MITSUBISHI ELECTRIC

Changes for the Better

Mr.SLIM Hyper Heating POWER INVERTER ZUBADAN R410A

Zuba-Dan Inverter

New Mr.SLIM Inverter
for colder climate regions

Mitsubishi Electric Corporation
Shizuoka Works

2007 JSRAE Technology Award

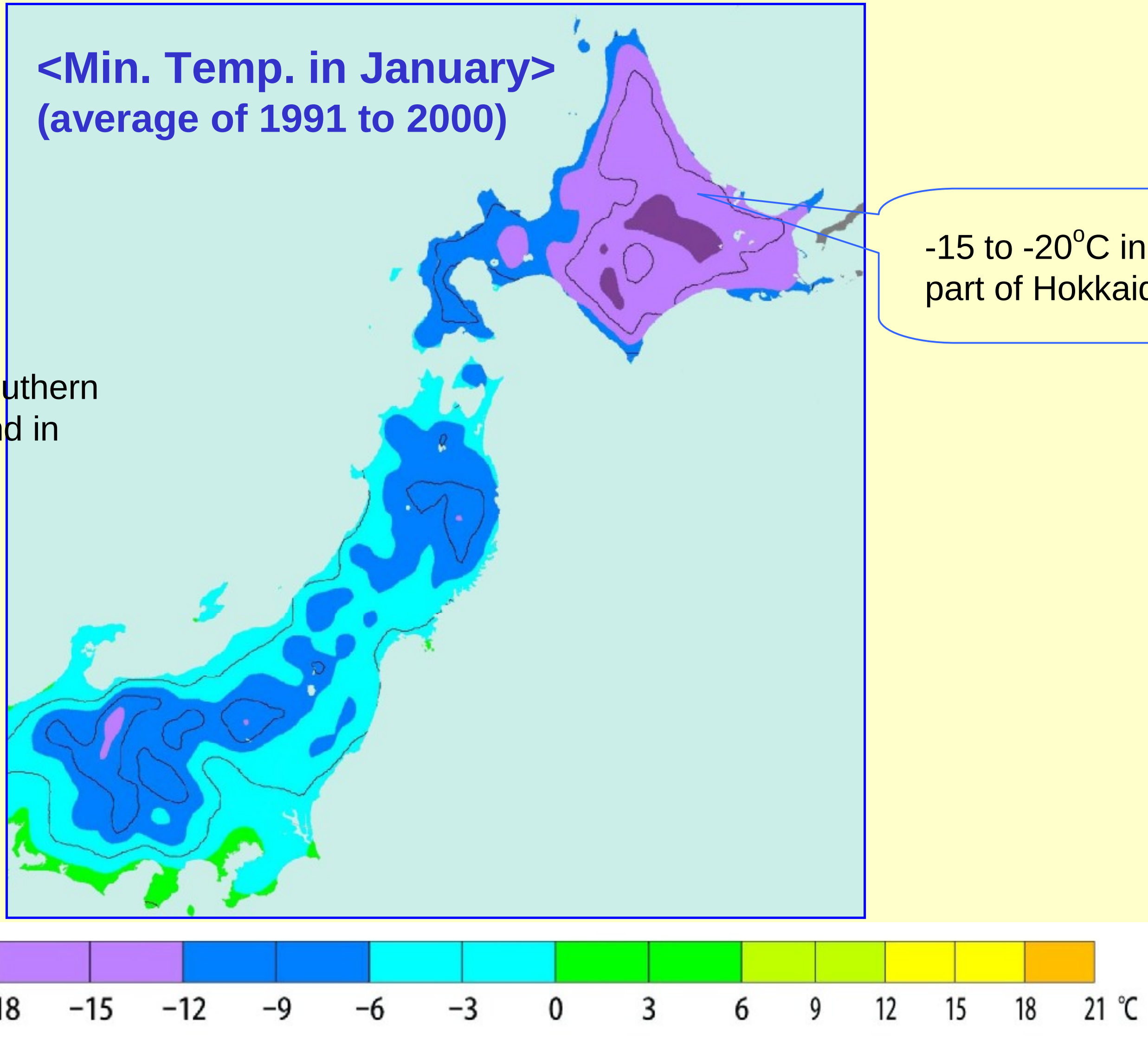
Mr. SLIM Zuba-Dan Inverter models

1. Development background
2. Features of Zuba-Dan models
3 Flash Injection Cycle & its characteristics
4. Improvement on Start-up & Defrost
5. Field Test Result
6. Summary

1. Development Background

Mr.SLIM Hyper Heating POWER INVERTER ZUBADAN R410A

1. Development Background

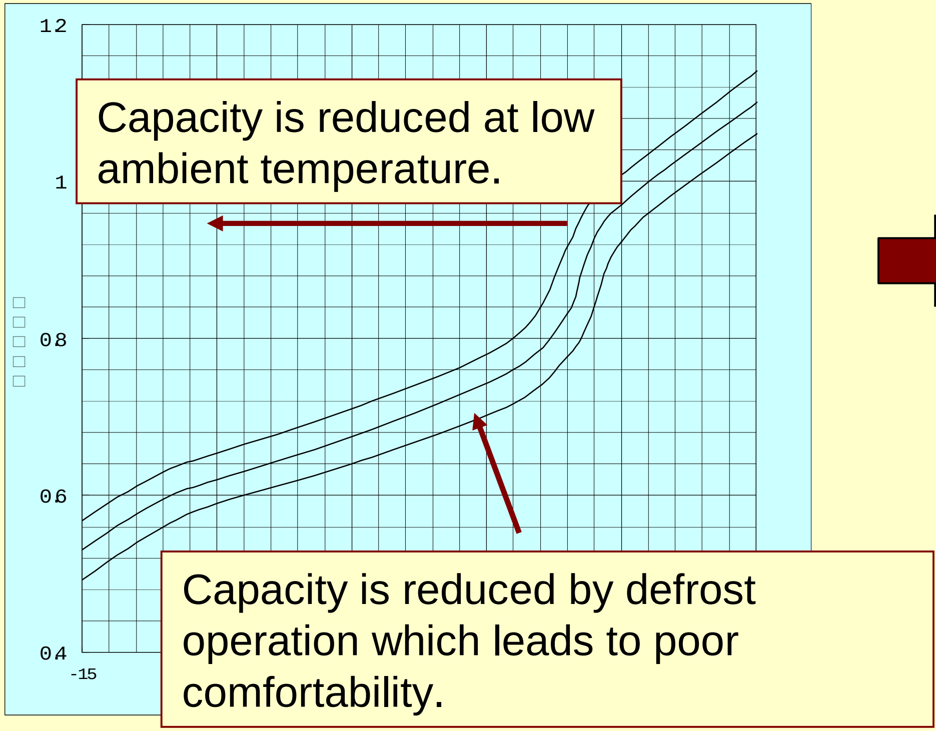


-15 to -20°C in Northern part of Hokkaido.

Around -10°C in Southern part of Hokkaido and in Tohoku region

1. Development Background

<in case of **Standard Heat Pump** air conditioner>



Heating Peformance Curve

- Electric heater assisted indoor unit
- Burner assisted indoor unit
- Liquid injection Heat Pump

1. Development Background

Challenges for Heat Pump

*Poor performance at low ambient temperature.
*Room temperature goes down during defrost.
Slow in starting up.
*Not adequate for use in northern part of Hokkaido.

Electric Heater assisted A/C

> Low in operation efficiency.

Burner assisted A/C

> Periodical servicing is required for burner.
> Requires big installation space.
> Big amount of the initial investment.

Liquid INJ COMP mounted A/C

> Limited in injection amount
(discharge temperature goes down too much)
> Operation efficiency should be improved
during injection.

Required functions for A/C for cold climate regions

(1)No periodical servicing is required.

(2)Keeps good performance even at low ambient temperature.

(3)Highly efficient operation at low ambient temperature.

(4)No drop in room temperature while defrosting.

(5)Can be used in all areas in Hokkaido.

solution: Zuba-Dan

2. Features of Zuba-Dan models

2. Features of Zuba-Dan models

(1)High heating capacity at low ambient temperature

Our **'Flash Injection cycle'** (patent to be filed) enables to **keep the maximum heating capacity even at -15°C.**

(2)Comfortability

*__Improved defrost control__:
Defrost duration is reduced to one third of the conventional model.

*__Quick start-up__:
Required time to reach the air blowing temperature of 40°C is halved.

(3)Wider operation range <Industry First!>

Heating operation even at -25°C is possible. (conventionally only to -20°C)
> Possible to be used in all areas in Hokkaido.

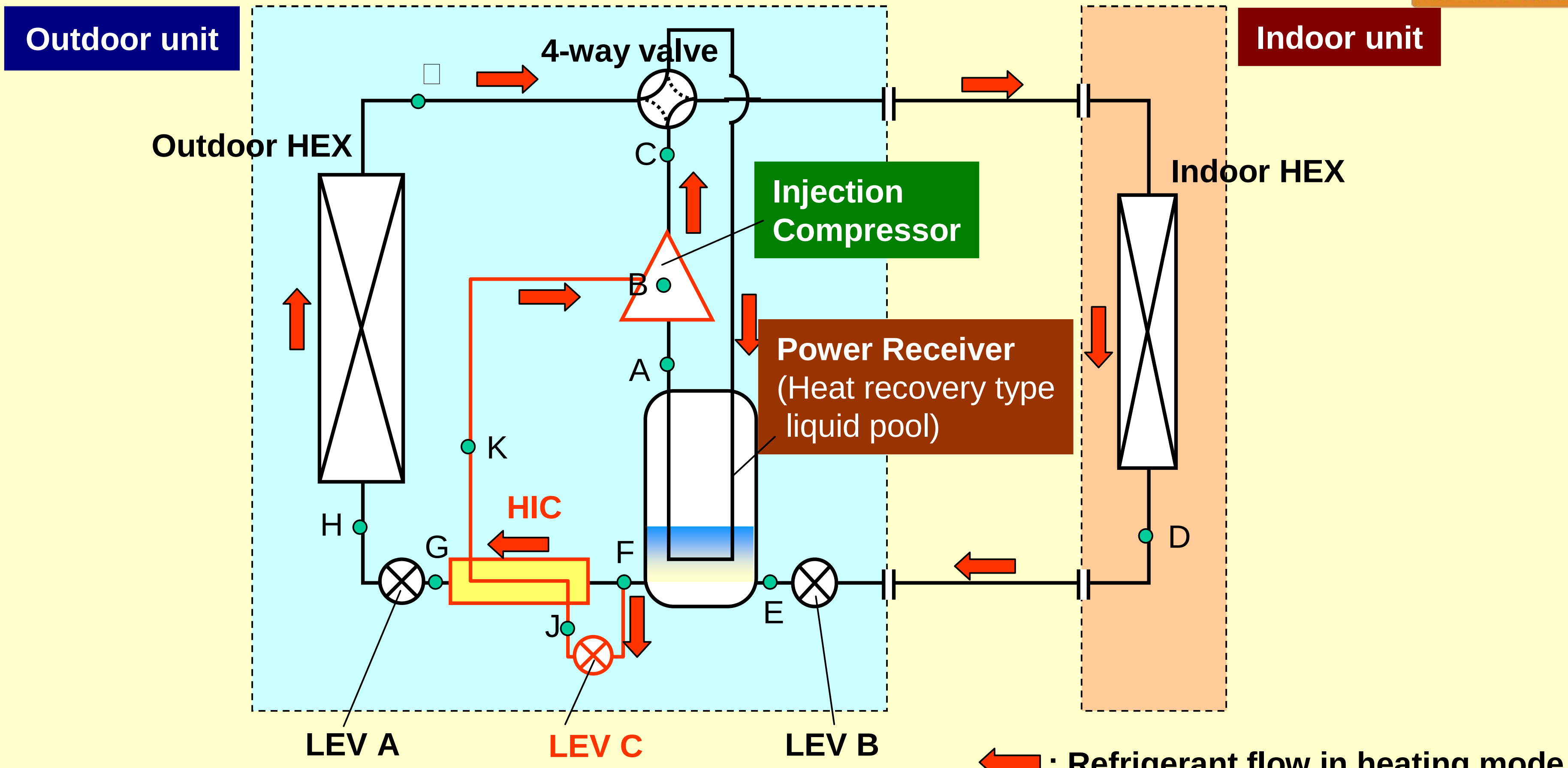
(4)Easy and quick installation <Industry First!>

The **'Activated carbon filter'** and the '**Wide strainer**' enable the **reuse of existing piping** even when the compressor is broken and the refrigerant oil is contaminated.

3. Flash Injection Cycle & its characteristics

3. Zuba-Dan refrigerant circuit

<Flash Injection + Power Receiver Circuit>

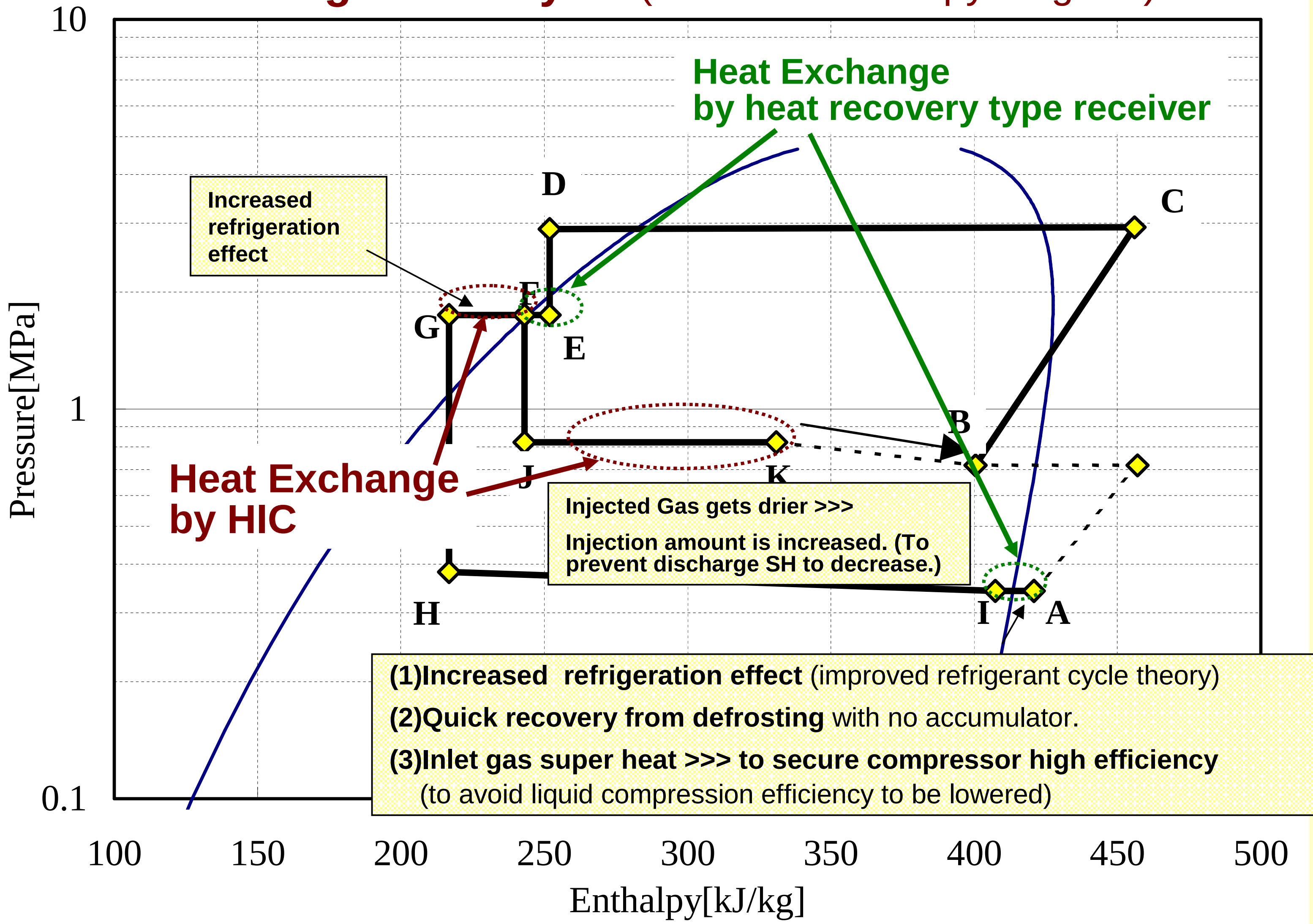


<Characteristics>

***Flash Injection** of refrigerant. Refrigerant heat is recovered by **HIC circuit**.
***Power Receiver circuit** without inlet accumulator (good in start up / inlet dry control)
***3 LEVs** optimally control evaporator, condenser and discharge temperature.

3. Zuba-Dan refrigerant circuit

<**Zuba-Dan refrigeration cycle** (Pressure-Enthalpy diagram)>



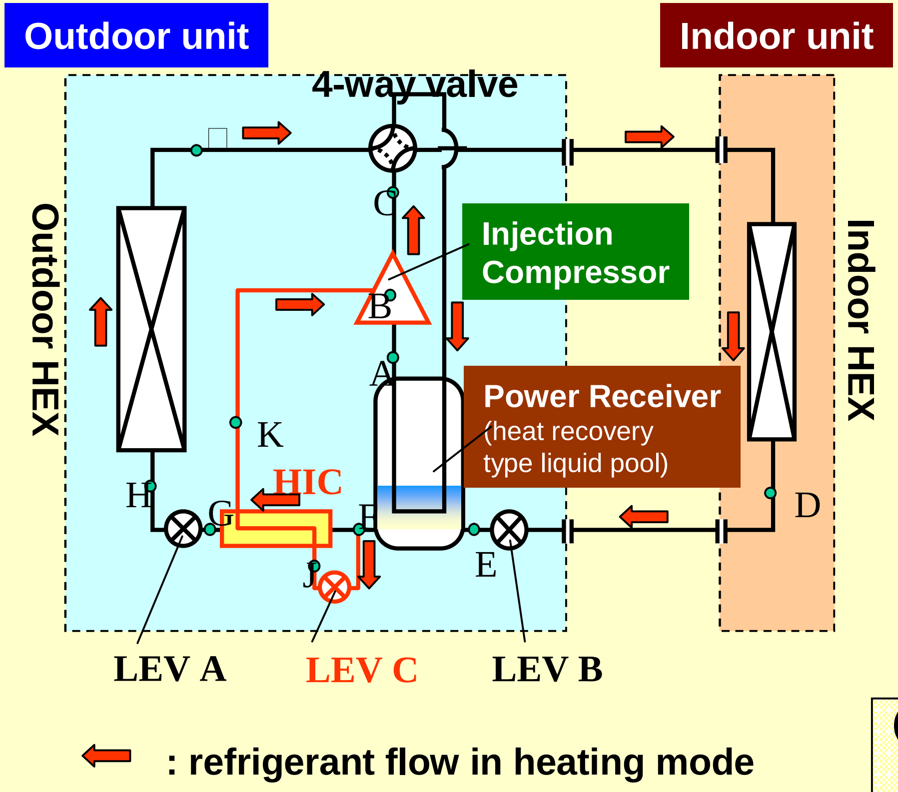
(1)Increased refrigeration effect (improved refrigerant cycle theory)

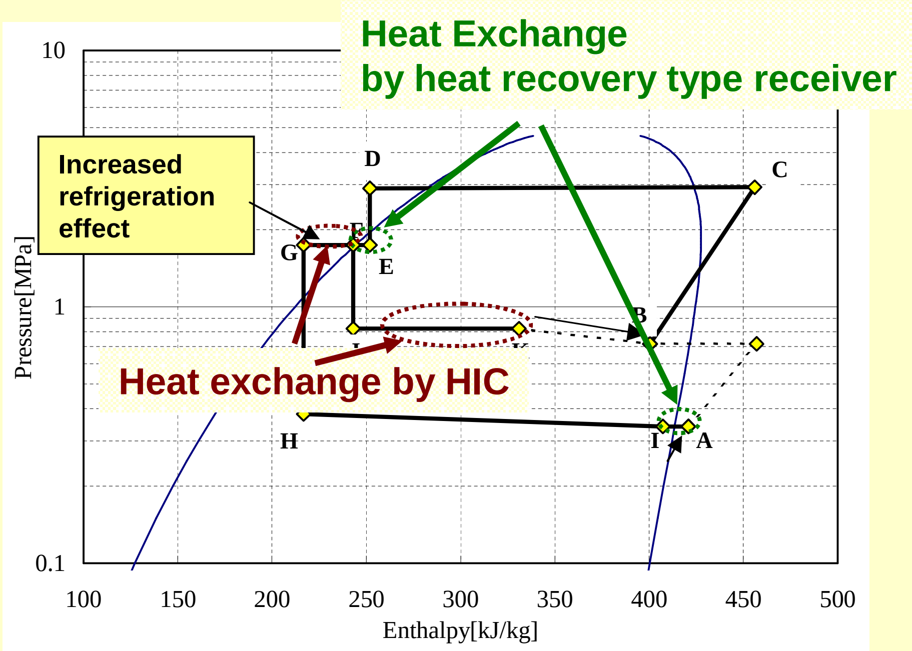
(2)Quick recovery from defrosting with no accumulator.

(3)Inlet gas super heat >>> to secure compressor high efficiency
(to avoid liquid compression efficiency to be lowered)

3. Zuba-Dan refrigerant circuit

<Flash Injection Cycle>





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>>> to secure compressor high efficiency
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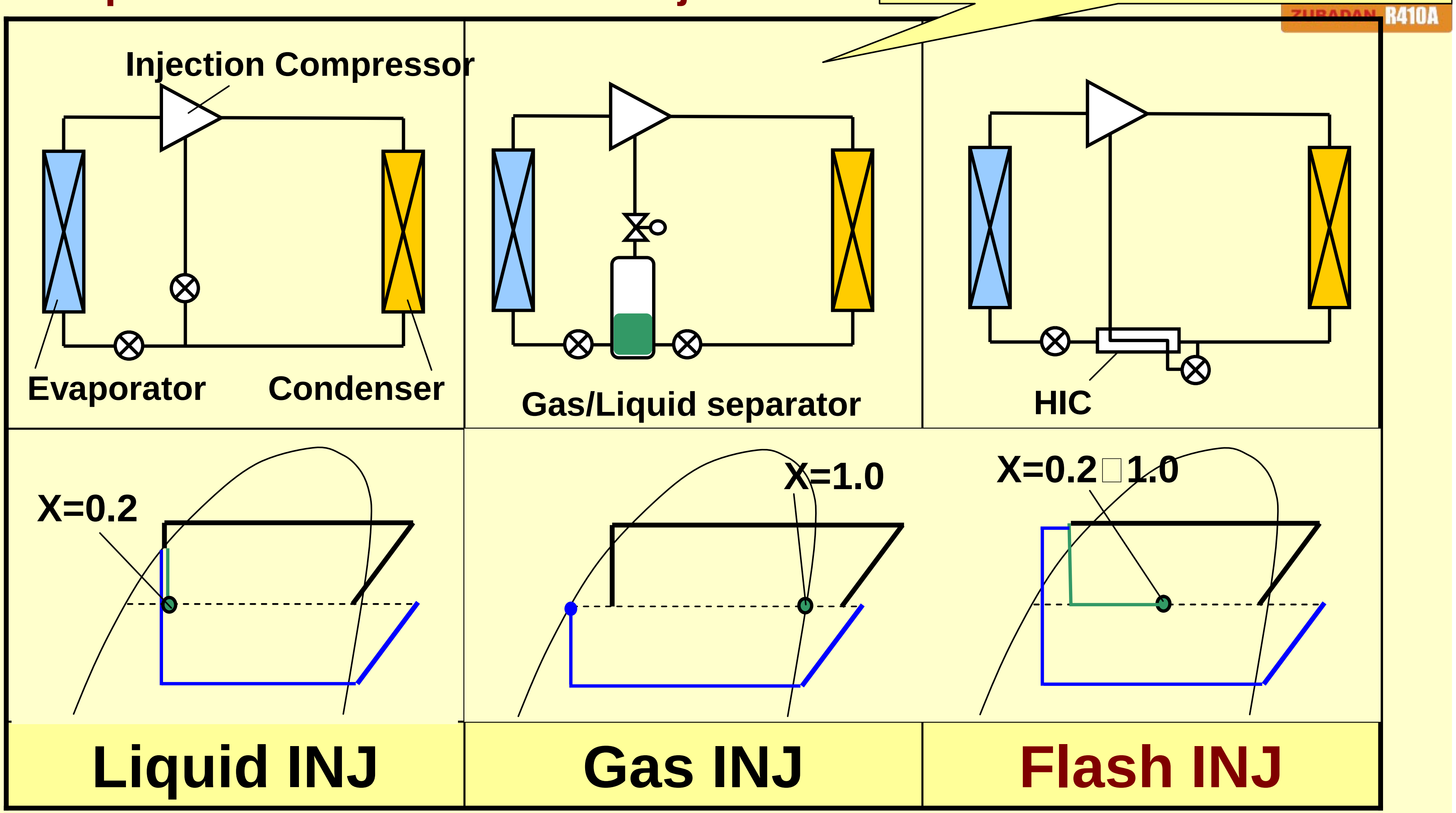
3. Zuba-Dan refrigerant circuit

<Comparison with conventional injection>

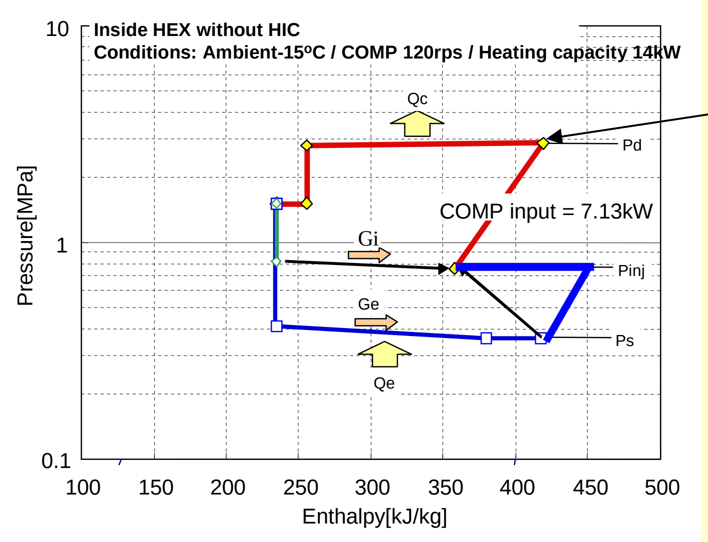
Discharge temperature increases
>>> capacity cannot be increased a lot
= not suitable for a/c for cold regions.



3. Zuba-Dan refrigerant circuit

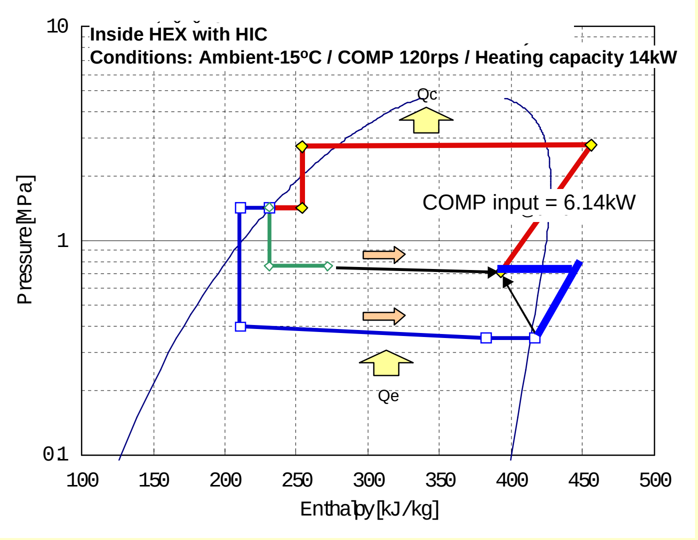
<Comparison of Flash INJ with Liquid INJ (same capacity basis)>

Liquid INJ
(w/o HIC)



Big amount of liquid injection
>>> discharge temperature
decreases.

Flash INJ

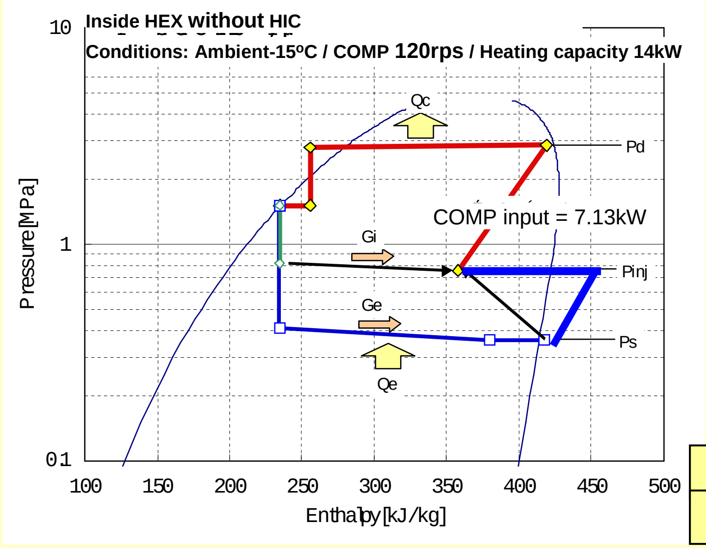


Inlet gas gets drier
>>> discharge SH
can be secured.

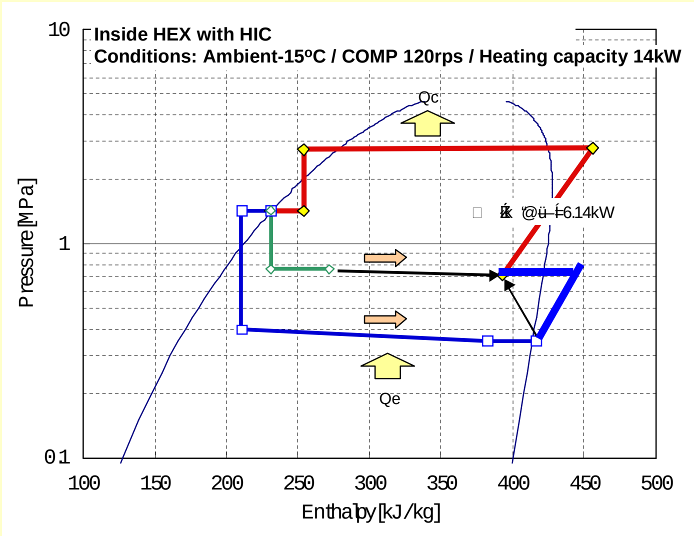
3. Zuba-Dan refrigerant circuit

<Flash Injection circuit>

Liquid INJ (w/o HIC)



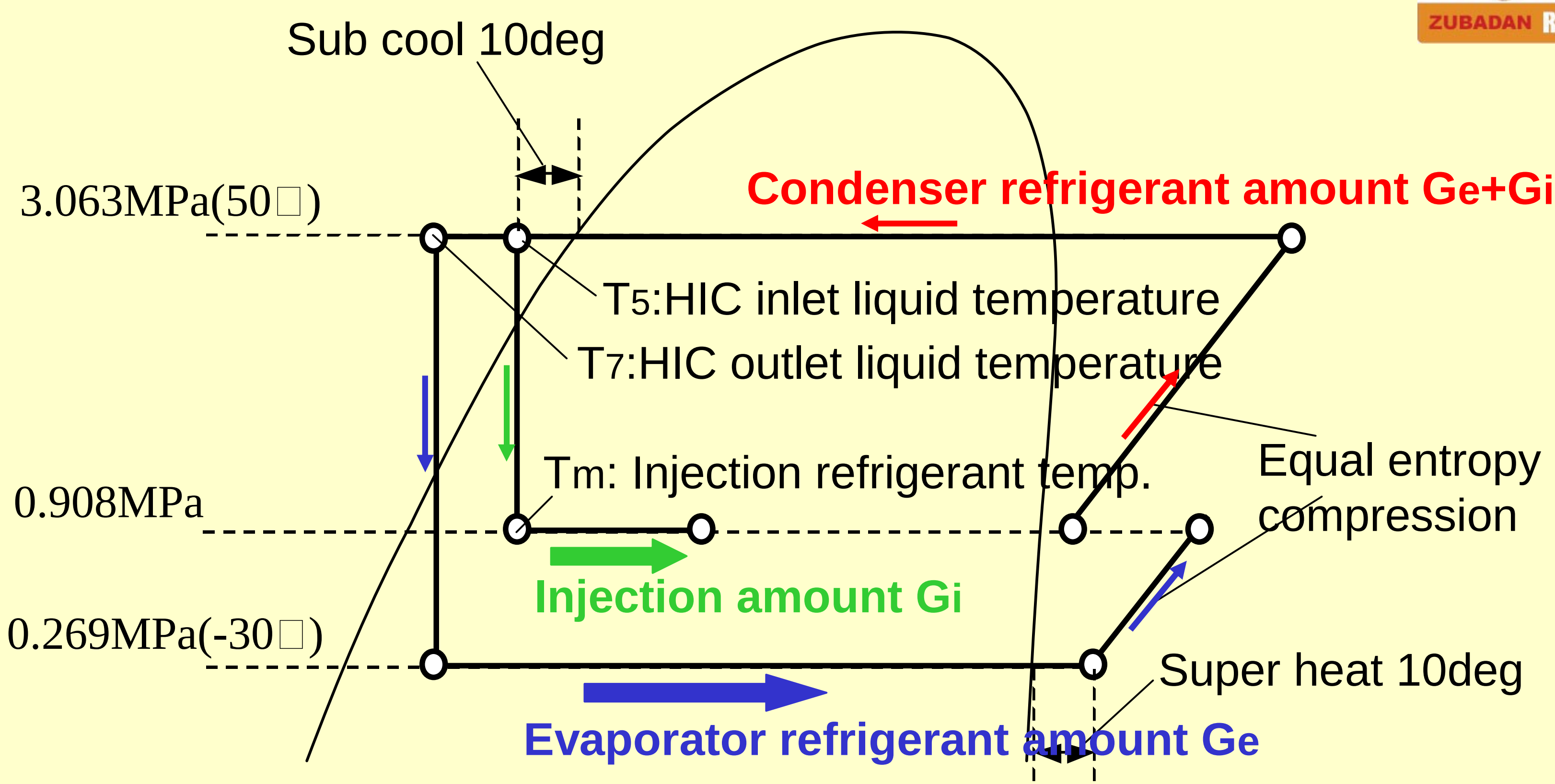
Flash INJ



		with HIC	w/o HIC
Ge	kg/h	168 4	174 2
Gi	kg/h	84 4	137 4
discharge SH	deg	20	0
COMP rotation	rps	120	120
Qc	,W	14 00	14 00
Qe	kW	8 03	7 01
input	kW	6 14	7 13
cop	□ |	2 28(116%)	1 96(100%)

3. Zuba-Dan refrigerant circuit

<Theoretical characteristics: calculation conditions>

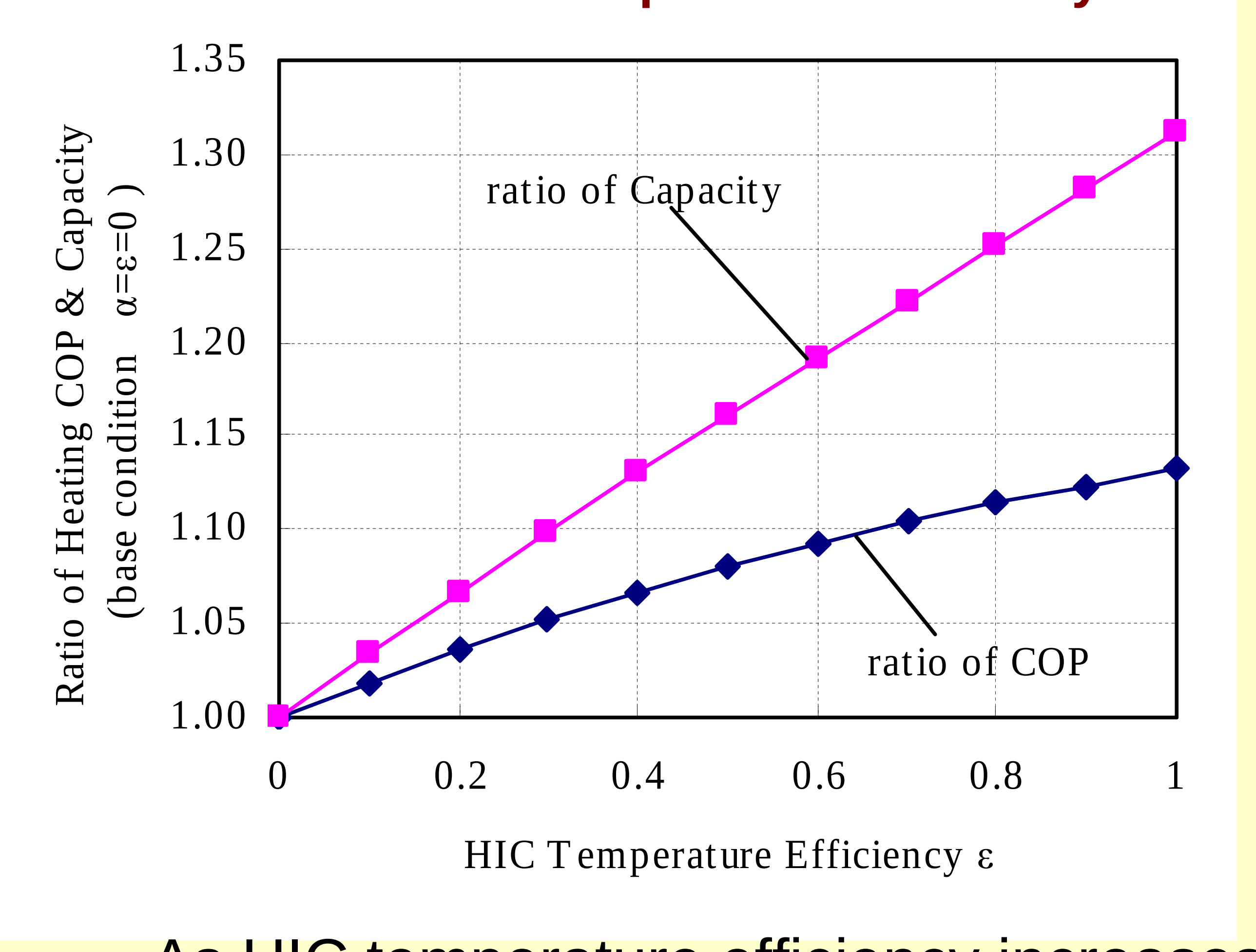


*Pomer množstiev $\alpha = G_i/G_e$

*HIC temperature efficiency ε $\varepsilon = (T_5 - T_7)/(T_5 - T_m)$

3. Zuba-Dan refrigerant circuit

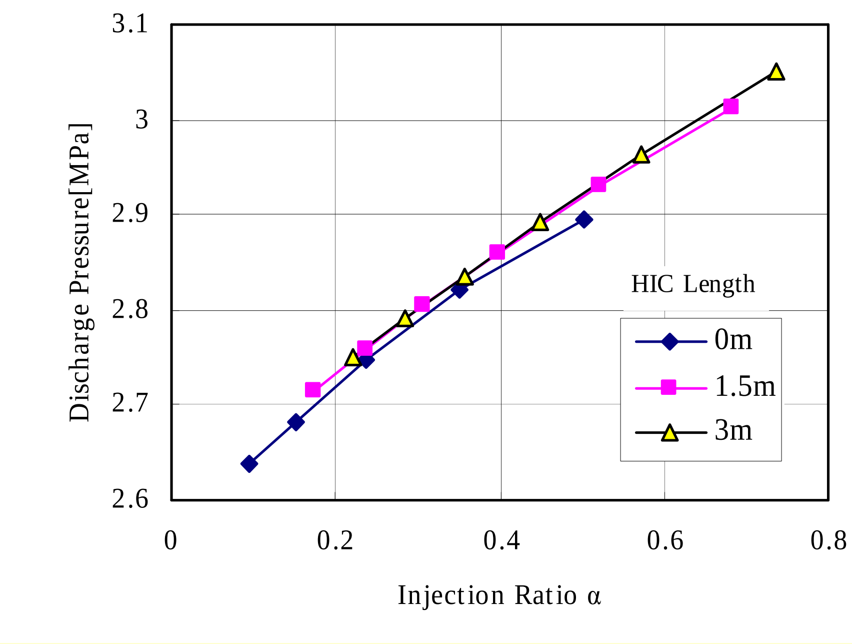
<Theoretical characteristics: temperature efficiency influence>

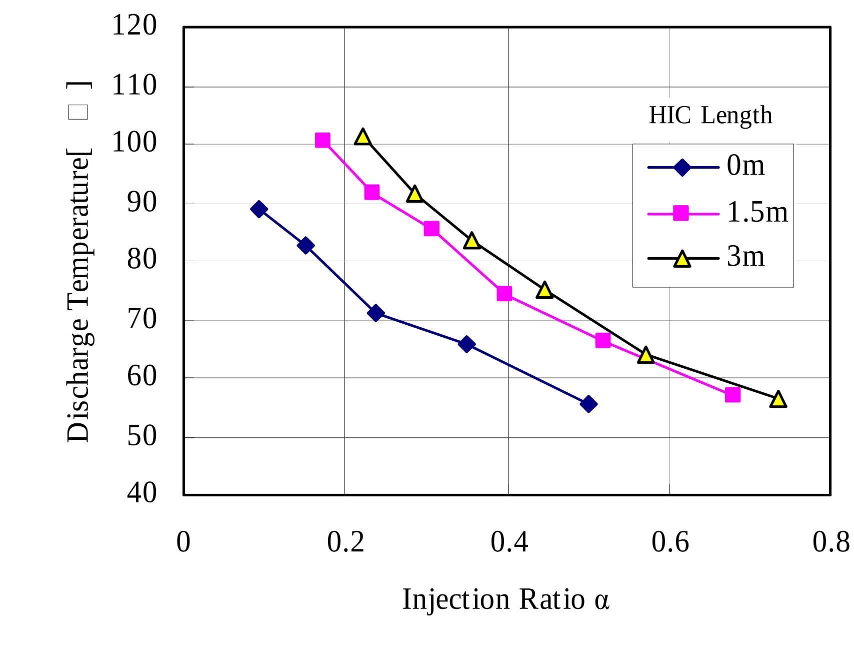


As HIC temperature efficiency increases, heating capacity and COP also increase.

3. Zuba-Dan refrigerant circuit

<Test Result (1)>



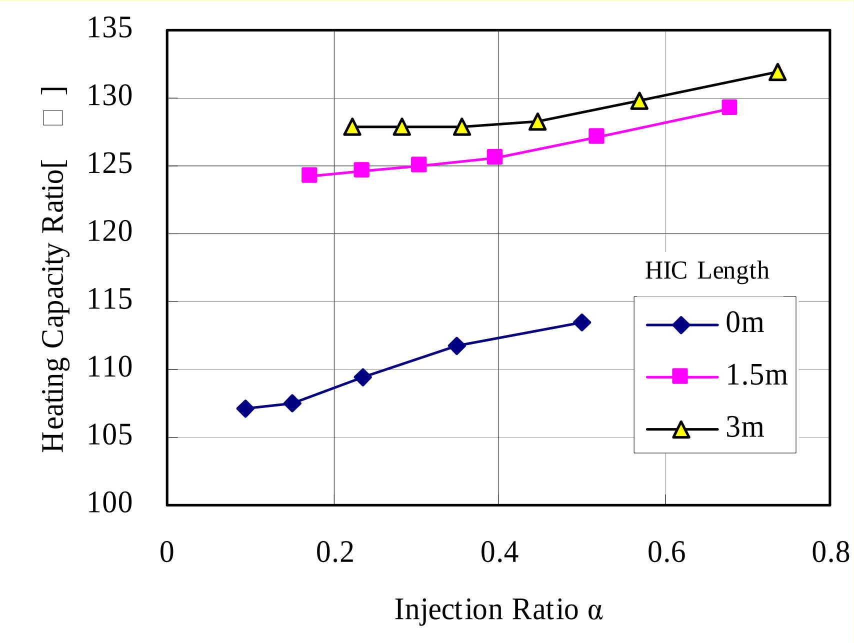


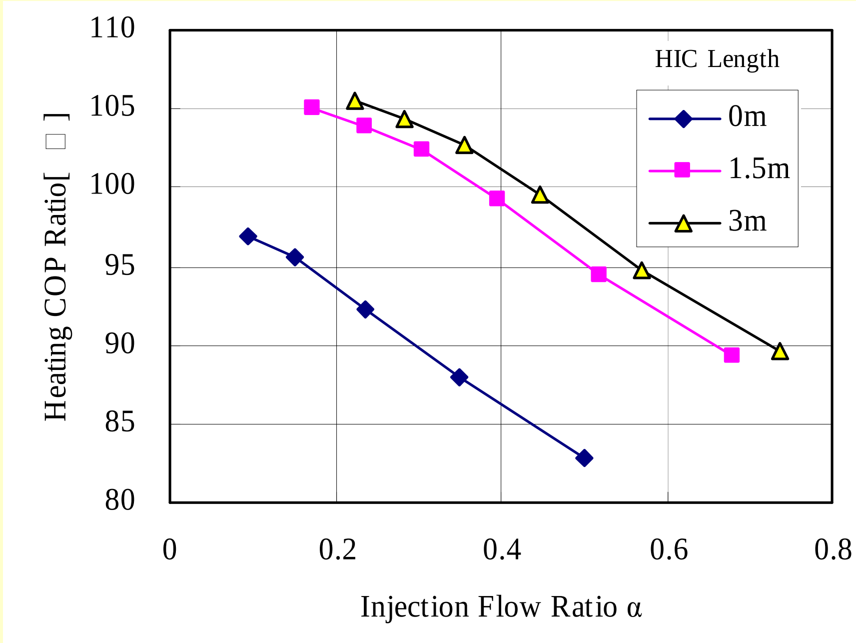
*Discharge pressure increases as Injection ratio increases.
It has got no relations with HIC length.

*Discharge temperature decreases as Injection ratio increases.

3. Zuba-Dan refrigerant circuit

<Test Result (2)>



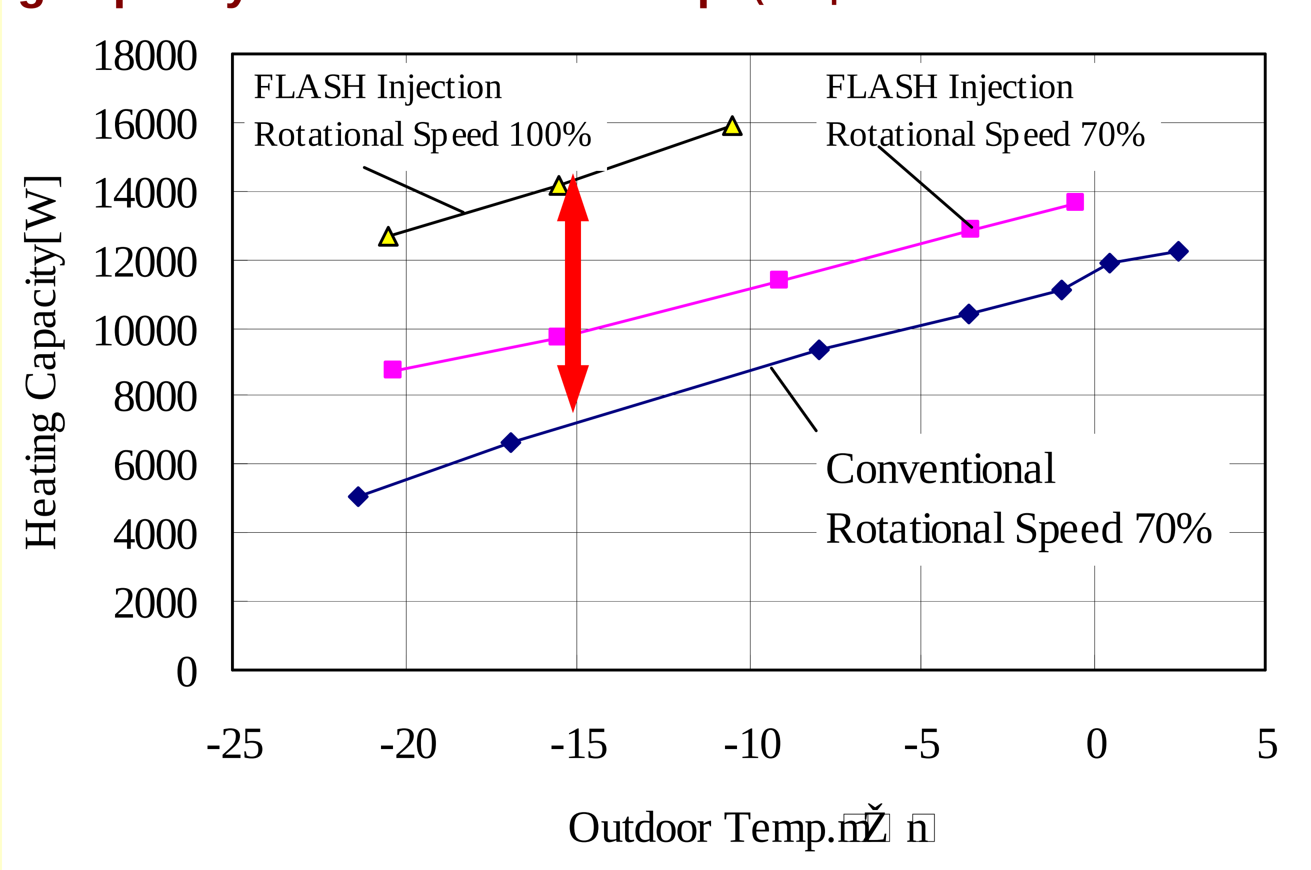


*Heating capacity gets bigger as the HIC length gets longer.
It depends on the Injection ratio as well but not largely.

*COP worsens as the Injection ratio gets bigger.
125% Heating capacity / 100% COP is realized when injection ratio is 0.4.

3. Zuba-Dan refrigerant circuit

<Heating capacity at low ambient temp. (comparison with conventional model)>



*Heating capacity is **improved by 30%** even at same COMP rotation speed (at -15°C)

*Heating capacity is **almost doubled** with increased COMP rotation speed. (at -15°C)

>>>This was impossible before due to the excessive temp.rise of discharge refrigerant.

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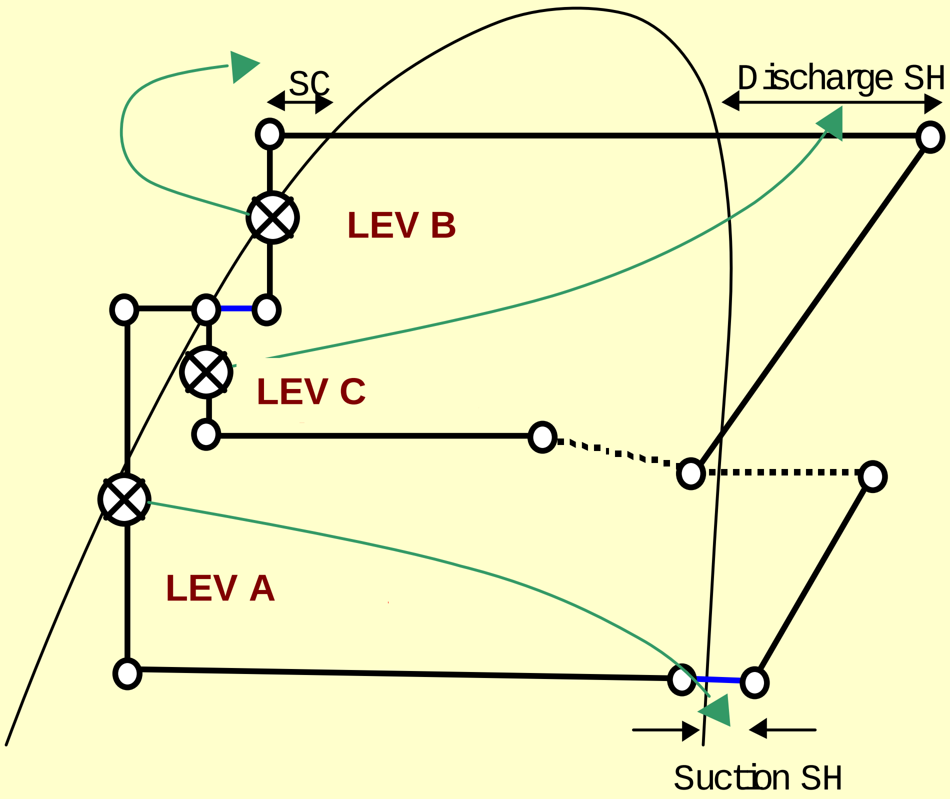
3. Zuba-Dan refrigerant circuit

<Flash Injection Cycle Control>



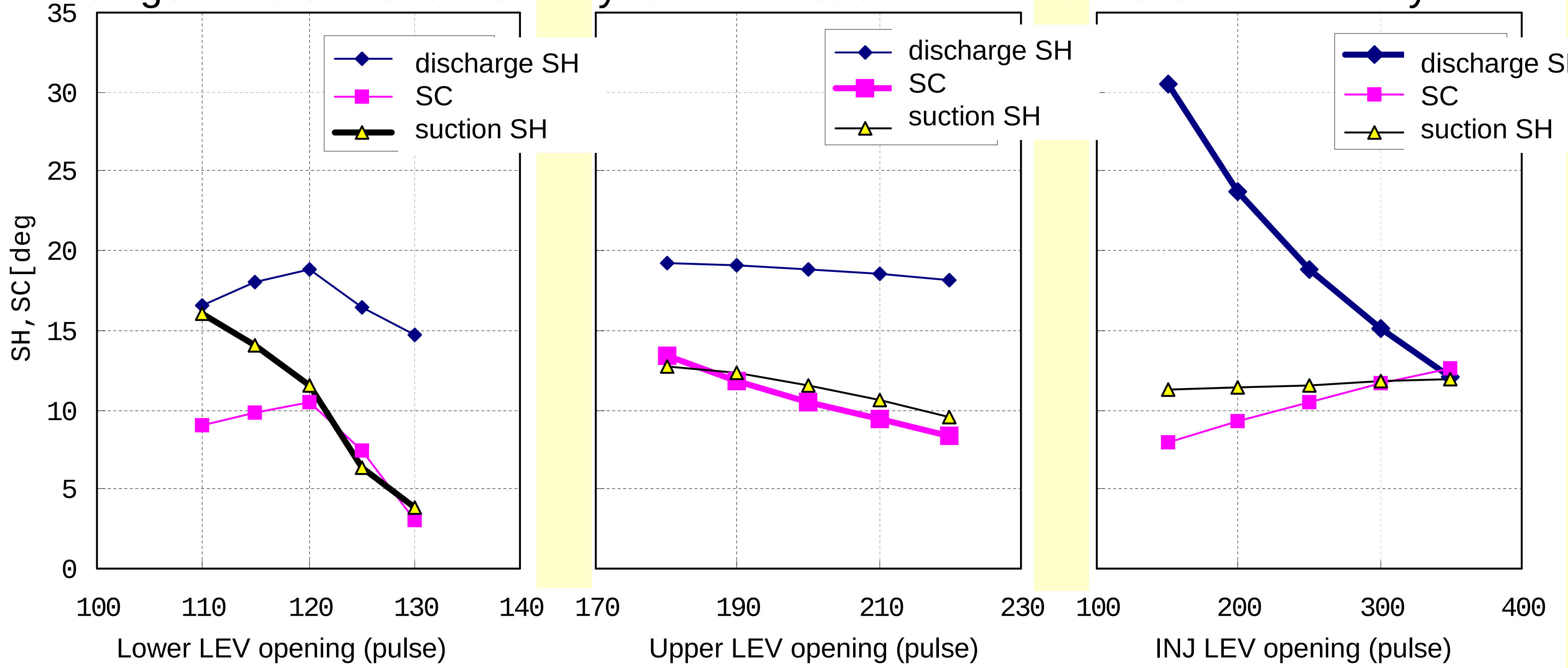
3 conditions (suction refrigerant, condenser and evaporator) is optimally controlled.

<LEV>	<controls on>
A:	Suction refrigerant Super Heat
B:	Condenser Sub Cool
C:	Discharge refrigerant Super Heat

3. Zuba-Dan refrigerant circuit

<LEV characteristics>

Refrigerant distribution is analyzed when each LEV is controlled individually.



Only suction SH responds to line shape.

Suction Super Heat control

Influence on refrigerant distribution.

Sub Cool control

Discharge SH responds acutely.

Discharge Super Heat control

3. Zuba-Dan refrigerant circuit

<Application of Quality Engineering>

<Background>

*3 LEVs operates individually towards different control targets.

*Does individual LEV control interfere each other
resulting in unstable refrigerant cycle?

*Most stable control constant is chosen.

<Purpose>

We apply '**Quality Engineering**' in order to check whether the currently chosen 'control constant combinations' (current control) is appropriate or not.

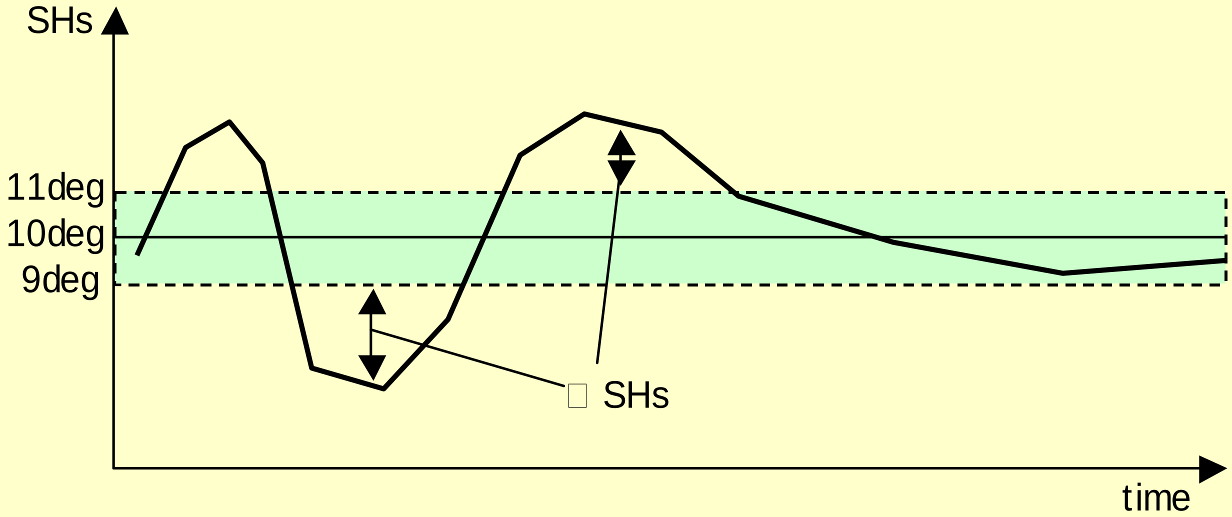
3. Zuba-Dan refrigerant circuit

<System Basic Functions>

*What is the stability of the refrigerant cycle?

<Definition of Basic Function>

Starting from the stable condition, compressor rotation should be increased from 60 to 70rps. If the integrated value of ΔSHs in the next 10 minutes is small, it means the stability is high.



$$\begin{cases} \Delta SHs = SHs - 9 \quad \ldots \ (SHs < 9) \\ \Delta SHs = SHs - 11 \quad \ldots \ (SHs > 11) \\ \Delta SHs = 0 \quad \ldots \ (9 \leq SHs \leq 11) \end{cases}$$

3. Zuba-Dan refrigerant circuit

<Injection Pressure calculation method>

Vst1[cc/r] = Compressor's suction volume
Vst2[cc/r] = Compression room volume at the end of injection

***Point 1**

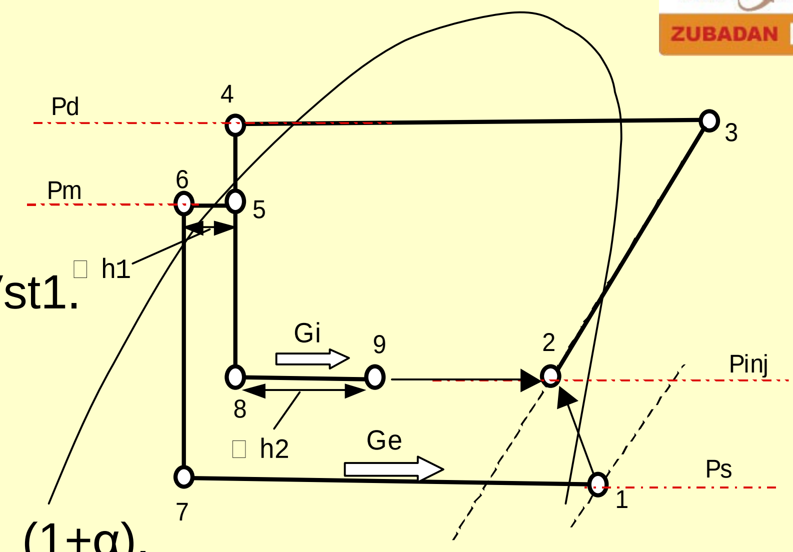
Inlet refrigerant (density D1) is trapped in Vst1.

***Point 1 >>> 2**

Injection refrigerant (condition 9) is poured into compression room
Existing refrigerant amount increases to D1 (1+α).

***Point 2 >>> 3**

Injection port is closed at the compression room volume of Vst2. Normal pressure rise process afterward.



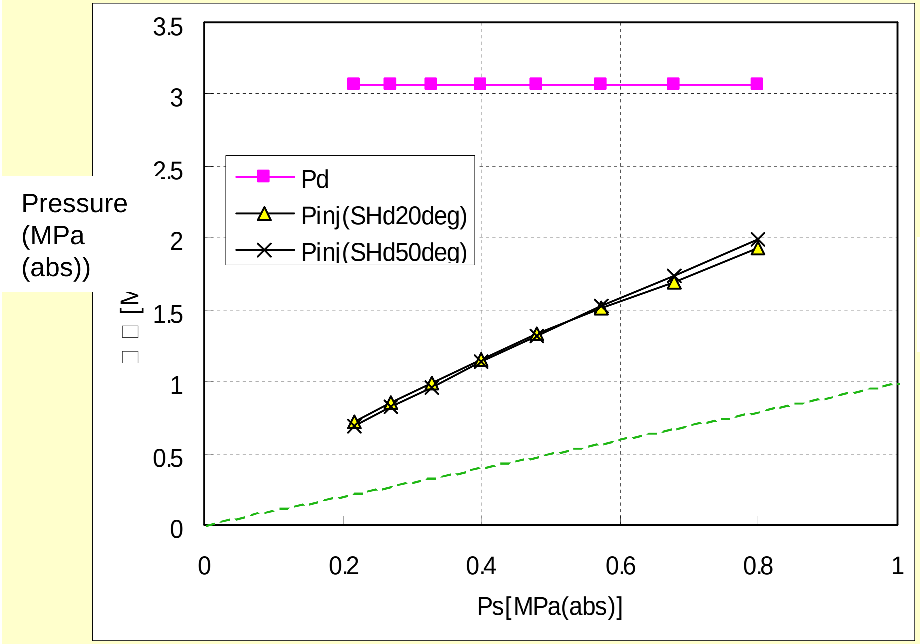
$\alpha = Gi / Ge$

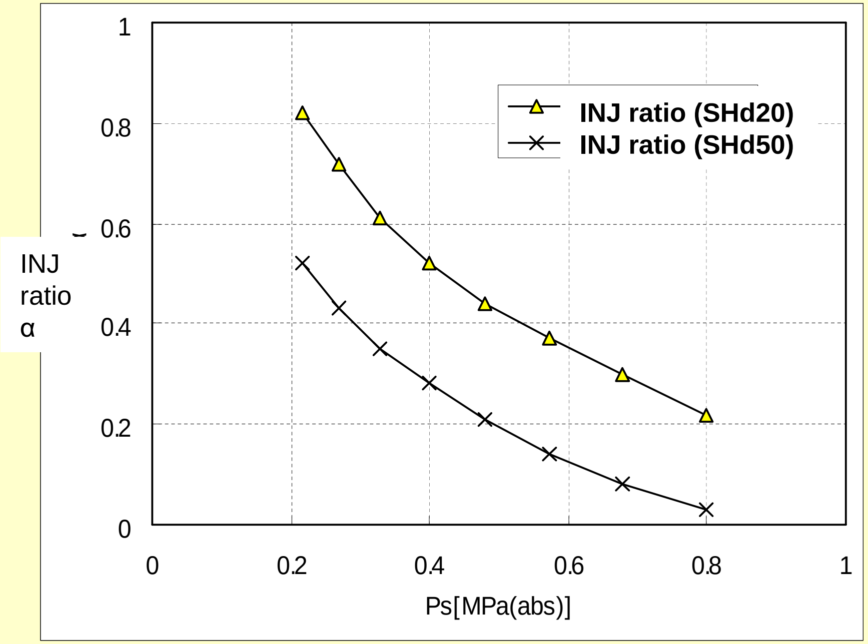
By adjusting the discharge SH at point 3 by α, and by adjusting Pinj to make the density at point 2 gets D2, Injection pressure can be calculated.

3. Zuba-Dan refrigerant circuit

<Injection Pressure>

Pd: stable, Ps: variation character





Pinj is about 2.5 times of Ps.
INJ amount (discharge SH) has just small influence.

The lower the Ps is, the bigger the INJ ratio α gets.

The smaller the discharge SH is, the bigger the α gets.

4. Improvement on Start up & Defrost

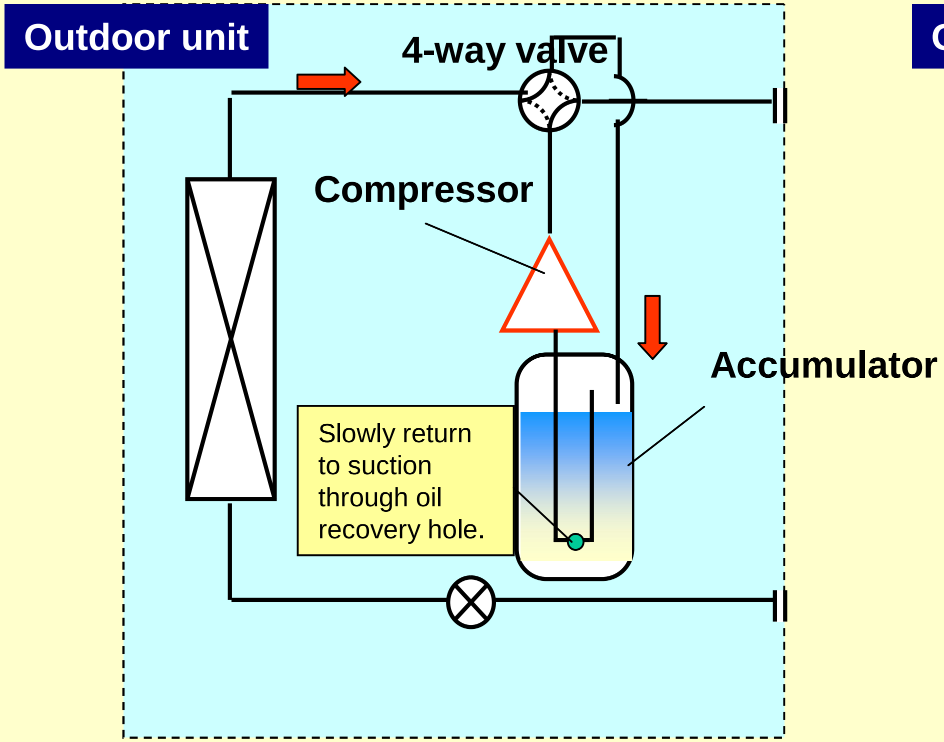
4. Improvement on Start up & Defrost

<Standard Accumulator circuit>

Refrigerant is pooled in the accumulator during start up and defrosting. As a result, it takes long time to start up due to insufficient refrigerant circulation.

Normal start up: Refrigerant within outdoor HEX moves into the accumulator.

Defrost: surplus refrigerant is pooled in the accumulator.

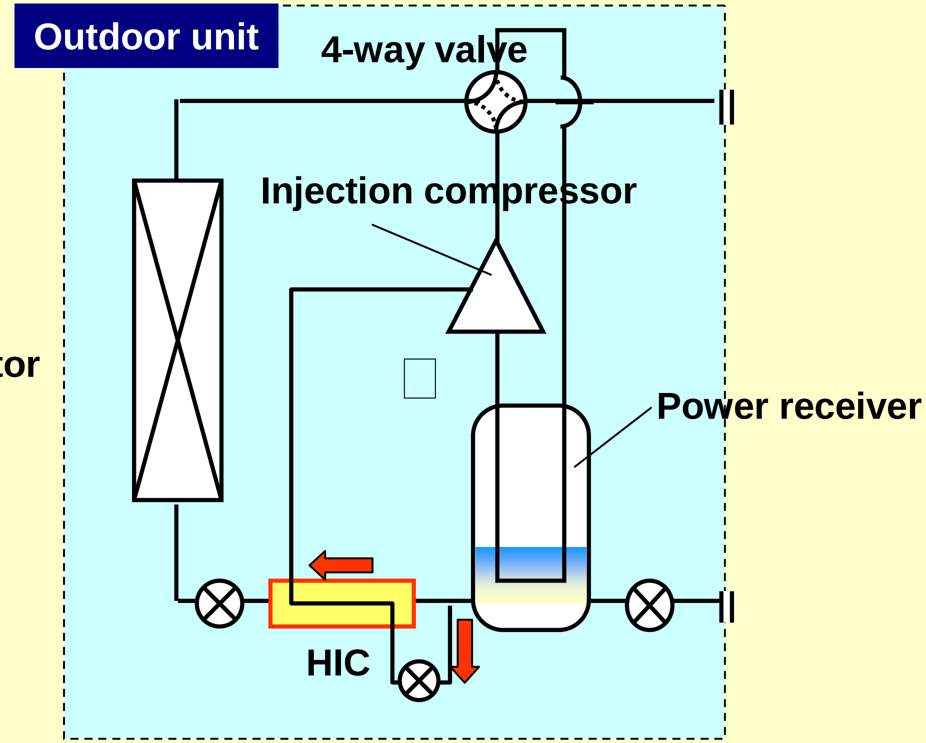


<Flash Injection cycle>

(1)Start up with a bit 'return in liquid' condition as there is no liquid pool on low pressure side. (to secure circulation amount)

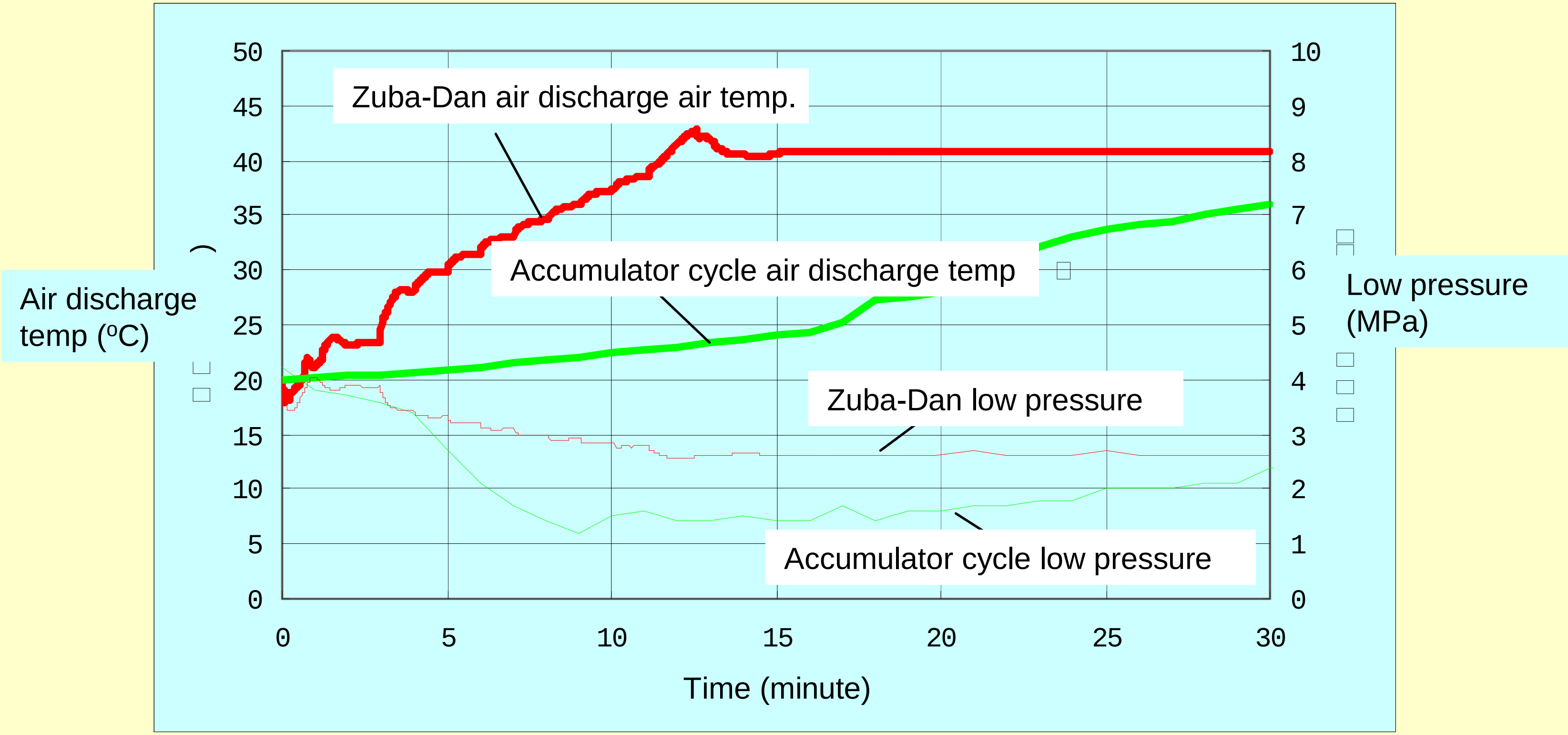
(2)Refrigerant pooled in the receiver during defrost is quickly let return to compressor from injection circuit. It contributes to improve start up characteristics.

(3)Refrigerant circulation amount at start up is secured by Injection.



4. Improvement on Start up & Defrost

<Start up characteristics (at -10ºC ambient)>



In accumulator cycle, the temperature does not rise rapidly due to insufficient refrigerant circulation when starting up.

On the other hand in Zuba-Dan, the discharge air temperature can reach high level in short time.

4. Improvement on Start up & Defrost

<Better comfort with better defrost control>

Better comfort is achieved
by ‘Flash Injection cycle’ and ‘new Defrost control’.

(1)Quicker start up

*Optimal supply of refrigerant by receiver circuit at start up.

*Refrigerant circulation amount is increased by Flash Injection.

(2)Shorter defrost

*Defrost is shortened by Flash Injection.

(3)Less frequent defrost

*Less frost on HEX with hydrophilic fins.

*Estimation control on Frost formation contributes to reduce defrost frequency largely, especially in low ambient temperature (low absolute humidity).

5. Field Test Result

5. FT Result (1): Office building in Asahikawa City

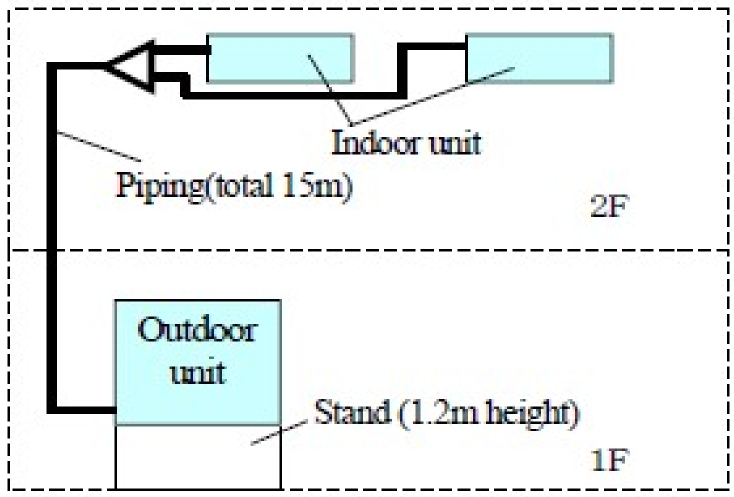
<Tested units and conditions>

*Test Period: From December 2004 to February 2005

*Test Location: At an office building in Asahikawa, Hokkaido

*Test Points

Outdoor unit: **11.2kW** class unit
Indoor unit: **2 units of 5.6kW** class
Piping length: about **15m**
Control specifications: **(1)with Injection** (control for cold regions) **(2)w/o Injection** (normal control) ***(1) & (2) are both realized alternatively**.
Test points: *Indoor inlet & outlet temperature *Indoor temperature distribution, Ambient temperature, Refrigerant temperature, Energy consumption

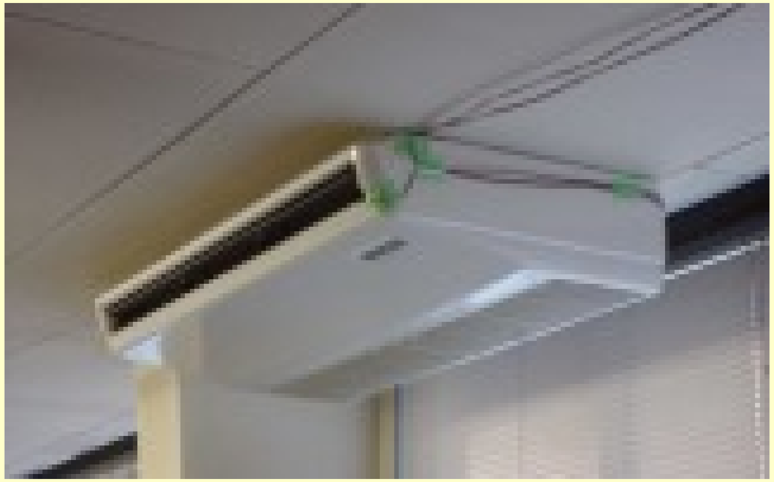


5. FT Result (1): Office building in Asahikawa City

Mr.SLIM
Hyper Heating
POWER INVERTER
ZUBADAN R410A

Outdoor unit

2 Indoor units

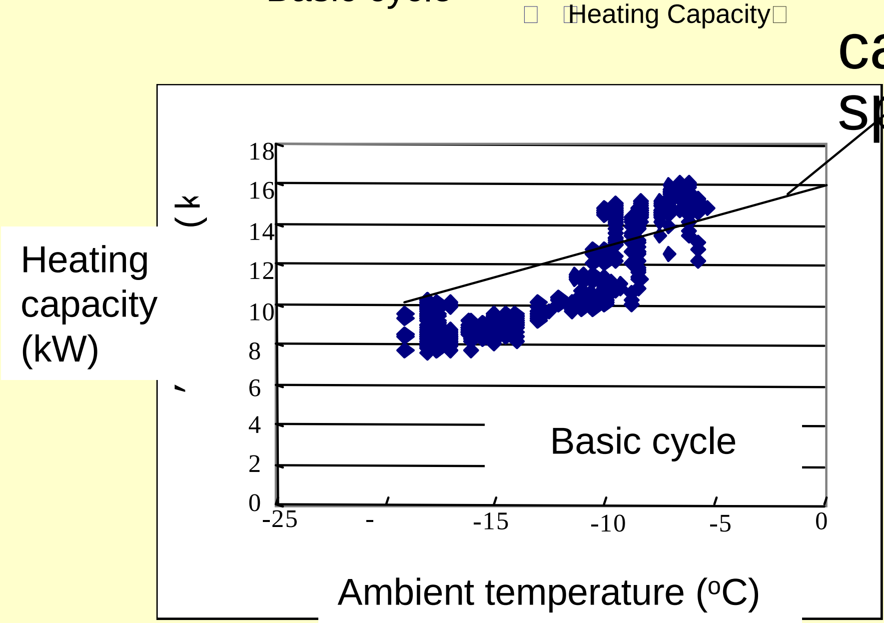


5. FT Result (1): Office building in Asahikawa City

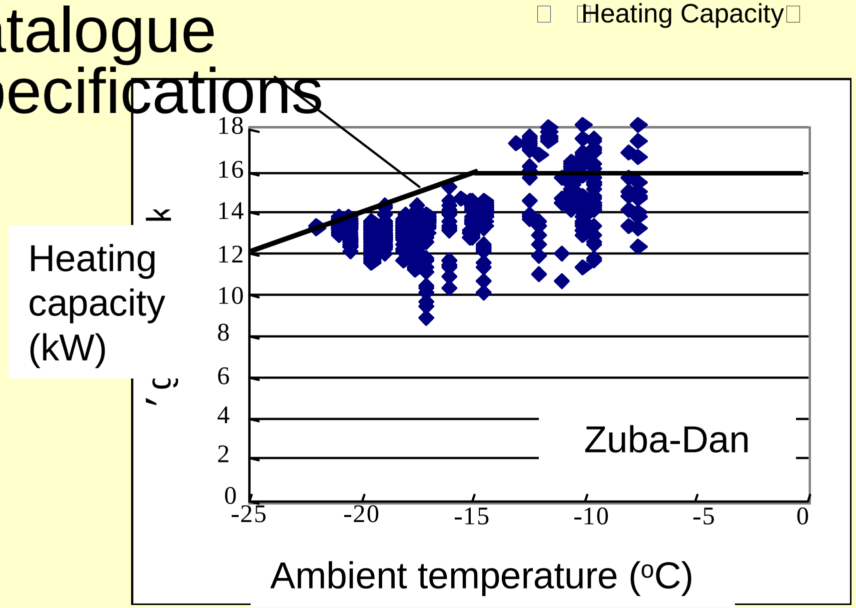
Heating Capacity & COP
based on the different ambient temperature

Heating capacity:
(indoor outlet – inlet) x air volume x density x specific heat

Basic cycle



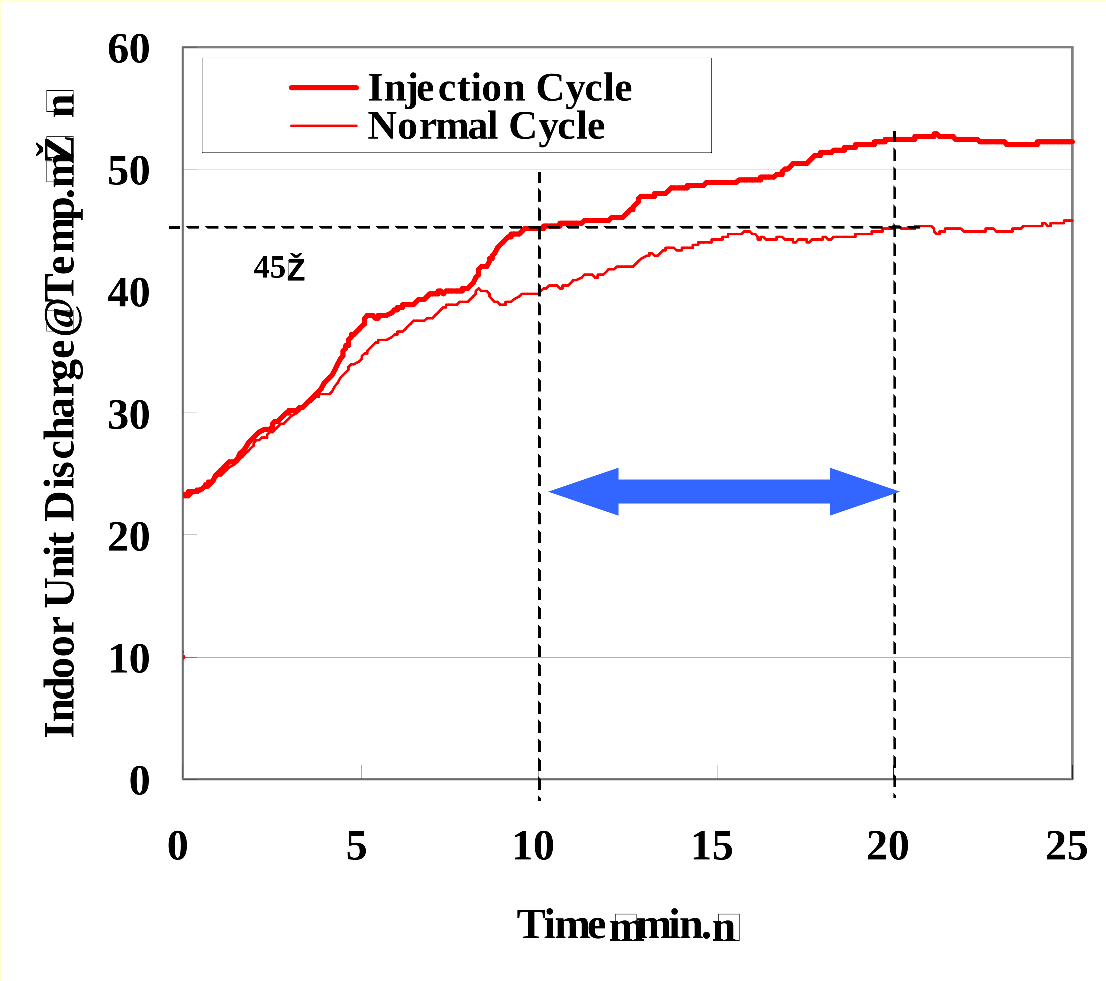
Injection cycle



without INJ >>> with INJ
Capacity increases by about 30%

5. FT Result (1): Office building in Asahikawa City

<Quicker Start up in Heating operation>



<with Injection>
*Indoor outlet temperature
in stable condition
>>> more than 50°C

*To reach indoor outlet temperature
of 45°C
>>> takes only about 10 minutes

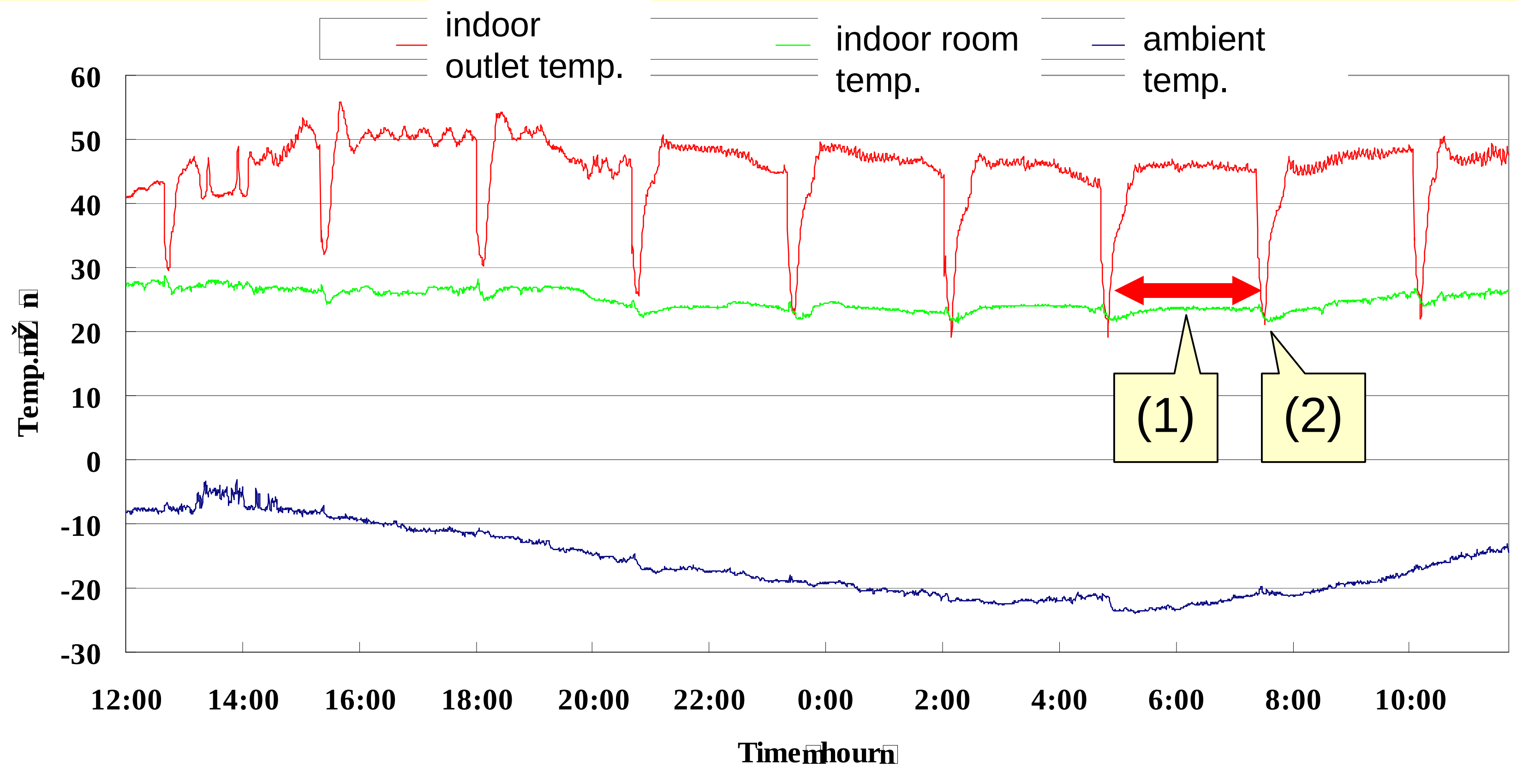
(when unit starts running
at the ambient temp of -15°C and
at the indoor room temp of 23°C)

<Shorter start up>
about ½ of conventional model

5. FT Result (1): Office building in Asahikawa City

<Defrosting characteristics>

<data taken between 25 Jan 2004 (noon) and 26 Jan 2005 (noon)>



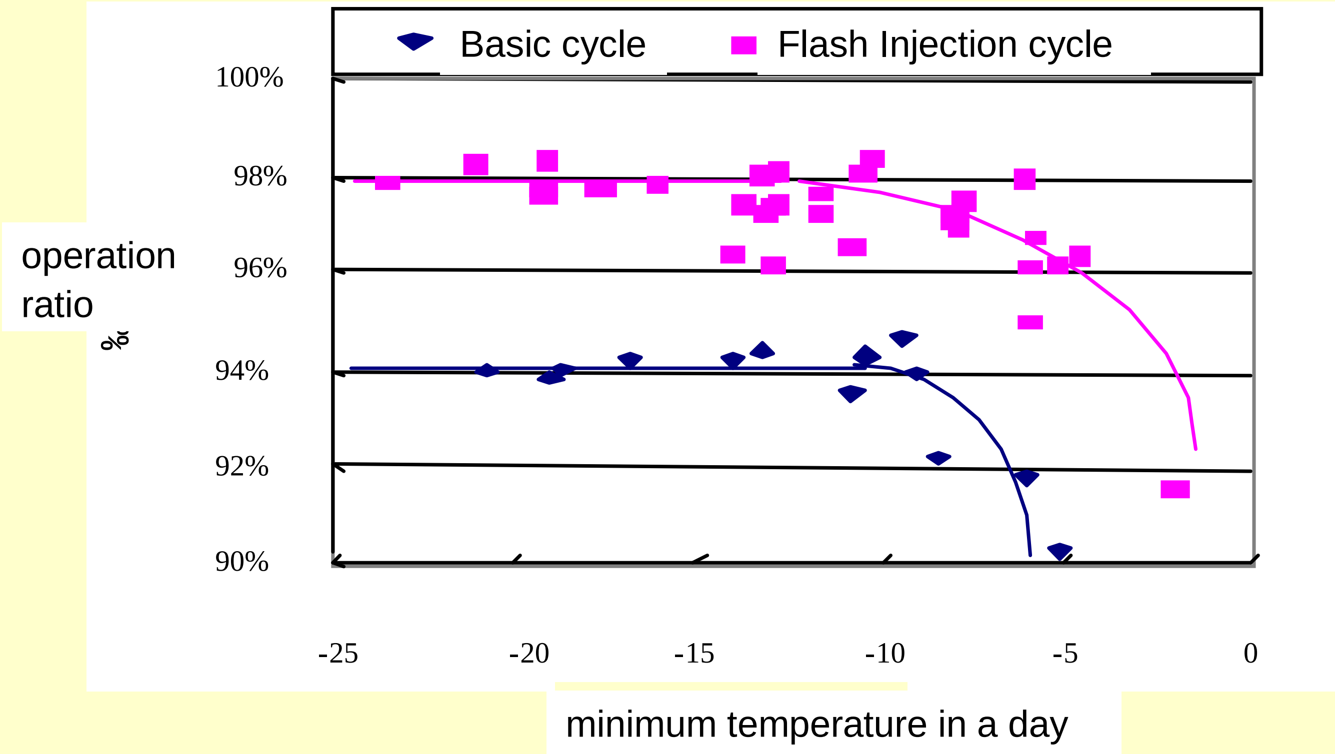
<ambient temp.: -20°C>

(1)continuous operation of more than 150 min.

(2)Defrosting only for about 3 minutes.

5. FT Result (1): Office building in Asahikawa City

<Defrosting characteristics (operation ratio)>



<Heating operation ratio>

(Heating operation duration – Defrost duration) / (Heating operation duration)

As the ambient temp. decreases (below 0ºC), the average heating operation ratio increases.
>>> The operation ratio improves more by extending the continuous operation duration with no frost on the coil.

5. FT Result (2): **Station waiting room (in Niigata pref.)**

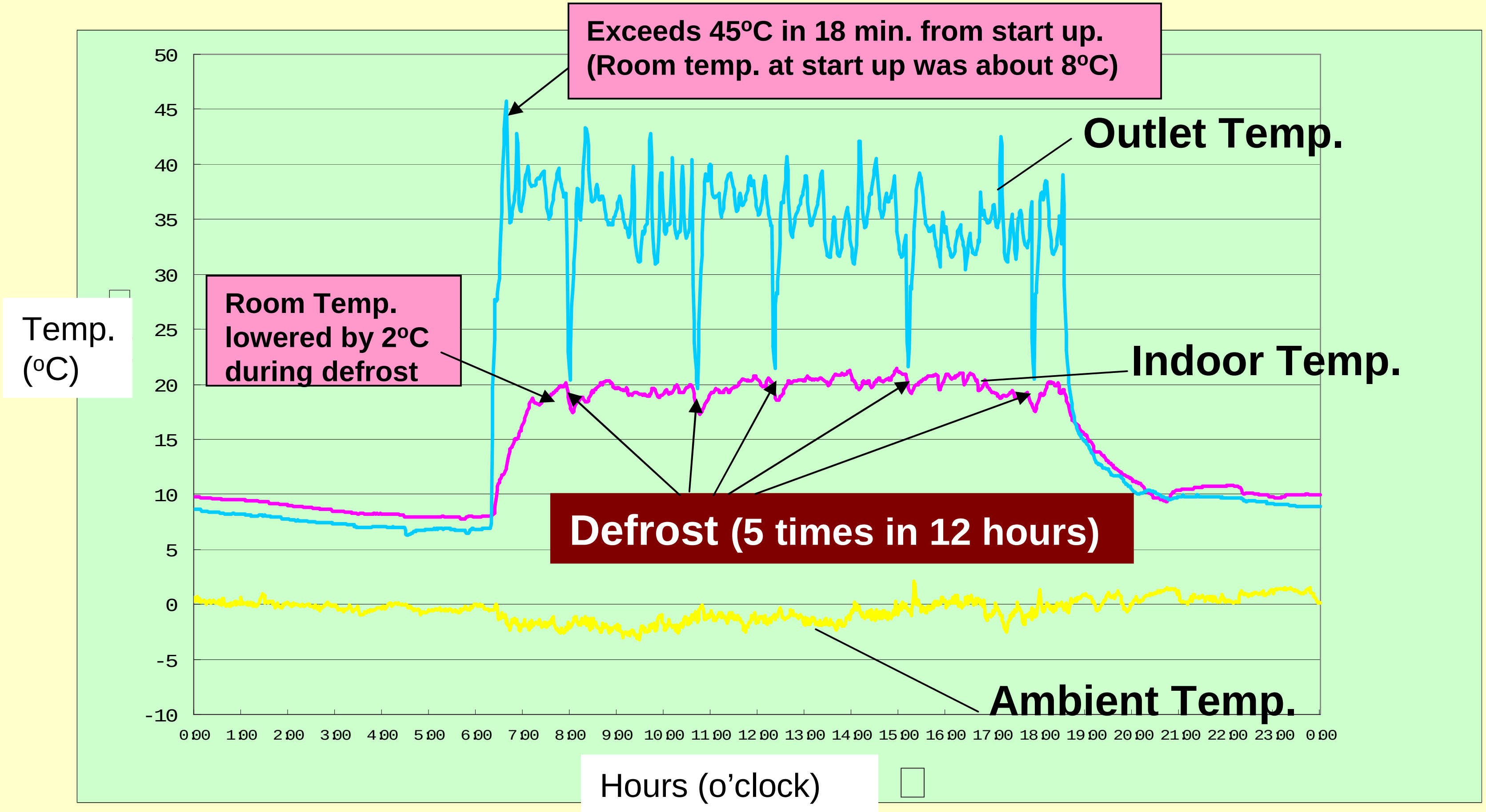
Feb 2006 (wooden building, door is opened frequently)

4HP wall mounted type indoor unit for about 30m² room.

Mr.SLIM Hyper Heating POWER INVERTER ZUBADAN R410A

5. FT Result (2): **Station waiting room (in Niigata pref.)**

<Measured Data> From 06.20 am to 18.30 on 12 Feb 2006.
Humidity: 60 – 80 %



Much better comfort can be achieved by 'quicker start up of heating operation' and 'improved defrost control'.

6. Summary

6. Summary: Following functions are realized as the A/C for cold regions

(1)Improved Heating Performance

*High heating performance & high COP achieved by Flash Injection.
*Operation range extended down to -25°C.

(2)Better Comfort

*Start up and Recovery from defrost are improved very much by Injection together with Receiver circuit.
*Defrosting frequency at below 0°C ambient is reduced to about 1/3.

(3)Exsisting piping can be reused even though the compressor was broken down.

*Since its launch in July 2005, Zuba-Dan has been **highly appreciated** in cold regions such as in Hokkaido.

*Zuba-Dan technology has also been adopted to our **City Multi (VRF)** since December 2006.

ZubaDan

What do you expect from ZubaDan?

For which application do you need ZubaDAN?

How do you calculate the cooling and heating capacity

Can you use Zuba Dan Air to Air without cooling function?

Which price is accaptable in comparison to Power Inverter?
5% 10% 20% 30% 40% 50 %

Thank you very much!