250	1,078
November	564	454	537	481

December	191	157	165	171
Total	13,342	10,611	12,909	11,123



(a) Case 1 (b)The optimized parameters of Case 1

Fig. 1: Monthly Peak Load by end use in ($) for base Case 1 using Kuwait Code parameters and using the optimized parameters values of base Case 1.



(a) Case 2 (b) The optimized parameter of Case 2

Fig. 2: Monthly Peak Load by end use in ($) for base Case 2 using Kuwait Code parameters and using the optimized parameters values of base Case 2.

7. Discussion

Payback period (PBP) analysis was applied as an optimality condition. The consumer benefit is less than five years. Optimization process for the large data was conducted. The PBP calculations for wall roof parameters depend on the insulation layer thickness. The cost increases with an increase in the insulation layer thickness. From Tables 1 and 2, the results show that the optimized values are equal to 0.08 (Btu/ft^{2}h^{o}F) and 0.056 (Btu/ft^{2}h^{o}F) for the eight north angles for the eight north angles of the building orientation for the range of U-Wall values and U-Roof, respectively. The optimized values were obtained for U-Wall value and U-Roof at –20%, with a north angle equal to zero degrees or 180º. The payback period was approximately less than two years for both assessed parameters. The optimized U-Wall value reduced the annual energy consumption by 0.5% compared to base Case 1. For base Case 2, the optimized U-Wall value has a good reduction percentage of 0.6% in the annual energy consumption. The optimized U-Roof values reduced the energy consumption to 0.42% and 0.47% for base Case 1 and base Case 2, respectively. The PBP analysis for the glazing depends on the type of glass material, type of frame and thickness of the glass used. Analyzing the window parameter case, the cost of the window increased tremendously when decreasing the U-Window value. The results show that the optimized value was equal to 0.557 (Btu/ft^2hºF) for base Case 1. The optimized value was obtained at –5.0% of the U-Window value. This is because of the high cost of the glass material. The results in Table 2 showed that the optimized value of the U-Window parameter value was 0.572 (Btu/ft^2hºF) for base Case 2. The optimized value was obtained at –2.5% of the U-Window value. The results of both base cases were at north angle equal to zero degrees or 180º and with payback period was less than five years. It should be noted that the optimized U-Window value of base Case 2 is greater than the optimized U-Window value of base Case 1; this was due to the significant effect of the occupancy and the plug loads. The annual energy consumption of base Case 1 is higher than base Case 2. Subject to this, the optimization results are different. To visualize the effect of using the optimized parameters values in a residential building in Kuwait, in base Case 1, a reduction of 0.12% on the annual energy consumption was achieved when using the optimized U-Window value. On the other hand, only a 0.05% reducing in the annual energy consumption for the optimized U-Window value of base Case 2. The PBP calculations of the SHGC parameter focused on the reflected absorbed cell shade and the shutters. The cost increased with a decrease in the SHGC value. Tables 1 and 2 show the optimized value of the SHGC was 0.237 for base Case 1 and was 0.244 for base Case 2. The result was obtained from the –17.5% SHGC value for base Case 1 and the –15% SHGC value for base Case 2, both results at north angle zero degrees or 180º. The optimized values of the SHGC parameter have a significant effect in energy conservation. A 0.96% to 0.98% reducing in the annual energy consumption for both base cases was achieved when using the optimized values of the SHGC parameter. SHGC parameter results had higher degree of effectiveness in the annual energy consumption than other previously assessed parameters. The optimized SHGC values had good results in the residential building energy savings. The PBP calculations for the EER depend on the motor type (the power of the motor) and capacity of the compressor. In addition, the price including maintenance and the spare parts of the cooling loads equipment. The cost increased as EER value increased. Tables 1 and 2 show the optimized value was 8.225 for base Case 1 and was 8.05 for base Case 2. The result was obtained from the +17.5% EER value of Case 1 and +15% EER value of Case 2 both at north angle zero degrees or 180º. The payback period is less than five years. In both base cases, the most effective parameter was the EER. A reduction percentage of 4.6% on the annual energy consumption was achieved using the optimized value of EER parameter compared to Kuwait code value in both base cases. For base Case 1 the total reduction percentage on the annual energy consumption was approximate of 6.1% using the optimized values of the assessed parameters. Furthermore, the total reduction percentage on the annual energy consumption was 5.3% using the optimized values of the assessed parameters in base Case 2.

Using the data of Table 1, the CO_2 emissions were reduced by 6.6% approximately for base Case 1. In base Case 2, the CO_2emission has a reduction percentage of 4.5% was applied by the optimized values of the assessed parameters (see Table 2). The reduction of the optimal solution in the CO_2emission of base Case 1 was higher than base Case 2. This is due the higher value of the EER and the lower values of the SHGC and U-Window.

8. Peak Loads

Figs. 1 and 2 represent the differences in the peak load between the base study and the optimum results in Tables 1 and 2. A reduction of 20.8% in the peak load was obtained using the optimized values of base Case 1 compared to base Case 1, as shown in Figs. 1 (a)-(b). In addition, a reduction of 18% in the peak load was obtained using the optimized values of base Case 2 rather than base Case 2, as illustrated in Figs. 2 (a)-(b). With the optimized values of base Case 1, implying an orientation towards the north and south, the energy consumption was cost of 1,730$ and 1,825$ of July and August respectively as shown in Fig. 1a. However, a peak load of 50.9 (KW) was registered at rush hour 2.00 to 3.00 pm. For the optimized value of base Case 2, it was found that the energy consumption was cost 1,806$ and 1,906$ of July and August as shown in Fig. 2. On the other hand the peak load of 52.2 (KW) was noticed at peak time 2.00 to 3.00 pm. This indicates the temperatures falling below 20°C, triggering heating to maintain comfort at the residential building.

Table 3 shows the HVAC total cost in a month ($) for four cases; the two base cases and the optimum results of the two base cases. As a result of peak load reductions was obtained using the optimized values of the both base cases. The energy consumption was cost of 1,730$ in July using the optimized values of base Case 1. It was found to cost 1,806$ using the optimized values of base Case 2 at the same month. In August, the optimized values of base Case 1 was cost of 1,825$ in the energy consumption, and the optimized values of base Case 2 was cost 1,906$, this increase which account for the significant effect of the two factors, occupancy and plug load. The peak load of the optimized assessed parameters values has an energy savings of approximately of 20.8% compared to base Case 1. The peak load of the optimized assessed parameters values has an energy savings of approximately of 20.8% compared to base Case 1. A reduction of approximately 15.5% and 15.1% in the peak load due to July and August, respectively when using the optimized assessed parameters values for base Case 2.

This shows a major reduction was obtained using the optimized assessed parameters values on the north and south sides of the two base Cases. In addition, the good choice of the north angle is protecting some of the indoor spaces from direct solar radiation (Chou, 2001). Usually, cooling loads cost was lower during the winter season and higher during the three quarters of the year for both base cases as seen in figs. 1 and 2. This was due to the lower and higher conductive gains as an effect of the mean outdoor temperatures during the year (Meteotest, 2008).

9. Conclusions

- In base Case 1, the increase in occupancy and plug loads fluctuations increases the total energy consumption and CO_2 emissions by at-most 13% over Case 2. This influences the increase in environmental pollution and harmful effects on human health. Energy consumption is anticipated to increase by increasing the occupancy and the plug load.
- Lower energy consumption and CO_2 emissions can be achieved by proper choice of glass which delivers a positive impact for the environment in energy savings. Through analyzing the U-Window and SHGC parameters, was found to be more effective is reducing the SHGC of the fenestration system of the residential building, which was critical to performance less energy consumption. A lower SHGC value is advantageous in cooling load consumption. The U-Window parameter was the most effective value on the incremental initial cost. A lower SHGC value a higher cost material construction.
- The north angle influence cooling loads of the building. The building orientation position has a big effect on the annual energy consumption with alteration of the U values and SHGC. Where, it has relatively poor effect on the annual energy consumption for building orientation with alteration of the EER value.
- The optimized values were found in both base cases at the north angles 0º and 180º for the five assessed parameters. The most effective parameter value was found to be the EER for both base cases. It was +17.5% of EER value for Case 1 with approximate saving of 4.6% of the annual energy consumption. Furthermore, it was +15% of EER value for Case 2 with approximate annual energy savings of 4.6%. The optimized value of the U-Roof parameter has the less effect on the annual energy consumption with only little reduction percentage of 0.42% in base Case 1 and of 0.47% in base Case 2.
- For base Case 1, a reduction of 6.1% in the annual energy consumption was obtained with the optimized values of the assessed parameters. Furthermore, a potential to save up to 5.3% of cooling energy in optimized values of the assessed parameters of base Case 2. The optimized values of the assessed parameters covered the annual costs within less than five years in comparison to Kuwait Code. An energy cost savings of 20.8% in the peak load was obtained using the optimized assessed parameters values for Case 1. In addition, it was an approximately of 15.5% and 15.1% due to July and August respectively, for Case 2.

Acknowledgments

I would like to express my deepest thanks and gratitude to my advisors Prof. Mohammad D. Al-Ansary and Prof. Walid Chakroun and for this support and encouragement.

Nomenclatures

IAQ	Indoor Air Quality
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
A/C	Air-Conditioning
HVAC	Heating, Ventilating and Air-Conditioning
EER	Energy efficiency ratio
U	The overall heat transfer coefficient
SHGC	Solar heat gain coefficient
OAT	Outside air temperature
PBP	Payback period
KWh	Kilowatt hour
M. KWh	Million Kilowatt hour
ºC	Temperature in degrees Celsius
ºF	Temperature in degrees Fahrenheit
KD	Kuwaiti Dinar
CO_2	Carbon dioxide

References

Al-Qabandi J. (2012). Parametric study leading to energy conservation in residential houses in Kuwait. *Thesis, July, 2012, Kuwait*.

Ascionea F., Bianco N., De Mas R. and Vanoli G. (2013). Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates, *Energy and Buildings, **60**, 2013, pp. 125–138*.

Chou, S.K. (2001). Seminar Proceedings, Energy Efficiency in Building Design: Building Energy Standard, Building and Construction Authority of Singapore, Singapore (18th April 2001), paper 2.

Han, X., Pei, J., Liu, J., and Xu, L. (2013). Multi-objective building energy consumption prediction and optimization for eco-community planning*. Energy and Buildings, 66: 22–32.*

Huang, J., Lv, H., Gao, T., Feng, W., Chen, Y., and Zhou, T. (2014). Thermal properties optimization of envelope in energy-saving renovation of existing public buildings. *Energy and Buildings, 75: 504–510.*

Kanagaraj, A., and Sharmila, S. (2015). Role of occupancy sensors in energy management. Second International Conference on Science, Technology and Management. 27/9/2015.

KOC, Kuwait Oil Company, 2015.

Kuwait Meteorological Office: Climate Statistics.

Kuwait Central Statistical Bureau, 2018.

Kuwait Code MEW R-6-2014.

Meteotest, (2008). Meteonorm Version 6.0, www.meteotest.ch.

MEW statistical year book, 2014.

Sun, C., Giles, H., Lian, Z. (2014).The dynamic impact of window characteristics on shading factor and energy consumption. *Solar Energy, 102: 1–13.*

Vakiloroayaa V., Samalib B., and Pishghadamc K. (2014). A comparative study on the effect of different strategies for energysaving of air-cooled vapor compression air conditioning systems. *Energy and Buildings **74** (2014) 163–172.*