DEVELOPMENT AND PERFORMANCE MEASUREMENT OF ROOM AIR-CONDITIONER SUITABLE FOR HOUSE IN COLD REGION

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Abstract: Recently, performance of insulation and air tightness for residential house has been improved in cold region. Therefore, heating load remains at low level through most of heating period. Inverter controlled heat pump is effective appliance to improve efficiency on partial load condition, but it is pointed out that COP operated in low load less than 1kW is not high due to on-off operation. To solve these problems, we make a prototype room air-conditioner with inverter-controlled dual compressor which is tuned to low heating load in low outside temperature. We measure COP in various conditions, and conduct the field test to clarify whether prototype room air-conditioner can provide excellent COP in low load. Measured COP on field test is 2.6.

Key Words: room air-conditioner, dual compressor, partial load efficiency, field test

1 INTRODUCTION

Recently, highly insulated and air tightened residential houses are widely recognized ,they have spread in cold climate region, Hokkaido. In addition, heating appliances are continuously operated all the day. Therefore, heating load of individual room remains at low level. Now, Split-type reversible air-to-air heatpump room air-conditioner (RAC) is expected as important appliance to reduce energy consumption. However, benchmark test of inverter controlled room air-conditioner reveal that heating partial load efficiency below 1kW drops to lower standard Coefficient of performance (COP), because of compressor is operated on-off under lower limit compressor rev speed. To achieve high efficiency by heatpump room air-conditioner at space heating in highly insulated and air tightened houses, improvement of partial load efficiency is most important. We focus on twin-rotary type dual compressor controlled by automatic cylinder shift mechanism that switches two-cylinder mode for high load and single-cylinder mode for low load, and we investigate whether prototype room air-conditioner with dual compressor can achieve high efficiency at low heating load in low temperature below 0^{o}C.

2 EXPERIMENTAL

At first, We measured partial load efficiency of proto type room air-conditioner with Psychrometric calorimeter which was regulated in Japan Industrial Standard(JIS).in addition, relationship between suction air velocity and suction air volume was measured to quantify suction air volume of room air-conditioner in field test. Secondary, room air-conditioner was

installed in the living room of the experimental house and measured actual performance.

3 MEASUREMENT OF PARTIAL LOAD EFFICIENCY

3.1 Specification of room air-conditioner with inverter controlled dual compressor

Table1 shows specification of prototype room air-conditioner. Dual compressor is twin-rotary compressor with two equally displacement cylinder, and it has automatic cylinder shift mechanism which can switch two cylinder mode or single cylinder mode depending on air conditioning load. In this paper, prototype room air-conditioner is tuned to permit to shift from 2 cylinder mode to 1 cylinder mode at temperature below 0 ^{o}C. For example, displacement at minimum revolution 8 rps on 1 cylinder mode is equivalent to 4 rps on 2 cylinder mode.

Table 1: Specification of proto type room air-conditioner

Heating capacity (outdoor temp)	3.2kW(7 ^{o}C) / 5.3kW (2 ^{o}C)
Power Supply	100V / 1phase / 50-60Hz
Dual compressor	DC hybrid inverter controlled Twin rotary compressor
Revolution speed range of compressor	10 rps - 110 rps (2 cylinder) 8rps - 45rps (1 cylinder)
Refrigerant	R410A
Indoor Unit	295(H) X 790(W) X 242(D)
Outdoor unit	550(H) X 780(W) X 290(D)

3.2 Test conditions on Calorimeter

Remote controller settings are as follows: operation mode is heating, control temperature is 23 ^{o}C, Airflow is automatic and downward direction. Relationship between heating COP and partial load is measured on each cylinder mode by fixed compressor revolution. Table2 show outdoor and indoor temperature conditions.

Table 2: Temperature condition on Calorimeter test

	Outdoor side		**Indoor side**	
	Dry bulb[^{o}C]	**Wet bulb[^{o}C]**	**Dry bulb[^{o}C]**	**Wet bulb[^{o}C]**
Case-1	12.0	10.81	24	18.44
Case-2	7.0	6.0		
Case-3	2.0	1.0		
Case-4	-7.0	-8.0		

3.3 Results

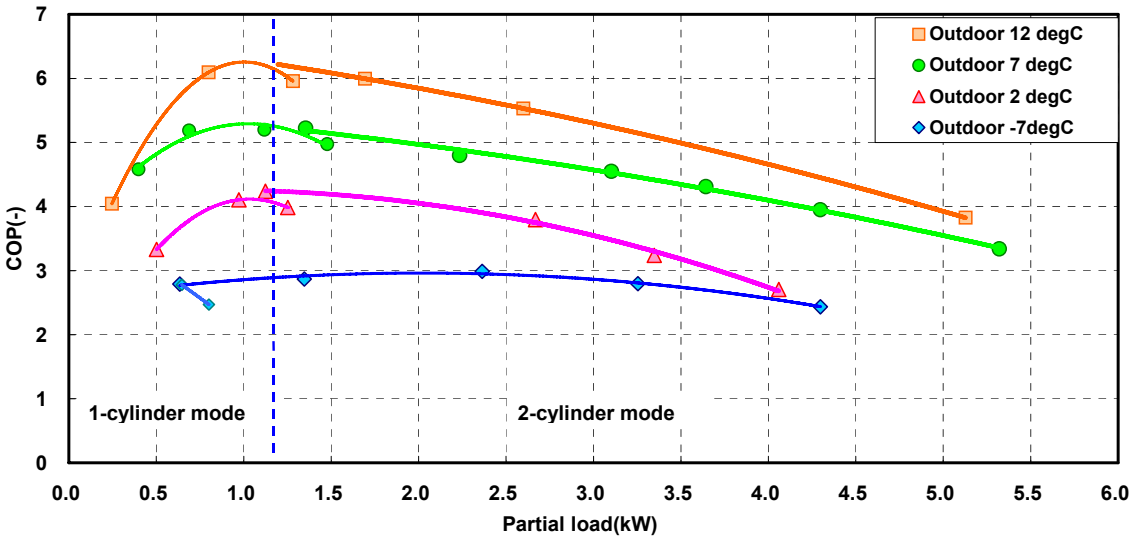


Figure 1: Partial load efficiency of proto type room air-conditioner

Figure.1 shows results of measurement of partial load efficiency. COP was measured under temperature of air chamber was steady state. When Airflow mode is automatic, maximum COP has been measured at 1 to 1.5kW at any outdoor temperature. COP has been measured to exceed 5.0 at outdoor 12 ^{o}C. COP has been measured to exceed 4.0 below partial load 2.5kW, but which declines at a partial load in the range of more than 4.0kW, because of frosting surface of outdoor heat exchanger at outdoor 2 ^{o}C .

3.4 Comparison of COP between continuous operation and on-off operation

Room air-conditioner with normal compressor has been expected on-off operation at heating load below 1kW. To compare continuous 1-cylinder mode operation with 2-cylinder on-off operation at minimum compressor revolution speed, room air-conditioner was operated 10 minutes on and 10 minutes off at 2-cylinder mode. Shown in Fig.2 is comparison of COP at 7 ^{o}C outdoor temperature. Average heating output was 0.5kW, and Average COP was 2.5 from three cycle average. From approximation of COP-concentration-partial load at continuous 1-cylinder mode, COP at 0.5kW partial load is estimated 4.8, which is 1.9 times of 2-cylinder on-off mode. The reason for decreasing COP under on-off operation is considered that refrigerant pressure reduce during compressor stops.

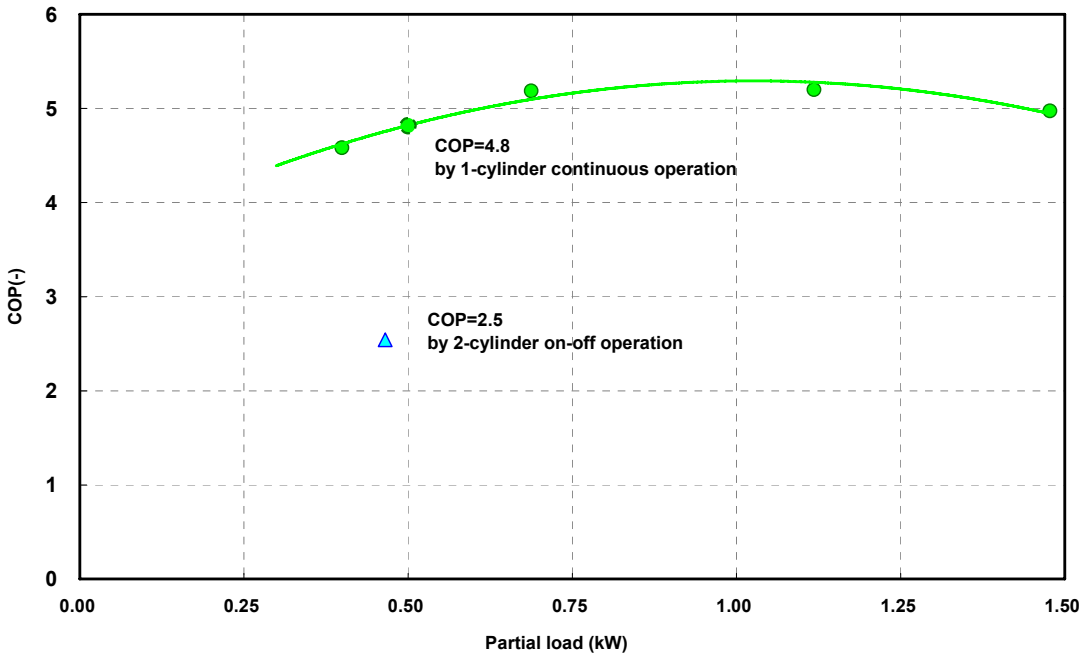


Figure 2: Comparison of COP between continuous operation and on-off operation (Outdoor temperature 7 °C)

4 FIELD TEST ON THE EXPERIMENTAL HOUSE

4.1 Outline of the experimental house

Floor plan of the experimental house in which field test was conducted is shown in Fig.3 Heating space is inside red line. The experimental house is located in Ebetsu city, completed in March 1997. Basement insulation system and Poly-Vinyl-Chloride Sash Windows are adopted, heat loss coefficient (Q-value) is 1.43W/ m^2K, which exceed existing insulation standards for Hokkaido area : Q-value 1.6W m^2K. Nobody lives in the experimental house, and there is no internal heat generation. Living room is oriented to the south direction. Curtains are automatically closed by timer at every 5 pm and opened at every 7 am. Space heating area is 36m^2, any other rooms are set to keep temperature above 20 °C by electric heater with thermostat. Indoor temperature are measured by thermocouple, the measurement point are 64.



Figure 3: Floor plan and heating area

4.2 Test schedule

Field test in the experimental house was conducted from 26th Dec 2009 to 15th Apr 2010. Room air- conditioner was operated in two modes. The dual mode allowed dual compressor to change from 1-cylinder drive to 2-cylinder drive. The other 2-cylinder restricted mode didn't allow dual compressor to 1-cylinder drive under low heating load condition.

Table 3: Field test operation schedule

Pattern	Start	End	Operation mode
1	12/26 2009	1/31 2010	Dual mode
2	2/1	2/15	2cylinder restricted mode
3	2/16	2/28	Dual mode
4	3/1	3/15	2cylinder restricted mode
5	3/16	4/15	Dual mode

4.3 Calculation of heating output

Heating output of room air-conditioner has been calculated by following formulation.

$$Q_{heat} = C_{air} \times G_{air} \times (T_{out} - T_{in})$$

In This method, three thermocouples were mounted on each suction and airflow to evaluate each average temperature considering variation in suction and airflow temperature. Air was taken as completely dry air. Air mass flow rate was calculated by suction air velocity as more relatively parameter than output airflow velocity. Relationship between suction airflow velocity and suction air volume is shown in Fig.4. Suction airflow velocity correlate highly with suction air volume.

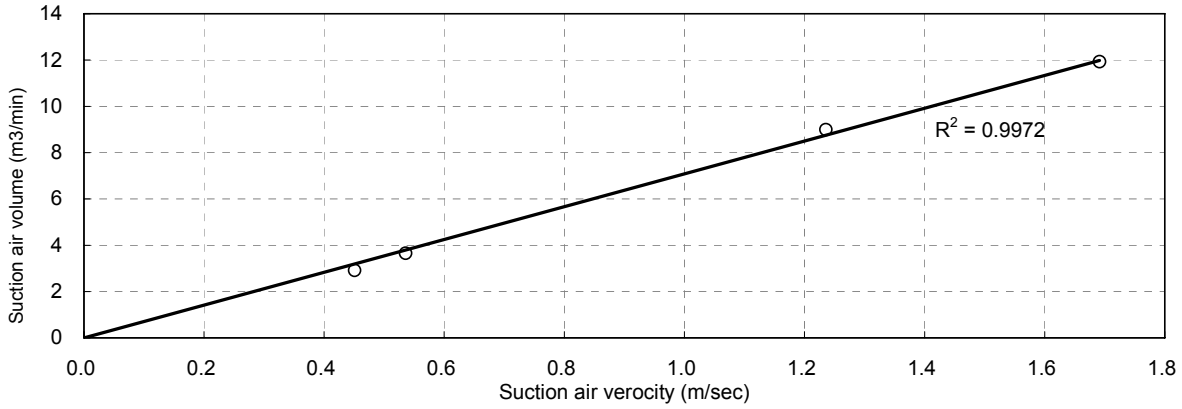


Figure 4 : Suction air velocity – Suction air volume relation

4.4 Results and discussions

4.4.1 Operation data in coldest day (3rd to 4th ,Feb 2010)

Figure 5 shows average room temperature and outdoor temperature from 3rd to 4th Feb.

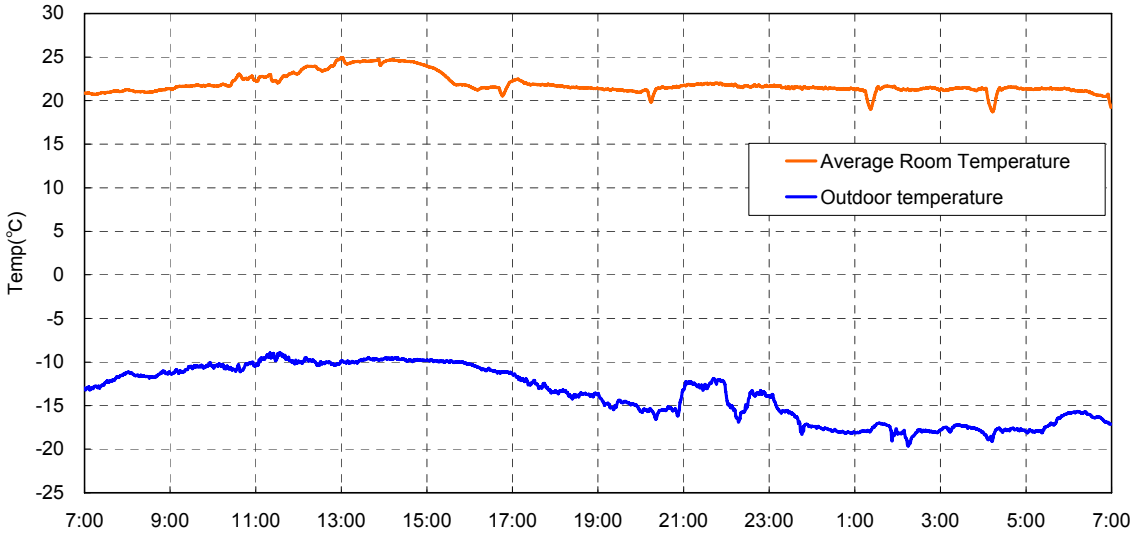


Figure 5: Living room average temperature and outdoor temperature on coldest day

Measured coldest temperature was –19.6 °C, average outdoor temperature per 24hours was –13.6°C. Figure 6 shows room air-conditioner heating operation data. Outdoor temperature on 11am was –11.0 °C, but heating load was less than 1.0kW because of input solar insolation. Because of restricting 2 cylinder driven mode, after room air-conditioner operated 2hours in minimum frequency, it stopped on 1pm. After 5pm, outdoor temperature gradually decreased, and heating load increased, but number of de-frosting was 4, maximum continuously operating time without de-frosting was 5 hours and 3 minutes. Maximum heating output per 24hours was 2.0kW, integral heating output was 104.4MJ/day(29.0kWh/day), integral electric power consumption was 13.9kWh/day, as a result, average daily COP achieved 2.1 .

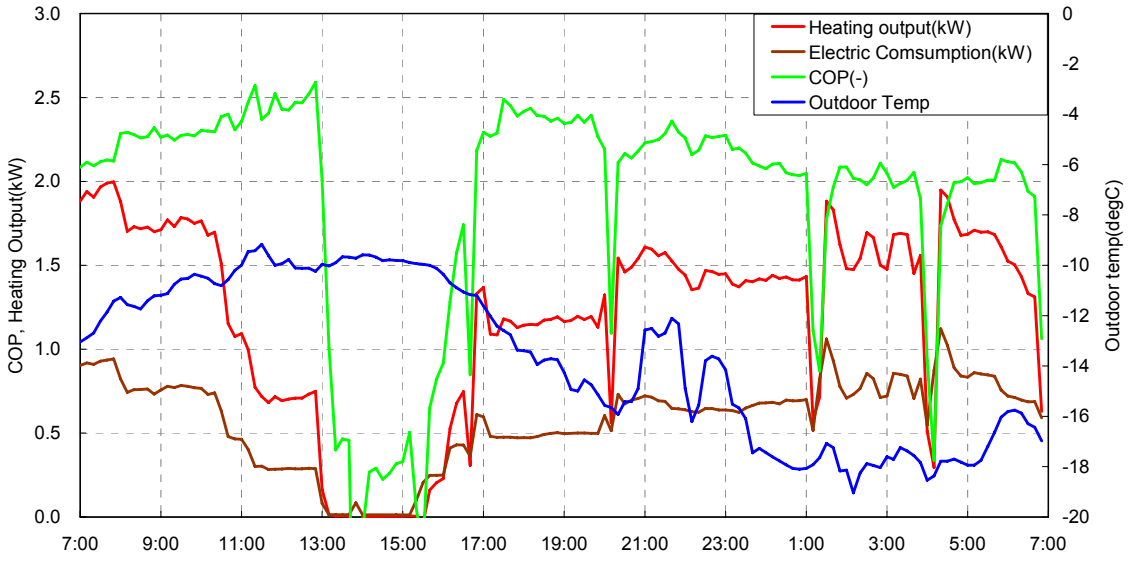


Figure 6 :Experimental operation results
On coldest day (3 – 4 Feb.2010)

4.4.2 Performance comparison on each operation mode

To clarify differences between 2-cylinder restricted mode and dual mode, we extracted a sample in each mode. Figure.7 shows changes in daily outdoor temperature and heating output of 5th March (2-cylinder restricted mode) and 24th March (Dual mode). Average outdoor temperature per 24hours on 5th March was 1.6°C, Average outdoor temperature per 24hours on 24th March was 1.7°C.

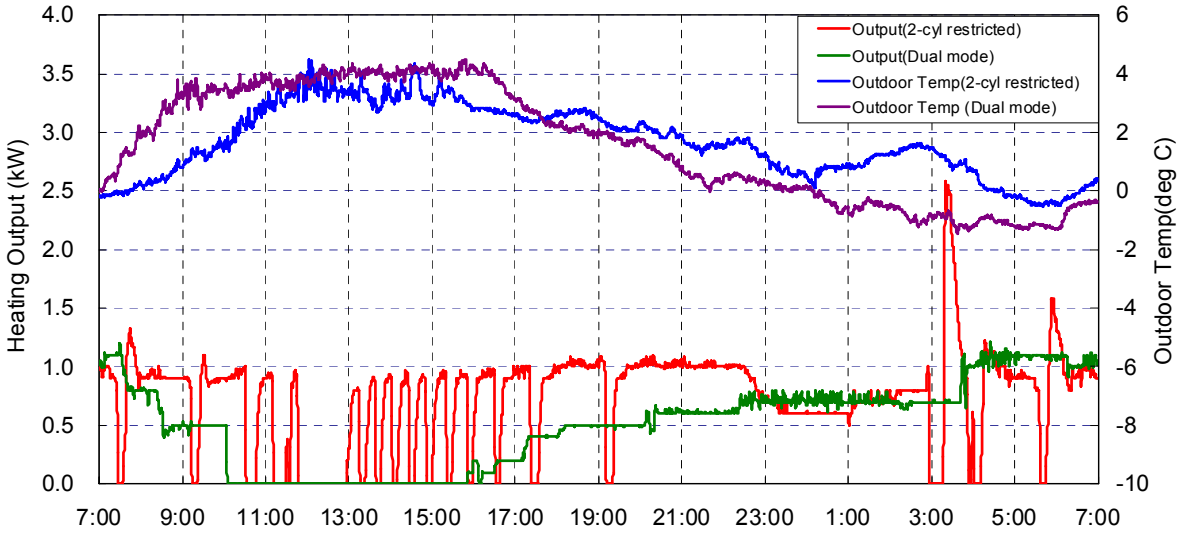


Figure 7 :Outdoor temperature and Heating output
5th Mar (2-cylinder restricted mode) and 24th Mar (Dual mode)

Integral heating output was 63.4MJ/day(17.6kWh/day) on 5th March, and Integral heating output was 44.4MJ/day(12.3kWh/day) on 24th March. Room air-conditioner had stopped around noon on both days, because of insolation. But on 2-cylinder restricted mode, compressor intermittently started and stopped after 1pm. Fig.8 shows changes in daily average room temperature on both days. On 24th March(dual mode), room temperature

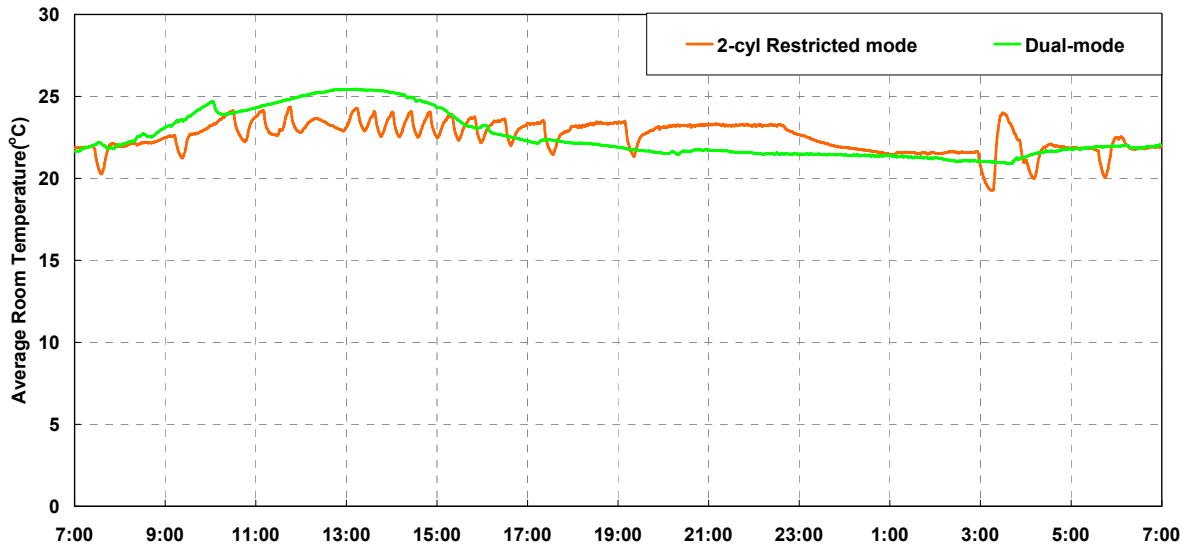


Figure 8 Comparison of average room temperature
5th March (2-cylinder restricted mode) and 24th March (Dual mode)

overshoot by solar radiation was measured during 11am to 3pm. After 5pm, Dual mode operation could widely follow changes of heating load, so that average room temperature was stable. On the other hand, by 2-cylinder restricted mode, average room temperature varied little by little, in addition, that varied widely by outdoor unit defrosting on 3:00 am 6th. On 4:00 am, outdoor unit defrosted again because of room air-conditioner turned up heating output to recover room temperature drop. As a result, These results provide that on-off operation could not accurately control refrigerant temperature on evaporator during heating output rise time, so that makes it easier to frost on heat exchanger surface.
Figure.9 shows experimental results for heating COP on both dual-mode and 2-cylinder restricted mode. On dual-mode operation, COP of room air-conditioner could achieve above 3.0. On the other, heating COP on 2-cylinder restricted mode was 2.5. We consider that room air-conditioner can accurately control refrigerant temperature on evaporator because dual compressor can operate without on-off.

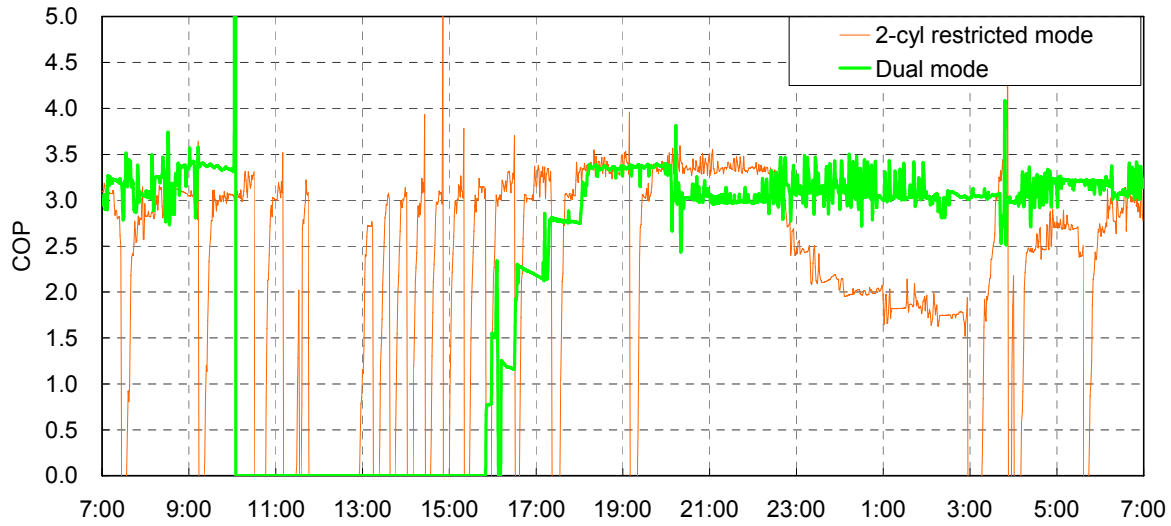


Figure 9: Comparison of COP
5th March (2-cylinder restricted mode) and 24th March (Dual mode)

4.4.3 Evaluation of heating by proto-type room air conditioner

Figure.10 shows histogram of average heating output per hour in heating period. Maximum heating output was 2.75kW, most frequent heating output ranges 1.0kW to 1.25kW in heating space.

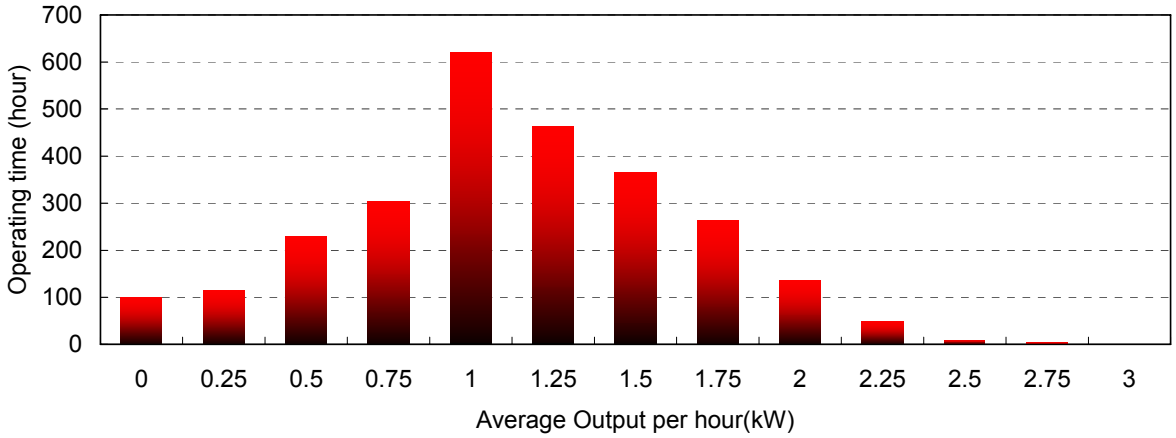


Figure 10: Histogram of average output per hour

Table 4 shows COP during experimental period. Total days for the experiment are 111 days, integral heating load during experiment is 9.7GJ(2692.8kWh), integral electric energy consumption is 1028.7kWh, average COP is 2.6 . These results provide that heat pump room air-conditioner with dual compressor can reduce primary energy consumption and CO2 emission less than fuel combustion system.

Conclusions

Table 4 : Experimental results for COP of each operation mode

Start	End	number of days	Heating	Electric	*COP*
			(kWh)	(kWh)	(-)
2009/12/26	***2010/4/15***	***111***	***2692.8***	***1028.7***	***2.6***

1. This proto type room air-conditioner with the dual compressor optimally tuned to heating load distribution of highly insulated and air tightened in cold region of Japan, has maximum efficiency at heating load around 1.0kW .
2. To extend inverter and compressor lower range can lead to increase annual COP because they can improve partial load efficiency at low load. Especially, in comparison continuous operation by 1-cylinder mode with on-off operation by 2-cylinder mode at 0.5kW output and 7^{o}C outdoor temperature, COP of continuous operation by 1-cylinder mode can achieve 4.8, which is 1.92 times on-off operation by 2-cylinder mode.
3. Heating load of living room 36m^2 in highly insulated and air tightened house (Q-value: 1.43 W/m^{2}K) have a great frequency below 1.25kW. Continuous operation by 1-cylinder mode at low load can lead to mitigate changes of room temperature. COP on field test has been measured to be 2.6.
4. Continuous operation at low load in low outdoor temperature can lead to reduce loss of on-off, and frosting on evaporator, and increase COP.

NOMENCLATURE

Q_{heat}
: heating output [kW]

C_{air}
: specific thermal capacity [kJ/kg/K]

G_{air}
: air mass flow rate [kg/s]

T_{out}
: average airflow temperature [^{o}C]

T_{in}
: average suction air temperature [^{o}C]

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