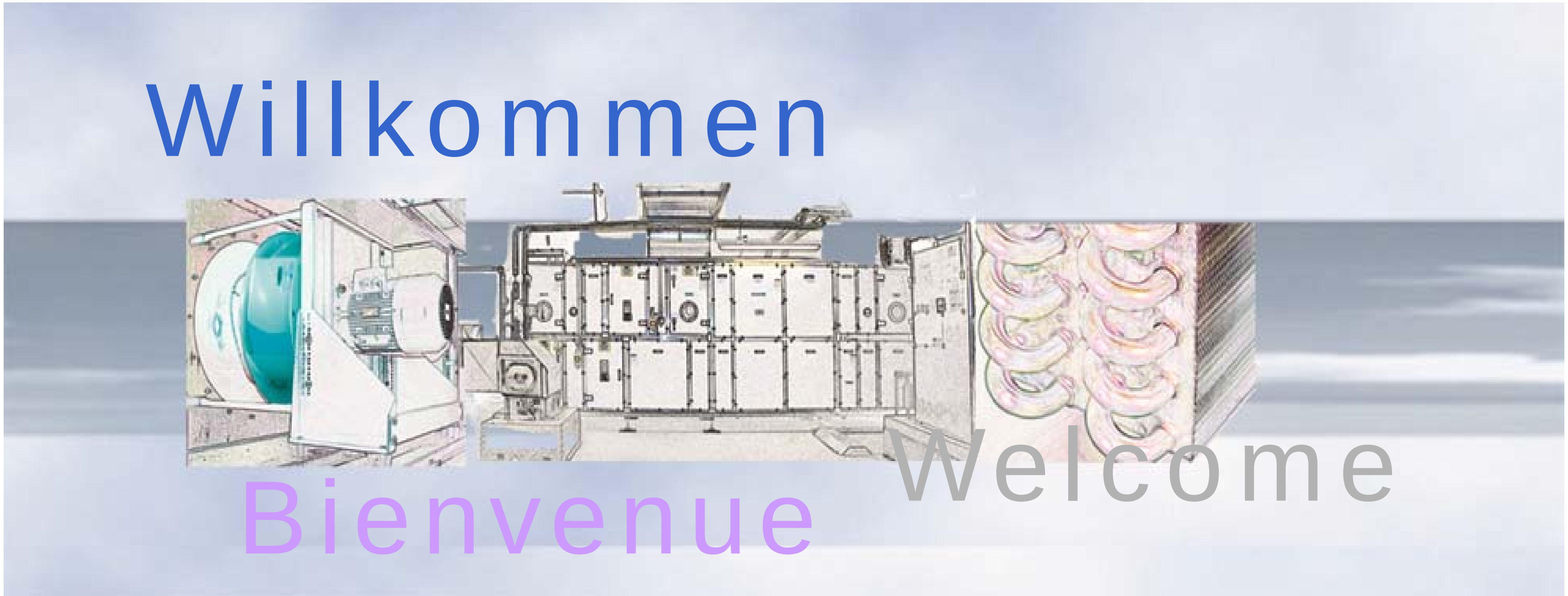


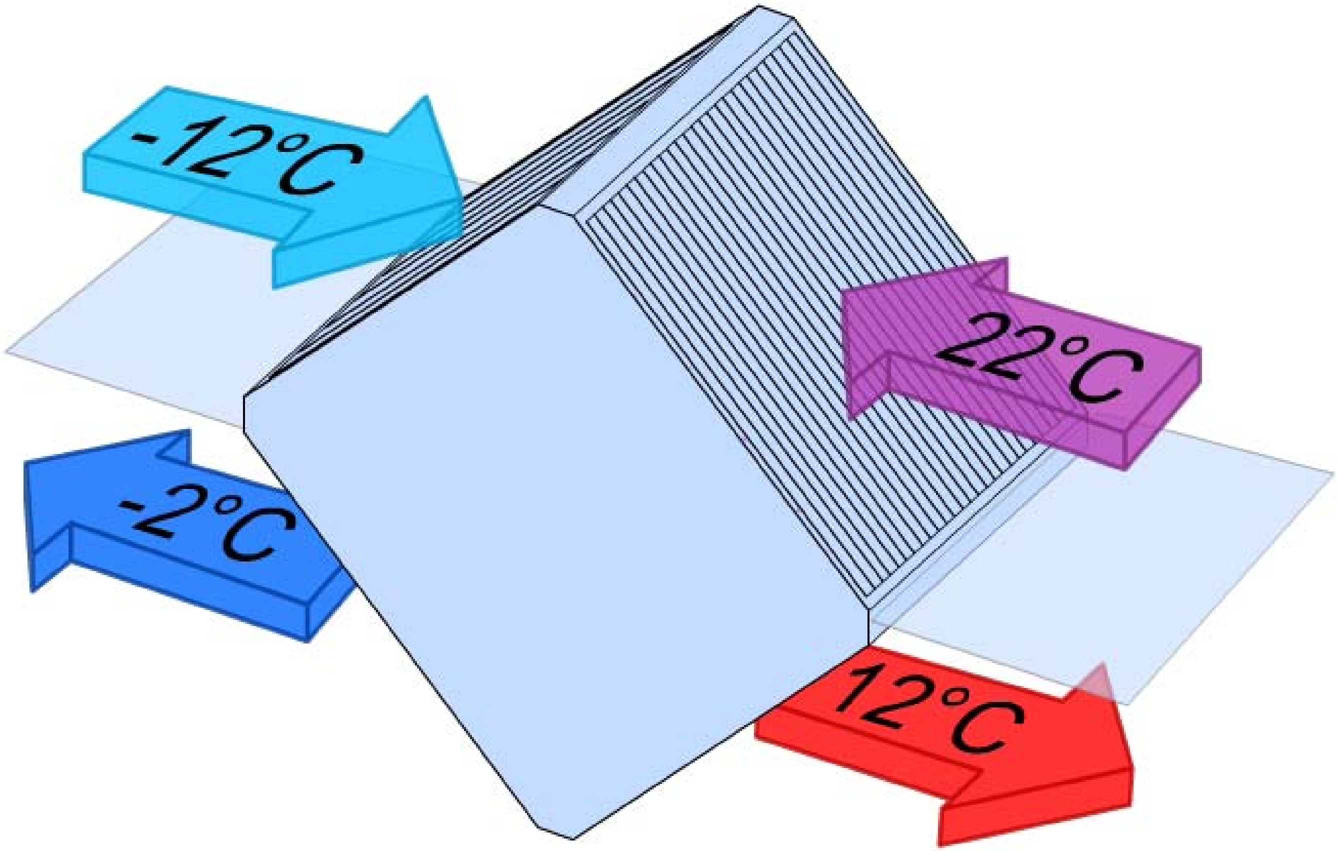
Multifunctional heatrecovery systems

Energy recovery in air handling units with high performance heatrecovery based on cycle compound system

Prof. Dr.-Ing. **Christoph Kaup**
c.kaup@umwelt-campus.de

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld
Umwelt macht Karriere.

Plate exchanger

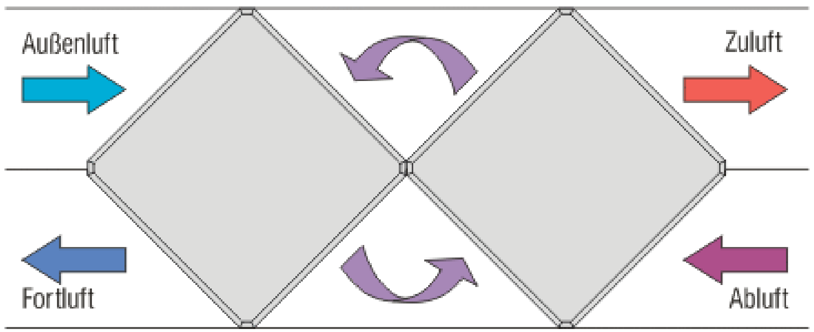


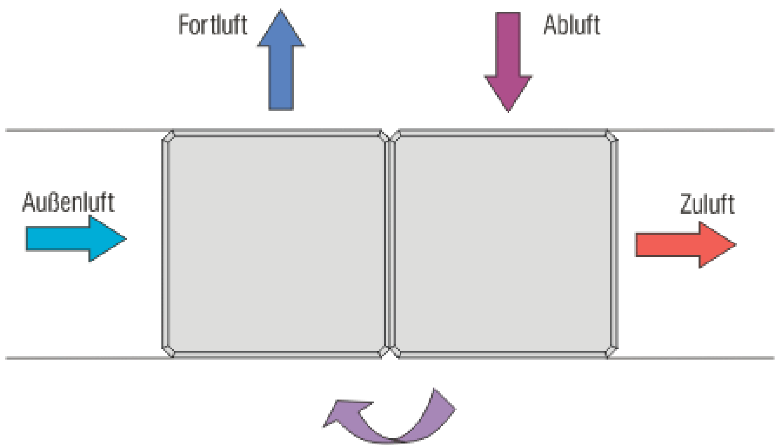
Quelle Klingenburg

Configuration of plate exchangers

Double plate exchanger (Counterflow configuration)

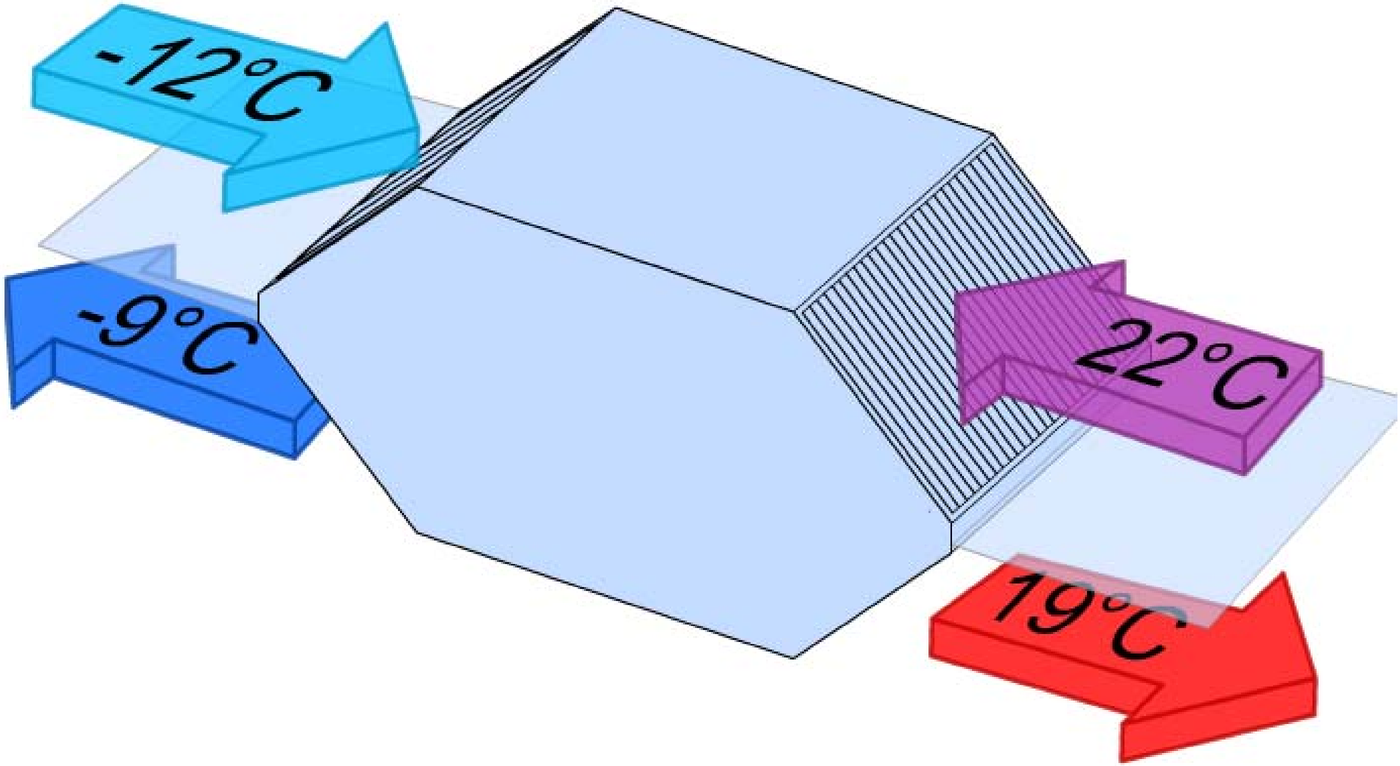
Diagonal | Aligned





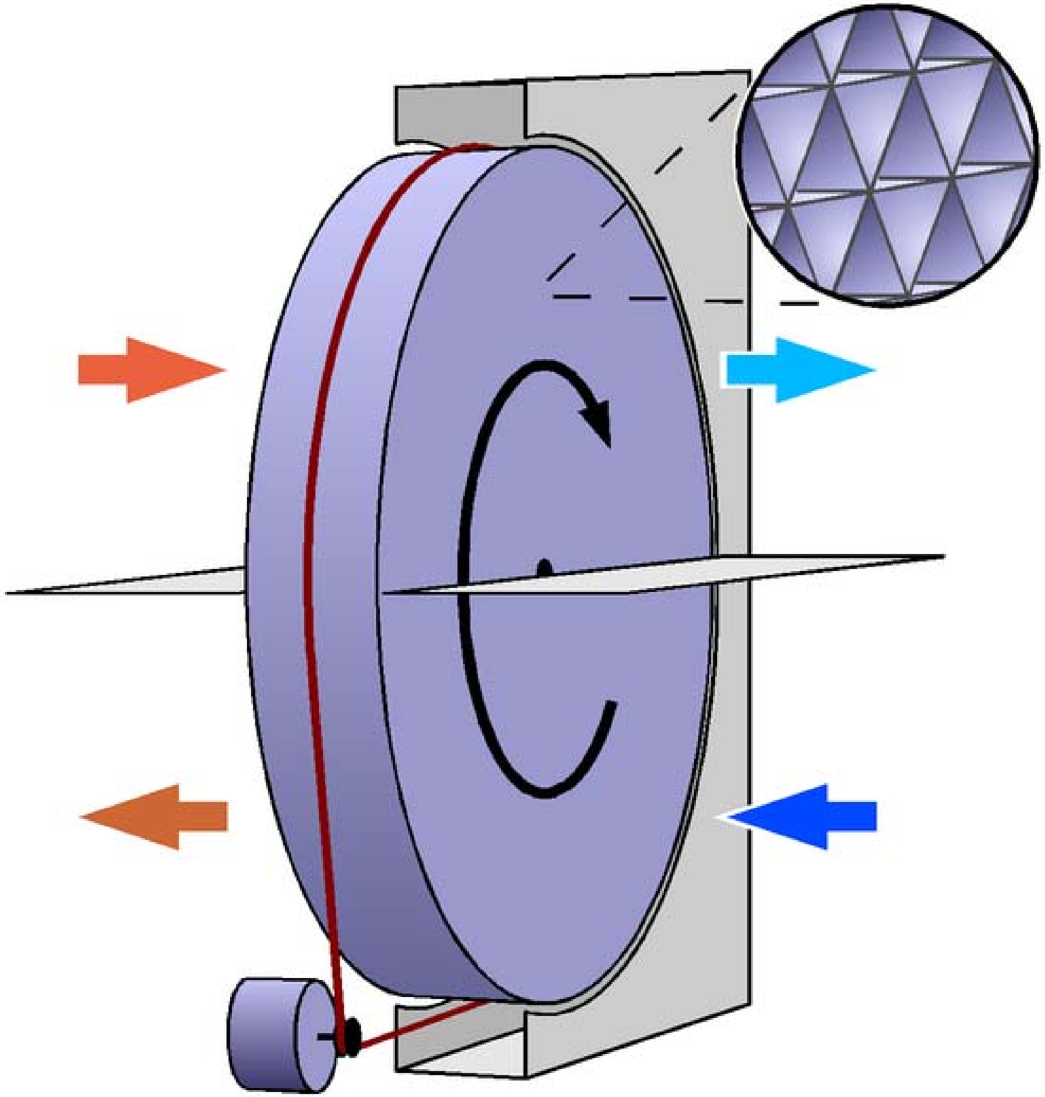
Quelle Klingenburg

Counter flow plate exchanger



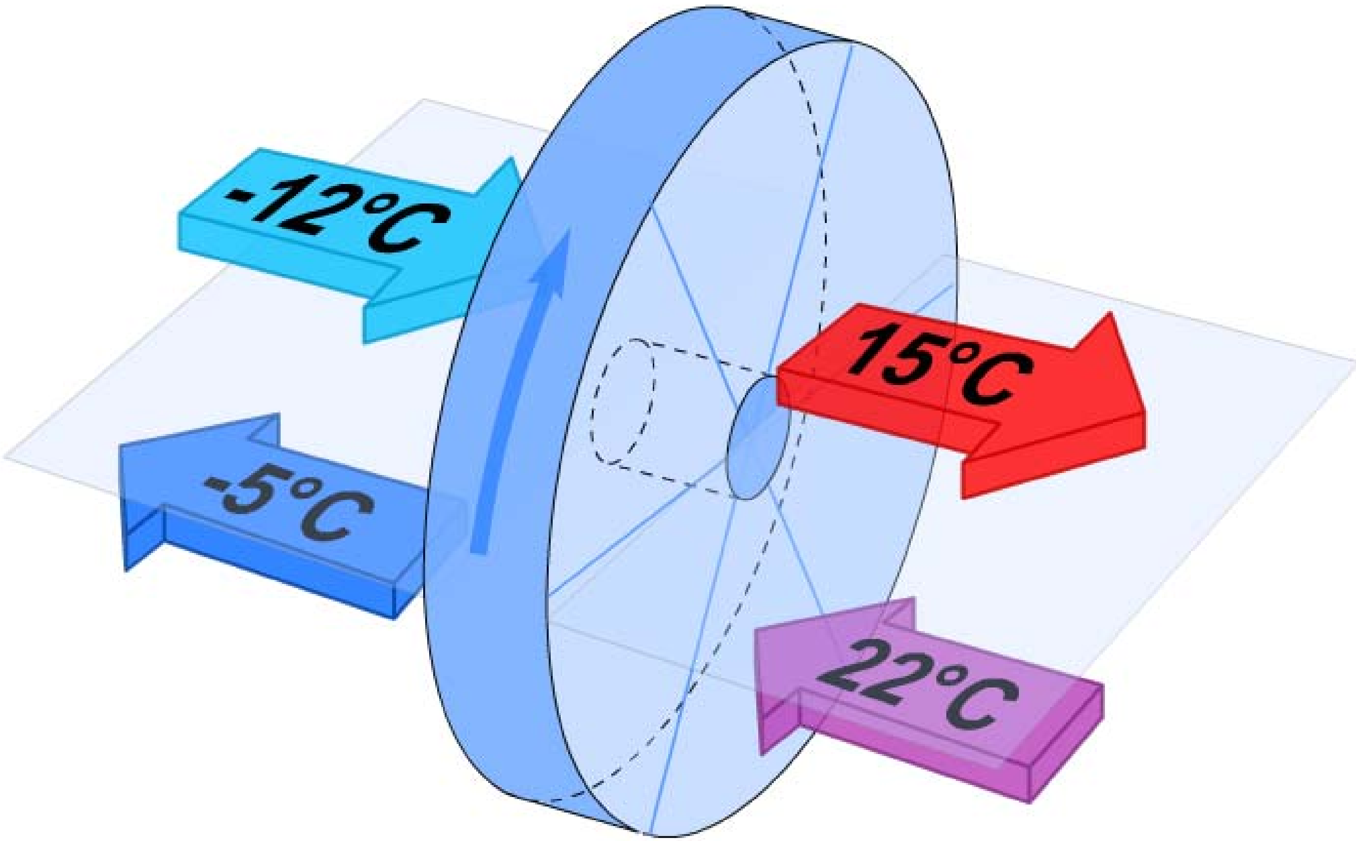
Quelle Klingenburg

Rotary wheel exchanger



Quelle Klingenburg

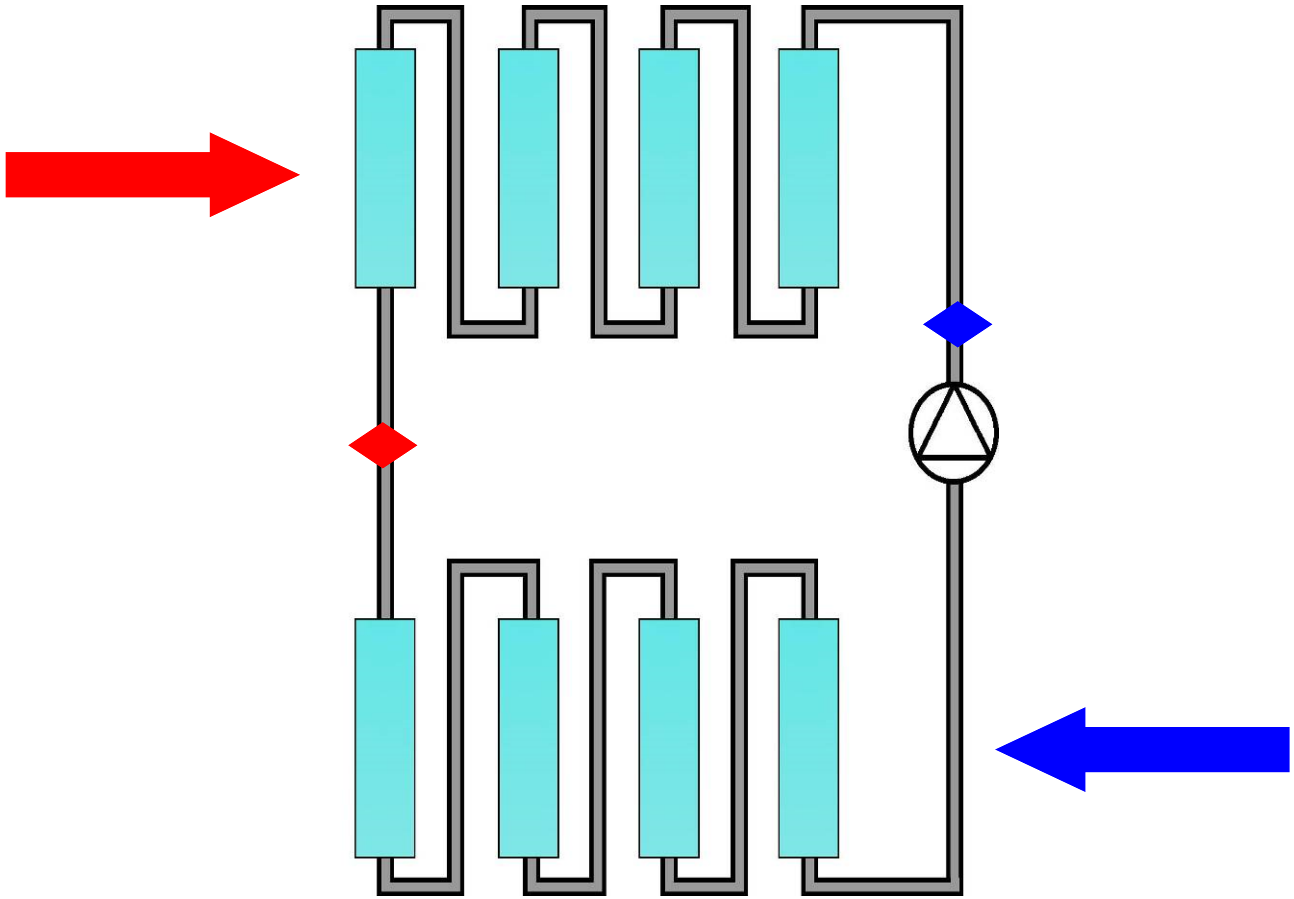
Rotary wheel exchanger



Quelle Klingenburg

Cycle compound system

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



Efficiency

Heat recovery classes (new)

EN 13053 : 2012

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Transfer efficiency

Thermal efficiency

$$\Phi = \frac{\dot{Q}_{HR}}{\dot{Q}_{P}} = \frac{t_2'' - t_2'}{t_1' - t_2'}$$

COP

$$\varepsilon = \frac{\dot{Q}_{HR}}{P_{el}}$$

Efficiency

Heat recovery classes (new)

EN 13053 : 2012

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Electric power consumption (HR)

$$P_{el} = \dot{V} \cdot \Delta p_{HR} \cdot 1 / \eta + P_{add}$$

P_{el}	Elektric power consumption [KW]
$\dot{V}$	air flow [m³/s]
Δp_{HR}	Pressure losses of HR Supply- and exhaust air [Pa]
η	System efficiency fan drive [./.]
P_{add}	additional auxiliary energy (e. g. pumps, etc.)

Heat recovery classes (new)

EN 13053 : 2012

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Total efficiency

Energetic efficiency

$$\eta = \frac{\dot{Q}_{HR} - P_{el}}{\dot{Q}_{P}}$$

$$\eta = \frac{1 - P_{el} / \dot{Q}_{HR}}{\dot{Q}_{P} / \dot{Q}_{HR}} = \frac{1 - 1 / \varepsilon}{1 / \Phi}$$

$$\eta = \Phi \cdot (1 - 1 / \varepsilon) = \Phi \cdot (1 - P_{el} / \dot{Q}_{HR})$$

Heat recovery classes

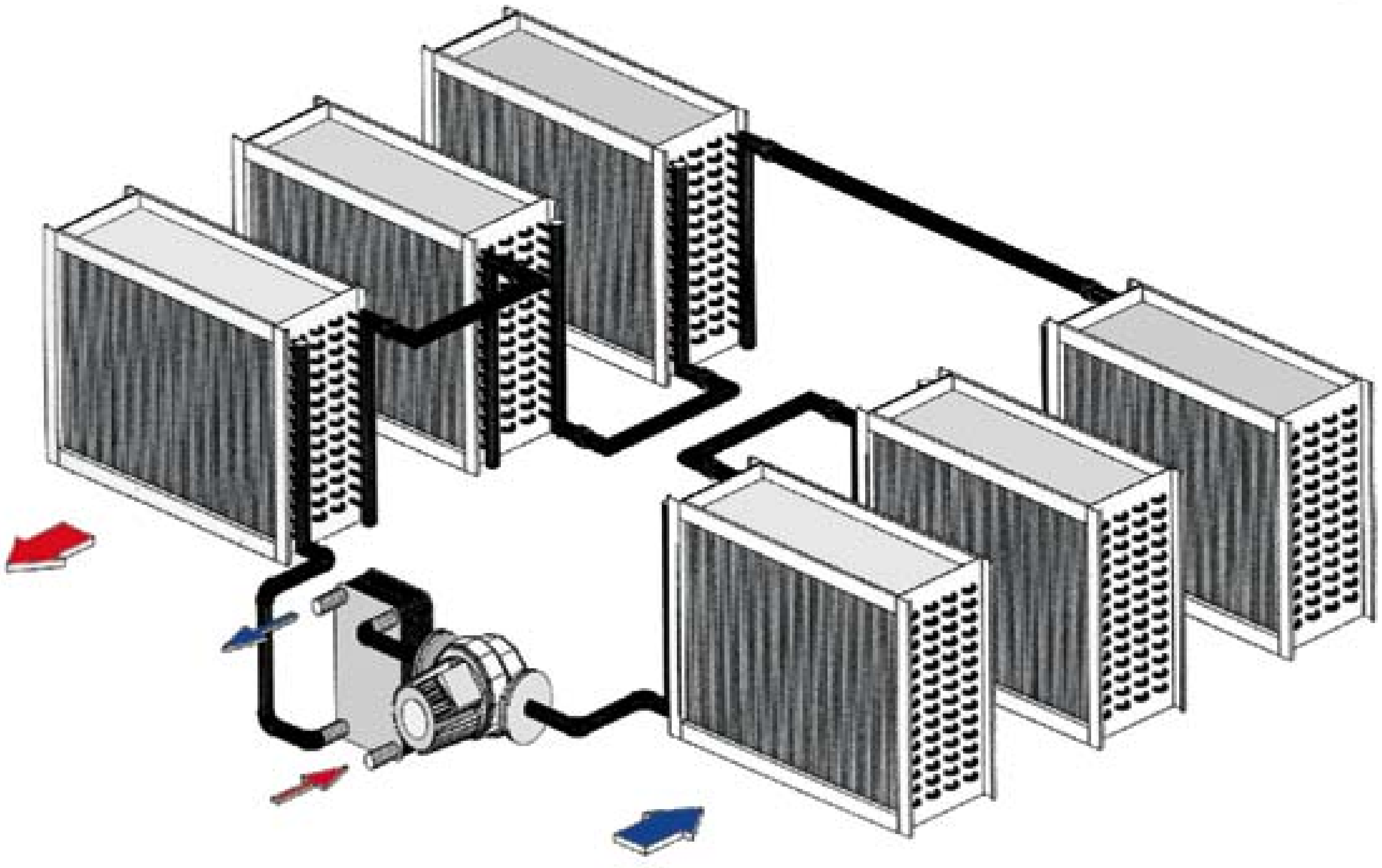
EN 13053 : 2012

European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

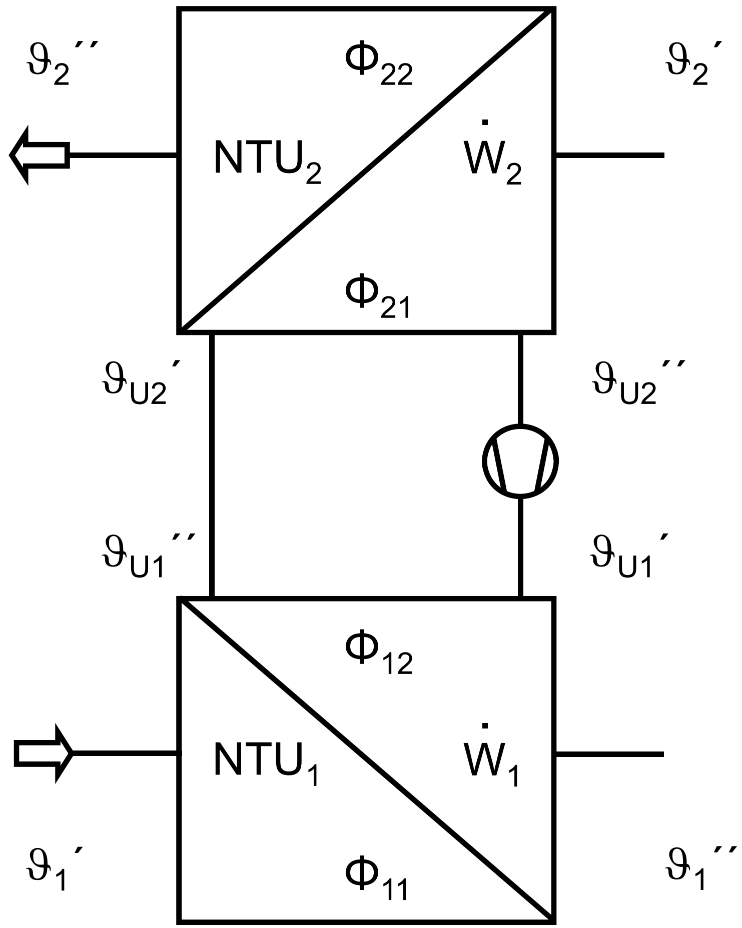
HR classes	η [%]	Φ [%]	ε	∆P [Pa]
H1	71	75	19.5	2 x 280
H2	64	67	21.2	2 x 230
H3	55	57	24.2	2 x 170
H4	45	47	27.3	2 x 125
H5	36	37	26.9	2 x 100
H6	< 36			

Values based on EN 308: t_{21} = + 5°C und t_{11} = 25 °C
Values are reference values and only valid for this operating point

Multistage system



Coupled heat exchangers



Coupled heat exchanger

Heat exchanger 1

$$NTU_{11} = (k \bullet A)_1 / \dot{W}_1$$

$$\mu_{11} = \dot{W}_1 / \dot{W}_u$$

$$\Phi_{11} = (\vartheta_1{}' - \vartheta_1{}'') / (\vartheta_1{}' - \vartheta_{u1}{}')$$

Coupled heat exchanger

Heat exchanger 2

$$NTU_{22} = (k \bullet A)_2 / \dot{W}_2$$

$$\mu_{22} = \dot{W}_2 / \dot{W}_u$$

$$\Phi_{22} = (\vartheta_2' - \vartheta_2'') / (\vartheta_{u2}' - \vartheta_2')$$

Coupled heatexchanger

For the system takes effect

$$\Phi_{2tot} = (\vartheta_2'' - \vartheta_2') / (\vartheta_1' - \vartheta_2')$$

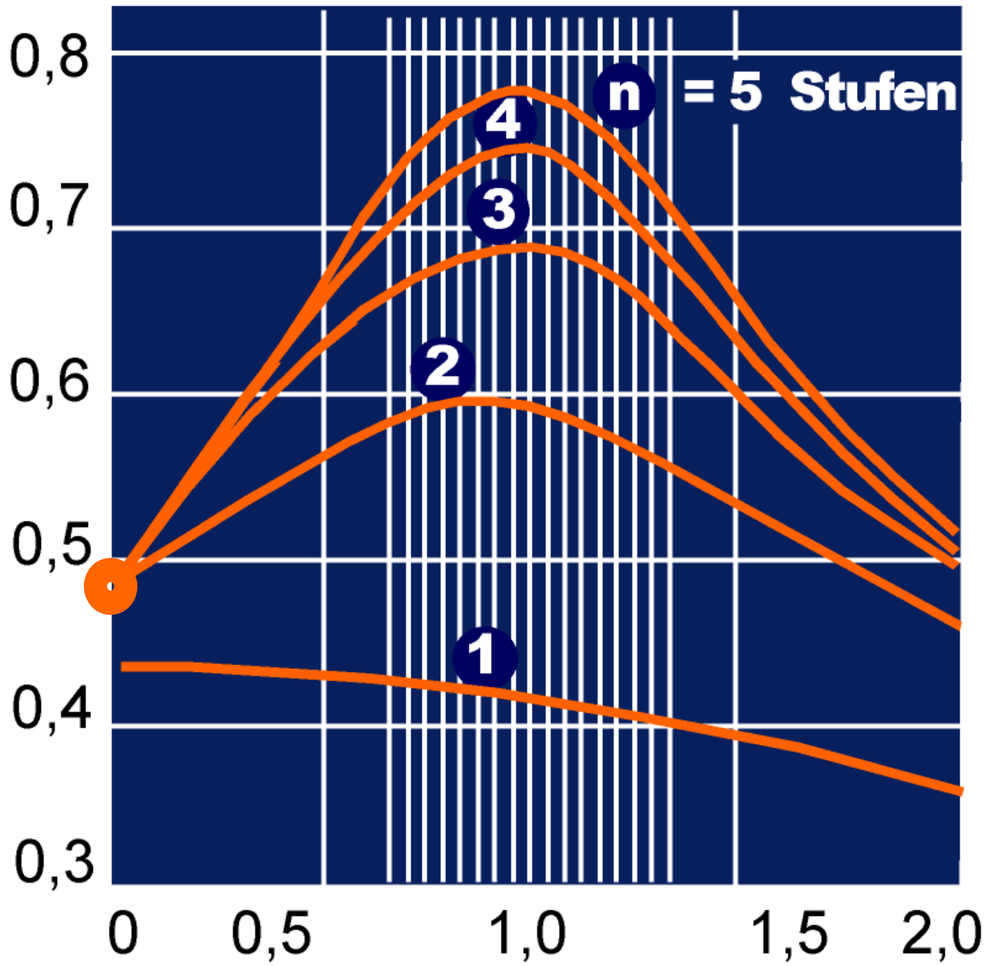
$$\mu_{2tot} = \dot{W}_2 / \dot{W}_1 = 1 / \mu_{1tot}$$

Coupled heatexchanger

Dimensionless temperature change of the system

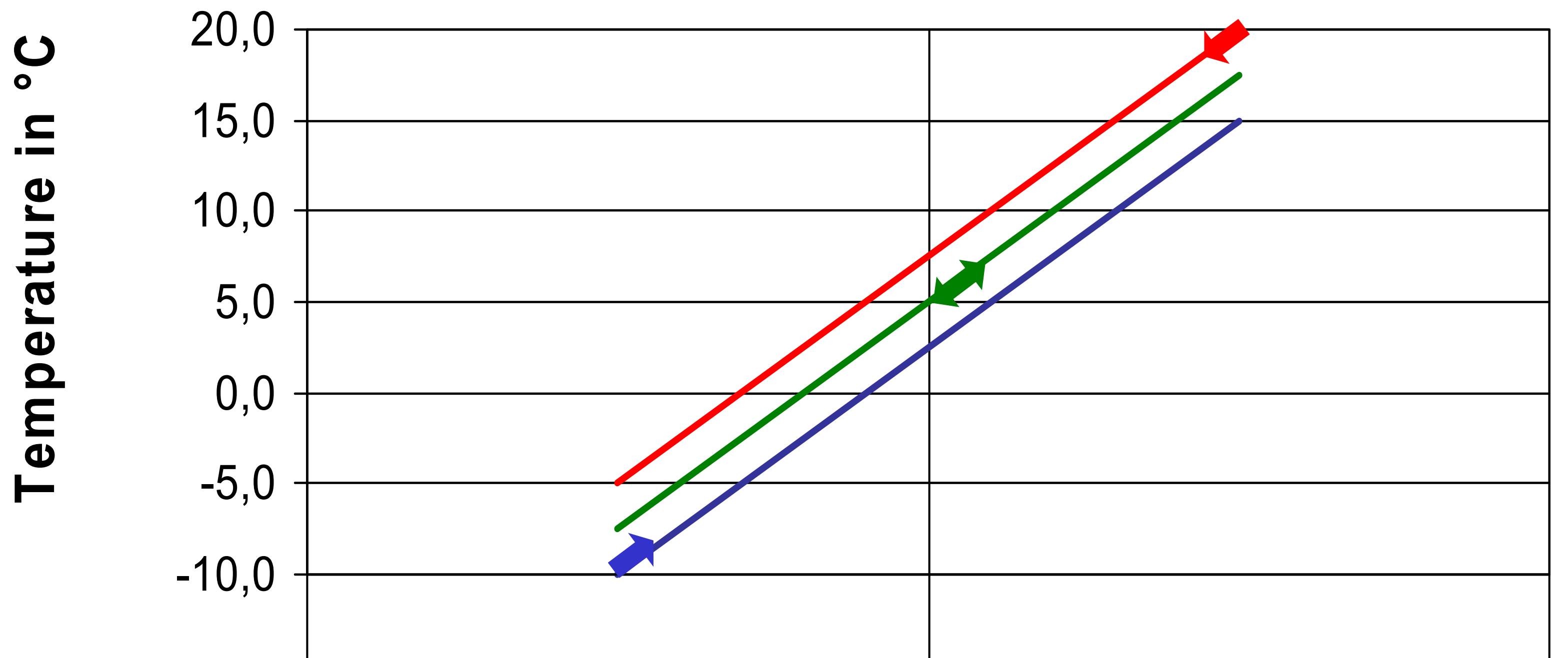
$$1 / \Phi_{2tot} = 1 / \Phi_{22} + 1 / \Phi_{11} \cdot \mu_{2tot} - \mu_{22}$$

Heat flow capacity relationship



Function

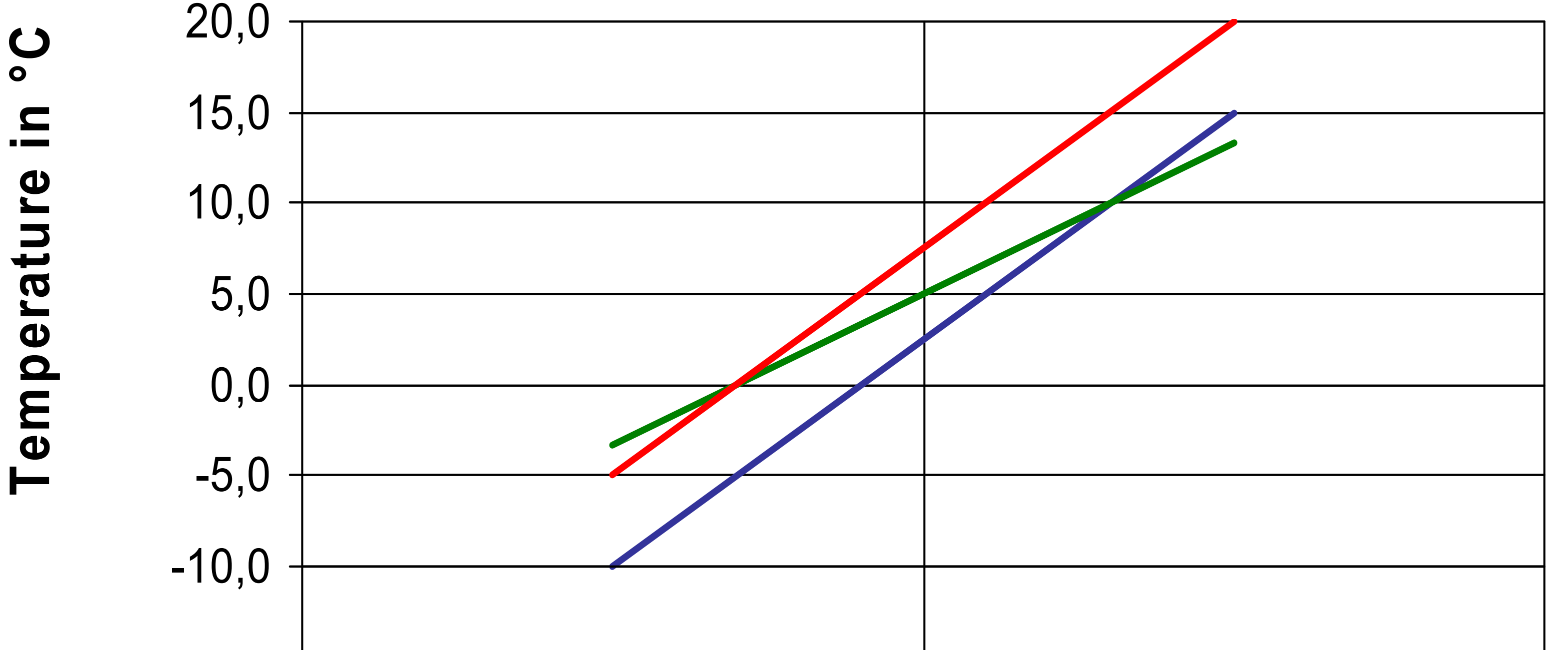
Temperaturediagram with ETA = 0.8



supply	-10,0	15,0
W1/W2 = 1.0	-7,5	17,5
exhaust	-5,0	20,0

Function

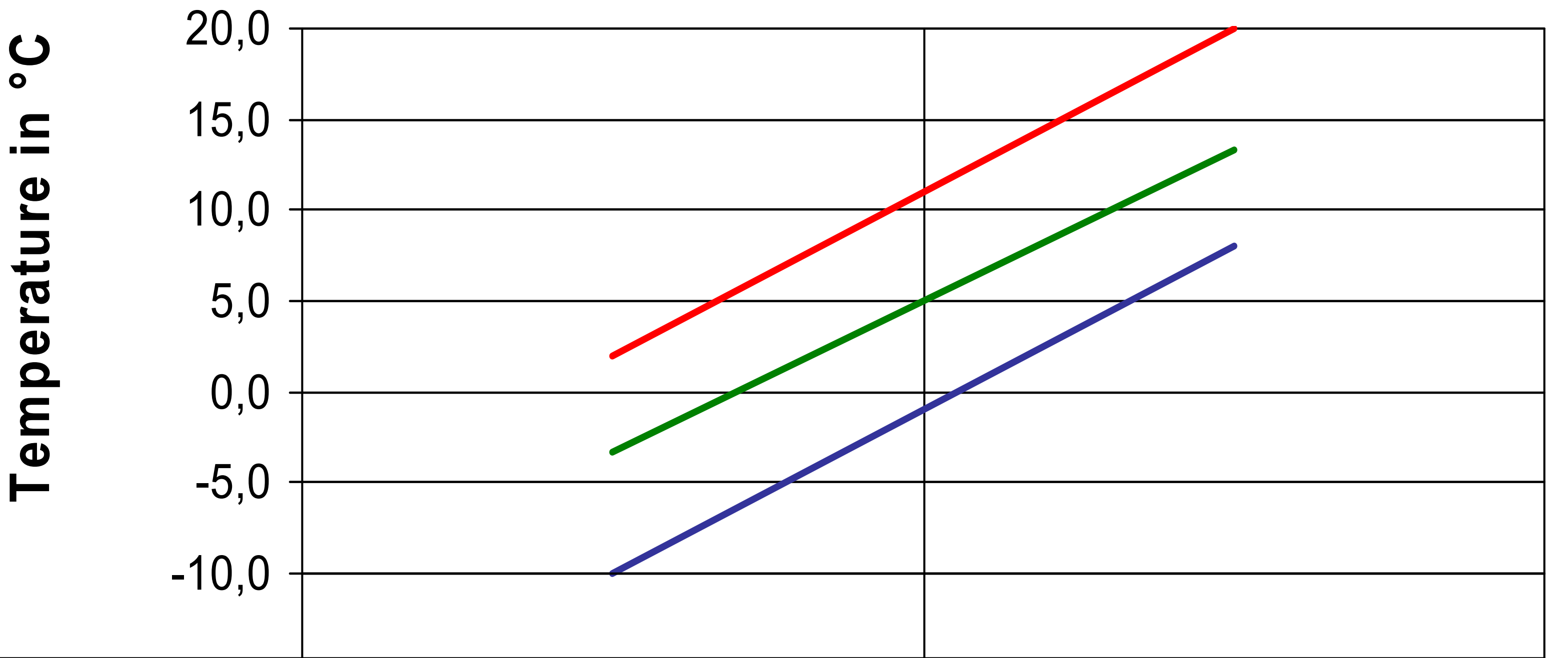
Temperaturediagram with ETA = 0.8



supply	-10,0	15,0
W1/W2 = 1.5	-3,3	13,3
exhaust	-5,0	20,0

Function

Temperaturediagram with ETA = 0.6



suppy	-10,0	8,0
W1/W2 = 1.5	-3,3	13,3
exhaust	2,0	20,0

Coupled heat exchangers

With optimal circulation flow:

$$1 / (k \cdot A)_{eff} = 1 / (k \cdot A)_1 + 1 / (k \cdot A)_2$$

With balanced air flow:

$$\mu_{2ges} = \dot{W}_1 / \dot{W}_2 = 1$$

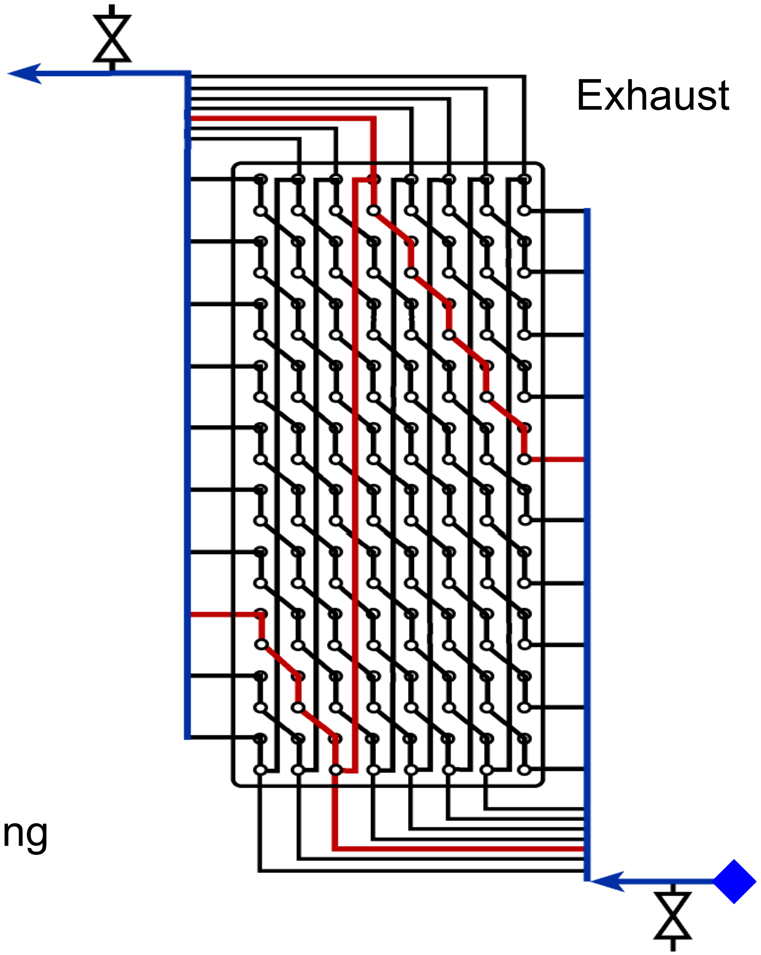
Coupled heat exchangers

with:

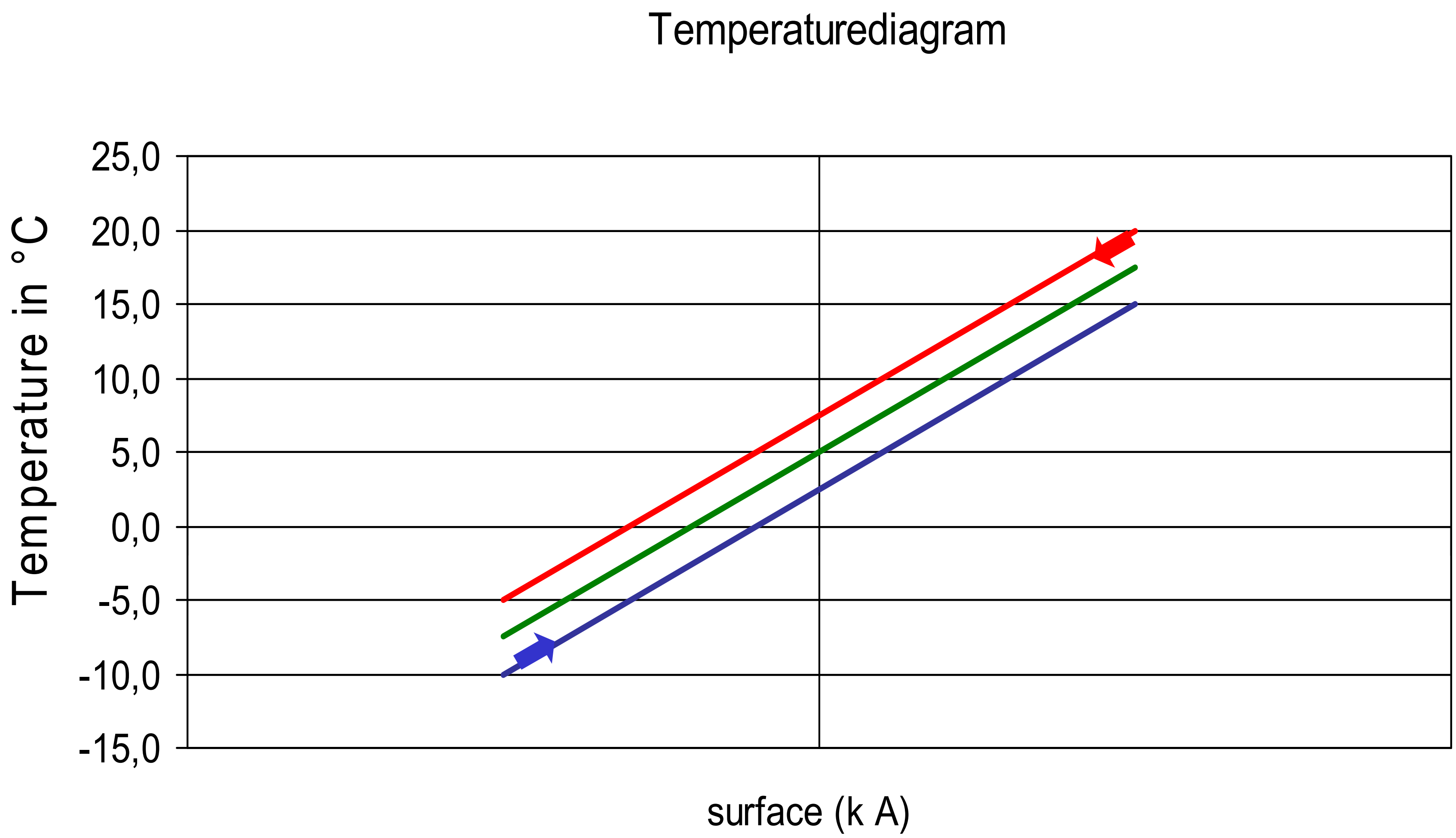
$\mu_{11} = \mu_{22} = 1$

Total efficiency

$1 / \Phi_{2tot} = 1 / \Phi_{22} + 1 / \Phi_{11} – 1$



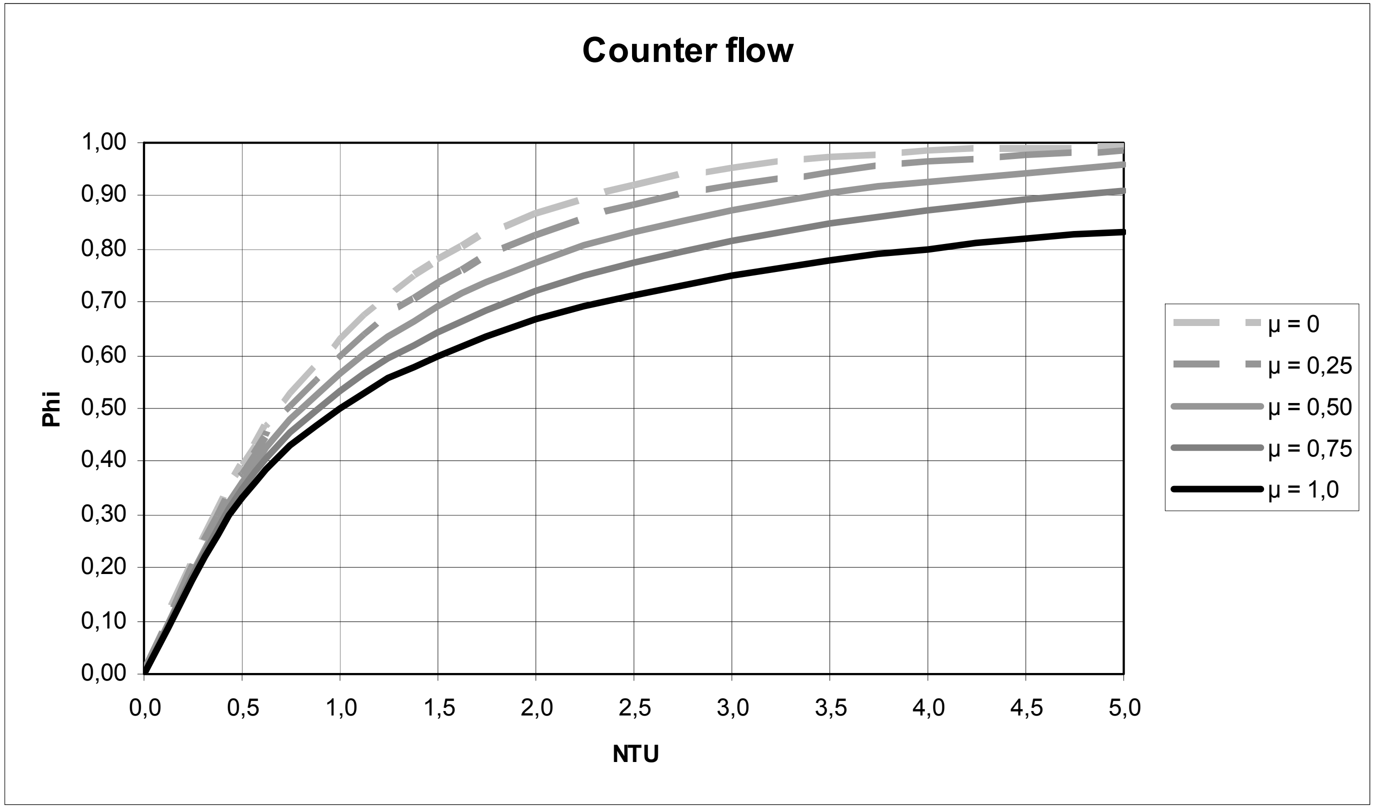
DE 198 08 753


Temperaturediagram
Temperature in °C
25,0
20,0
15,0
10,0
5,0
0,0
-5,0
-10,0
-15,0
surface (k A)

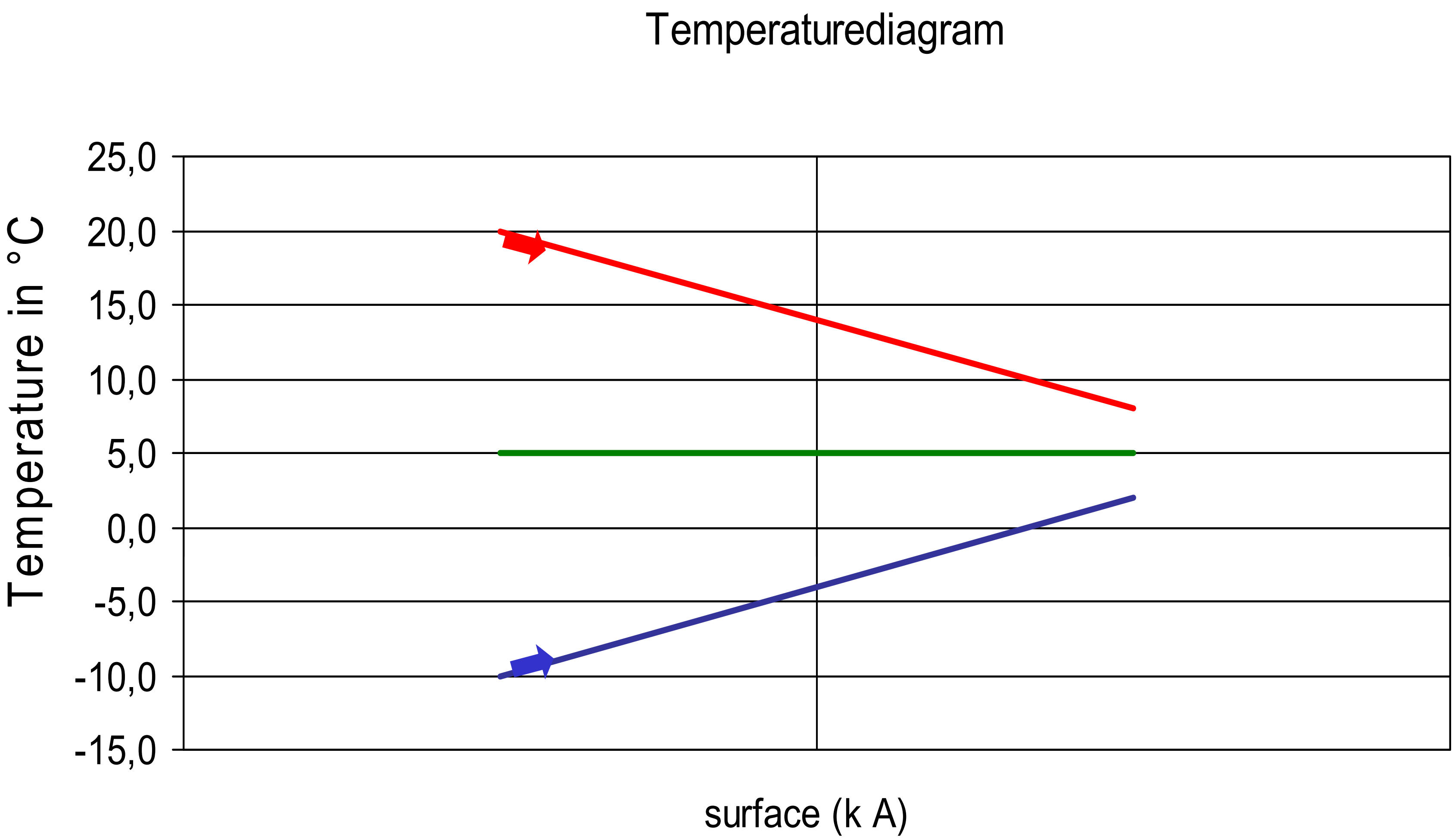
Thermal efficiency in pure counter current

$\Phi_i = (1 - e^{[(\mu_i - 1) \cdot NTU_i]}) / (1 - \mu_i \cdot e^{[(\mu_i - 1) \cdot NTU_i]})$ bei $\mu <> 1$

$\Phi = NTU / (1 + NTU)$ bei $\mu = 1$

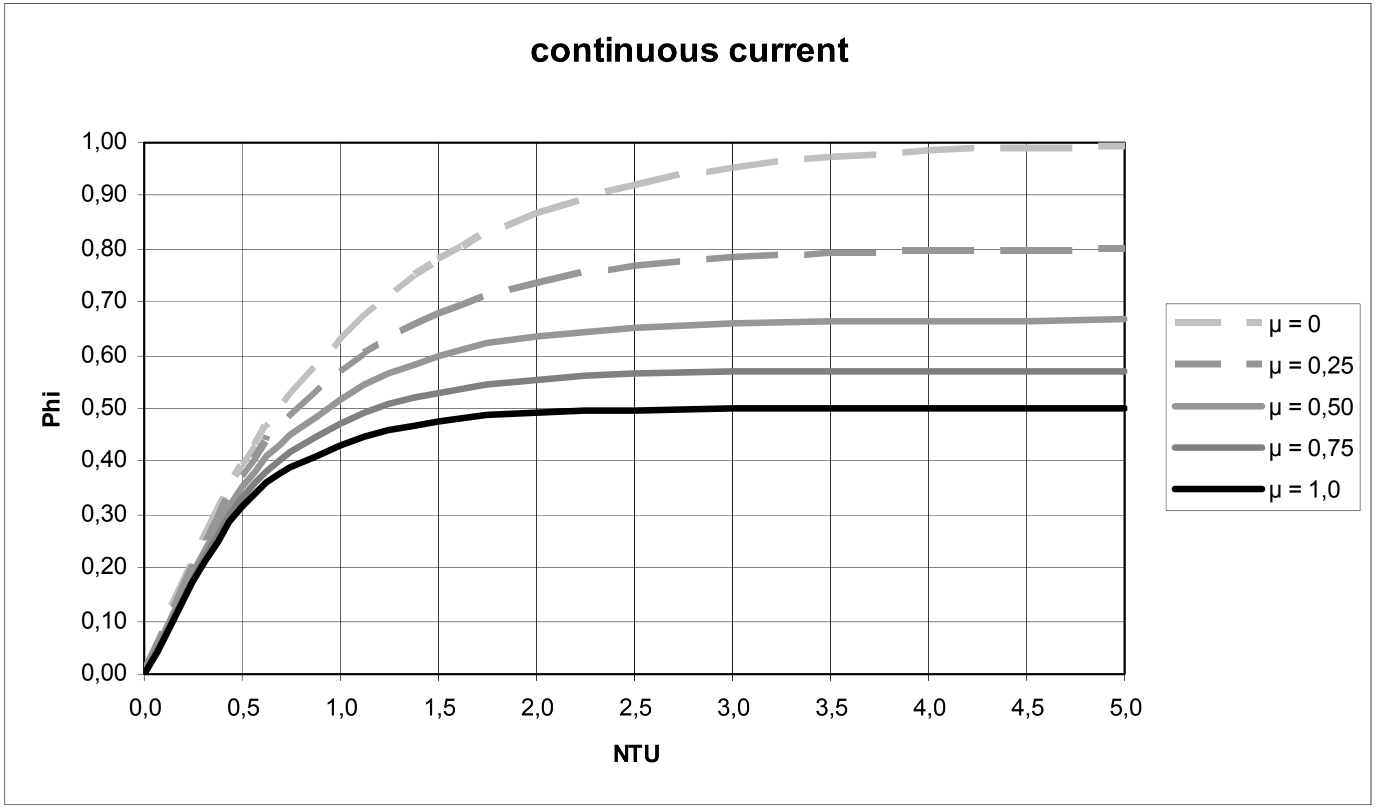


Continuous current



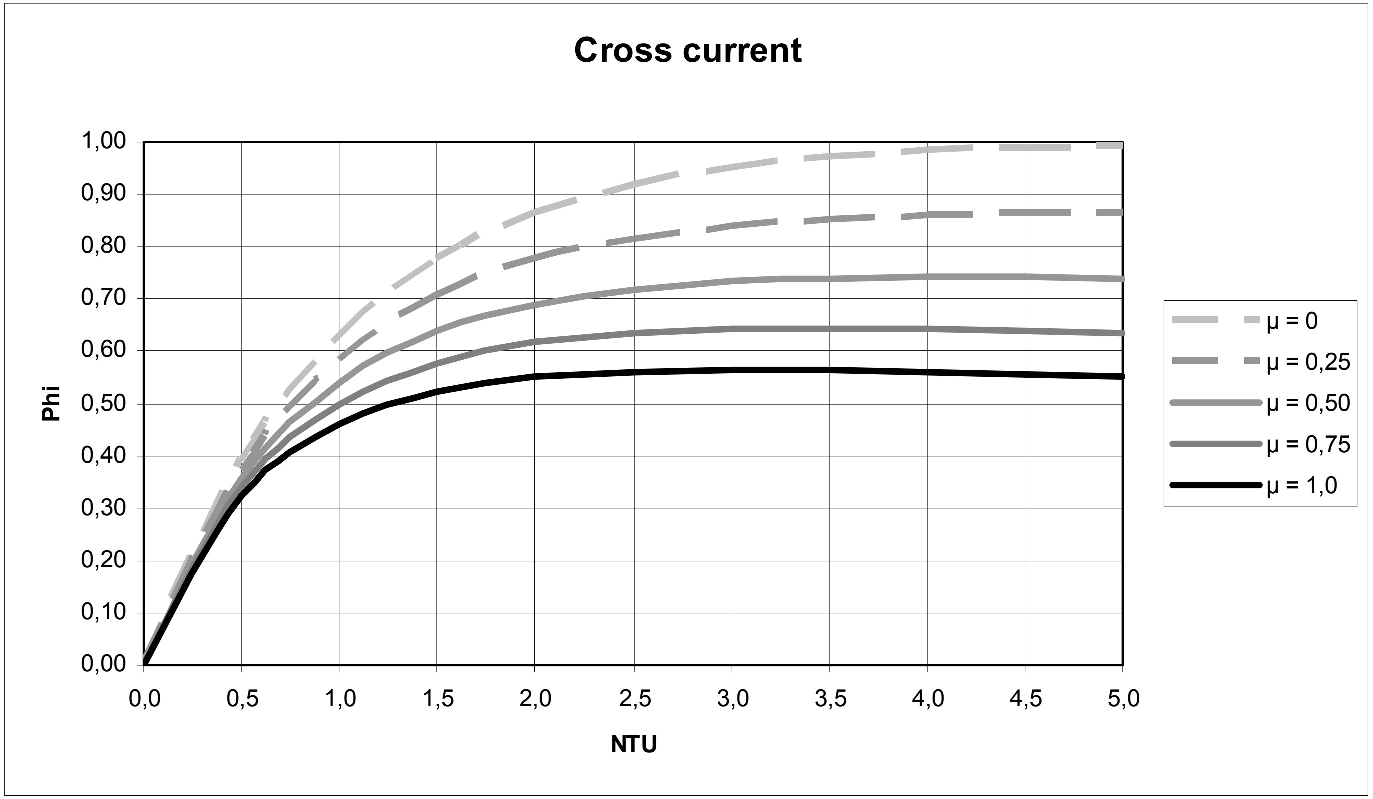
Thermal efficiency in pure continuous current

$$\Phi_i = \left(1 - e^{[-NTU_i \cdot (1 + \mu_i)]}\right) / (1 + \mu_i)$$



Thermal efficiency in pure cross current

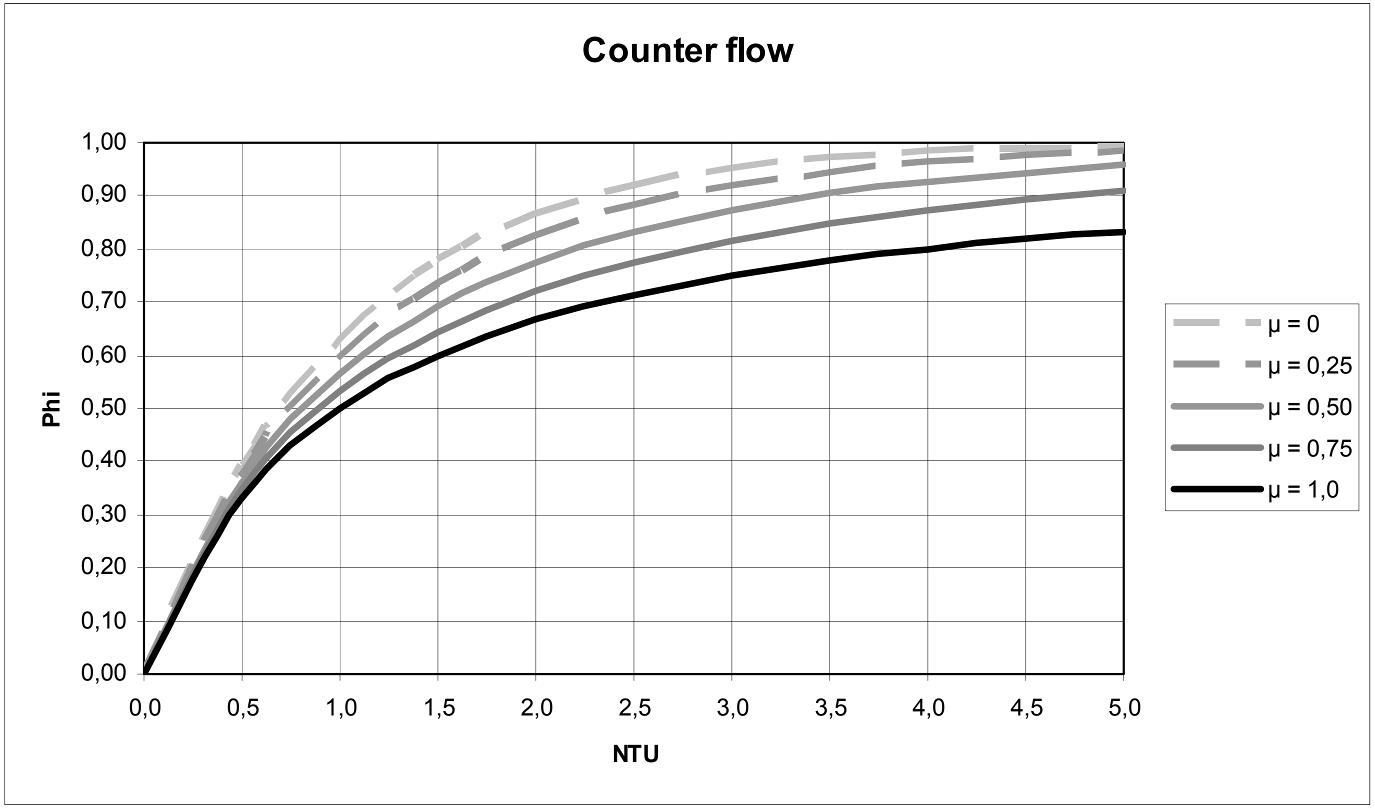
$$1 / \Phi_i = 1 / (1 - e^{[-NTU_i]}) + \mu_i / (1 - e^{[-\mu_i \cdot NTU_i]}) - 1/ NTU_i)$$



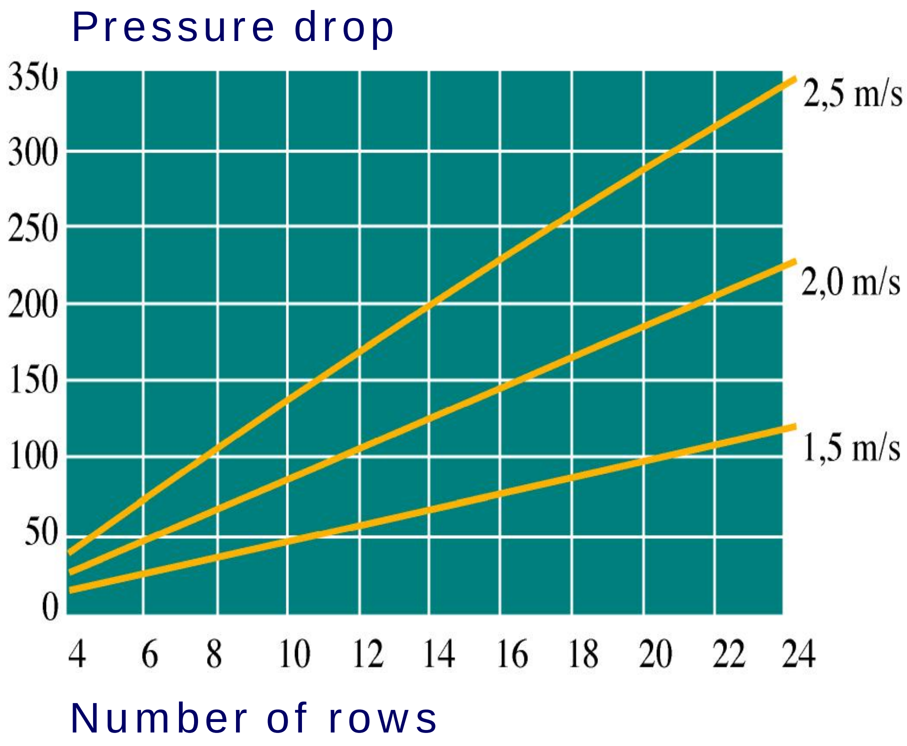
Thermal efficiency in pure counter current

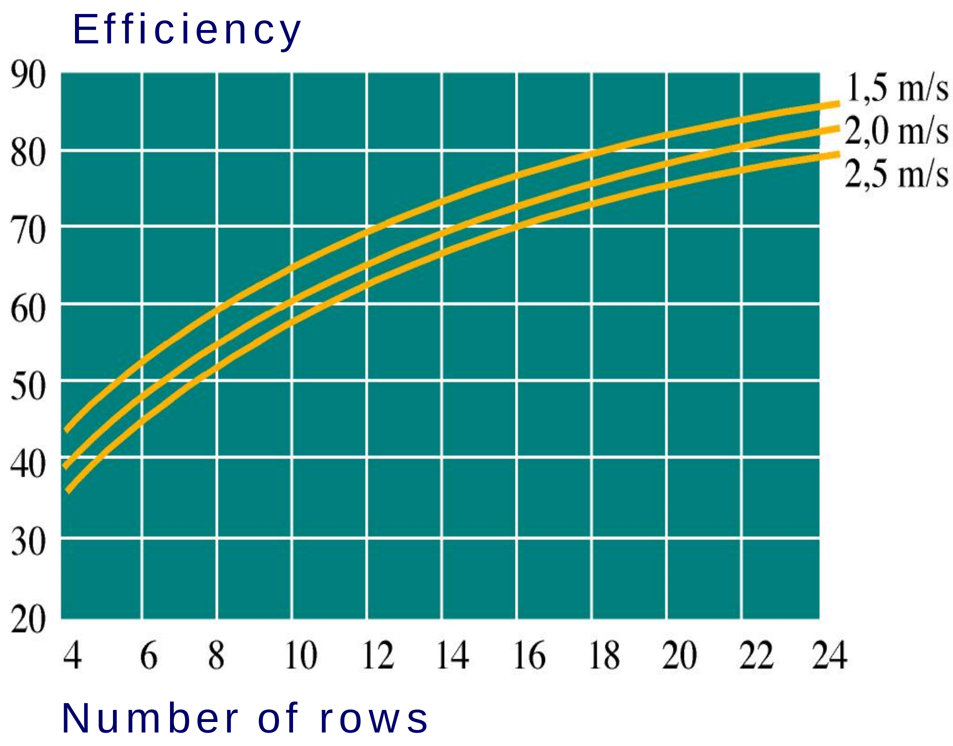
$\Phi_i = (1 - e^{[(\mu_i - 1) \cdot NTU_i]}) / (1 - \mu_i \cdot e^{[(\mu_i - 1) \cdot NTU_i]})$ bei $\mu <> 1$

$\Phi = NTU / (1 + NTU)$ bei $\mu = 1$



Capacity and pressure drop





Test results

24 rows		
aligned tube arrangment	68 % at 2.5 m/s	74 % at 1.5 m/s
3 stages with 300 mm depth	285 Pa	130 Pa

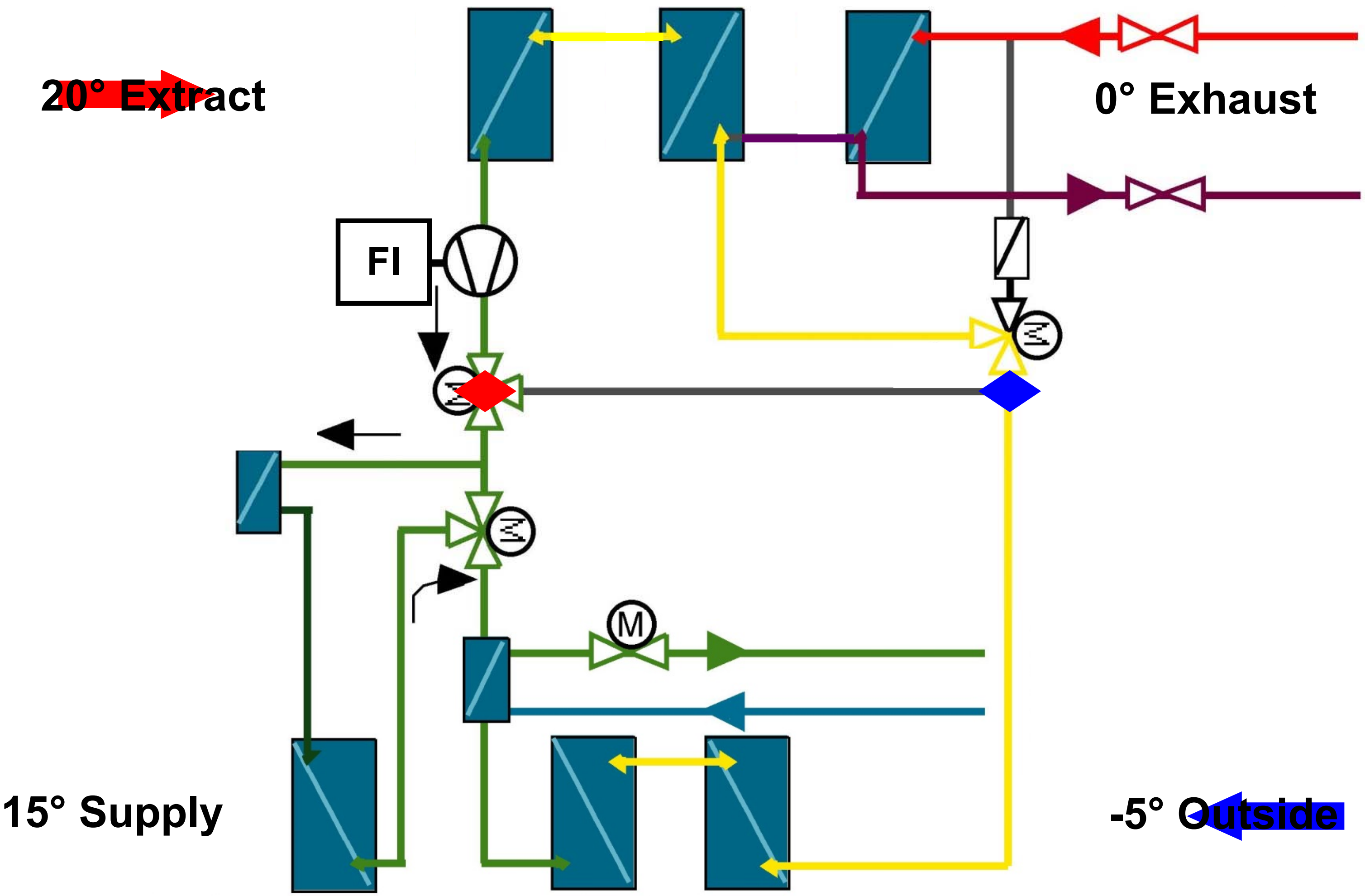
24 rows		
staggered tube arrangment	73 % at 2.5 m/s	77 % at 1.5 m/s
3 stages with 300 mm depth	367 Pa	167 Pa

Betriebscharakteristik-Übertragungsgrad-Druckverluste RWTÜV freiwillig GEPRÜFT

Zentralschweizerisches
Technikum Luzern
Ingenieurschule HTL

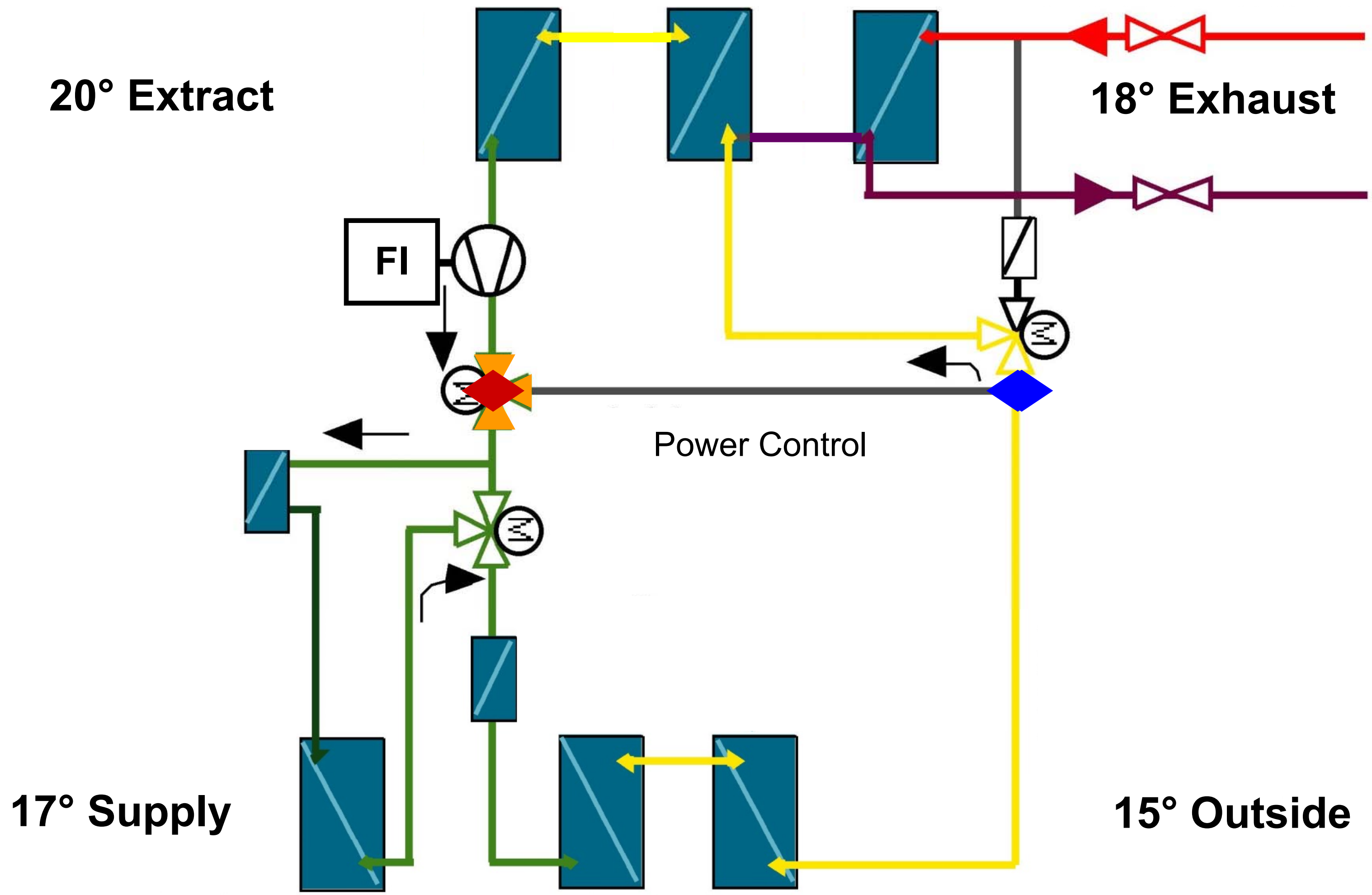
SWISS TESTING

Winter operation

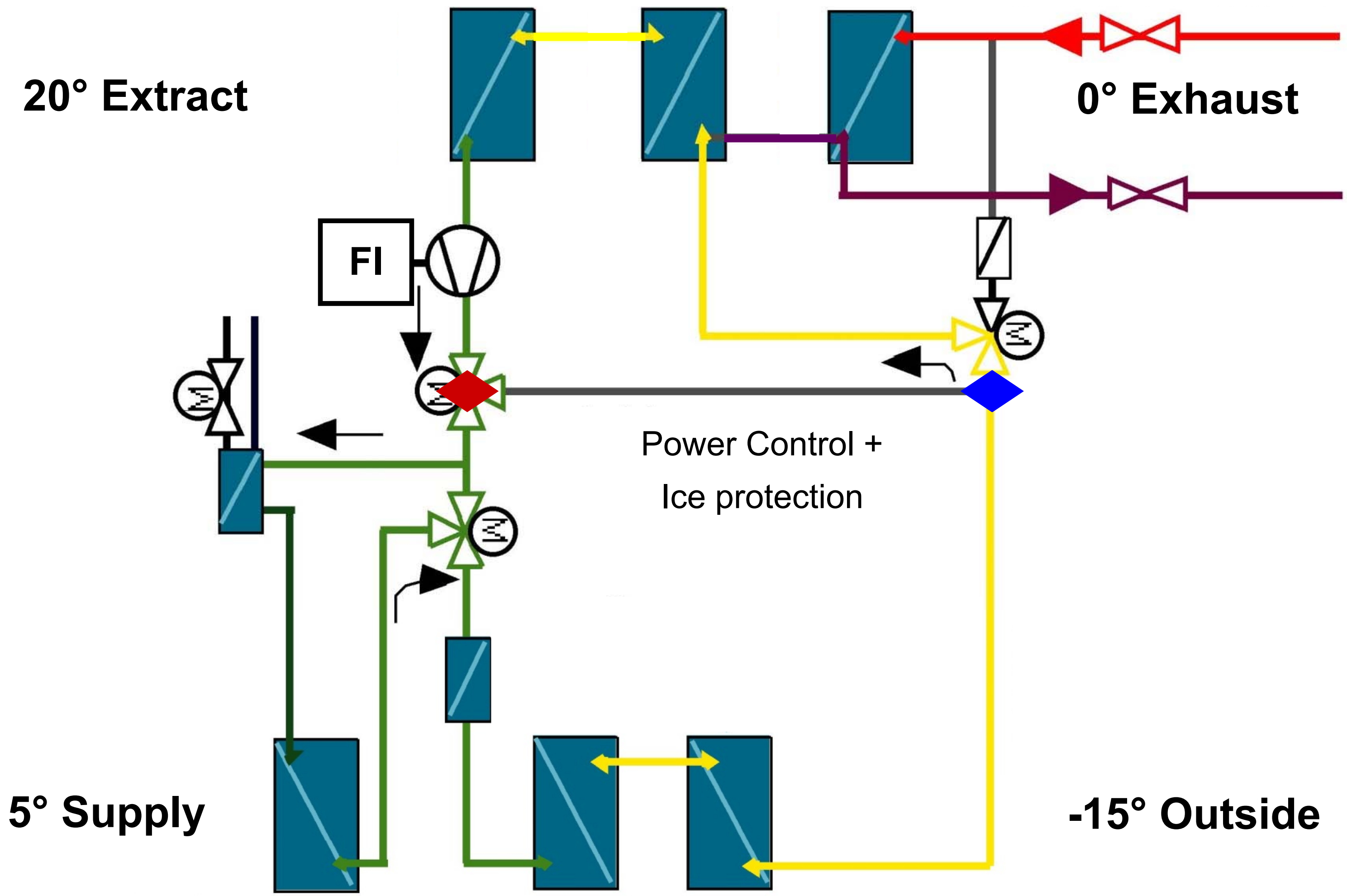


Partload operation

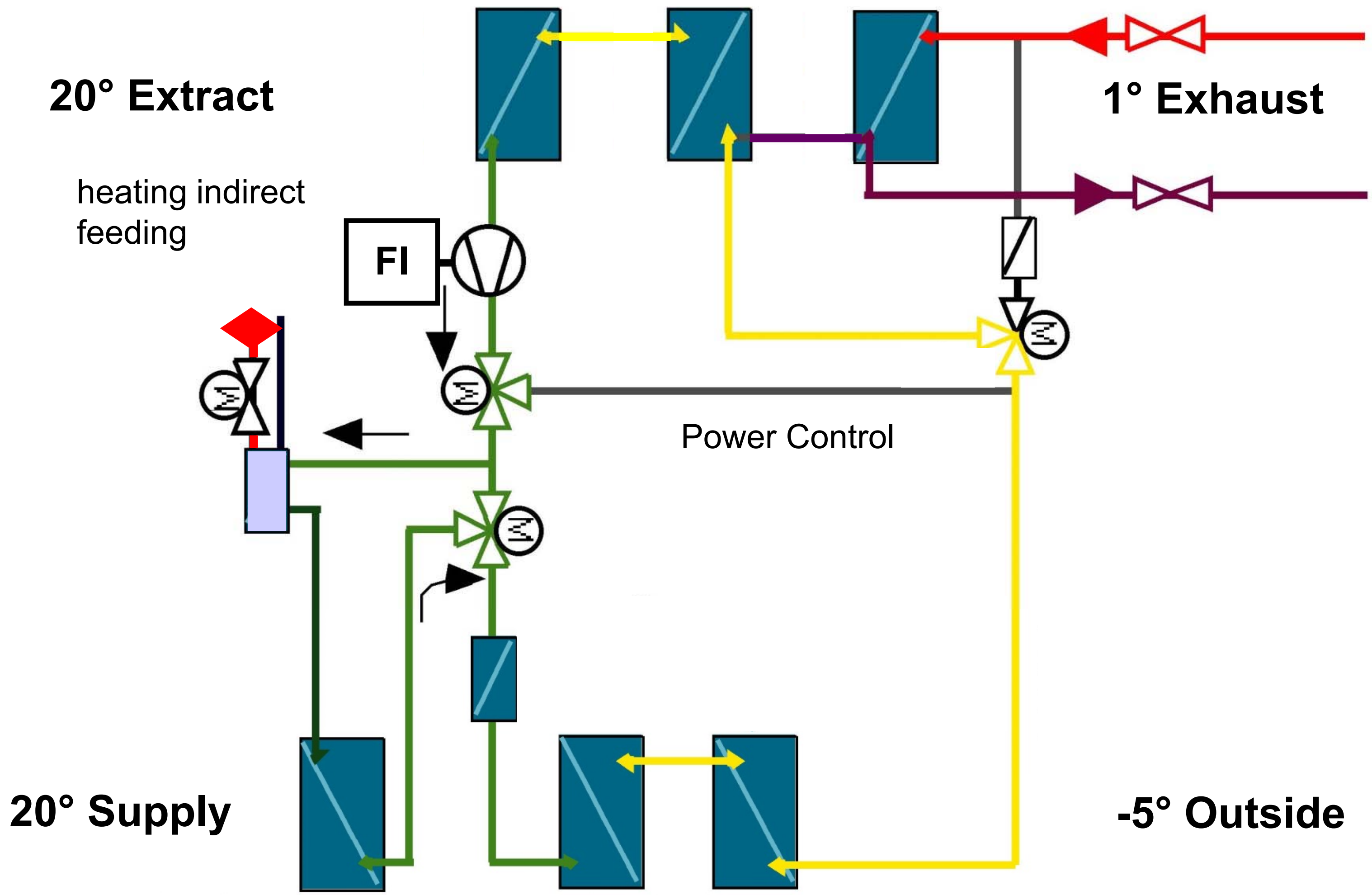
HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



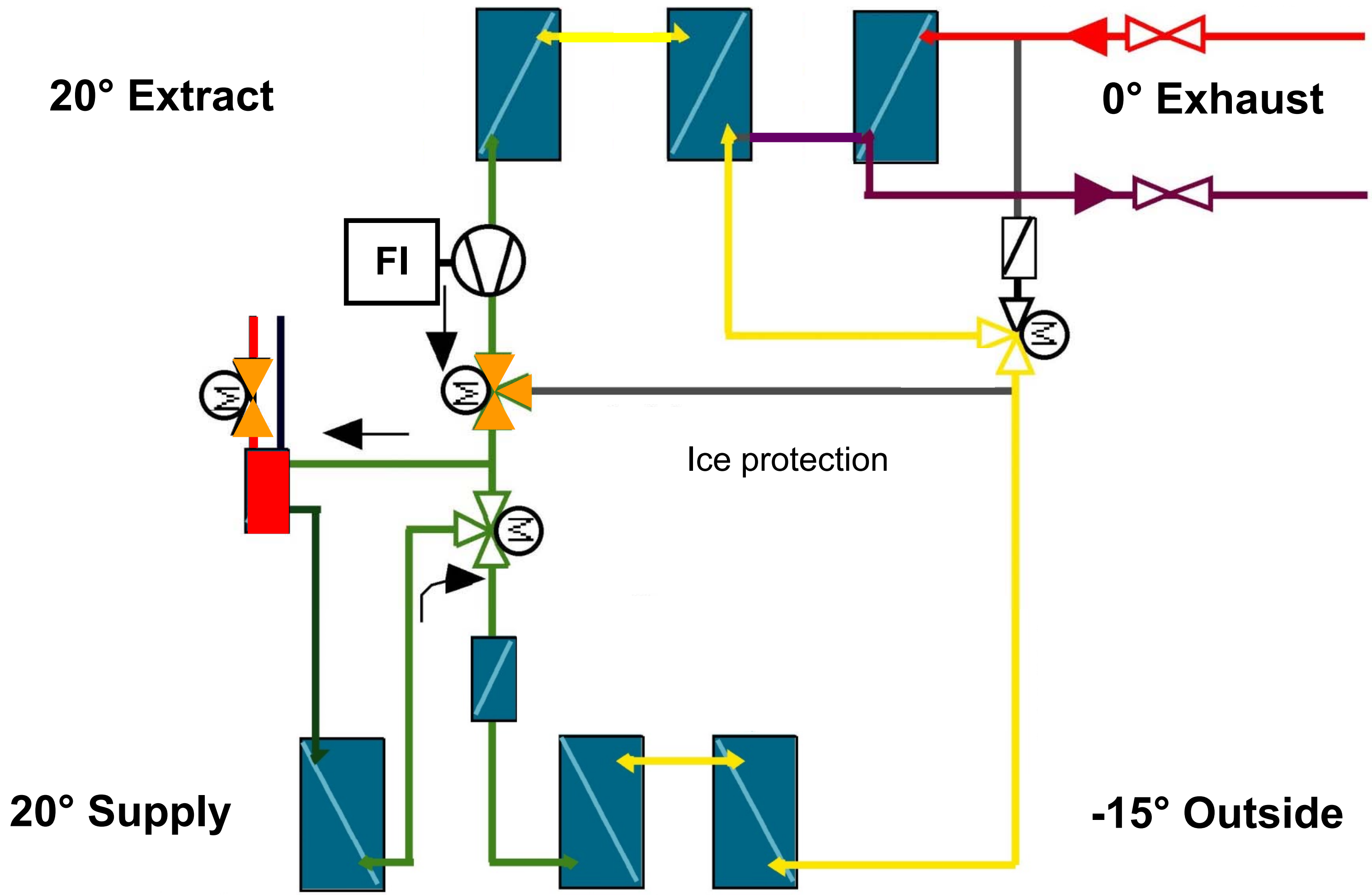
Winter operation with de-iceing



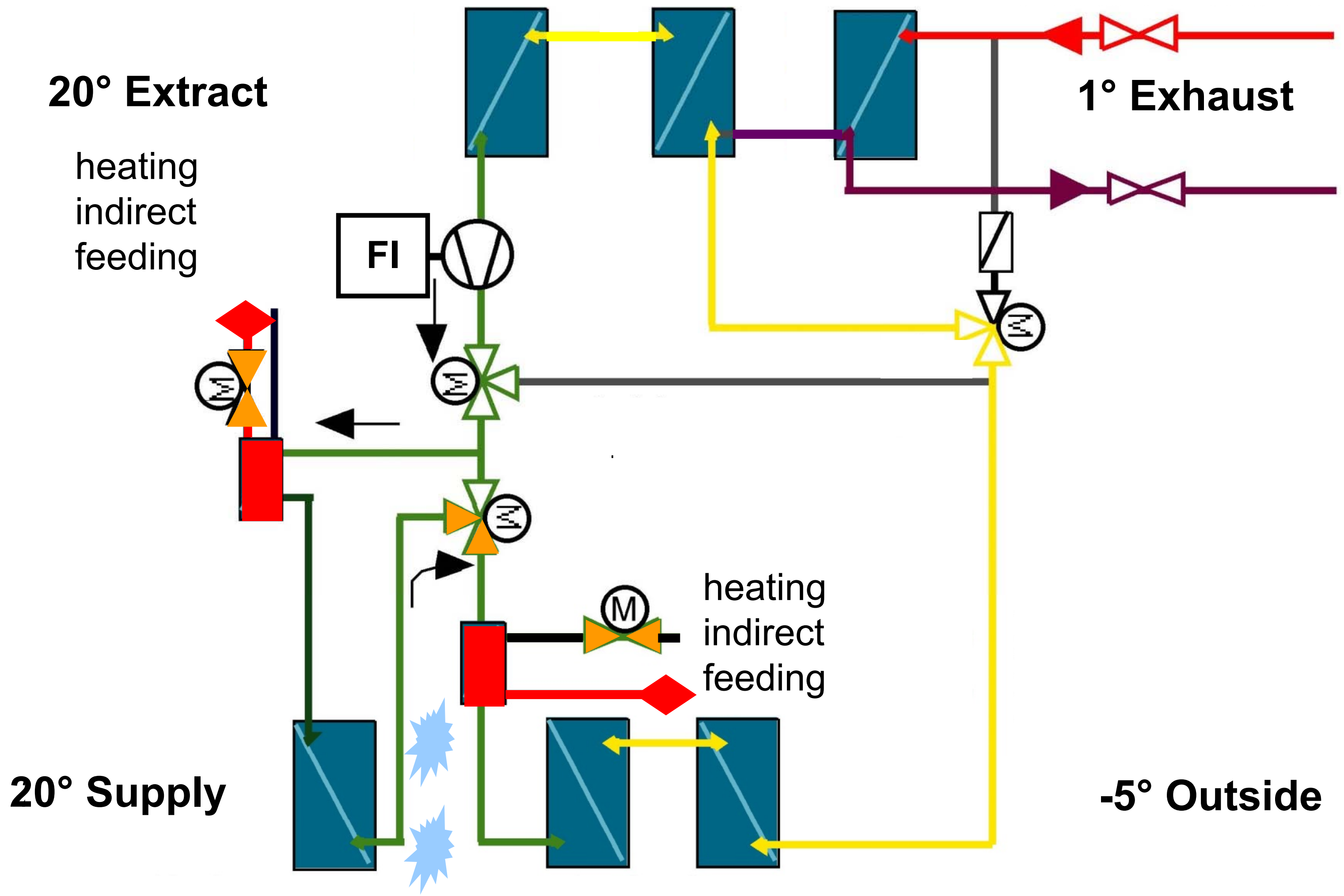
Winter operation with heating



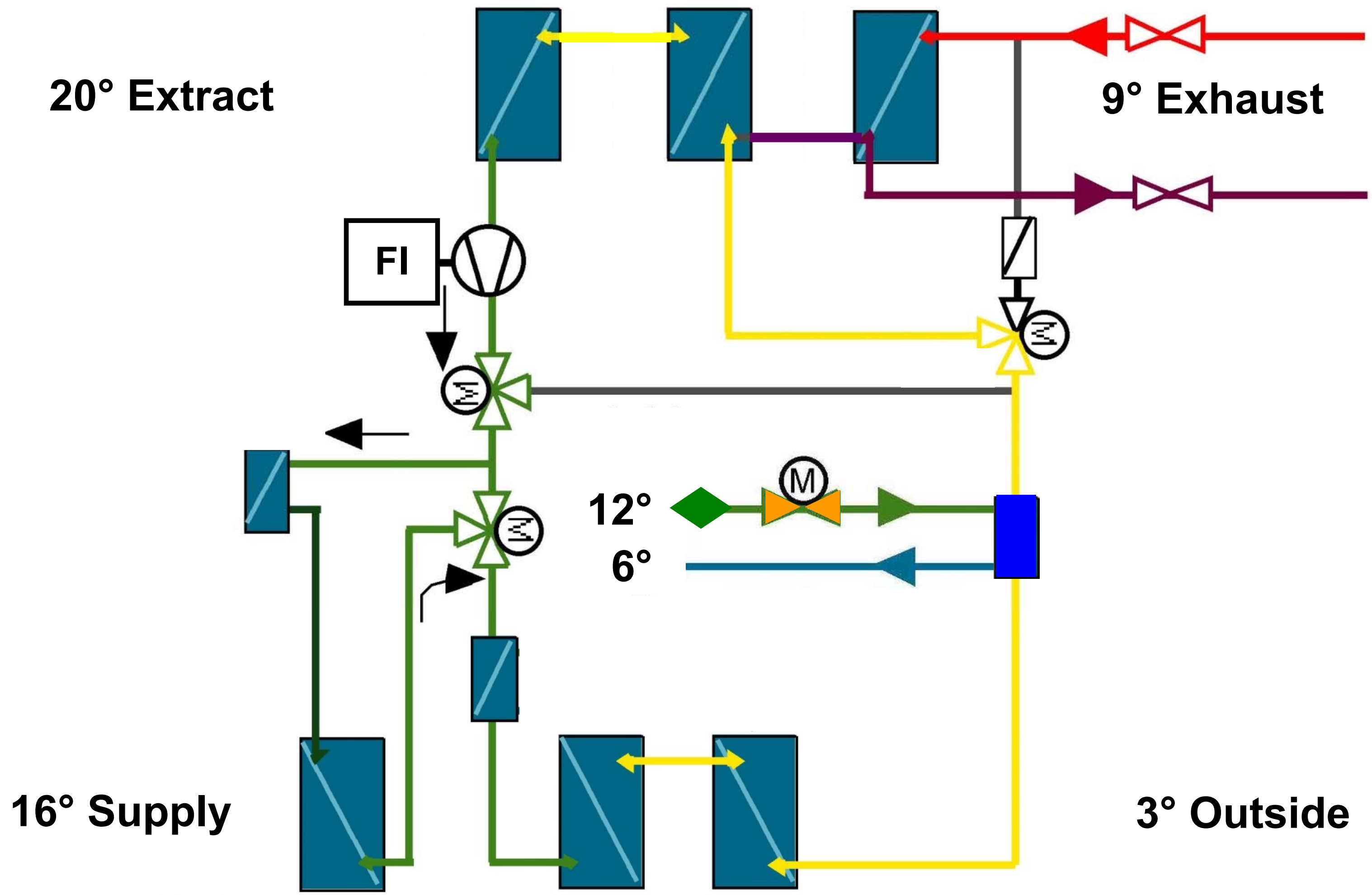
Winter with heating and de-ice

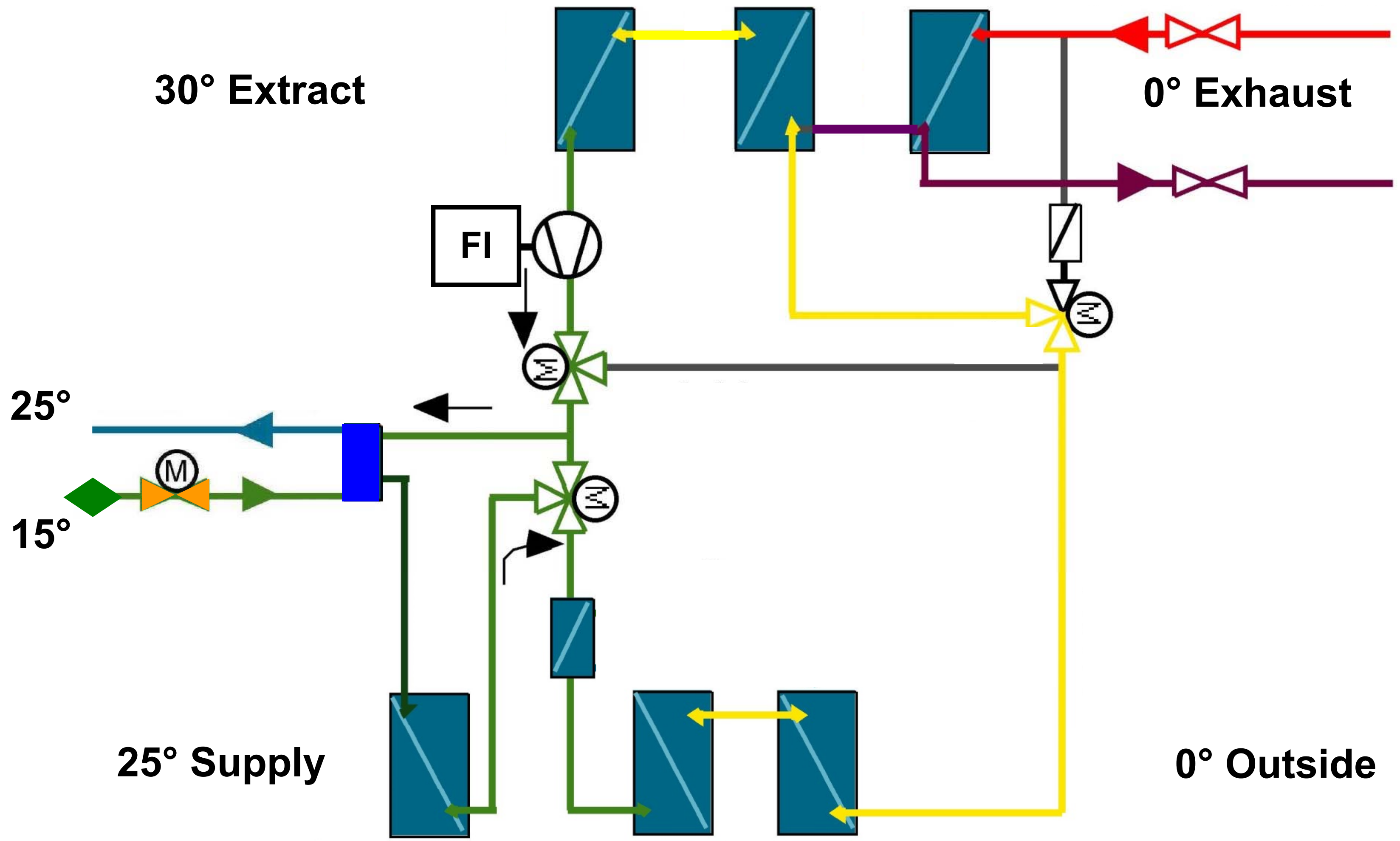


Winter operation with humidifying

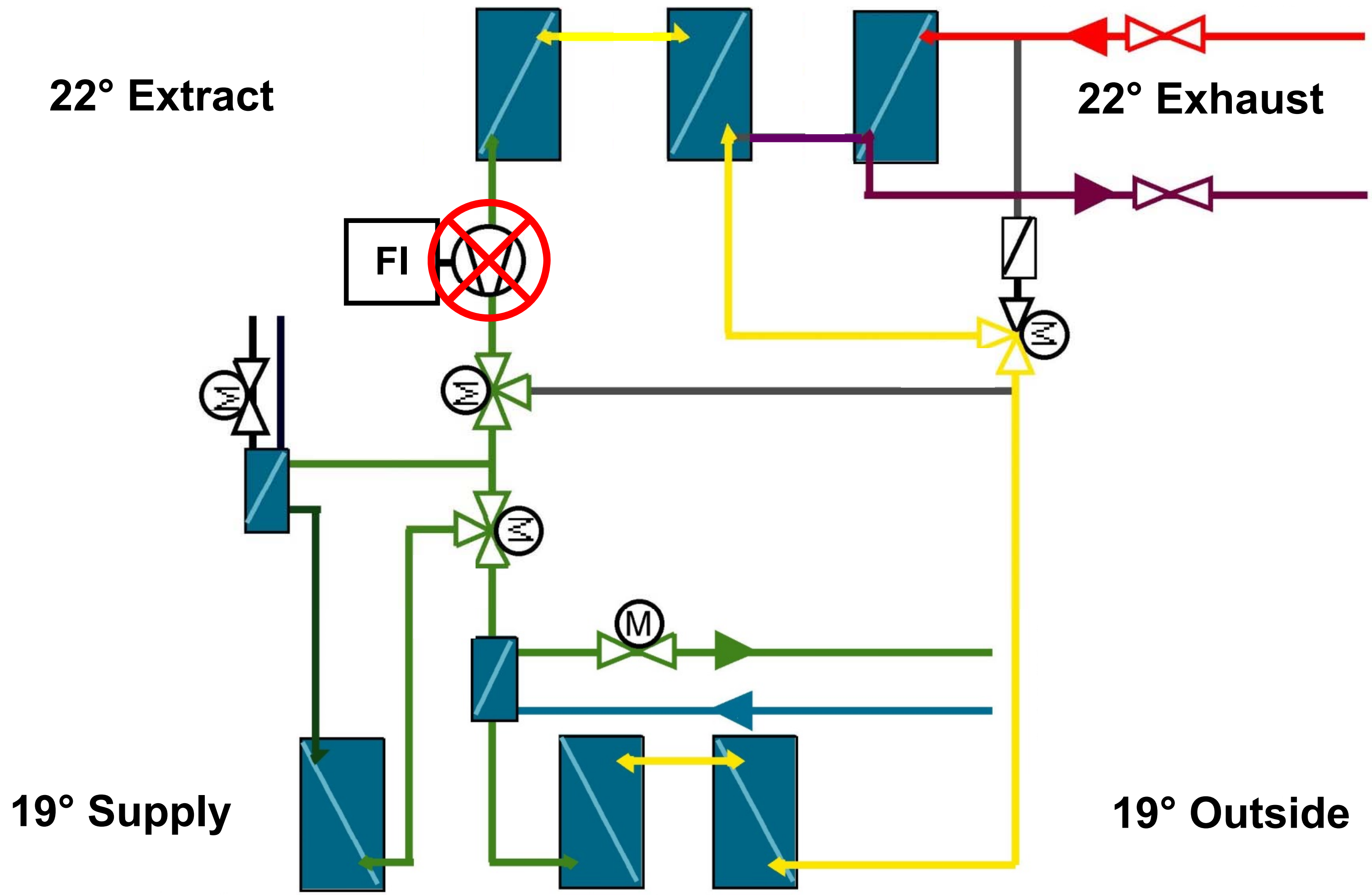


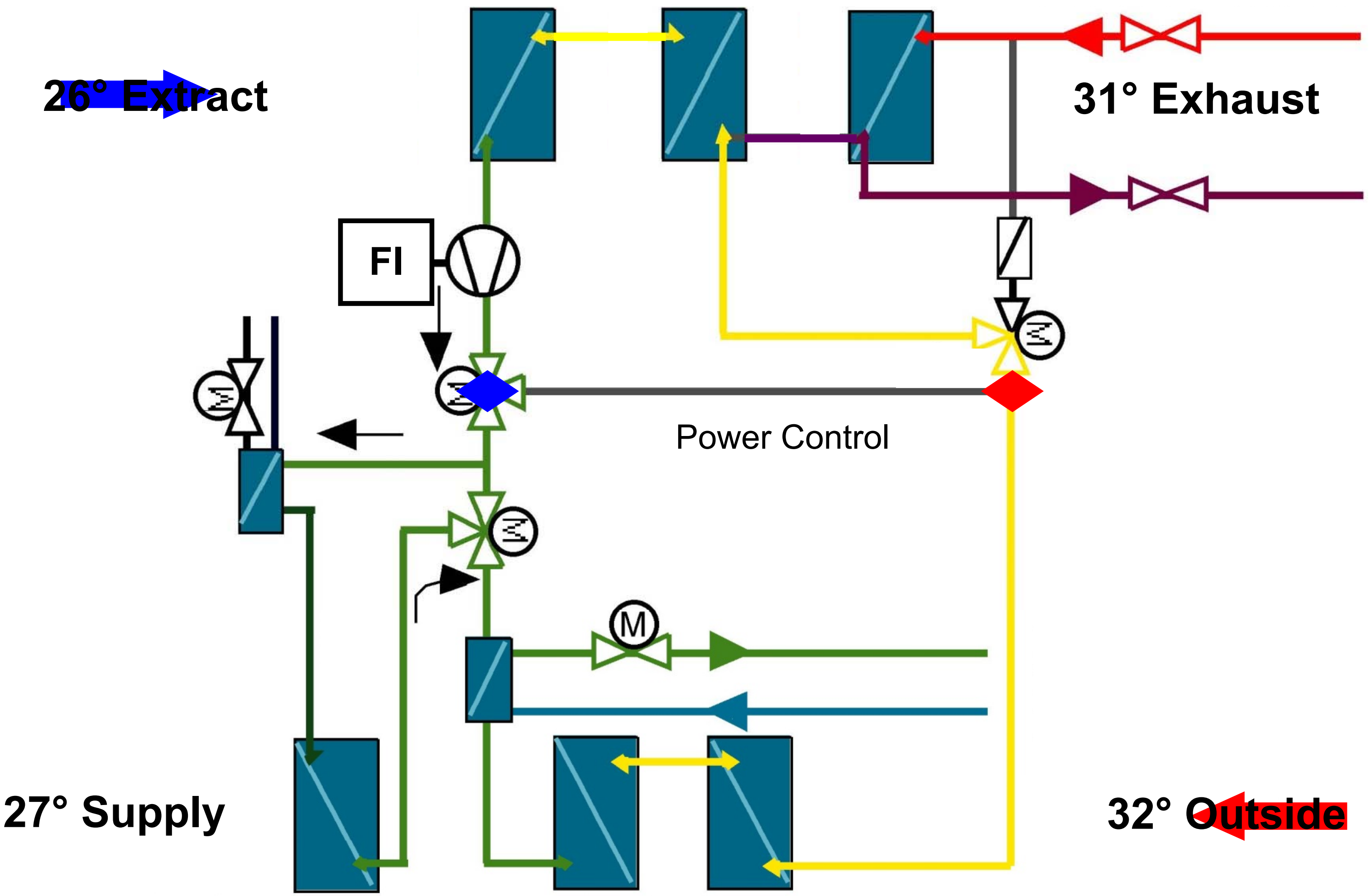
Free cooling




30° Extract
0° Exhaust
FI
25°
15°
M
25° Supply
0° Outside

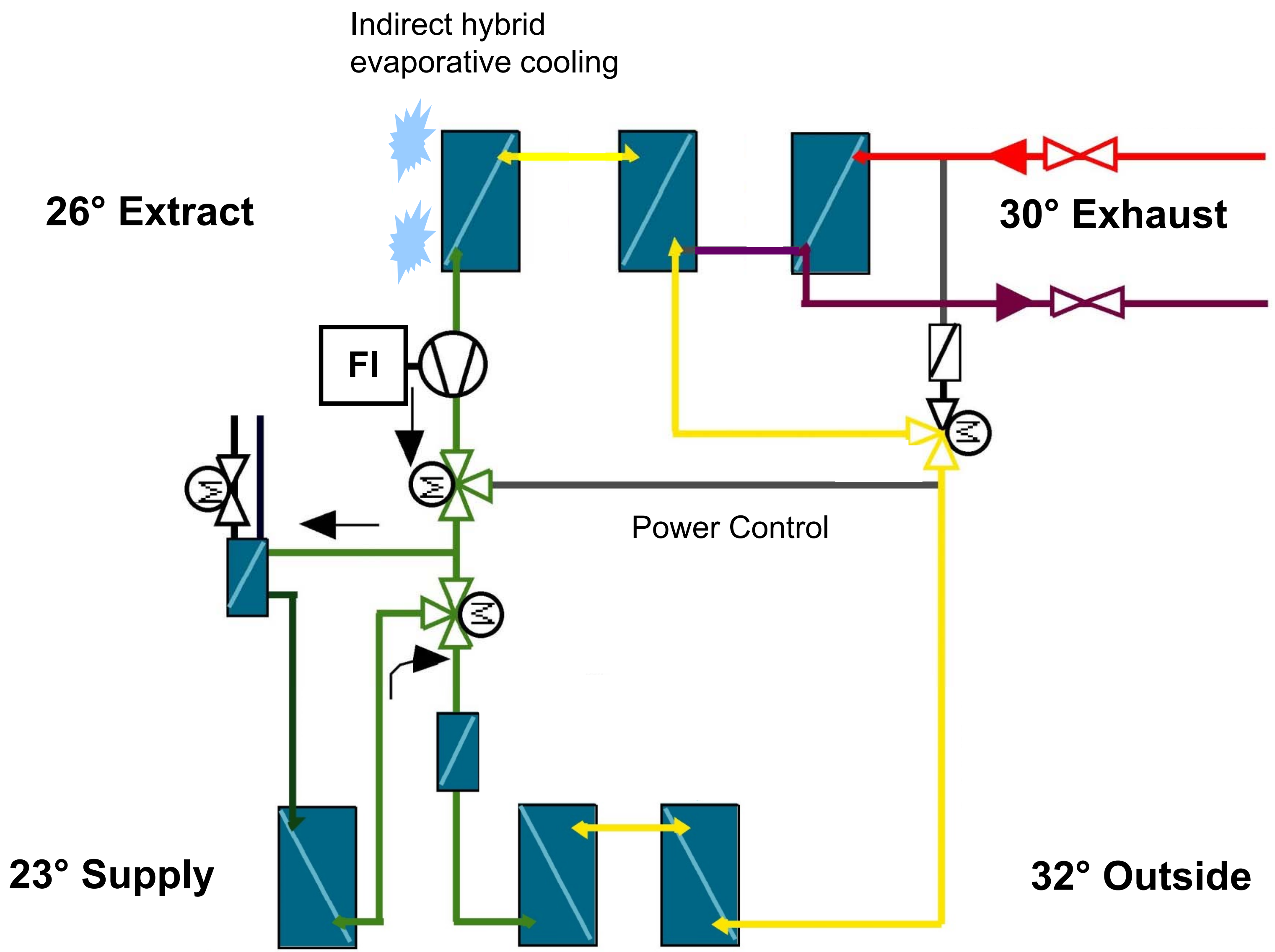
Transition operation



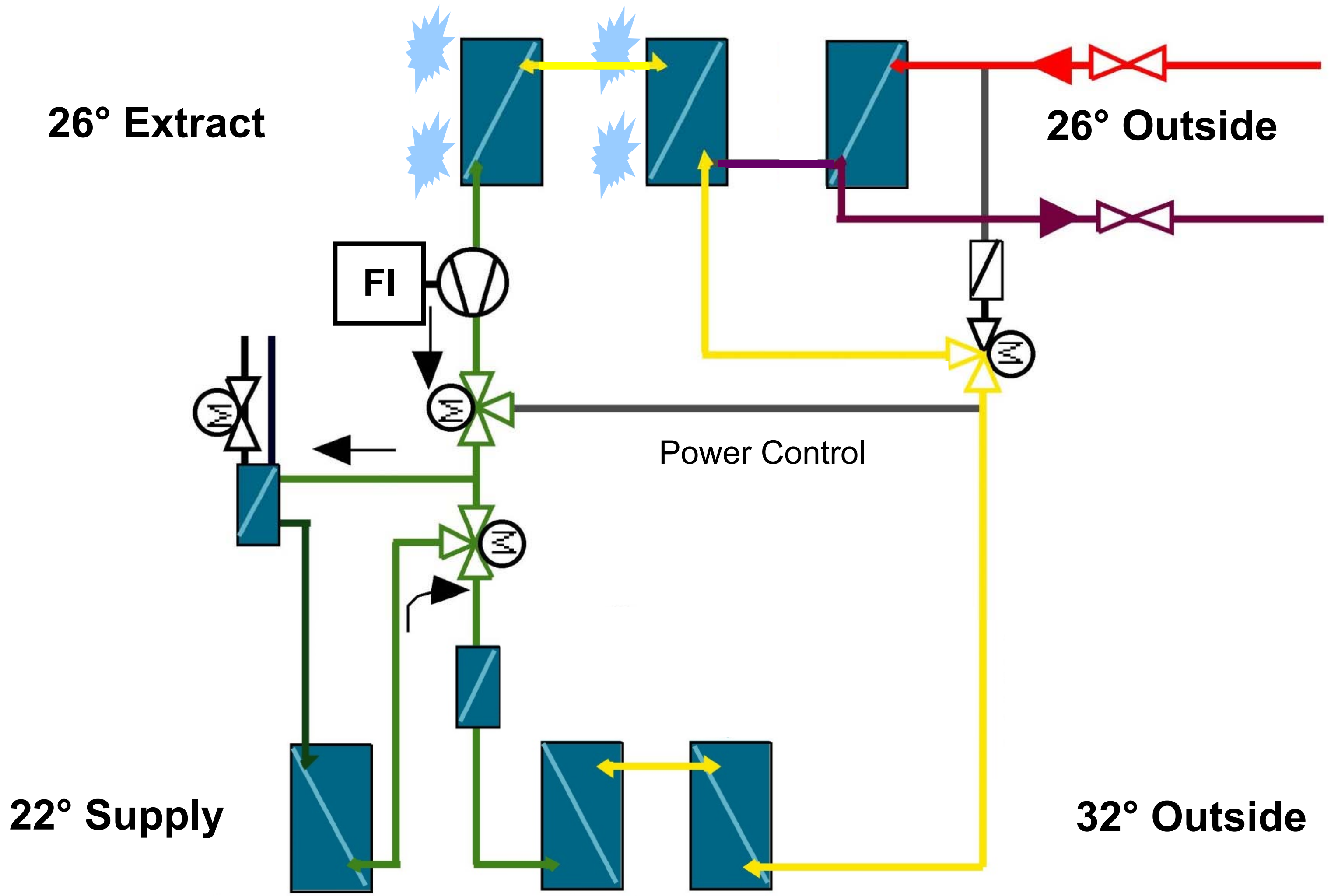

26° Extract
31° Exhaust
FI
M
Power Control
27° Supply
32° Outside

Hybridsystem

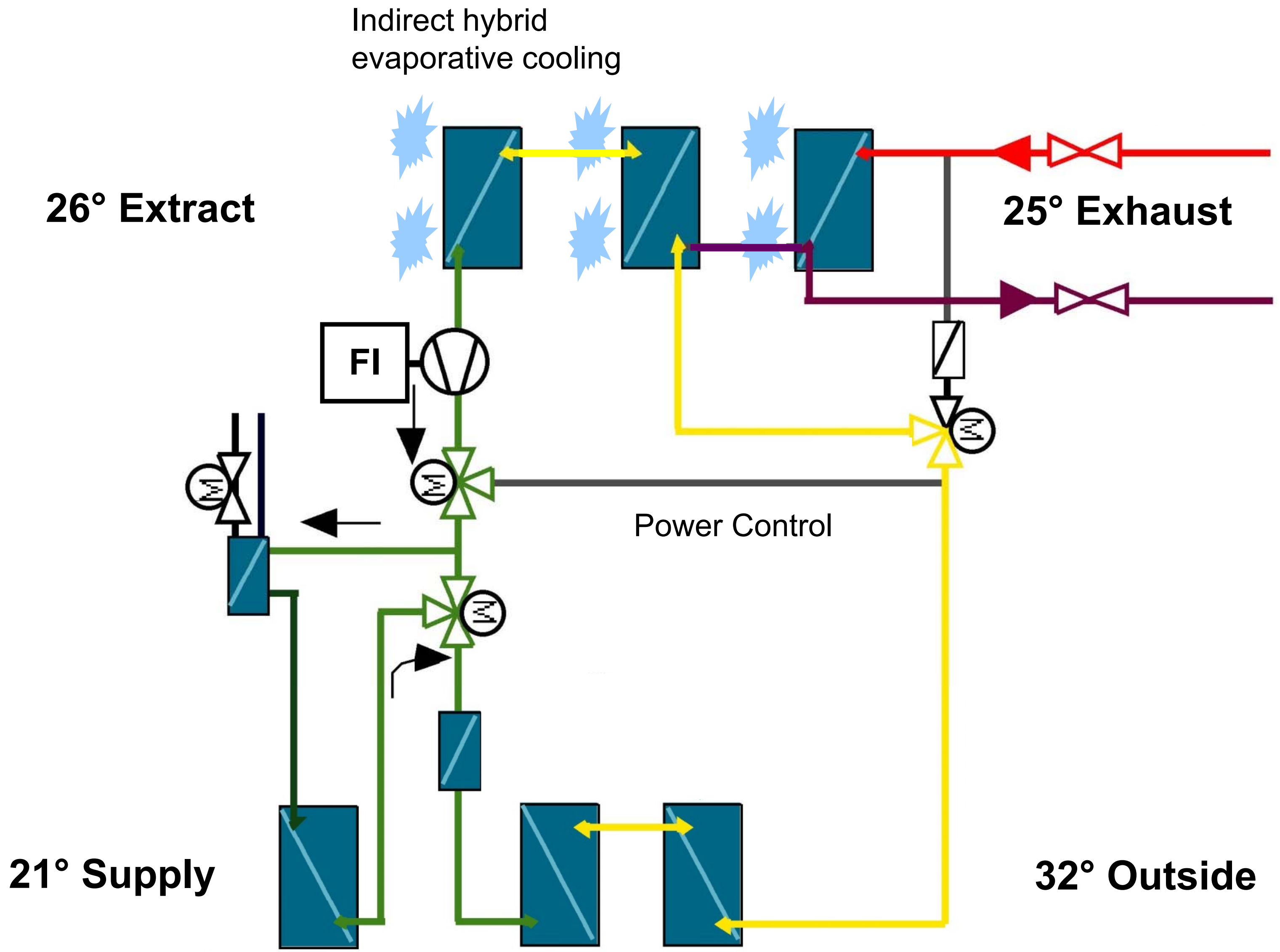
Summer with 1 hum. stage



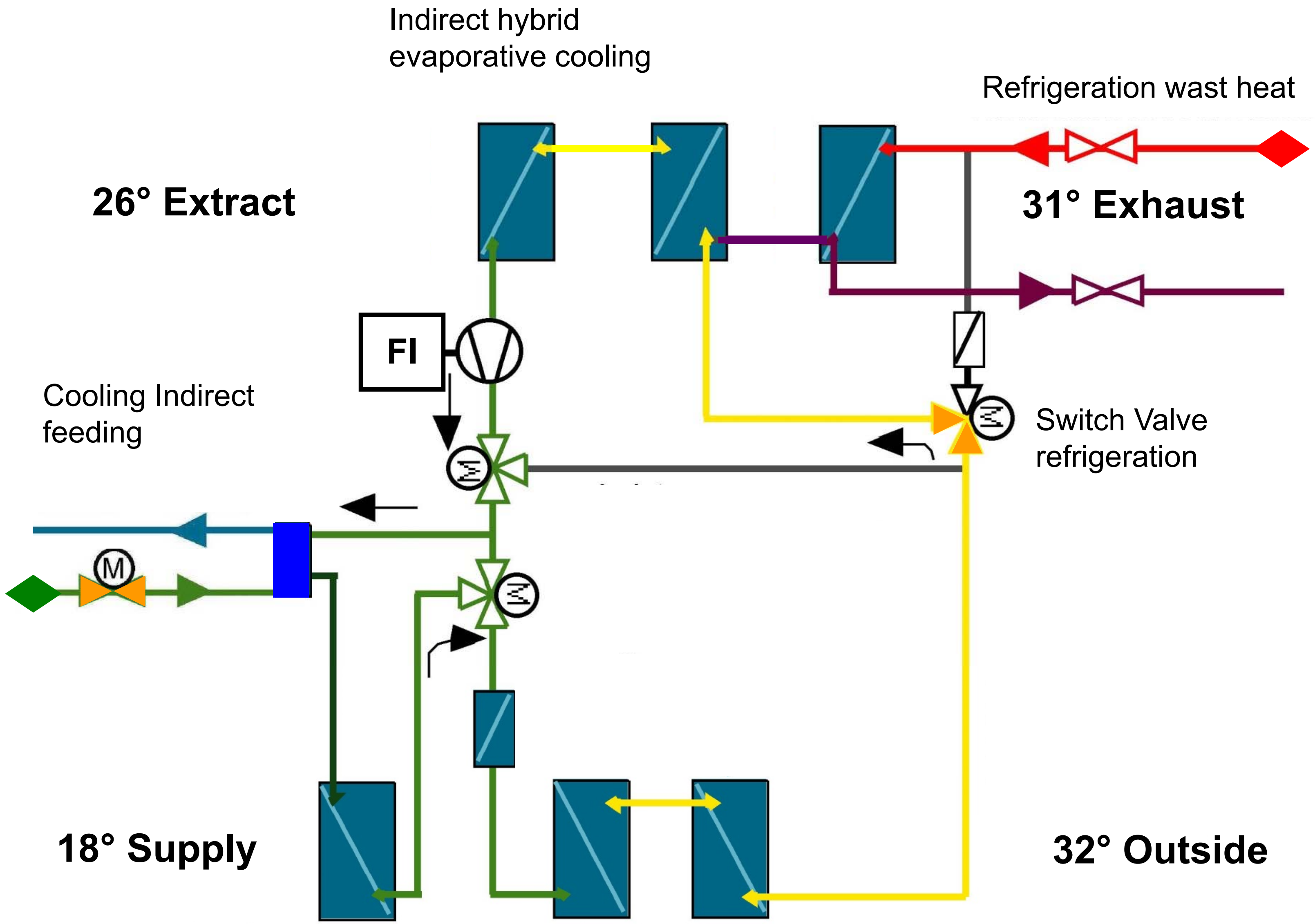
Summer with 2 hum. stages



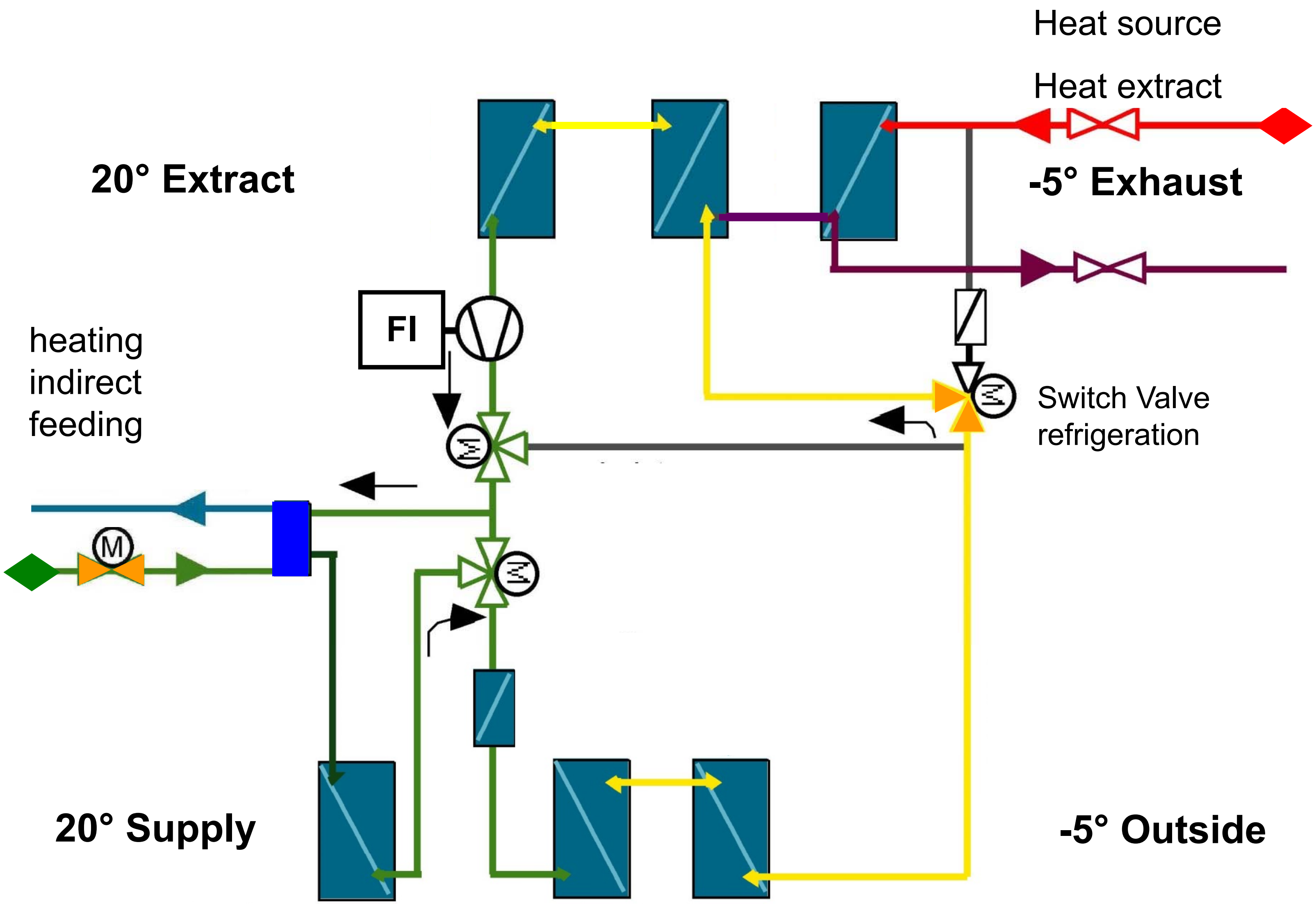
Summer with 3 hum. stages

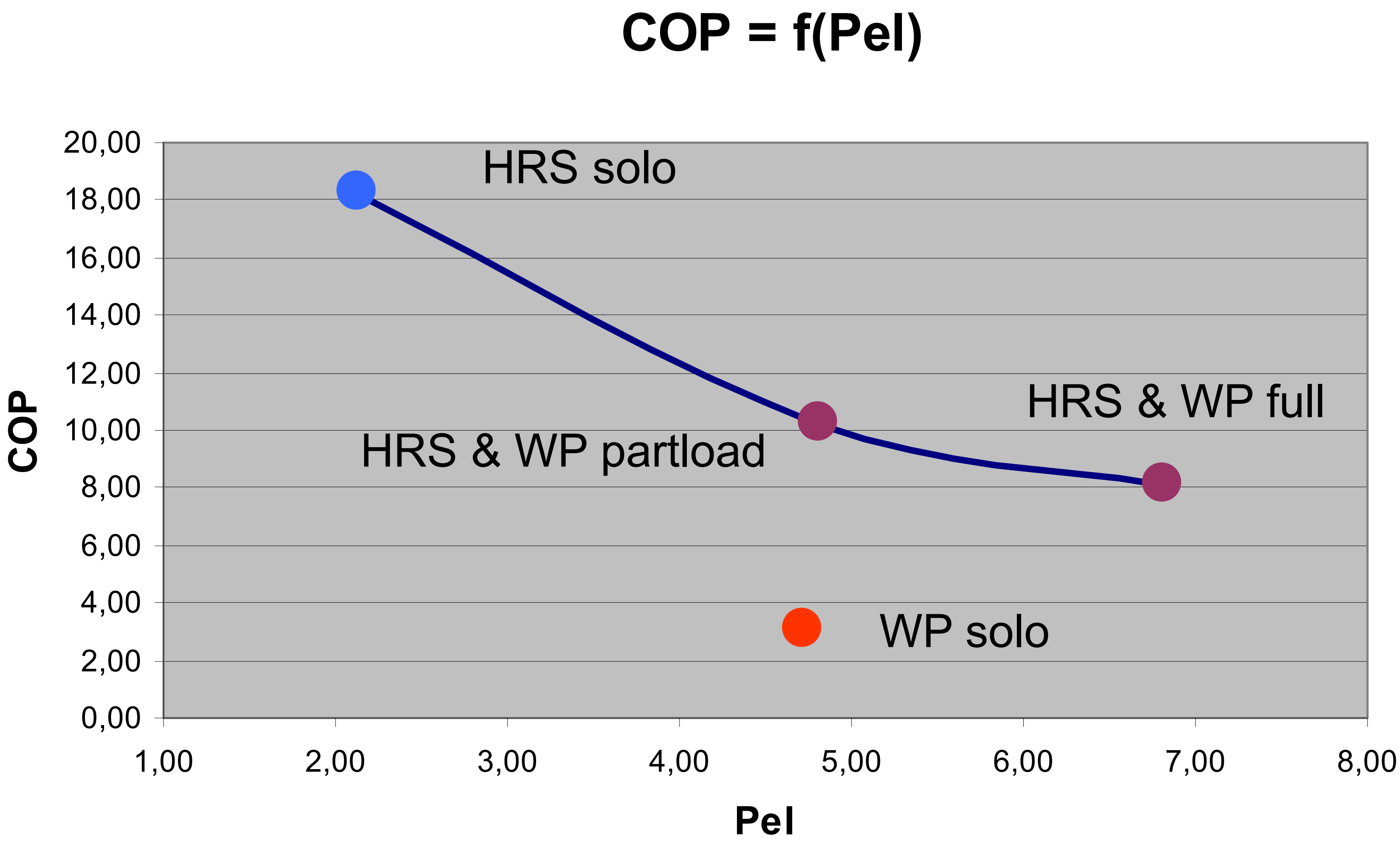


Cooling and refrigerator wast heat



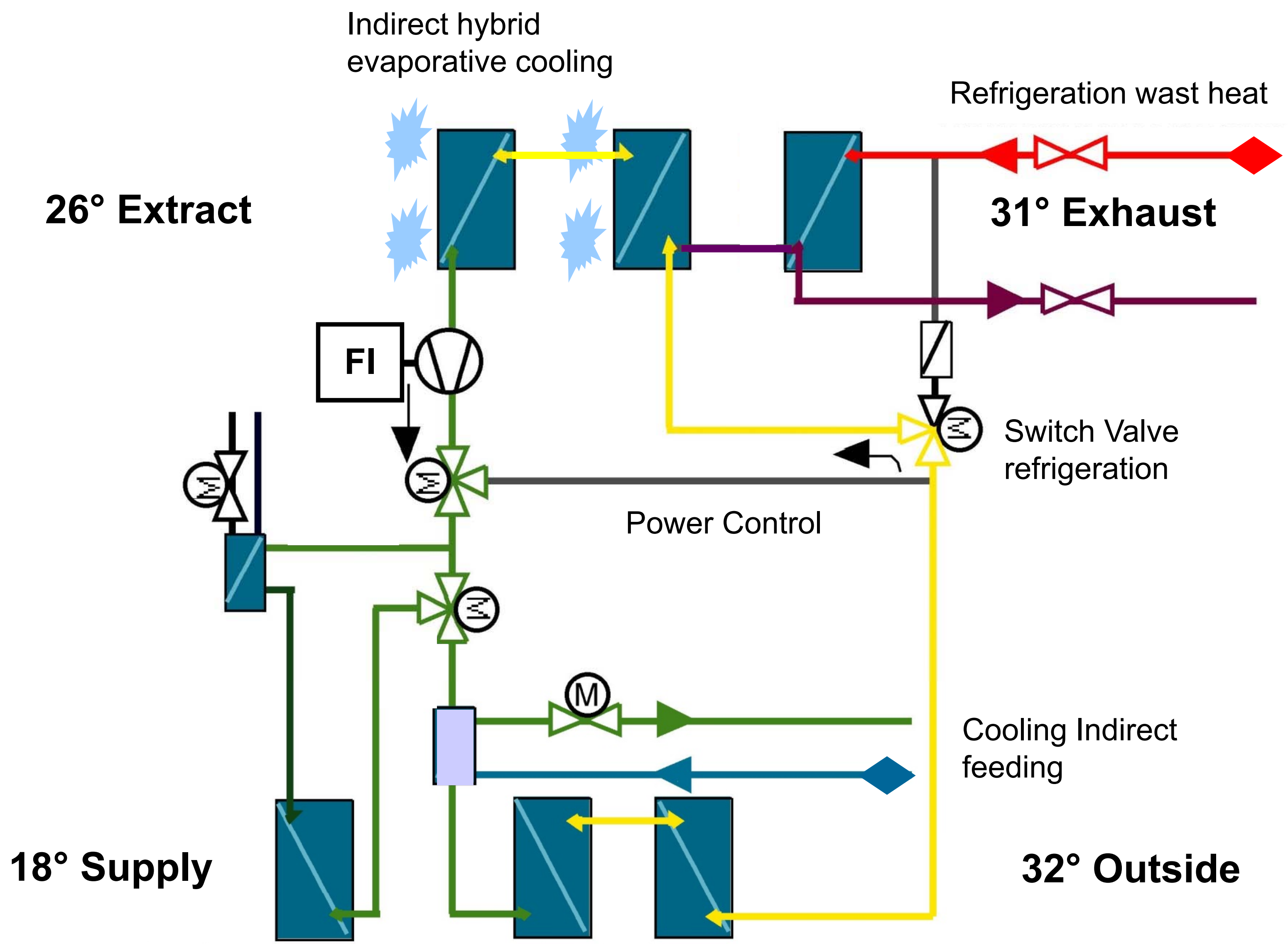
Heatpump operation




COP = f(Pel)
20,00
18,00
16,00
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
COP
1,00
2,00
3,00
4,00
5,00
6,00
7,00
8,00
Pel
HRS solo
HRS & WP full
HRS & WP partload
WP solo

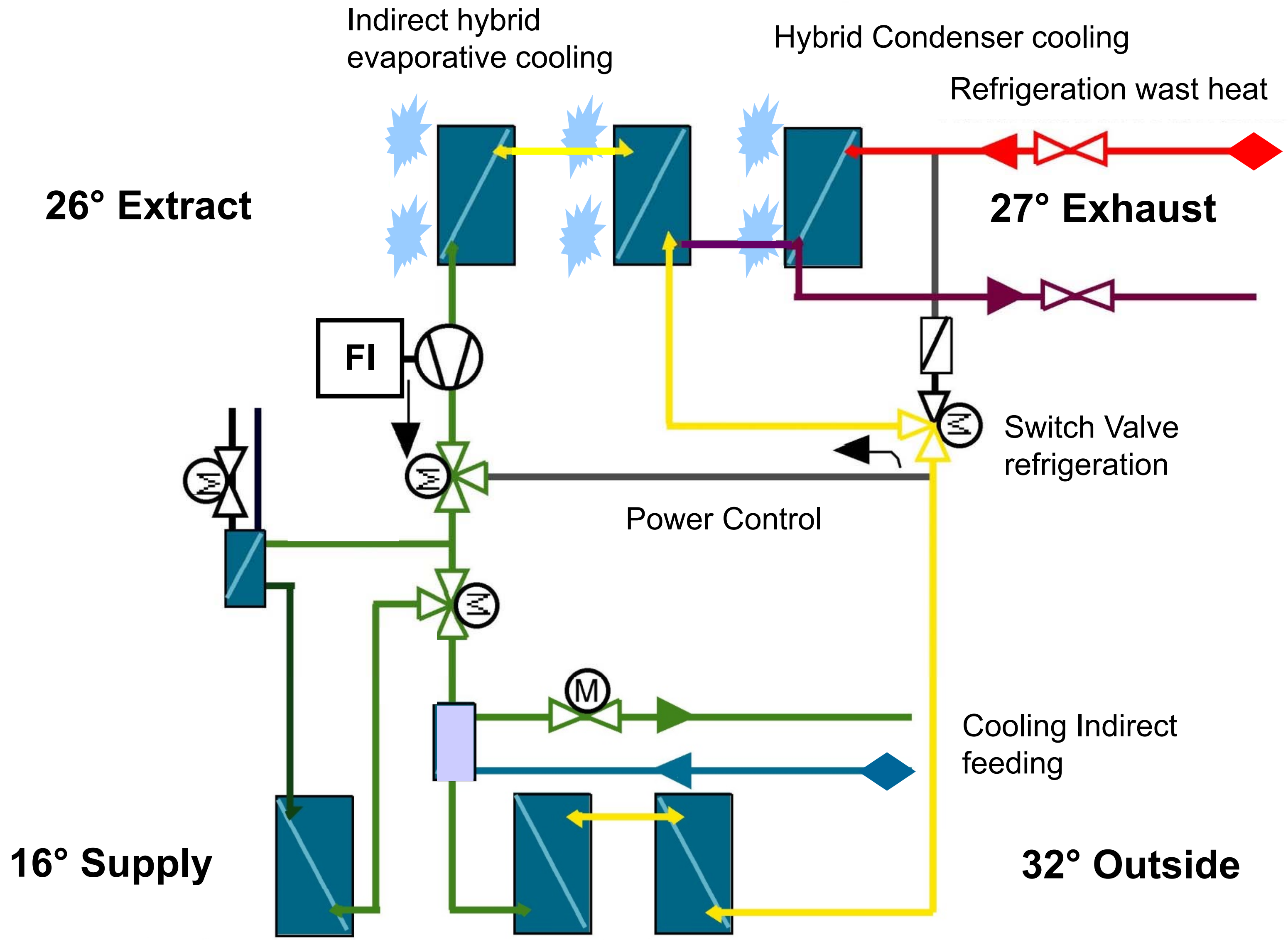
Cooling and refrigerator wast heat

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



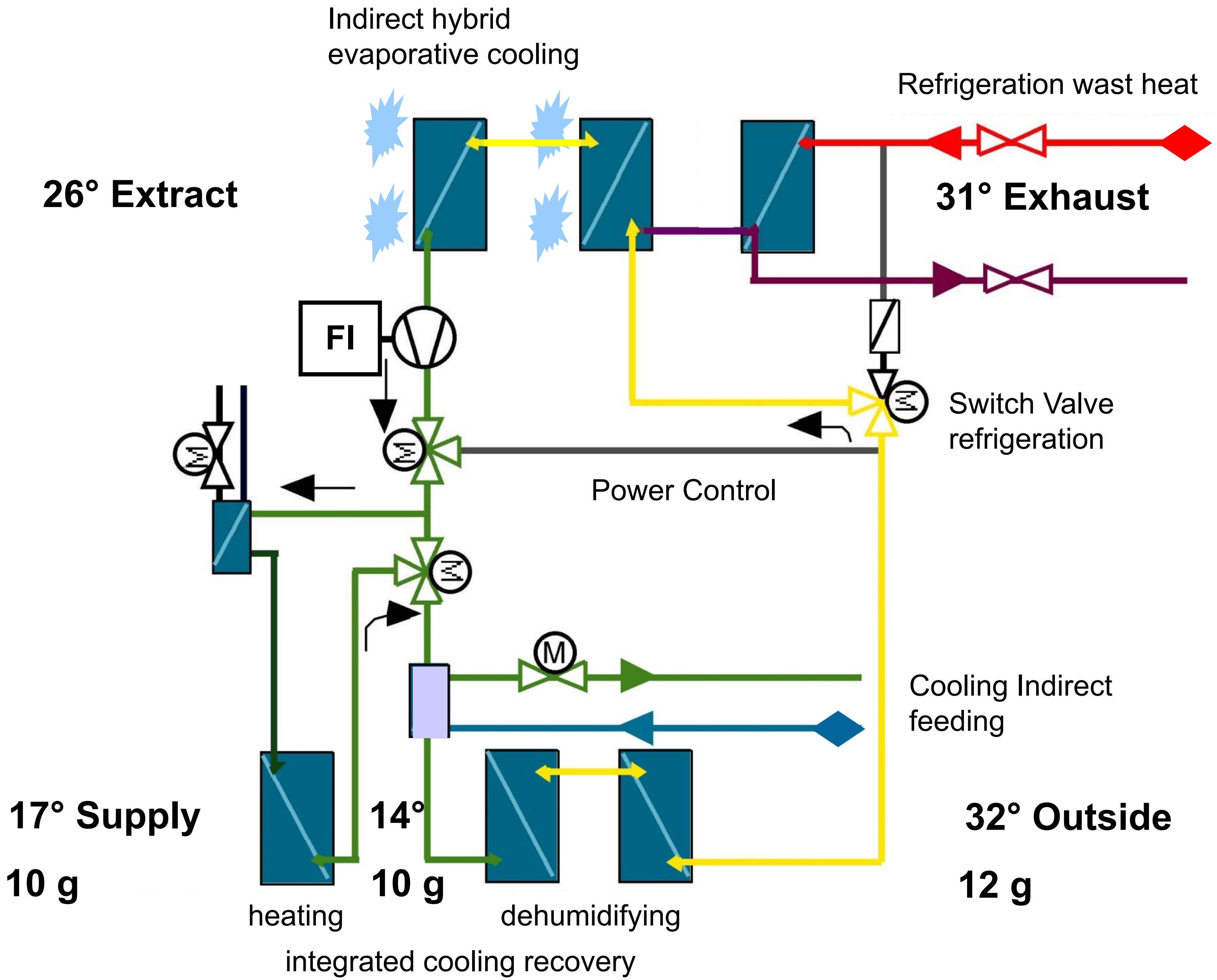
Hybride Refrigerator waste heat

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



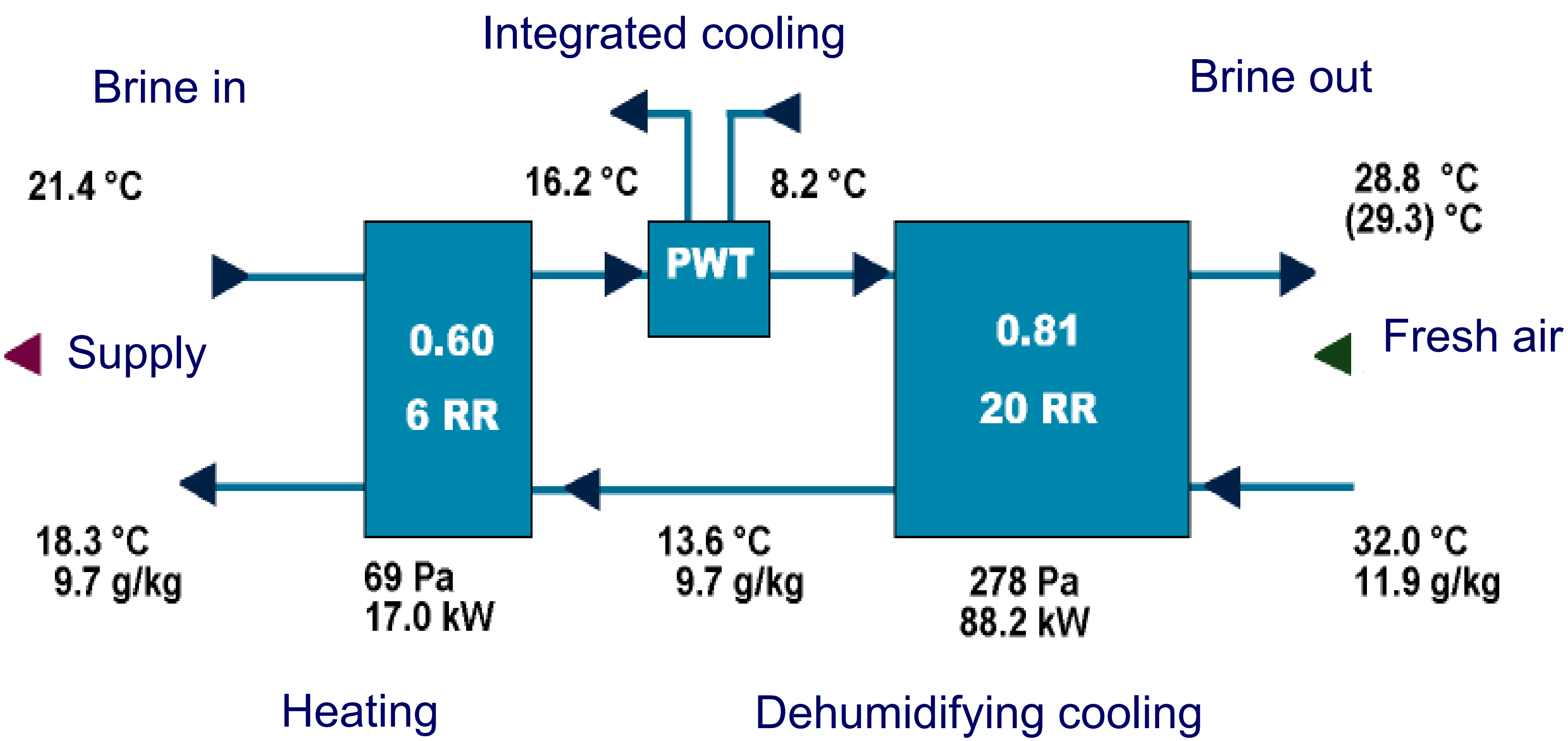
Dehumidifying circuit

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



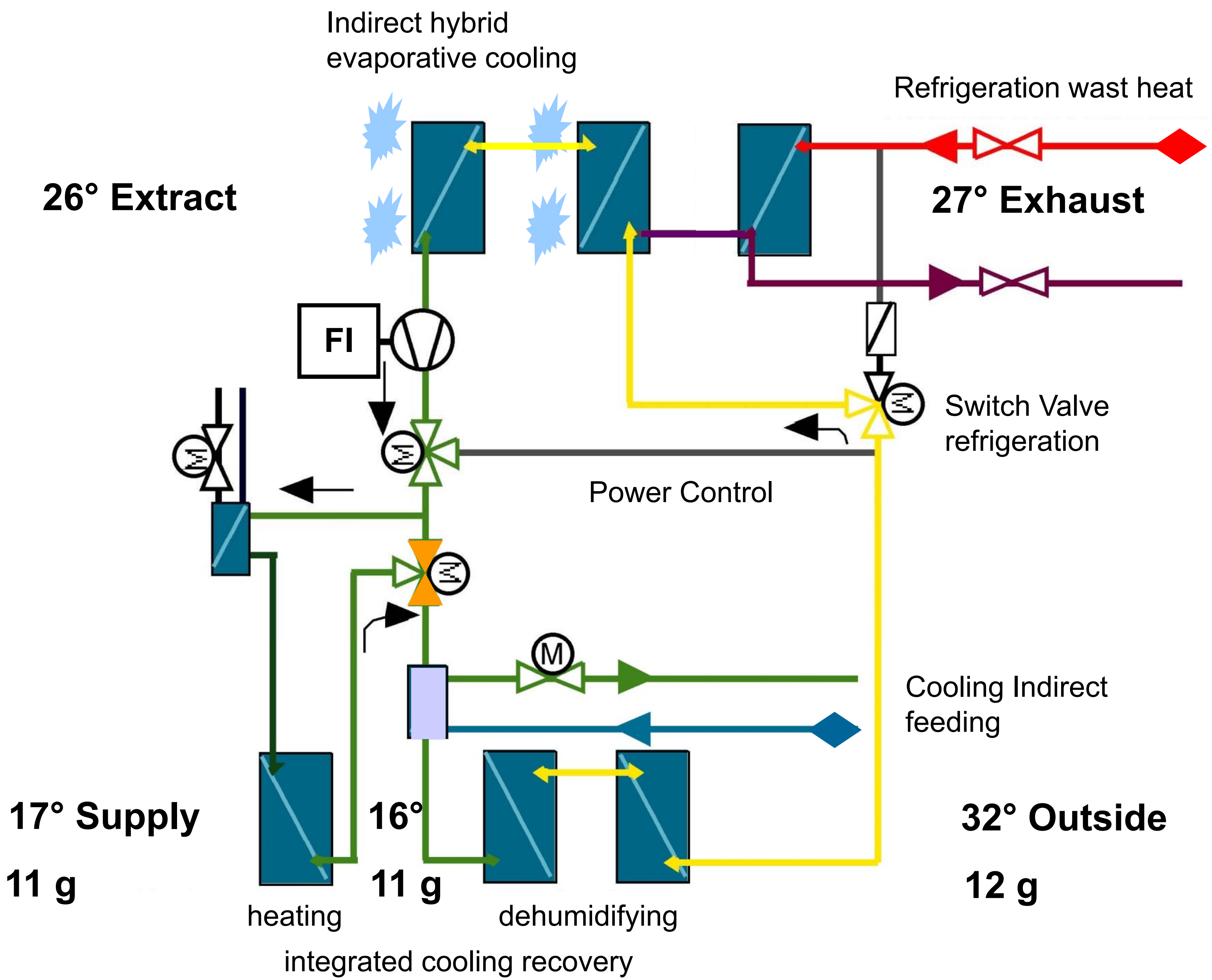
Dehumidifying circuit

HRC Supply side



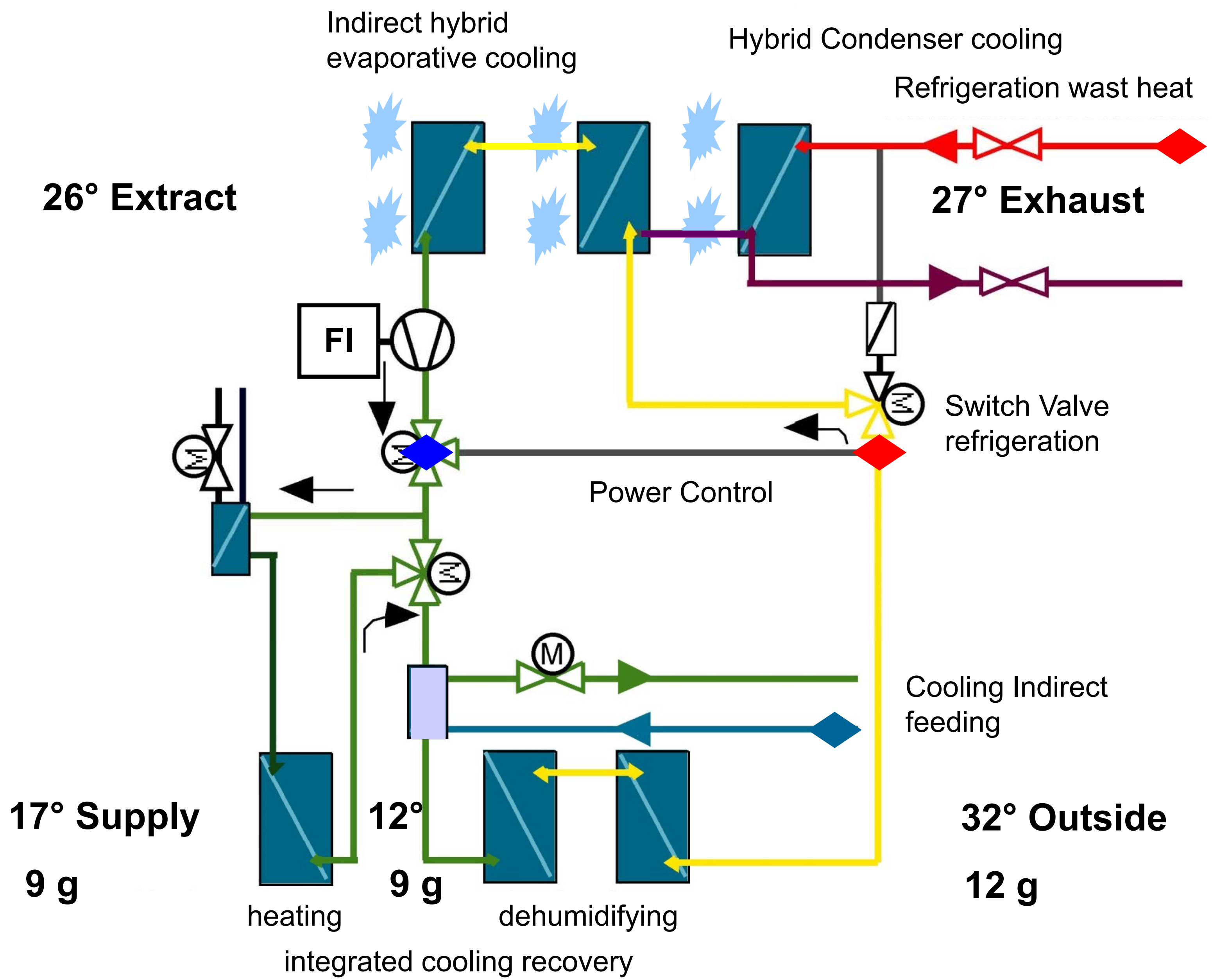
• Evaporative cooling	35.7 kW
• Recovery dehumidifying cooling	17.0 kW
• Additionall cooling	35.5 kW
• Air flow	10.000 m³/h

Dehumidifying circuit

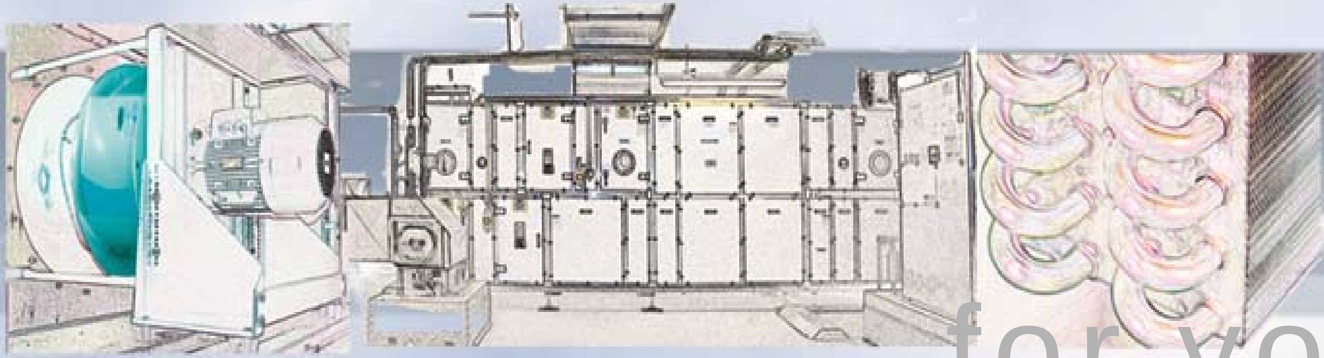


All functions

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld



Thank you very much



for your Attention

Multifunctional heatrecovery systems

Energy recovery in air handling units with high performance heatrecovery based on cycle compound system

Prof. Dr.-Ing. **Christoph Kaup**
c.kaup@umwelt-campus.de

HOCHSCHULE TRIER
Umwelt-Campus Birkenfeld
Umwelt macht Karriere.