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ENERGY SAVING POTENTIALS OF AN 100% OUTDOOR AIR SYSTEM INTEGRATED WITH INDIRECT AND DIRECT EVAPORATIVE COOLERS FOR CLEAN ROOM

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ABSTRACT

In general, HVAC systems for clean room facility are required significant energy to maintain the required indoor environment. Due to high air change rates, reducing operating energy consumptions has been the critical issue. The purpose of this paper is to investigate energy saving potentials of 100% outdoor air system integrated with indirect and direct evaporative coolers (IDECOAS) serving a clean room. This research also provides a practical insight how cooling and heating coil loads can be reduced and how to design the proposed system.

In this study, it was assumed that a clean room is served by four different types of HVAC systems; a variable air volume system (VAV), an air washer system(AIRWASH), a dedicated outdoor air system (DOAS), and IDECOAS. It was found that DOAS and IDECOAS can reduce the annual cooling and heating coil loads over 65.7% and 59.5%, respectively, compared with the VAV.

INTRODUCTION

The purpose of an air handling system in a clean room is not only to control the indoor thermal environment, but also to provide environmental conditions fit into a given industrial process (ASHRAE. 2007). However, large amount of supply and exhaust air flows, and HEPA filters with high pressure drop are causing significant energy consumption. Significant energy penelty in clean room operation has not been the primary issue to resolve because the facility is generally used for high-end industrial products or processes (Hu and Chuah, 2003). However, energy conservation is also a critical issue even in the industrial sector.

In the open literature, one may find that Hu et al. (2008) experimentally showed that clean room energy consumption can be redued by applying a new water circulating pump system in an air handling system. Olim (1998) and Xu (2008) suggested a renovated fan-filter units (FFUs) saving fan energy compaired with the conventional system. However, existing researches on energy conservation in a clean room facility is still rare.

In this study, energy saving potentials of three different air handling systems applicable to the clean room are analyzed by comparing the energy performance of each system with that for a conventional VAV. Three systems considering in this research are as followings;

- AIRWASH: air washer system (Fujisawa et al. 2002; Song et al. 2009)
- DOAS: dedicated outdoor air system (Jeong and Mumma, 2003; 2007; 2006)
- IDECOAS: 100% outdoor air system integrated with indirect and direct evaporative coolers (Costelloe and Finn , 2007; Gasparella and Longo, 2003)

These systems are known as energy conservative air handling system in conventional building applications. Given that, one may also expect that they can provide excellent energy saving in clean room applications, althogh it has not been studed yet. Therefore, in this research, energy saving potentials of above three air handling systems are investigated by esimating energy consumption with the assumpiton that they serves an identical clean room facility.

SYSTEM OUTLINE

The definition of clean room is to control floating particles in the air within a specific range of numbers and territory. It is largely divided into an industrial clean room (ICR) and a bio clean room (BCR).

The ICR is a space which is to control minute particles out of the air used in an industrial facility such as semiconductor plants.

The BCR is used for the intercepting the infection of microbes in the aseptic facilities of hospitals and biological laboratories or food manufacturing facilities.

Owing to recent progress in various super precision industrial technologies, the demand for clean room facilities is increasing.

Classification of clean room air handling systems

Air handling systems applied to clean room facilities can be classified into two types;

- TYPE 1 is a 100% outdoor air system (Figure 1) conditioning the clean room using the outdoor air (OA) only. The room air is exhausted to outside without re-circulation.

DOAS and IDECOAS can be used as TYPE 1 systems.

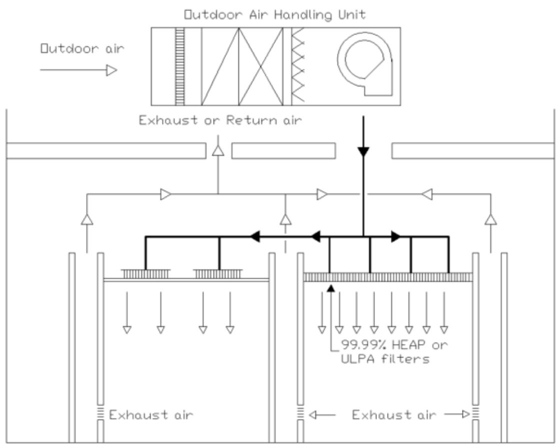


Figure 1. 100% outdoor air system (TYPE 1)

- TYPE 2 is a make-up air system (Figure 2) which recirculate most room return air into the space after filtering return air using HEPA or ULPA filters to minimize airborne contamination in recirulation air. The make-up air system provides the minimum outdoor air only required for the ventilation perpose. All three air handling systems are applicable as TYPE 2 systems.

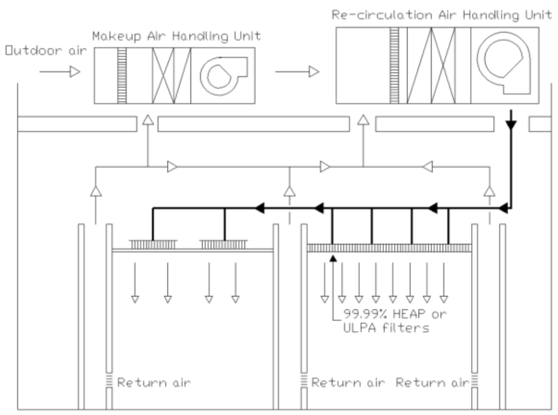


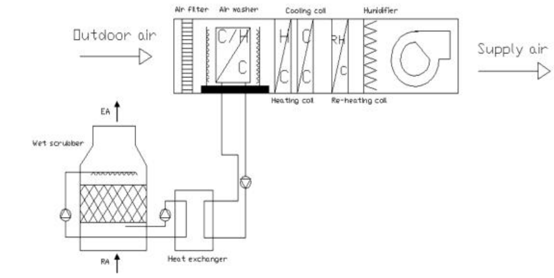
Figure 2. Make-up system (TYPE 2)

In TYPE 2, the latent load and some of the sensible load are accomodated by the make-up air handler. And.then the pre-conditioned outdoor air is mixed with the room return air,in the recirculation or main air handler. The supply air setpoint condition is (i.e. temperature and humidity level) is maintained by the main air handler.

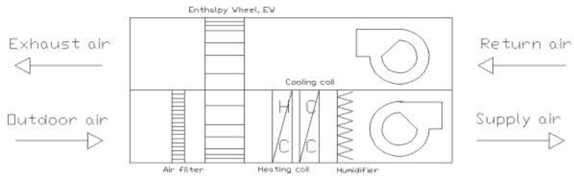
SIMULATION

This study performed energy simulation for the three different systems (Figure 3) with the assumption that they are serving an identical clean room. These systems can be used as the form of both TYPE 1 and TYPE 2 systems.

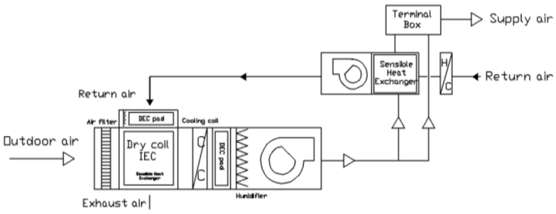
However, DOAS is commonly used as a make-up air handler, so the simulation was performed with considering DOAS as TYPE 2 system.



(a) Air washer system (AIRWASH)



(b) Dedicated outdoor air system (DOAS)



(c) IDECOAS

Figure 3. Simulated systems

Indoor air codition for the clean room was set to 24℃ dry-bulb temperature (DBT) and 50% relative humidity (RH). The supply air (SA) flow rate was adjusted based on the air conditioning load of the space. The SA DBT was set to 20℃ (i.e. neutral temperature) in all alternative systems. The SA dew point temperature (DPT) was set to 13℃. It was assumed that the facility was located in Seoul, South Korea. All the systems were simulated by modeling each system using the EES program (f-Chart Software. 2009) which enables the mathematical modeling and the analysis of various thermal systems.

Air washer system (AIRWASH)

AIRWASH is composed of the air washer and the wet scrubber. The RA is discharged into the wet scrubber and then exhausted to outside. The heat withdrawn from the RA is recovered by the water sprayed into the unit. The OA is cooled or heated by cooling and heating coil (CH/C) installed in air washer (Figure 3a). The SA passed through the air washer is delivered into the clean room after the target condition of the SA is acquired by the coils at the downstream of the unit.

When AIRWASH is applied as both TYPE 1 and TYPE 2 systems, the DPT setpoint of the SA (i.e. 13℃) is met by the CH/C and cooling coil. In case of TYPE 1 application, however, the reheat coil would be required to meet the SA DBT (i.e. neutral temperature). AIRWASH is simulated based on the theoretical analysis and the experimental model suggested by Song et al. (2009).

Dedicated outdoor air system (DOAS)

DOAS is composed of an enthalpy wheel, a cooling coil, and supply and exhaust air fans. The OA entering in the DOAS unit is preconditioned by the enthalpy wheel. It porvides pre-cooling and pre-dehumidification of the SA during cooling season, and pre-heating/pre-humidification during heating season. The cooling coil locasted at the enthalpy wheel downstream takes charge of additional dehumidification (Figure 3b). DOAS is considered as a TYPE 2 system, and the system is simulated based on the system model suggested by Jeong and Mumma (2005).

Evaporative cooling assisted 100% OA system (IDECOAS)

IDECOAS consists of an indirect evaporative cooler (IEC), a cooling coil (CC), and a direct evaporative cooler (DEC) at the SA side, and a heating coil (HC) and a sensible heat exchanger (SHE) at the scavenger air side (Figure 3c). The SA volume is adjusted based on the air conditioning load variation similar to the VAV system. During the cooling season, the OA entering into the unit is primarily cooled by IEC. The SA DPT setpoint (i.e. 13℃) is met by the CC. During the intermediate season with relatively dry OA, the CC load can be reduced additionally by the DEC operation.

In both TYPE 1 and TYPE 2 applications, the SA passed through IEC and CC is reheated to the neutral temperature (i.e. 20℃) by recovering the sensible heat from the scavenger air side using the SHE. When the neutral temperature cannot be acquired by the sensible heat recovery, additional heat is supplied through the HC located at the scavenger air side.

Estimation of required OA flow

In order to avoid infiltation and maintain the cleanliness class in the clean room, international standards, such as ISO 14644-7(2004) and IEST-RP-CC028.1(2002) are generally applied. Maintaing positive or negative pressure in the clean room is also an important role of the air handling system (Xu, 2007).

In both TYPE 1 and TYPE 2 applicaitons, the required room pressure is maintained by modulating SA and RA flows of the air handling unit. According to recent research (Lee and Jang, 2007), it is recommended to provide 1.2-1.5mmAq of positive pressure in order to prevent unnecessary infiltration. Generally, such level of pressure difference could get in case which SA volume is 15～20% higher than that of RA.

Humidity control

In case of AIRWASH and DOAS, the required indoor humidity level is maintained by the conditioned SA. However, when the absolute humidity of SA is below 0.0092kg/kg (i.e. target condition), an additional humidifier should be used.

In IDECOAS, in order to meet the room humidity setpoint (i.e. 50% RH) during intermediate season with dry OA, the SA is passed through IEC and CC for getting 36.24kJ/kg of SA enthalpy. And then the SA delivered to DEC for additional cooling and humidification. When the enthalpy of OA is below 36.24kJ/kg, an additional humidifier is required to maintain the target humidity level of the space.

SIMULATION RESULTS

Comparison of cooling coil load

Monthly and annual comparison of the CC load aquired from the energy simulation for each TYPE 1 system are shown in Figures 4 and 5.

In Figure 4, one can see that IDECOAS and AIRWASH are showing lower monthly CC loads compared with conventional VAV. In case of the annual CC load (Figure 5), both IDECOAS and AIRWASH consume less CC energy than the VAV. IDECOAS and AIRWASH reduce 38.5% and 36.6% of the annual CC load, respectively, with respect to the conventional VAV.

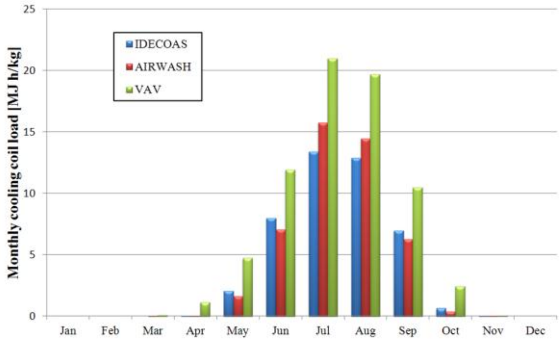


Figure 4. Monthly cooling coil load (TYPE 1)

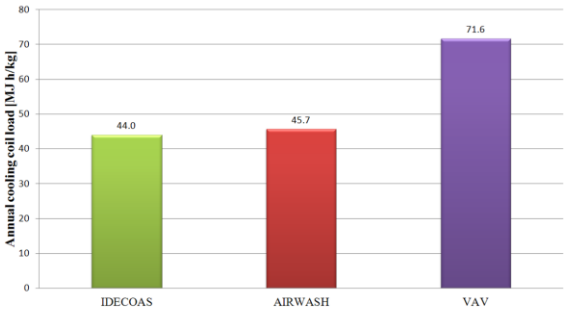


Figure 5. Annual cooling coil load (TYPE 1)

Monthly and annual CC loads for each TYPE 2 system are compared with those for the conventional

VAV (Figures 6 and 7). IDECOAS and AIRWASH show lower monthly and annual CC loads similar to the results observed in TYPE 1 cases. DOAS provides the lowest CC load for the almost entire operating period.

Consequently, DOAS shows 46.8% less annual CC load compared with the conventional VAV. The benefit of DOAS comes from the total heat (i.e. both sensible and latent heat) recovery at the enthaly wheel. The CC load reduction obsered in IDECOAS and AIRWASH is also caused by the pre-conditioning of the entering OA at the upstream of the CC.

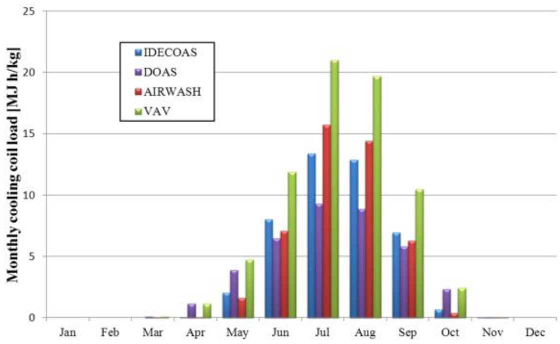


Figure 6. Monthly cooling coil load (TYPE 2)

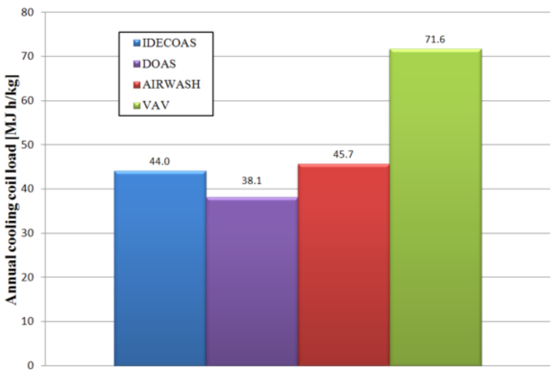


Figure 7. Annual cooling coil load (TYPE 2)

Comparison of heating coil load

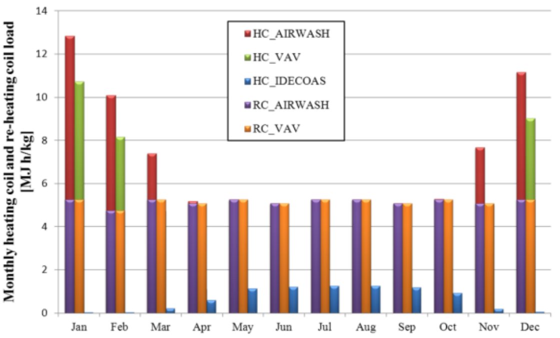


Figure 8. Monthly HC and RC loads (TYPE 1)

Monthly and annual HC (including reheat coil (RC)) loads for each TYPE 1 system are compared with those for the conventional VAV (Figures 8 and 9). In Figure 8, all systems except IDECOAS shows high HC and RC loads. In IDECOAS, the IEC and SHE reclaim the sensible heat from the scavenger air, so significant heating and reheat coil loads reduction can be acquired.

In Figure 9, IDECOAS shows 92% of heating and reheat coil load savings with respect to the conventional VAV, and 90.5% reduction over the AIRWASH system.

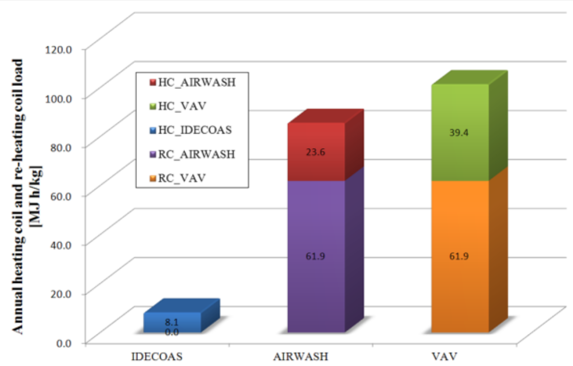


Figure 9.Annual HC and RC loads (TYPE 1)

Figure 10 and Figure 11 present monthly and annual HC load comparison results for each TYPE 2 system. DOAS shows the lowest monthly and annual HC load. It is the benefit of the enthalpy wheel recovering the sensible heat from the exhaust air side. DOAS could maintain the SA temperature with minimizing HC energy consumption.

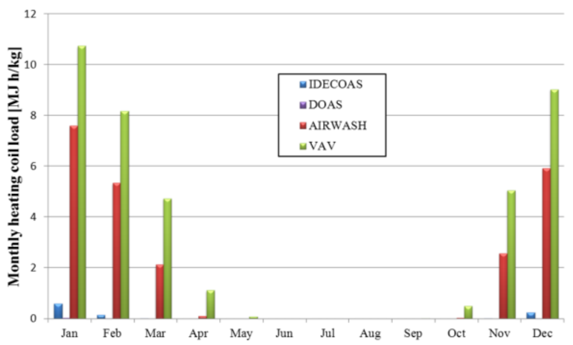


Figure 10. Monthly HC load (TYPE 2)

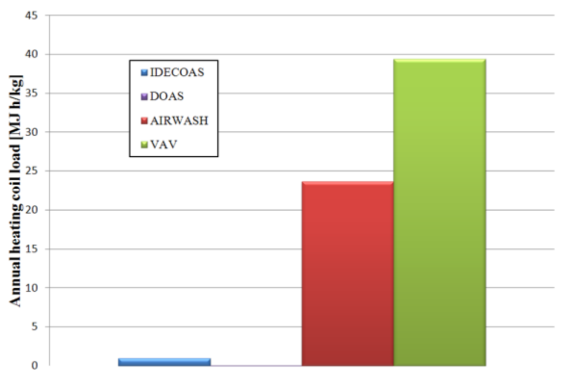


Figure 11. Annual HC load (TYPE 2)

Table 1. Selected cities for climate zone

Location	**Latitude (N+/S-)**	**Longitude (E+/W-)**	**Time Zone (+/- GMT)**	**Elevation (m)**	**Köppen classification**	**ASHRAE Std. 90.1-2007**
Singapore	1.03	103.98	7	16	Af (Tropical wet)	1A (Very hot, Humid)
New Delhi	28.58	77.2	6	212	BSh (Hot subtropical)	1B (Very hot, Dry)
Hong Kong	22.3	114.17	8	62	Cfa (Humid subtropical)	2A (Hot, Humid)
Melbourne	-37.82	114.97	10	38	Csb (Mediterranean)	3C (Warm, Marine)
Seoul	37.57	126.97	9	86	Dfa (Humid continental)	4A (Mixed, Humid)
Moskva	55.83	37.62	3	156	Dwb (Moist continental)	6A (Cold, Humid)

On the other hand, in order for maintaining appropriate indoor humidity level during the heating season, additional humidification would be required in all the systems considered in this research.

From the simulation, it was found that TYPE 1 systems would have identical annual humidification load (i.e. 29.4kg·h/kg). However, in TYPE 2 systems (Figure 12), DOAS shows 25% reduction of the humidification load compared with other systems. It is casused by the enthalpy wheel used in DOAS, which is recovering the latent heat from the exhaust air during the winter operation.

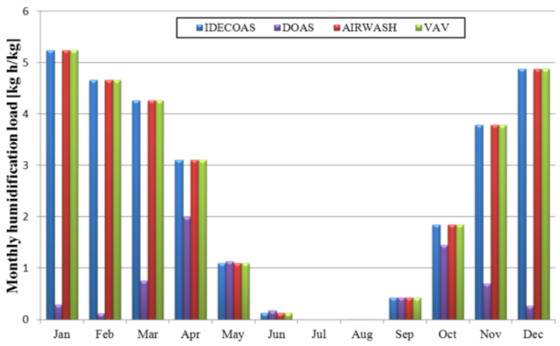


Figure 12. Monthly humidifying load (TYPE 2)

Comparison of annual total coil load

Annual total coil load (i.e annual CC load + annual HC load) for each TYPE 1 and TYPE 2 systems are presented in Figures 13 and 14.

In Figure 13, one may see that the annual total coil load of IDECOAS is 69.8% less than that of the conventional VAV, while the AIRWASH system shows 24.1% less annual total coil load. It means that IDECOAS can be the most energy-efficient system in TYPE 1 applications (i.e. 100% outdoor air systems).

In TYPE 2 applications (Figure 14), one may see that DOAS provides the largest annual total coil load saving (i.e. 65.7%) with respect to the conventional VAV, while IDECOAS and AIRWASH provide 59.5% and 37.6% reduction, respectively. DOAS system would be the most effective solution to TYPE 2 applications.

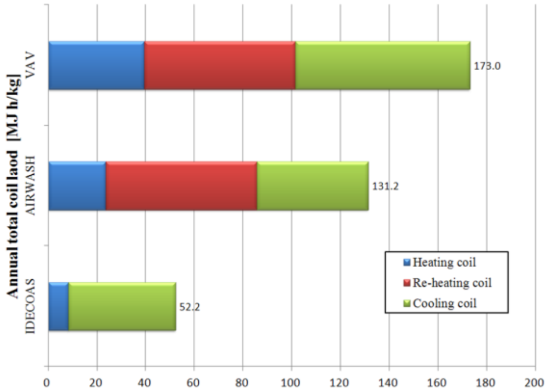


Figure 13. Annual total coil load (TYPE 1)

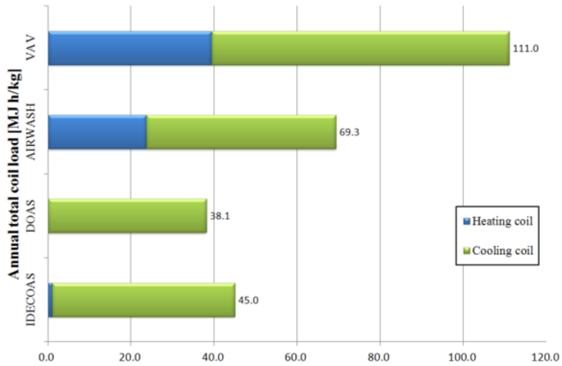


Figure 14. Annual total coil load (TYPE 2)

IMPACT OF CLIMATE CONDITIONS

In this research, the impact of climate conditions on the total coil load savings in each TYPE 1 and TYPE 2 system operation was estimated quantitatively via the energy simulation.

In general, the climatic zone can be determined based on Köppen's climate classification or ASHRAE Std. 90.1-2007 (ASHRAE, 2007). In this study, six cities which can represent six different climate zones classified by Köppen and ASHRAE Std. 90.1 were selected for the simulation (Table 1). It was assumed that the clean room modeled in the research would be located at selected cities. And then, annual total coil loads were estimated for each TYPE 1 and TYPE 2 applications. The results for each system were compared with those for the conventional VAV system case. The TMY2 meteorological data for each selected city was used for the energy simulation.

The operating condition of each TYPE 1 and TYPE 2 systems were identical with those mentioned in SIMULATION section.

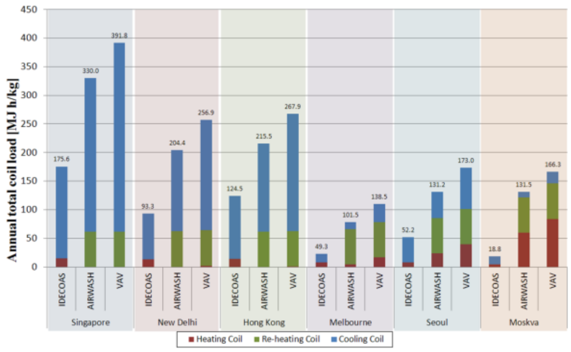


Figure 15. Annual total coil load (TYPE 1)

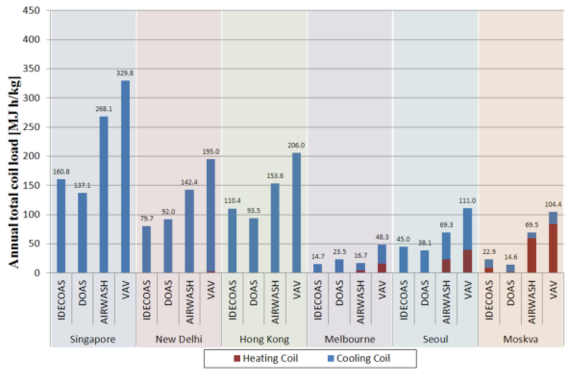


Figure 16. Annual total coil load (TYPE 2)

Annual total coil load for each climatic zone

Annual total coil loads of TYPE 1 systems in six different climate cities are presented in Figure 15. From Singapore (i.e. tropical climate) to Moscow (i.e. continental climate), the annual total coil load reduction of IDECOAS and AIRWASH with respect to the VAV are 53.5%～88.7% and 15.8～26.7%, respectively. Consequently, one may conclude that IDECOAS could be the most energy efficient solution in nearly all the climatic zones when it used as TYPE 1 application (i.e. 100% OA system).

Figure 16 presents the annual total coil load for each TYPE 2 system in six different climate cities. As expected DOAS provides 58.4%～86.0% of annual total coil load savings compared with the conventional VAV in selected cities, while IDECOAS shows 46.4～78.0% reduciton rates. It means DOAS could be the best alternative in any climatic zone when it is applied as TYPE 2 system (i.e. make-up air system).

Interestingly, IDECOAS shows higher energy saving ratio than DOAS in some dry climate cities (i.e. New Delhi, India and Melbourne, Australia). From this observation, one may conclude that IDECOAS which is based on the evaporative cooling process would be an energy efficient system in relatively dry climates.

CONCLUSION

In this study, air handling systems which can be applied to clean room facilities are classified in two categories; TYPE 1 (i.e. 100% OA system) and TYPE 2 (i.e. make-up air system). By performing energy simulation, energy saving potentials of each TYPE 1 and TYPE 2 applications over the conventional VAV system were estimated. From the results of this research work, the following conclusions were aquired:

(1) In TYPE 1 systems serving the clean room using 100% outdoor air only, IDECOAS provides 69.8% of annual total coil load saving with respect to the conventional VAV. One may also see that IDECOAS achieves 53.5%～88.7% of annual coil load reduction in any climate zones.

(2) In TYPE 2 applications pre-conditioning the entering make-up OA for ventilation, DOAS shows the highest annual coil load saving (i.e. 65.7%) comparing with other systems. Simulation results for the six different climate cities also show that DOAS would be the best alternative in any climatic zone and save 58.4%～86.0% of the annual coil load. However, IDECOAS would be better solution than DOAS in some dry or mediterranean climatic zones.

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