Comparison of CFL lights and LED lights reviewed from the side of the price, strong light and heat caused

N. Hudallah, Isdiyarto, S. Sukamta, P. K. Nashiroh, M. Harlanu, S. Purbawanto

Electrical Engineering Department, Faculty of Engineering, Universitas Negeri Semarang, Gd. E11 Kampus Sekaran, Gunungpati, Semarang, 50229, Indonesia

noorhudallah@mail.unnes.ac.id

Abstract. Electrical energy has become a major requirement in supporting daily activities. The use of electricity in the community is increasing, while the supply of electrical energy is limited. Natural resources in the form of petroleum, coal as the main raw material in producing electrical energy are running low. Therefore, it is necessary to think of alternative solutions to save the use of electrical energy and one solution that can be done is to conserve energy. Energy conservation can be done in various ways, one of which is to use energy efficiently following needs. Electric lights are one of the objects being studied in the conservation of electrical energy. This study aims to examine the energy conservation in the use of electrical energy for lighting needs, namely the efficiency of CFL lamps (Compact Fluorescent Lamp), and LED lamps (Light Emitting Diodes) in terms of price, electricity consumption, and environmental heat generated. The research methodology used is an experiment by selecting and treating the lamp that is the object of research. The choice is based on the price of the lamp and the treatment that is done includes the provision of electric voltage and measured lighting intensity and the resulting ambient temperature. The results of the study are 1). the average price of CFL lamps is cheaper than LED lights. 2). strong lighting produced by the LED lights is greater (6.92 Lux / Watt) compared to CFL lamps (1.003 Lux / Watt) and 3). Environmental heat by CFL lamps is higher (35.4 0C) than LED lights (33.0 0C) and 4). Based on overall variables: price, lighting strength, and lamp temperature, LED lights are superior, especially on the resulting lighting strength. For conservation purposes, select the type of lamp according to the allotment of space and the value of the importance of space. If the consideration is lower prices, choose CFL lamps, but if the consideration is stronger, bigger lighting, choose LED lights.

1. Introduction

Electrical energy is one of the energies needed in everyday life. Currently, electrical energy has become the main requirement as a driving force for daily activities. Over time, the need for electrical energy use in the community is increasing, while the supply of available electrical energy has limitations because natural resources in the form of oil and coal as the main raw materials for producing electrical energy are running low. This situation requires efforts to manage the energy available today and in the future. Efforts that can be done are using renewable energy to produce electrical energy and conserve energy.
Conservation is an effort to regularly maintain and protect something to prevent damage and destruction through preserving, preserving, and preserving. One form of conservation is the use of clean energy. This pillar aims to save energy through a series of policies and actions in utilizing energy wisely, as well as developing environmentally friendly renewable energy.

Energy conservation is the management of energy and its use wisely and ensuring the sustainability of the energy supply. Energy conservation is the use of energy efficiently without reducing energy use which is needed. Energy conservation is one solution that can be taken when the need for electrical energy consumption in households or offices continues to increase. The basic principle of energy efficiency is the ability to use less energy to perform the same functions and performance [1].

One of the main functions of electrical energy is for the lighting system. As much as 50% of the electricity load in Indonesia comes from lighting [3] Lighting is the main need for basic electricity use for the community. Efforts to conserve the use of electrical energy in the lighting system are by reducing the use of electrical energy by choosing the type of lighting. The use of energy-efficient lamps can be a solution in efforts to conserve electrical energy.

The development of lamp production in the market is currently dominated by energy-saving lamps. Energy-saving lamps are lamps that consume minimal electrical power, but produce visible light that is used as much as possible [2]. There are various kinds of lamps on the market, including incandescent lamps, fluorescent tubes, CFL (Compact Fluorescent Lamps), and LED (Light Emitting Diodes) lamps. In choosing the type of lamp used, the public uses more considerations of affordable prices and is widely sold in the market, even though the use of energy-saving lamps to conserve electrical energy that must be considered is energy savings, namely choosing lamps with small Watt but light intensity, or Lux is big.

Energy-saving lamps that are widely circulating in the market and widely used by the public are CFL lamps and LED lamps. CFL lamps are a type of tube lamp (Tube Lamp-TL) that has been used by the public so far, while LED lamps are a type of lamp that uses an LED light source. Regarding which type of lamp is better, it is necessary to carry out further studies regarding the economic aspects of using the two lamps in both technical and cost considerations. Therefore, it is necessary to have a comparative study of the two types of lamps to determine their efficiency and economic value.

Regarding efforts to determine efficiency and economic value, the following problems are formulated:
1. How do the prices compare between CFL and LED lamps at various power and price variations?
2. How does electric power consumption compare between CFL and LED lamps at various power and price variations?
3. How do you compare the environmental heat generated between CFL and LED lamps at various power and price variations?

Based on this research, it is expected that the comparison of the economic value and efficiency of CFL and LED lamps with various price and power variations can be seen. These results are expected to help people in choosing lamps with economic value and high efficiency to use. The effort was made to achieve one form of electrical energy conservation, namely saving electrical energy efficiently without reducing the use of energy that is needed, especially for lighting.

According to Government Regulation no. 70 of 2009, energy conservation is defined as a systematic, planned, and integrated effort to conserve domestic energy resources and increase the efficiency of their utilization. Based on this definition, every energy user must utilize this energy efficiently and efficiently. Energy conservation is carried out to obtain energy savings without reducing the quality of energy use.

Conservation according to Putra et al [5] is the act of reducing the amount of energy use or optimal energy use following needs so that it will reduce energy costs incurred. The objective of energy conservation is to maintain the preservation of natural resources in the form of energy sources through a policy of selecting technology and utilizing energy efficiently and rationally to realize the ability to supply energy.
Energy conservation is carried out as an effort to increase the efficiency of electrical energy. Energy efficiency according to [4] is a general term that refers to using less energy to produce the same amount of service or useful output. This efficiency can be done by using lamps with high efficiency [7].

CFL (Compact Fluorescent Lamp) is a type of fluorescent lamp made to replace incandescent/tungsten lamps (incandescent lamps). Compared to tungsten lamps, with the same illumination wattage, CFL lamps use less energy. CFL lamps are fluorescent lamps that are shaped like tungsten lamps, or incandescent lamps. Common CFL lamps use 220 Volt AC voltage. CFL lamps have several different forms, including the Essential Type CFL, which is a straight-shaped CFL, then there is also a Tornado Type CFL, a spiral-shaped CFL lamp and there is also a CFL lamp with the PL Type (radius), namely the PL-S, PL-C, and PL-L. The series of CFL lamps consist of a glass discharge tube, tube reflection clip, mounting plate, electronic ballast components, polycarbonate housing, ecision screw base, discharge path, phosphor coating, electrodes, bridge, base pins, rfi suppression capacitor, and starter, which are one unit incorporated in the CFL lamp array.

Currently, LED lights are widely used by the community. LED lamps have many advantages compared to other types of lamps. The advantages of LED lamps include saving electricity costs, being more environmentally friendly, and more durable than other types of lamps [7]. LEDs are semiconductors that convert electrical energy into light when an electric current passes it. LED is a solid and hard device so that it has a long life. This type of lamp uses relatively low power consumption over a longer life.

Figure 1. Forms of CFL Lamp (conventional-tornado-PL radius 3-PL radius 2)

The advantages of LED lamps according to Suwandi and Farian [7] are: (1) they have a longer service life than ordinary lamps; (2) has an energy efficiency of up to 80-90 percent; (3) The light produced by the LED lamp is not hot; (4) the light produced by the LED lamp also does not distort the surrounding color, so it is safer to use for street lighting; (5) smaller size so that it can be applied more practically; (6) does not contain mercury so it is more environmentally friendly; and (7) with a suitable optical lens, the LED light can be directed as desired.

While the shortcomings of LED lamps according to Suwandi and Farian [7] include: (1) the price of LED lamps is still relatively expensive, (2) the ambient temperature can affect the life of the LED lamps; and (3) light intensity which is small. LEDs have a higher lumen per watt rating than TL and CFL lamps. The various kinds of LED lamps include: tube type LED lamps, bulb type LED lamps, downlight type LED lamps.

Praveen et al. [8] measured variation of case and junction temperature and the optical characteristic of LED for different heat sinks. They found that heat sink with higher surface area shows the best result in terms of lower case and junction temperature. The higher luminous intensity was observed for the parallel fin type 1 heat sink due to the higher surface area. The thermal analysis of an 80 W LED streetlamp was investigated by Luo et al. [9]. Thermocouples were used to measure the temperature.
points at the aluminium base and fins. It was revealed that the temperatures near the chip were nearly the same. The numerical results of the thermal resistance analysis showed that at an environment temperature of 45°C, the maximum junction temperature of the LED chips on the present 80 W LED street lamp would be equal to the critical temperature 120°C leading to poor reliability and lower life and optical efficiency of the LED street lamp. Ahn et al. [10] investigate the energy use in commercial buildings by evaluating lighting energy saving methods and the effect of using dimmer controls with a heat control method, which can both maximize the cooling load reduction during summer and save energy. They found that the total energy from the reference commercial building could be decreased by 20.9% by replacing LFL T12 bulbs with LEDs, together with an additional saving of 19.9% in cooling energy by using the lighting heat & dimming control method.

2. Research Methods

The research was conducted in the Electrical Engineering Laboratory, Faculty of Engineering, Semarang State University. To be able to measure the magnitude of light intensity (Lux) which is pure only from the light source without any environmental reflectance factors, a black box with dimensions of 1 m long, 1 m wide, and 1 m high is used and all the inner walls are painted black.

For research data collection, the samples in this study are:

1. 9 CFL lamps with a combination of 3 power variations and 3 variations of lamp brands with low, medium, and expensive price categories.
2. 9 LED lamps with a combination of 3 variations of power and 3 variations of lamp brands with low, medium, and expensive price categories.

The research approach is experimental research. Experiments were conducted to measure the strength of illumination (Lux) and heat generated (heat in the light source and heat in the environment) by CFL and LED lamps for 3 variations of different lamp brands with low, medium, and expensive price categories.

The research data was collected in a black box where all types of lamps, both CFL and LED, were given a voltage of 220 Volt and the measured variables were:

1. strong luminance (Lux) produced by CFL and LED lamps
2. The measured heat in the light source of CFL and LED lamps
3. The measured heat in the environment (a distance of 1 m at the bottom of the BlackBox) from the light source of CFL and LED lamps

Meanwhile, the 3 variations of different lamp brands were taken from the low, medium, and expensive price categories.

The measuring instruments used are:

1. Siemens digital Lux meter for measuring illumination intensity (Lux)
2. Sanwa digital multimeter to measure power and voltage (Volt)

The digital thermometer is used to measure the temperature of the light source and the ambient temperature. The selection and use of digital measuring instruments are intended to obtain more valid or accurate data.

3. Research Results and Discussion

3.1. Research Results

The results of the study for a comparison in terms of price, consumption of electrical power, and environmental heat are as follows:

3.1.1. Price Based Lamp Category

The research sample lamps were purchased not only from one lighting shop but from various lighting stores. The purchase of lamps is not only from one shop because it is necessary to obtain several lamps
according to the research sample category. Table 1 illustrates the results of price comparisons of various CFL lamps.

### Table 1. Prices of CFL Lamps in Various Power and Price Variations

| No. | Lamp Brand | Type of Lamp | Watt | Price (Rp) |
|-----|------------|--------------|------|------------|
| 1.  | Integra    | √            | 12 Watt | 9,000,-   |
| 2.  | Integra    | √            | 16 Watt | 9,000,-   |
| 3.  | Chunma     | √            | 20 Watt | 9,000,-   |
| 4.  | Visalux    | √            | 5 Watt  | 24,000,-  |
| 5.  | Visalux    | √            | 8 Watt  | 26,000,-  |
| 6.  | Visalux    | √            | 15 Watt | 28,000,-  |
| 7.  | Philips    | √            | 11 Watt | 29,500,-  |
| 8.  | Philips    | √            | 14 Watt | 31,500,-  |
| 9.  | Philips    | √            | 18 Watt | 33,500,-  |
|     | **Average price:** |              |      | **Rp. 22,166,-** |

The average CFL (Compact Fluorescent Lamp) price is Rp. 22,166,- (twenty-two thousand one hundred sixty-six thousand rupiah). Please note, this price standard cannot be used as a benchmark, or in other words, it is not valid because several sample lamps are not purchased from the same shop so that the price of the lamps cannot be compared.

### Table 2. Prices of LED lamps at various power and price variations

| No. | Lamp Brand | Type of Lamp | Watt | Price (Rp) |
|-----|------------|--------------|------|------------|
| 1.  | Badalex    | ---          | 7 Watt | 7,000,-   |
| 2.  | Badalex    | ---          | 9 Watt | 8,000,-   |
| 3.  | Badalex    | ---          | 15 Watt | 12,500,-  |
| 4.  | Hori       | ---          | 6,5 Watt | 30,000,-  |
| 5.  | Hori       | ---          | 8,5 Watt | 38,000,-  |
| 6.  | Hori       | ---          | 11 Watt | 50,000,-  |
| 7.  | Philips    | ---          | 6 Watt  | 31,000,-  |
| 8.  | Philips    | ---          | 8 Watt  | 35,500,-  |
| 9.  | Philips    | ---          | 10 Watt | 40,000,-  |
|     | **Average price:** |              |      | **Rp. 28,000,-** |

Unlike CFL lamps, the LED (Light Emitting Diode) lamps have a higher average price of Rp. 28,000,- (twenty-eight thousand rupiah) per lamp unit. As with CFL lamps, this price standard cannot be used as a benchmark, or in other words, it is less valid because several sample lamps are not purchased from the same shop so that the lamp prices cannot be compared.

### 3.1.2. Lamp Category Based on The Strength of The Resulting Luminance

The resulting luminous strength (Lux) from various types of CFL lamps is illustrated in Table 3 below:
Based on Table 3 above, it is known that the average luminance or Lux produced for CFL type lamps is 1.003 Lux / Watt, where for the cheap category lamps (No.1 to No.3) it has a smaller average Lux, namely 0.44 Lux / Watt, for the medium price category (No. 4 to No.6) has an average Lux of 1.44 Lux / Watt and for the expensive price category (No.7 to No.9) has an average Lux of 1.13 Lux / Watt. What is interesting is that CFL lamps in the medium price category have a larger Lux / Watt.

For this type of LED lamp, the resulting luminance or Lux measured from various types of lamp brands is described as in Table 4 below:

Based on Table 4 above, it is known that the average luminance or Lux produced for LED lamps is 6.92 Lux / Watt, where for the cheap category lamps (No.1 to No.3) it has an average Lux of 2.54 Lux / Watt, for the medium category (No. 4 to No.6) has an average Lux of 9.95 Lux / Watt and for the expensive category (No. 7 to No.9) has an average Lux of 8.28 Lux / Watt. As with CFL lamps, LED lamps with the medium price category have higher Lux / Watt.

### 3.1.3. Lamp Category Based on Heat Generation

Each type of lamp will not only convert electricity into light / lighting but part of it will be converted into heat. The heat generated occurs in the lamp and affects the environmental heat. For this type of CFL lamp, the heat generated is shown in Table 5 below:

---

### Table 3. Strong Lighting CFL Lights at Various Power Variations

| No. | Lamp brand | Type of Lamp | Watt | Lux | Information |
|-----|------------|--------------|------|-----|-------------|
| 1.  | Integra    | √            | 12 Watt | 6 Lux | 0.5 Lux/Watt |
| 2.  | Integra    | √            | 16 Watt | 6 Lux | 0.375 Lux/Watt |
| 3.  | Chunma     | √            | 20 Watt | 9 Lux | 0.45 Lux/Watt |
| 4.  | Visalux    | √            | 5 Watt | 9 Lux | 1.8 Lux/Watt |
| 5.  | Visalux    | √            | 8 Watt | 10 Lux | 1.25 Lux/Watt |
| 6.  | Visalux    | √            | 15 Watt | 19 Lux | 1.27 Lux/Watt |
| 7.  | Philips    | √            | 11 Watt | 10 Lux | 0.91 Lux/Watt |
| 8.  | Philips    | √            | 14 Watt | 16 Lux | 1.14 Lux/Watt |
| 9.  | Philips    | √            | 18 Watt | 24 Lux | 1.33 Lux/Watt |

Average: 1.003 Lux/Watt

---

### Table 4. Powerful Illumination of LED Lights at Various Power Variations

| No. | Lamp brand | Type of Lamp | Watt | Lux | Information |
|-----|------------|--------------|------|-----|-------------|
| 1.  | Badalex    | ---          | 7 Watt | 24 Lux | 3.45 Lux/Watt |
| 2.  | Badalex    | ---          | 9 Watt | 25 Lux | 2.78 Lux/Watt |
| 3.  | Badalex    | ---          | 15 Watt | 21 Lux | 1.4 Lux/Watt |
| 4.  | Hori       | ---          | 6.5 Watt | 61 Lux | 9.38 Lux/Watt |
| 5.  | Hori       | ---          | 8.5 Watt | 86 Lux | 10.12 Lux/Watt |
| 6.  | Hori       | ---          | 11 Watt | 114 Lux | 10.36 Lux/Watt |
| 7.  | Philips    | ---          | 6 Watt | 45 Lux | 7.5 Lux/Watt |
| 8.  | Philips    | ---          | 8 Watt | 66 Lux | 8.25 Lux/Watt |
| 9.  | Philips    | ---          | 10 Watt | 91 Lux | 9.10 Lux/Watt |

Average: 6.92 Lux/Watt
### Table 5. Comparison of Environmental Heat Generated in CFL Lamps

| No. | Lamp brand | Type of Lamp | Watt | Lamp Temperature | Environmental Temperature |
|-----|------------|--------------|------|------------------|----------------------------|
| 1.  | Integra    | √            | 12 Watt | 42.0 °C          | 35.4 °C                     |
| 2.  | Integra    | √            | 16 Watt | 42.0 °C          | 35.4 °C                     |
| 3.  | Chunma     | √            | 20 Watt | 42.0 °C          | 35.4 °C                     |
| 4.  | Visalux    | √            | 5 Watt  | 42.0 °C          | 35.4 °C                     |
| 5.  | Visalux    | √            | 8 Watt  | 42.0 °C          | 35.4 °C                     |
| 6.  | Visalux    | √            | 15 Watt | 42.0 °C          | 35.4 °C                     |
| 7.  | Philips    | √            | 11 Watt | 42.0 °C          | 35.4 °C                     |
| 8.  | Philips    | √            | 14 Watt | 42.0 °C          | 35.4 °C                     |
| 9.  | Philips    | √            | 18 Watt | 42.0 °C          | 35.4 °C                     |

Average: 42.0 °C 35.4 °C

In this type of CFL lamp, the average heat generated is 42.00°C, both for the cheap lamp category (No.1 to No.3), the medium lamp category (No.4 to No.6), and the expensive lamp category (No. 7 to No.9). Likewise for environmental heat (measured 1 m from the light source) both for the cheap lamp category, the medium lamp category, and the expensive lamp category had an average temperature of 35.40°C. For this type of LED lamp, the heat generated is shown in Table 6 below:

### Table 6. Comparison of Environmental Heat Generated in LED Lamps

| No. | Lamp brand | Type of Lamp | Watt Light | Lamp Temperature | Environmental Temperature |
|-----|------------|--------------|------------|------------------|----------------------------|
| 1.  | Badalex   | ---          | 7 Watt     | 36.3°C           | 33.0°C                     |
| 2.  | Badalex   | ---          | 9 Watt     | 33.0°C           | 33.0°C                     |
| 3.  | Badalex   | ---          | 15 Watt    | 33.0°C           | 33.0°C                     |
| 4.  | Hori      | ---          | 6.5 Watt   | 33.0°C           | 33.0°C                     |
| 5.  | Hori      | ---          | 8.5 Watt   | 36.4°C           | 33.0°C                     |
| 6.  | Hori      | ---          | 11 Watt    | 40.0°C           | 33.0°C                     |
| 7.  | Philips   | ---          | 6 Watt     | 38.1°C           | 33.0°C                     |
| 8.  | Philips   | ---          | 8 Watt     | 42.0°C           | 33.0°C                     |
| 9.  | Philips   | ---          | 10 Watt    | 42.0°C           | 33.0°C                     |

Average: 37.09°C 33.0°C

In this type of LED lamp, the average heat generated is 37.09 °C. For environmental heat, both the cheap lamp category, the medium lamp category, and the high-cost lamp category have an average temperature of 33.0°C.

#### 3.2. Research Discussion

For the price category of lamps, CFL lamps are cheaper than LED lamps because the average price of CFL lamps is Rp. 22,166,- / unit while the LED lights are Rp. 28,000, - / lamp unit.

Especially for the price category of this lamp, there is no complete comparison between the price of CFL lamps and the prices of LED lamps. This is because the samples of the research lamps did not come from the same lighting shop.
3.2.1. Luminous Power (Lux) - Watt Electric
From the research data obtained, it is known that CFL lamps have a lower luminance (Lux) than LED lamps for the average per Watt. The average lighting strength or Lux produced for this type of CFL lamp is Rp. 1,003 Lux / Watt while the LED lights are 6.92 Lux / Watt.

The average lighting strength or Lux produced for cheap CFL type lamps (No.1 to No.3) is 0.44 Lux / Watt, for the medium category (No.4 to No.6) has an average Lux of 1.44 Lux / Watt and for the expensive category (No. 7 to No.9) has an average Lux of 1.13 Lux / Watt.

The resulting Lux for low-cost category LED lamps (No.1 to No.3) is 2.54 Lux / Watt, for the medium category (No.4 to No.6) has an average Lux of 9.95 Lux / Watt and for the expensive category (No. 7 to No.9) have an average Lux of 8.28 Lux / Watt.

In other words, CFL type lamps have Lux / Watt which is smaller than Lux / Watt from the type of LED lamps. As for the price-based category, both the CFL type and the LED type in the low price category have Lux / Watt which is smaller than the medium and high price categories.

3.2.2. Heat Lamp
In the Lamp heat category, CFL lamps have a higher average lamp heat than LED lamps. The average heat value of CFL lamps is 42.00C while the LED lamps are 37.090C. Meanwhile for environmental heat, the CFL lamp is 35.40C and the LED lamp is 330C.

4. Conclusion
The conclusions obtained from this research are:
1. If the price is considered, then CFL lamps are an option because they are cheaper.
2. If the consideration is the strength of the resulting light (Lux), then the LED lamp can be chosen because it provides a higher light strength per lamp Watt.
3. If lamp heat and environmental heat are a consideration, then choose LED lamps because they have lower heat and ambient heat.
4. Based on the consideration of all variables including price, lighting strength, lamp heat, and environmental heat, LED lamps to have advantages, especially in terms of the strength of the light they produce.

References

[1] Asmawati E, Marlina, and Idayani J 2016 Analisis Ekonomi Penggunaan Energi Listrik untuk Penerangan. Prosiding Seminar Nasional FMIPA-UT 2016: Peran Matematika, Sains, dan Teknologi dalam Mendukung Gaya Hidup Perkotaan (Urban Lifestyle) yang Berkualitas, 22 September 2016, Balai Sidang Universitas Terbuka (UTCC)

[2] Chumaidy A 2017 Analisa Perbandingan Penggunaan Lampu TL, CFL dan Lampu LED (Studi Kasus Pada Apartemen X. Sinusoida-Jurnal Penelitian dan Pengkajian Elektro ISTN 19

[3] Faridha M and Ifan 2016 Studi Komparasi Lampu Pijar, LED, LHE dan TL yang Ada Dipasaran Terhadap Energi yang Terpakai Jurnal Teknik Mesin Unisda 02

[4] Kartika S A 2018 Analisis Konsumsi Energi dan Program Konservasi Energi (Studi Kasus: Gedung Perkantoran dan Kompleks Perumahan TI) Jurnal Sebatik 22

[5] Putra IWS, Kumara INS, Arjana IGD 2015 Studi terhadap Konservasi Energi pada Gedung Sewaka Dharma Kota Denpasar yang Menerapkan Konsep Green Building E- Journal SPEKTRUM 2

[6] Republik Indonesia 2009 Peraturan Pemerintah Republik Indonesia Nomor 70 Tahun 2009 Tentang Konservasi Energi

[7] Suwandi A and Fardian F 2016 Analisa Pemakaian Lampu LED Terhadap Energi dan Efisiensi Biaya di PT. Total Bangun Persada Tbk Jurnal Inovasi TM 12
[8] Praveen AS, Jithin R, Kumar KN and Baby M 2019 Analysis of thermal and optical characteristics of light-emitting diode on various heat sinks *International Journal of Ambient Energy*

[9] Luo X, Cheng T, Xiong W, Gan Z and Liu S 2007 Thermal analysis of an 80 W light-emittingdiode street lamp *IET Optoelectron* 1 191–196

[10] Ahn B-L, Jang C-Y, Leigh S-B, Jeong H 2014 Analysis of the effect of artificial lighting on heating and cooling energy in commercial buildings *Energy Procedia* 61 928 – 932