LATEST HEAT PUMP AND IT'S SIMULATION TECHNOLOGIES

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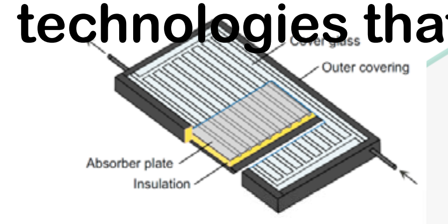
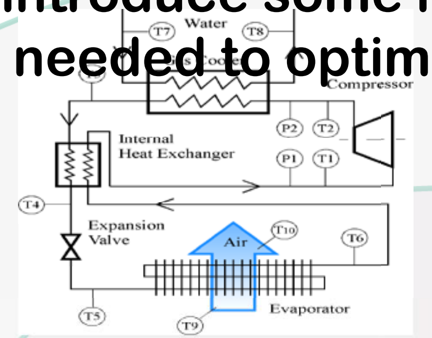
INTRODUCTION

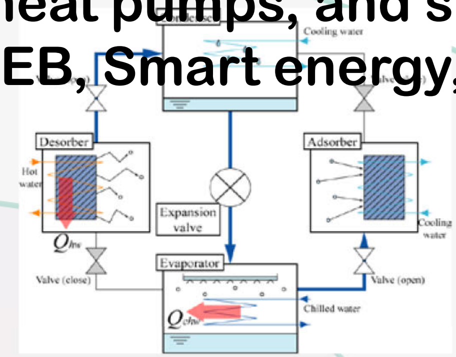
I focus on heat pump researches more than 20 years.
Today, I would like to introduce some new heat pumps, and simulation technologies that are needed to optimize ZEB, Smart energy, and so on-



Solar thermal collector



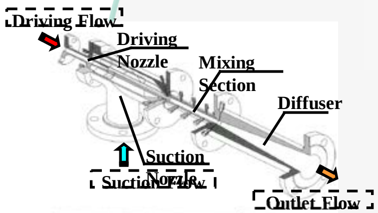
Compression heat pump



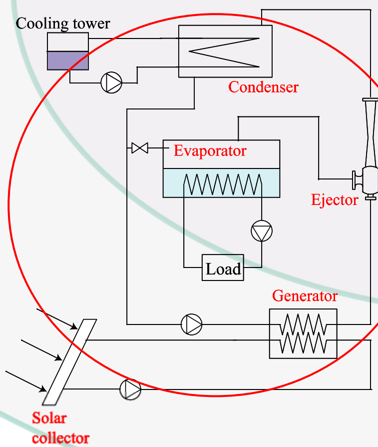
Ads. heat pump

Research field

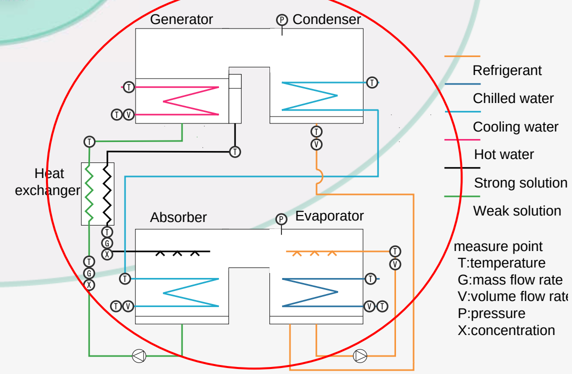
Desiccant



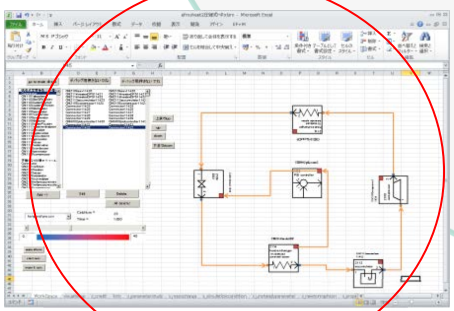
Ejector



Ejector heat pump



Abs. heat transformer

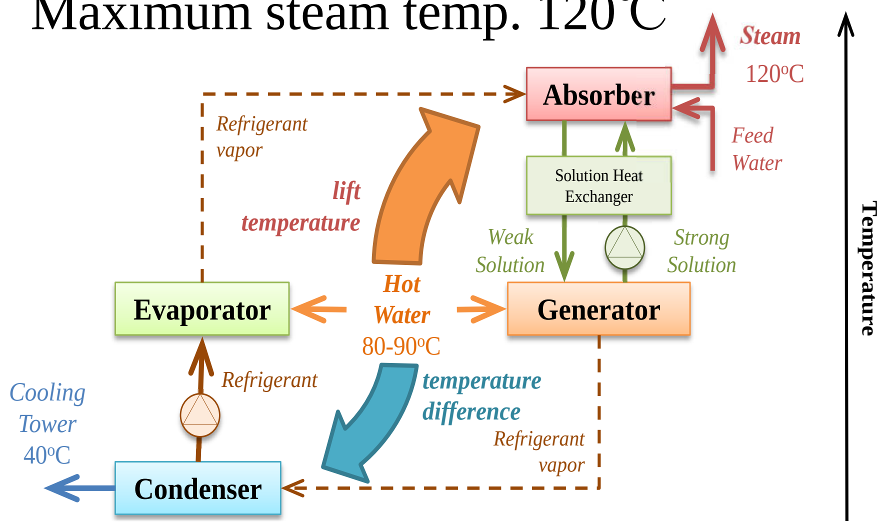


Simulator

Show case

ABSORPTION HEAT TRANSFORMER

Maximum steam temp. 120℃



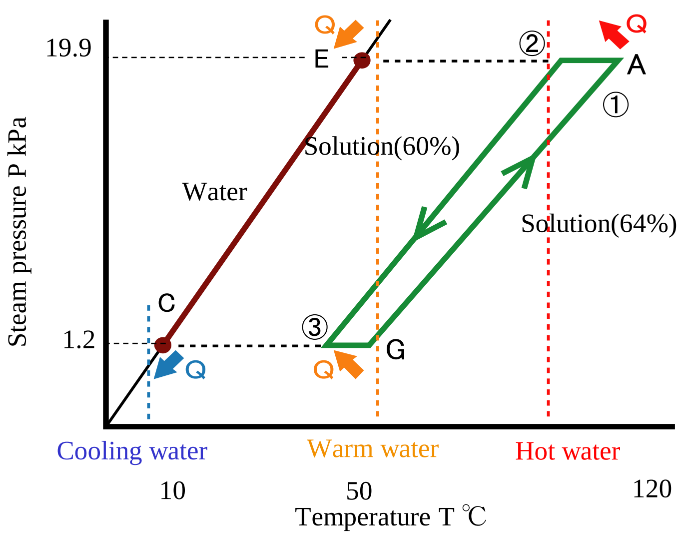
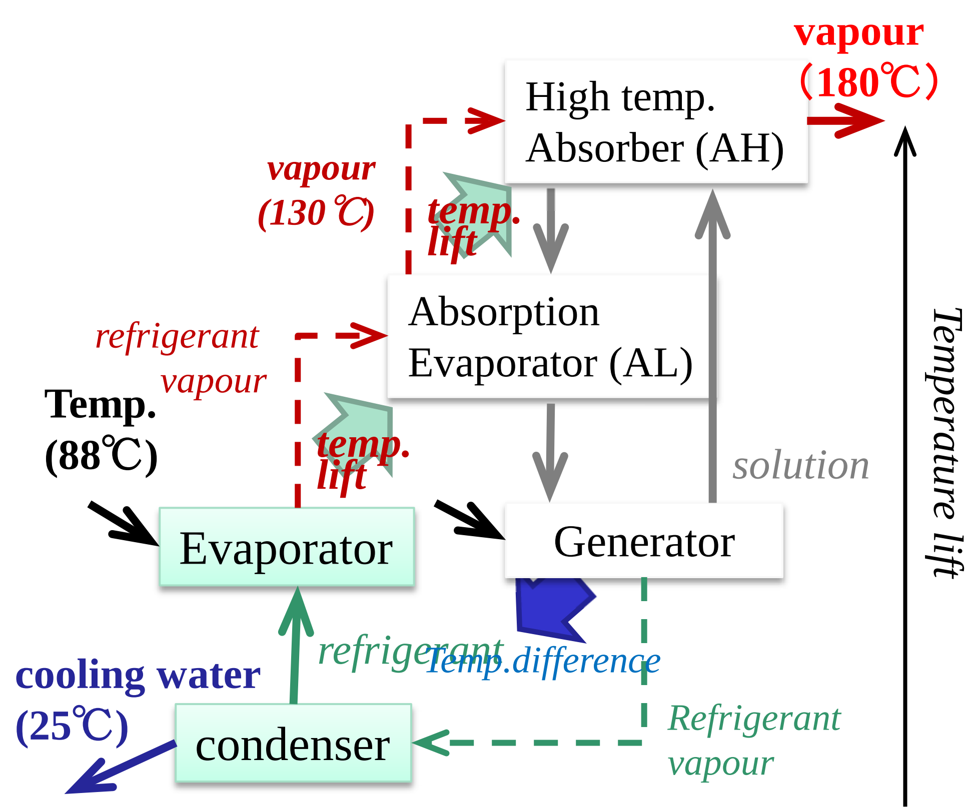


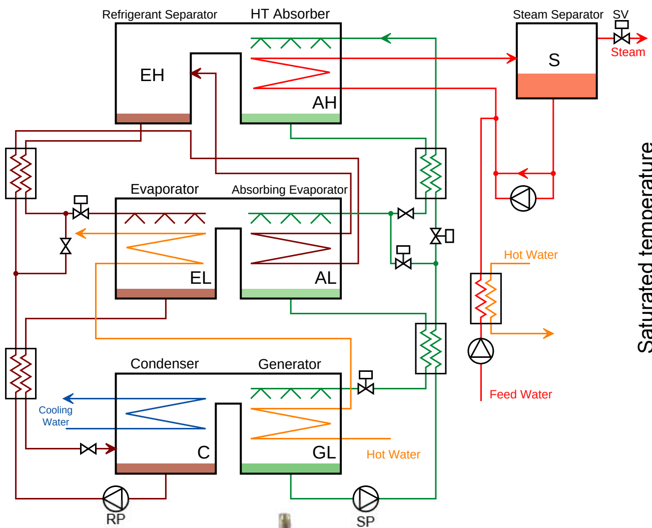
Fig. Single stage abs. heat transformer

Maximum steam temp. 180℃



Two stage cycle(NEDO project)

ABSORPTION HEAT TRANSFORMER



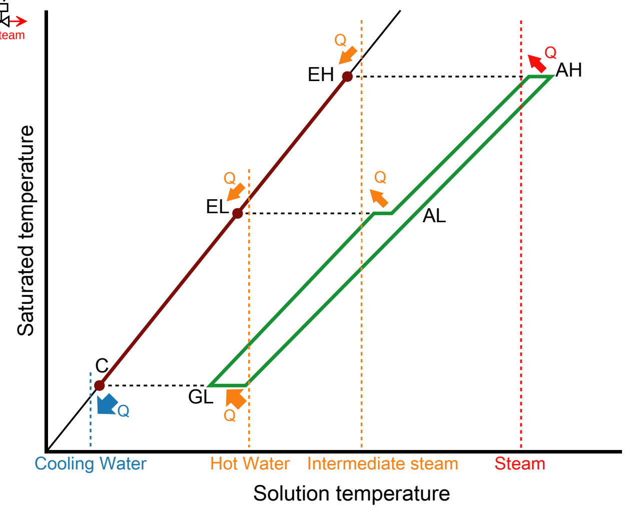


Fig. Double stage abs. heat transformer

Table Specifications

Steam Temperature	180 ℃
Steam Generation rate	20 kg/h
Hot water Temperature	88 ℃
Cooling water Temperature	25 ℃

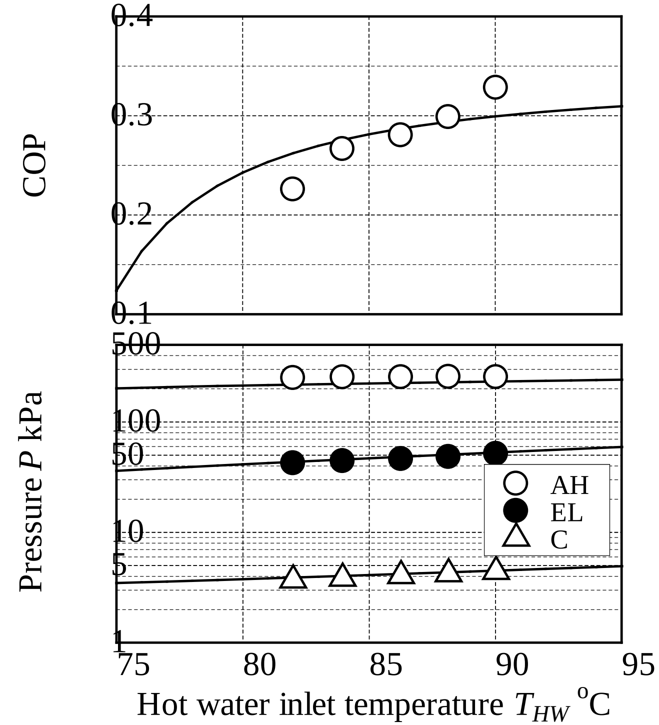


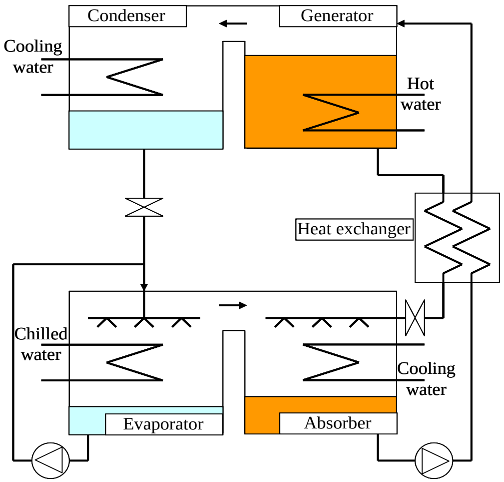
Fig. Effect of hot water inlet temperature

- 180°C vapor can be got from about hot water 88°C for actual machine
- Waste heat based COP is about 0.3, but electricity based COP is about 15

EJECTOR HEAT PUMP

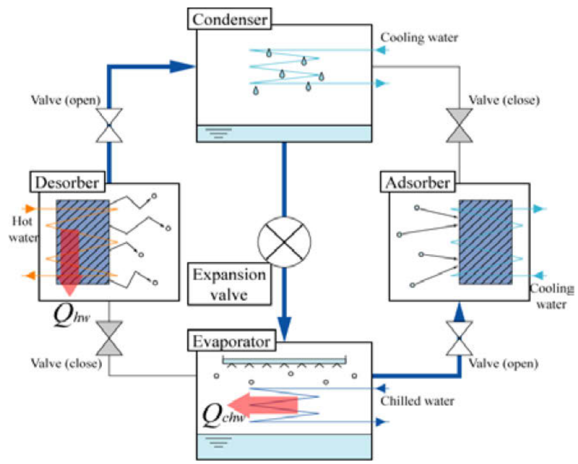
Heat-driven Refrigerator

Absorption Type



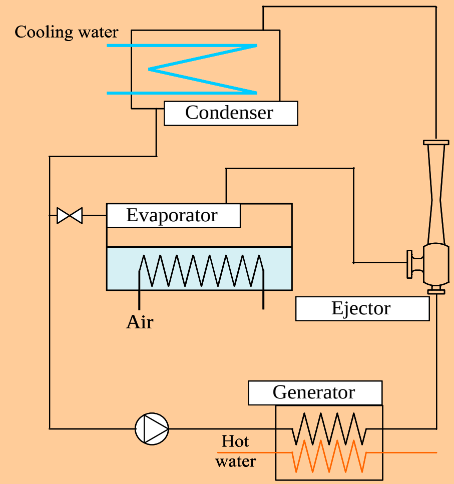
Advantage
•Natural refrigerant
•Driven by low temp. heat sources
Disadvantage
•Maintenance cost is high
•Difficulty in keeping up vacuum

Adsorption Type



Advantage
•Driven by lower temperature heat sources
•Use of natural refrigerant
•Long life
Disadvantage
•Lower COP

Ejector Type



Advantage
•Can by driven by lower temp. heat sources
• make system smaller
Disadvantage
•Difficulty in designing ejector
•COP is not so high
•Control is not easy

Pay attention to ejector cooling system

EJECTOR HEAT PUMP

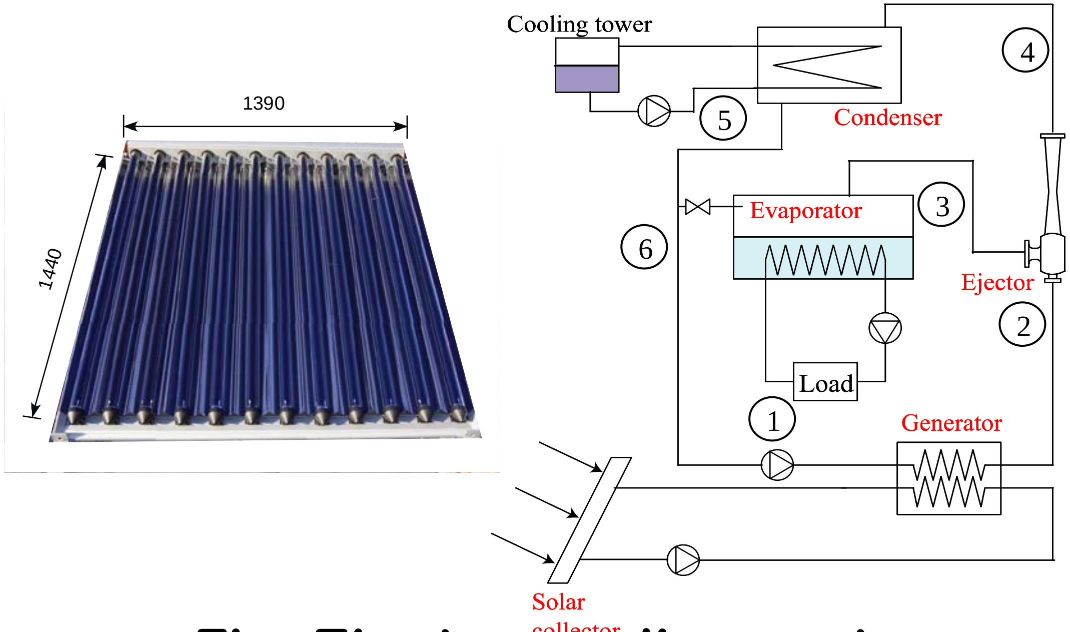


Fig. Ejector cooling system driven by solar energy

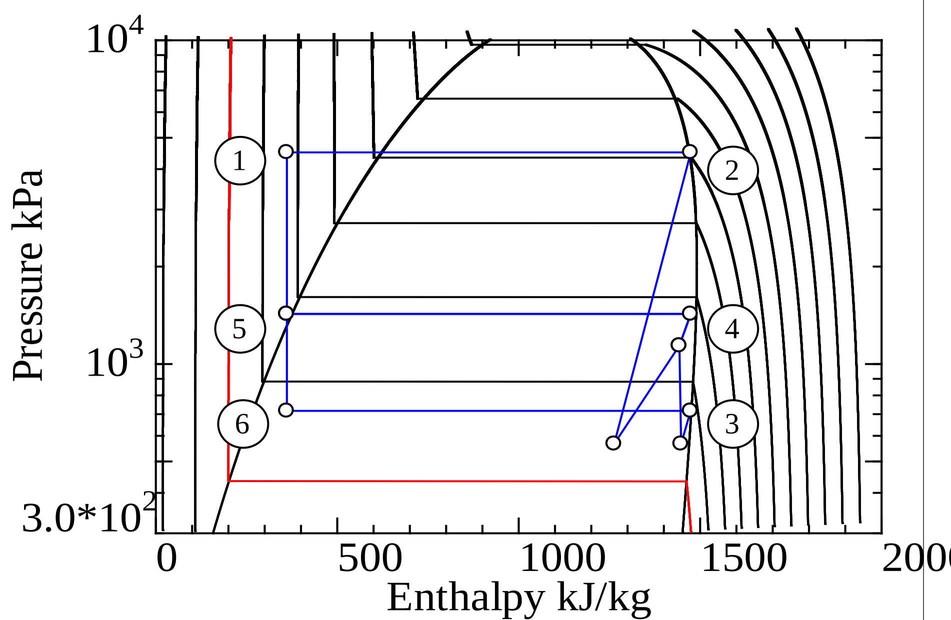


Fig. P-h diagram

Working Principal

- In generator, refrigerant is vaporized in a higher pressure vessel ①→②
- In ejector, high pressure refrigerant from generator goes through nozzle and pressure is lowered. Then this refrigerant absorbs refrigerant vapor from evaporator and pressurized in the diffuser ②→③→④
- In evaporator, refrigerant is vaporized ⑥→③
- In condenser, refrigerant vapor is condensed. ④→⑤

EJECTOR HEAT PUMP

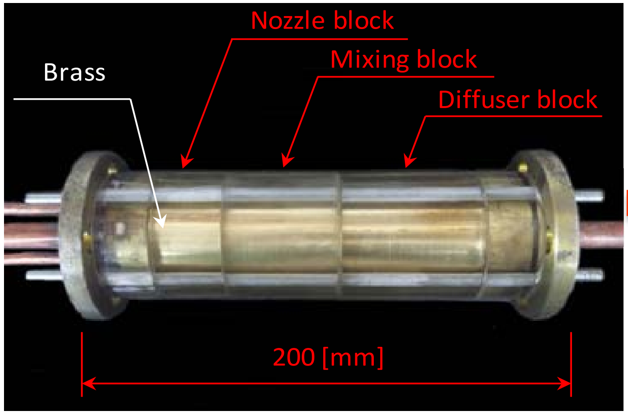


Fig. Ejector Element

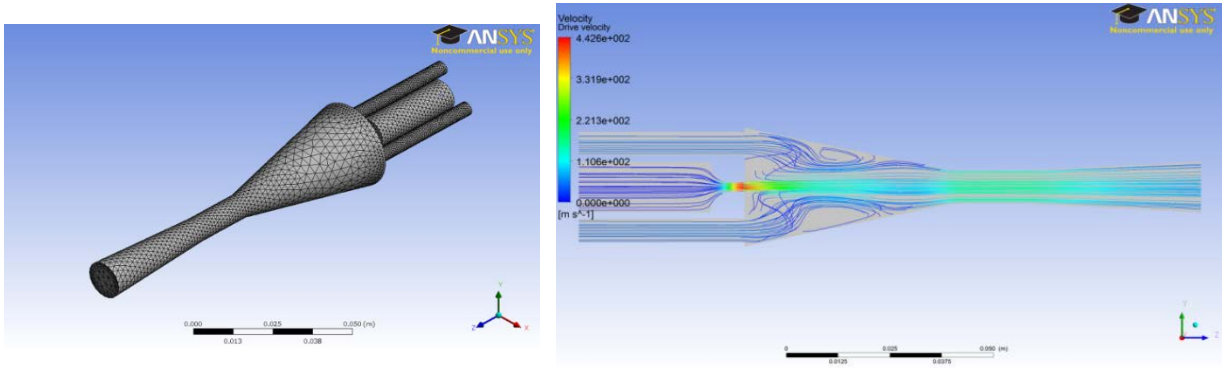


Fig. CFD for ejector element

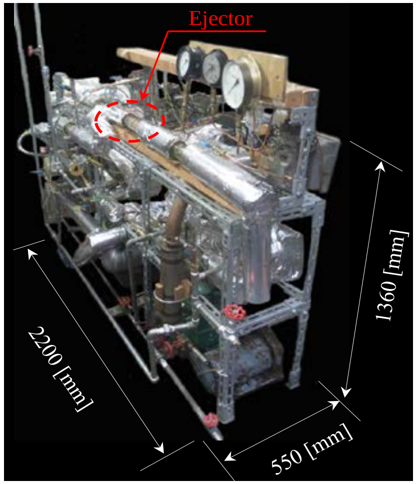


Fig. Experimental apparatus

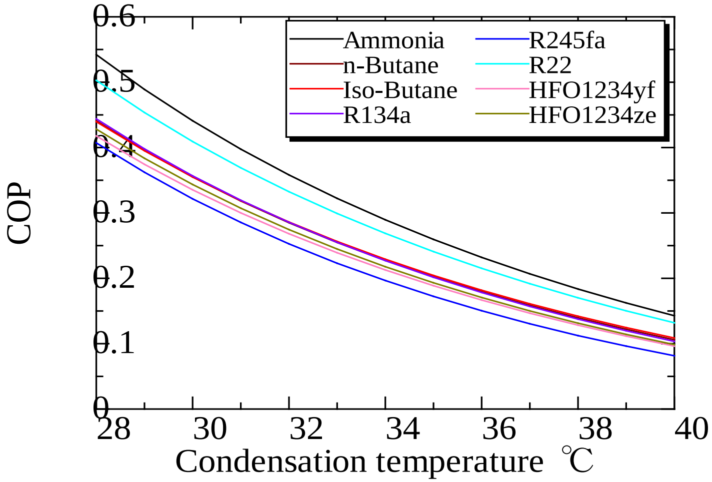


Fig. System COP depending on refrigerant

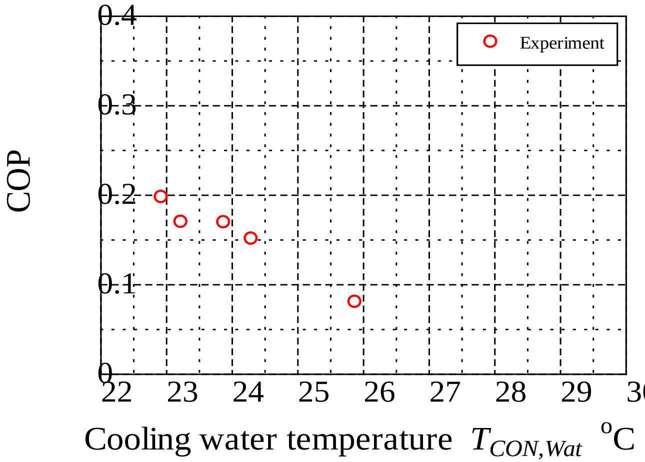
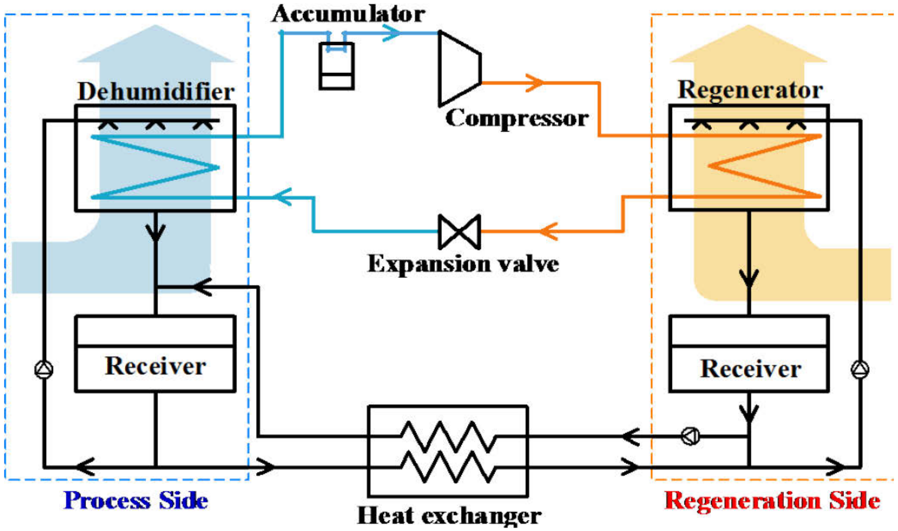
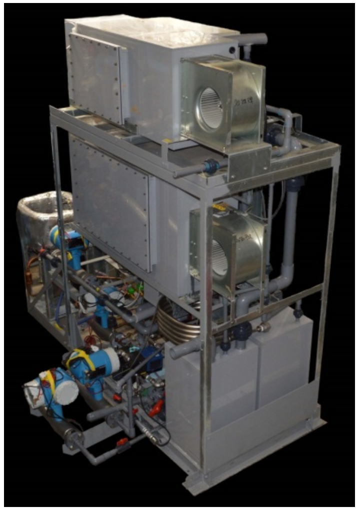


Fig. Experimental result (R245fa)

HYBRID LIQUID DESICCANT DEHUMDIFICATION HEAT PUMP



- Process air and strong LiCl solution are directly contact with each other on media. Process air is dehumidified by LiCl solution.
- Heat pump is used to cool down and regenerate solution



SPECIFICATION

- Cooling capacity : 4.2 kW
- Refrigerant : R407C
- Solution : LiCl
- Air flow rate : 300 m³/h
- Size : W1790×D650×H1510

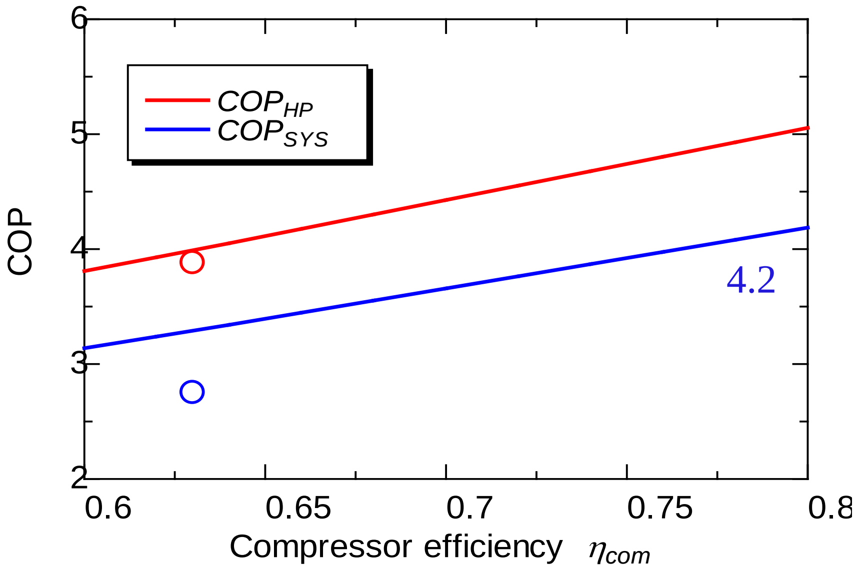
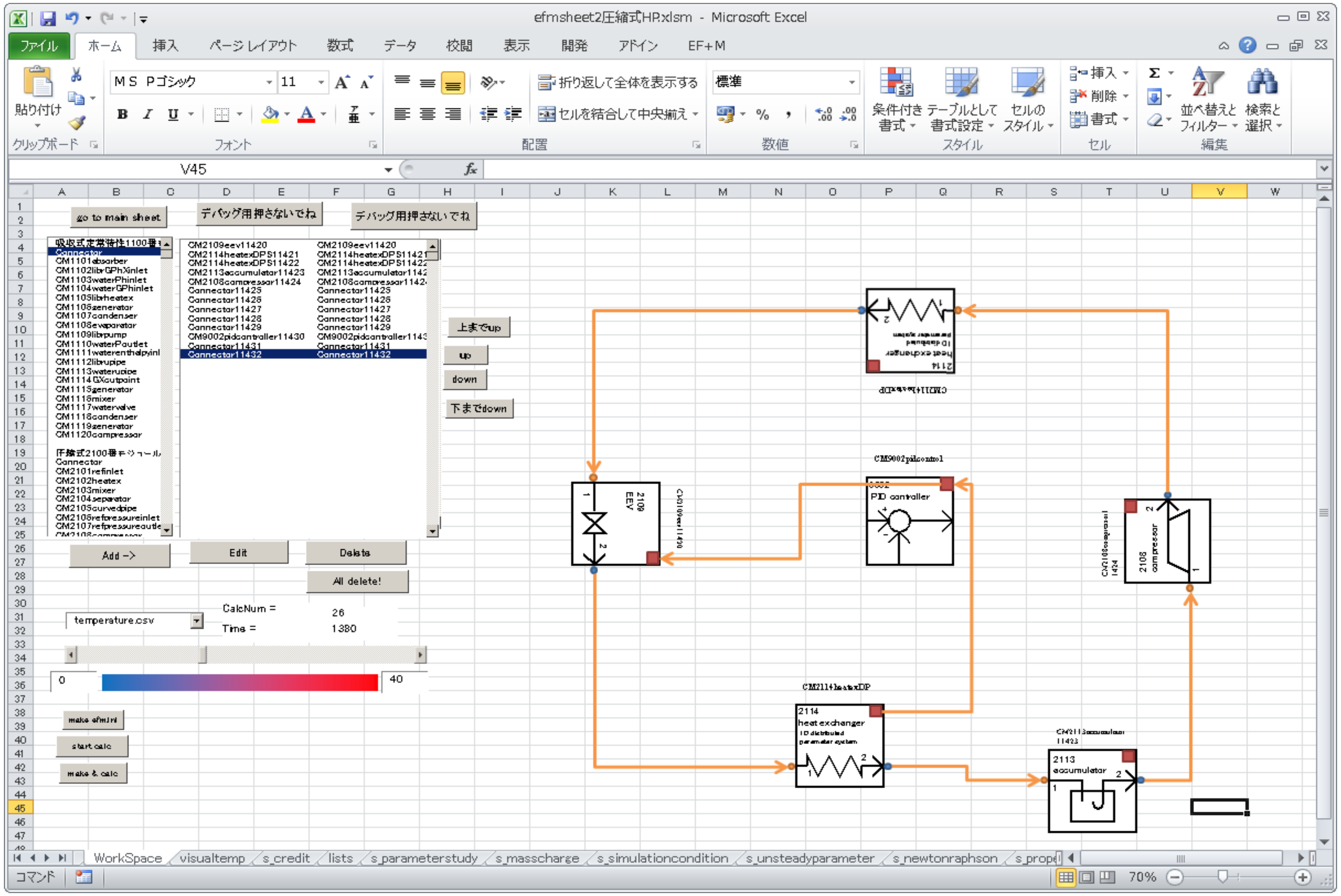


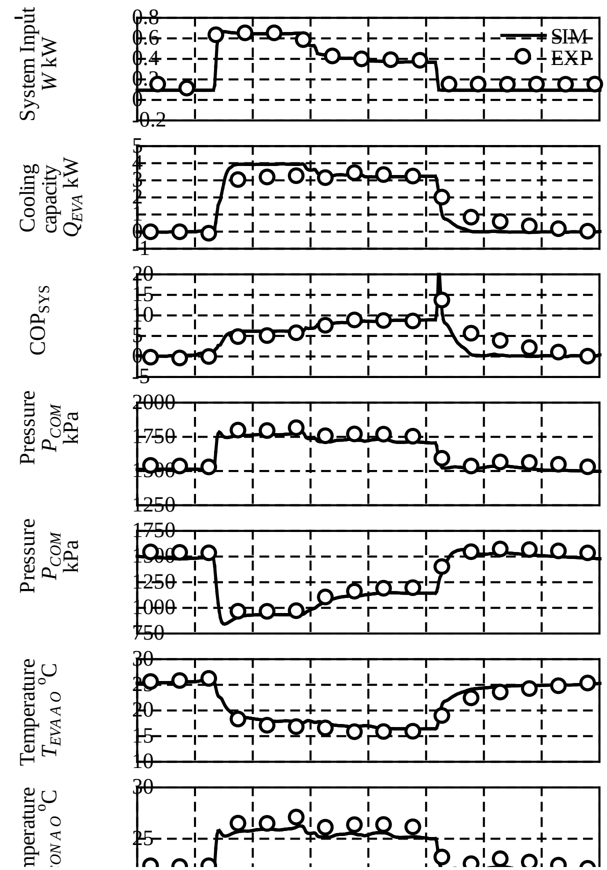
Fig. System performance

Extremely higher COP can be achieved in dehumidification process

SIMULATOR ～ENERGY FLOW +M

Heat pump & Air-conditioner calculation Developed by NEDO's project





SIMULATOR ~ENERGY FLOW +M

Heat exchanger calc.

Ref. side

Continuity
$$\frac{\partial \rho_{HEX\ R}}{\partial t}+\frac{\partial\left(\rho_{HEX\ R} v_{HEX\ R}\right)}{\partial x}=0$$

Pressure drop
$$\frac{\partial P_{HEX\ R}}{\partial x}=-C_{HEX\ PD\ R} C_{HEX\ OIL\ PD\ R}\, f_{HEX\ R} \frac{2\rho_{HEX\ R} v_{HEX\ R}^2}{D_{HEX\ In}}$$

Energy
$$\frac{\partial\left(\rho_{HEX\ R} u_{HEX\ R}\right)}{\partial t}+\frac{\partial\left(\rho_{HEX\ R} v_{HEX\ R} h_{HEX\ R}\right)}{\partial x}=-\frac{\pi D_{HEX\ In}}{S_{HEX\ R}} q_{HEX\ In}$$

Tube energy
$$\frac{\partial\left(\rho_{HEX\ M} u_{HEX\ M}\right)}{\partial t}=\frac{fin_x\, fin_{pitch}}{fin_T S_{HEX\ Out}}\left(q_{HEX\ Mi}-q_{HEX\ Mo}\right)+\frac{\pi D_{HEX\ In}}{S_{HEX\ M}} q_{HEX\ In}-\frac{A_P+\eta_{FIN} A_F}{S_{HEX\ M} L_{HEX}}\left(q_{HEX\ Out}-h_{VAP} J_{HEX}\right)$$

Air side

Continuity
$$\rho_{HEX\ A\ O} v_{HEX\ A\ O} l_{HEX\ A\ O}-\rho_{HEX\ A\ I} v_{HEX\ A\ I} l_{HEX\ A\ I}=-\frac{A_P+\eta_{FIN} A_F}{L_{HEX}} J_{HEX}$$

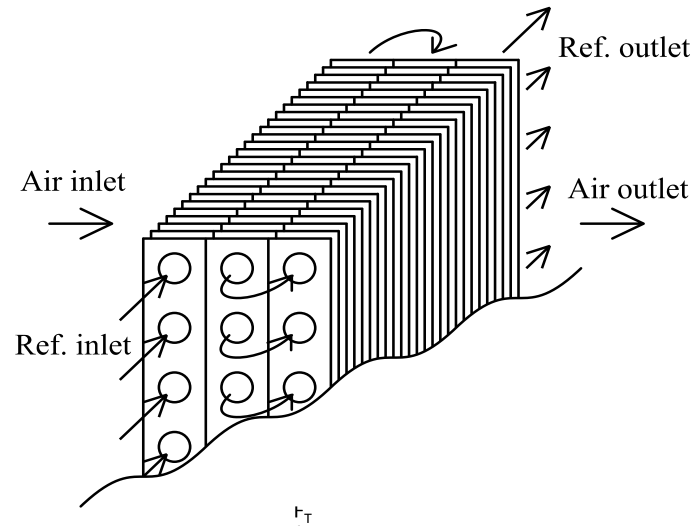
Water continuity
$$\rho_{HEX\ A\ O} v_{HEX\ A\ O} X_{HEX\ A\ O} l_{HEX\ F}-\rho_{HEX\ A\ I} v_{HEX\ A\ I} X_{HEX\ A\ I} l_{HEX\ F}=-\frac{A_P+\eta_{FIN} A_F}{L_{HEX}} J_{HEX}$$

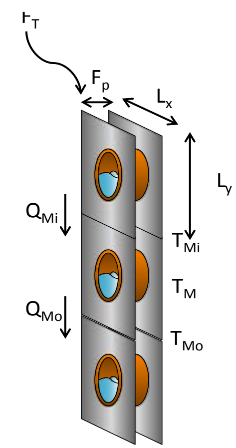
Pressure drop
$$P_{HEX\ A\ I}-P_{HEX\ A\ O}=C_{HEX\ PD\ Out}\, f_A \frac{2 L_x \rho V_{ac}^2}{D_{ec}}$$

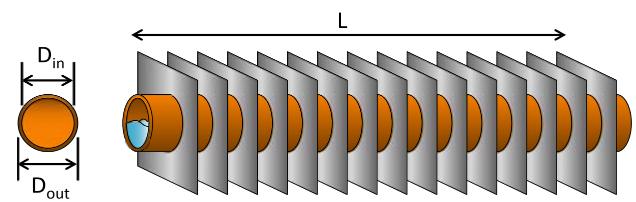
Energy
$$\rho_{HEX\ A\ O} v_{HEX\ A\ O} h_{HEX\ A\ O} l_{HEX\ A\ O}-\rho_{HEX\ A\ I} v_{HEX\ A\ I} h_{HEX\ A\ I} l_{HEX\ A\ I}=\frac{A_M+\eta_{FIN} A_F}{L_{HEX}}\left(q_{HEX\ Out}-h_{VAP} J\right)$$

Inside heat trans. coefficient
$$q_{HEX\ In}=C_{HEX\ HT\ In} C_{HEX\ OIL\ HT} \alpha_{HEX\ In}\left(T_{HEX\ R}-T_{HEX\ M}\right)$$

Outside heat trans. coefficient
$$q_{HEX\ Out}=C_{HEX\ HT\ Out} \alpha_{HEX\ Out} \frac{\left(T_M-T_{AI}\right)-\left(T_M-T_{AO}\right)}{\ln \frac{\left(T_M-T_{AI}\right)}{\left(T_M-T_{AO}\right)}}$$







SIMULATOR ~ENERGY FLOW +M

Heat exchanger calc.

Straight tube

Ref. single phase pressure drop Blasius $f_R = 0.079\,\mathrm{Re}_R^{-0.25}$

Ref. two phase pressure drop Chisholm $f_R = 0.079\,\mathrm{Re}_{R.l}^{-0.25}\,\phi_l^2$ $\phi_l^2 = 1 + \dfrac{20}{Xtt} + Xtt^2$

Ref. single heat transfer coef. Dittus-Boelter $Nu_R = 0.023\,\mathrm{Re}_R^{0.8}\,\mathrm{Pr}_R^n$

Ref. evaporating heat trans. coef. Yoshida $\dfrac{\alpha_{MR}}{\alpha_{MR.l}} = 3.7\left\{Bo\times10^4 + 0.23\left(Bo\times10^4\right)^{0.67}\cdot\left(\dfrac{1}{Xtt}\right)^2\right\}^{0.44}$

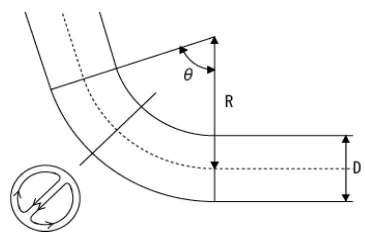
Ref. condensing heat trans. coef. Nozu

$$Nu_{R.f} = 0.018\left(\mathrm{Re}_{R.l}\sqrt{\rho_{R.l}/\rho_{R.g}}\right)^{0.9}\left(\frac{X_R}{1-X_R}\right)^{0.1X_R+0.8}\left(\mathrm{Pr}_{R.l}+\frac{8.0\times10^3}{\mathrm{Re}_{R.l}^{1.5}}\right)^{1/3}\cdot\left(1.0+\frac{C_1H}{\mathrm{Pr}_{R.l}}-0.2\frac{H_{R.v}}{\mathrm{Pr}_{R.v}}\right)$$

$$Nu_{R.b} = 0.725\left(\frac{Ga\cdot\mathrm{Pr}_{R.l}}{H}\right)^{0.25}\left\{1.0+0.003\sqrt{\mathrm{Pr}_{R.l}}\cdot C_3^{\,3.1-\frac{0.5}{\mathrm{Pr}_{R.l}}}\right\}^{0.3}\left(1.0+C_2\cdot C_4\right)^{-0.25}$$

Air side heat trans. coef. Sejimo $Nu_A = 2.1\left(\dfrac{\mathrm{Re}_A\,\mathrm{Pr}_A\,d_{ec}}{l_{x_A}}\right)^{0.38}$

Bend



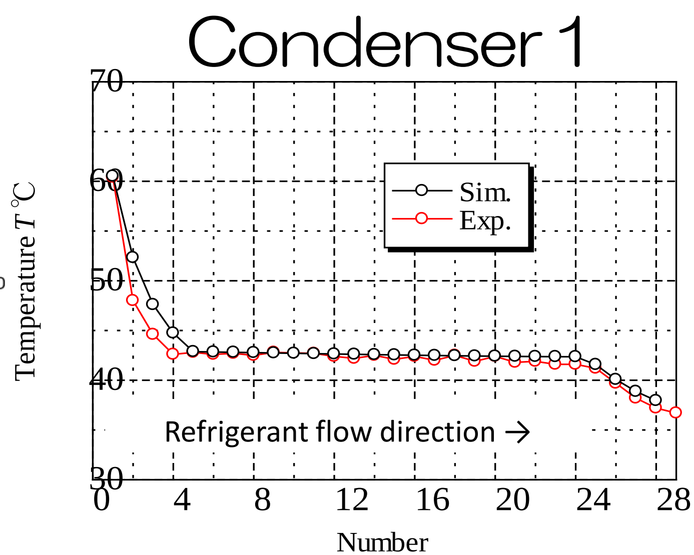
Ref. continuity $\dfrac{\partial\rho_R}{\partial t}V = G_I - G_O$

Ref. pressure drop $P_I - P_O = \varsigma\dfrac{u^2\rho}{2} + \rho g 2r\sin\theta_2$

Ref. energy $\dfrac{\partial\left(\rho_R u_R\right)}{\partial t}V = G_I h_I - G_O h_O$

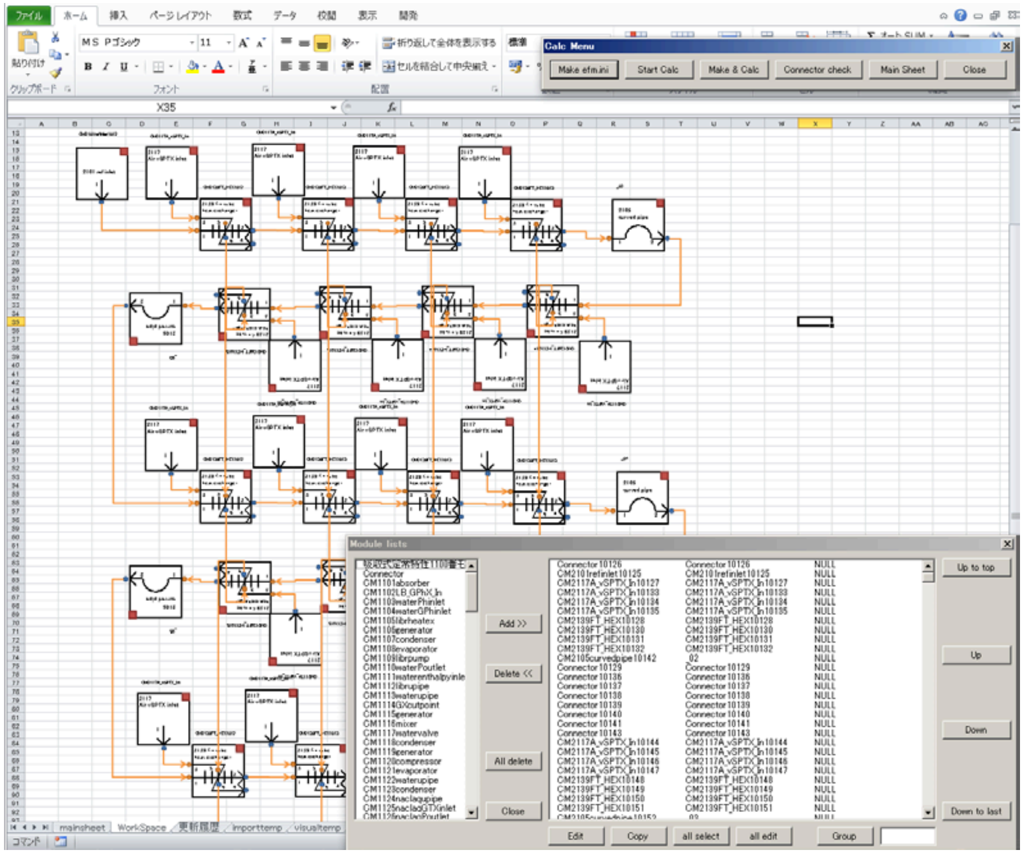
Ito's equation for bend $\varsigma = 0.00431\cdot\alpha\cdot\theta\cdot\mathrm{Re}^{-0.17}\left(\dfrac{R}{D}\right)^{0.84}$ $\mathrm{Re}\left(D/R\right)^2 > 364$

$\alpha = 1 + 5.06\left(\dfrac{R}{D}\right)^{-4.52}$



SIMULATOR ~ENERGY FLOW +M

Heat exchanger calc.



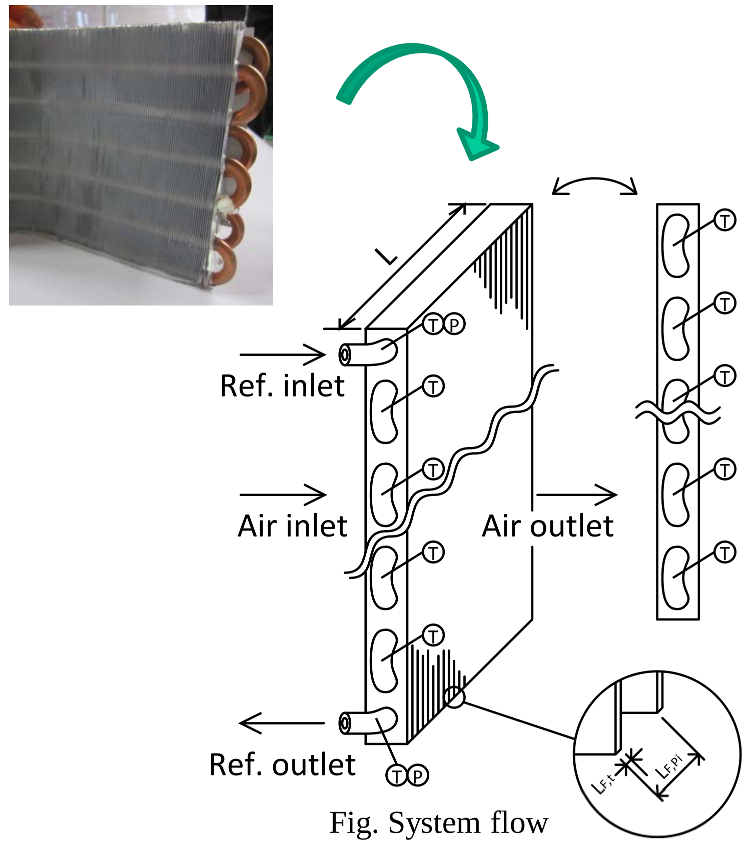
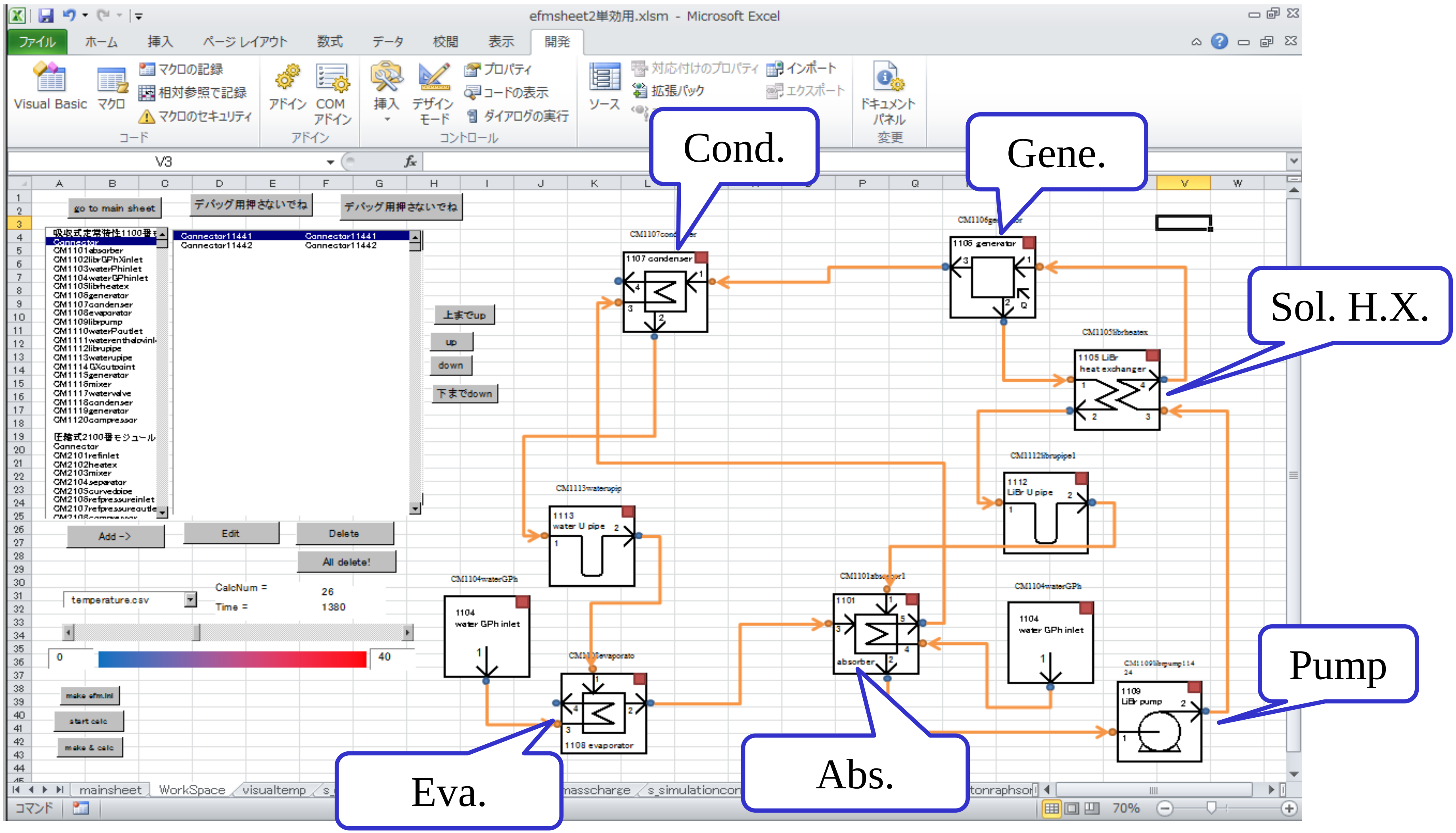


Fig. System flow

SIMULATOR ~ENERGY FLOW +M

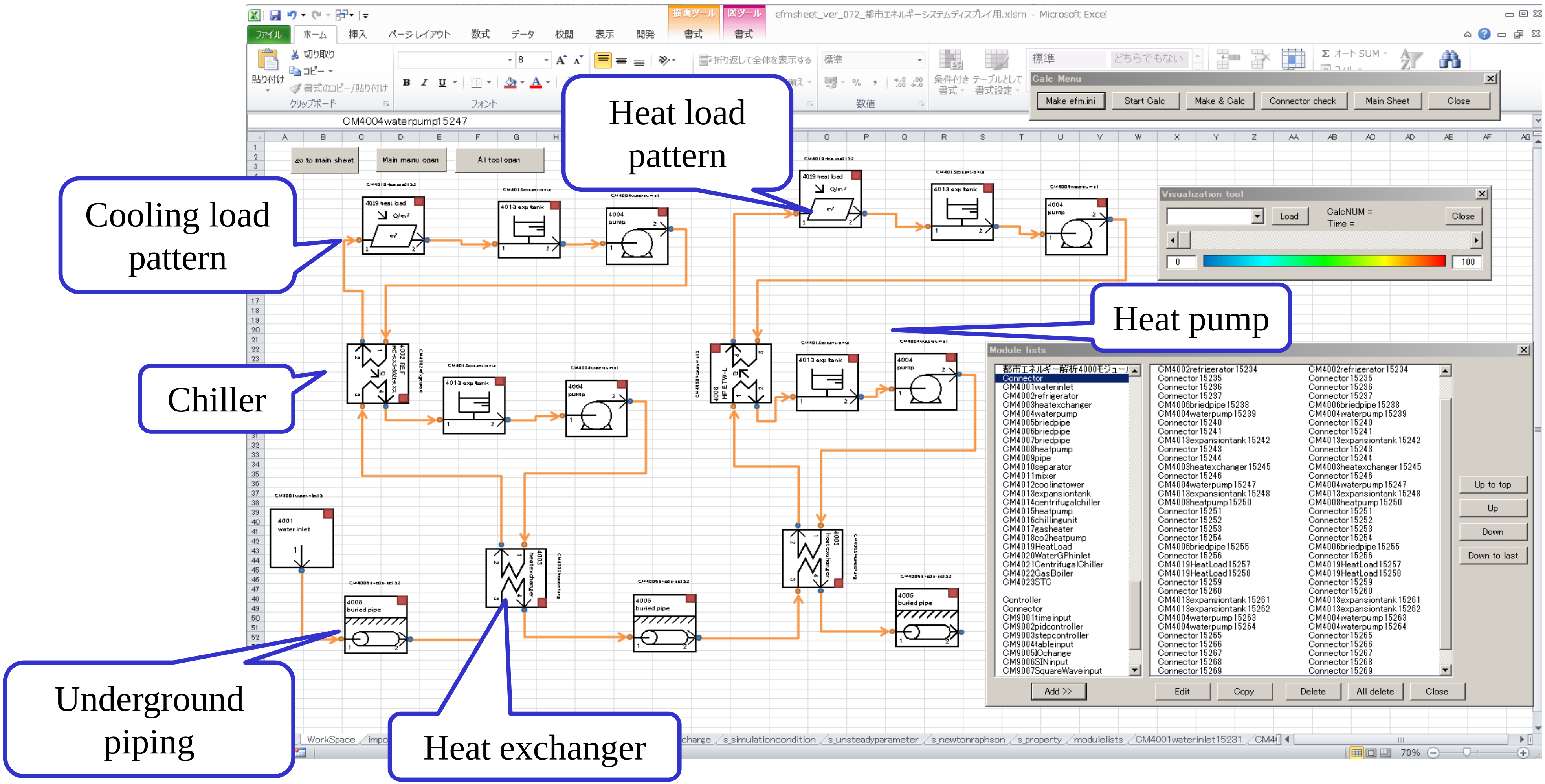
Absorption chiller & heat pump calc.



SIMULATOR ~ENERGY FLOW +M

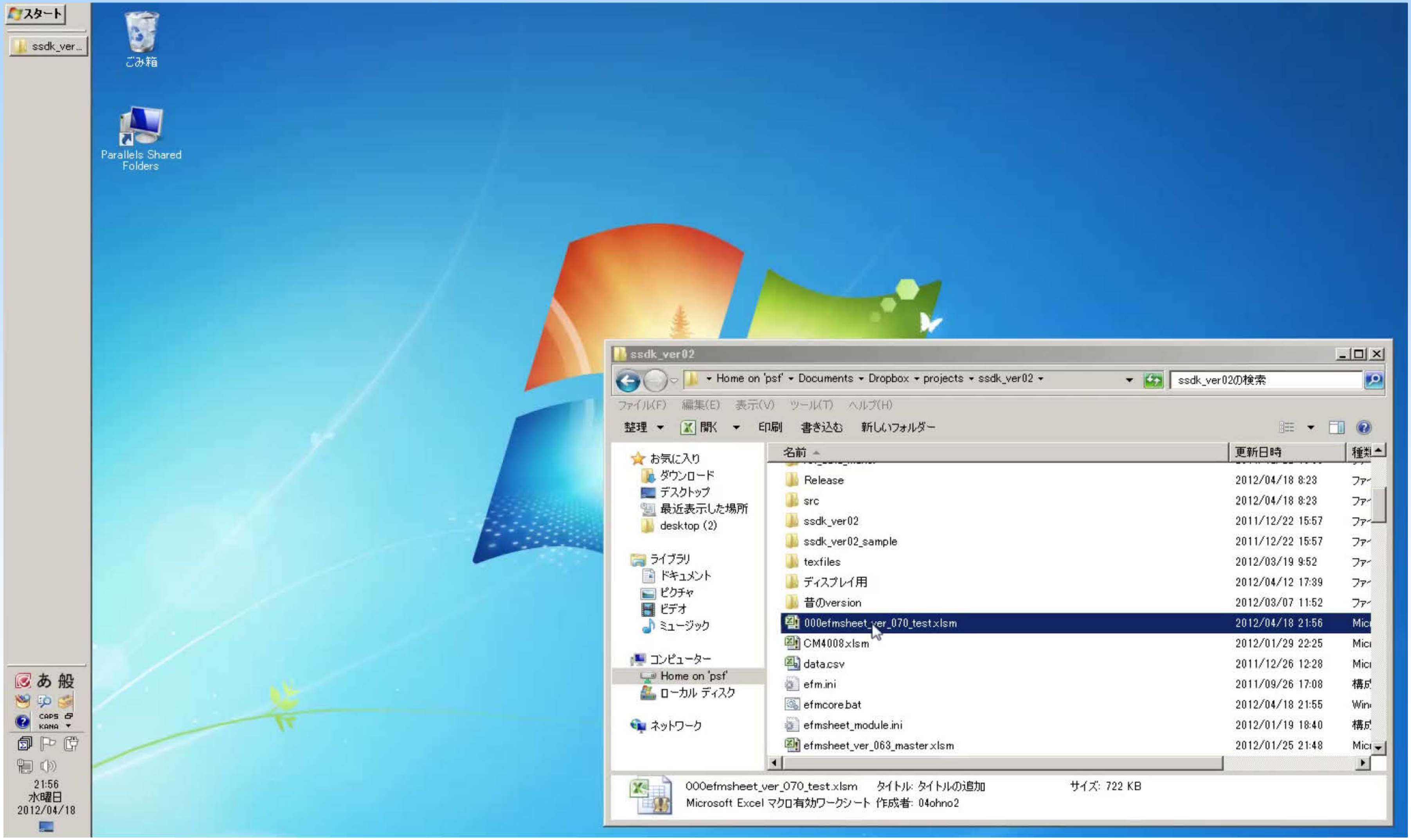
Heat pump whole system calc.

～This is example of underground piping heat usage heat pump system～



SIMULATOR ～ENERGY FLOW +M

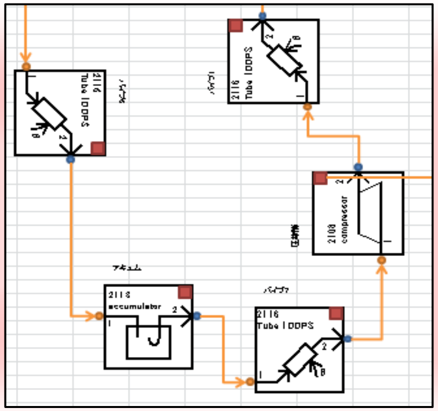
DEMO



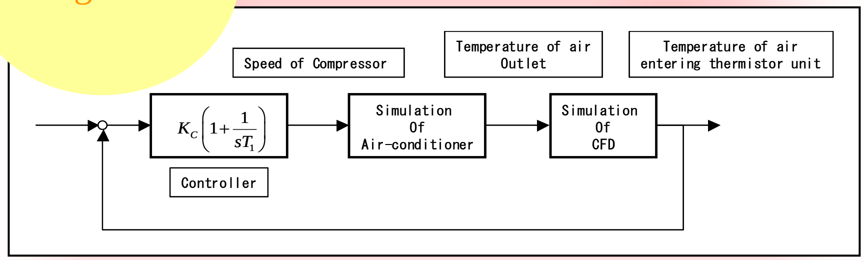
ENERGY FLOW – IAE

Realization of coupled multi-physics simulations are on going project

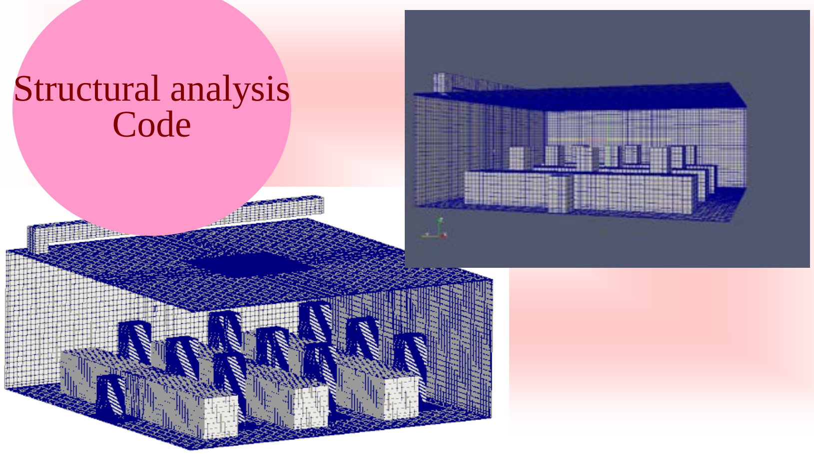
EF+M
Modular
Code



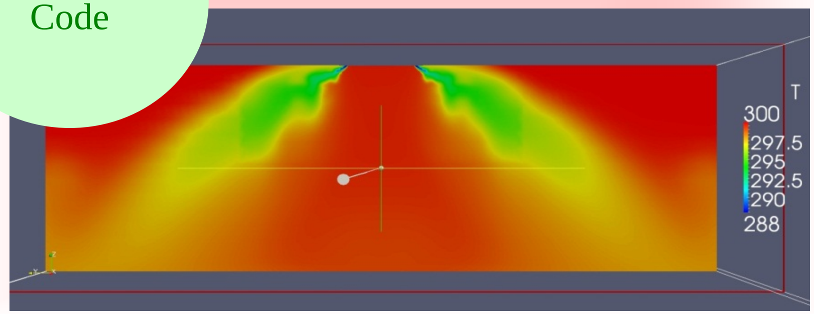
Controller
Design Code



Structural analysis
Code



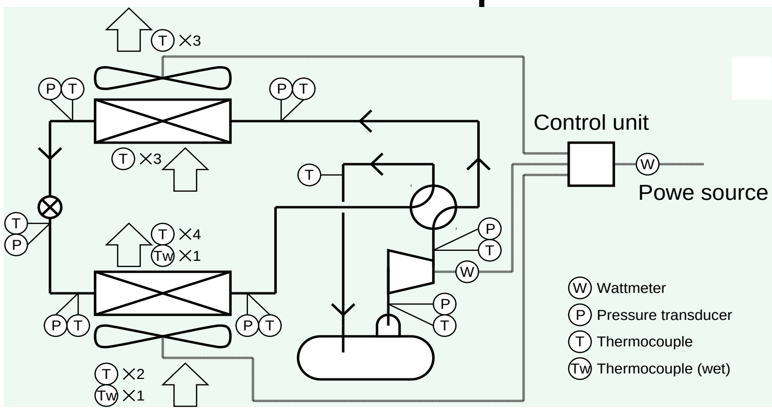
CFD
Code

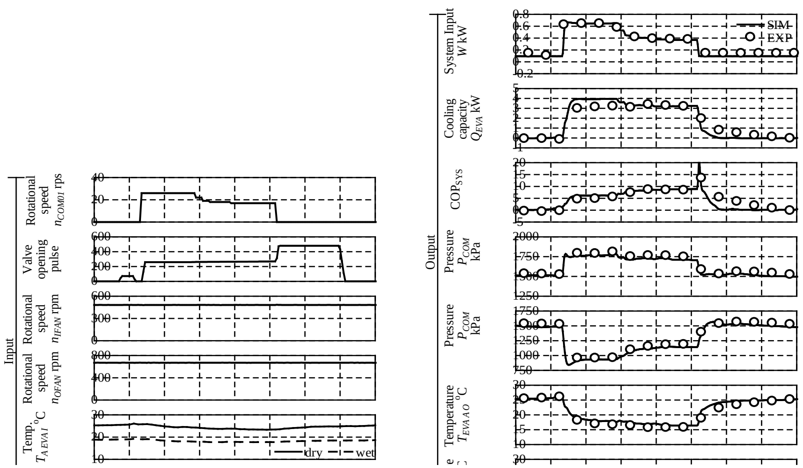


ENERGY FLOW -IAE

COUPLED SIM. OF AIR-CONDITIONER AND ROOM CFD

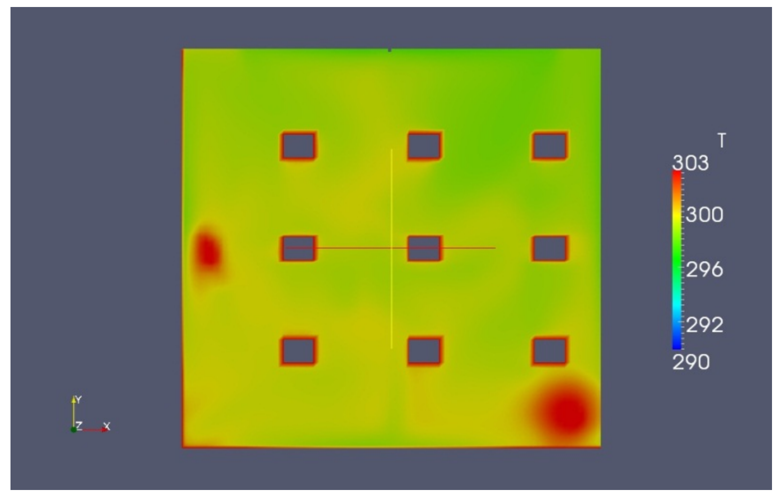
We carried out coupled dynamic simulation with the air-conditioning system simulator we developed and CFD calculation





Supplied air conditions

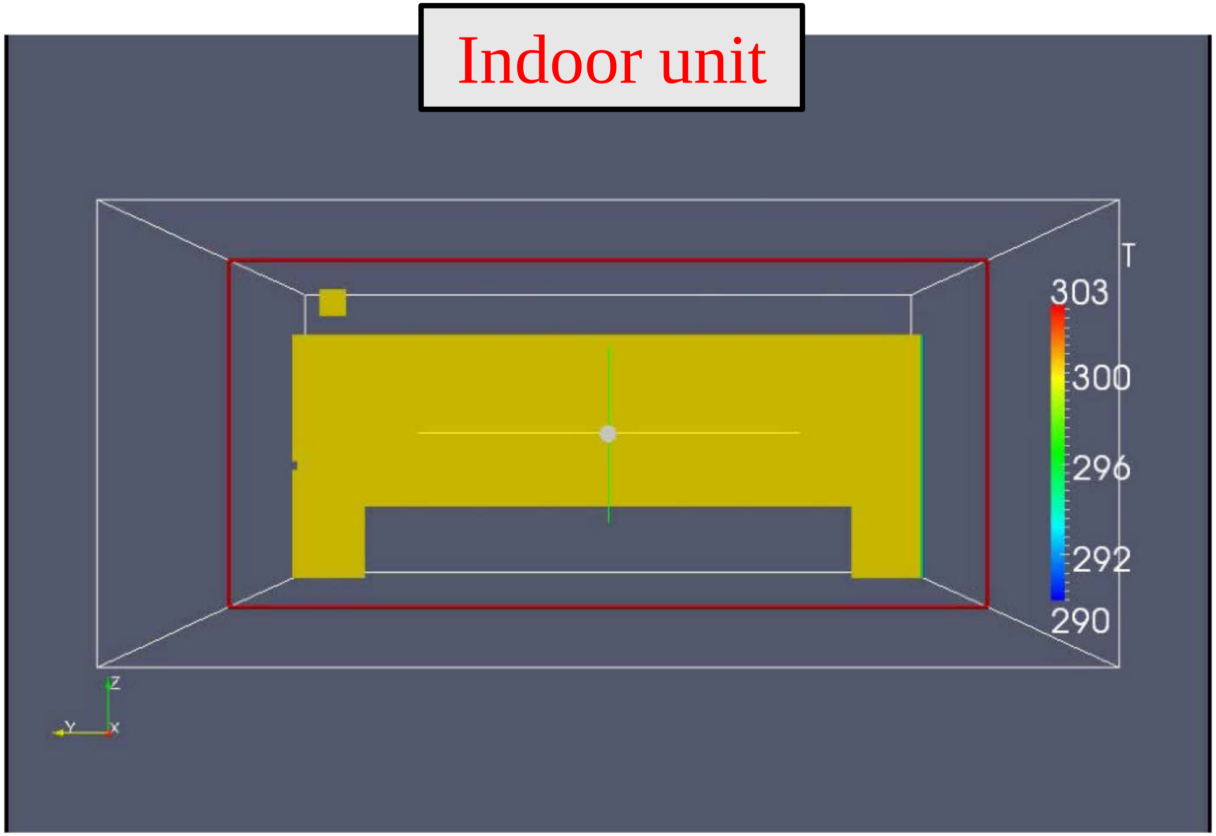
Return air conditions



Air-conditioning system Simulator

CFD OF Space

COUPLED SIM. OF AIR-CONDITIONER AND ROOM CFD



We can carry out coupled simulation of air-conditioning system unsteady state simulation and CFD of space.
We are just now investigating optimum control method of air-conditioning system based on this simulation.

CONCLUDING REMARKS

Today, I introduce latest heat pump system-double stage absorption heat transformer, ejector heat pump, and hybrid liquid desiccant heat pump-.

We develop new simulator " Energy flow+M" that can calculate detailed heat pump performance and optimize heat pump system that uses renewable energy, waste heat and so one.

We introduce coupled multi-physics simulation using " Energy flow+M".

With help of simulation, we pursue what is the best heat pump, heat pump system, control method for next generation heat pump system.