Development of industrial heat pump simulator

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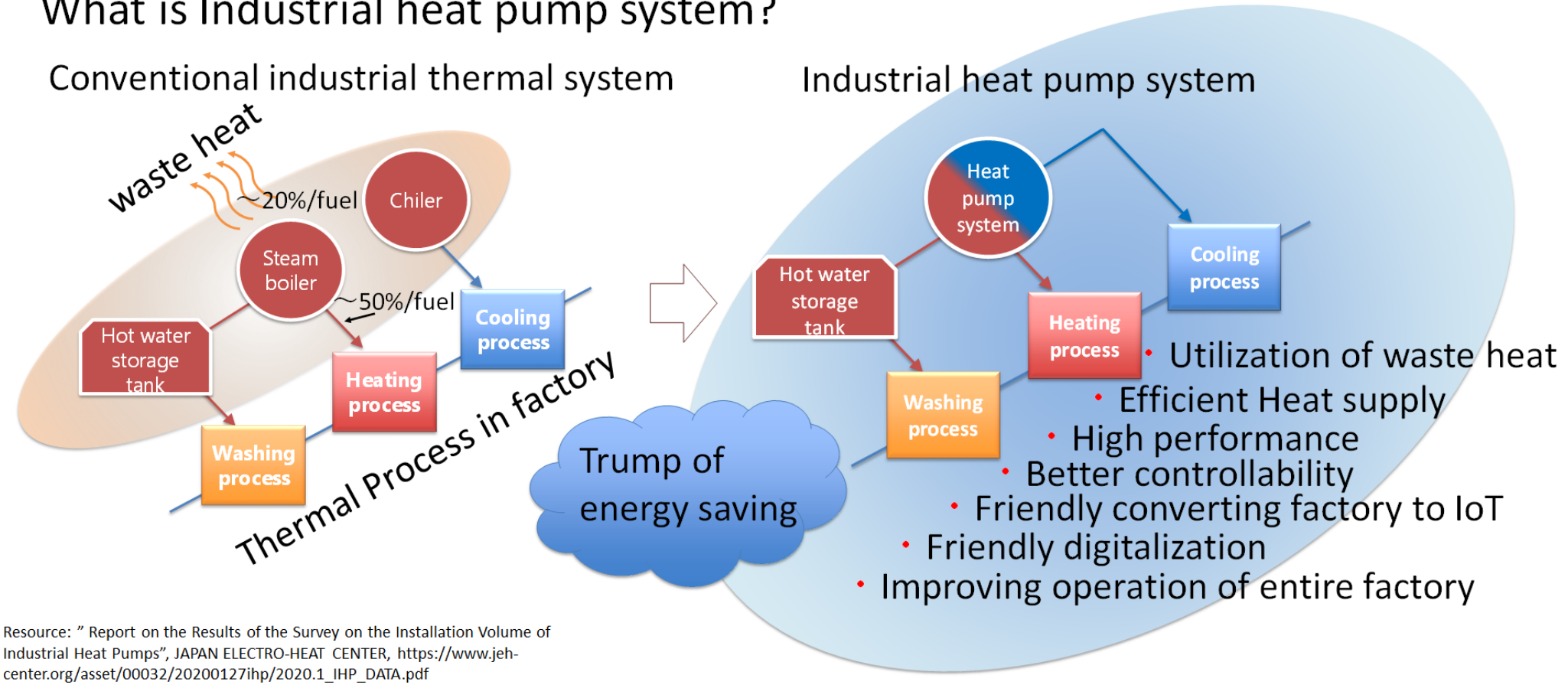
Background

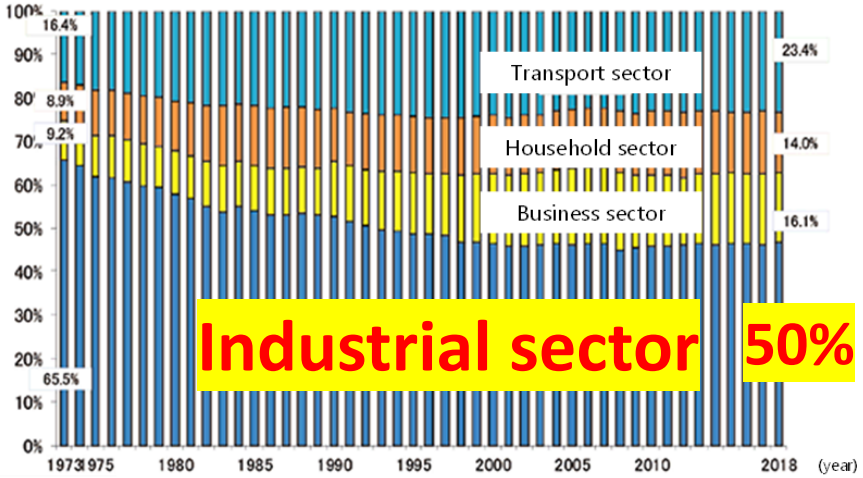
What is Industrial heat pump system?



Resource: " Report on the Results of the Survey on the Installation Volume of Industrial Heat Pumps", JAPAN ELECTRO-HEAT CENTER, https://www.jeh-center.org/asset/00032/20200127ihp/2020.1_IHP_DATA.pdf

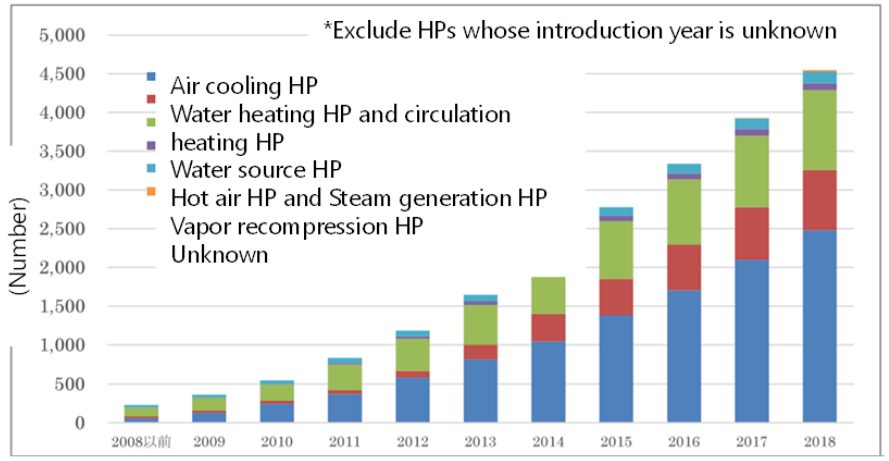
Background

- Japan government raised the realization of a carbon-neutral society in 2050 as a goal



Energy consumption ratio in Japan

Resource: "Energy white paper 2020", Ministry of Economy, Trade and Industry, https://www.enecho.meti.go.jp/about/whitepaper/2020html/2-1-1.html



Cumulative number of industrial heat pumps

Resource: " Report on the Results of the Survey on the Installation Volume of Industrial Heat Pumps", JAPAN ELECTRO-HEAT CENTER, https://www.jeh-center.org/asset/00032/20200127ihp/2020.1_IHP_DATA.pdf

Increase

- Spread of industrial heat pump system in whole of Japan

- Estimation of over 80PJ/Year for energy saving effect based on 2030.
  - Over 1% of total energy in industrial field
  - Over $1 billion if converted to fuel import cost per year

Purpose

To spread industrial heat pump system, What should we do?

We consider

- How satisfactory system performance?
- How large economic efficiency?
- How much introduction effect?
- How easy converting to heat pump?

for industrial heat pump system

Problems ：

Huge system
System introduction cost
Long time operation evaluation

Introduction of simulation technology

Development of a general-purpose evaluation tool on introduction effects of industrial heat pumps

Requirement for simulator

1 Industrial thermal system process logic analysis

- Pattern classification of HP by type, application, and operation method
- Simplification and generalization through patterning

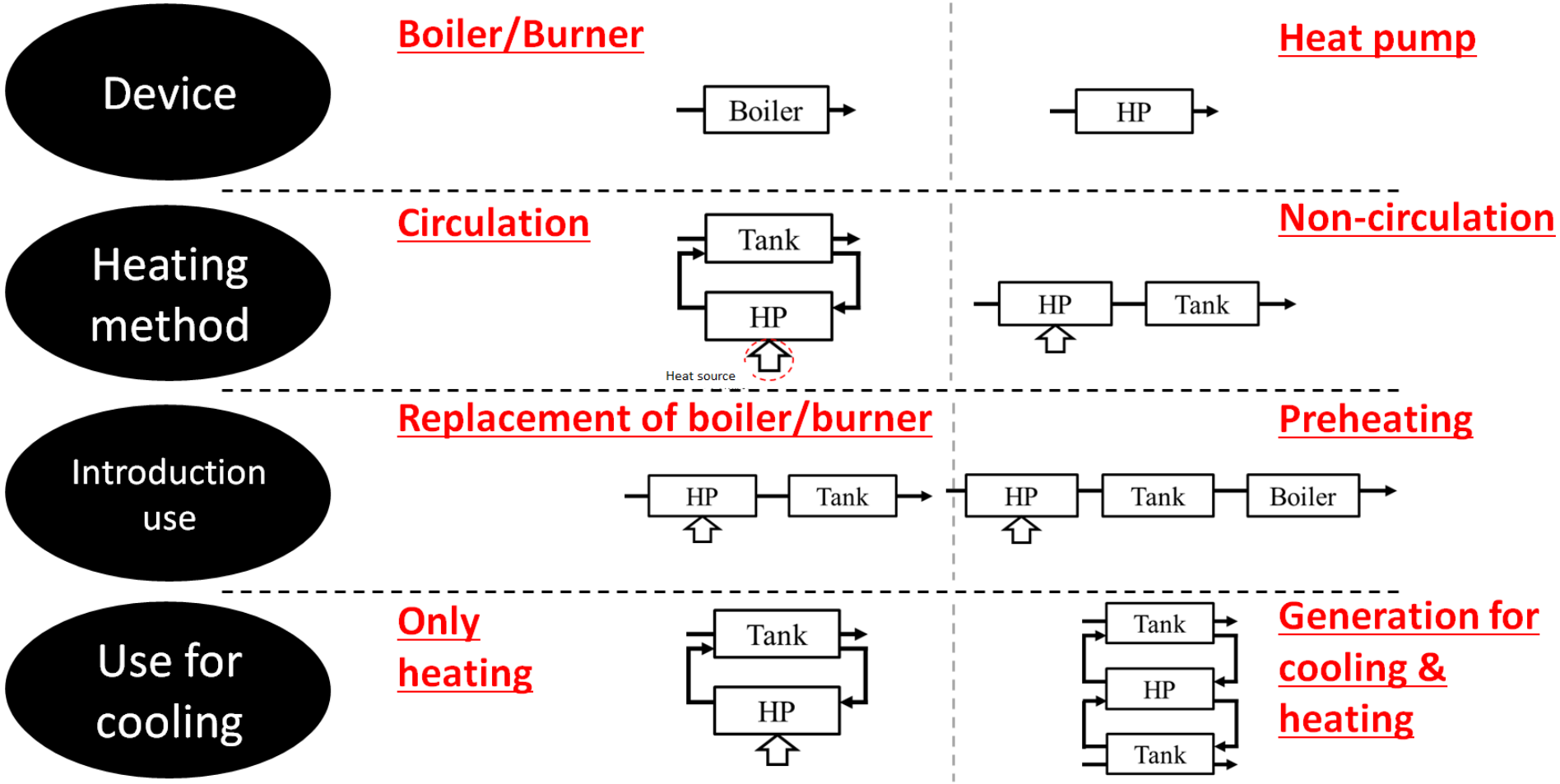
2 Mathematical model

- considering both accuracy and calculation speed for annual performance evaluation
- Capable of calculating transient characteristics for short periods of time

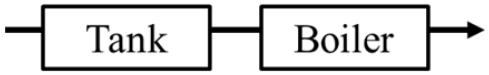
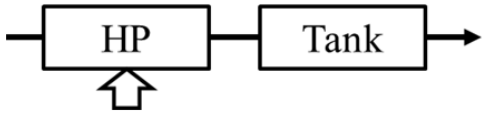
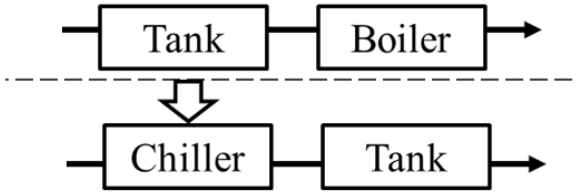
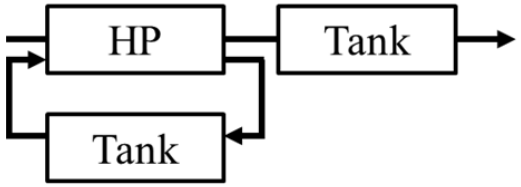
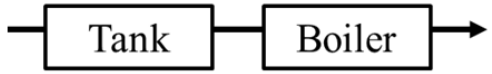
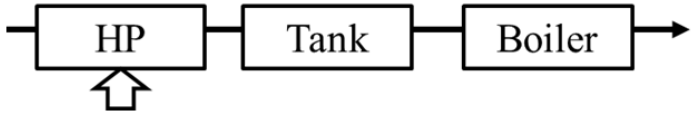
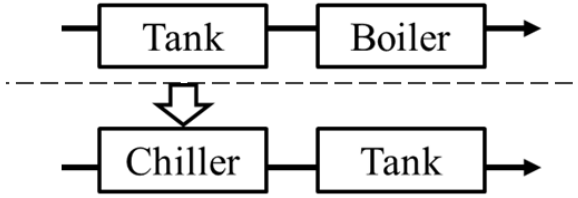
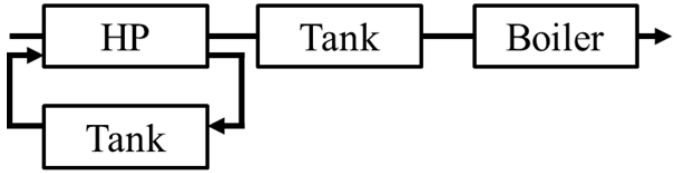
3 User interface

- Proposal for UI with excellent operability
- Improving usability by getting feedback from users

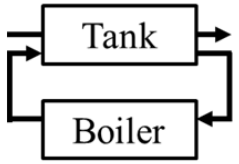
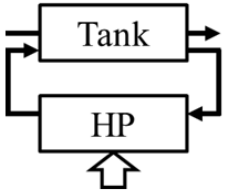
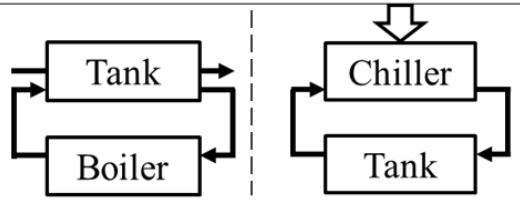
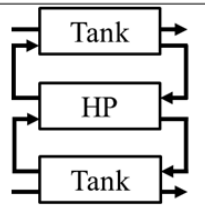
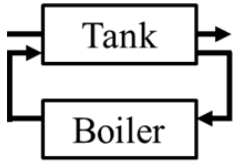
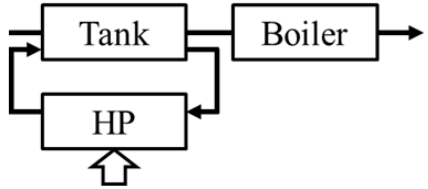
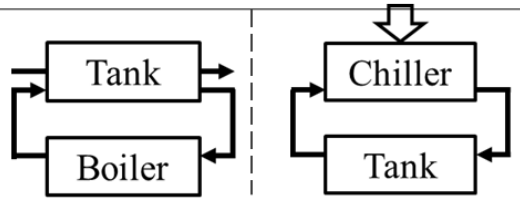
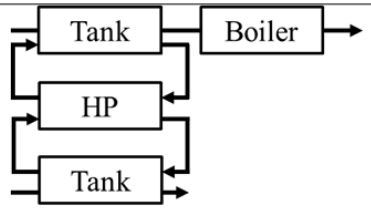
Industrial thermal system process logic analysis



Pattern classification 1

	Conventional type	Alternative type
Type1 ・Non-circulation ・Replacement ・Hot heat generation		
Type2 ・Non-circulation ・Replacement ・Cold/Hot heat generation		
Type3 ・Non-circulation ・Preheating ・Hot heat generation		
Type4 ・Non-circulation ・Preheating ・Cold/Hot heat generation		

Pattern classification 2

	Conventional type	Heat pump type
Type5 ・Circulation ・Replacement ・Hot heat generation		
Type6 ・Circulation ・Replacement ・Cold/Hot heat generation		
Type7 ・Circulation ・Preheating ・Hot heat generation		
Type8 ・Circulation ・Preheating ・Cold/Hot heat generation		

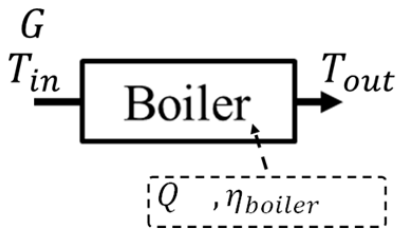
Evaluation indices

- **Mathematical model for annual performance evaluation**

  ensure sufficient validity while focusing on the calculation speed based on,

  Continuity and energy equations

Boiler



Heating amount

$$Q = Gc_p(T_{out} - T_{in})$$

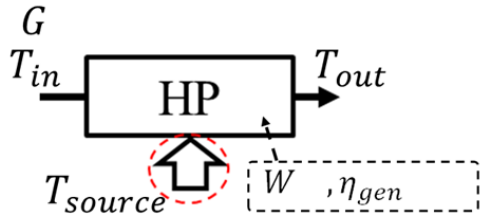
Primary energy

$$W_{pri} = \frac{Q}{\eta_{boiler}} \times 100$$

CO_2 emission(gas)

$$CO_2\ e = W_{pri} \times f_{CO2,gas} \times \frac{dt}{3600}$$

Heat pump: based on the pinch temperature



Heating amount

$$Q = Gc_p(T_{out} - T_{in}) \quad COP = f(T_{in}, T_{out}, T_{source}, T_{pinch}, SH)$$

Primary energy

$$W_{pri} = \frac{\dot{W}}{\eta_{gen}} \times 100\ ,\ \dot{W} = \frac{\dot{Q}}{COP}$$

CO_2 emission(electricity)

$$CO_2\ e = W_{pri} \times \eta_{pef} \times f_{CO2,ele} \times \frac{dt}{3600}$$

Simulator overview

Simplified simulator

1. Select two types that users want to compare
2. Ph diagram in a heat pump is displayed
3. Primary energy on a time, primary energy consumption, carbon dioxide production and LCCP are displayed for environmental assessment.
4. Economic assessment

Fig. Graphic user Interface

Simulator overview

Integrated simulator

1. High degree of flexibility for calculation requests
2. Auxiliary devices such as pump or blower are also considered
3. Equipped with a database of examples of various heat pump system installations
4. Environmental and economic assessment

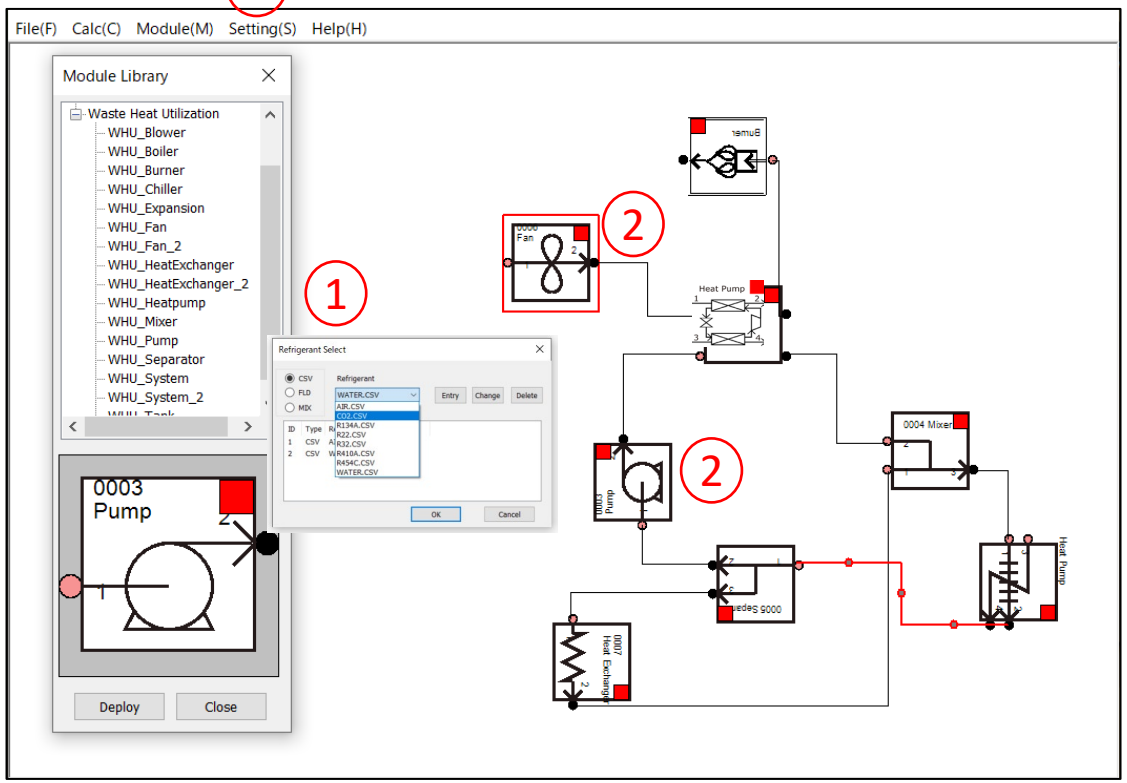


Fig. Graphic user Interface

3

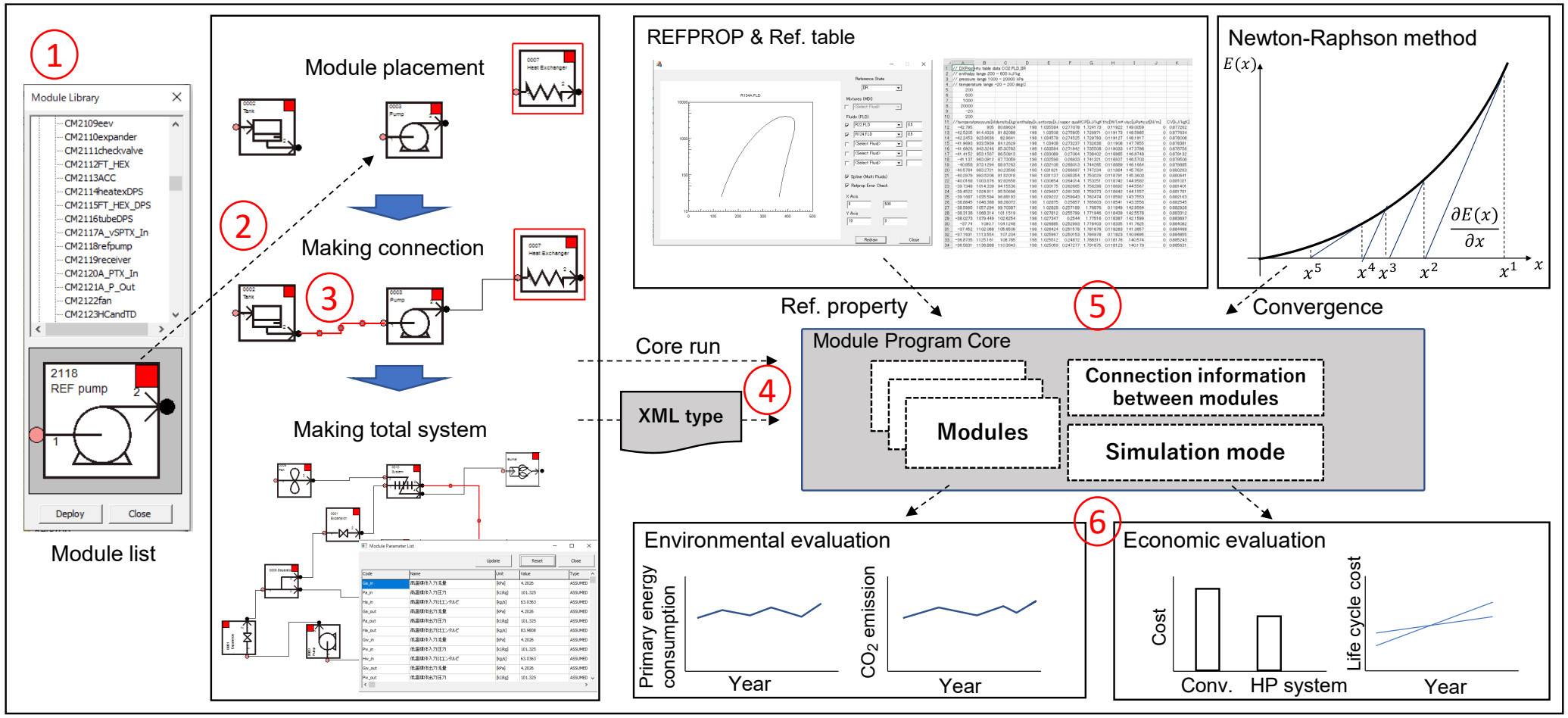
LIBRARY OF CASE STUDY			
Type of industry	**Use**	**Heat pump installation system**	**Use media**
Manufacture of electrical equipment	**Dryness**	Coating and drying A	**Hot wind**
Dairy product manufacturing	**Heat insulation**	Dairy products	**Hot water**
Food Manufacturing	**Washing and hot water supply**	Food Manufacturing	**Hot water**
Food Manufacturing	**Washing and hot water supply**	Cookware	**Hot water**
Manufacture of alcoholic beverages	**Washing and sterilizing**	Cleaning and sterilization	**Hot water**
Manufacture of electric cables for ships	**Dryness**	Coating and drying B	**Hot water**

Fig. Library of case study

Simulation overview

Integrated simulator

1. Module selection from module library
2. Module placement
3. Building System
4. Core run based on XML
5. System calculation using Ref. property and Solver
6. Simulation results



Environmental assessment of heat pump

Overview of Heat Pump Installation

- Applied to: Coating and drying process
- Conventional heat source: gas burner
- Installed heat pump: Hot air heat pump
  (Heating capacity 110 kW, power consumption 30 kW)
- Type of introduction: Introduced as a preheating system for conventional burners

Comparison and evaluation points

- Environmental assessment
  - Primary energy consumption
  - CO_2 emission

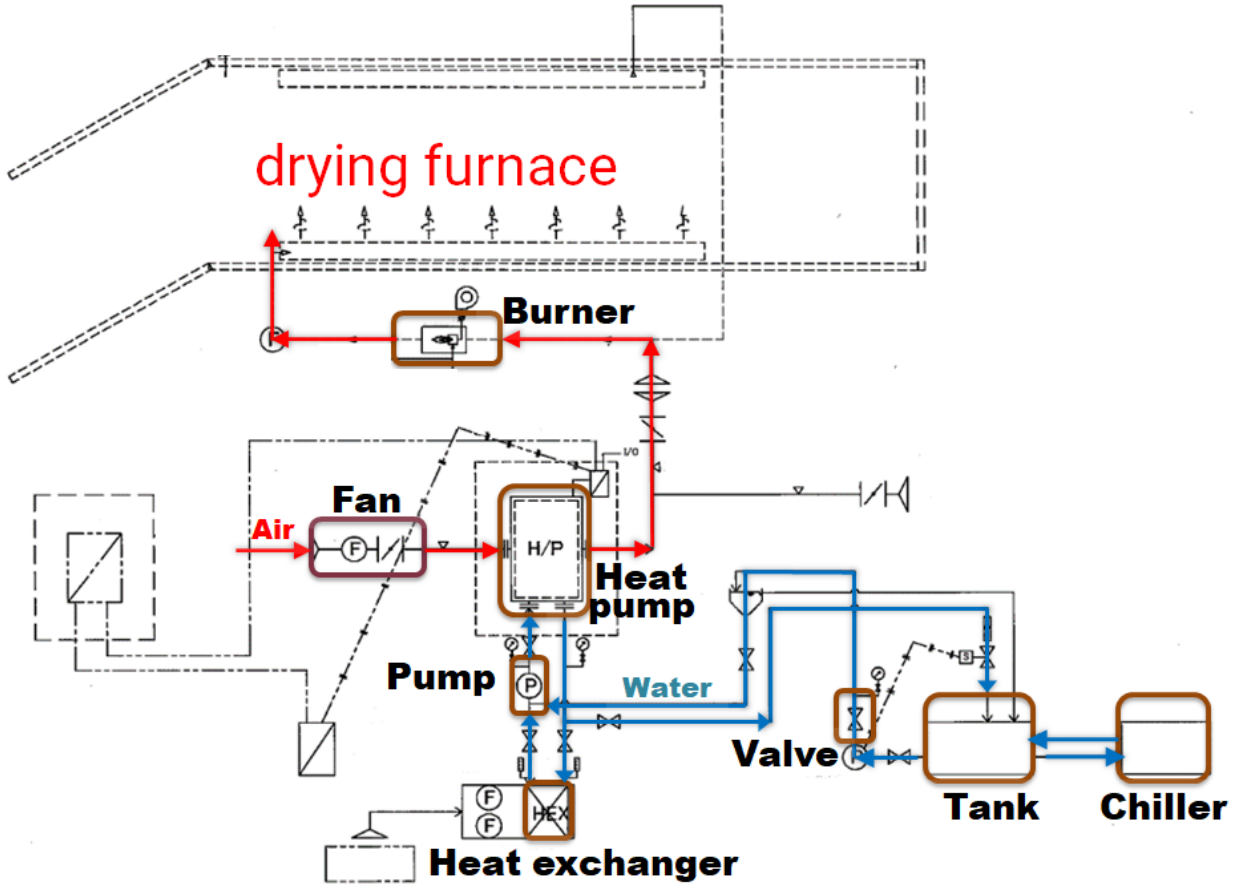


Fig. Heat pump system installed in the coating and drying process

System before and after installing heat pump

TYPE **IV**

- Non-circulation
- Preheating
- Cold/Hot heat generation

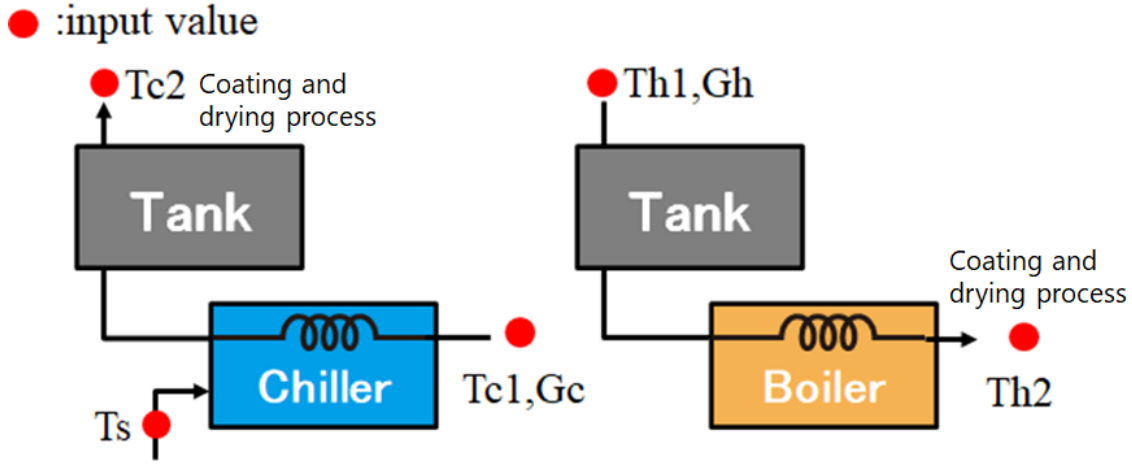


Fig. System before heat pump installation

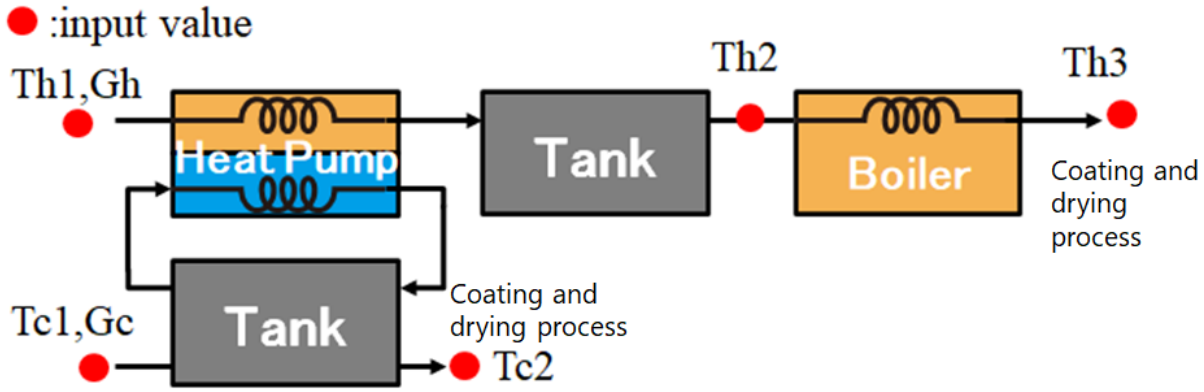


Fig. System after heat pump installation

Applied to GUI of simplified simulator and integrated simulator

GUI set of simplified simulator

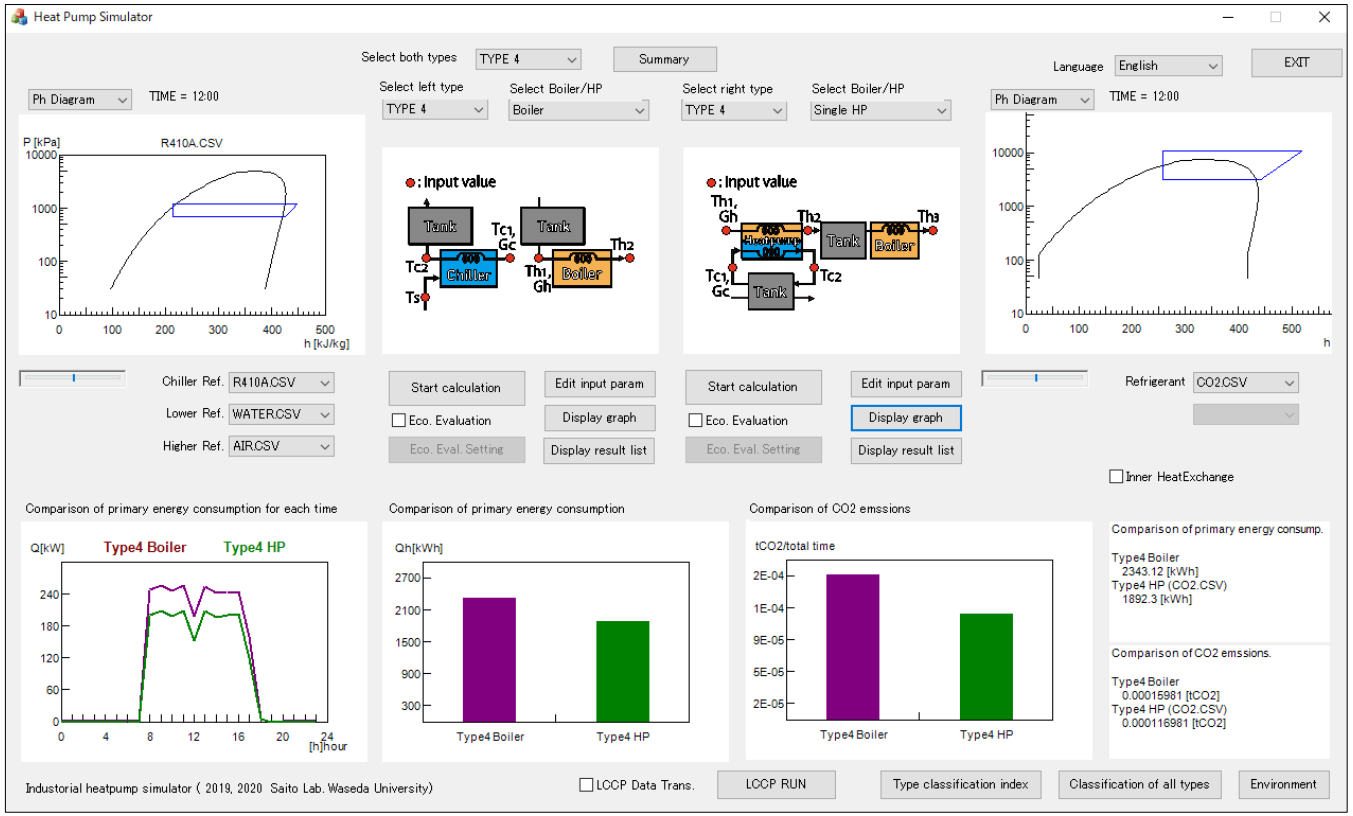


Fig. GUI of simplified simulator

GUI set of integrated simulator

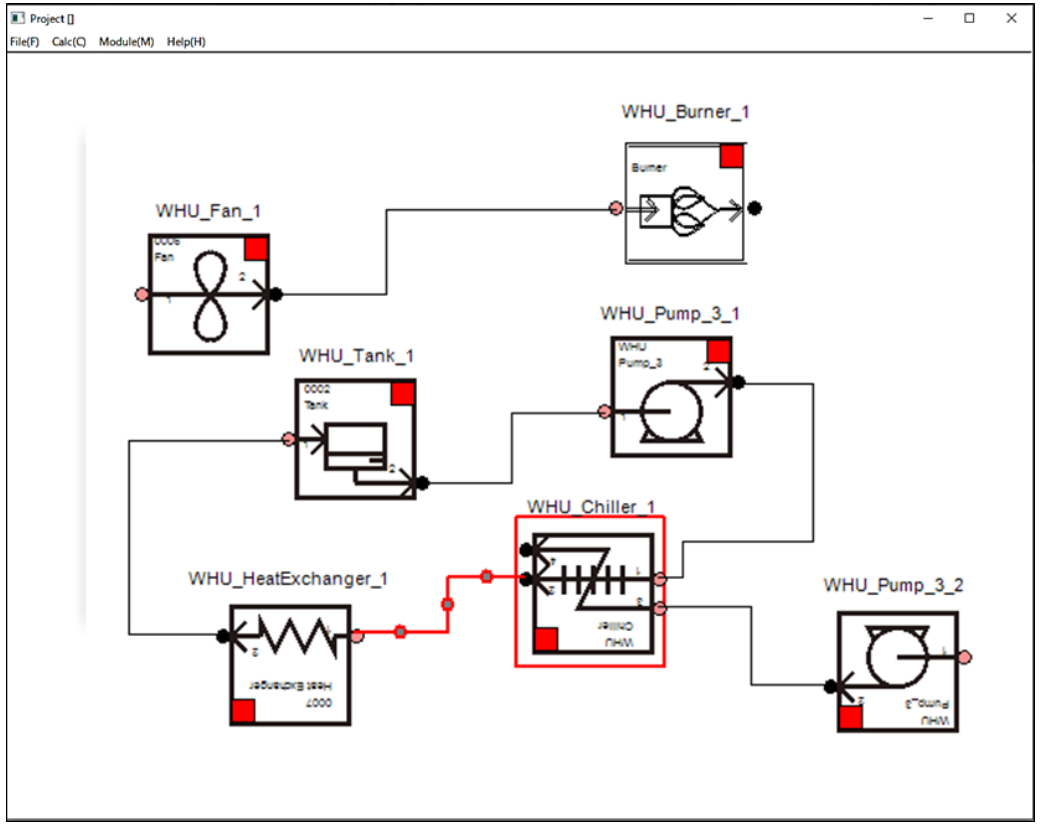


Fig. System before heat pump installation

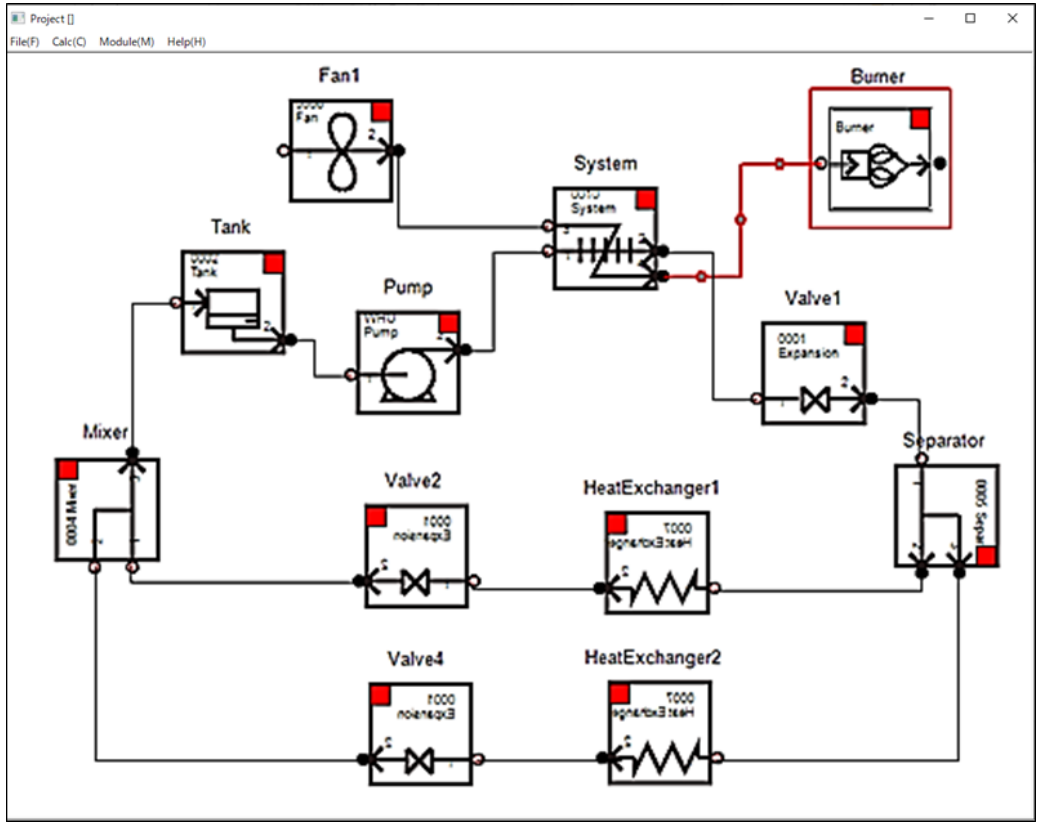
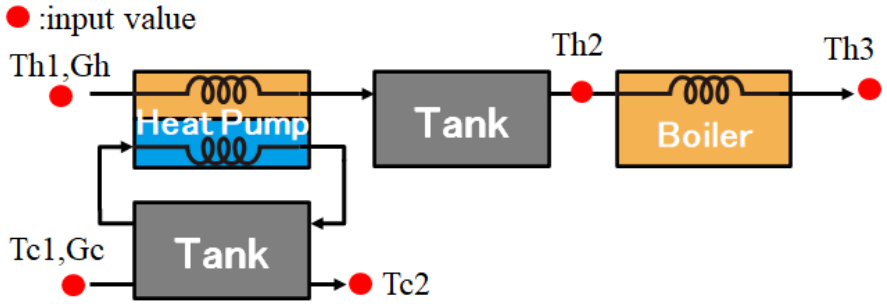
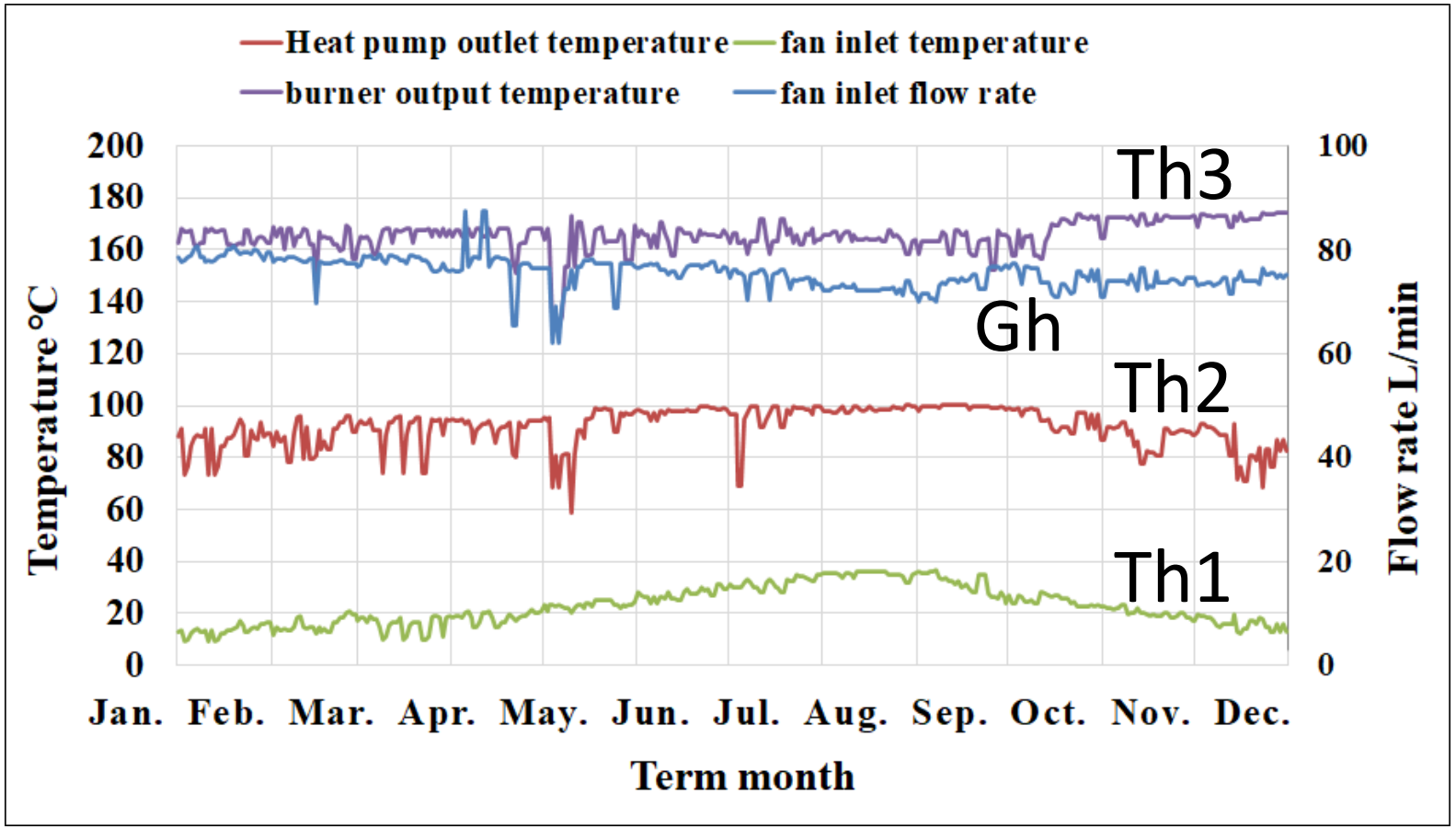


Fig. System after heat pump installation

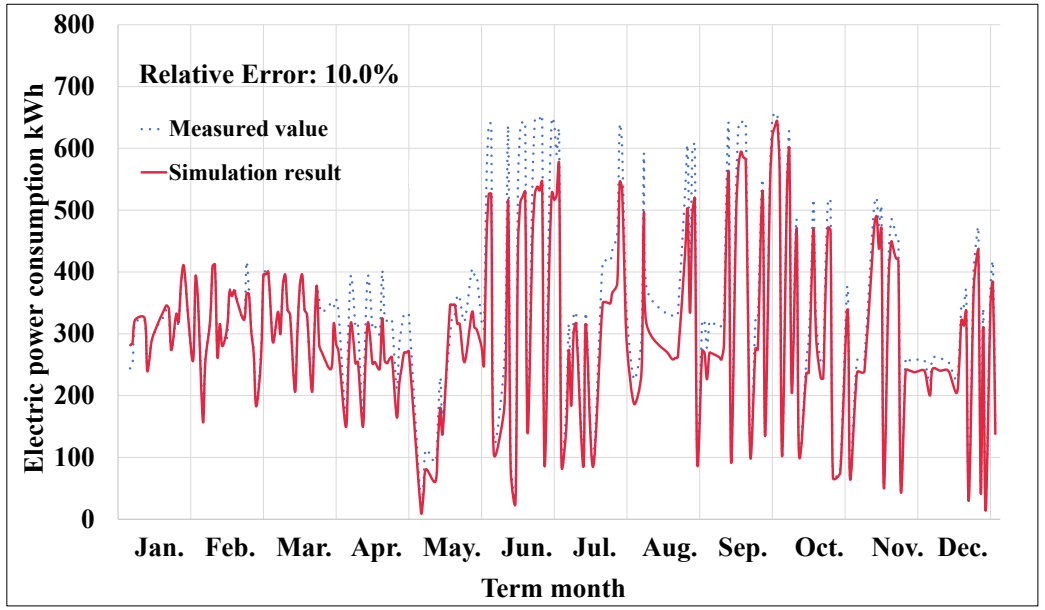
Annual measured operation data





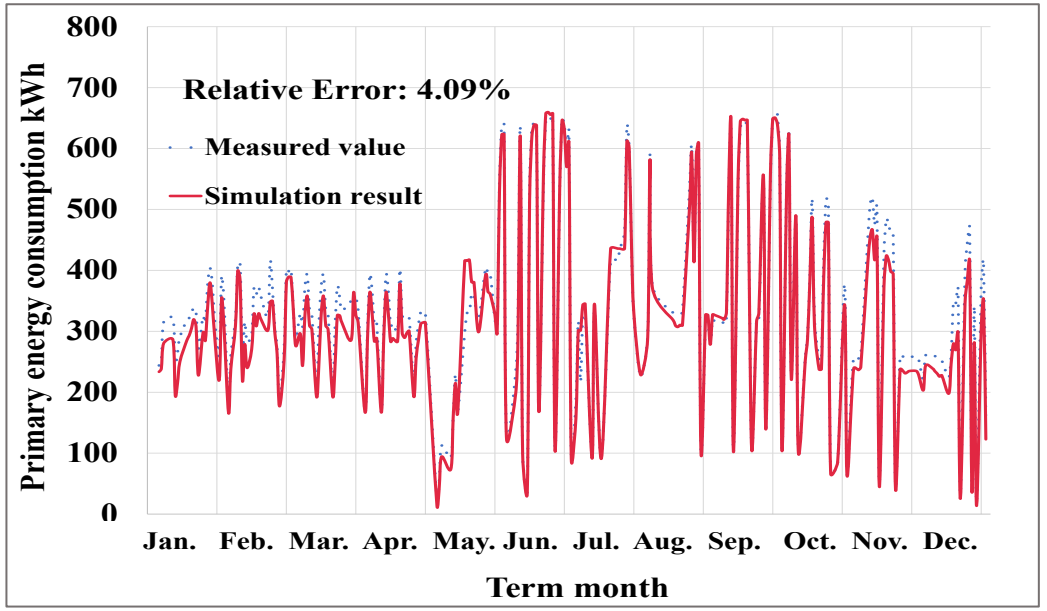
Comparison of simulation & measured values

Simulation results by simplified simulator



Relative errors : Approx. 10%
Auxiliary equipment (fan, pump): not considered

Simulation results by integrated simulator



Relative errors : Approx. 4%
Auxiliary equipment (fan, pump): considered

Comparison of primary energy consumption

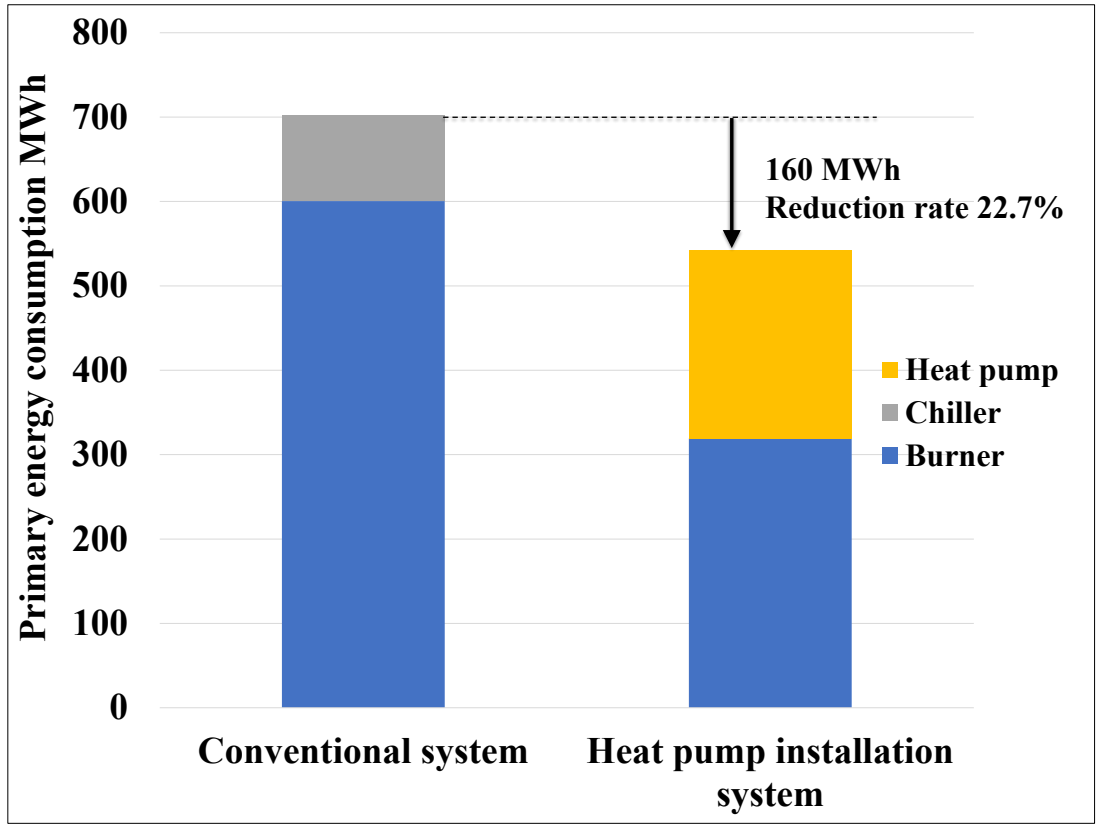


Fig. Primary energy consumption by simplified simulator

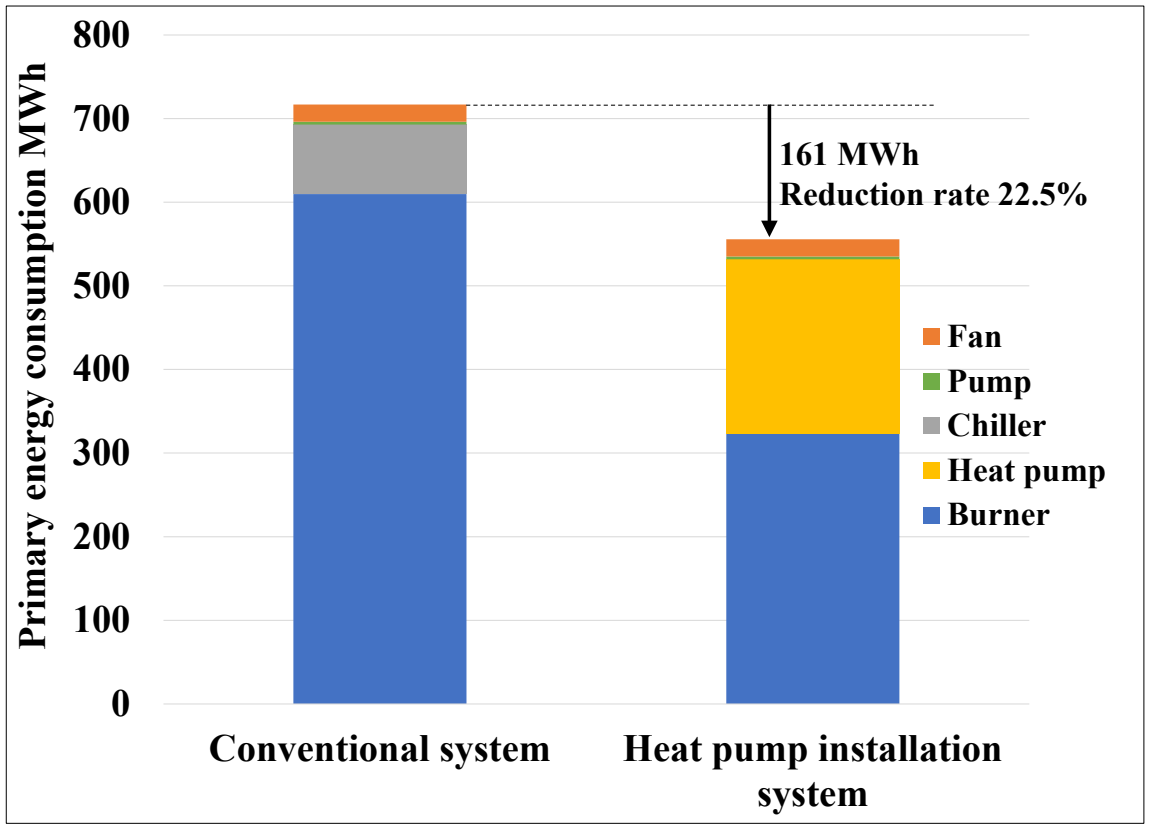


Fig. Primary energy consumption by integrated simulator

Comparison of CO_2 emission

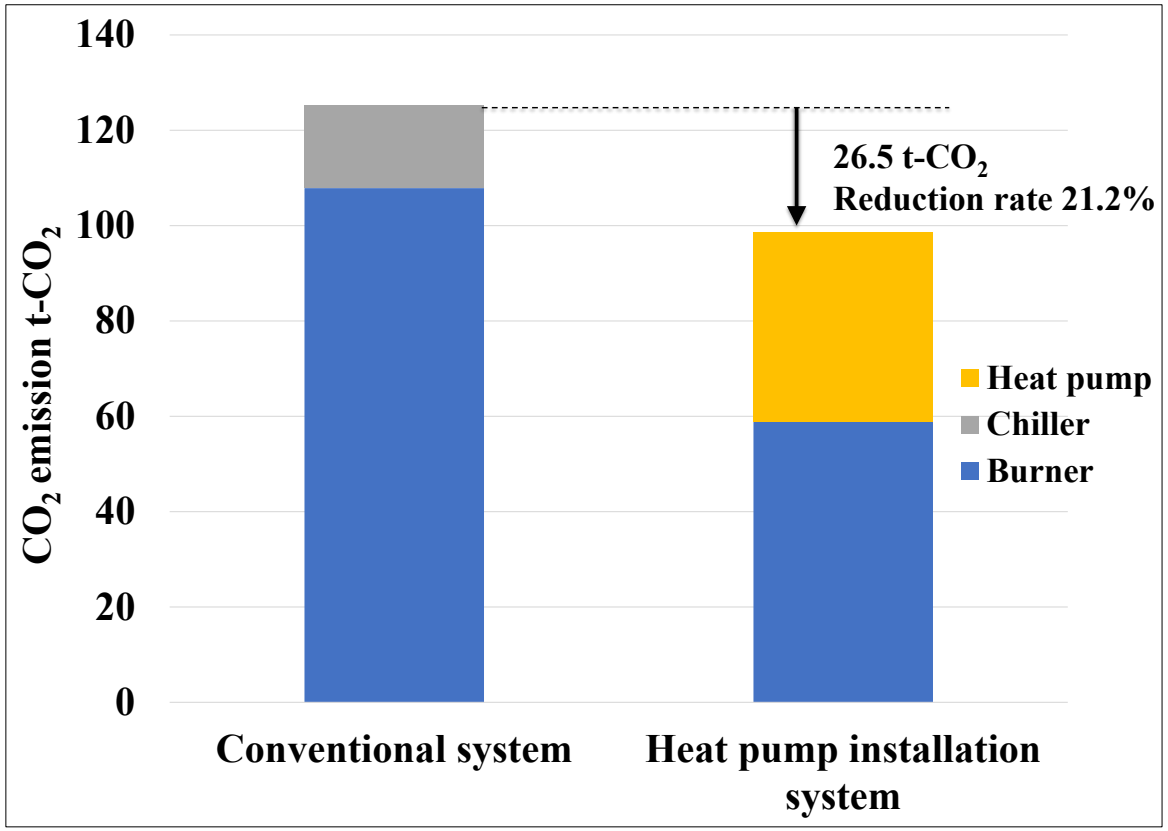


Fig. CO_2 emission by simplified simulator

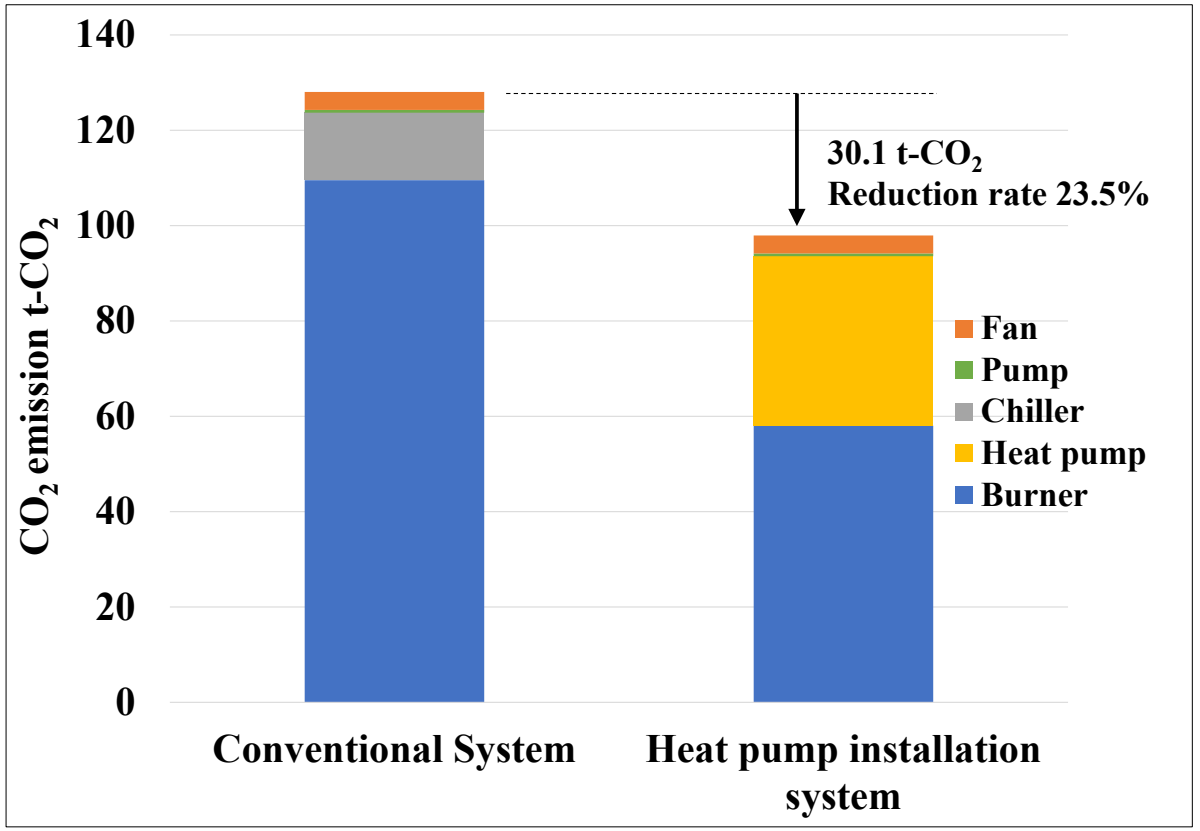


Fig. CO_2 emission by integrated simulator

Conclusions

We developed a "Simplified simulator" and an "Integrated simulator" that can study the effects of introducing heat pumps from both environmental and economic perspectives in order to help expand the use of heat pumps in the industrial field toward the targeted energy conservation.

Build analysis logic for simulators that allows analysis of simplified and integrated simulators

Results of analysis accuracy verification using annual measured data

- Relative error: 10% for simplified simulator , 4% for the integrated simulator

As an environmental evaluation, it is possible to quantitatively evaluate the effect of the introduction using environmental assessment indices such as energy consumption and CO2 emissions.

Future plan

Economic assessment needs to be evaluated to increase further the usefulness and practicality of the simulators.

Acknowledgements

These results were obtained as a result of the commissioned work (JPNP15007) of the New Energy and Industrial Technology Development Organization (NEDO), and we would like to express our gratitude to all concerned.

Thank you for your kind attention