13th IEA Heat Pump Conference
April 26-29, 2021 Jeju, Korea

Study on Short Circuit of Airflow in Outdoor Unit of Air Conditioner

Hiroyuki Miyazaki[a*], Tsubasa Ito[b], Hiroshi Nakayama[a], Masafumi Hirota[b]

[a]Chubu Electric Power Co.,Inc., 20-1, Kitasekiyama, Midori-ku, Nagoya city, Aichi, 459-8522, Japan
[b]Mie University, 1577, Kurimamachiya-cho, Tsu-city, Mie, 514-0102, Japan

Abstract

In air conditioners installed in commercial buildings, their efficiencies are often deteriorated by short circuits of airflows in which hotter (cooling operation) or cooler (heating operation) air blown out from the outdoor units is sucked again in the outdoor units. From viewpoints of energy savings of air conditioners, it is necessary to understand the influence of short circuits of airflows on operations of air conditioners quantitatively and to take measures against them. The purpose of this study is to make clear the influence of installation conditions of the outdoor unit of an air conditioner on the short circuit of airflow issued from it.

We made laboratory measurements and field measurements of airflow temperatures around the outdoor unit of a packaged air conditioner. The short circuit of the airflow from the front face to the side face of the outdoor unit was enhanced when there was a wall near the side face. In such cases, linear relationships were found between suction air temperatures of the outdoor unit and outdoor air temperatures.

Keywords: Air conditioner, Outdoor unit, Airflow, Short circuit, Suction air temperature ;

1. Introduction

Individual distributed air conditioner may cause a short circuit of air flow in which high-temperature air blown from its outdoor unit (cooling operation) is directly sucked by its suction face, depending on the outdoor unit installation situation (close to walls, under the roof, concentrated equipment installation, etc.). It is known that the performance of the air conditioner is deteriorated by this short circuit. In addition, there are cases in which the air conditioner shuts down due to capacity control when the impact of the short circuit becomes large. In order to save energy and keep proper operation, it is required to quantitatively understand the influences of short circuits and take measures against them.

Several papers on short circuits have been reported so far [1][2], but there are few reports on the influences of outdoor unit installation conditions, changes in outdoor air temperature and load factors on short circuits and capacity degradation of an air conditioner.

The purpose of this study is to quantitatively understand the influences of short circuits of air flow in the outdoor unit on the performance of air conditioners, taking the outdoor unit installation conditions, outdoor air temperature and load factor as parameters.

In the first half of this paper, we show the results obtained in the environmental test laboratory in which influences of a building wall or an obstacle on the performance of a packaged air conditioner were examined to clarify the relationship between the outdoor unit's suction temperature and the outdoor air temperature. In the second half, we will clarify the effect of short circuits when two or more air conditioners installed in an actual building are operated with walls around the outdoor unit.

* Corresponding author. Tel.: +81-52-621-6101; fax: +81-52-624-9234.
E-mail address: Miyazaki.Hiroyuki2@chuden.co.jp.

2. Laboratory Test

2.1. Test Method

This test was conducted in the environmental test laboratory of the Chubu Electric Power Co., Inc. by installing one side blown 5-horsepower packaged air conditioner with a specification shown in Table 1. Figure 1 shows the outdoor unit installation conditions. Pattern 1 is a standard installation in which there are no obstacles around the suction face (back and side faces) and the blowing face (front face) of the outdoor unit.

On the other hand, since many outdoor units are often installed near the building walls, a test was performed on Pattern 2 in which walls simulating building walls were installed near the back and side faces (suction faces) of the outdoor unit. Here, the distances between the wall and those faces were set to effective spaces of 0.3 m as described in the manufacturer's installation manual. In addition, a test was also conducted on Pattern 3 that simulated an installation in a small space with walls near the back, side (suction) and the front (blowing) faces of the outdoor unit. The distance between the front face of the outdoor unit and the wall was set at 1.0 m as described in the manufacturer's installation manual.

Figure 2 shows the positions of thermo-sensors set on the suction and the blowing faces with the wall setting situation of Pattern 2 in the environmental test laboratory.

Table 1. Specifications of test air conditioner

5 HP packaged air conditioner (manufactured in 2017)		
	Cooling operation	Heating operation
Rated capacity	12.5 kW	14.0 kW
Rated power consumption	3.31 kW	3.30 kW
APF*(2015)	6.3	

*APF: Annual Performance Factor

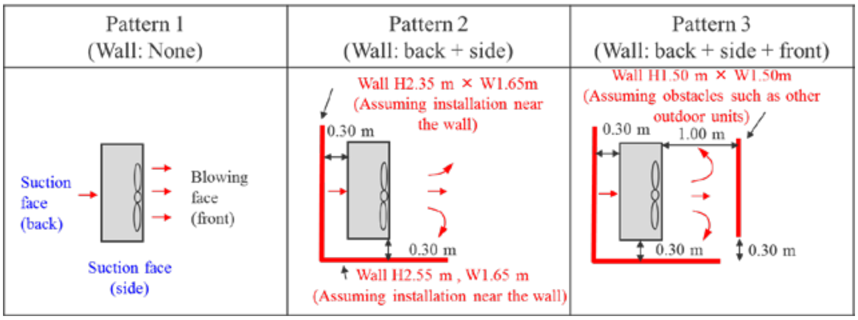

Fig. 1. Wall installation patterns around the outdoor unit of the air conditioner

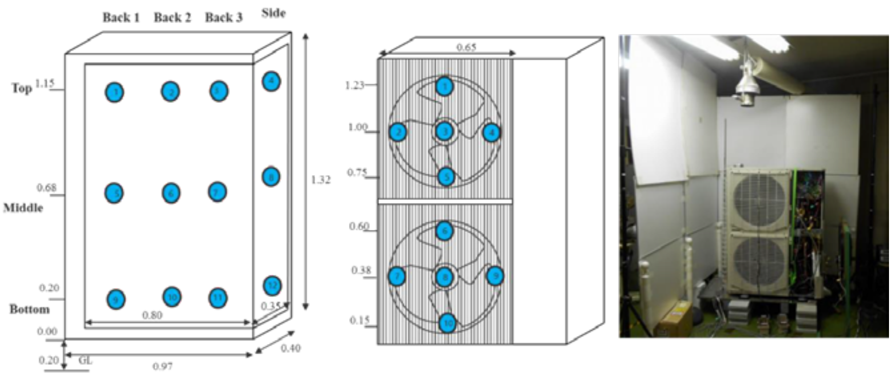

Fig. 2. Positions of sensors on the outdoor unit and wall installation condition of Pattern 2

2.2. Test Conditions

The air conditioning capacity was measured by the indoor enthalpy method. Test conditions are shown in Table 2, the air dry bulb temperature in the outdoor test room was set at 35 ºC, 30 ºC or 25 ºC in the cooling performance test, and at 12 ºC, 7 ºC or 2 ºC in the heating performance test.

A part of tests was conducted considering the situation that the air conditioning load is large and the air conditioner is always operating at full power (100%). In these tests, the indoor test room was controlled at 27 ºC and the remote control temperature was set to 18 ºC in the cooling operation, and the indoor test room was controlled at 20 ºC and the remote control temperature was set to 30 ºC in the heating operation.

Tests were also conducted assuming the situation that the air conditioning load is reduced in the intermediate period. In the case of cooling, the air conditioning load was set at 25% and 50% of the actual rated cooling capacity of the tested air conditioner, and the air temperature of the indoor test room was controlled at 27 ºC by the air conditioner itself. In the heating performance test, the indoor air temperature was controlled at 20 ºC with the heating load corresponding to 25% and 50% of the actual rated heating capacity.

Measurement data were sampled at 10-second intervals, and they were averaged in 60 minutes for the steady operation and in one cycle for the intermittent (on-off) operation.

Table 2. Test conditions (dry bulb temperature / wet bulb temperature)

Operations	Outdoor temperature conditions	Indoor temperature conditions	Load factor
Cooling	35 ºC / -	27 ºC /19 ºC	100%
Cooling	30 ºC / -	27 ºC /19 ºC	50%
Cooling	25 ºC / -	27 ºC / 19 ºC	25%
Heating	12 ºC / 11 ºC	20 ºC / -	25%
Heating	7 ºC / 6 ºC	20 ºC / -	50%
Heating	2 ºC /1 ºC	20 ºC / -	100%

2.3. Results

2.3.1. Influence of Wall Installation

Table 3 shows the results of average suction air temperatures (back, side, and overall average) and Table 4 shows the average blowing air temperature in each pattern in the cooling performance test at the outdoor air temperature of 35 ºC with full power operation.

In Pattern 1, the suction air temperatures on the back and side faces are about 37 ºC, and the difference from the outdoor air temperature is not so large. It should be noted that the temperature sensor position for setting the test room was different from the positions of the thermo-sensors on the suction face, so there was a difference between the test room setting temperature and the suction air temperature in Pattern 1.

In Pattern 2 in which the walls are installed on the back and side of the outdoor unit, the suction temperature is about 2 ºC higher than Pattern 1 on average. In particular, the suction air temperature is as high as 41.2 ºC on the side face, and it can be seen that the influence of the short circuit is greatly reflected on the side of the outdoor unit. Pattern 3 shows a similar trend to Pattern2.

Regardless of the change in the suction air temperature, the blowing air temperature is almost constant at about 48 ºC in all patterns as shown in Table 4.

Table 3. Average of suction air temperature during cooling operation at the outdoor air temperature of 35 ºC with 100% operation

Suction air temperature	Pattern 1	Pattern 2	Pattern 3
Back	37.0ºC	38.6ºC	39.1ºC
Side	37.6ºC	41.2ºC	42.3ºC
Overall	37.1ºC	39.2ºC	39.9ºC

Table 4. Average of blowing air temperature during cooling operation at the outdoor air temperature of 35 ºC with 100% operation

	Pattern 1	Pattern 2	Pattern 3
Blowing air temperature	48.1ºC	47.9ºC	48.6ºC

For more detailed changes in the air temperature on the suction face, Table 5 shows differences between suction air temperatures in Pattern 2 and Pattern 1, and Table 6 shows a comparison with Pattern 3. Here, the positions described in these tables correspond to the sensor positions shown in Figure 2. As can be seen from Table 5, the place where the temperature change is particularly large is from the center to the bottom of the back and side faces of the outdoor unit, rising by 6-7 ºC. Table 6 of Pattern 3 shows a similar tendency. It is thought that hot air blown from the front face of the outdoor unit stayed around the bottom of the side face where there was little air flow.

In addition, from the overall average temperature change in Table 5 and Table 6, it rises to 2.1 ºC by wall setting on the back and side, whereas it rises to 2.8 ºC by wall setting on the back, side and front. It can be seen that the influence of the back and side walls on the short circuit is greater than that of the front wall.

Table 5. Difference of suction temperatures of pattern 2 from pattern 1 at the outdoor air temperature of 35 ºC with 100% operation

	Back 1	Back 2	Back 3	Side
Top	-0.1ºC	-0.3ºC	-0.6ºC	-0.5ºC
Middle	-0.9ºC	0.8ºC	3.6ºC	5.1ºC
Bottom	1.3ºC	3.5ºC	7.2ºC	6.2ºC
Average of Back		1.6ºC		-
Average of Side		-		3.6ºC
Average of Overall		2.1ºC		

Table 6 Difference of suction temperatures of pattern 3 from pattern 1 at the outdoor air temperature of 35 ºC with 100% operation

	Back 1	Back 2	Back 3	Side
Top	0.2ºC	0.5ºC	0.7ºC	0.7ºC
Middle	-0.8ºC	1.7ºC	5.2ºC	6.3ºC
Bottom	1.5ºC	3.5ºC	6.4ºC	7.2ºC
Average of Back		2.1ºC		-
Average of Side		-		4.7ºC
Average of Overall		2.8ºC		

Table 7 shows the power consumption, cooling capacity and COP of the air conditioner during 100% cooling operation at the outdoor air temperature of 35 ºC for each pattern. From these results, the power consumption increased by 2-4%, the cooling capacity decreased by 1-3% and consequently COP decreased by 3-6% in Patterns 2 and 3 compared to Pattern 1, due to the short circuit.

Table 7 Power consumption, Cooling capacity and COP at the outdoor air temperature of 35 ºC with 100% operation

	Pattern 1	Pattern 2	Pattern 3
Power consumption	4.43kW	4.54kW	4.62kW
(Rate of change)	(Basis)	(+2.36%)	(+4.12%)
Cooling capacity	14.19	14.04	13.81
(Rate of change)	(Basis)	(-1.06%)	(-2.68%)
COP	3.20	3.09	2.99
(Rate of change)	(Basis)	(-3.34%)	(-6.53%)

2.3.2. Influence of Partial Load Operation

In actual use an air conditioner is often operated under a partial load. Therefore, we conducted partial load performance tests. In order to understand the influence of the short circuit under partial load, the setting of outdoor temperature and lord factor of the environmental test laboratory was changed, and the relationship between the suction average temperature, the outdoor air temperature and load factor was investigated. As mentioned in Section 2.3.1, there was a difference between the test room setting temperature and the suction air temperature in Pattern 1, in which the influence of the short circuit was negligibly small. Hence, in order to clarify the difference between Patterns 2 and Pattern 3 that have a strong influence of short circuit, the suction air temperature of Pattern 1 was used as the outdoor air temperature.

2.3.2.1 Cooling Operation

Figure 3 shows the relationship between the outdoor air temperature and the mean suction air temperature at each load factor close to actual operations measured under the test conditions shown in Table 2.

In Pattern 2, it can be seen that the lower the outdoor air temperature and the load factor, the smaller the difference from Pattern 1 and the smaller the influence of the short circuit. As for Pattern 3, only the result of one high outdoor air temperature is shown, and the difference from Pattern 2 is negligibly small. This suggests that the wall installed in the side of the outdoor unit is more dominant in the occurrence of the short circuit than that installed in the front. From this result, it should be noted that the short circuit of airflow may occur even if the outdoor unit is installed at a distance from the building wall recommended by the manufacturer. It is recommended that the distance between the suction face of the outdoor unit and the building wall be set larger than the manufacturer's recommendation value.

Table 8 shows the difference between the blowing air temperature and the suction air temperature. Compare to low outdoor air temperature and the load factor, the difference is large at high outdoor air temperature and the load factor.

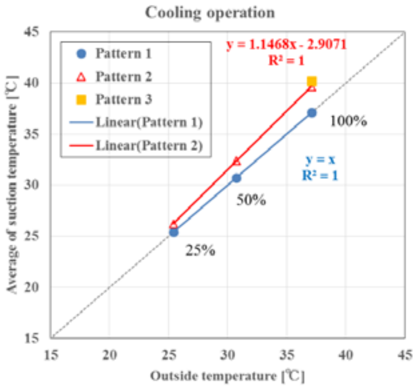

Fig. 3. The relationships between outdoor air temperature and suction air temperature in cooling operation

Table 8. Blowing air temperature during cooling operation

Outdoor temperature conditions	Pattern 1	Pattern 2	Pattern 3
25ºC	28.6ºC (+3.1)	29.0ºC (+2.8)	-
30ºC	36.1ºC (+5.3)	37.3ºC (+4.9)	-
35ºC	48.1ºC (+11.0)	47.9ºC (+8.3)	48.6ºC (+8.4)

( ) Indicates the difference between the blowing air temperature and the suction air temperature

In order to quantitatively express the influence of the short circuit, the short circuit ratio (SCR) [3] shown in Equation (1) was calculated.

$$SCR[\%] = \frac{Suction\ air\ temperature - Outdoor\ air\ temperature}{Blowig\ air\ temperature - Outdoor\ air\ temperature} * 100 \quad (1)$$

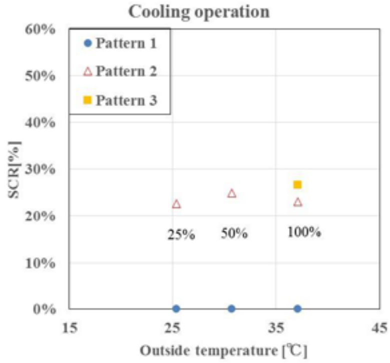

Fig. 4. SCR during cooling operation

Figure 4 shows the results of SCR under the low load conditions in each pattern. It can be seen that the SCR is about 20-25% in Patterns 2 and 3.

2.3.2.2 Heating Operation

Next, the influence of the short circuit during heating operation is examined. Figure 5 shows the suction air temperature during heating operations at 100% load at 2 ºC and partial loads shown in Table 2. It can be seen that there is no significant difference among the results for three patterns. The reason why the influence of the short circuit (decrease in the suction air temperature) was small in comparison with the cooling operation may be that the difference between the suction air temperature and the blowing air temperature was small in the heating operation. In 100% cooling operation, the difference between the blowing air temperature and the suction air temperature was as large as 8 ºC to 11 ºC (Table 8). On the other hand, the difference in the heating operation was smaller than 3 ºC (Table 9).

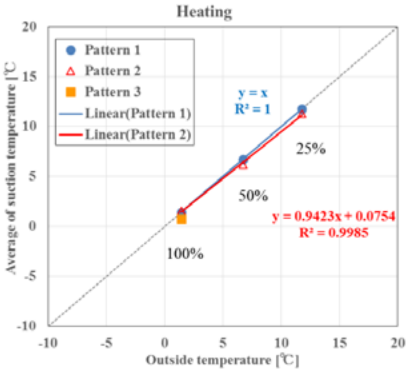

Fig. 5. The relationships between outdoor air temperature and suction air temperature in heating operation

Table 9 Blowing air temperature during heating operation

Outdoor temperature conditions	Pattern 1	Pattern 2	Pattern 3
2ºC	-1.7ºC (▲3.1)	-1.3ºC (▲2.8)	-2.2ºC (▲2.9)
7ºC	4.4ºC (▲2.3)	4.1ºC (▲2.1)	-
12ºC	10.4ºC (▲1.4)	10.2ºC (▲1.0)	-

( ) Indicates the difference between the blowing air temperature and the suction air temperature

3. Field Test

3.1. Test Method

In this test, we used two packaged air conditioners installed in a building of Mie University. By measuring the blowing air temperature, suction air temperature, outdoor air temperature, etc. of the outdoor unit, the occurrence of the short circuit was examined. We also examined the installation conditions of outdoor units where short circuits are likely to occur. The measurements were conducted mainly in September and October to avoid the cooling capacity shortage in midsummer that might be caused by the short circuit.

The air conditioner used for the measurement was a packaged air conditioner with a rated cooling capacity of 8 kW (manufactured in 2009). As shown in Figure 6, the left side (air conditioner No.1) of two adjacent outdoor units was the main measurement target. As for the air conditioner on the right side (air conditioner No.2), we measured only power consumption in order to understand its operating state.

As can be seen from this figure, there were building walls on the back side of these outdoor units, but there were no walls on the side and front. Therefore, as shown in Figure 7, a partition wall (height 2.0 m, width 1.0 m) simulating the building wall was put on the side and/or front of the outdoor unit of air conditioner 1 to generate the short circuit artificially. An experiment was conducted based on the air conditioner installation manual, and the distance between the outdoor unit and the partition wall was set at 0.15 m when the wall was installed on the side of the outdoor unit and 1.0 m when it was installed on the front.

Figure 8 shows the positions of the thermos-sensors installed in the outdoor unit of air conditioner 1. The temperatures of the blowing and suction air were measured at 1 minute intervals. In addition, the outdoor air temperature was measured at a position away from the outdoor unit, and the power consumptions of both air conditioners were also measured.

No1 No2

Fig. 6 Air conditioner installation condition (the air conditioner 1 to be measured is on the left)

Fig. 7 Wall installation conditions (left: Side, right: Side + Front)

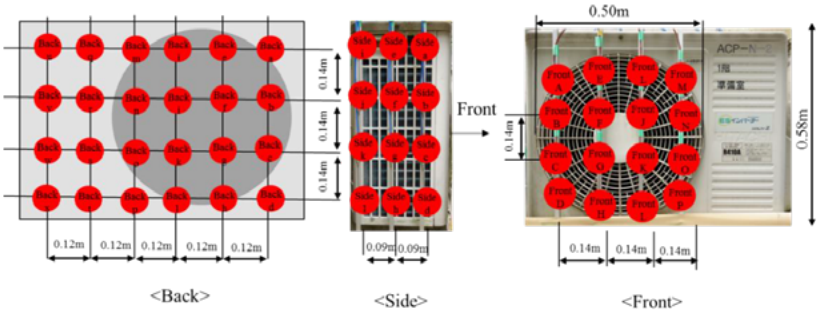

Fig. 8 Measurement position of suction (Back and Side) and blowing (Front) air temperature

3.2. Results

3.2.1. Influence of Wall

Table 10 shows the results of temperature measurements. When the adjacent air conditioner 2 was not operating and the wall was installed on the side, the suction air temperature on the side face increased by 4.6 ºC. On the other hand, the temperature rise on the back face was not so much. The same tendency is observed when the wall was installed in the front. These results are very similar to those of the laboratory tests.

When the air conditioner 2 was operating, the temperature rise in the side and back faces is remarkable. The situation when the air conditioner 2 was operating is described in detail in the next chapter.

Table 10 Rise of average suction air temperature under each condition

Wall	Air-conditioner 2	Side suction temperature – Outdoor air temperature	Back suction temperature – Outdoor air temperature
None	OFF	-0.2ºC	-1.1℃
	ON	0.7 ºC	0.8℃
Side	OFF	4.6 ºC	1.0 ºC
	ON	6.1 ºC	3.2 ºC
Side + Front	OFF	5.0 ºC	1.4 ºC
	ON	4.3 ºC	2.4 ºC

3.2.2. Influence of Adjacent Air-Conditioner

Figure 9 shows the temporal change of the suction air temperature at the representative point "Back 1" on the back of the air conditioner 1 when the air conditioner 2 was operated without any walls. Here Δt on the ordinate denotes the difference between the suction air temperature and the outdoor air temperature. For comparison, the suction air temperature of “Back 1” when the air conditioner 2 was stopped is also shown. The suction air temperature at “Back l” with the operation of air conditioner 2 is 2 ºC higher than that without the operation of air conditioner 2. From this result, it is presumed that when the adjacent air conditioner 2 is in operation, the air blown from the air conditioner 1 wraps around the back of the outdoor unit due to the influence of air blown from air conditioner 2.

Next, let us describe the case where the wall was installed on the side of the outdoor unit. Figure 10 shows the blowing air temperature and the suction air temperature on the back face ("Back a" to "Back d") when the air conditioner 2 was operating. Figure 11 shows changes in the power consumption of the air conditioner 2 and the suction air temperature at the back of the air conditioner 1. The rise of the suction air temperature at the back of the outdoor unit increases compared to the results without the wall (Figure 9). In addition, the influence of air conditioner 2 is more noticeable.

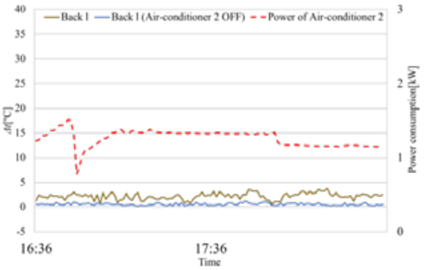

Fig. 9 Comparison of suction air temperature on the back-face and power consumption of air conditioner 2 (No walls)

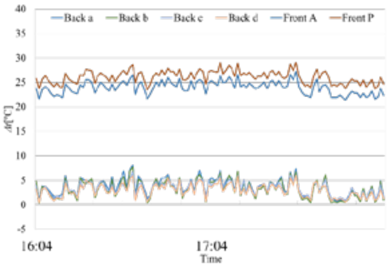

Fig. 10 Comparison of blowing air temperature and back-face suction air temperature (Wall: side installation)

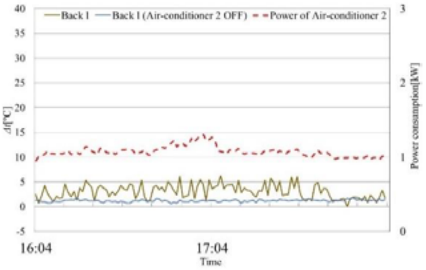

Fig. 11 Comparison of suction air temperature on the back-face and power consumption of conditioner 2 (Wall: side installation)

Table 11 Example of correlation coefficients between blowing air temperature and suction air temperature

Wall	Blowing position	Suction position	Correlation coefficient (Air-conditioner 2 OFF)	Correlation coefficient (Air-conditioner 2 ON)
None	Front D	Side a	0.147	0.258
		Side b	0.128	0.464
		Side c	0.509	0.437
		Side d	-0.008	0.760
Side	Front D	Side a	0.239	0.896
		Side b	0.454	0.832
		Side c	0.020	0.746
		Side d	0.091	0.780
Side + Front	Front D	Side a	0.540	0.775
		Side b	0.535	0.718
		Side c	0.413	0.523
		Side d	0.272	0.715

3.2.3. Correlation Coefficient between Blowing Air Temperature and Suction Air Temperature

In this study, we obtained the correlation coefficient of the time-series changes of the blowing air temperature and the suction air temperature. Based on this correlation coefficient, we can estimate the position at which the air blown from the front of the outdoor unit was easily sucked.

As an example of the correlation coefficient calculation results, Table 11 shows the correlation coefficient calculated between "Front D" (blowing air) on the front face of the outdoor unit and "Side a" to "Side d" (suction air) on the side face. The correlation coefficient between the blowing position "Front D" and the suction position "Side a" is expressed as follows.

$$\text{Correlation coefficient} = \frac{\overline{t_D' \cdot t_a'}}{\sqrt{\overline{t_D'^2}} \cdot \sqrt{\overline{t_a'^2}}} \quad , \quad t_D' = t_D - \overline{t_D} \;\text{ and }\; t_a' = t_a - \overline{t_a}$$

Here t_D and t_a are instantaneous air temperatures at "Front D" and "Side a" measured at every one minute, and overbar means time-averaged values. Therefore, t_D' and t_a' designate the temperature fluctuations of blowing and suction air with time. The value of the correlation coefficient was calculated based on air temperatures measured in two hours.

The correlation coefficient with the wall installation is generally higher than that without the wall. In addition, when the air conditioner 2 was in operation, the correlation coefficient further increases. This suggests that a short circuit tends to be strengthened due to the synergistic effect of the wall and air blown from air conditioner 2. When there were no walls, the correlation coefficient tends to be higher on the lower side face, whereas when the wall was installed, the correlation coefficient on the upper region of the side face tends to be higher. It is thought that the air tends to go to the upper side by the influence of the wall.

4. Conclusions

In this report, in the environmental test laboratory and in an actual building, a wall simulating a building wall or an obstacle was installed near the outdoor unit of the air conditioner, and the relationship between the outdoor air temperature, load factor and the performance degradation were investigated. Due to the influence of the wall installation, SCR and power consumption increased, and COP decreased. The main results are shown below.

1. In the cooling operation, when there are walls near the back and side faces of the outdoor unit, the suction air temperature becomes higher than the case of no wall installation. The increase in the suction air temperature is particularly remarkable on the side face of the outdoor unit.
2. Short circuit is more likely to occur when the wall is installed on the side than when the wall is installed on the front of the outdoor unit.
3. COP decreased by 6.5% in the case of patern3, high outdoor air temperature and the load factor in cooling operation.
4. In the cooling operation, a short circuit may occur in 100% load operation even at low outdoor air temperatures, but the influence of the short circuit is reduced under lower load operation.
5. Under the partial load operation, the influence of the short circuit is large in the cooling operation, whereas the influence of the short circuit is small in the heating operation.
6. In the cooling operation, the suction air temperature also increases on the back face of the outdoor unit, and the temperature rise becomes more remarkable when the adjacent air conditioner is operating.

References

[1] Yumoto,Y., Ichikawa,T., Nobe,T., Kametani,S., Study on Performance Evaluation of a Split Air Conditioning System Under the Actual Conditions, International Refrigeration and Air Conditioning Conference 2006,R067.

[2] Narumi,D.,Tanaka,K.,Shimoda,Y.,Mizuno,M., Improvement of the Thermal Environment around the Air-cooled Outdoor Units of Air Conditioning System. Transactions of the Japan Society of Refrigerating and Air Conditioning Engineers, 2011,Volume 26, Issue 1, pp. 81-92.

[3] Kotani,H.,Yamanaka,Y.,Momoi,Y.,Sagara,K., Study on Short-Circuit Phenomenon around Outdoor Air-Conditioning Units Part 3 Short-Circut Ratio using Inlet Air Temperature by Wind Tunnel Test. The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan 2012, I-64, in Japanese.