DRAWINGS

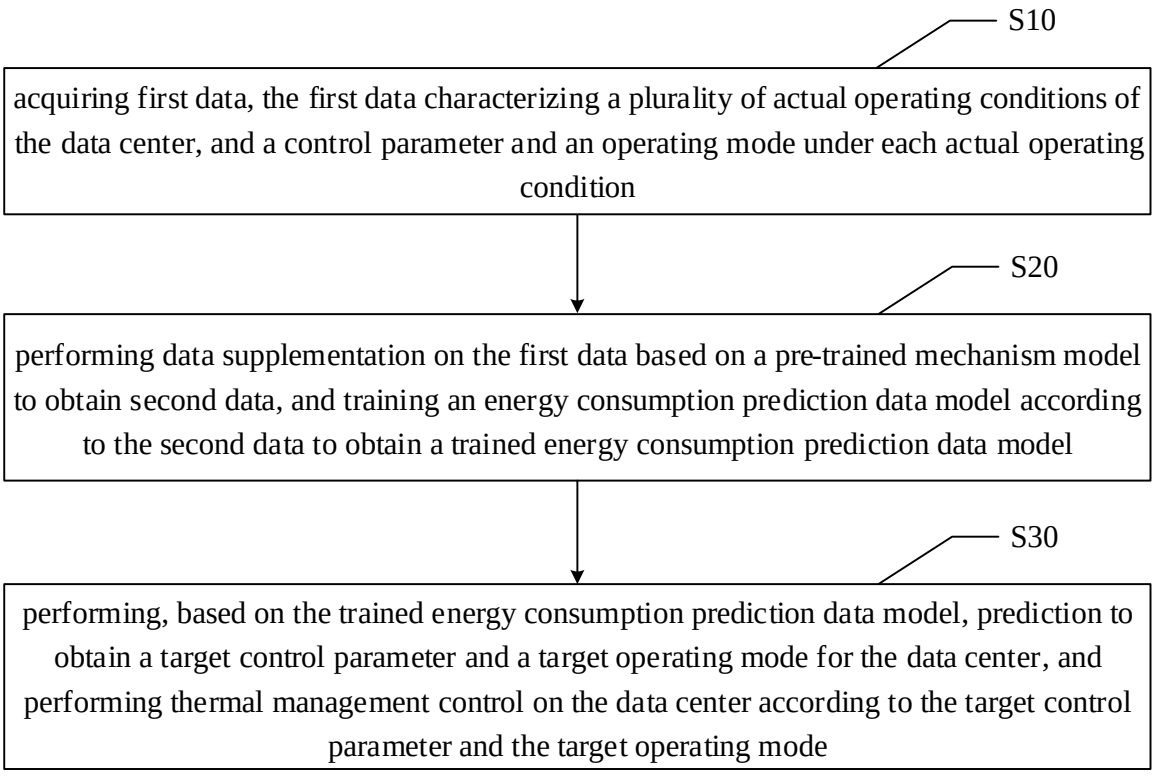


FIG. 1

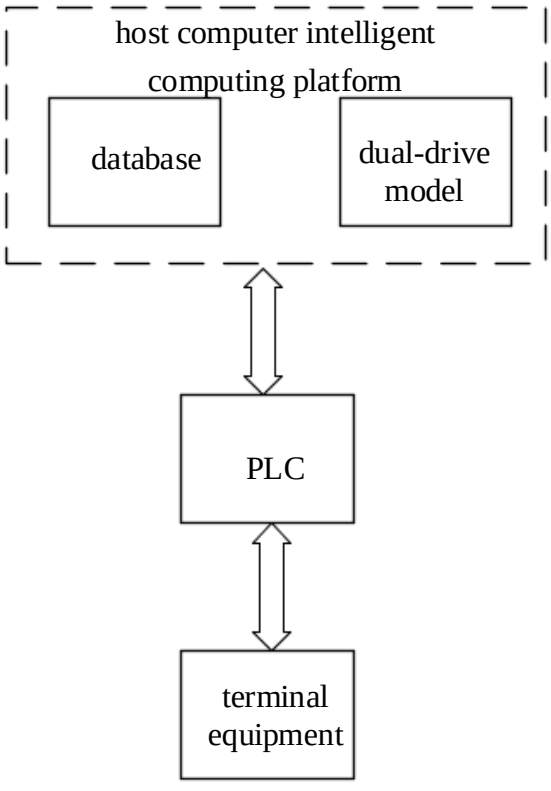


FIG. 2

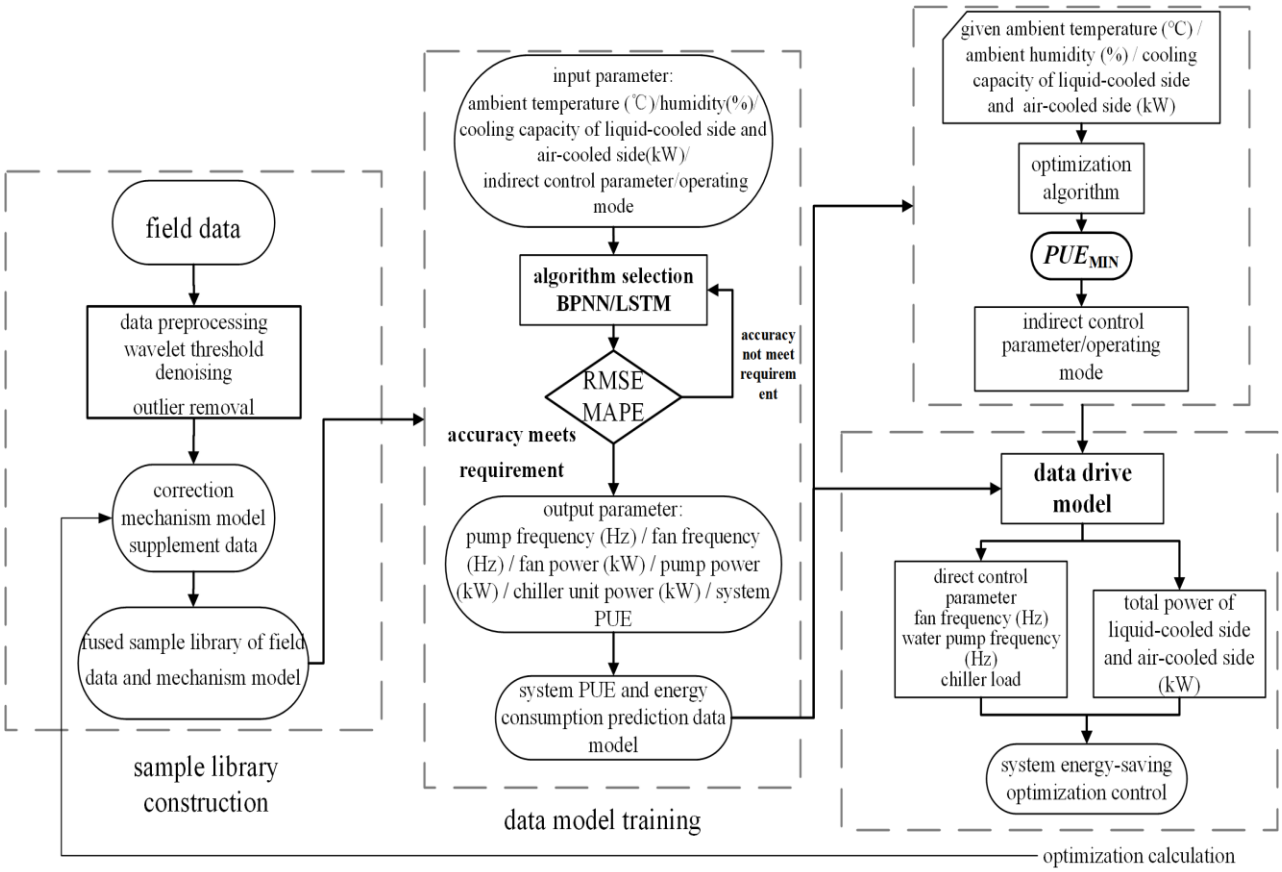

field data
data preprocessing
wavelet threshold denoising
outlier removal
correction mechanism model supplement data
fused sample library of field data and mechanism model
sample library construction
input parameter:
ambient temperature (℃)/humidity(%)/
cooling capacity of liquid-cooled side and air-cooled side(kW)/
indirect control parameter/operating mode
algorithm selection
BPNN/LSTM
RMSE
MAPE
accuracy not meet requirement
accuracy meets requirement
output parameter:
pump frequency (Hz) / fan frequency (Hz) / fan power (kW) / pump power (kW) / chiller unit power (kW) / system PUE
system PUE and energy consumption prediction data model
data model training
given ambient temperature (℃) / ambient humidity (%) / cooling capacity of liquid-cooled side and air-cooled side (kW)
optimization algorithm
PUE_{MIN}
indirect control parameter/operating mode
data drive model
direct control parameter
fan frequency (Hz)
water pump frequency (Hz)
chiller load
total power of liquid-cooled side and air-cooled side (kW)
system energy-saving optimization control
optimization calculation

FIG. 3

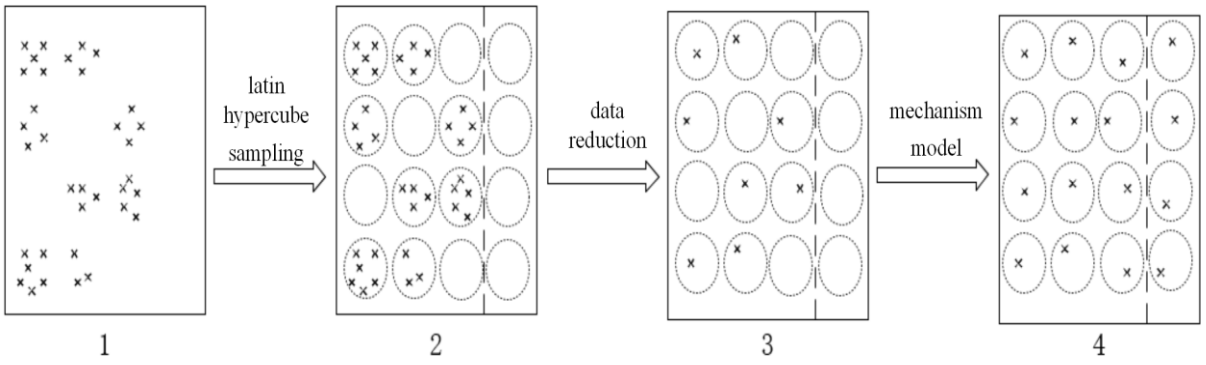

latin hypercube sampling
data reduction
mechanism model
1
2
3
4

FIG. 4

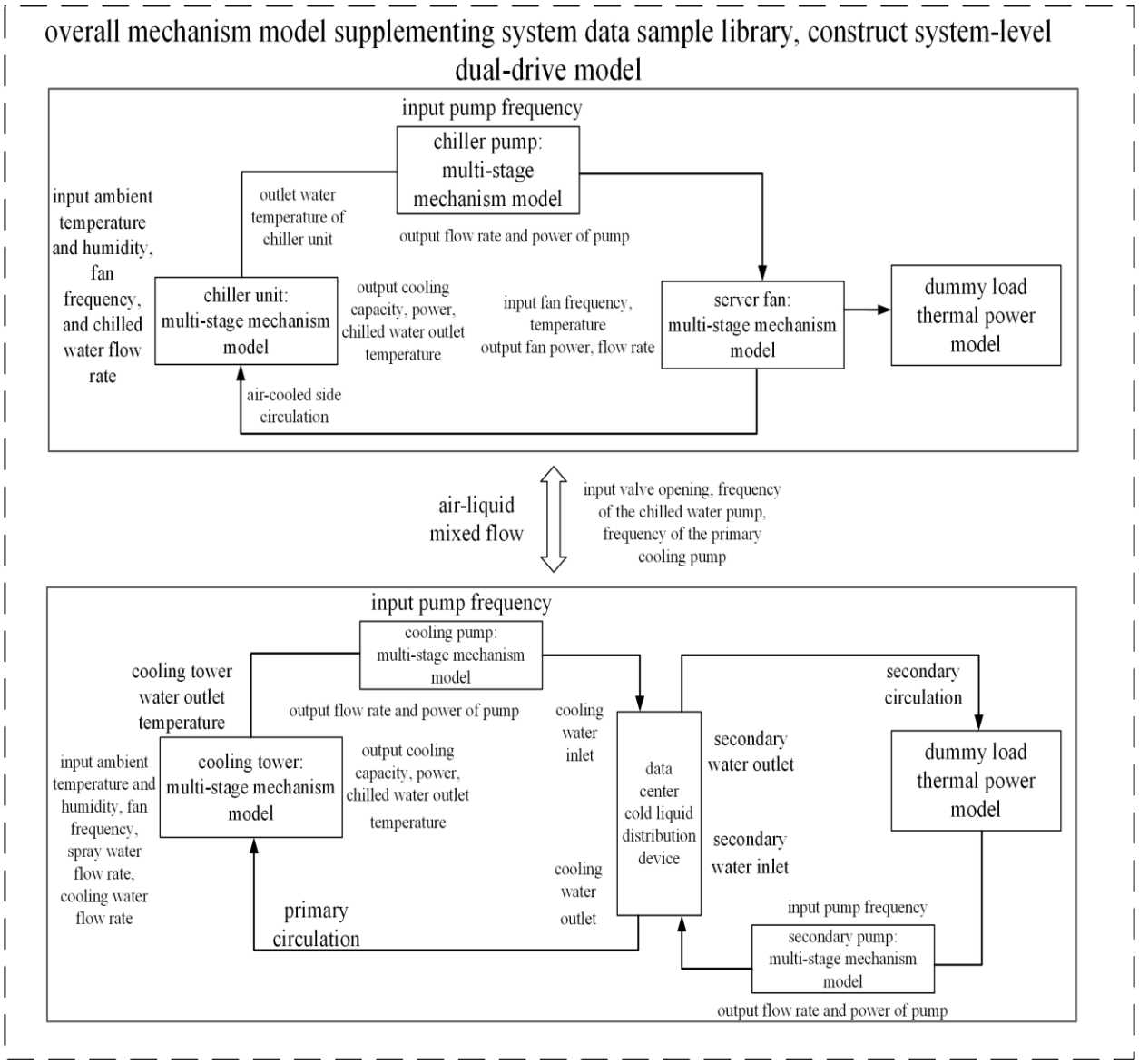

overall mechanism model supplementing system data sample library, construct system-level dual-drive model
input pump frequency
chiller pump: multi-stage mechanism model
input ambient temperature and humidity, fan frequency, and chilled water flow rate
outlet water temperature of chiller unit
output flow rate and power of pump
chiller unit: multi-stage mechanism model
output cooling capacity, power, chilled water outlet temperature
input fan frequency, temperature
output fan power, flow rate
server fan: multi-stage mechanism model
dummy load thermal power model
air-cooled side circulation
air-liquid mixed flow
input valve opening, frequency of the chilled water pump, frequency of the primary cooling pump
input pump frequency
cooling pump: multi-stage mechanism model
cooling tower water outlet temperature
output flow rate and power of pump
cooling water inlet
secondary circulation
secondary water outlet
dummy load thermal power model
input ambient temperature and humidity, fan frequency, spray water flow rate, cooling water flow rate
cooling tower: multi-stage mechanism model
output cooling capacity, power, chilled water outlet temperature
data center cold liquid distribution device
secondary water inlet
cooling water outlet
primary circulation
input pump frequency
secondary pump: multi-stage mechanism model
output flow rate and power of pump

FIG. 5

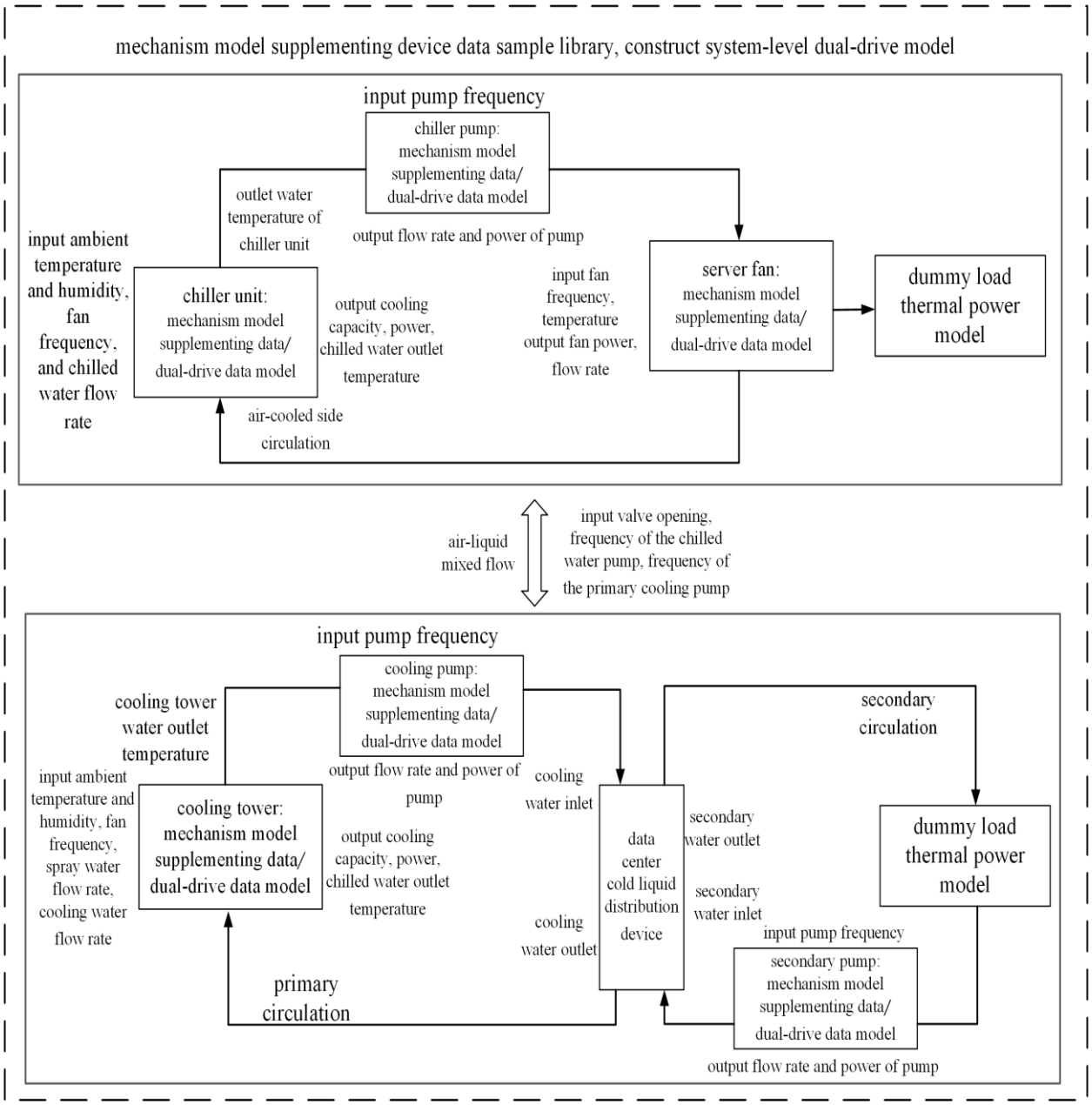

mechanism model supplementing device data sample library, construct system-level dual-drive model
input pump frequency
chiller pump: mechanism model supplementing data/ dual-drive data model
outlet water temperature of chiller unit
output flow rate and power of pump
input ambient temperature and humidity, fan frequency, and chilled water flow rate
chiller unit: mechanism model supplementing data/ dual-drive data model
output cooling capacity, power, chilled water outlet temperature
input fan frequency, temperature output fan power, flow rate
server fan: mechanism model supplementing data/ dual-drive data model
dummy load thermal power model
air-cooled side circulation
air-liquid mixed flow
input valve opening, frequency of the chilled water pump, frequency of the primary cooling pump
input pump frequency
cooling pump: mechanism model supplementing data/ dual-drive data model
cooling tower water outlet temperature
output flow rate and power of pump
secondary circulation
input ambient temperature and humidity, fan frequency, spray water flow rate, cooling water flow rate
cooling tower: mechanism model supplementing data/ dual-drive data model
output cooling capacity, power, chilled water outlet temperature
cooling water inlet
data center cold liquid distribution device
secondary water outlet
secondary water inlet
dummy load thermal power model
cooling water outlet
input pump frequency
primary circulation
secondary pump: mechanism model supplementing data/ dual-drive data model
output flow rate and power of pump

FIG. 6

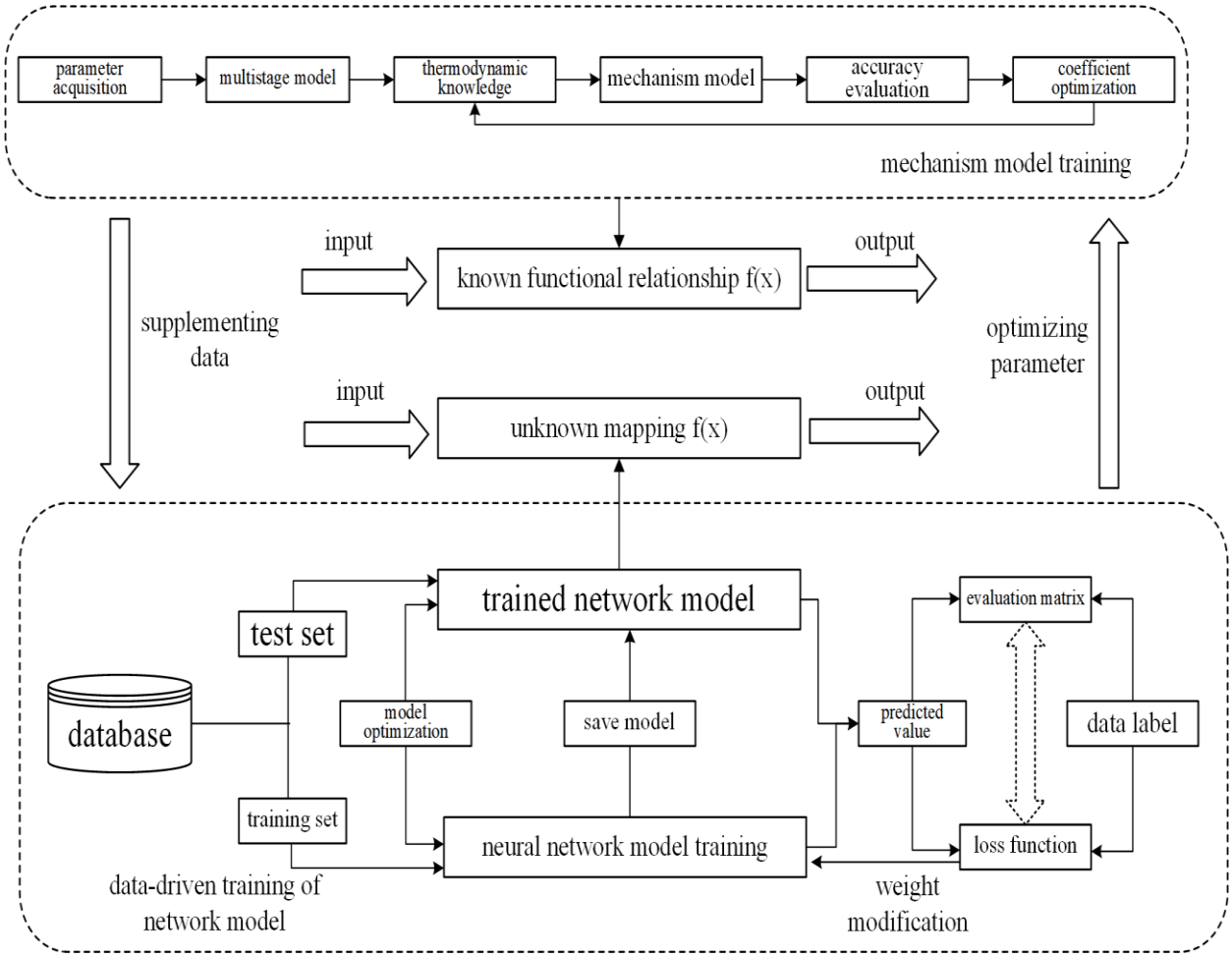

parameter acquisition
multistage model
thermodynamic knowledge
mechanism model
accuracy evaluation
coefficient optimization
mechanism model training
input
known functional relationship f(x)
output
supplementing data
optimizing parameter
input
unknown mapping f(x)
output
trained network model
test set
evaluation matrix
database
model optimization
save model
predicted value
data label
training set
neural network model training
loss function
data-driven training of network model
weight modification

FIG. 7

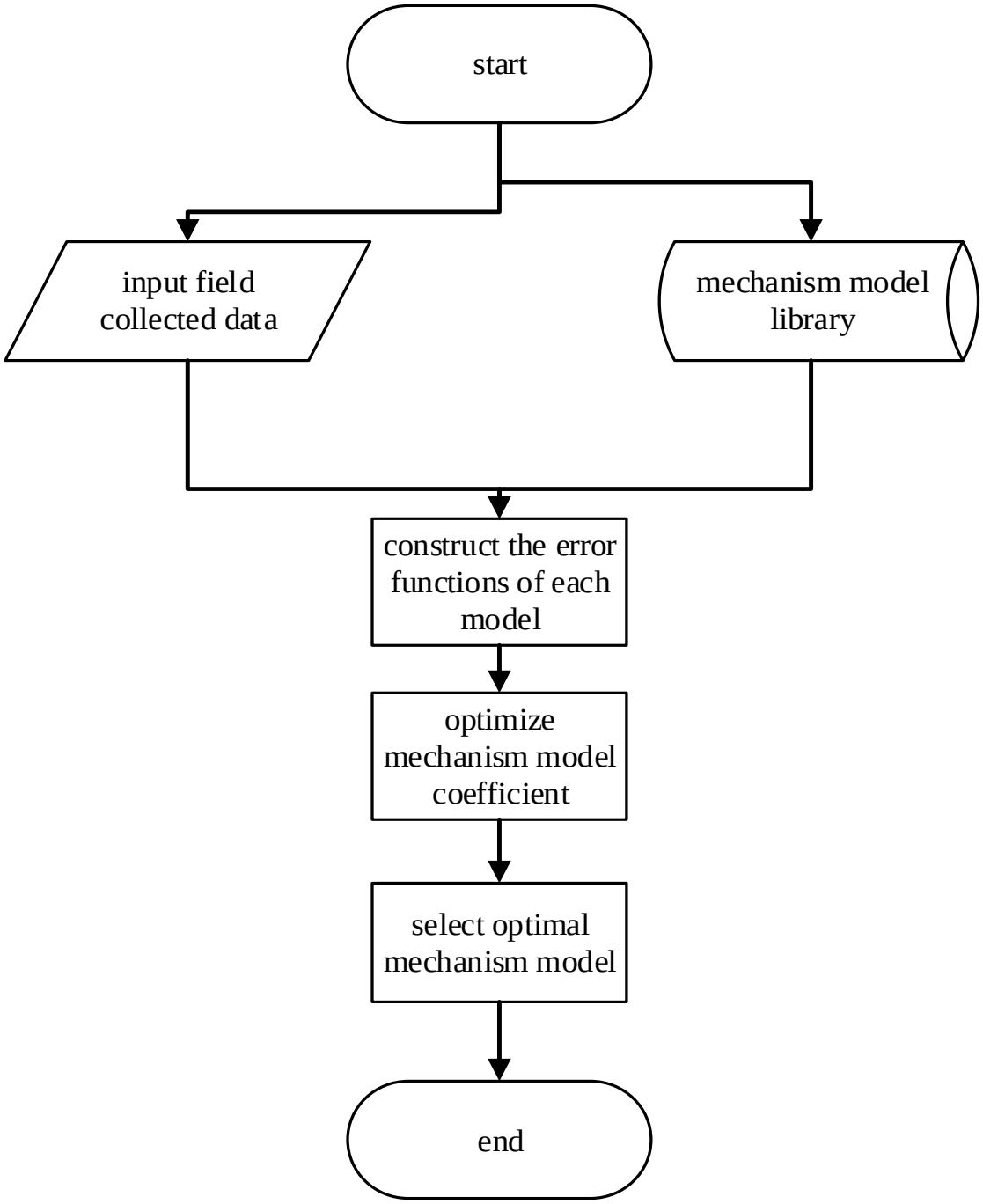

start
input field collected data
mechanism model library
construct the error functions of each model
optimize mechanism model coefficient
select optimal mechanism model
end

FIG. 8

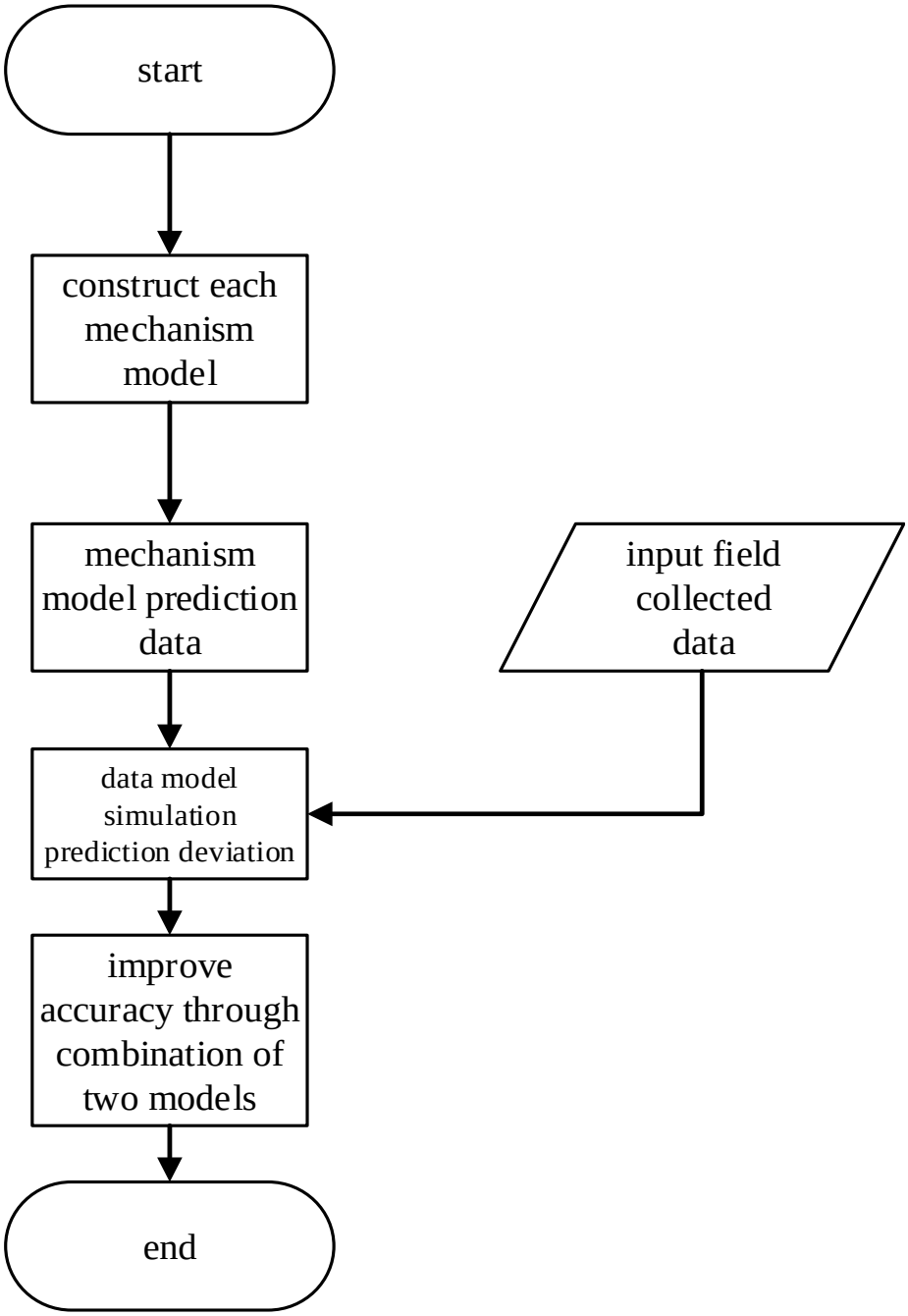

start
construct each mechanism model
mechanism model prediction data
input field collected data
data model simulation prediction deviation
improve accuracy through combination of two models
end

FIG. 9

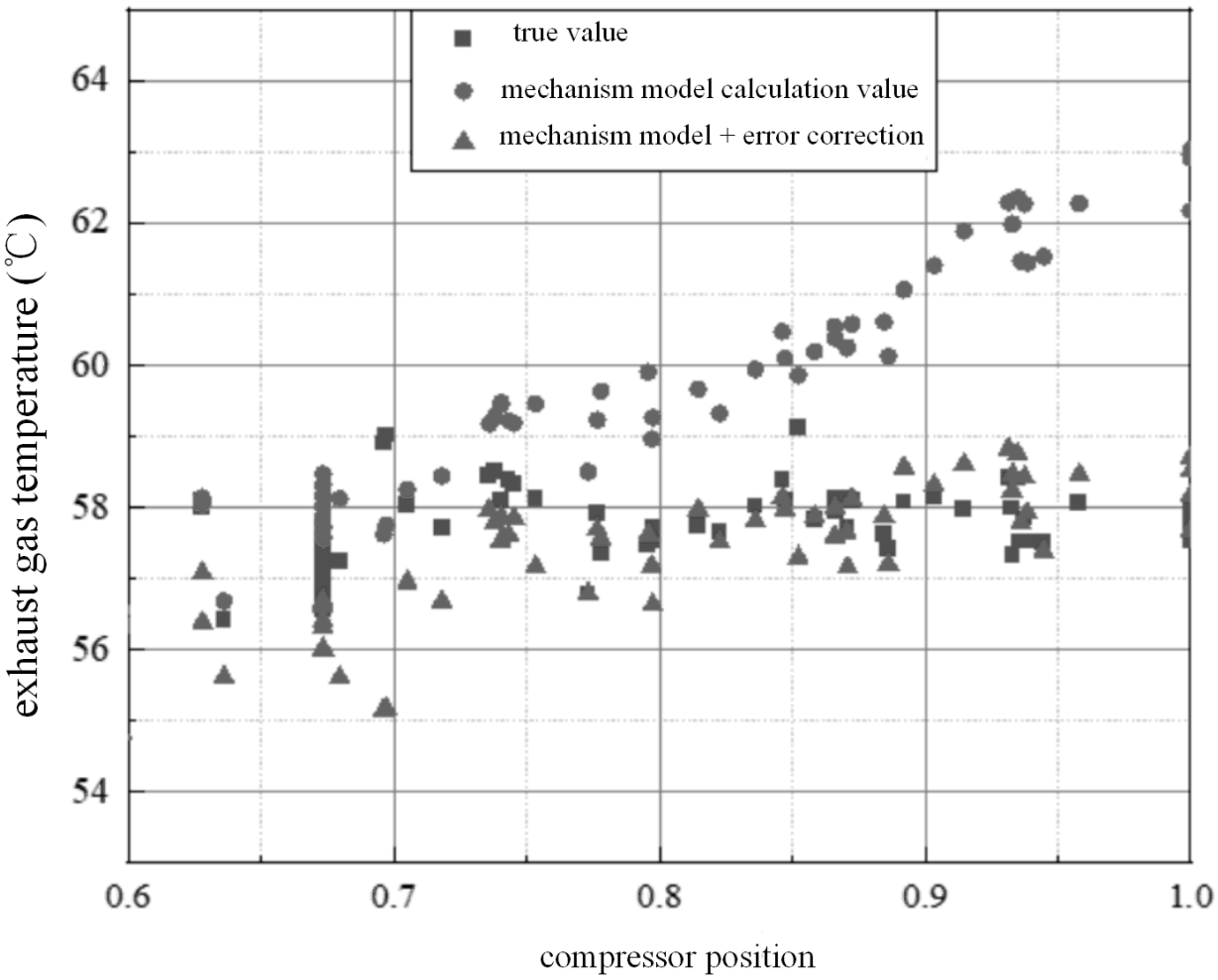

true value
mechanism model calculation value
mechanism model + error correction
exhaust gas temperature (℃)
64
62
60
58
56
54
0.6
0.7
0.8
0.9
1.0
compressor position

FIG. 10

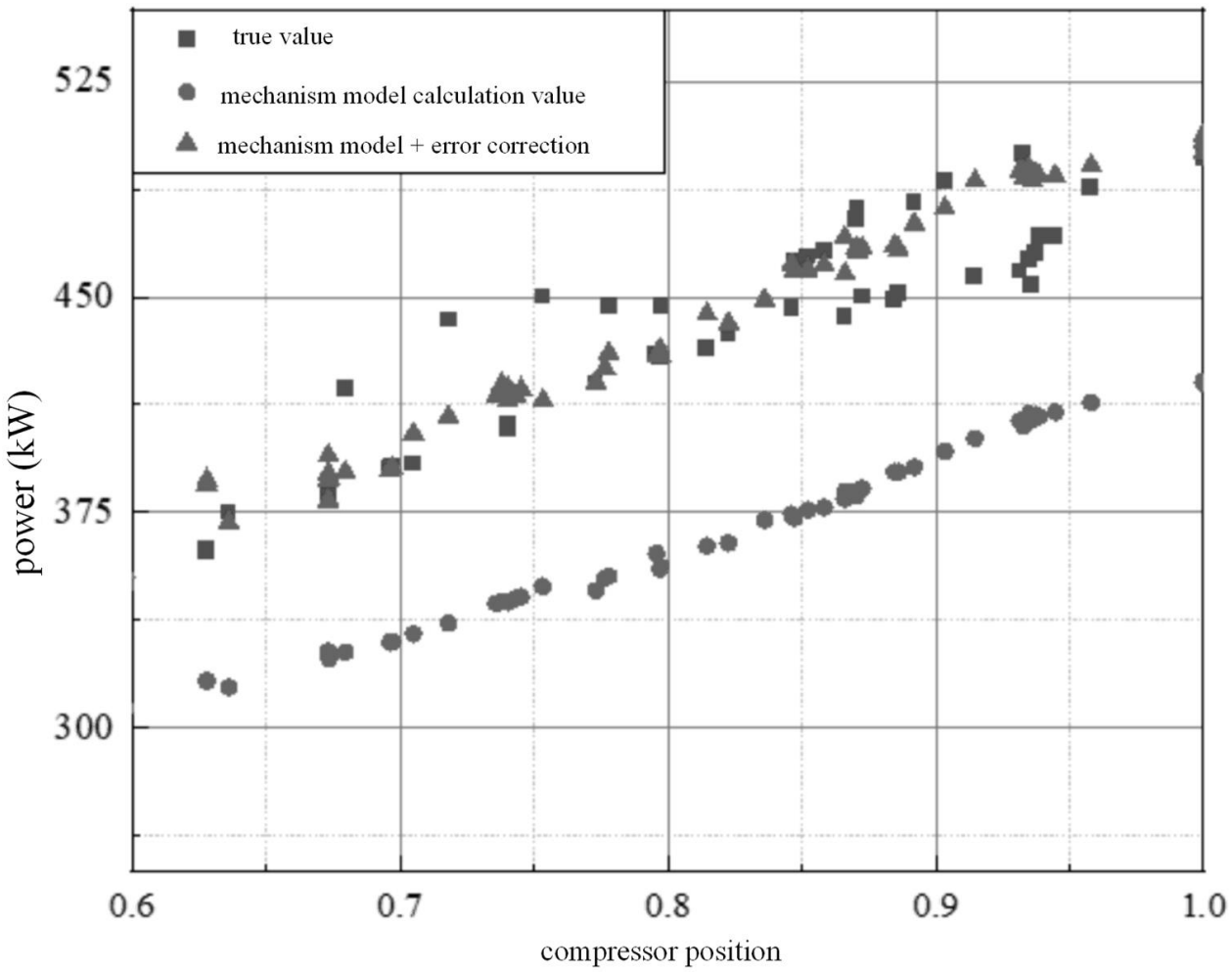

true value
mechanism model calculation value
mechanism model + error correction
525
450
375
300
power (kW)
0.6
0.7
0.8
0.9
1.0
compressor position

FIG. 11

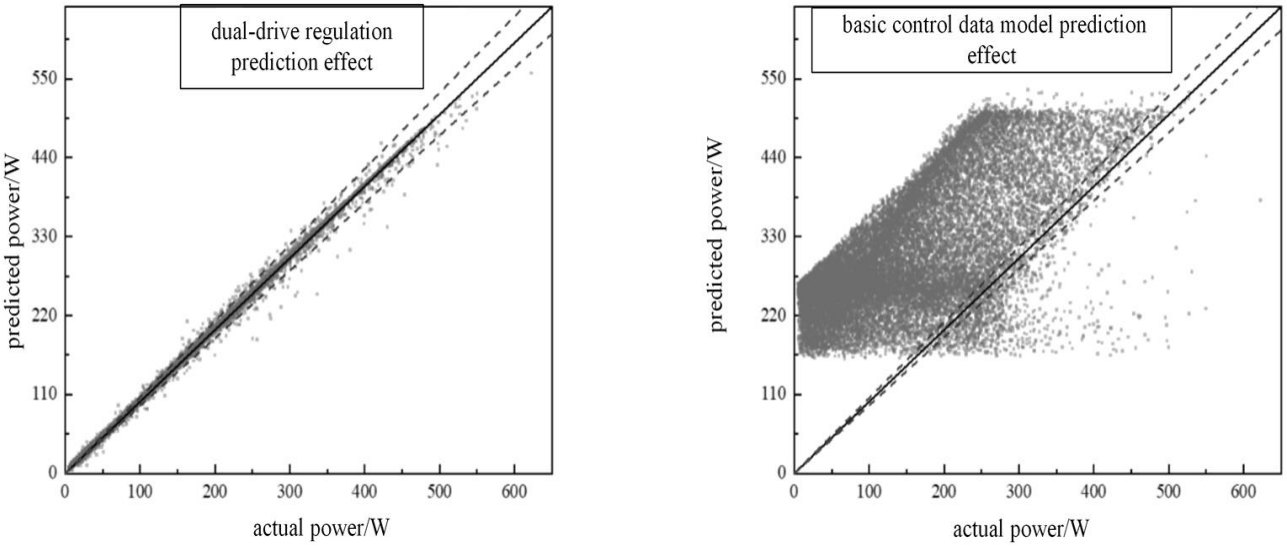

dual-drive regulation prediction effect
predicted power/W
actual power/W
basic control data model prediction effect
predicted power/W
actual power/W

FIG. 12

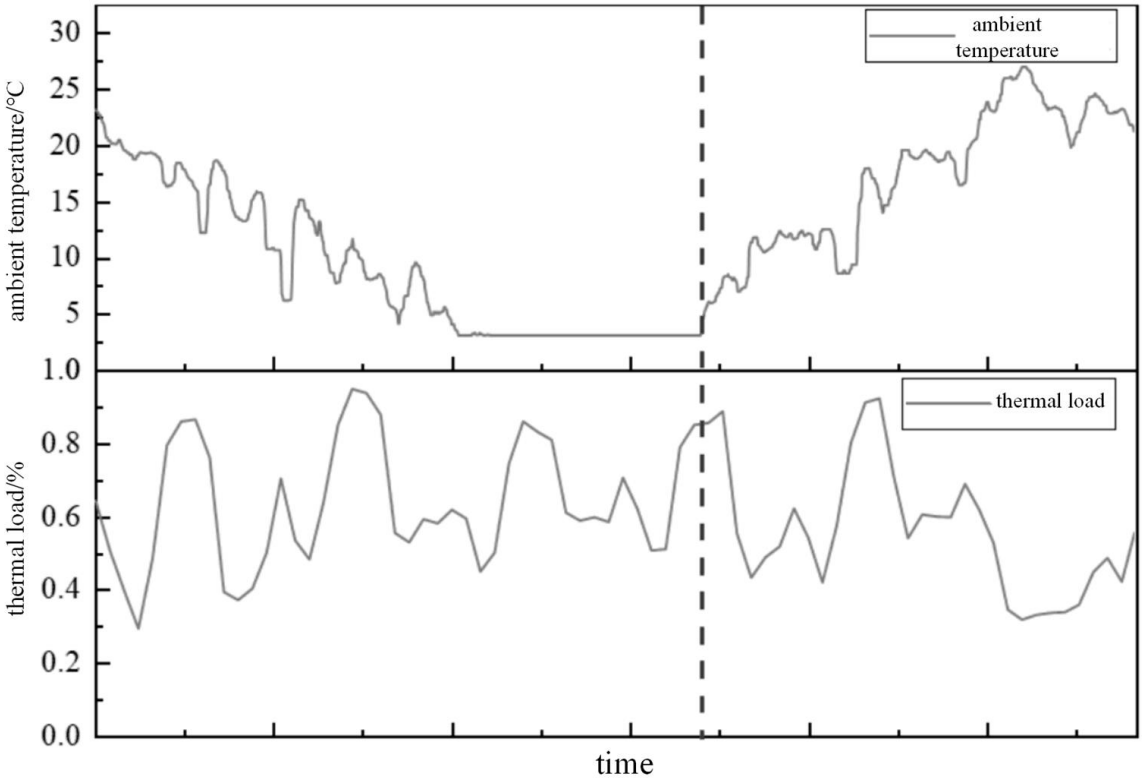

ambient temperature/°C
30
25
20
15
10
5
1.0
ambient temperature
thermal load/%
0.8
0.6
0.4
0.2
0.0
thermal load
time

FIG. 13

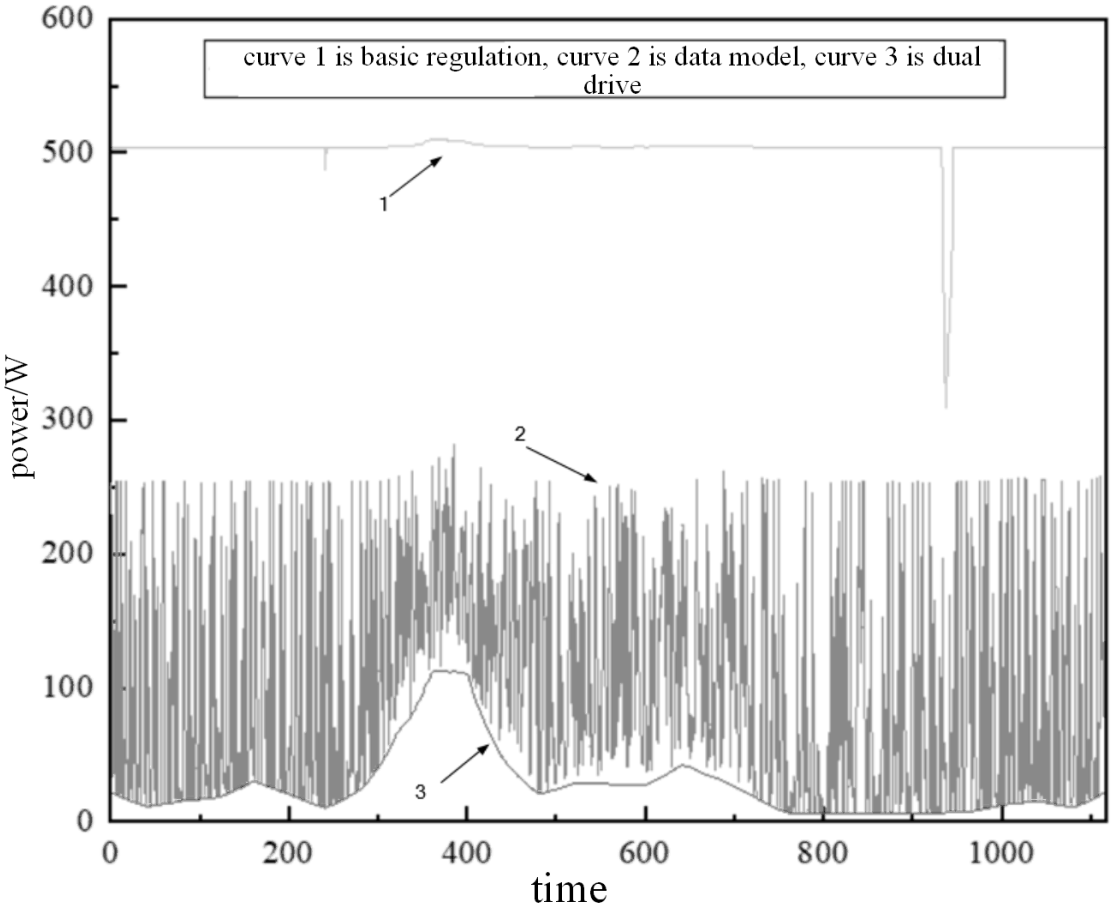

curve 1 is basic regulation, curve 2 is data model, curve 3 is dual drive
600
500
400
300
200
100
0
power/W
1
2
3
0
200
400
600
800
1000
time

FIG. 14

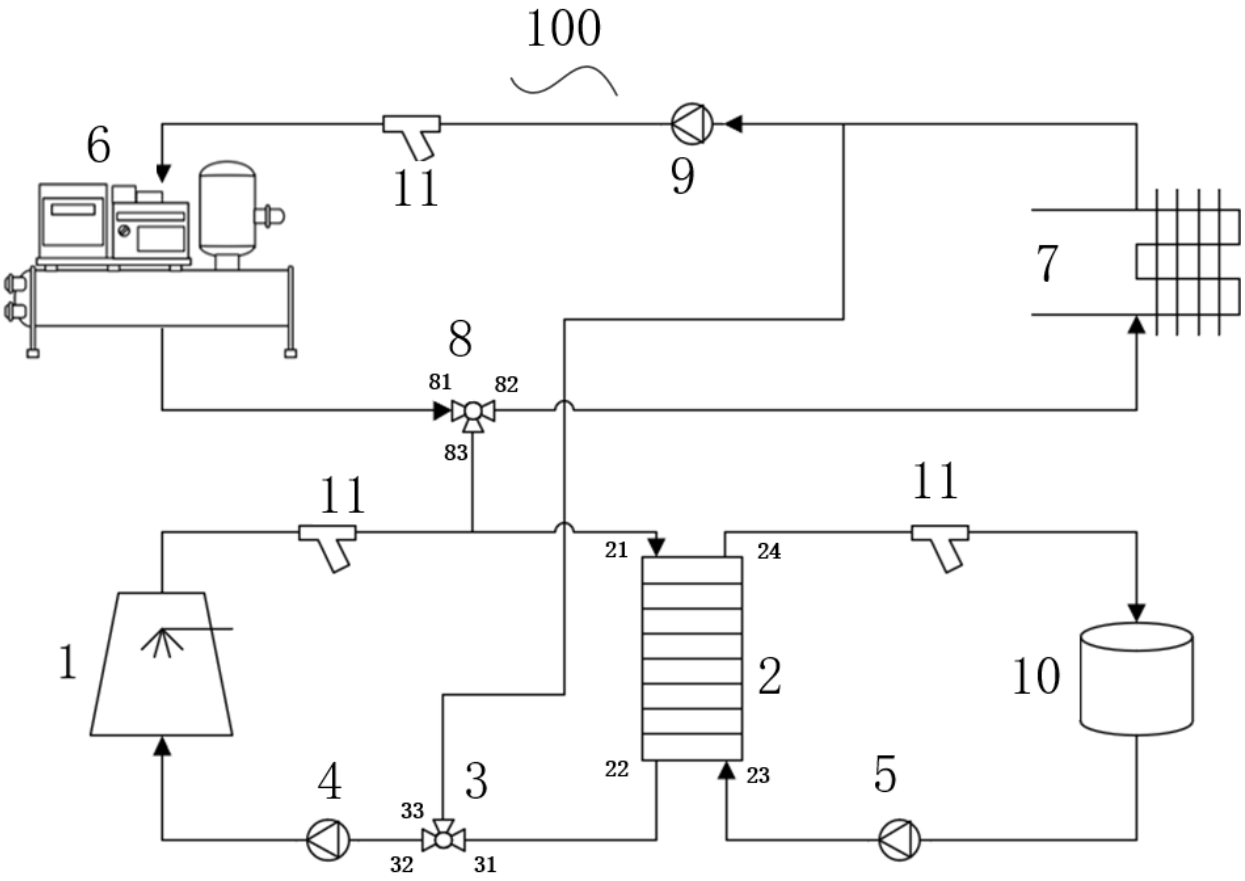

100
6
11
9
7
8
81
82
83
11
11
21
24
1
2
10
22
23
4
3
5
33
32
31

FIG. 15

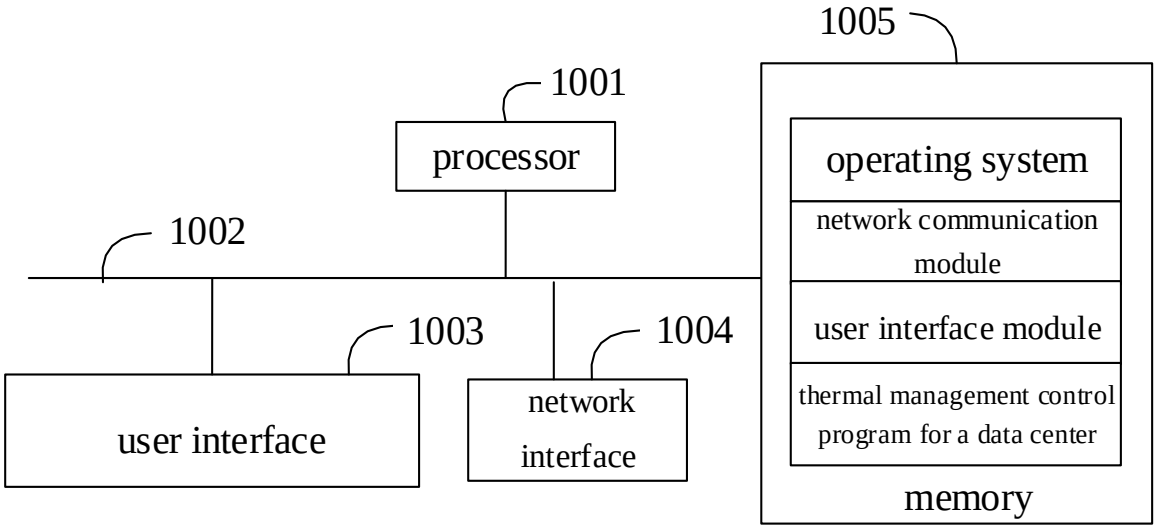

1005
1001
processor
operating system
network communication module
1002
user interface module
thermal management control program for a data center
1003
1004
user interface
network interface
memory

FIG. 16