An energy efficiency evaluation method based on least squares combination weight in refrigeration system

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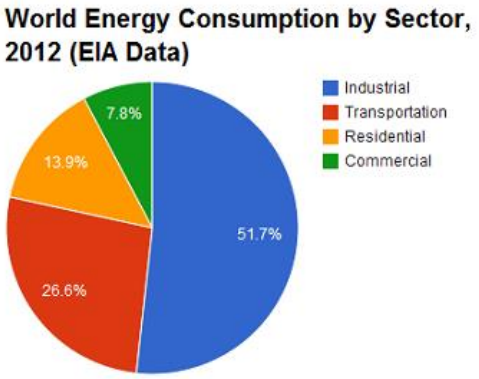
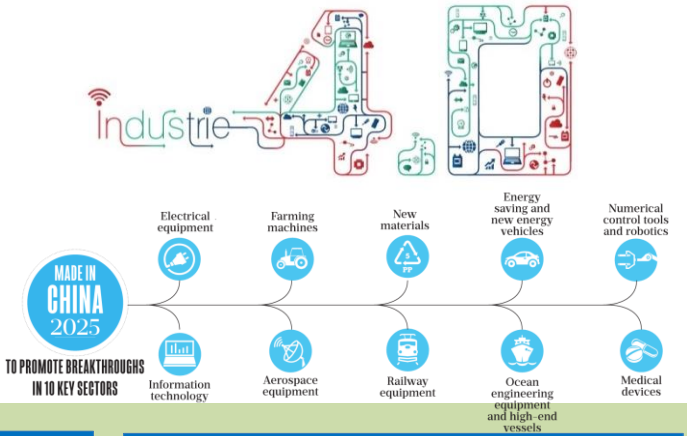
Reference: https://de.fotolia.com/id/84080677

Background & Motivation

- Background
- Energy consumption control
- Information management



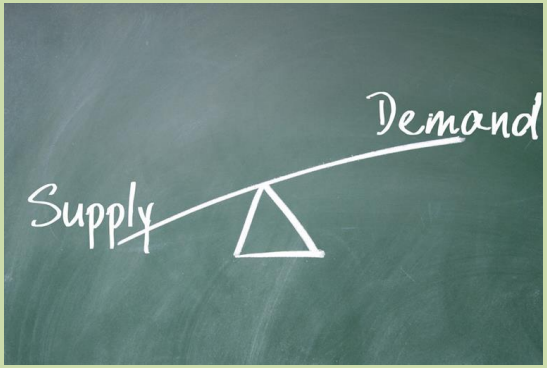


Problem

- Lack of energy efficiency evaluation of the working-state

Problem

- Disequilibrium between supply and demand



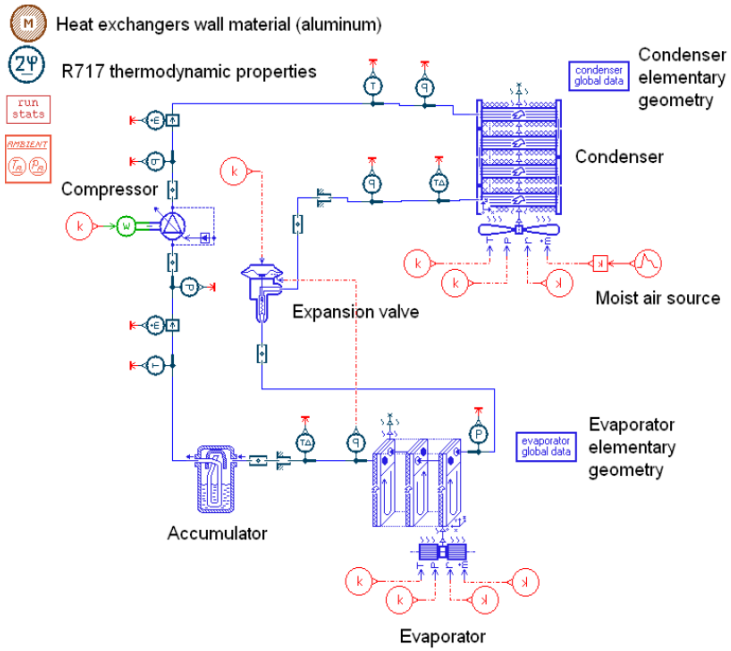
Problem

- Out-dated management system (Manual meter reading)

Reference: http://www.zdnet.com/article/google-facebook/

Modelling & Simulation

- Modelling of ARS by AMESim



- Simulating based on the basic working range

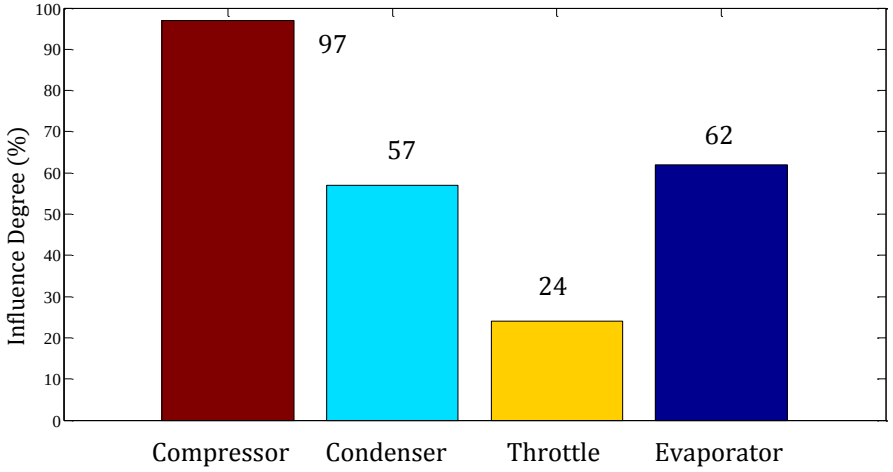
Component	Parameter	Working range	Component	Parameter	Working range
Compressor	$p_{suc}(MPa)$	0,10~0,30	Throttle /Expansion Valve	$T_{ta,in}(℃)$	20~35
	$p_{dis}(MPa)$	1,10~1,50		$T_{ta,out}(℃)$	-10~-5
	$T_{suc}(℃)$	3,0~6,0		$p_{t,in}(MPa)$	0,8~1,4
	$T_{dis}(℃)$	60~90		$p_{t,out}(MPa)$	0,17~0,35
	$K_c(\%)$	10~100		$K_t(\%)$	10~100
	$T_{oil}(℃)$	25~65	Evaporator	$T_{ea,in}(℃)$	0~3
	$p_{oil}(MPa)$	0,15~0,30		$T_{ea,out}(℃)$	4~7
Condenser	$T_{ca,in}(℃)$	55~85		$T_{ew,in}(℃)$	7~10
	$T_{ca,out}(℃)$	20~38		$T_{ew,out}(℃)$	2~5
	$T_{atm}(℃)$	-5~38		$T_{eva}(℃)$	-15~5
	$T_{cw,in}(℃)$	5~22		$\theta_{sh}(℃)$	2~15
	$T_{cw,out}(℃)$	9~26		$m_w(m^3/min)$	3,39~4,71
	$T_{con}(℃)$	20~40		$m_a(m^3/min)$	5,30~7,66

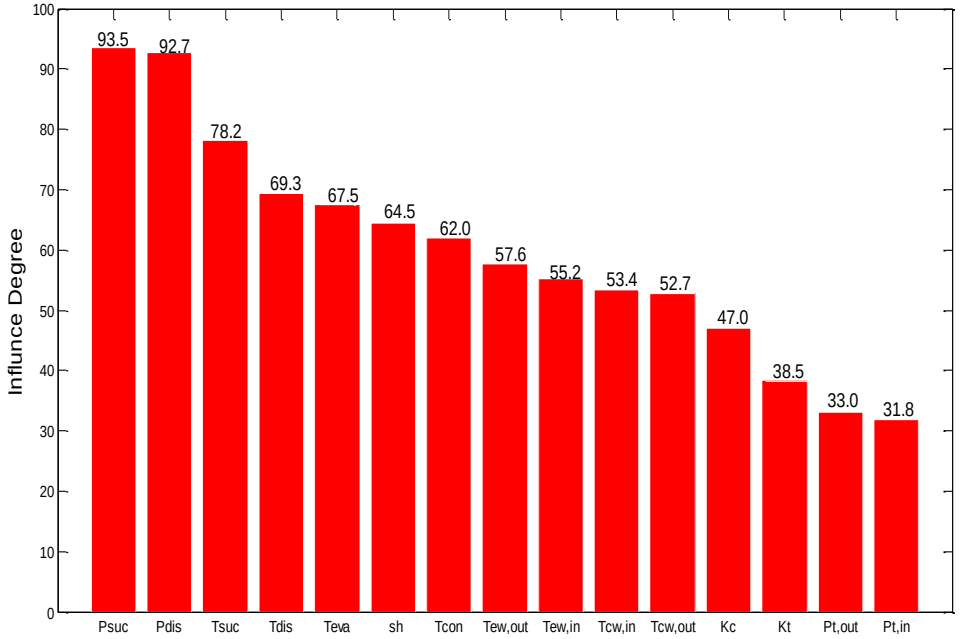
- $$COP = \frac{Q_{eva,w}}{W_{com}+W_{others}} = \frac{C_{eva,w}m\Delta t}{W_{com}+W_{others}}$$

Reference: https://blog.angel.co/12-startups-to-join-founded-by-ex-google-engineers

Modelling & Simulation

- Selection of Critical Parameters





- Two-dimension matrix

- $U = (u_{ij})_{mn} = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & u_{22} & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{m1} & u_{m2} & \cdots & u_{mn} \end{bmatrix}_{mn}$

- Standardized matrix: $R = (r_{ij})_{mn}$
- Evaluation weight: $w = [w_1, w_2, \cdots, w_m]$
- Energy efficiency evaluation value:
- $W = [W_{s1}, W_{s2}, \cdots, W_{sm}] = R \cdot w^T$

where W_{sm} is the evaluation of working status m^{th} .

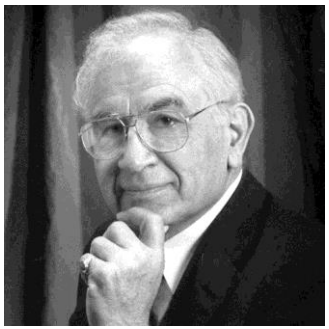
1 Background & Motivation

2 Modelling & Simulation

3 Energy efficiency evaluation method of LSCW

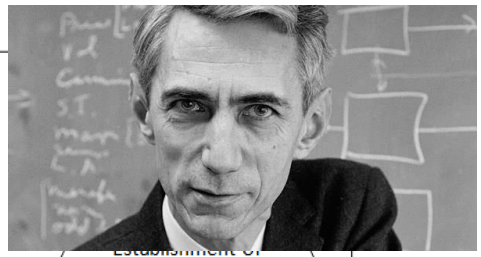
Energy efficiency evaluation method of LSCW

- Fuzzy analytic hie



Thomas L. Saaty
(1971)

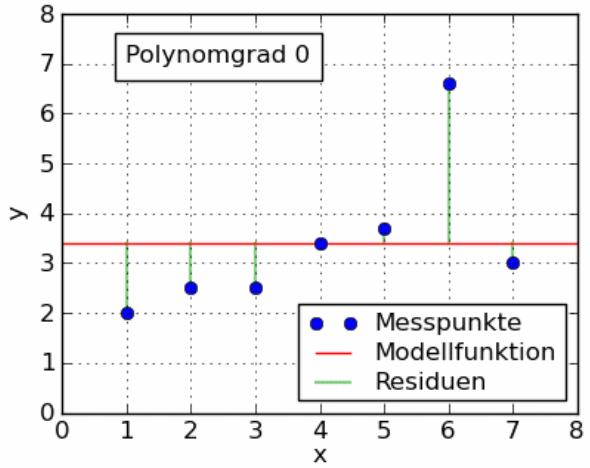
- Information Entropy (IE)



Claude E. Shannon
(1948)

Least Squares Combination Weight (LSCW)

- Weight by FAHP (subjective weight):
  $w_{FAHP} = [w_{F1}, w_{F2}, \cdots, w_{Fm}]^T$
- Weight by IE (objective weight):
  $w_{IE} = [w_{I1}, w_{I2}, \cdots, w_{Im}]^T$



- Combination evaluation model $D(w)$:

$$minD(w) = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[r_{ij}\left(xw_{Fj} - w_j\right)\right]^2 + \left[r_{ij}\left(yw_{Ij} - w_j\right)\right]^2\right\}$$

x, y are set to be the coefficient of w_{FAHP} and w_{IE}.

- Lagrange Function:

$$F = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[r_{ij}\left(xw_{Fj} - w_j\right)\right]^2 + \left[r_{ij}\left(yw_{Ij} - w_j\right)\right]^2\right\} + 4\lambda\left(\sum_{j=1}^{m} w_j - 1\right)$$

- The application matrix is defined as: $\begin{bmatrix} A & e \\ e^T & 0 \end{bmatrix}\begin{bmatrix} w \\ \lambda \end{bmatrix} = \begin{bmatrix} B \\ 1 \end{bmatrix}$

$$A = diag\left[\sum_{i=1}^{n} r_{i1}^2, \sum_{i=1}^{n} r_{i2}^2, \cdots, \sum_{i=1}^{n} r_{im}^2\right]$$

$$B = \left[\sum_{i=1}^{n}\frac{1}{2}(xw_{F1} + yw_{I1}) \times r_{i1}^2, \sum_{i=1}^{n}\frac{1}{2}(xw_{F2} + yw_{I2}) \times r_{i2}^2, \cdots, \sum_{i=1}^{n}\frac{1}{2}(xw_{Fm} + yw_{Im}) \times r_{im}^2\right]^T$$

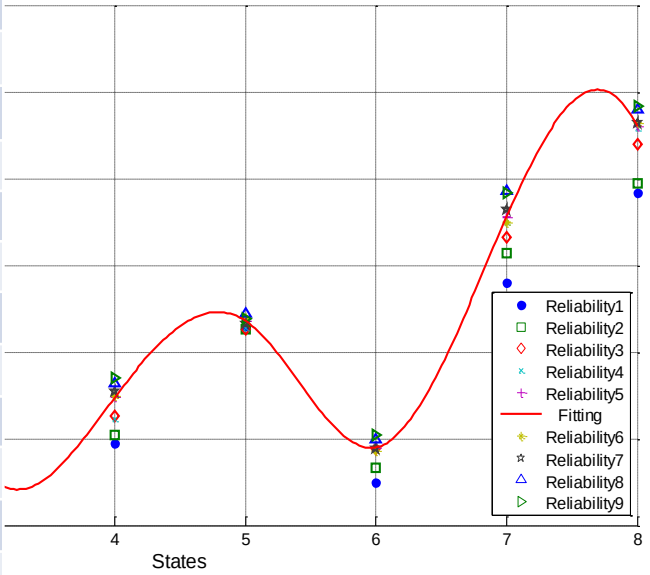
- Solving the equation, the combination weight can be obtained.

$$w = A^{-1} \cdot \left[B + \frac{1 - e^T A^{-1} B}{e^T A^{-1} e} \cdot e\right]$$

Calculation of Energy efficiency evaluation value

- Evaluation values in different reliabilities between *FAHP* and *IE*

Parameters	Evaluated working states							
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
$p_{suc}(MPa)$	0.24	0.28	0.20	0.20	0.22	0.20	0.26	0.28
$p_{dis}(MPa)$	1.25	1.20	1.28	1.27	1.26	1.26	1.22	1.20
$T_{suc}(℃)$	4.7	4.4	6.0	5.8	5.5	6.0	5.0	4.0
$T_{dis}(℃)$	70.2	66.2	85.6	80.0	78.5	82.6	70.0	65.0
$K_c(\%)$	50	47	67	70	60	65	60	60
$T_{ca,in}(℃)$	24	24	24	24	23	23	23	22
$T_{ca,out}(℃)$	33	32	36	37	35	36	33	30
$T_{con}(℃)$	34	33	40	38	36	38	34	32
$T_{ew,in}(℃)$	32	32	32	33	33	33	32	32
$T_{ew,out}(℃)$	4.2	3.6	4.8	4.8	5.0	5.0	4.0	3.2
$T_{eva}(℃)$	-6.0	-4.0	-7.0	-6.5	-6.0	-6.6	-5.0	-4.0
$\theta_{sh}(℃)$	10	8	13	12	11	13	10	8
$p_{t,in}(MPa)$	1.24	1.19	1.27	1.26	1.25	1.25	1.20	1.18
$p_{t,out}(MPa)$	0.26	0.30	0.21	0.22	0.24	0.23	0.27	0.30
$K_t(\%)$	70	70	82	85	80	85	75	75



$0.316, 0.057]$

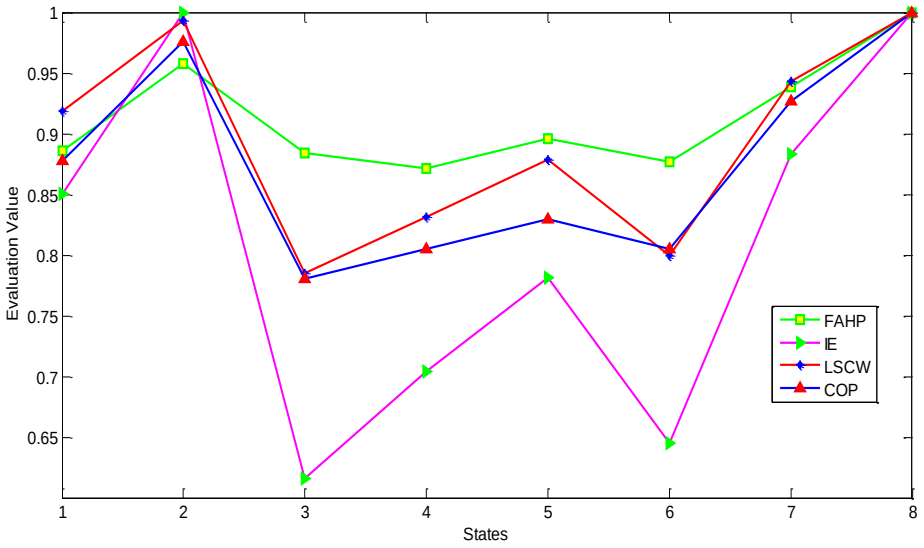
- Comprehensive evaluation value:
  $W_{LSCW} = R \cdot w^T = [0.857, 0.927, 0.732, 0.776, 0.820, 0.746, 0.880, 0.933]$

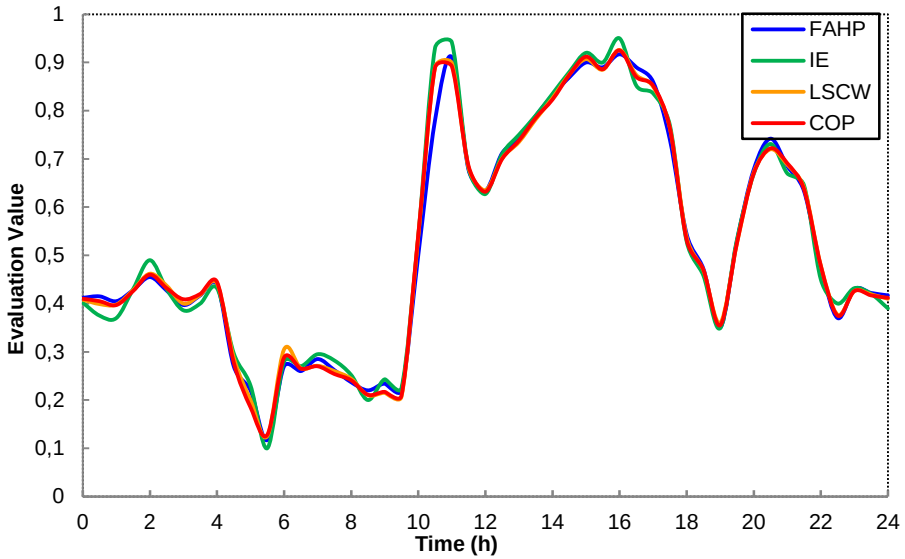
Comparison

- Comparison of different evaluation methods

	Results of normalization
FAHP	[0.8859, 0.9577, 0.8841, 0.8717, 0.8960, 0.8770, 0.9383, 1.000]
IE	[0.8507, 1.000, 0.6157, 0.7037, 0.7813, 0.6447, 0.8831, 1.000]
LSCW	[0.9185, 0.9936, 0.7846, 0.8317, 0.8789, 0.7996, 0.9432, 1.000]
S_{COP}	[0.8780, 0.9756, 0.7805, 0.8049, 0.8293, 0.8049, 0.9268, 1.000]

Methods	Total points	Deviation points	Relative error (%)
FAHP	1440	217	15.07
IE		193	13.40
LSCW		49	3.34

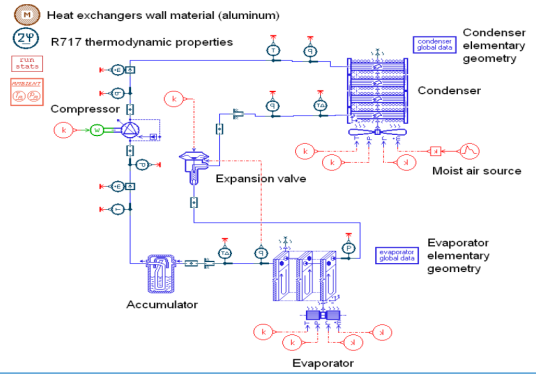




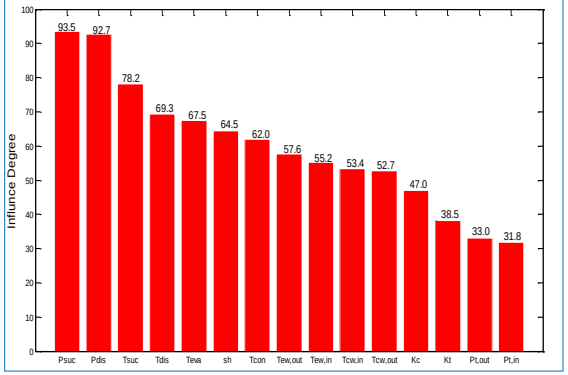
Summary

Analyze of the problems

Modelling and simulation



Selection of the critical parameters



Proposal of the new evaluation method (LSCW)

Optimized combination evaluation model:

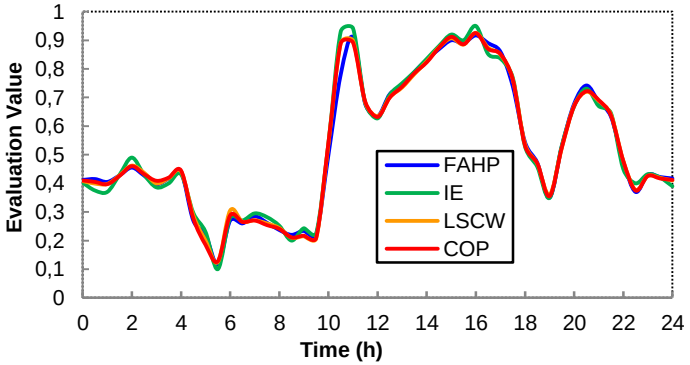
$$minD(w) = \sum_{i=1}^{n}\sum_{j=1}^{m}\left\{\left[r_{ij}\left(xw_{Fj}-w_j\right)\right]^2+\left[r_{ij}\left(yw_{Ij}-w_j\right)\right]^2\right\}$$

Combination weight:

$$w = A^{-1}\cdot\left[B+\frac{1-e^TA^{-1}B}{e^TA^{-1}e}\cdot e\right]$$

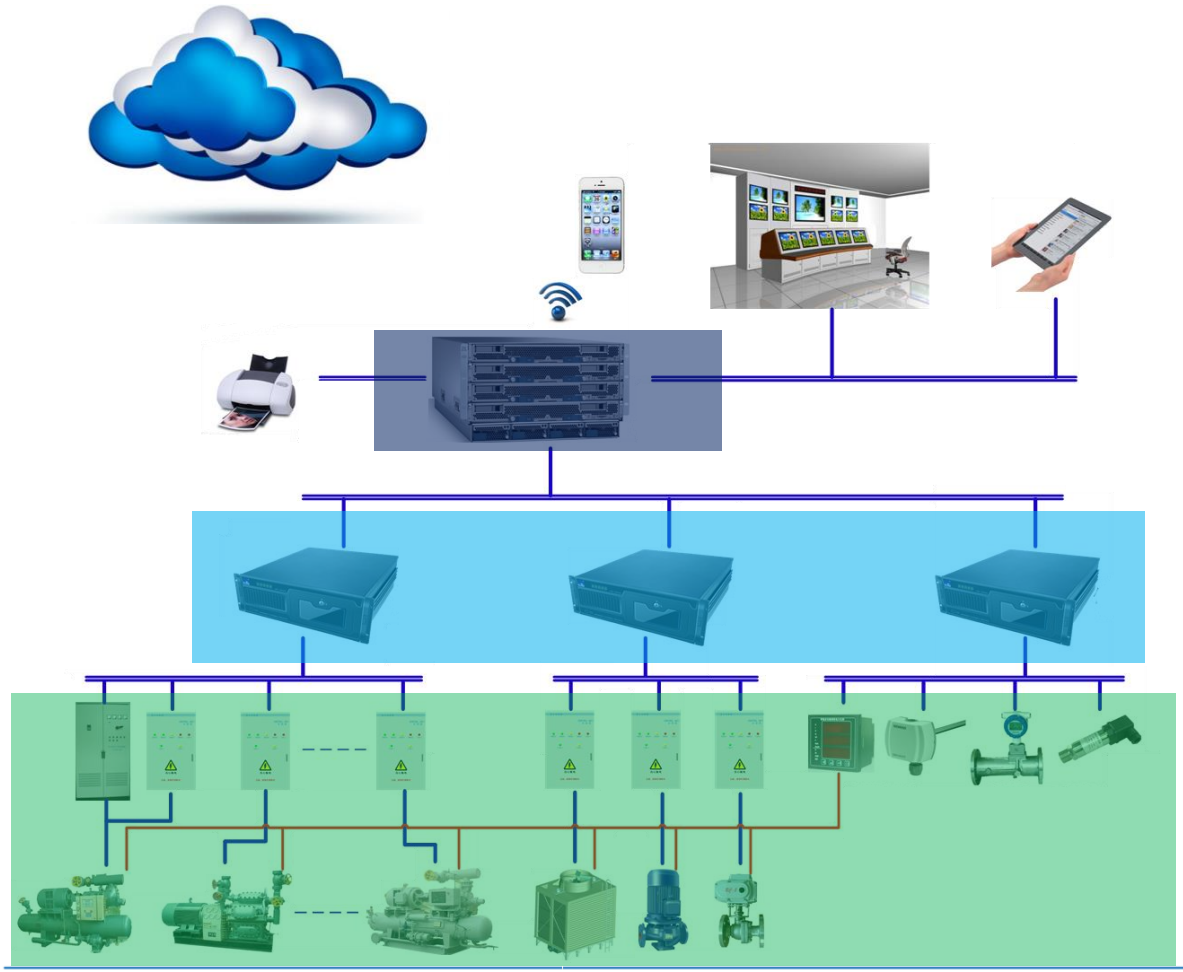
Comparison

- Higher precision
- Smaller relative error (3,34%)
- Better consistence



Outlook

- Intelligent efficient management system



Information Management

Intelligent Control Algorithm

Energy Efficiency Evaluation

Data Acquisition and Processing

Thank you for your attention!

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Reference: https://www.foodengineeringmag.com