

DEVELOPMENT OF HIGH EFFICIENCY LARGE CAPACITY HEAT PUMP CHILLING UNIT USING R410A “SUPER FLEX MODULAR CHILLER”

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Abstract: Promoting a high efficient electrical heat pump chiller in substitution for cool and hot water supply with fossil fuel can contribute to the reduction of CO₂ emissions, and can contribute greatly as the measures against global warming. We developed the high efficiency large capacity heat pump chilling unit using high-efficient refrigerant R410A by the name of “Super Flex Modular Chiller”. This product is consisted of some 30USRT modules with X-frame chassis, which was created from study of air-flow analysis data. The optimized air distribution allows ‘side by side’ installation without deteriorating the chiller’s performance. The module can be combined from 3 to 12 modules. As a result, the unit capacity range can be expanded from 90USRT to 360USRT. The main features are energy saving and reduction of carbon dioxide emissions by the high part load efficiency.

Key Words: *chilling unit, energy conservation, coefficient of performance, partial load performance, R410A, X-frame chassis*

1 INTRODUCTION

The Kyoto Protocol requires industrially developed nations to cut their emissions of greenhouse gases by specified degrees from 1990 levels in five years from 2008 to 2012. Japan is required to cut its emissions by 6%. But Japan’s output of greenhouse gases has continued to expand: In fiscal 2006, it increased to a level 6.4% above that of 1990. Urgent measures for emissions of greenhouse gases in the commercial field are especially requested because of the slow progress compared with the industrial field. In the commercial field, energy consumption of an air conditioning system is approximately one-third of the whole building energy consumption; therefore some studies about higher efficient air-conditioners had been accomplished so far and gotten good results on packaged air-conditioners used for small-scale buildings and centrifugal chillers used for large-scale buildings. On the other hand, low efficient absorption water chilling and water heater package had been widely used for middle-scale buildings because heat source of both cold and hot water are generally necessary in the middle-scale buildings with total floor space 10,000 – 30,000 m². Introduction of heat pump chillers and centrifugal chillers using HCFC refrigerant had been avoided because of the Montreal Protocol adopted from ozone layer protection standpoint in 1987. In such a situation, the market share of absorption chillers had been extended as a substitute for the electrical chillers using HCFC refrigerant. As a result, it is estimated that stock of the absorption chillers with around 1.0 COP is approximately 10,000,000 USRT in the current Japanese market.

By revision and reinforcement of the law regarding the rationalization of energy use, energy saving intention has risen in the commercial field and therefore it has been demanded to

change low efficient absorption chillers to high efficient electrical heat pump chillers. But the practical use of the leading electrical chillers in the commercial field, which have 200-300 USRT capacity and have both cooling and heating modes, has been late so far. Although some high efficient heat pump screw chillers using refrigerant R407C or R407E were developed, those chillers could not be influential rivals against the absorption chillers because of the following problems: (a) The maximum capacity was about 100 USRT. Control of the air conditioning system with such chillers in the middle-scale buildings was difficult because it was necessary to install more than one chiller to meet the required capacity. (b) The part load efficiency was not so high although the full load efficiency at nominal load condition was very high.

To meet the above-mentioned market needs, our new electrical heat pump chiller was developed by a novel idea of modular concept to obtain the large capacity as one chiller. In addition, use of refrigerant R410A with none ozone depleting potential was enabled by the modular concept although it was difficult to use R410A for such a large capacity chiller because of the disadvantage of high pressure in spite of the advantage of high capacity. Moreover, we could make full use of the modular benefits, e.g. the high part load efficiency, flexible combination of heat pump and cooling only modules, etc. In this paper, we will provide many features of this new modular chiller.

2 SPECIFICATIONS

Base module has 30 USRT nominal cooling capacity. Table 1 shows the specifications of the base module. Even if some modules are combined, the nominal coefficient of performance is the same as one module because the same modules are combined. Standard series with normal air heat exchangers and high efficiency series with evaporative condensers are lined up. In addition, some options, such as low leaving brine temperature (minimum -15C), resistance to damage from salt breeze, heat machine and so on are available.

Table 1: Specifications of Base Module

Items		Specifications
Cooling Mode *1)	Capacity	95kW / 106kW (High Efficiency Series *3)) 85kW / 95kW (Standard Series)
	COP *4)	4.8 / 4.3 (High Efficiency Series*3)) 3.6 / 3.2 (Standard Series)
Heating Mode *2)	Capacity	90kW / 100kW
	COP *4)	3.8 / 3.5
Refrigerant		R410A
Dimensions		Depth 3,000 x Width 1,000 x Height 2,300
Shipping Weight		1,060kg

*1) Rated cooling conditions are entering water temperature 14C, leaving water temperature 7C, and outdoor air temperature 35C.

*2) Rated heating conditions are entering water temperature 38C, leaving water temperature 45C, and outdoor air temperature 7C/6C (dry bubble/wet bubble).

*3) At evaporative condensing mode.

*4) Coefficient of performance (cooling capacity / input or heating capacity / input).

The module can be combined from 3 to 12 and the combined modules can work as one chiller. The product lineup is shown in Table 2. 10 sizes are available by the combinations. Power voltage variation is 200V-3ph-50/60Hz, 400V-3ph-50Hz and 440V-3ph-60Hz.

Table 2: Product Lineup (Cooling Capacities of Heat Pump Series, kW)

Number of Modules	3	4	5	6	7	8	9	10	11	12
Nominal Capacity Class	90 USRT	120 USRT	150 USRT	180 USRT	210 USRT	240 USRT	270 USRT	300 USRT	330 USRT	360 USRT
Standard (50Hz)	255	340	425	510	595	680	765	850	935	1,020
High-Efficiency (50Hz)	285	380	475	570	665	760	855	950	1,045	1,140
Standard (60Hz)	285	380	475	570	665	760	855	950	1,045	1,140
High-Efficiency (60Hz)	318	424	530	636	742	848	954	1,060	1,166	1,272

3 COMPONENTS

The outline of the combined modules and the main component parts are shown in Figure 1. The unique design, X-frame chassis, accomplished performance improvement by optimized air distribution, footprint reduction by 'side by side' installation, easier installation and easier construction.

3.1 Refrigerant

Refrigerant R410A with none ozone depleting potential was used in the developed chiller for the first time in the industry of large capacity chillers. R410A has been used for small air-conditioner owing to the advantage of high capacity and small pressure drop. On the other hand, R410 had not been used for large air-conditioner owing to the disadvantage of high pressure. But the disadvantage was conquered by installing not one large compressor but three small compressors in one module.

3.2 Compressor

Three scroll compressors are installed in parallel. High performance throughout the year is possible by the means of on/off control at partial load. In case of 12 combined modules, the capacity control is 25 gradual steps. Benefit of the on/off control is no efficiency decline like a compressor with a bypass unloader.

3.3 Water Pump

A VFD water pump is factory-installed in each module. Water flow rate is automatically controlled with the VFD water pump to adjust leaving water temperature of each module to a set point. Because of the variable flow, electricity consumption of the water pump can be reduced at part load; accordingly it can contribute to energy conservation of the whole air conditioning system. In addition, it can contribute to easier installation and easier construction because the water pump is factory-installed in advance.

3.4 Heat Exchangers

Air heat exchangers were newly designed for this chiller. The refrigerant circuiting pattern and length of the refrigerant circuit were optimized for refrigerant R410A. In addition, evaporative condensers with water spray nozzles are optionally available.

A new water heat exchanger was adopted for this chiller. The refrigerant distribution system was optimized for refrigerant R410A.

3.5 Expansion Valve

Optimized refrigerant flow control at not only full load but also part load was established by using new processing board and electric expansion valves.

3.6 Fan

High efficient fans and DC motors are used in this chiller. The efficiency was improved 21% compared to our conventional fans. In addition, optimized condensing temperature at part load by VAV can improve part load efficiency.

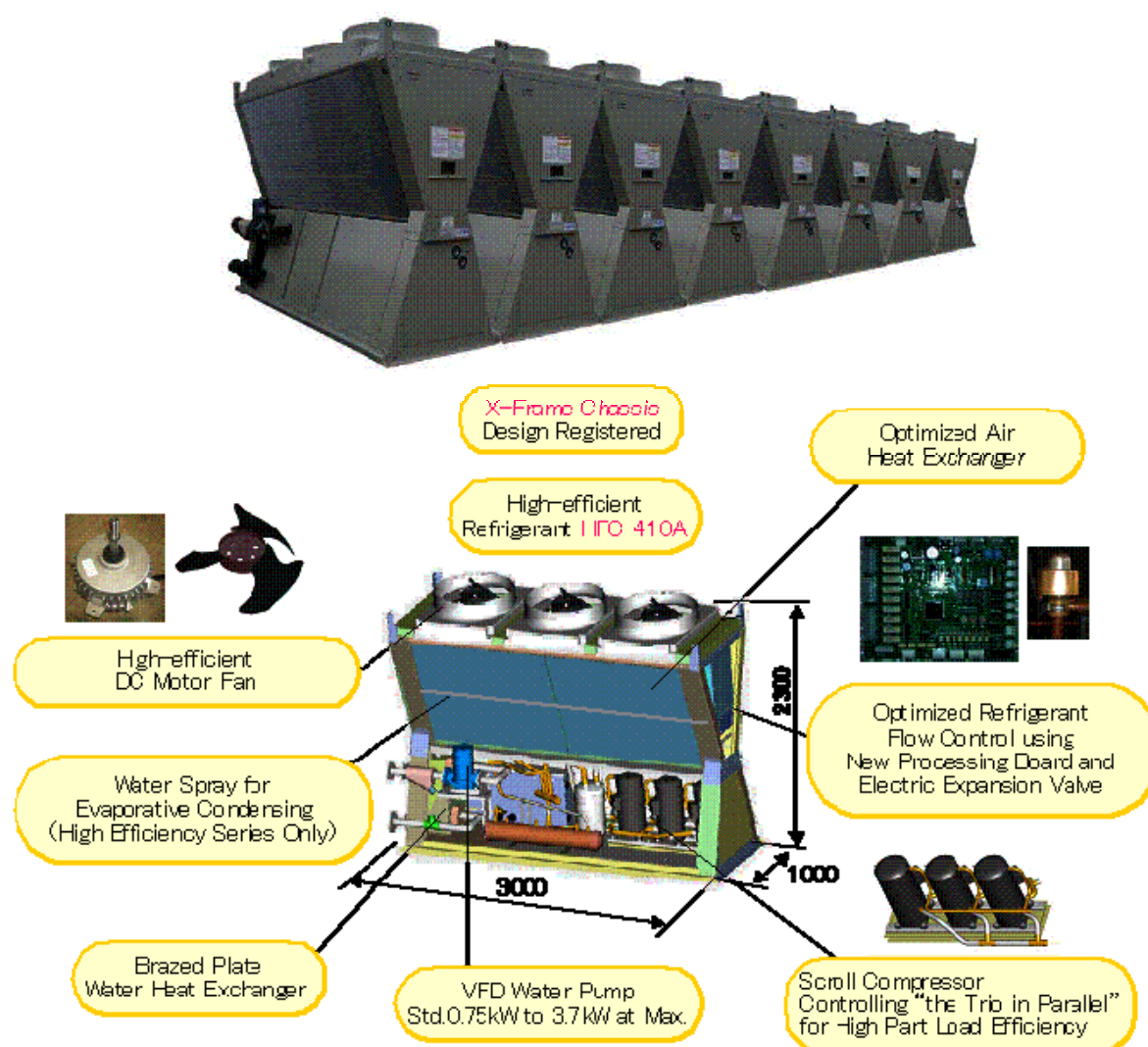


Figure 1: Outline of Developed Chiller and Main Components

4 X-FRAME CHASSIS

Unique chassis design, X-frame, is created from the study of air-flow analysis data as shown in Figure 2. Optimized air distribution allows 'side by side' installation without deteriorating the chiller's performance. The space between the modules is no more than 30mm. Although the conventional chillers generally needs about 1000-3000mm space between the chillers for air distribution, such a wide space is not necessary for the developed modules. In comparison with the typical conventional chiller (RUA-SB35503H-A x 3sets), the installation space of the typical developed chiller (RUA-TBP3001HNV x 1set) can be reduced 15%. In addition, lightweighting was accomplished for the module. The shipping weight can be reduced 14% compared to the conventional chiller.

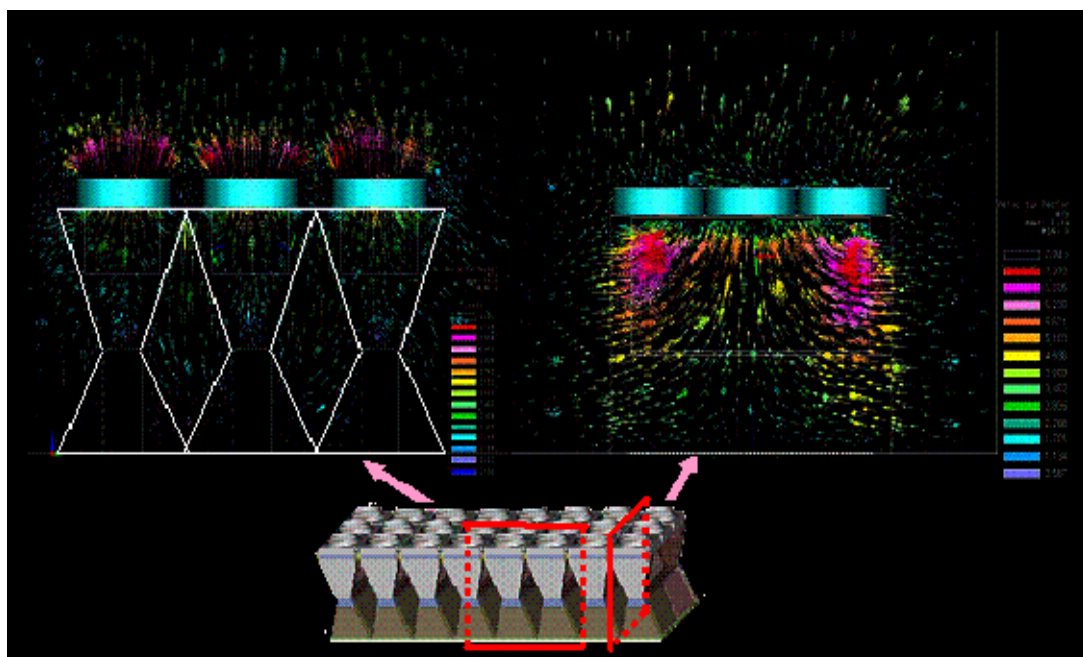


Figure 2: Example of Air-flow Analysis

5 PERFORMANCE IMPROVEMENT

5.1 Nominal COP at Rating Condition

Higher efficiency than our conventional chiller was achieved by using refrigerant R410A for the first time in the industry of large capacity chillers, developing optimized heat exchangers for refrigerant R410A, etc. Figure 3 shows comparison of nominal COP between the typical developed chiller (RUA-TBP3001HNV x 1set) and the typical conventional chiller (RUA-SB35503H-A x 3sets). For the standard series, cooling COP was improved 20%, heating COP was improved 9% and the average COP was improved 12%.

In addition to the standard series, high efficiency series was optionally lined up. High efficiency series have evaporative condensers utilizing evaporative latent heat of water more efficiently by nozzle spraying as shown in Figure 4. Evaporative latent heat cools entering air as primary vaporization and air heat exchangers directly as secondary vaporization. Sensible heat cools air heat exchangers directly. Because condensing pressure is lower with the evaporative condenser, more cooling capacity and less power consumption can be obtained. The supplied water flow rate is 7.1L/min per module, which is less than 2-10% loss of the

circulating water in the typical system of absorption chiller and cooling tower. As a result, the first-rate cooling COP (4.8) and the averaged COP (4.3) was achieved as shown in Figure 4. Compared to our conventional chiller, cooling COP was improved 60% and the average COP was improved 30%.

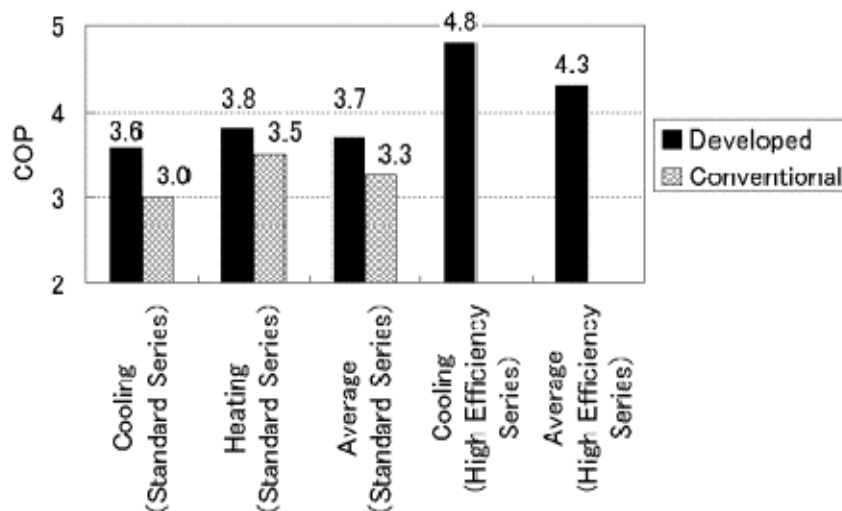


Figure 3: Nominal COP Comparison

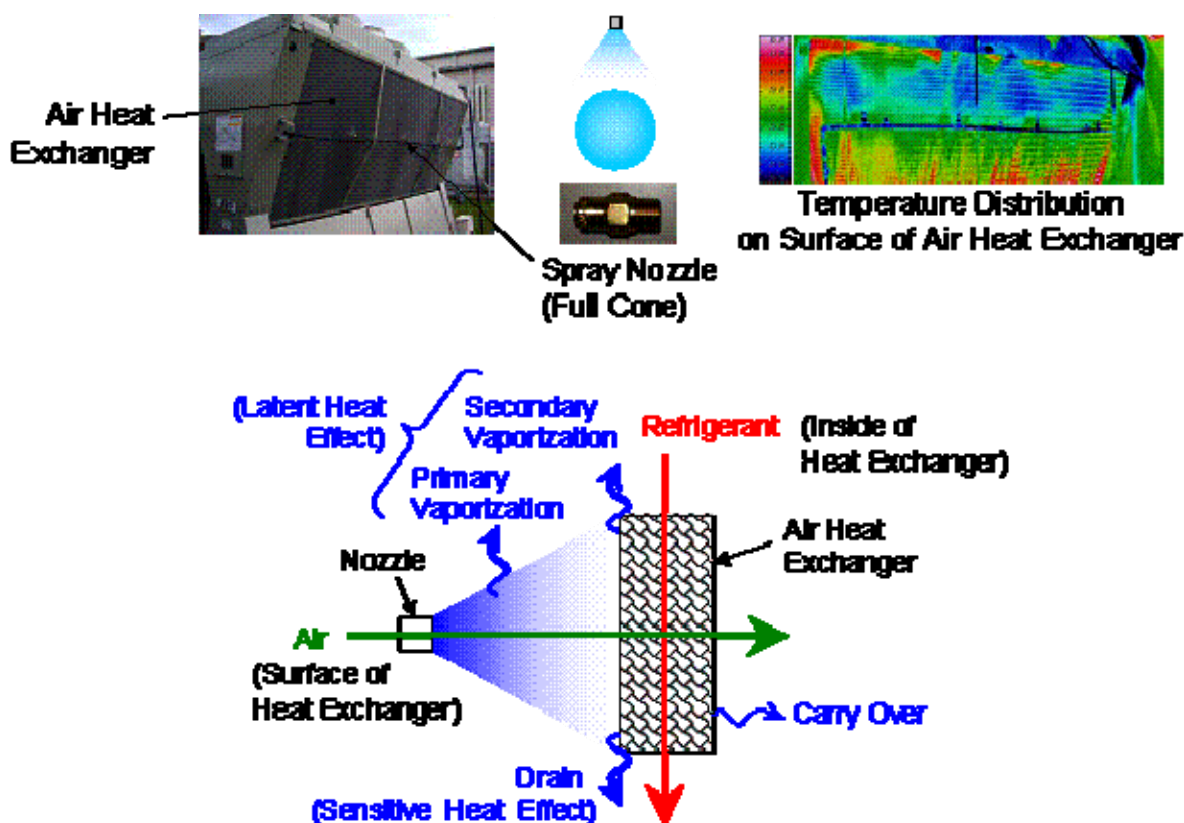


Figure 4: Evaporative Condenser

5.2 Energy Conservation by High Part Load Efficiency

For one module, three compressors operate in parallel at full load (100%) and two compressors operate in parallel at part load (67%). COP at the part load is very higher than COP at the full load because high-pressure is decreased and low-pressure is increased by no efficiency decline of the compressors at the part load. As shown in Figure 5, for the whole modules, the unloading control system let the compressors operate at unloading condition as long as possible because of the superior part load performance. As a result, part load performance of the developed chiller was extremely improved 76% compared to our conventional chiller as shown in Figure 6.

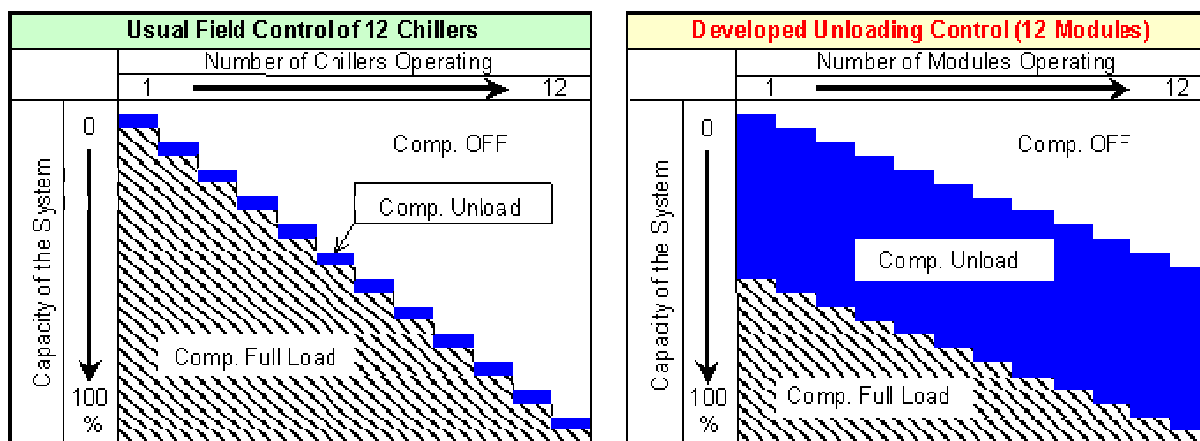


Figure 5: Unloading Control for Whole Modules

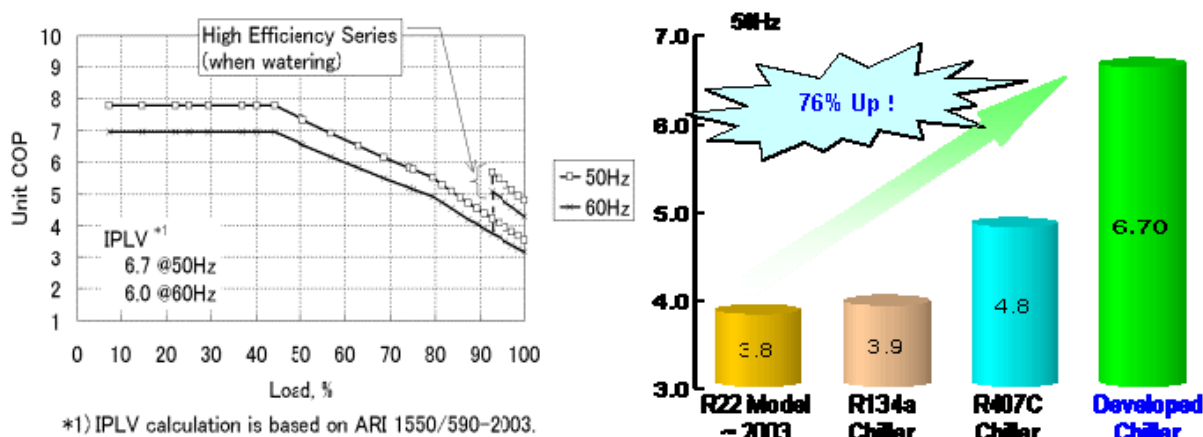
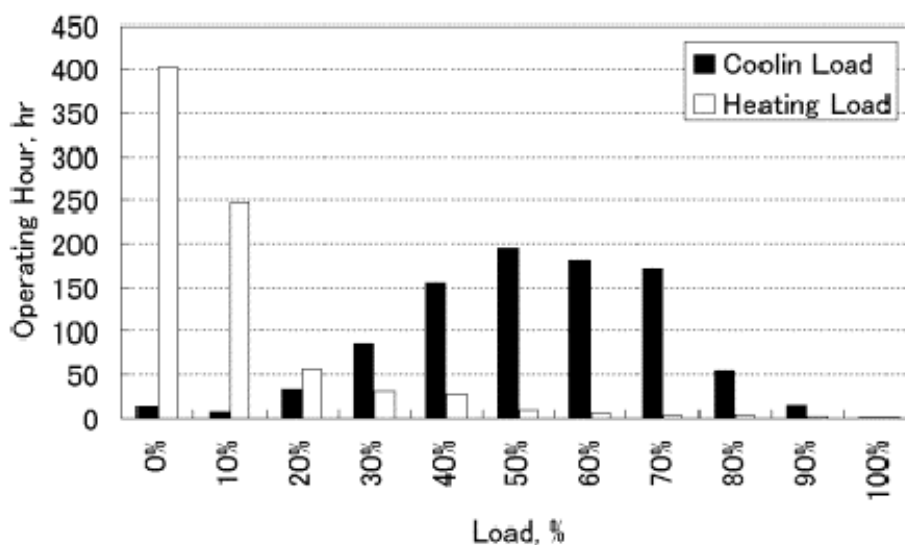


Figure 6: Part Load Efficiency Comparison (IPLV)

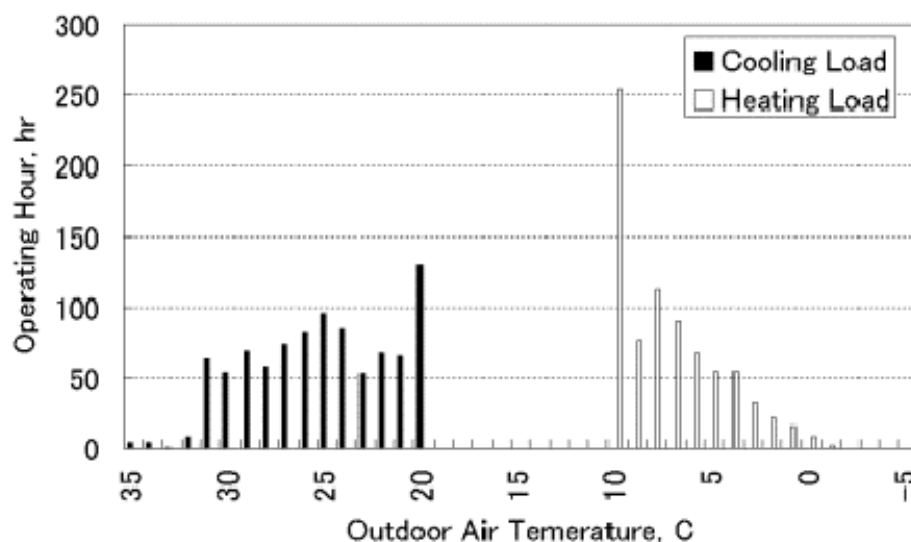
In general air conditioning system, chiller running time at low and medium loads is very long compared to that at high load all the year round. Figure 7 shows cooling and heating load frequency in an office building in Tokyo as an example. In case of the cooling load, 77% of the total operating hours is occupied by 40 to 70% cooling load. In case of the heating load, operating hour increase as load is lower. Hence efficiency at low and medium loads is very important from an energy conservation standpoint. Needless to say, the developed chiller with high part load performance is good for energy conservation.

Figure 8 shows comparison of primary energy consumption and CO₂ emission from trial calculations, which was executed for 300USRT products including the developed chiller. The thermal load characteristics of a certain office building in Tokyo as shown in Figure 7 was

used for the calculation. In this calculation, CO₂ emission intensity is 0.372kg-CO₂/kWh based on Tokyo Electric Power Company's data in 2005. Compared to the absorption chiller, which is the most influential competitor against the developed chiller, primary energy consumption can be reduced 49% and CO₂ emission can be reduced 60%.



(a) Operating Hour vs. Load



(b) Operating Hour vs. Outdoor Air Temperature

Figure 7: Typical Cooling and Heating Loads

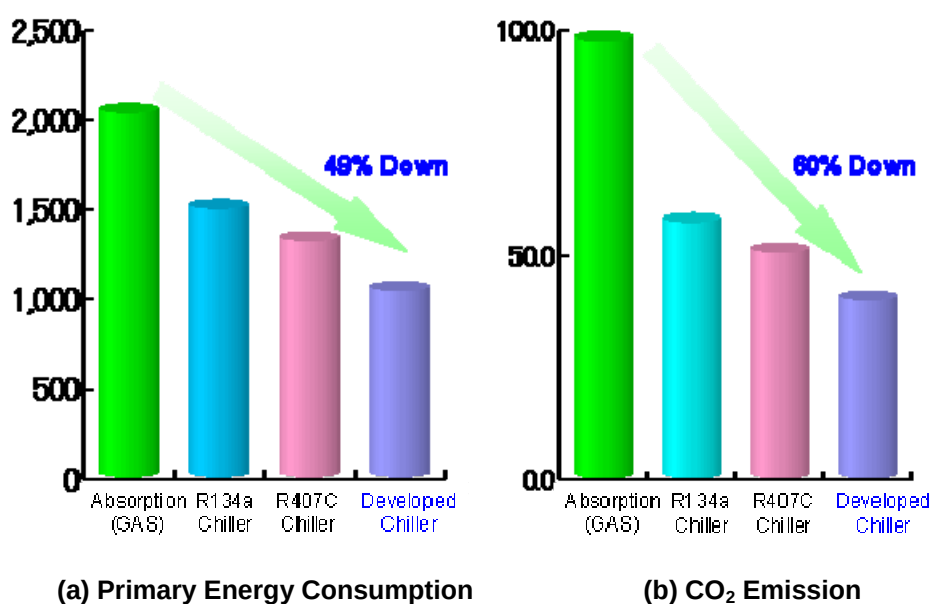


Figure 8: Comparison of Primary Energy Consumption and CO₂ Emission

6 OTHER BENEFITS OF MODULAR CHILLER

6.1 Risk Avoidance

In general, when a chiller with large capacity shuts down by any troubles, the capacity decrease has very big impact on the air conditioning system because the whole chiller stop running. In case of the developed chiller, it is consisted of some 30USRT modules. If a certain module shuts down by any troubles, the capacity decrease is not so much in the chiller because other modules is automatically kept running and therefore the developed modular chiller is suitable for risk dispersion in the air conditioning.

6.2 After-sales Service

Power supply to the module in maintenance can be separately shut down, so that other modules can continue to operate during the maintenance. Maintenance, service work and part replacement are possible when the chiller is left running. Furthermore, if required cooling and/or heating loads increase, additional modules to meet the thermal load can be installed to the original system.

6.3 Flexible Module Selection

Flexible combination of heat pump and cooling only modules is available for the most suitable to thermal load. For example, in case of 210USRT system (@50Hz), whose maximum necessary load is 750kW for cooling and 500kW for heating, 5 heat pump modules and 3 cooling only modules are combined. Initial cost can be saved by installing necessary number of heat pump modules to meet heating load, instead of installing all modules as heat pump.

6.4 Flexible Module Grouping

Flexible module grouping, i.e., two separate water systems in the combined modules, is available by switching operating patterns with external signals. Four operating patterns can be registered in advance. Operating mode (cool/heat) and water temperature set point can be individually set for each operating pattern.

Figure 9 (a) shows an example of the module grouping. In case of (i) in Figure 9 (a), each group runs at different water temperature set point in the same cooling mode. For example, group-1 supplies 7C water for fresh air introduction and group-2 supplies 13C water for sensitive cooling. In such a usage, it can contribute to energy conservation because of higher efficiency of the modules in group-2. This operating pattern can be useful for a building and a clean room in a factory. In case of (ii) and (iii) in Figure 9 (a), each group runs at different operating mode with different water set point. For example, group-1 operates in heating mode and group-2 operates in cooling mode. To satisfy various demanded cooling/heating loads in all seasons, ratio of cooling and heating modules can be changed for each season and each group can operate more efficiently at each suitable water temperature set point. In addition, the flexible module grouping can reduce initial cost.

More advanced usage is shown in Figure 9 (b). This system is useful for widely changed load due to outdoor air temperature change throughout the year like a museum where constant dry bulb and wet bulb temperatures are demanded.

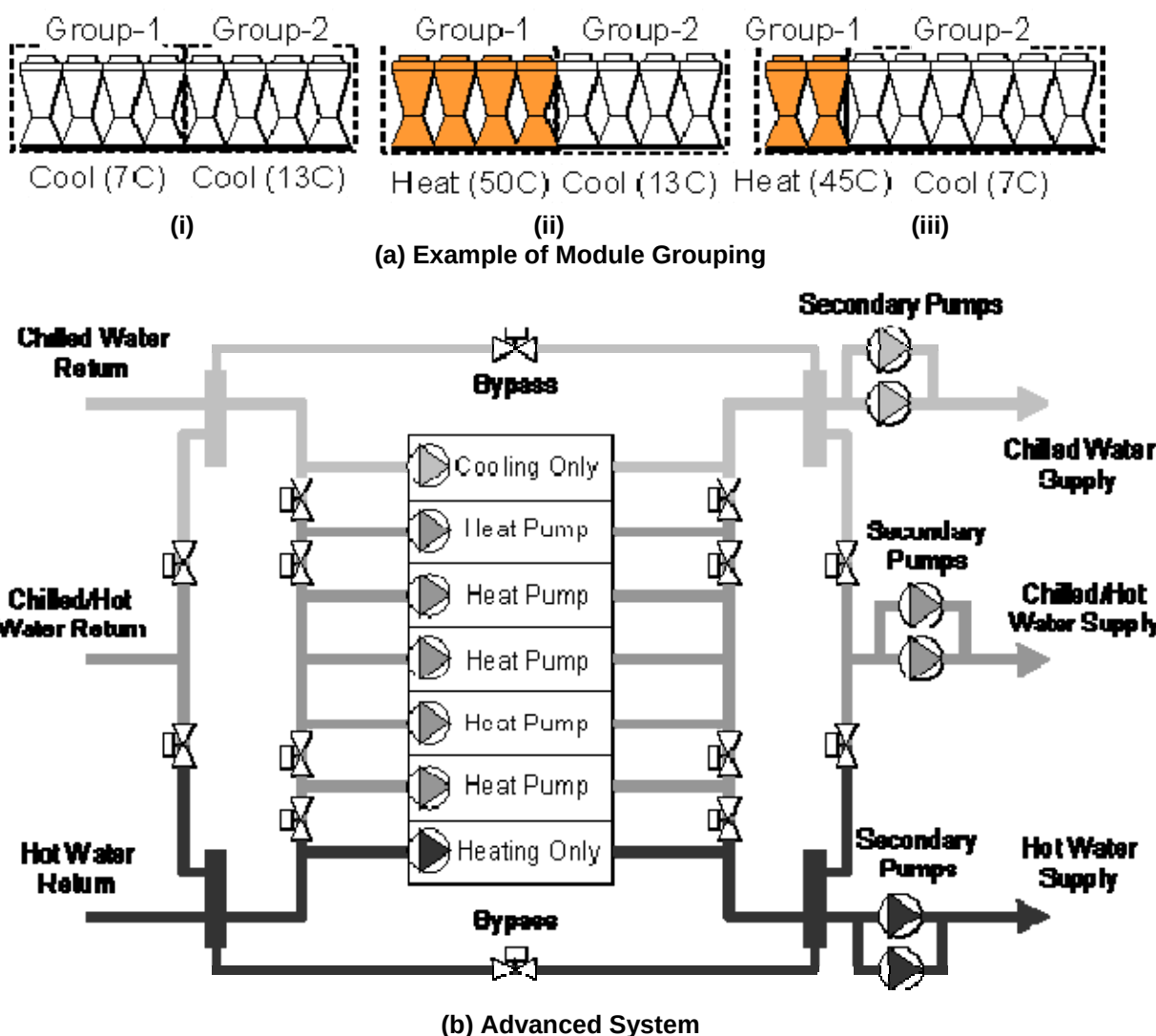


Figure 9: Flexible Module Grouping

6.5 Easier Installation and Construction

When installing the developed chiller, each module is separately carried into a site without a big crane truck; therefore easier installation and cost reduction can be achieved. In addition to the factory-installed water pump in each module, wiring kits and water piping kits are optionally prepared for easier installation as well.

6.6 Japanese High Pressure Gas Safety Code

One module (30USRT) is under 20tons in Japanese high pressure gas safety code's capacity rating; consequently procedure for that law is not required. Even if any modules are combined such as 360USRT chillers with 12 modules, the procedure is not necessary. For the modular chiller, individual 'ton' figure of each module is used to decide whether the procedure is needed or not.

6.7 Module Capacity Control

All modules are controlled with one module controller as shown in Figure 10. The module controller determines optimum capacity-step for the modules. Each module runs at the step directed by the module controller. This multi-step capacity control allows wider operating capacity range. In case of 12 combined modules (360USRT), minimum capacity-step is 5.5% because just one module runs at unloading and the other modules stops. Moreover, this multi-step capacity control allows longer product life cycle. Lead compressor is rotated to equalize total operating hours.

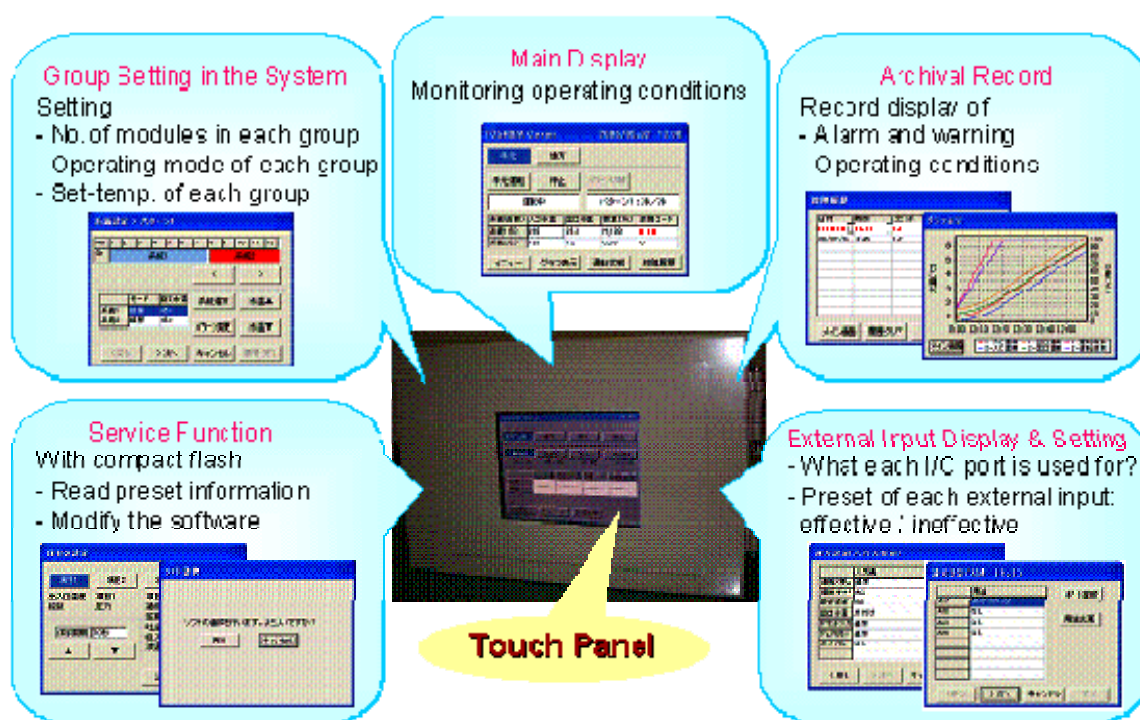


Figure 10: Module Controller

7 CONCLUSIONS

Promoting the substitution of cooling/heating and hot water supply with the fossil fuel in a high efficiency heat pump chiller can contribute to the reduction of CO₂ emissions, and can contribute greatly as a global warming measures. We developed the high efficiency large capacity heat pump chilling unit using high-efficient refrigerant R410A. This product is consisted of some 30USRT modules with X-frame chassis, which is created from study of air-flow analysis data. Optimized air distribution allows 'side by side' installation without deteriorating chiller's performance. The module can be combined from 3 to 12 modules. As a result, the unit capacity range can be expanded from 90USRT to 360USRT. The main features are as follows.

- (1) Large and wide capacity range ability by modulation.
- (2) Electric heat pump that can generate chilled/hot water.
- (3) High coefficient of performance with evaporative condensing, utilizing the evaporative latent heat of water more efficiently by nozzle spraying. The coefficient of performance is 4.8 at 35°CDB/24°CWB outdoor air temperature, 14°C entering water temperature and 7°C leaving water temperature.
- (4) Energy saving and the reduction of carbon dioxide emissions by high part load efficiency. 60% reduction of carbon dioxide emissions compared with our absorption chiller.
- (5) Simplification of installation and high installation degree of freedom suitable for renewal.
- (6) Flexible combination of heat pump and cooling only modules most suitable to the thermal load.
- (7) 24hour remote operation monitoring (Option).
- (8) Power supply to the module under maintenance can be separately shut down, so that other modules can continue to operate during the maintenance.
- (9) Productivity improvement by adopting modular design.

8 REFERENCES

2003 Standard for "Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle", p.3, Air-Conditioning & Refrigeration Institute, Virginia.