## Details for dynamic energy hub model

1. Energy conservation equations at each energy bus:

For gas bus:



For electricity bus:



For heat bus:



For cooling bus:



1. Energy conversion constraints:

For combined heat and power plant (CHP):





For gas boiler (GB):



For electric heat pump (EHP):





For absorption chiller (AB):



1. Charging/discharging of energy storages:

For electric energy storage (EES):



For thermal energy storage (TES):



For ice storage (IS):



For temperature-controlled load (TCL) of the heat load:



For TCL of the cooling load:



where the energy flows between the node  and gas, electricity, heat, and cooling buses are denoted as , , , and , respectively.  is a binary variable;  and 0 represents winter and summer, respectively;  and  are the heat production and electricity generation efficiencies of CHP, respectively;  is the efficiency of GB;  is the efficiency of AB;  and  are the coefficient of performance of EHP for cooling and heating modes, respectively.

Then, we determine the control variables and output variables. It should be noted that there is more than one choice for state variables, control variables, and output variables. Here we choose the capacity of EES, TES, IS, and TCLs as the state variables , choose the energy flows in the DEH as the control variables, and choose the energy consumption of DEH as output variables . Other variables can be eliminated. Then, the above equations can be summarized into two groups of equations, i.e., system state equations, and output equations:

1. System state equation:



1. Output equation



Then, the two groups of equations can be written in the matrix form:

1. System state equation:



1. Output equation:



According to the above formulations, the value of  and  can be determined.

## Derivation process of state transition rates of CHP

Equation (12) is:



where  represents the state transition rate of CHP; , ,  and , ,  are the failure and repair rates of the electricity-generation, heat-production, and primary systems, respectively.

The CHP system contains three subsystems, namely, the prime mover system, electricity-generation system, and heat-production system. Each subsystem has two states, namely, the normal state and the failure state. Therefore, the original state space has 23 = 8 states in total, as presented in Fig. D1. We further notice that in some states, the performance of the CHP system are the same. For example, the original state 2, 5, 6, 7, and 8 is all complete failure state, so they can be merged into one state. After state reduction, the original state space can be reduced to four states, as presented in the simplified state space in Fig. D1. Then, regarding the state transition rate from state 4 to state 2, we can see that in state 4, the original state 5 and state 7 can transit to state 2 at the state transition rates of  and , respectively. Then, the state transition rate from state 4 to state 2 can be calculated as:



where  and  are the probabilities of state 5 and state 7 in the original state space;  is the probability of state 4 in simplified state space.  can be calculated similarly.



Fig. D1 State space diagrams of the CHP system