ICR2015 WORKSHOP

Heat Pump Systems R&D by NEDO

Research and development of innovative energy-saving controls for multi zone heat pump system for buildings

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1. Objectives/Targets

1.1. Background

In an office building, energy usage for air conditioning system amounts to 30% - 40% of its total energy consumption.

Development of air conditioning systems with higher efficiency is strongly demanded for the energy-saving of buildings.

**NEDO:** R & D project on “Next-generation Heat Pump Systems”, which aimed to increase COP by 1.5 times higher than the conventional systems. (2010 – 2013)

This presentation describes the development of a **new controller for the VRF system** which was conducted as a part of this NEDO project.
Air conditioning systems in commercial buildings are mostly operated under less than 50% heat load through the year.

COP of the conventional VRF systems becomes lower under low heat load conditions.

In order to achieve the actually effective energy saving of the VRF system, it is important to **improve its performance under the low heat load condition**.
1. 3. Purpose of this R&D project

- Development of a **new A/C controller** that can improve the energy efficiency of the **VRF system** operated under low heat load condition.

- Evaluation of the performance that annual average COP with the new A/C controller is more than 1.5 times as high as that with the conventional one, by
  
  1. Part-load performance tests in the test facility
  2. Field test in an actual office building
2. Features of Developed/Developing Systems

2.1. Features of the new A/C controller

Comparison of operating states of compressor under low heat load

Due to the mismatch between the capacity and the heat load, the compressor repeats startup/shutdown operations, then COP gets worse.

As the above figures, the new A/C controller optimizes the capacity in response to the heat load predicted from the trend of room temperature variation etc.

⇒ Model predictive control is applied to the new A/C controller.

*Heat Pump Systems R&D by NEDO*
2. 2. Other technology to improve performance of VRF

New A/C controller:

(1) Minimization of the heat loss in the outdoor heat exchanger in heat recovery operation

(2) Minimization of the standby energy consumption

(3) Reducing the energy consumption of fan motors of outdoor unit by optimizing outdoor unit fan speed

(4) Reducing the energy consumption of fan motors of indoor units by using DC fan motors

(5) Reducing the energy consumption of fan motors of indoor units by fan off control during thermo-off
## 3. R&D Technologies

### 3. 1. Organization of R&D

<table>
<thead>
<tr>
<th>Organization</th>
<th>Activities</th>
</tr>
</thead>
</table>
| **NIHON SEKKEI, INC** | 1. Selection of a building for field test and development of energy simulation of it  
                        2. Field test  
                        3. Improvement of the models of BEST*  
                        4. Estimation of heat load |
| **Chubu Electric Power, Co. Inc.** | 1. Selection of a building for field test and development of energy simulation of it  
                                   2. Part-load performance tests in test facility  
                                   3. Field test |
| **Mie University** | 2. Part-load performance tests in test facility  
                     3. Field test |
| **DAIKIN INDUSTRIES, LTD** | 1. Selection of a building for field test and development of energy simulation of it  
                               2. Part-load performance tests in test facility  
                               3. Field test  
                               [Co-Researcher] Control for VRF / Analysis |

* Building Energy Simulation Tool by institute for building environment and energy conservation (IBEC)
3.2. Methods of R&D

Evaluation of the performance that annual average COP with the new A/C controller is more than 1.5 times as high as that with the conventional one by part-load performance tests in test facility

Combination of A/C controller and indoor fan motors:

Outdoor-air processing VRF:
- conventional controller + AC motor indoor fans
- new controller + AC motor indoor fans

Heat recovery VRF:
- conventional controller + AC motor indoor fans
- new controller + AC motor indoor fans
- new controller + DC motor indoor fans

Exterior of test facility (Chubu Electric Power)
3. 2. Methods of R&D

Field tests were conducted in the one floor of the office building in Nagoya to evaluate that annual average COP using the new A/C controller is more than 1.5 times as high as that with the conventional one.

New control : Jan, 2012〜Dec, 2012

Only the new controller was implemented
Same indoor and outdoor units were used

Office building and reference floor used for field tests
3. 3. Detail of the developed controller

Capacity is optimized by the combination of “the real-time prediction of the indoor heat load using model predictive control” and “the capacity characteristics of the heat exchanger of the indoor units”. Then, optimum combination of the indoor fan speed and target Te/Tc are calculated.

\[
\rho_d C_p V_r \frac{dT_r}{dt} = Q_{hex} + Q_i + Q_o
\]

\[
Q_{hex} = f(T_r, T_e, T_c, SH, SC, \omega)
\]

(1) Room temperature model

(2) Heat exchanger model

(3) Fan speed control
Send Te/Tc to OU

(4) Select Te/Tc from the targets of Te/Tc from all indoor units

(5) Compressor speed control
3. 4. Results of the study (Part-load Tests)

How to calculate annual average COPs

The annual average COPs of the VRF systems were calculated by combining the results of part-load performance tests and the time (hours) of appearance of heat load ratio and outdoor temperature that had been measured in the office building through a year.
3. 4. Results of the study (Part-load Tests)

The Annual Average COP with the new controller + AC fan can be achieved 1.3 times as high as the COP with conventional one. The Annual Average COP with the new controller + DC fan can also be achieved 1.71 times as high as the conventional one.

### Seasonal / annual average COPs on part-load performance test

The graph above shows the seasonal and annual average COPs for different conditions: Conventional, New (AC fan), and New (DC fan). The COP values are represented for cooling, heating, and annual performance.

### Annual average COPs predicted based on part-load performance tests

<table>
<thead>
<tr>
<th></th>
<th>Annual average COPs</th>
<th>Increase ratio of annual average COPs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A/C controller</td>
<td>Air processing</td>
<td>Heat recovery</td>
</tr>
<tr>
<td>Conventional</td>
<td>2.50</td>
<td>1.98</td>
</tr>
<tr>
<td>New + AC fan</td>
<td>2.86</td>
<td>2.74</td>
</tr>
<tr>
<td>New + DC fan</td>
<td>2.99</td>
<td>4.13</td>
</tr>
</tbody>
</table>
3. 4. Results of the study (Field Tests)

Field measurements in the actual office building in two years:
01/2012 ~ 12/2012: New controller with AC motor indoor fans

The new controller can show its full energy-saving performance with the DC motor indoor fans.

COPs with the new controller + DC motor indoor fans were estimated based on the results of the part-load performance tests.
3.4. Results of the study (Field Tests)

Comparison of annual and monthly average COPs measured in the actual office building

Annual average COPs in the actual office building

<table>
<thead>
<tr>
<th>A/C controller</th>
<th>Air processing</th>
<th>Heat recovery</th>
<th>Total</th>
<th>Increase ratio of annual average COPs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Air processing</td>
</tr>
<tr>
<td>Conventional</td>
<td>2.58</td>
<td>2.16</td>
<td>2.28</td>
<td>Base</td>
</tr>
<tr>
<td>New + AC fan</td>
<td>3.08</td>
<td>2.94</td>
<td>2.98</td>
<td>19%</td>
</tr>
<tr>
<td>New + DC fan</td>
<td>3.23</td>
<td>4.23</td>
<td>3.85</td>
<td>25%</td>
</tr>
</tbody>
</table>

COP increase ratio by use of the DC motor fans (cooling)

Comparison of annual and monthly average COPs measured in the actual office building
### 3.5. Achieved outcome

<table>
<thead>
<tr>
<th>Total Plan</th>
<th>Final Goal</th>
<th>Technologies Level at the beginning</th>
<th>Attained level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of a new A/C controller that can improve COP of VRF systems under low heat load condition</td>
<td>1.5 times higher annual average COP</td>
<td>Annual average COP = 2.28</td>
<td>Annual average COP = 3.85 ( \Rightarrow 3.85/2.28 = 1.69 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Items</th>
<th>Final Goal</th>
<th>Technologies Level at the beginning</th>
<th>Attained level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Develop of an energy simulation to estimate the effect of the new A/C controller</td>
<td>Estimation of performance of the new controller and the possibility of 1.5 times higher COP</td>
<td>There were some energy simulation such as “LCEM”, but not include simulation of controllers</td>
<td>The goal had been achieved</td>
</tr>
<tr>
<td>(2) Part-load test in the facility</td>
<td>Evaluation of possibility of 1.5 times higher COP from the measurement data in the facility</td>
<td>Annual average COP = 2.14</td>
<td>Annual average COP = 3.65 ( \Rightarrow 3.65/2.14 = 1.71 )</td>
</tr>
<tr>
<td>(3) Field test in the actual building</td>
<td>Evaluation of 1.5 times higher COP from the measurement data in the filed test</td>
<td>Annual average COP = 2.28</td>
<td>Annual average COP = 3.85 ( \Rightarrow 3.85/2.28 = 1.69 )</td>
</tr>
<tr>
<td>(4) Improvement of models of BEST</td>
<td>To make a proposal of model improvement of BEST than can improve accuracy of estimation of heat load to BEST committee</td>
<td>There was no proposal from the measurement data in facility tests and field tests</td>
<td>The goal had been achieved</td>
</tr>
</tbody>
</table>
4. Next step for Commercialization

4. 1. New VRF products

New VRF products “VRV X” with the new controller have been launched since March, 2015 in Japan by DAIKIN INDUSTRIES. These products will be launched to overseas market in the future, and the new controller also will be applied to other VRF systems, such as heat recovery VRF systems etc.

VRV X outdoor unit (heat pump, capacity range: 22.4-118kW)

VRT* Smart control
*variable refrigerant temperature

“VRV X” products

VRV X indoor unit

Ceiling- mounted round flow cassette

Ceiling mounted 2-way flow cassette

Ceiling mounted 1-way flow cassette

Ducted concealed ceiling unit
4. 2. Estimation of energy-saving effect

Prediction of the number of VRF system stocks in Japan

Prediction of energy-saving effect using the new controller

Energy-saving will increase 2977GWh/year (76.57kL/year in crude oil equivalent) at 2030.

Assumption
1) Diffusion of new VRF systems will be as fast as that of existing VRF systems.
2) Renewal cycle of VRF systems is 13 year.
3) The capacity of VRF systems and the amount of heat load referred from typical buildings in Japan.
Thank you very much for your kind attention!