DEVELOPMENT OF HIGH EFFICIENCY LARGE CAPACITY HEAT PUMP CHILLING UNIT USING INVERTER TWIN-ROTARY COMPRESSOR "UNIVERSAL SMART X"

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Abstract: 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 CO_2 and energy consumption. We developed the high efficiency large capacity heat pump chilling unit using large capacity inverter twin-rotary compressors by the name of "Universal Smart X". This product is consisted of 30, 40 and 50HP capacity modules with X-frame chassis, which is created from study of air-flow analysis. The main features are energy saving and reduction of CO_2 emissions by the high part load efficiency.

Key Words: ***modular heat pump, coefficient of performance, inverter twin-rotary compressor, part load efficiency, X-frame chassis***

1 INTRODUCTION

Recent years, the global environment is attached to importance, and making the air-conditioning equipment efficient has accelerated. We have worked on the development of the highly efficient heat pump chilling module to contribute to the low carbon society. Especially, the use expansion to a wide usage such as further making to highly efficient modules and industrial use has been expected for our "Super-Flex module chiller (released in 2006)" though the general air-conditioning usage is mainly adopted for a lot of customers in Japan. To meet the above-mentioned market needs, our new electrical modular heat pump chiller was developed fitting user's various cooling and heating load and usages name as "Universal Smart X". In this paper, we will provide many features of this new modular chiller.

2 PRODUCT SPECIFICATIONS

Figure 1 shows product outline of "Universal Smart X" (Connect it 12 modules). "Universal smart X" achieved cooling COP 6.30 (30HP high COP type) by adopting the inverter twin rotary compressor of the largest capacity in which the maximum capacity of 12.5 considerable horsepower. The reduction of CO_2 and making the energy cost conserved were achieved by highly effective operation. Moreover, making of high performance such as an exact temperature control was achieved by having developed the optimized group control system from which two or more modules that adopted the inverter control for all compressors, built in water pumps, and fans. As a result, developed product can be used for not only the conservation of energy air-conditioning in various buildings but also can the use even of the property temperature control system such as the data server centers and the production

process temperature management in the factory to various usages, and any problem solutions of a productivity enhancement and a steady quality. Table 1 shows the product specification. This product prepares each ability machine 30, 40, and 50HP, and the series for the heat pump and cooling only is prepared respectively, and two kinds (a standard type and the high COP type (with evaporative condensing mode)) are prepared. In addition, because the ability to match to the required capacity by combining the module, the optimization of the power supply capacity becomes possible as a result. Moreover, many special specification models are prepared, and it meets the user needs.



Figure 1: Product outline (Connect it 12 modules)



1. **Wider Capacity modulation range.**
   （Achieve high efficiency part load operation ）
2. **Perform high efficiency for wider range**
   (Improve energy consumption by using high efficiency DC motor and Rotary compression system)
3. **High Power weight ratio**
   (Perform maximum 12.5HP capacity by the size of 5HP fixed speed compressor dimension)
4. **High design and production technology**
   (Perform lower oil discharge amount, high performance and reliability)

Figure 2: Inverter twin rotary compressor

Table 1: Specifications (one module)

Items		Specifications					
		Standard Type			High COP Type *3)		
		30HP	40HP	50HP	30HP	40HP	50HP
Cooling Mode *1)	Capacity(kW)	85.0	118	150	85.0	118	150
	COP *4)	3.97	3.54	3.07	6.30	5.62	4.78
Heating Mode *2)	Capacity(kW)	85.0	118	150	85.0	118	150
	COP *4)	3.94	3.72	3.41	3.94	3.72	3.41
Cooling and Heating Average COP		3.96	3.63	3.24	5.12	4.67	4.10
Refrigerant		R410A					
Dimensions		Depth 3,400 x Width 1,080 x Height 2,300					
Shipping Weight(kg)		1340	1340	1365	1350	1350	1375

*1) Rated cooling conditions are entering water temperature 14degC, leaving water temperature 7degC, and outdoor air temperature 35degC.
*2) Rated heating conditions are entering water temperature 38degC, leaving water temperature 45degC, and outdoor air temperature 7degC/6degC (dry bulb/wet bulb).
*3) At evaporative condensing mode in Cooling Mode.
*4) Coefficient of performance (cooling capacity / input or heating capacity / input).

The module can be combined up to 12 and the combined modules can work as one chiller.

3 MAIN FEATURE

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 Expansion of the range of heat pump usage

The expansion of the range of operating envelope and capacity modulation and the stability improvements of the water supply temperature were attempted by adopting the new inverter twin rotary compressor. As a result, the water supply of cooling and heating in the middle temperature region (range of 25-30degC) that was not able to correspond by our current product so far became possible, and the introduction of the heat pump was enabled to new fields of the usage and various waste water treatment plants, the snow melting systems, food processing and the machine cooling systems etc.
Moreover, "Module in module" design that composed one module of four independent refrigerant circuits as shown in Figure 3 was newly adopted. Capacity and water temperature stabilization and diversification of risks were achieved at as other refrigerant circuits operated the high power backup operation even when one another refrigerant circuit stopped and decentralization of defrost operation. The extension in the industrial area such as heated swimming pool and the painting preprocessing process, etc. is expected by achieving stable warm water temperature supply for the heating operation in summer (Correspond up to the highest outside temperature degree 43degC) through the year.

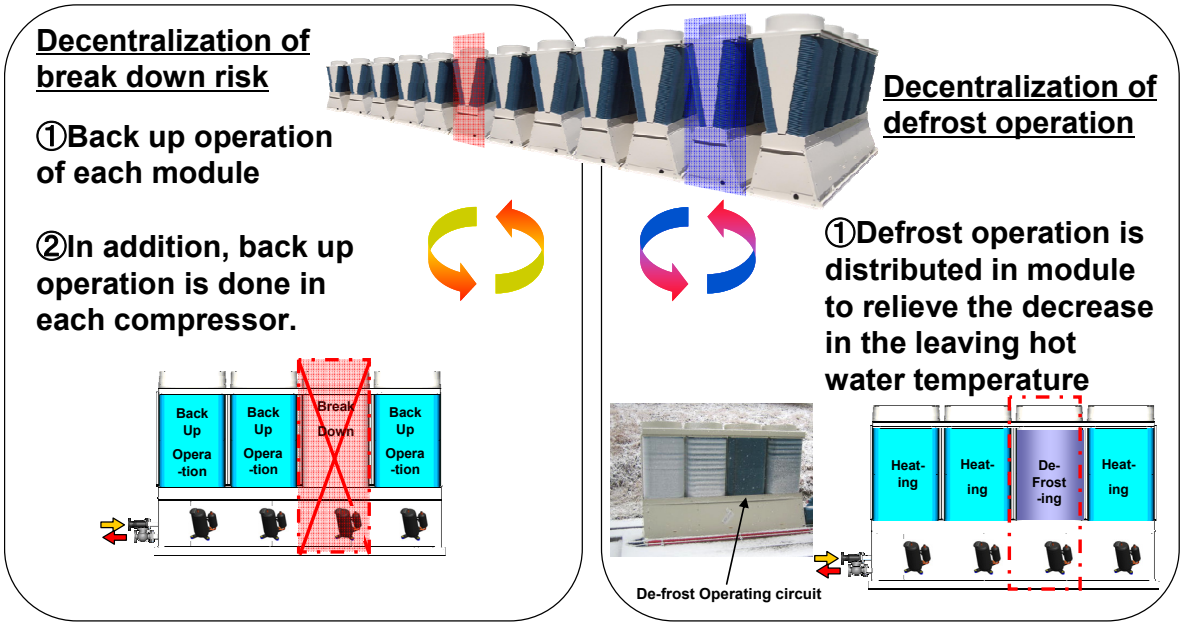


Figure 3: Benefit of "Module in Module" design

3.2 Cooling COP 6.30 of an average turbo chiller level

Figure 4 shows elemental technology of making high effective and performance of "Universal Smart X". In the high COP type of 30HP, COP 6.30 which almost equals to turbo chiller (TOSHIBA Carrier RS-C series) performance was achieved with an air-cooled chiller.
Figure 5 shows COP characteristics of 30HP module and Figure 6 shows transition of part load efficiency improvement of our products from 1995. Adopting of inverter compressor and

highly effective operation including the fan and build in water pump, IPLV 7.50(*5) was achieved for the high COP type of 30HP.

*5) IPLV(Integrated Part Load Value) is an index where the operating efficiency of the chilling unit through year is shown by the result coefficient of the period provided by ARI (United States Refrigeration and Air Conditioning Industry Association) 550/590 – 2003.

IPLV in that case becomes 6.96 (calculation by 14degC at the entering cold water, the leaving cold water 7degC, and the variable water volume for the high COP type of 30HP) though The Japan Refrigeration and Air Conditioning Industry Association JRA 4062:2010 "Calculation standard of integrated Part Load Value of the heat source machine for air-conditioning" was enacted in September, 2010.

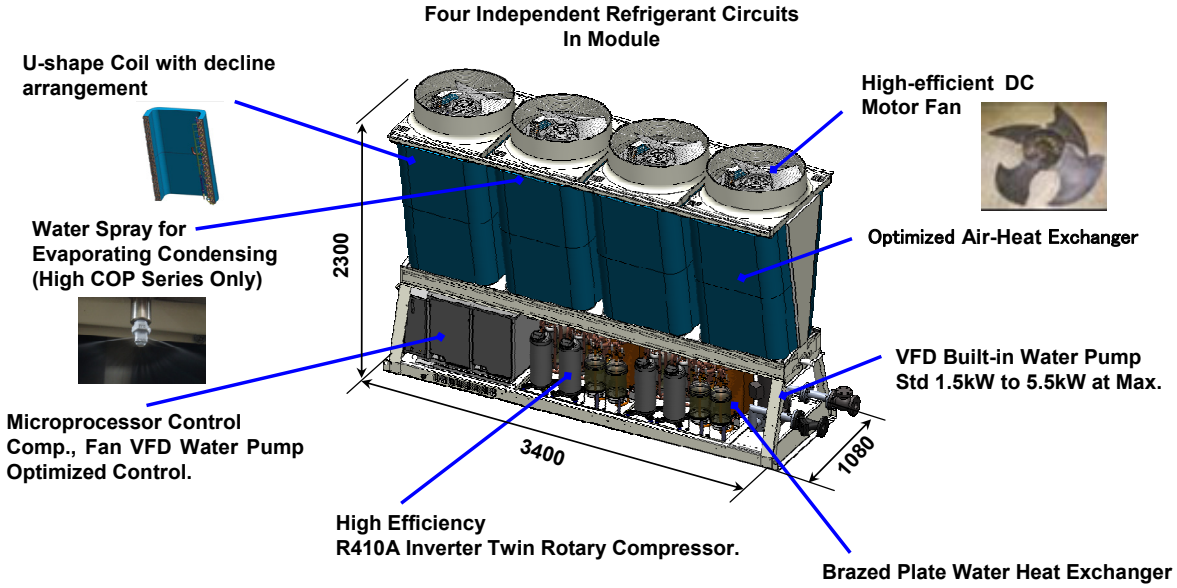


Figure 4: Elemental technology of making High effective and performance

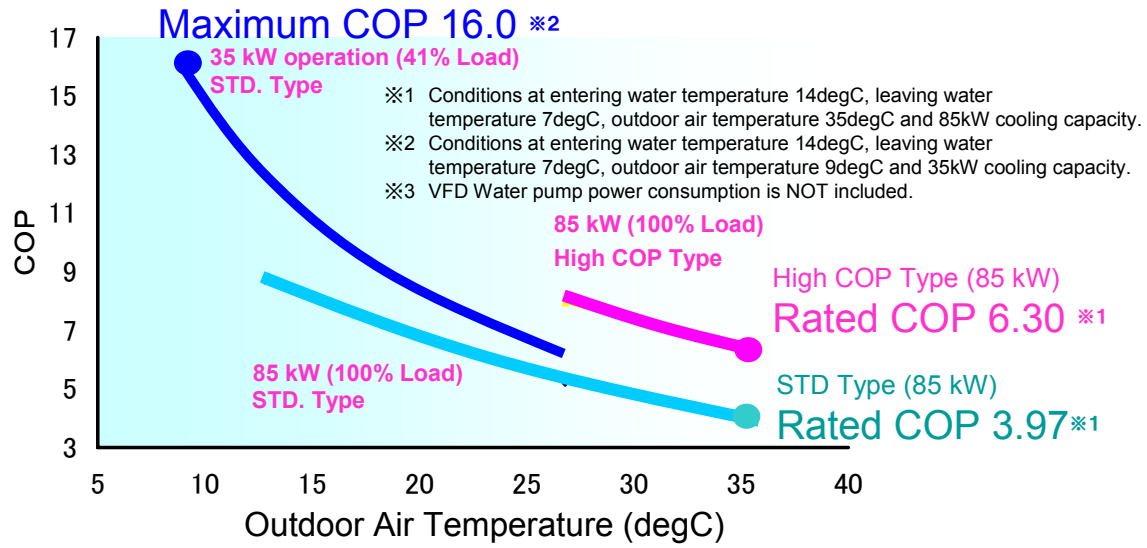


Figure 5: Rated and Part Load operating efficiency (30HP module)

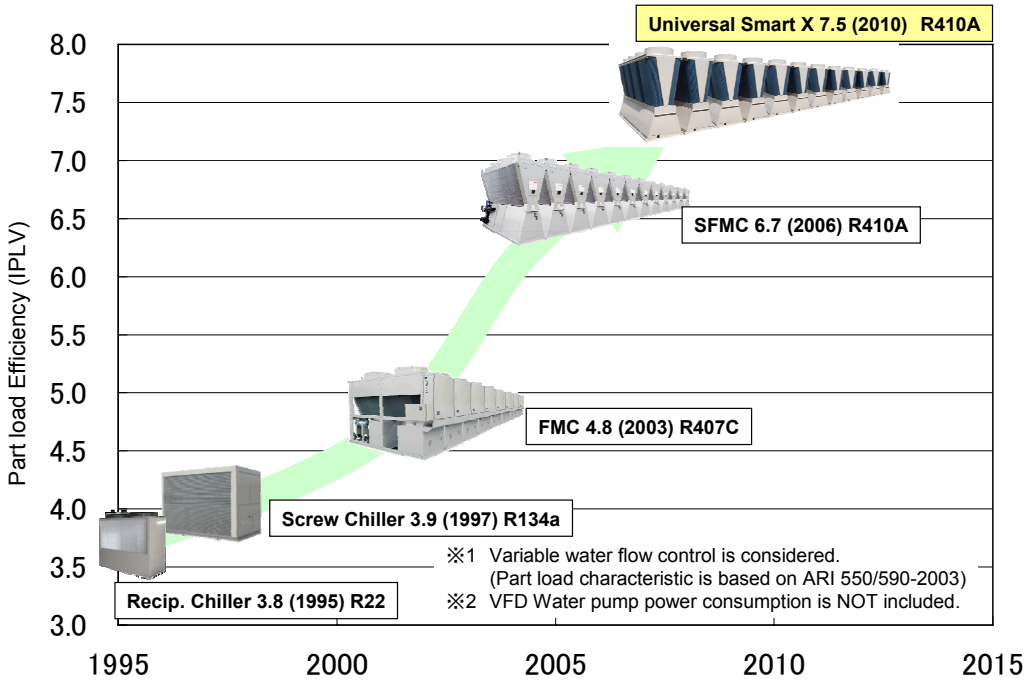


Figure 6: Transition of part load efficiency improvement

One of the big factors to achieve making to highly effective includes the improvement of the partial load performance of the compressor. Figure 7 shows the relations between the rotor rotation angle and the refrigerant pressure of the scroll compressor used for our chiller and the rotary compressor newly adopted for “Universal Smart X”.
For a general scroll compressor, the over-compression might be caused because of it operates a fixed compression volume ratio, and the energy loss is generated in case of the operating condition changes from its design point. On the other hand, because the rotary compressor is operating a changeable compression volume ratio, and the discharge pressure changes according to its operating condition, extra compression is not done. Therefore, a higher partial load efficiency operation becomes possible by combines the rotary compressor and inverter control. Other factors of higher efficiency include the optimization of the rotational speed control of the fan etc.

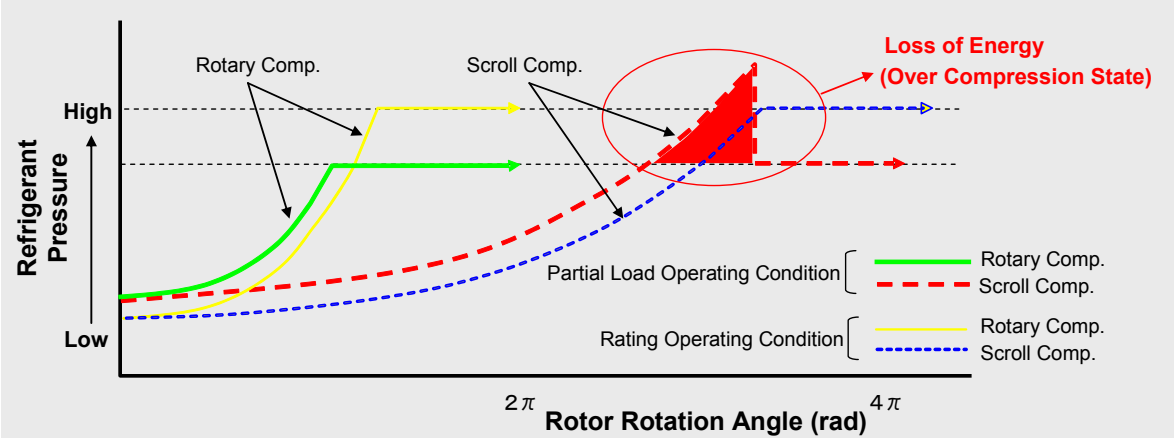
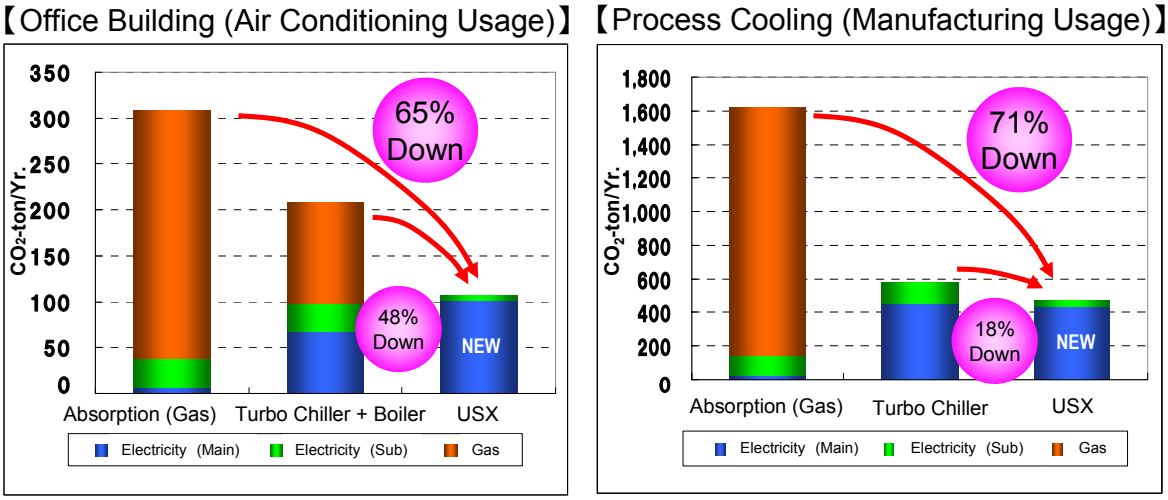


Figure 7: Comparison of compression process of compressor

Figure 8 shows the trial calculation results about the effect of the CO_2 amount reduction. Trial calculation was performed for two different applications. One is office building where both cooling and heating operation and another is process cooling (manufacturing usage) that did only the cooling operation are done through the year.

In this calculation, CO_2emission intensity is 0.332kg-CO_2/kWh based on Tokyo Electric Power Company's data in 2008. Compared to the absorption chiller, which is the most influential competitor against the developed chiller, CO_2 emission can be reduced 65% for office building and 71% for process cooling. Compared to the turbo chiller, CO_2 emission can be reduced 48% for office building because of boiler can be eliminated and 18% for process cooling. It is possible to contribute to the CO_2 amount reduction by both office building (air-conditioning) and industrial area. It is not only a power reduction of the main components of the products such as compressors but also one of the big features is to reduce the water transportation power by the inverter control of the built in water pump becomes possible.



(a) Office building **(b) process cooling**

Figure 8: Comparison of CO_2 emission

The trial calculation condition is as follows.

[Office building]

Estimated Scale	: 800m^2 (130W/ m^2)	
Peak Load	: Cooling 1,020 kW	Heating 668 kW
Operating period	: Cooling April – October	Heating November – March
Operating days, hours	: 5 days / week 14 hours / day	

[Process Cooling]

Estimated Scale	: Constant Cooling load
Peak Load	: Cooling 1,020 kW
Operating period	: Cooling April – December
Operating days, hours	: 7 days / week 24 hours / day

[Common conditions for both trial calculations]

CO_2emission intensity	: 0.332 kg-CO_2/kWh (Tokyo Electric Power Company's data in 2008)
	: 2.29 kg/Nm^3
Outdoor temperature	: Based on average temperature of TOKYO, Japan (2000-2005)
Absorption Chiller System	: TAG-NL032 with cooling tower (cooling fan input) Water pump (cooling water and chilled/hot water)
Turbo Chiller System	: RS-C30EV with cooling tower (cooling fan input) + Boiler Water pump (cooling water and chilled/hot water)
"Universal Smart X"	: 30HP x 12 modules with Water pump (chilled/hot water)

3.3 Flexible group control system

A flexible system control that corresponds to a super-large-scale article up to 4800 HP is achieved. New designed group controller (optional parts) is able to integrate up to 96(12 connection and 8 groups) modules as shown in Figure 9. The controller can operates two or more systems like the single heat source system and achieve the best conservation of energy operation control. It also enabled 24hour remote operation monitoring (Option) and

operation monitoring by user's personal computer by the WEB monitoring function etc, and achieve the "Implementation of visual control" that is useful for the conservation of energy management.

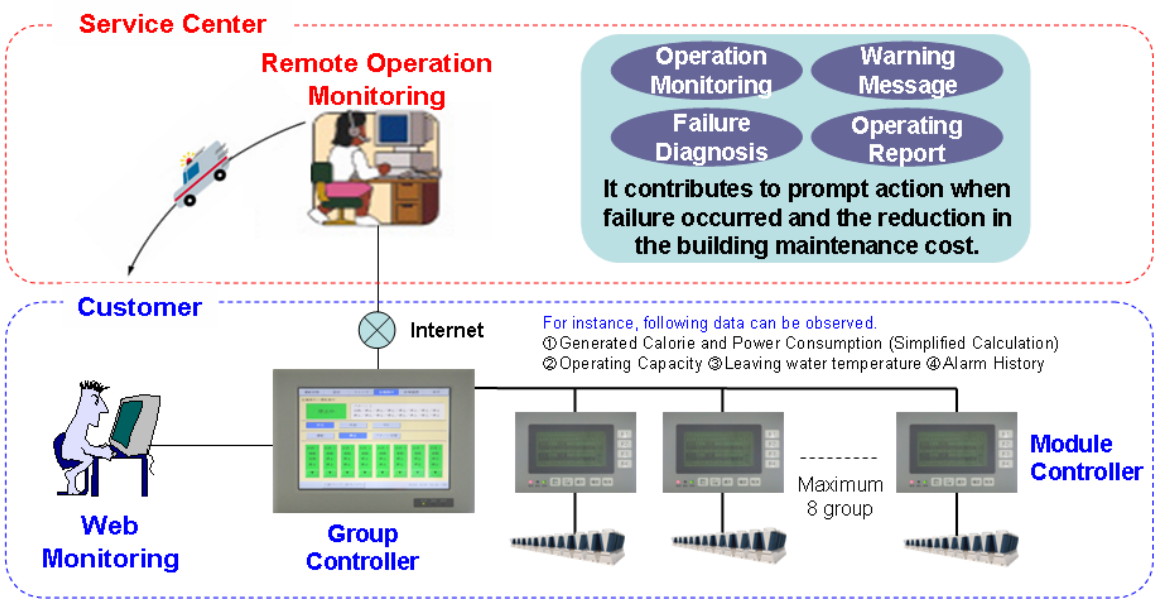


Figure 9: Group controller and system management

4 FURTHER USE EXPANSION FOR INDUSTRIAL USAGE

"Universal smart X" is made the best use of the above-mentioned feature, and can fit user's various needs exceeding the concept of our current chiller. It became available further more widely not only the air-conditioning usage but also an industrial areas.

For instance, the user who wants to reduce the use of the boiler for constant temperature and humidity air-conditioning system shown in Figure 10 can achieve all electrification by the cooling and heating module coexistence operation such as some module operates cooling mode and other modules operated heating mode in one group. As a result, not only the CO_2 amount reduction but also the simplification of the operation and maintenance can be attempted.

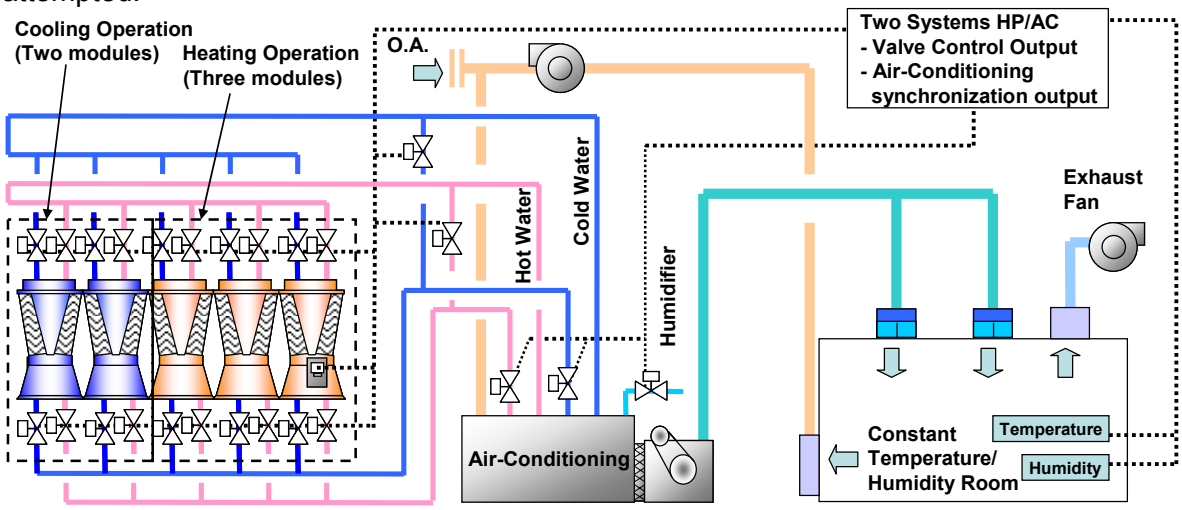


Figure 10: Constant temperature humidity air-conditioning system with steam free

Or, the temperature management in the aeration and digestion tank corresponding to the situation can activate bacteria of waste water treatment to the user who wants to raise the

performance of waste water treatment according to an increase of production by the expansion of the water temperature range as shown in Figure 11.

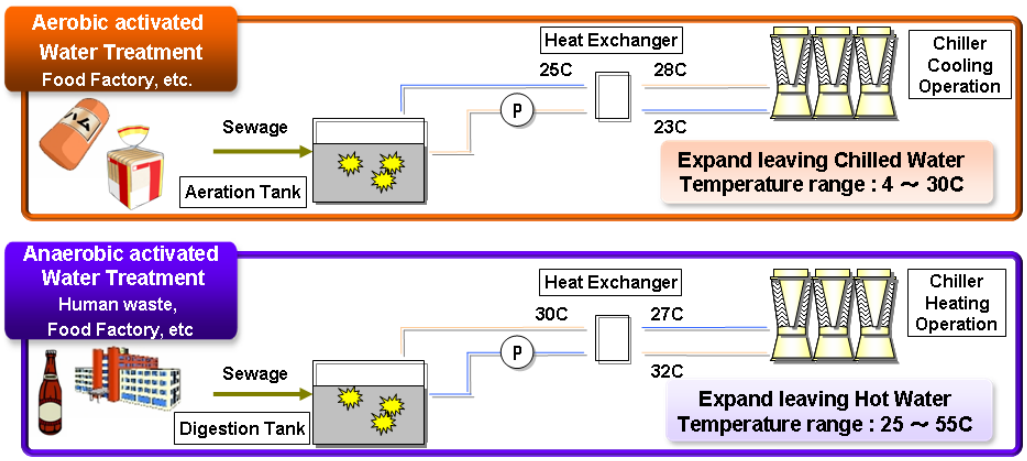


Figure 11: Temperature control fit to its production system

5 EXAMPLE OF WATER SYSTEM USAGE

Figure 12 and Figure 13 show the example of the primary pump system and the secondary pump system. The control has improved to our current chiller that detects only a water temperature to do the control that detects necessary water flow quantity on the load side in both water systems. Control procedure of the built in water pump and the compressor are as follows;

* Built in inverter water pump operation : To approach necessary water flow quantity on the load side, the number of operating pumps and the operating flow volume are controlled.
* Compressor : To approach necessary leaving water temperature of each modules, the number of operating compressors and the operating capacity are controlled.

In addition for the primary pump system, variable water pressure and flow rate control can be enabled by controlling not only build in water pump but also the differential pressure by-pass valve by “Module Controller”, and it contribute to conservation of energy further more.

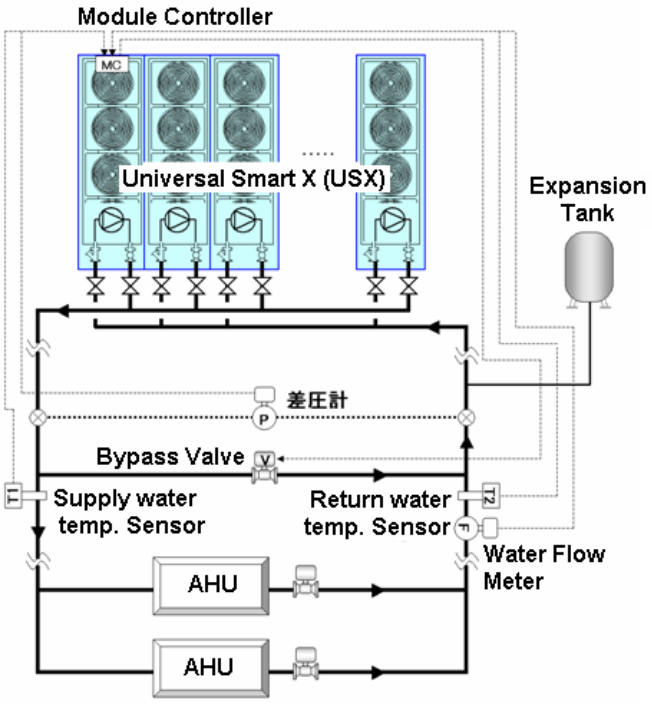


Figure 12: Example of Primary pump system

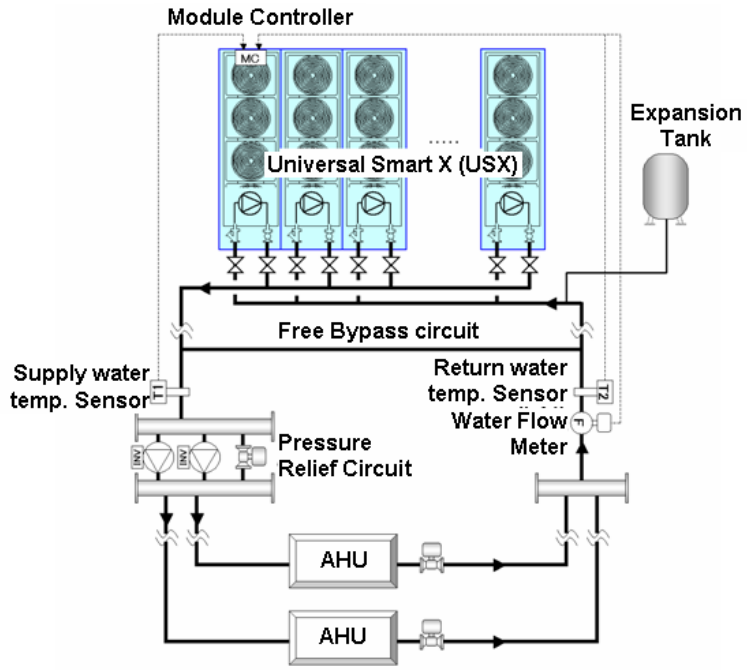


Figure 13: Example of Secondary pump system

6 CONCLUSIONS

We developed higher efficiency products name of "Universal Smart X", and it came to be able to fit various needs from customer by preparing following features.

(1) Perform wider operating envelope and capacity range by adopting New developed large capacity inverter twin-rotary compressors.
(2) Energy saving and the reduction of carbon dioxide emissions by high part load efficiency.
(3) One module is consist of four independent refrigerant circuits by the name of ”Module in Module” design and it can perform stable leaving hot water by dispersing defrost circuits.
(4) High coefficient of performance with evaporative condensing, utilizing the evaporative latent heat of water more efficiently by nozzle spraying.
(5) Flexible combination of H/P and C/O modules most suitable to the thermal load.
(6) New developed group controller (option) can combine maximum 96 modules (12 modules x 8 group) and perform integrate control.
(7) New developed group controller (option) can prepare 24hour remote operation monitoring and Web monitoring.

7 REFRERNCES

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

JRA 4062:2010 : "Calculation standard of integrated Part Load Value of the heat source machine for air-conditioning", Japan Refrigeration and Air Conditioning Industry Association.