HVAC Systems for Hyper-Efficient Buildings (a.k.a Passive) based on ASHRAE Journal May 2019

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Introduction

- Originated back in the 70s from super-insulated house movement in US and Canada
- Used mostly at first for single family attached dwellings has now moved to high rise residential buildings and small commercial buildings
- Most know is PHI (Germany) and PHIUS (US)

Hyper Efficient

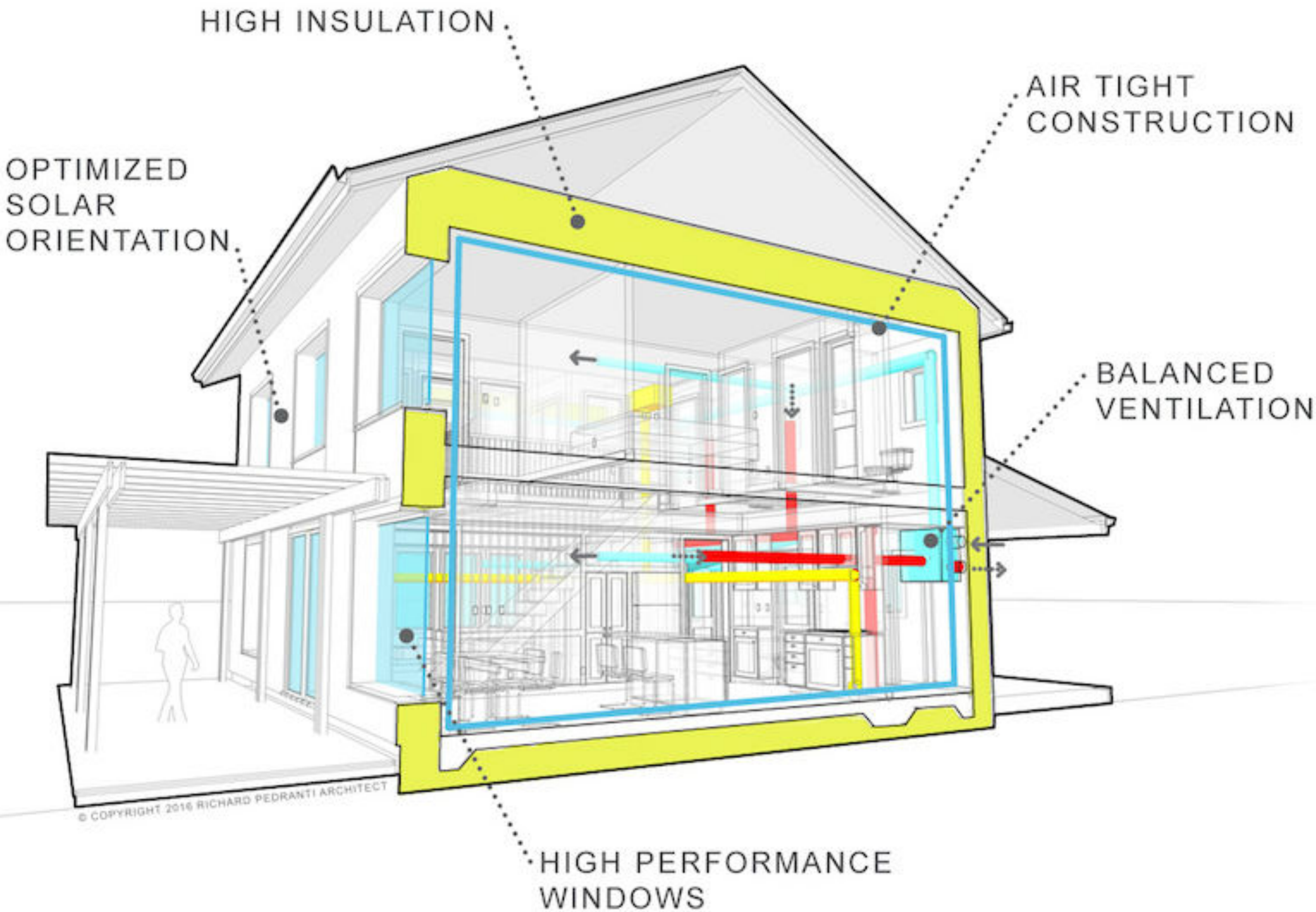
- Because the required calculated source energy use intensity (EUI), is far below that of conventional buildings and is comparable to the net zero ready building classification.

Introduction

- Super insulated Buildings
- Airtight (minimize infiltration)
- Triple Glazing
- Air Handling Units/ Mechanical Ventilation
- Zero Thermal Bridges

PHI -PHIUS

- **1.** The **Space Heating Energy Demand** is not to exceed 15 kWh per square meter of net living space (treated floor area) per year or 10 W per square meter peak demand.
- In climates where active cooling is needed, the **Space Cooling Energy Demand** requirement roughly matches the heat demand requirements above, with an additional allowance for dehumidification.
- **2.** The Renewable **Renewable Primary Energy Demand (PER, according to PHI method),** the total energy to be used for all domestic applications (heating, hot water and domestic electricity) must not exceed 60 kWh per square meter of treated floor area per year for Passive House Classic. .
- **3.** In terms of **Airtightness**, a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states).
- **4.** Thermal **comfort** must be met for all living areas during winter as well as in summer, with not more than 10 % of the hours in a given year over 25 °C. For a complete overview of general quality requirements (soft criteria)


HIGH INSULATION
AIR TIGHT CONSTRUCTION
OPTIMIZED SOLAR ORIENTATION
BALANCED VENTILATION
HIGH PERFORMANCE WINDOWS
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Data

- Insulation 20cm U< 0,15 W/m^2 K
- Glazing triple U< 0,9…0,7 W/m^{2}K
- Mechanical Ventilation with 80-90% Heat Recovery
- Airtightness with Blowerdoor (50Pa)

Requirements- Limitations

- HRV- ERV
- Max Fan Energy Absorbed
- Annual Heating+Cooling Demand
- Airtightness
- Annual EUI of the building (Energy Use Intensity)

Complexity

- The reality of providing comfort conditioning (ASHRAE STD 55) in a building with a very high performance envelope and very low internal heat gains introduces a new level of complexity to HVAC system design for the project.

“Malfunctions”

- LOW ventilation Rates (Typically 0.3 ACH which is far lower than ASHRAE standard 62.1 and 62.2)

- HVAC might seem only as a system to accommodate load reductions

- As a result we have significant problems with Indoor Air Quality, HUMIDITY and Part-Load operation

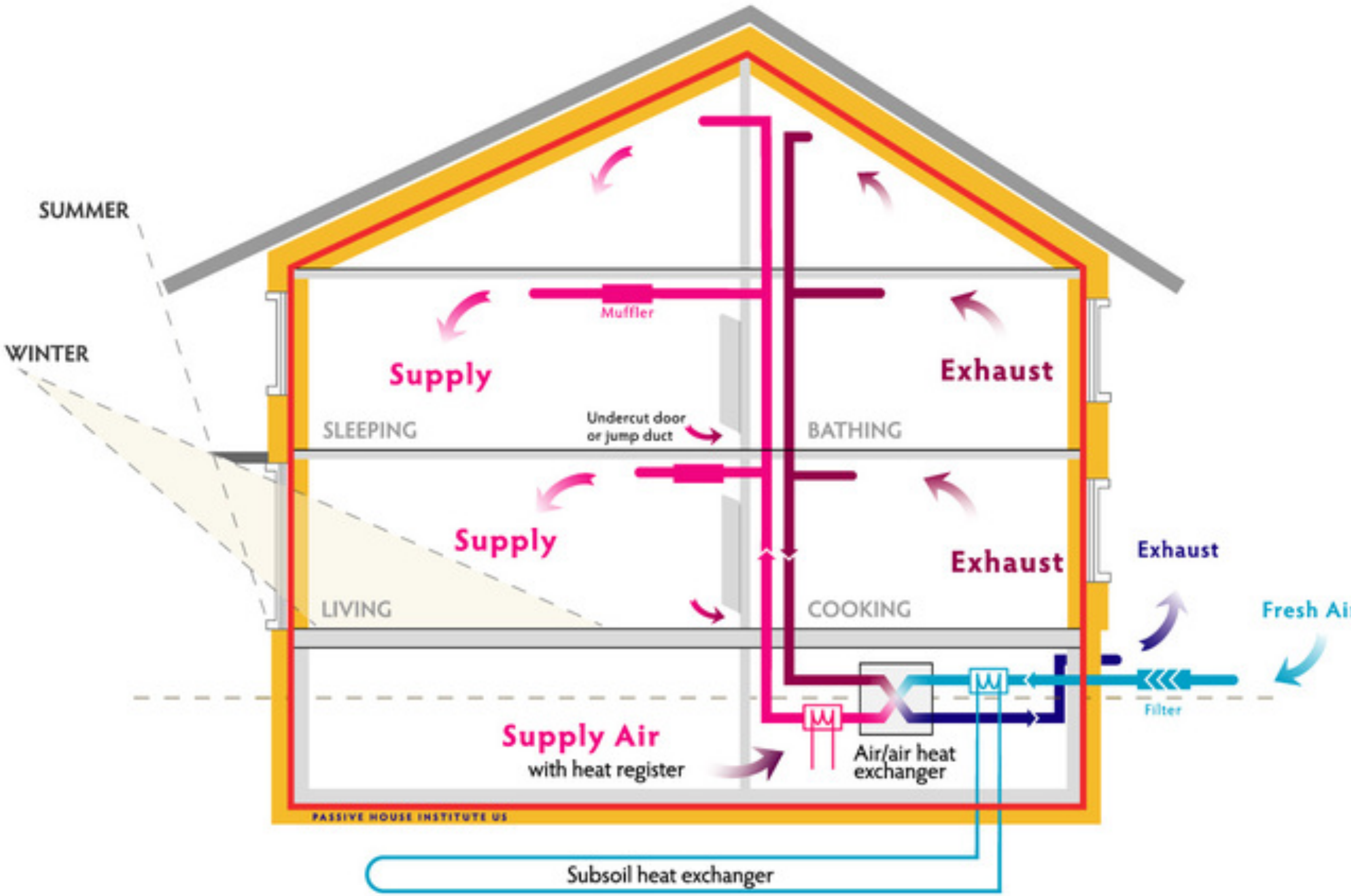
(not so) Energy Efficient Ventilation

- When outdoor air is moderate any conditioning savings may be outweighed from the fan energy from the pressure drop of the heat exchanger

“Balanced” Ventilation

- Exhaust always on for Kitchens and Bathrooms
- Make up air if needed (fireplaces, dryers etc)

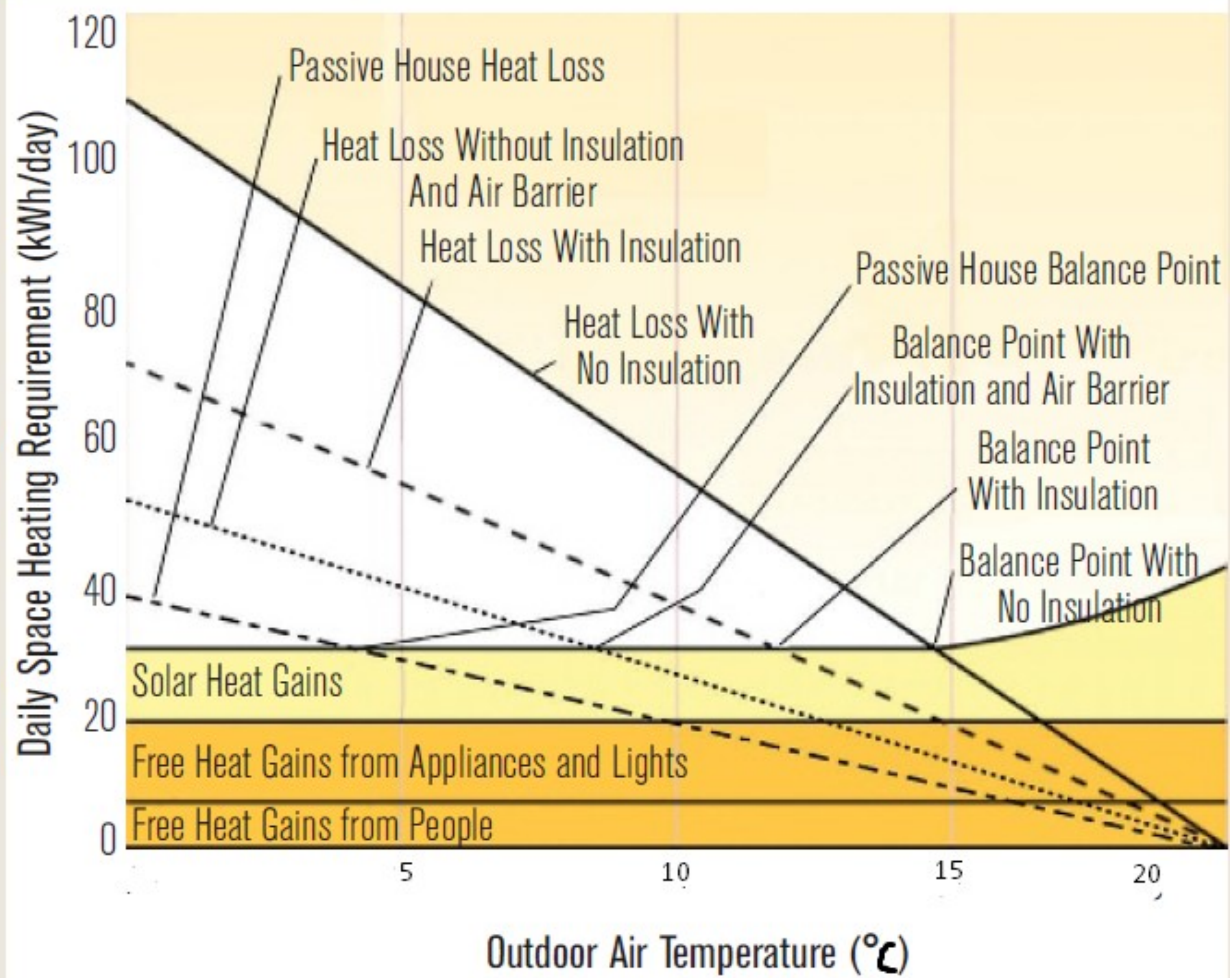
Example


SUMMER
WINTER
Supply
Muffler
Exhaust
SLEEPING
Undercut door
or jump duct
BATHING
Supply
Exhaust
Exhaust
LIVING
COOKING
Fresh Air
Filter
Supply Air
with heat register
Air/air heat
exchanger
PASSIVE HOUSE INSTITUTE US
Subsoil heat exchanger

Design Characteristics

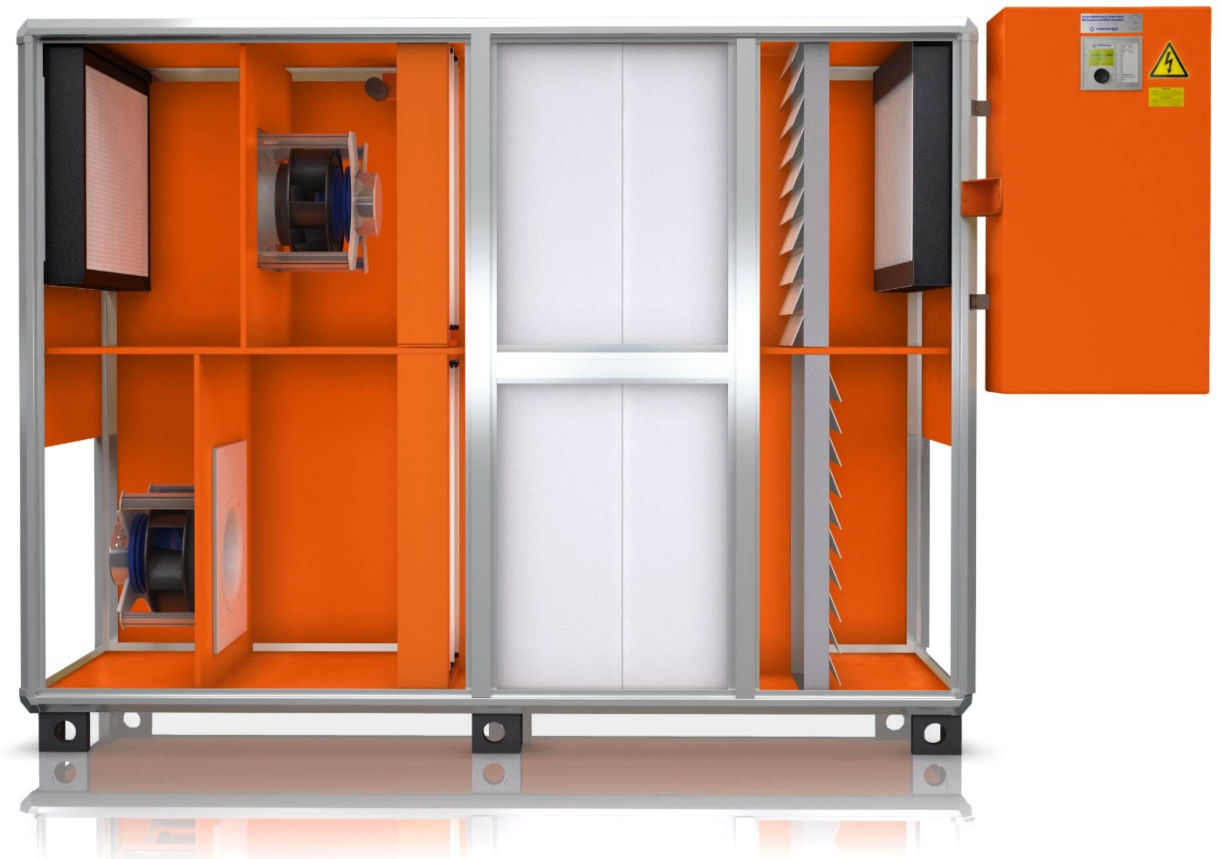
- Very Low Heating/Cooling Loads
- Very Low user equipment power density due to EUI limitations
- Very Low Balance Point Temperature

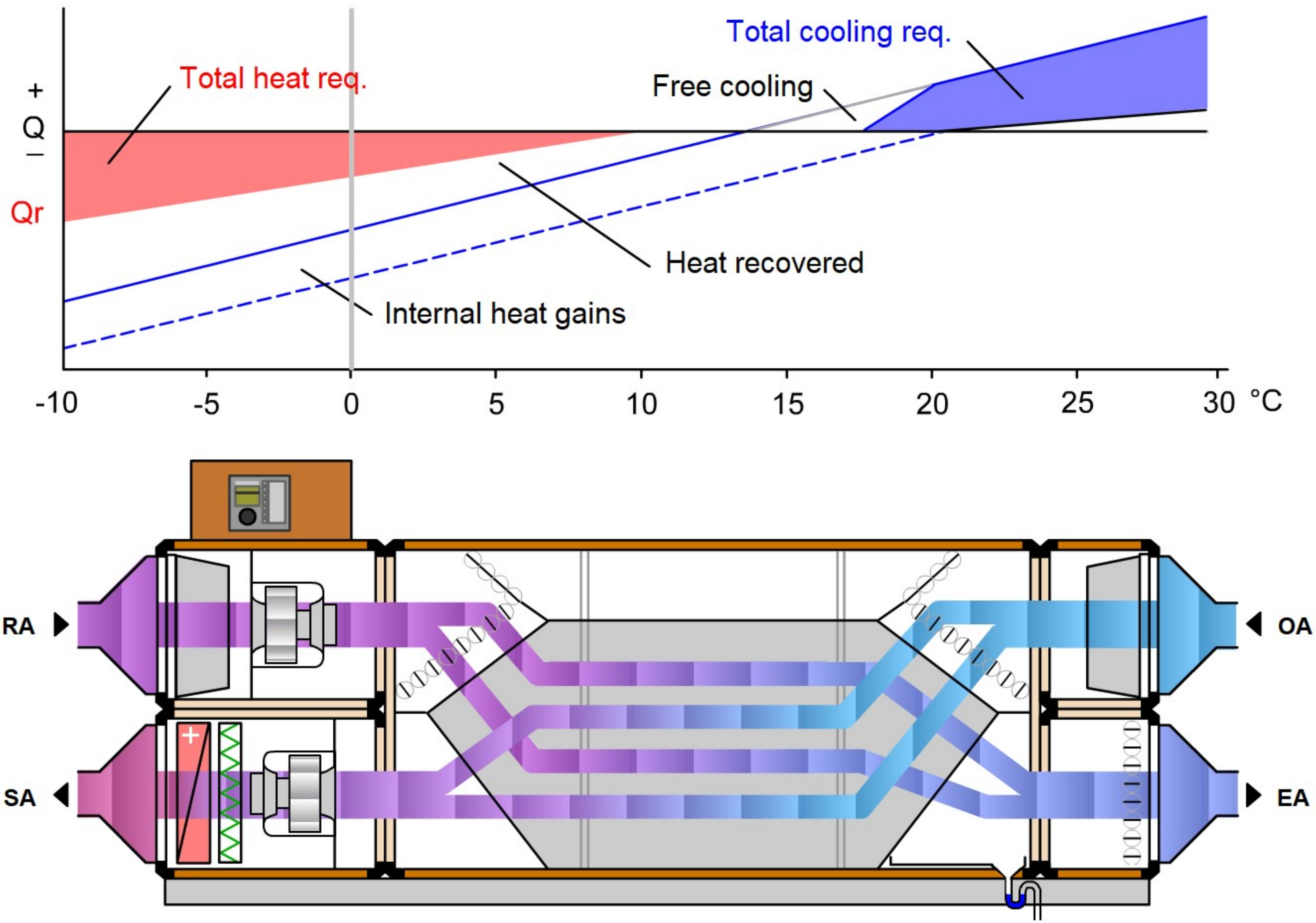
FIGURE 1 Heating requirements for different envelope performance levels as a function of outdoor temperature.



HRV

ERV




Total cooling req.
Total heat req.
Free cooling
+
Q
–
Qr
Heat recovered
Internal heat gains
-10
-5
0
5
10
15
20
25
30
°C
RA
SA
OA
EA

Humidity Control- Cooling

- Advanced Insulation/Glazing/airtightness etc can only reduce Sensible Loads
- Internal **Latent loads** + Ventilation need to be taken into serious consideration which may be HIGHER than sensible.
- So SHR (Sensible Heat Ratio) will be very low

  SHR = Sensible Cooling Load / Total Cooling Load
- Resulting Unacceptably High Indoor Humidity

Humidity Control- Cooling

- Example an apartment 92.9m^2 (1000ft^2) with 2 bedrooms , 2 baths and 1 kitchen and 3 occupants
- PHI- 0,3 ACH
- ASHRAE 62.1 requires 0.65 L/s m^2 plus 2,4 L/s per person for a total 35.3 L/s for the whole apartment
- BUT we also require EXTRACTION 11,8 L/s for each bathroom and 23.6 L/s for each kitchen which sums up to 47.2 L/s or **0.7ACH**

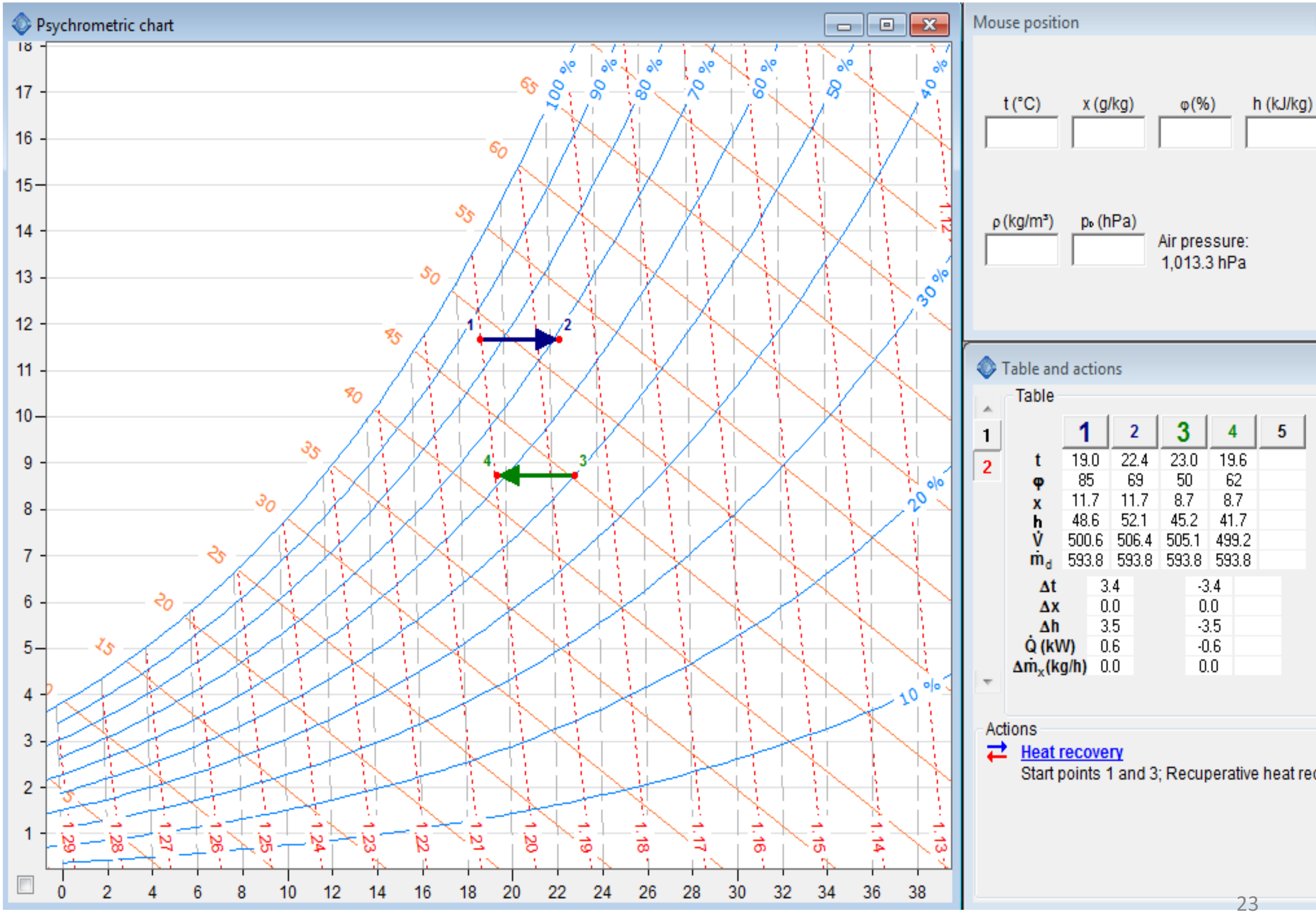
Humidity Control- Cooling

- ASHRAE 62.2 requires 0.33 L/s m^2 plus 3,6 L/s per person BUT we also require EXTRACTION 9,4 L/s for each bathroom and 5 ACH for each kitchen which sums up to 50.5 L/s

Space conditions Resulting Different Ventilation protocols

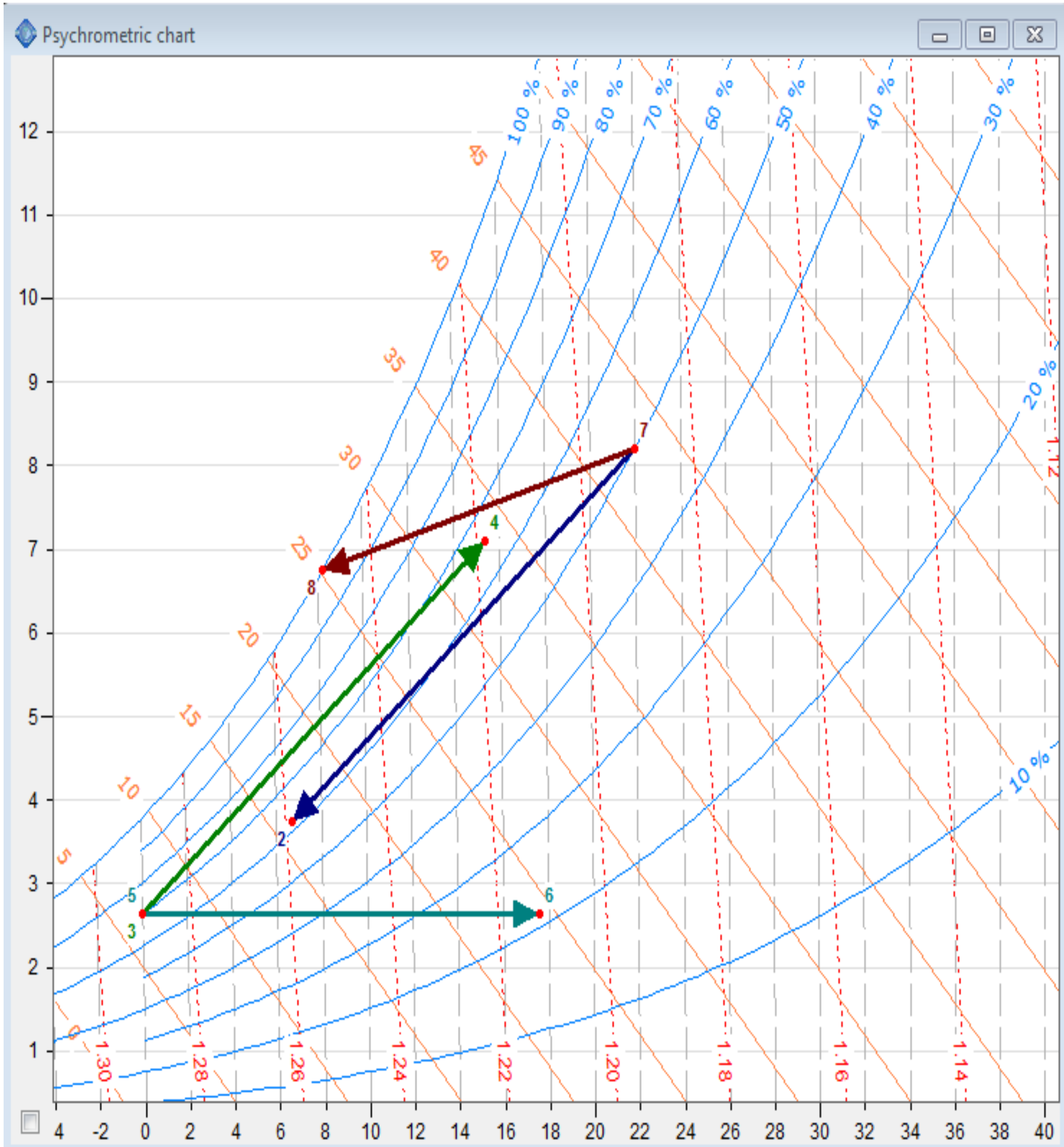
TABLE 1 New York City space conditions with different ventilation delivery strategies.

	SHR	SPACE DBT	SPACE RH
ASHRAE VENT RATE HRV	47%	76°F	68%
PHI VENT RATE HRV	66%	76°F	58%
ASHRAE VENT RATE ERV	71%	76°F	54%
PHI VENT RATE ERV	76%	76°F	52%
ASHRAE VENT DOAS HRV	66%	76°F	58%
ASHRAE VENT DOAS ERV	75%	76°F	53%


Psychrometric chart
Mouse position
t (°C)
x (g/kg)
φ (%)
h (kJ/kg)
ρ (kg/m³)
pₔ (hPa)
Air pressure:
1,013.3 hPa
Table and actions
Table
1 2 3 4 5
t 19.0 22.4 23.0 19.6
φ 85 69 50 62
x 11.7 11.7 8.7 8.7
h 48.6 52.1 45.2 41.7
V̇ 500.6 506.4 505.1 499.2
ṁd 593.8 593.8 593.8 593.8
Δt 3.4 -3.4
Δx 0.0 0.0
Δh 3.5 -3.5
Q̇ (kW) 0.6 -0.6
Δṁx (kg/h) 0.0 0.0
Actions
Heat recovery
Start points 1 and 3; Recuperative heat

Humidity Control - Heating

- ERV’s can go up to 80% humidity recovery. In these cases we recover all the moisture/water content from inside the building as a latent load and provide it to the fresh air making it humid again, resulting an unacceptably high relative humidity in the space



Mouse position

t (°C)	x (g/kg)	φ(%)	h (kJ/kg)
6.0	8.3	100	20.7

ρ (kg/m³)	p_D (hPa)
1.26	9.4

Air pressure: 1,013.3 hPa

Project

Table and actions

Table

	1	2	3	4	5	6	7	8	9
t	22.0	6.7	0.0	15.4	0.0	17.6	22.0	8.2	
φ	50	62	70	65	70	21	50	100	
x	8.2	3.7	2.6	7.1	2.6	2.6	8.2	6.7	
h	42.9	16.1	6.6	33.4	6.6	24.3	42.9	25.2	
$\dot{V}$	296.2	278.8	271.7	289.1	271.7	289.2	296.2	281.7	
$\dot{m}_d$	349.7	349.7	349.7	349.7	349.7	349.7	349.7	349.7	

Δt	-15.3	15.4	17.6	-13.8
Δx	-4.5	4.5	0.0	-1.5
Δh	-26.8	26.8	17.7	-17.7
$\dot{Q}$ (kW)	-2.6	2.6	1.7	-1.7
$\Delta\dot{m}_x$ (kg/h)	-1.6	1.6	0.0	-0.5

Actions

Heat recovery

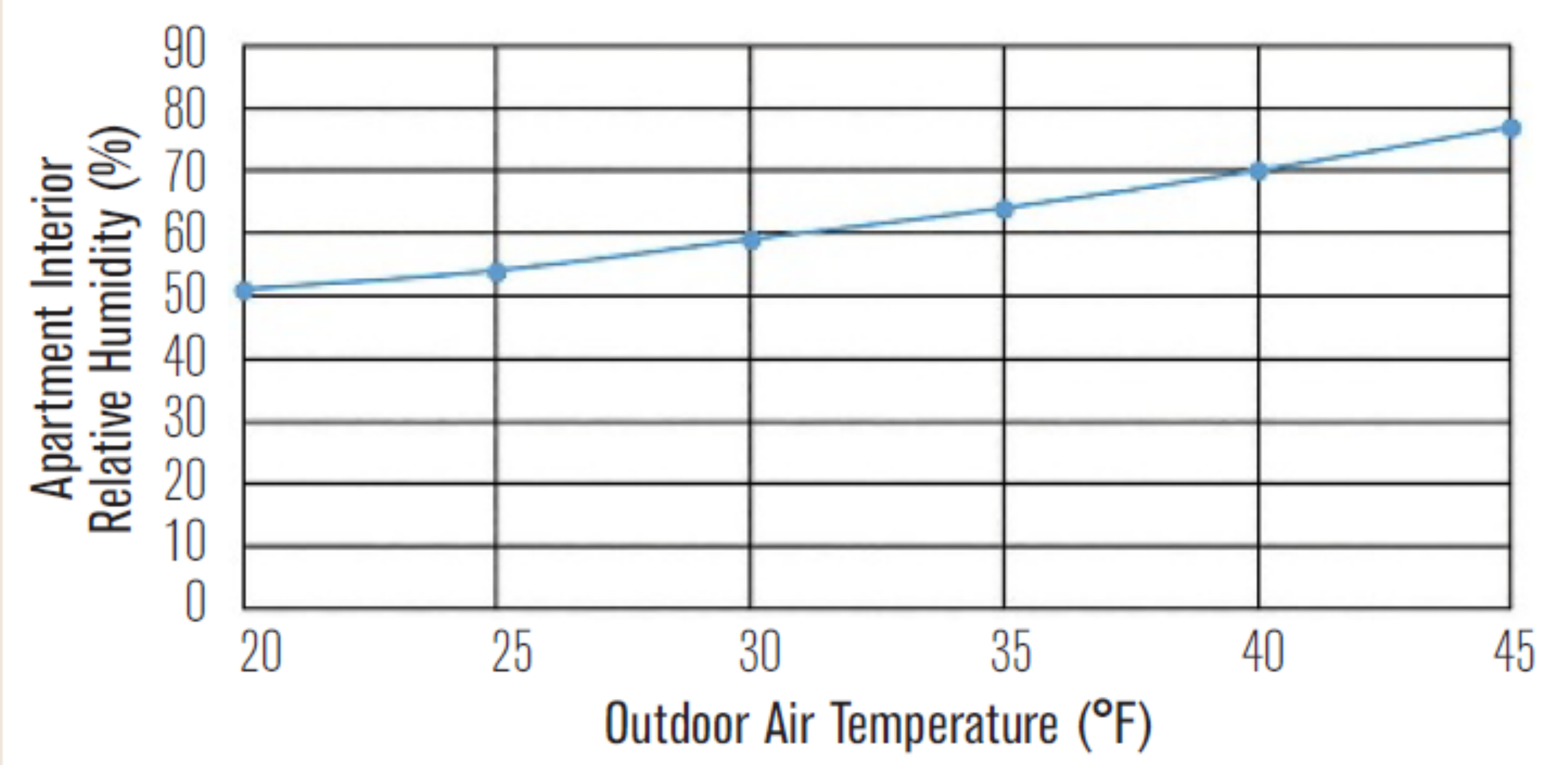
Start points 3 and 1; Regenerative heat recovery with temperature tran

Start points 5 and 7; Recuperative heat recovery with temperature tran

- Total internal latent load for the space is 0.44 kg/hr from 3 persons, one 15-minute shower and 0.09 kg/hr miscellaneous latent loads. The space is maintained at 21.1°C. The ERV is assumed to have an efficiency of 80%. Total ventilation air meets the ASHRAE Standard 62.1 exhaust requirements.

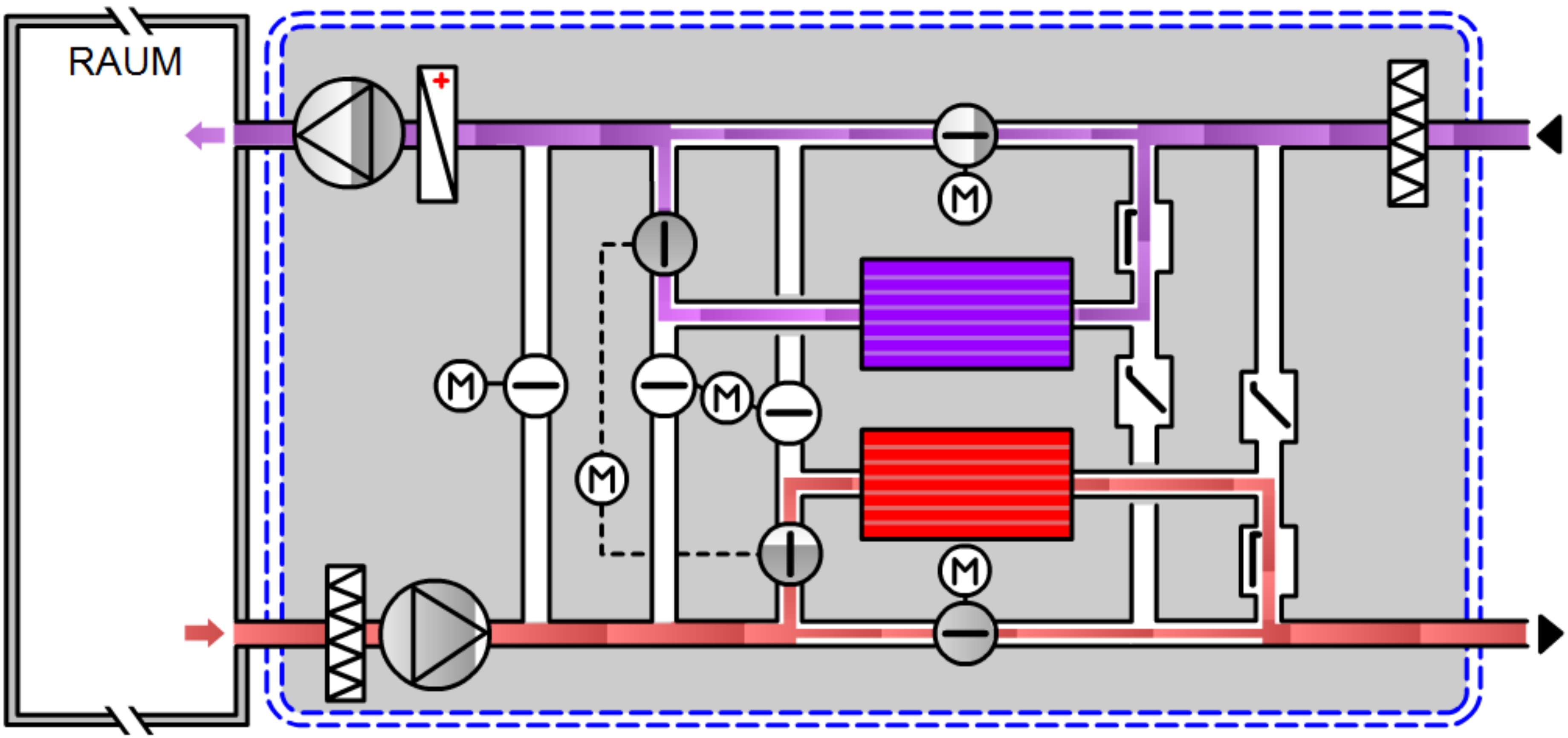
The apartment with ERV

FIGURE 2 Space relative humidity as a function of outdoor dew-point temperature.



BYPASS?

- A possible solution may be to disable the energy recovery and work with free cooling (assuming you can by pass that) and the energy penalty for disabling recovery is likely to be minimal, since the balance point temperature of the building is so low.


RAUM
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M
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Terminal Sizing and Location

- Indoor units usually too big (minimum vrf units around 7.000btu) for sow low demand
- In many circumstances, consolidating multiple rooms into a single zone may not be advisable, due to different load profiles for the various rooms.
- Locating the thermostat in one room may result in discomfort in other rooms

Terminal Sizing and Location

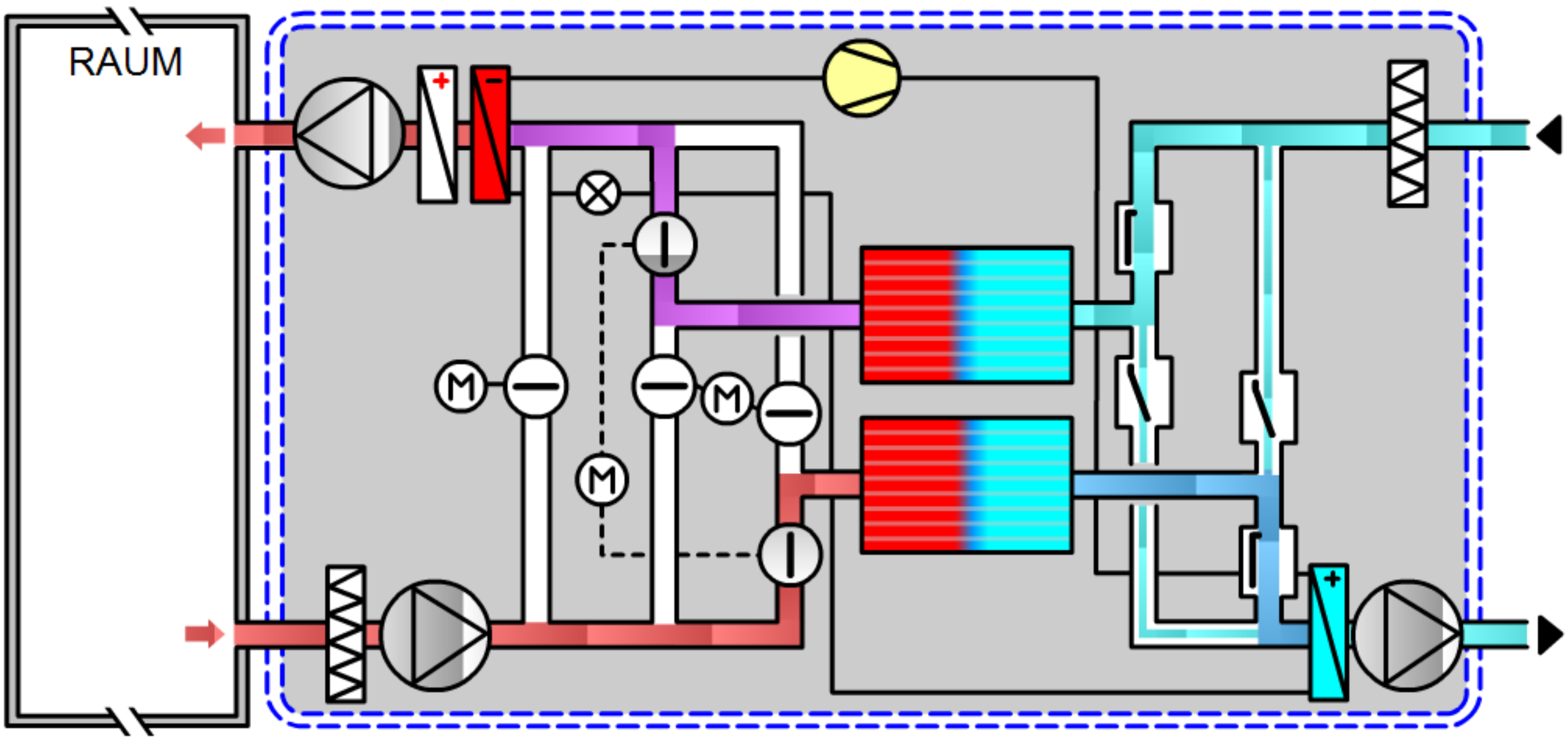
- Using an oversized terminal may not be an acceptable alternative, if consistent cooling loads below the minimum part load of the terminal result in cycling, diminishing the terminal's ability to provide adequate <u>dehumidification</u>

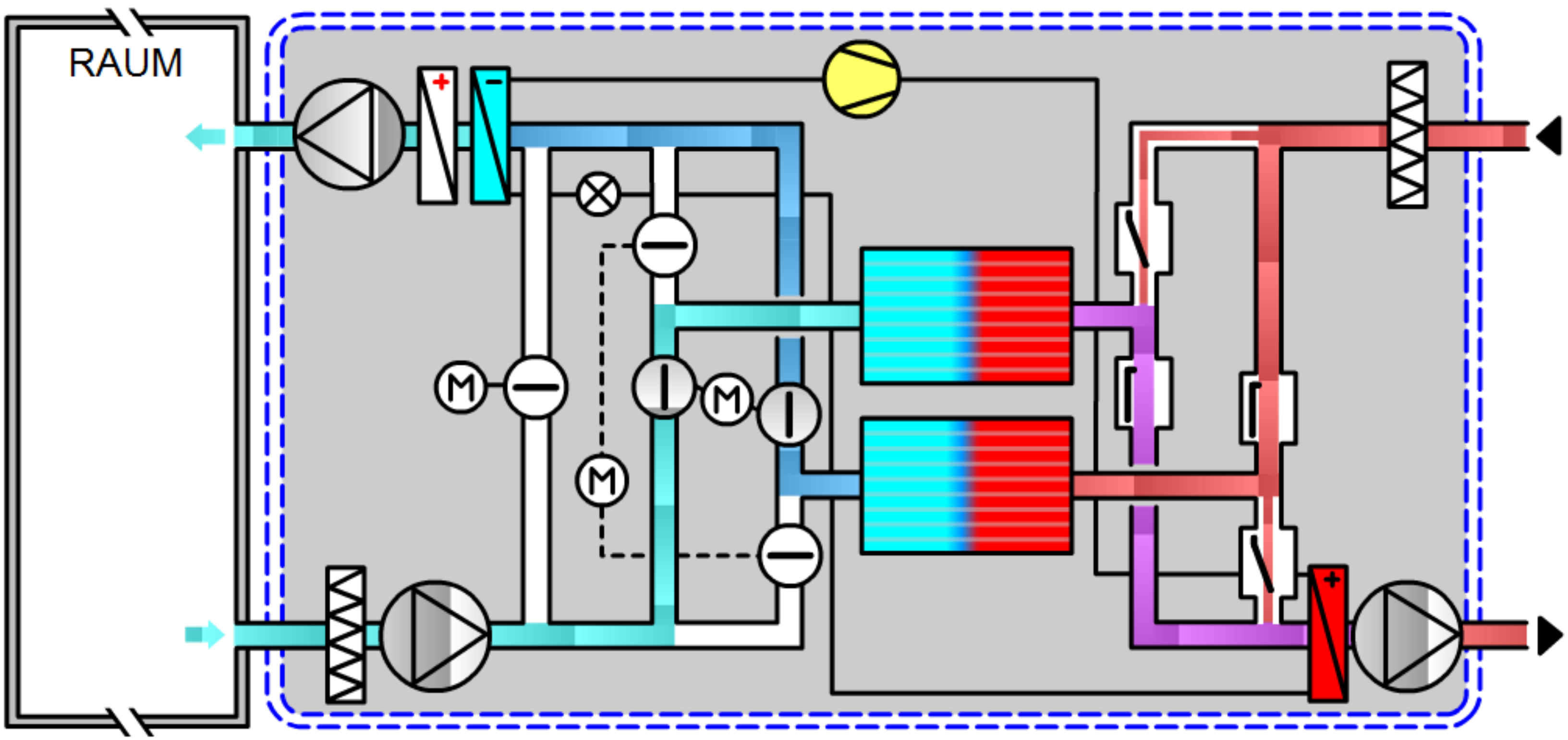
- Low conditioning airflow per unit area may create difficulty in achieving uniform distribution of ventilation air and maintaining uniform conditions through the space.
- In a hyper-efficient building, distribution system design can be critical

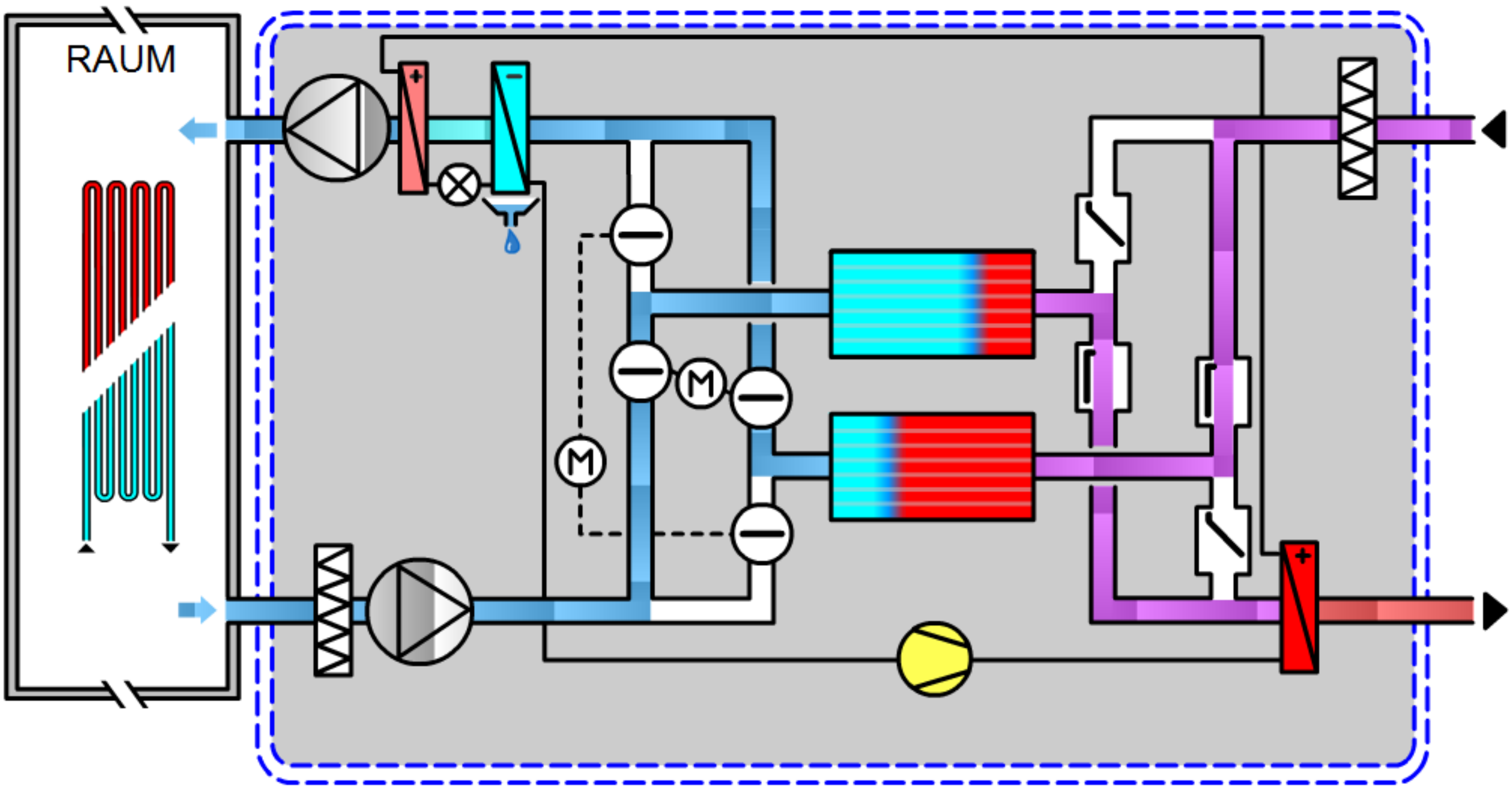
PROS

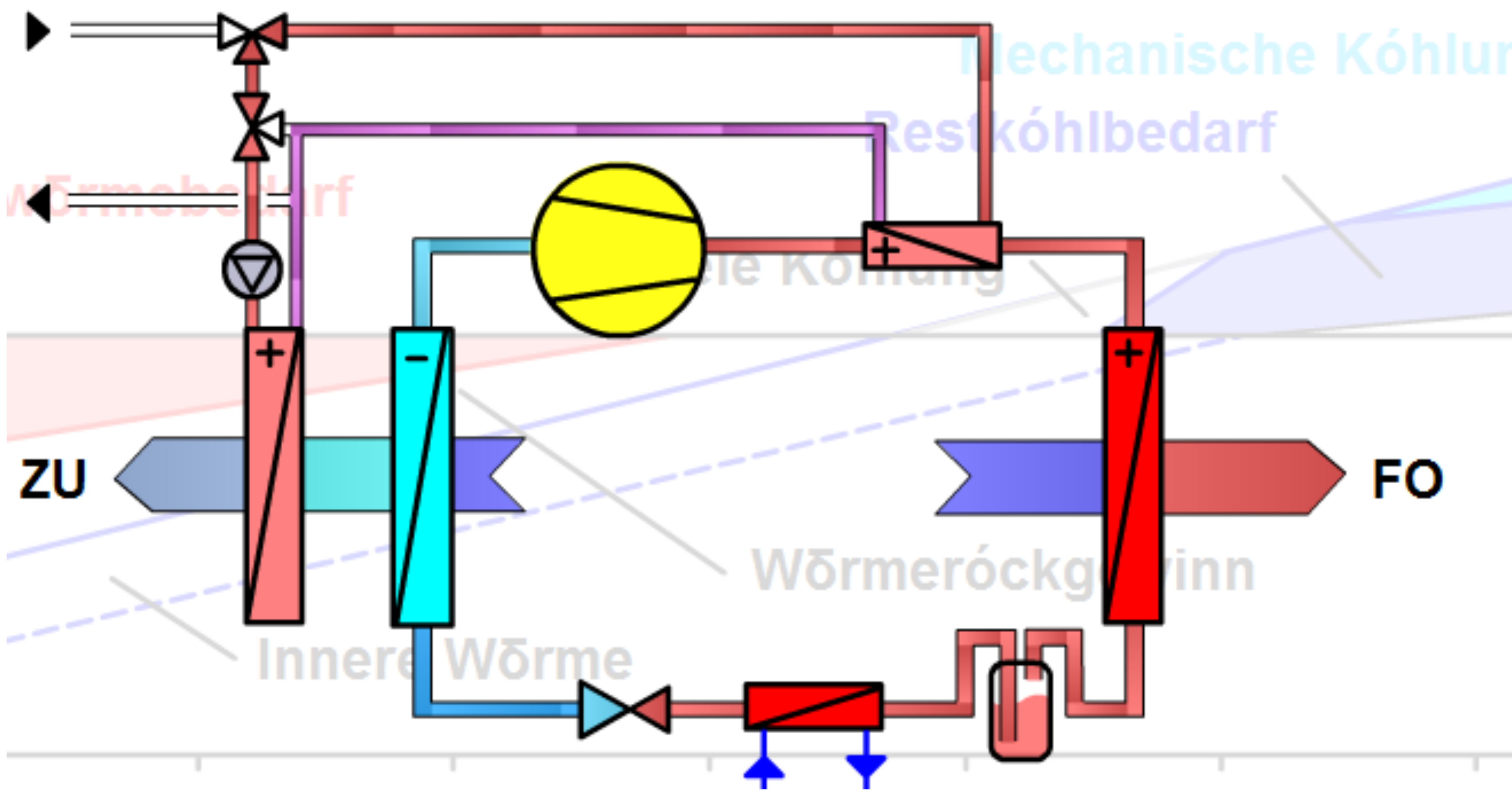
- Terminal location, however, is not as critical as in a conventional building since peak perimeter heating and cooling loads are reduced a lot.
- For commercial buildings, reduction in intensity of the perimeter loads may allow simplification of the HVAC system and controls, eliminating the need for simultaneous heating and cooling within the same building.

Suggestions




RAUM


RAUM


ZU
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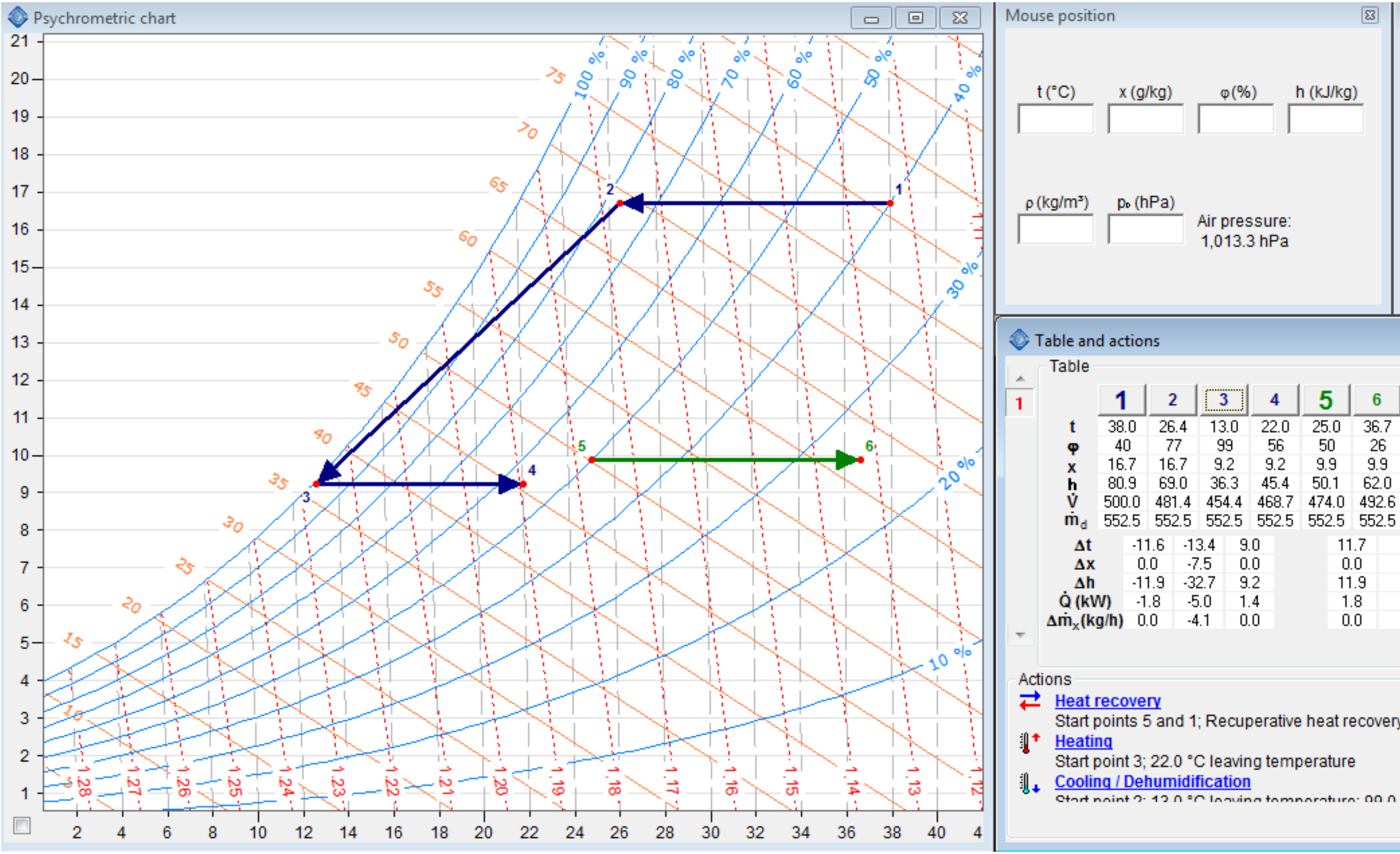
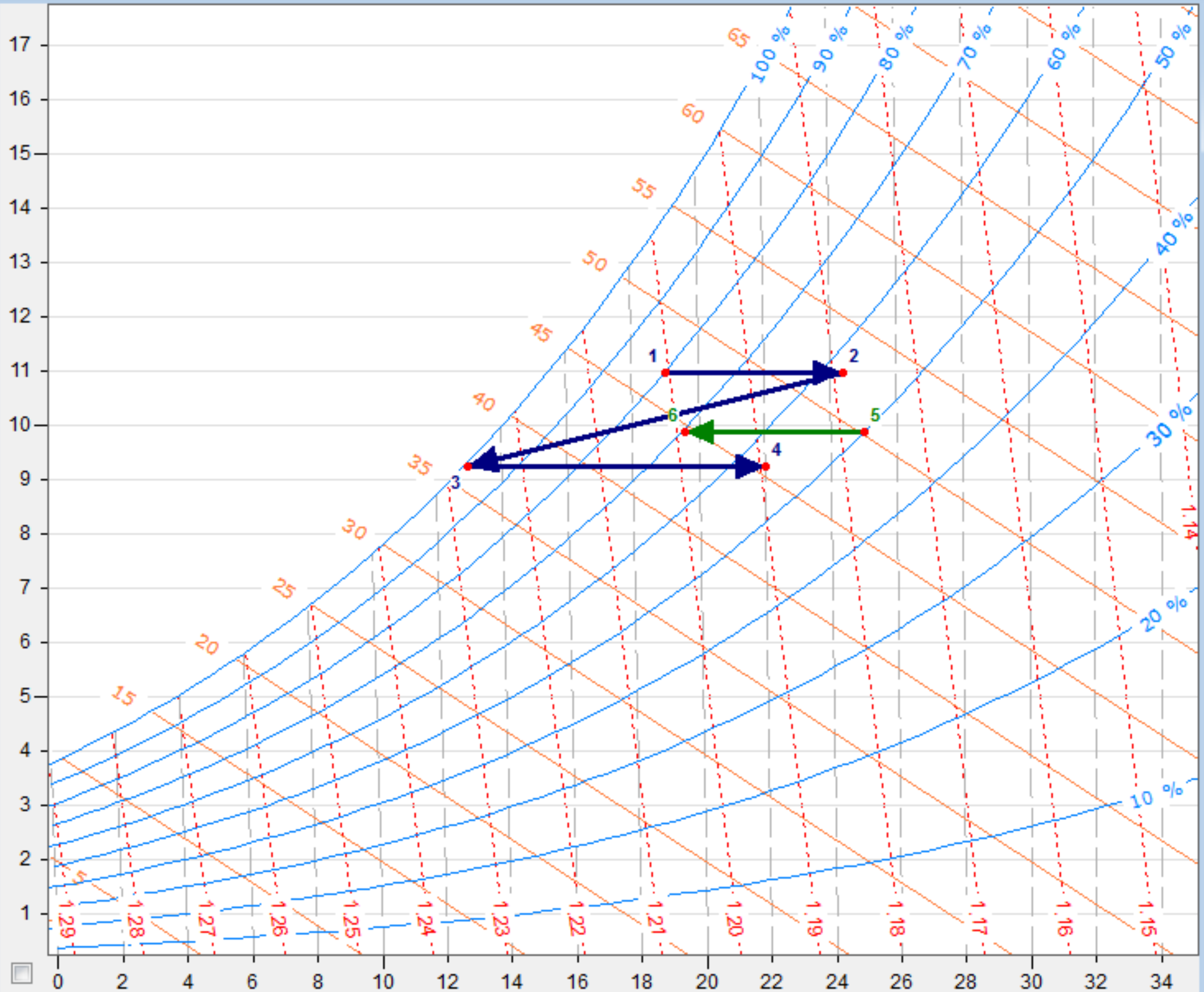
Summer



	1	2	3	4	5	6
t	38.0	26.4	13.0	22.0	25.0	36.7
φ	40	77	99	56	50	26
x	16.7	16.7	9.2	9.2	9.9	9.9
h	80.9	69.0	36.3	45.4	50.1	62.0
$\dot{V}$	500.0	481.4	454.4	468.7	474.0	492.6
$\dot{m}_d$	552.5	552.5	552.5	552.5	552.5	552.5
Δt		-11.6	-13.4	9.0		11.7
Δx		0.0	-7.5	0.0		0.0
Δh		-11.9	-32.7	9.2		11.9
$\dot{Q}$ (kW)		-1.8	-5.0	1.4		1.8
$\Delta\dot{m}_x$(kg/h)		0.0	-4.1	0.0		0.0

Mid Season High Due Point

Psychrometric chart



Mouse position

t (°C) x (g/kg) φ(%) h (kJ/kg)

ρ (kg/m³) pₛ (hPa)

Air pressure: 1,013.3 hPa

Table and actions

Table

	1	2	3	4	5	6
t	19.0	24.4	13.0	22.0	25.0	19.6
φ	80	58	99	56	50	69
x	11.0	11.0	9.2	9.2	9.9	9.9
h	46.8	52.3	36.3	45.4	50.1	44.6
$\dot{V}$	465.3	473.8	454.4	468.7	474.0	465.4
$\dot{m}_d$	552.5	552.5	552.5	552.5	552.5	552.5

Δt	5.4	-11.4	9.0		-5.4
Δx	0.0	-1.7	0.0		0.0
Δh	5.5	-16.0	9.2		-5.5
$\dot{Q}$ (kW)	0.8	-2.5	1.4		-0.8
$\Delta\dot{m}_x$(kg/h)	0.0	-1.0	0.0		0.0

Actions

Heat recovery
Start points 5 and 1; Recuperative heat recovery

Heating
Start point 3; 22.0 °C leaving temperature

Cooling / Dehumidification

Conclusions

- Configure ventilation systems to be compliant with the relevant version of ASHRAE Standard 62.1
- Follow ASHRAE Thermal comfort Standard 55 (dehumidify etc)
- Use a certified energy recovery ventilator.
- Control the energy recovery device to maximize energy efficiency and indoor comfort
- Design space zoning to be consistent with available terminal sizes

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