International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0089

INTEGRATION AND APPLICATION OF THE FAB ENERGY SIMULATION (FES) TOOL AND ENERGY CONVERSION FACTORS (ECF) FOR HIGH-TECH FACTORIES

Tee Lin [1], Shao-Huan Huang [1], Ben-Ran Fu [2]*, Ming-Hsuan Hu [3], Shih-Cheng Hu [1]*

[1] Department of Energy and Refrigerating Air-conditioning Engineering, National Taipei University of Technology, Taipei, Taiwan

[2] Department of Mechanical Engineering, Ming Chi University of Technology, New Taipei City, Taiwan

[3] Department of Energy Technology, Royal Institute of Technology (KTH), Stockholm, Sweden

ABSTRACT

Semiconductor or optoelectronic manufacturing is a high-energy consumption industry in Taiwan. Detailed energy consumption data for a manufacturing plant (called fab) is important to calculate energy savings and for energy management. The objective of this study is to integrate the fab energy simulation (FES) tool and energy conversion factor (ECF) to analyze the energy use of high-tech fabs and to identify some possible energy savings from the results. We used data from a Taiwanese semiconductor manufacturing fab as an example. In addition to the process equipment, the highest energy consumers in the fab were the compressed (or clean) dry air (22.1%), water chiller (20.6%), process cooling water (5.8%), de-ionized water (3.2%), and exhaust systems (2.0%). When compared to the original data, the results from the studied case showed that the highest energy savings for the compressed (or clean) dry air system were 3,050 MWh (1.81% of the overall energy consumption).

Keywords: energy consumption, fab energy simulation, energy conversion factors

1. INTRODUCTION

The electronics industry in Taiwan mainly focuses on semiconductor and optoelectronic manufacturing. Based on Taiwanese's annual report on the energy consumption from 2016 [1], electricity consumption of the industrial manufacturing sector was 53.1% of total electricity consumption in Taiwan. This high value may indicate that high-tech manufacturing is a high-energy consumption industry. Detailed energy consumption data for a fab is very important for energy savings and energy management. Hu and Chuah [2] reported that semiconductor factory facilities used 56.6% of the total energy consumed in a fab, while process equipment accounted for 40.4%; the major energy consumer in the fab they studied was the air-conditioning system. Wang et al. [3] reported that process equipment energy consumption was 41.6% of total energy consumed in the TFT-LCD fab they studied, which was very close to that of semiconductor manufacturing fabs [2]. However, they found that a compressed (or clean) dry air (CDA) system consumed the largest portion of energy in the studied fab (19.8%), which was much different from Hu and Chuah's [2] results. CDA is employed in fabs to drive pneumatic components of manufacturing process equipment, control valve functioning, or clean the materials/equipment. To smooth the manufacturing processes, however, the energy efficiency of the CDA system is often neglected during operation, resulting in unnecessary, wasted energy. For example, Saidur et al. [4] reported that the energy use efficiency of a clean (or compressed) air (CA) system may be only 10–20%, and energy loss was mainly from heat dissipation and leakage of air during the process.

Semiconductor Equipment and Materials International (SEMI) published guidelines (SEMI S23-0813) for energy, electricity, and production conservation for semiconductor facility systems [5]. SEMI S23-0813 provides the energy conversion factors (ECFs, energy consumption per unit flow rate) for important utilities. The ECFs can be employed to estimate the energy consumption of utilities and, consequently, they can be used to discover energy savings for high-tech fabs. Recently, Hu et al. [6] applied SEMI's ECFs to semiconductor and LCD manufacturing plants, and they further developed a new ECF calculator with corresponding mathematical models for each subsystem

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

or utility in high-tech fabs. Their calculated ECF values were very close to SEMI's ECFs under the same operating conditions. Their ECF calculator can be used to understand the detailed contribution of each variable to the energy consumption of each system in the fab; it can be used as a tool to determine energy savings.

At present, high-tech product development focuses on multi-function and miniaturization. The functions of electronic components are becoming increasingly complex, the line size of the wafer process is constantly shrinking, and the size of the panel is constantly increasing. Therefore, factory system precision is important. The level of cleanliness and product manufacturing yield are closely related to the cleanroom. The subsidiary facilities in laboratories and production regions are also important. Semiconductor and panel manufacturing factories have many similarities in production processes and facilities. The facilities can be mainly divided into the cleanroom, air-conditioning, power/instrumentation systems, process cooling water (PCW), CDA, ultra-pure water (UPW), exhaust, and gas supply systems. Manufacturers aim for every link to work efficiently, and they also seek possible energy savings to reduce production costs as well as to maintain competitiveness. Considering the issues raised above, the objective of this study, complementary to previous studies [6,7], is to integrate the fab energy simulation (FES) tool and energy conversion factor (ECF) to analyze the energy use of high-tech fabs. The energy performance of the utility system of a fab can be realized and therefore the specific influences on each system can be analyzed. The FES open a door to let the energy monitors understand the structure and cause of the energy consumption of a complicated facility of a fab.

2. METHODOLOGY

2.1 FES tool and ECF calculator

In addition to the energy use of the product process equipment, the energy consumption in a fab is generally from several parts, including the HVAC system, the exhaust system, PCW, UPW, CDA, nitrogen, vacuum, fans, pumps, process tools, and the lighting system. These facilities and materials are all considered in the FES, as described in a previous study [7]. Hu et al. [6] developed a new ECF calculator, based on SEMI S23-0813, to understand the energy consumption in fabs with different operating conditions and/or scale. The detailed description and mathematical models for the different systems are described in Refs. [6,7]. In the FES tool, the MAU system can be rearranged according to the needs or conditions of a fab, and three control methods can be employed for each component (i.e., dry-point temperature control, dew-point temperature control, and enthalpy control). For practical application in a fab, the coils integrated with pre-cooling, pre-heating, and re-heating functions are used to control the dry-point temperature; the second cooling coil, with washer-type humidification and fans, is used to control the dew-point temperature. Each control variable can be changed at any time in the FES. Therefore, the FES can accurately model the MAU system's energy consumption. The ECF may be required for the FES when exact operating data are absent. In the present study, the ECFs for the exhaust system, PCW, UPW, CDA, nitrogen, and vacuum were estimated using the measured data of the fab we studied or the ECF calculator developed by Hu et al. [6]. Therefore, we obtained detailed energy consumption for a fab by integrating the FES tool and the ECF calculator with the measured data.

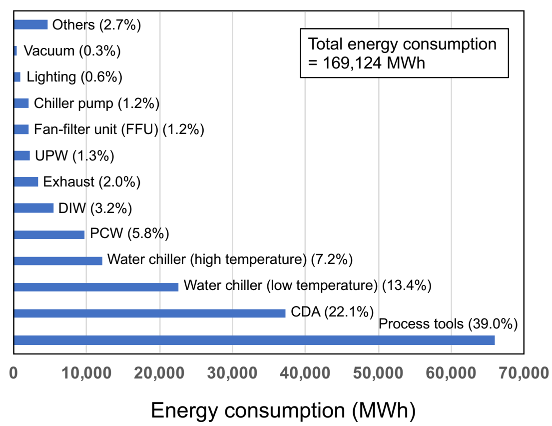

Figure 1. Annual energy consumption of components in the studied fab.

2.2 Details of the fab and studied approaches

We used data from a semiconductor manufacturing fab (in Hsinchu, Taiwan) as an example to demonstrate the integration and application of the FES tool and the ECF calculator. Eight MAU systems were used in the fab we studied. The temperature and relative humidity in the fab's cleanroom were 23 °C and 45%, respectively. The lighting intensity was 0.0119 kW/m^2 with a 60% loading factor, and the cooling load of each worker was estimated as 0.16 kW. Figure 1 details fab's annual energy consumption of components which was measured and collected by the present research team and fab's collaborators. The proportion of energy consumption for each component was also marked in this figure. The annual energy consumption was 169,124 MWh. Based on the measured data, the process equipment accounted for approximately 39.0% of the total energy consumption, which is very close to the proportion reported by Hu and Chuah [3]. In addition to the process equipment, the highest energy consumers in the fab were the CDA (22.1%), the water chiller (13.4% + 7.2% = 20.6%), PCW (5.8%), de-ionized water (DIW) (3.2%), and the exhaust systems (2.0%). In studied Approach, we divided the single supply-pressure system of the CDA into a dual supply-pressure system and replaced the non-heated adsorption dryer with a heated adsorption dryer with a blower. The detailed conditions of Approaches A-1 to A-4 were described below:

A-1: non-heated adsorption dryer and single-pressure supply = 7.5 kg/cm^2 (original condition).

A-2: heated adsorption dryer with blower.

A-3: dual-pressure supply = 5.5 and 7.5 kg/cm^2.

A-4: heated adsorption dryer with blower and dual-pressure supply = 5.5 and 7.5 kg/cm^2.

3. RESULTS AND DISCUSSION

3.1 ECFs for the fab

Table 1 shows the calculated ECFs for the main components of the fab (based on the measured data) corresponding to their working flow rate. The ECF for the CDA system was 0.154 kWh/m^3, which is similar to the value in SEMI S23-0813 (with a deviation of only 4.8%); however, the ECFs for the PCW, DIW, exhaust, and UPW systems were much lower than the SEMI ECFs. For example, the PCW ECF of the fab and the SEMI suggested value were 0.994 and 1.56 kWh/m^3, respectively; the fab PCW's ECF was 36.3% less than the SEMI ECF. This result indicates that the SEMI ECFs may not be suitable for a fab with different operating conditions. It is for this reason that Hu et al. [6] developed a new ECF calculator.

Table 1. ECFs for main components of the studied fab.

Component	Flow rate (m^3/h)	Calculated ECF (kWh/m^3)	SEMI ECF (kWh/m^3)	Deviation to SEMI ECF
CDA	27,593	0.154	0.147	4.8%
PCW	1,122	0.994	1.56	–36.3%
DIW	103	5.99	9.0	–33.4%
Exhaust	213,304	0.00142	0.0037	–61.6%
UPW	58	4.34	9.0	–51.8%

3.2 The CDA system

The fab's CDA system included eight air compressors, three air storage tanks, eight dryers, and three filters. The effect of the dryer type (i.e., non-heated adsorption dryer and heated adsorption dryer with blower) in the CDA system on energy consumption was investigated in this study. The non-heated adsorption dryer not heated during the regeneration process, and the heated adsorption dryer is heated during this process. A non-heated adsorption dryer was originally used in the fab we studied. In general, a non-heated adsorption dryer provides approximately 15% to 20% of the CDA into the CDA system's regeneration tank for drying purposes (also called purge loss), indicating that no additional heating and blowing equipment is needed. However, the operating costs of this system is high due to the CDA consumed during its generation period.

A heated adsorption dryer requires a blower and heater to heat the air during the desiccant's regeneration process. The air is usually heated to 180 °C, and it is used to desorb the humidity in the desiccant. Typical desiccants used in a dryer are active aluminum, a molecular sieve, or silica gel; they have different operating conditions and costs. However, a heated adsorption dryer also consumes approximately 5% of the CDA generated to cool the desiccant, and it needs a longer cycle time than a non-heated dryer. Table 2 lists the design parameters imported into the ECF calculator to calculate the corresponding ECFs for these two types of dryers; the ECFs were used as inputs for the FES. The calculated ECFs for the non-heated and heated dryers were 0.0139 and 0.0111 kWh/m^3, respectively, under design conditions. These results showed that the heated dryer with a blower had a 20% energy savings when compared with a non-heated dryer. Note that as only focusing on CDA, no FES was used. So, there is no concern on sensitivity concern of simulation tool.

Table 2. The design parameters of two studied types of the dryer.

Parameter	Non-heated type	Heated type with blower
Flow rate (m^3/min)	80	80
Ambient temperature (°C)	35	35
Inlet temperature (°C)	25	25
Inlet pressure (kg/cm^2)	7.5	7.5
Dew-point temperature (°C)	–70	–70
Adsorption efficiency	10%	10%
Water amount (kg/m^3)	0.0019	0.0025
Purge loss	15%	5%
Switch period	15 min	8 hours
Heating time	–	3 hours
Blower power (kW)	–	11.2 (15 HP)
Heating power (kW)	–	72

The on-site survey of the CDA used in the fab showed that nine process tools consumed the CDA with different operating pressures, as summarized in Figure 2. However, the supply pressure of the fab's CDA system was only at one level (7.5 kg/cm^2) with a total flow rate requirement of 27,593 m^3/h. Consequently, the CDA system wasted a lot of energy due to the mismatch between the operating pressure and the pressure required for different process tools. Dividing the CDA supply pressure into different levels may reduce this energy loss. Based on the survey, we classify the CDA supply pressure as 5.5 kg/cm^2 (used for an operating pressure less than or equal to 5.5 kg/cm^2) and 7.5 kg/cm^2 (used for an operating pressure higher than 5.5 kg/cm^2); therefore, the corresponding flow rate requirements would be 7,004 and 20,589 m^3/h.

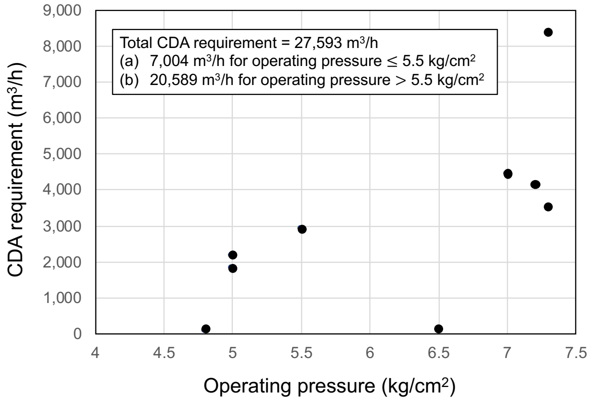

Figure 2. The CDA requirement with different operating pressures for nine process tools in the studied fab.

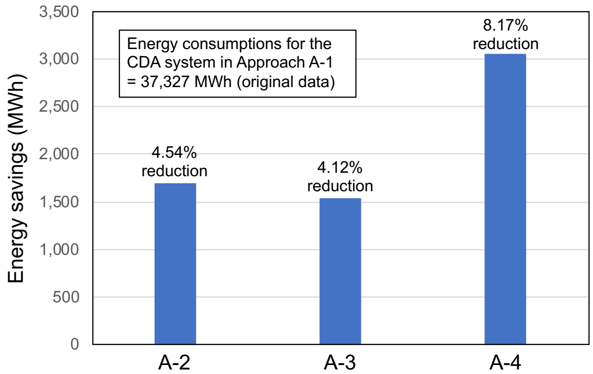

Figure 3. Annual energy savings for the CDA system under Approaches A-2 to A-4.

For the CDA system with a non-heated dryer, the calculated ECFs for the 5.5 and 7.5 kg/cm^2 supply pressure levels were 0.129 and 0.154 kWh/m^3, respectively; the ECFs were 0.121 and 0.143 kWh/m^3 for the CDA system with a heated dryer. More specifically, under the case with a heated dryer, the ECF for a supply pressure of 5.5 kg/cm^2 was 15% less than the ECF for supply pressure at 7.5 kg/cm^2. Figure 3 summarizes annual energy savings for the CDA system under Approaches A-2 to A-4 when compared to the original data (i.e., Approach A-1). The CDA system's highest energy savings (i.e., Approach A-4) was 3,050 MWh (i.e., the energy consumption for the CDA system was reduced by 8.17%). The annual energy savings for Approaches A-2 and A-3 were 1,696 and 1,538 MWh (i.e., reductions of 4.54% and 4.12%), respectively. The overall energy savings for the fab for Approaches A-2, A-3, and A-4 were 1.00%, 0.91%, and 1.81%, respectively.

4. CONCLUSIONS

This study complements our previous studies [6,7] and demonstrates the integration and application of the FES tool and the ECF calculator. The fab CDA system's ECF was 0.154 kWh/m^3, which is approximately equivalent to the suggested value in SEMI S23-0813; however, the ECFs for the PCW, DIW, and the exhaust systems were significantly lower than the SEMI ECFs. The CDA system in the fab was classified as a system with two pressure levels using a heated-type dryer. When compared to the original data, the highest energy savings for the CDA system was 3,050 MWh (i.e., the CDA system's energy consumption was reduced by 8.17%); this energy savings was 1.81% of the fab's overall energy consumption. By using the present tools, the result of energy saving approaches can be visualized. As the fab consumes huge percentage of energy in Taiwan, several percent of energy saving of fabs results a huge number of power saving in fab where most of energy is provided by electricity due to contamination concern.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Science and Technology, Taiwan (MOST 106-2221-E-027-111).

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