Interaction Analysis Investigations of Multiple Supply Duct Split-type Air-conditioning units in an Open Space

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Abstract. Oversizing has been seldom concerning in Thailand. However, oversizing causes short-term operations of an air-conditioning (AC) unit and excessive power consumptions. In addition, multiple operations of oversized AC units can be faulty operations when they are used to serve in an open space area because interaction among AC units are not considered before installations. This paper collects data operations of the multiple supply duct split-type air-conditioning (SAC) units used in an open space from additional sensors installed in zone and return temperature. Significant wireless sensors are added for measuring temperature effect among a interaction area between two SAC units. To measure the system variation caused by system interaction, runtime fraction (RTF) is used to quantify the compressor runtime ratio which equals to a stage-on time operation over the cycle time at an AC design condition. The results show that one of the four SAC units performs under-sizing instead of oversizing performance because it runs continuously without off cycling. To diagnose this issue, interactions between zone and return temperature are quantified in terms of correlation coefficient, which demonstrates that this SAC results in higher oversizing of the rest SAC units. This interaction analysis can be further used to design a soft-repair algorithm to reduce oversizing effect of the multiple SAC operations.

Keywords: Oversizing; Interaction; Split-type air-conditioning; Operations of multiple air-conditioning units.

1. Introduction

Nowadays, developing counties are promoting and implementing energy efficiency policies and codes to reduce unnecessary energy consumption and increase energy efficiency in both buildings and factories. Thailand is one of the developing counties in ASEAN formally issued the Energy Conservation Promotion Act B.E. 2535 (1992) which was revised in Edition B.E. 2550 (2007) [1].

The promotion states that all designated buildings and factories are required to follow energy management procedures and to comply with the energy conservation standard, criteria and methodologies that are prescribed in the ministerial regulation based on ethical standards and
engineering approaches. In the method guidelines, efficient machine installations are significantly emphasized to enhance the understandings of practical engineers and technicians in terms of energy conservation measures. Most of significant machines in the designated buildings and factories are heating, ventilation and air-conditioning (HVAC) systems. Especially, split-type air-conditioning (AC) units or packaged AC units have been intensively used to provide thermal comfort in conditioned space. Although oversizing issue is intensively concerned in developed countries because the effect leads to short cycling, humidity problem and degraded life cycle before time, an oversizing understanding is seldom considered in Thailand [2].

To firstly reduce the oversizing issue, a proper selection of packaged air-conditioning units (PACs) is one of the important processes to properly control zone conditions in small commercial offices and retail stores. In previous interviews [3] and surveys [4], a number of designers estimate an rooftop units (RTU) sizing using oversizing internal load or related safety factors by software tools for commercial buildings [5]; it could incur oversized PACs resulting in waste of energy. Since the compressor of a PAC is manipulated by an on–off controller with non-synchronized individual control function such as a variable speed drive of a supply fan, the oversizing may resulting in the short-time period of a PAC cycle operation at a peak design condition, not running continuously in a hour. This frequent cycling over manufacturer’s data causes over usage of the induction in the compressor motor, which results in loss cycling in terms of longer transient response before reaching a state-state value. This problem also results in higher operation cost due to the lower efficiency from the improper operation of the PAC machine [5].

In terms of energy penalty from field tests, at least 15% of the actual calculated capacity is over designed to ensure adequate cool and heat in the hottest and coldest periods. Based on real-time trended data in many field tests, it was found that the RTUs have the average oversized capacity of 84% for cooling. The lowest peak energy penalty for 12 stores with 268 RTUs was 34.66 kW in a cooling mode, while the highest peak energy penalty went to 226.41 kW in a cooling mode [5]. These RTU field tests were operated without supply ducts.

Moreover, multiple supply duct split-type air-conditioning units (SACs) have been seldom studied for field tests, especially in an open space. From the interaction engineering point of view between SACs, there are two significant points: (1) each SAC is typically controlled individually; it could lead to cooling fighting due to a non-coordinated control function between SAC units [6], and (2) heat transfer situation happens between an active control zone and the adjacent off-control SAC zones. Thus, a wrong return sensor position will cause inefficient control performance. The study of the interactions between SAC units is very useful for designing coordination control or improved performance of SAC installations without machine replacement.

2. Backgrounds

In the method analysis of this paper, significant backgrounds associated with oversizing are briefly explained for using in interaction analysis and essential effect for sensor installations.

2.1. Typical SAC operations

Multiple SAC units provide constant air volume to an open conditioned space. However, they are individually controlled without functions coordination, which perform inefficiency in practice:

1) Ventilation control practically associates with mixing damper and full speed of fan operations for maintaining comfort purpose which is only required the range of 0.12–0.20 cfm/ft². In reality, 1.00 cfm/ft² is approximately used (12-20% from fresh air plus 80-88% from circulating air).

2) Cooling staging control is manipulated by on-off cycling control of a thermostat sensing zone air temperatures in a conditioned space. During most times, SAC units are operated at inefficient partial load conditions.

3) Humidity control is an indirect action based on absorbing latent load on a cooling coil. During partial load conditions, humid outside air enters the zone without fully processing because compressor cycling periods are too short; it will lead to inefficiency of latent load absorption on a coil surface.
3. Sensor Installations for interaction analysis

In Figure 1, it is a layout of an example building that interaction analysis of four SAC units in an open space is investigated. Each SAC was sized 123,000 BTU/hour to provide cooling via a duct supply system. No. 1 to No. 4 are the order of SAC position with the return temperature sensors on the ceiling to provide the zones. By simply walkthrough audit, the authors noticed the inefficient performance of the three duct supply patterns in Area 1, 2 and 3, respectively. The supply duct lines of these three SAC units were installed without return duct lines, so that the indoor air is impossible to circulate correctly to the return temperature sensor. As a result, the temperature sensor will sense wrong return temperature, which may be affected from temperature of the adjacent SAC. Beyond other SAC units, SAC No.1 has a straight supply duct line, and then it is possible that the supply air will circulate back to the return sensor if cooling load is suitable enough to incur practical air movement; however, SAC No.1 is used in the open space, so that heat transfer will occur between the zone and adjacent zones. These issues degraded each SAC performance due to interaction effect.

![Figure 1. Layout of an example building](image)

To investigate the interaction issue used for system improvement, sensor positions are designed to install for sensing temperature profile and system performance of each SAC unit as depicted in Figure 2. R1 to R4 stand for return temperature and humidity sensors positions of SAC No. 1 to No. 4, respectively.

Meanwhile, Z1, Z2 and Z4 are the zone temperature and humidity sensors of SAC No. 1, No. 2 and No.4. The Z3, Z4 and Z5 positions are all used to measure the zone temperature and humidity values of SAC No. 3 because this SAC unit is utilized to provide cooling load near the mirror and has too long supply duct line; many sensors are installed more than other SAC units to efficiently analyze any effect in the open space. For the rest sensor positions, Z7 and Z8 are used to measure the zone interaction between SAC No. 3 and No. 4, and zone interaction between SAC No. 2 and No. 3.
4. Interaction Analysis Method

To perform the interaction analysis, Pearson correlation ($r$ value) is used to compute significant relation between two independent variables in Equation (1).

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}}$$  \hspace{1cm} (1)
Where: \( X_i \) = zone or return temperature of a zone; \( \bar{X} \) = the mean value of \( X_i \); \( Y_i \) = zone or return temperature of the adjacent zone; \( \bar{Y} \) = mean value of \( Y_i \); and \( n \) = number of data points.

Note: low level (0-0.50), medium level (0.51-0.89) and high level (0.9-1.0) [6]

In Figure 3, there are interactions between two AC units. For example, two return sensors are located closely. Thus, two possible situations can be occurred: (1) cooling fighting if the two AC stages are concurrently on; and (2) inefficient operations if one of them is activated until the return temperature of the rest is under a set-point temperature. To measure and study these occurrences, the \( r \) value of return temperature and zone temperature between the two adjacent units can be used to explain differences between a typical SAC unit in a zone and multiple SAC units in an open space.

5. Interaction results

The \( r \) values of relations are estimated for zone temperature and return temperature of each SAC unit because zone temperatures will correlate with return temperature if zone air can circulate normally from a supply to return position. In this case, the \( r \) value should be in the least medium range because there is a linear relation between two temperature positions. In contrast to the first case, the \( r \) value is low if the relation is weak or another parameter is disturbance.

This section will investigate: (1) relations between zone and return temperature to examine temperature circulation of each SAC; and (2) relations between two SAC units. The results of \( r \) values using equation (1) are tabulated in Table 1.

| Relation      | \( r \) value | SAC investigations       |
|---------------|---------------|--------------------------|
| R1 and Z1     | 0.79          | No. 1                    |
| R2 and Z2     | 0.97          | No. 2                    |
| R3 and Z3     | 0.85          | No. 3                    |
| R4 and Z6     | 0.16          | No. 4                    |
| R4 and Z1     | 0.57          | Interaction between No. 1 and No. 4 |
| R4 and Z2     | 0.98          | Interaction between No. 2 and No. 4 |
| R4 and Z3     | 0.92          | Interaction between No. 3 and No. 4 |

From Table 1, the relations of R1 and Z1, R2 and Z2, and R3 and Z3 are at least medium level for return and zone temperatures relation of SAC No. 1, 2 and 3, respectively. This notification shows temperature profile relation between zone and return sensor positions of each SAC. However, in the testing, SAC No. 4 is turned on manually, whereas the other units are turned off. This situation confirms that the medium \( r \) values are caused by heat transfer from high to low temperature area when a SAC is off-time period. In contrast to the first notification, the \( r \) value of R4 and Z6 is low which means that the occurrence of mechanical cooling effect or other disturbances.
From the field investigations, SAC No. 4 is turned on manually leading to the low r value between zone and return temperatures, whereas other zones have good relation based at least medium r value level because of heat transfer occurrence, without mechanical cooling.

The possibility of another notification is the mechanical cooling from zone 4 to other zones because the layout is an open space area. To assure this notification, the interaction of SAC. No. 4 and other SAC units can be investigated via the r value between return temperature of No. 4 and other zone temperatures. The results show the strong relation with No. 2 and No. 3 (r values are 0.98 and 0.92, respectively). It can be concluded that mechanical cooling of No. 4 moves to zone No. 2 and 3. Meanwhile, zone No. 1 is the farthest distance from zone No. 4 causing the low r value (0.57).

To further illustrate this operation, Figure 4 shows the temperature profiles between return and zone temperatures. The profiles confirm the results from the two notifications of heat transfer and mechanical cooling. In addition, by using graphical method, the third notification is analyzed based a sensor position. From Figure 4, it can be noticed that return temperature profile of No. 1, 2 and 3 follow the return temperature trend. Especially, when R4 is controlled between 24 and 26 °C (set point at 25°C with ±1°C operating differential range), other return temperatures are moved similarly with different lower and upper temperature ranges. The finding is useful for developing coordinated control or soft-repair algorithms used for this system improvement for reduced oversizing issue and energy savings.

6. Conclusions

Oversizing is seldom studied and concerned in Thailand leading to misunderstanding and wrong design and installation of multiple SAC units in an open space due to lacking of a guideline. This paper investigates the possible interaction between SAC units in the open space by installing zone and return temperature sensors to observe temperature profiles and heat transfer effect between off-time control and mechanical control. Pearson’s correlation is used to quantify relations between associated variables. The findings are: (1) the different operations between off-control SAC and activated SAC; and (2) return temperature position should be considered during installations and can be further used to design coronation control of multiple SAC units to reduce oversizing effect without supply duct or SAC replacement.
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