Chilled Beam Technology for Excellent Indoor Climate in Sustainable Buildings

Risto Kosonen
Carlos Lisboa

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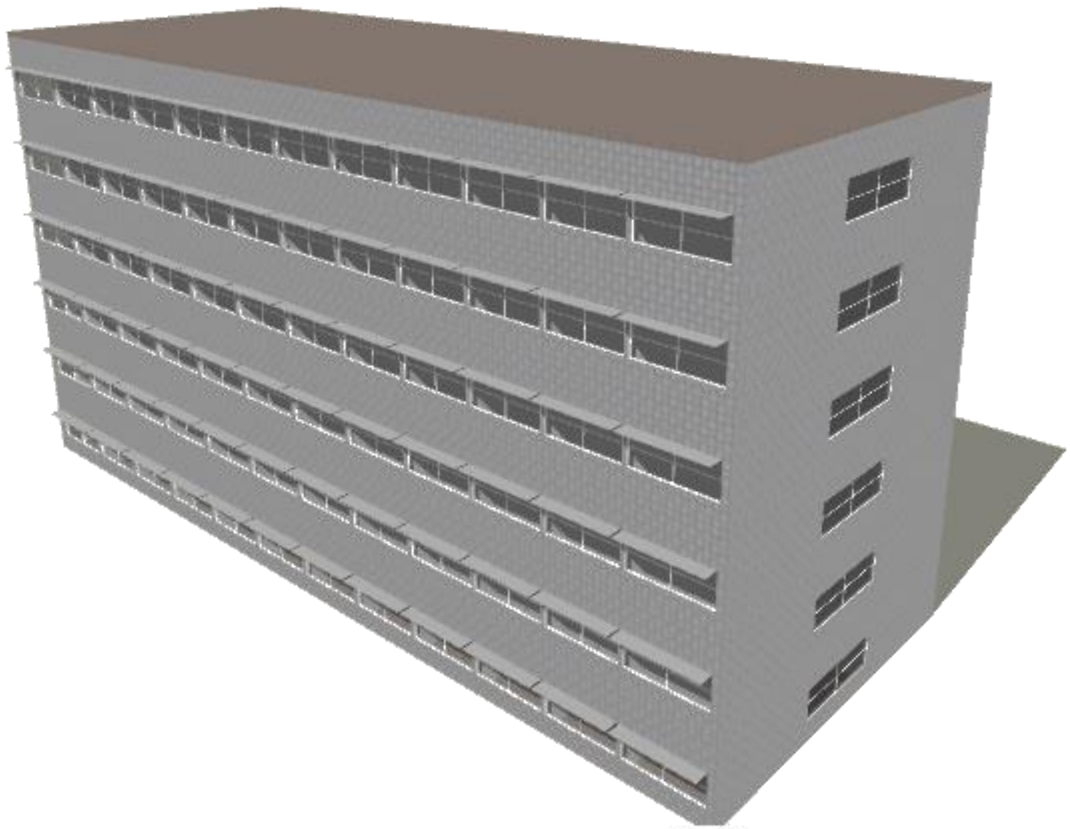
Contents of Training

Heating&Cooling Demands

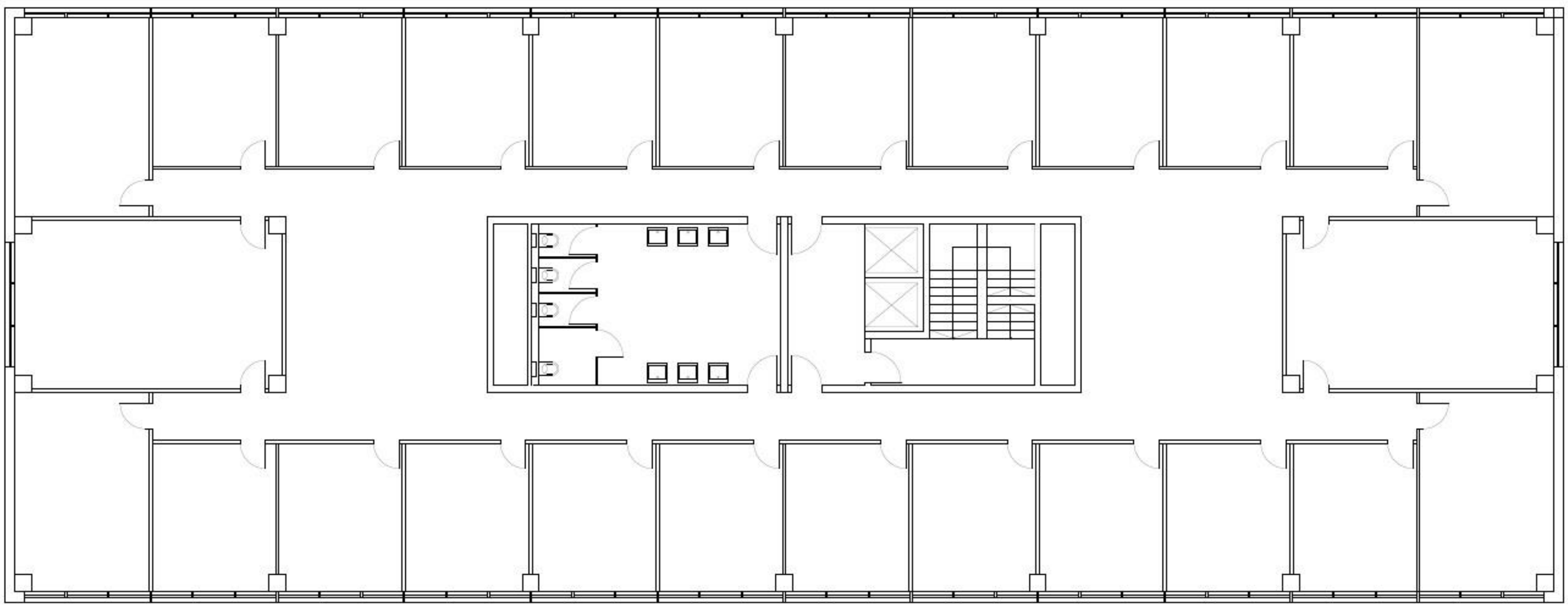
- Office building,
- North/South orientation,
- Cellular Offices, Open Plan Offices, Meeting rooms,
- Flexible use of space



Heating&Cooling Demands

- <u>Flexible use of space</u>

  HVAC system design must take into account the flexible use of floor space, allowing for easy (not expensive) adaptation of the system to different kinds of layout and design occupancy density.



Cellular Offices

Heating&Cooling Demands

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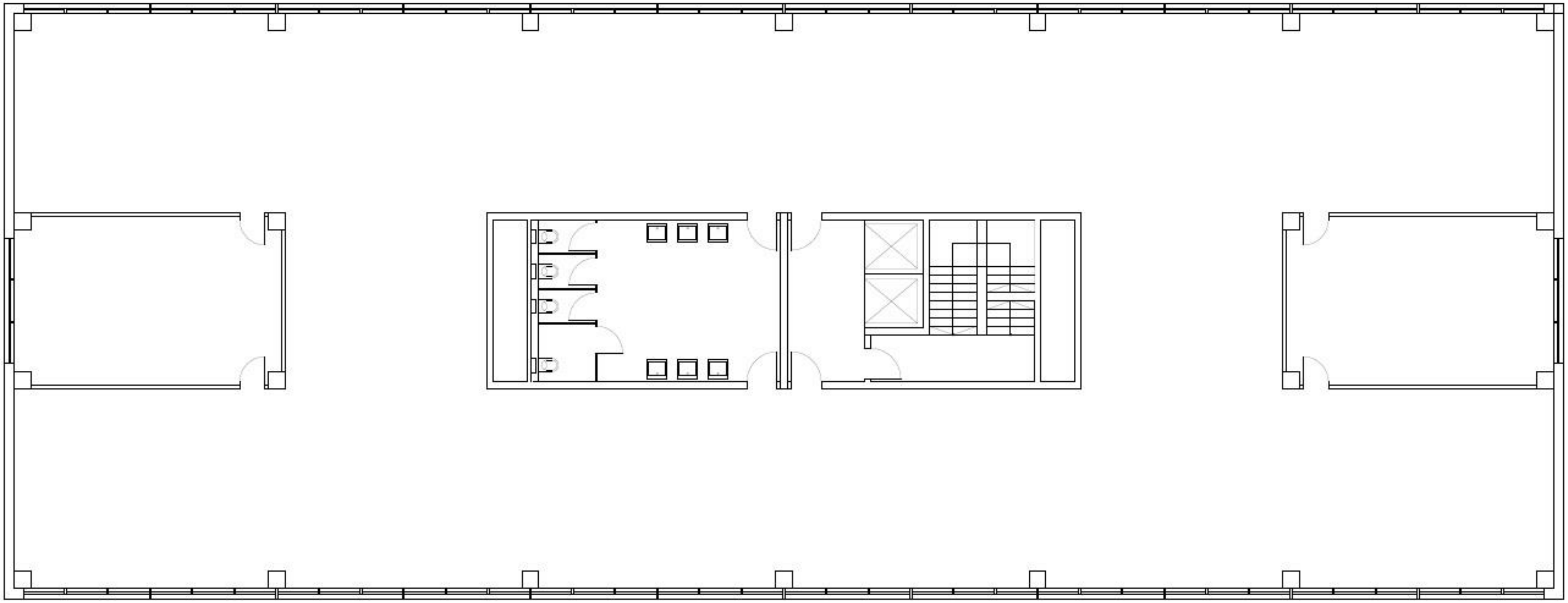

Open Plan Offices, meeting rooms

Heating&Cooling Demands

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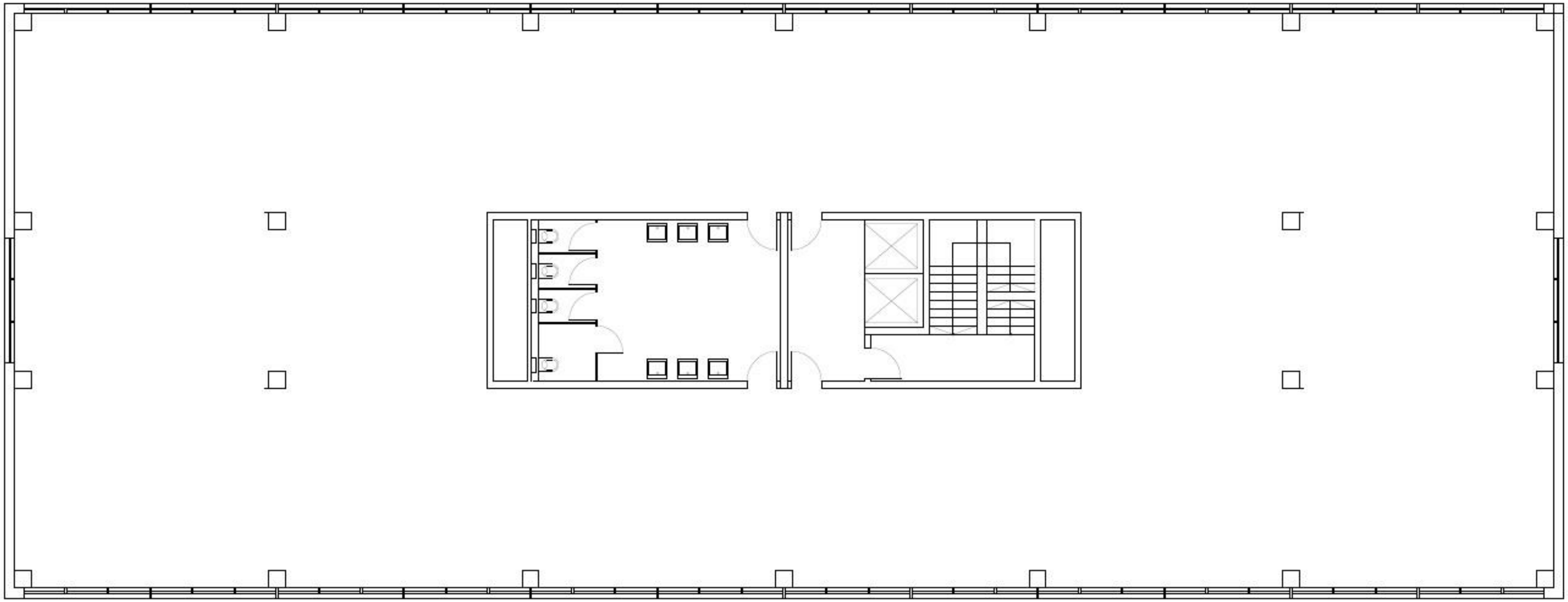
  HVAC system design must take into account the flexible use of floor space, allowing for easy (not expensive) adaptation of the system to different kinds of layout and design occupancy density.



Full Open Plan

Heating&Cooling Demands

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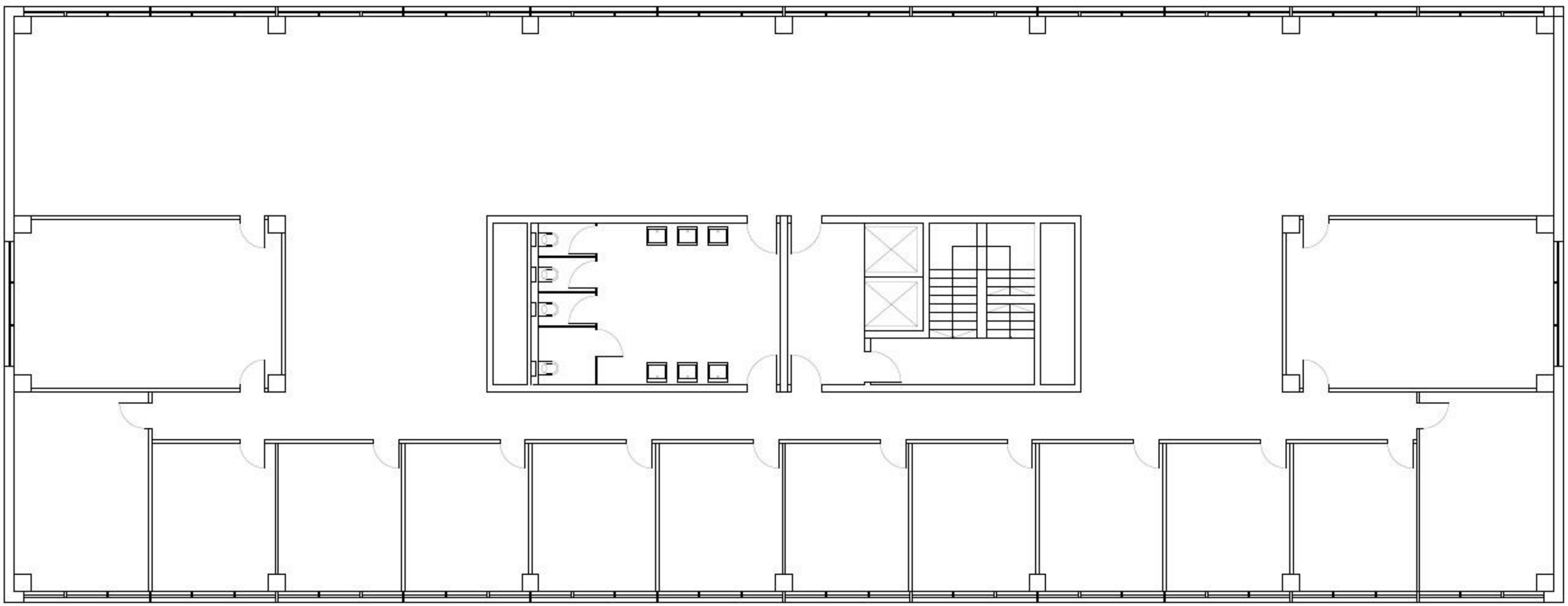


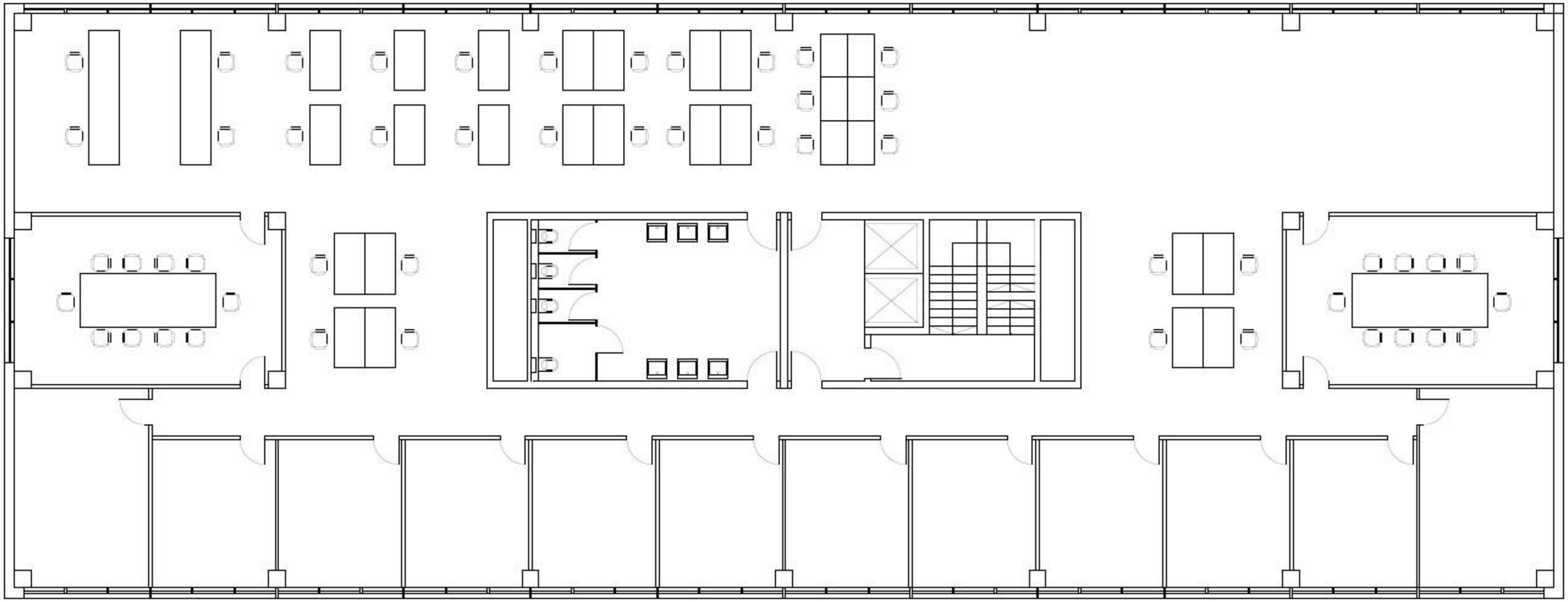
Cellular and Open Plan Offices

Heating&Cooling Demands

Design occupant density can vary widely and consequently zone loads and ventilation air flow requirement for the zone. Typical values are;

8m2/ person < cellular offices < 20m2 / person

3m2 / person < open plan offices < 11m2/person



Occupancy

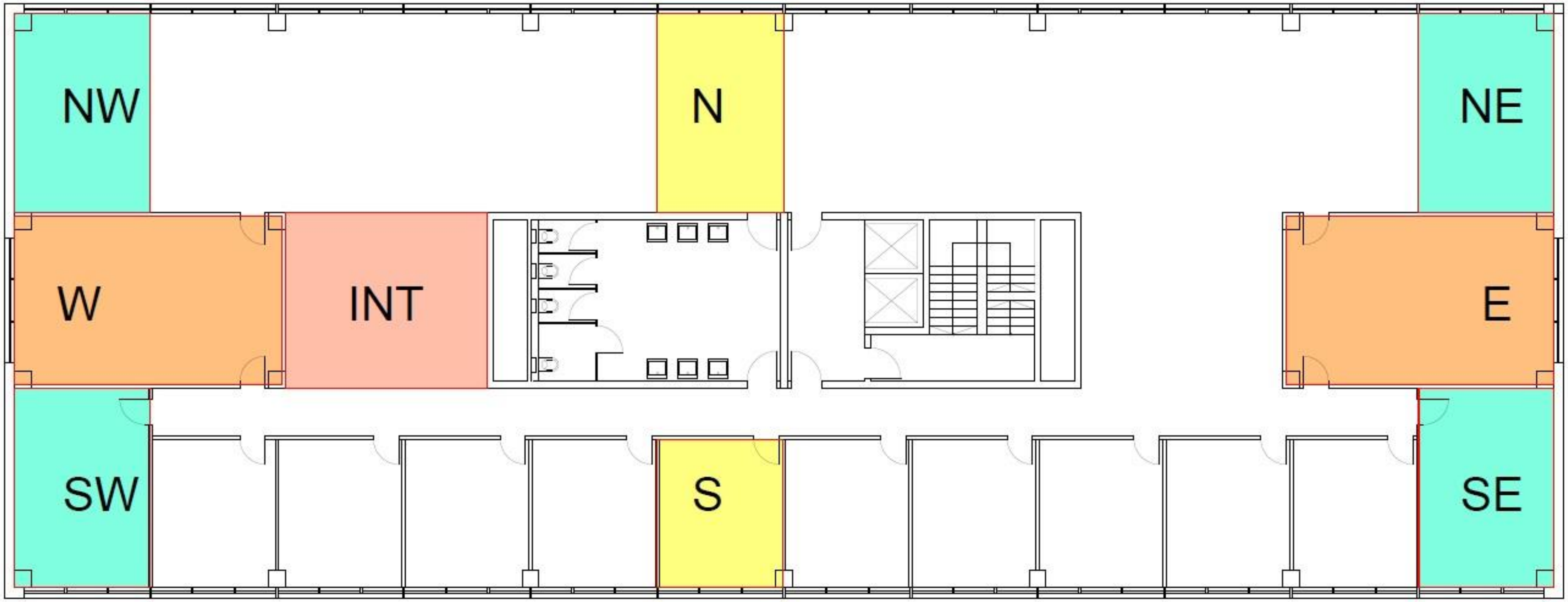
Heating&Cooling Demands

Nine typical zones;

•four façades modules (North, South, East, West),

•four corners (Northeast, Northwest, Southeast, Southwest)

•interior zone

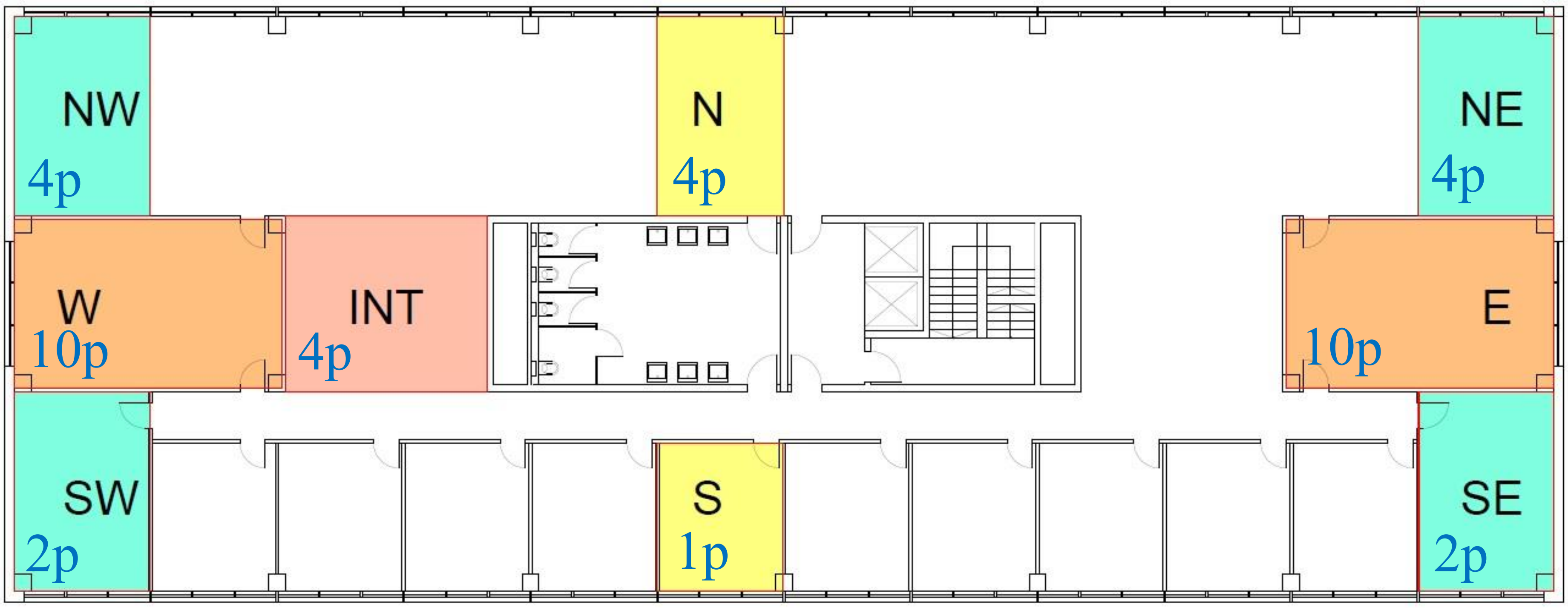


Occupancy

Heating&Cooling Demands

Occupancy;

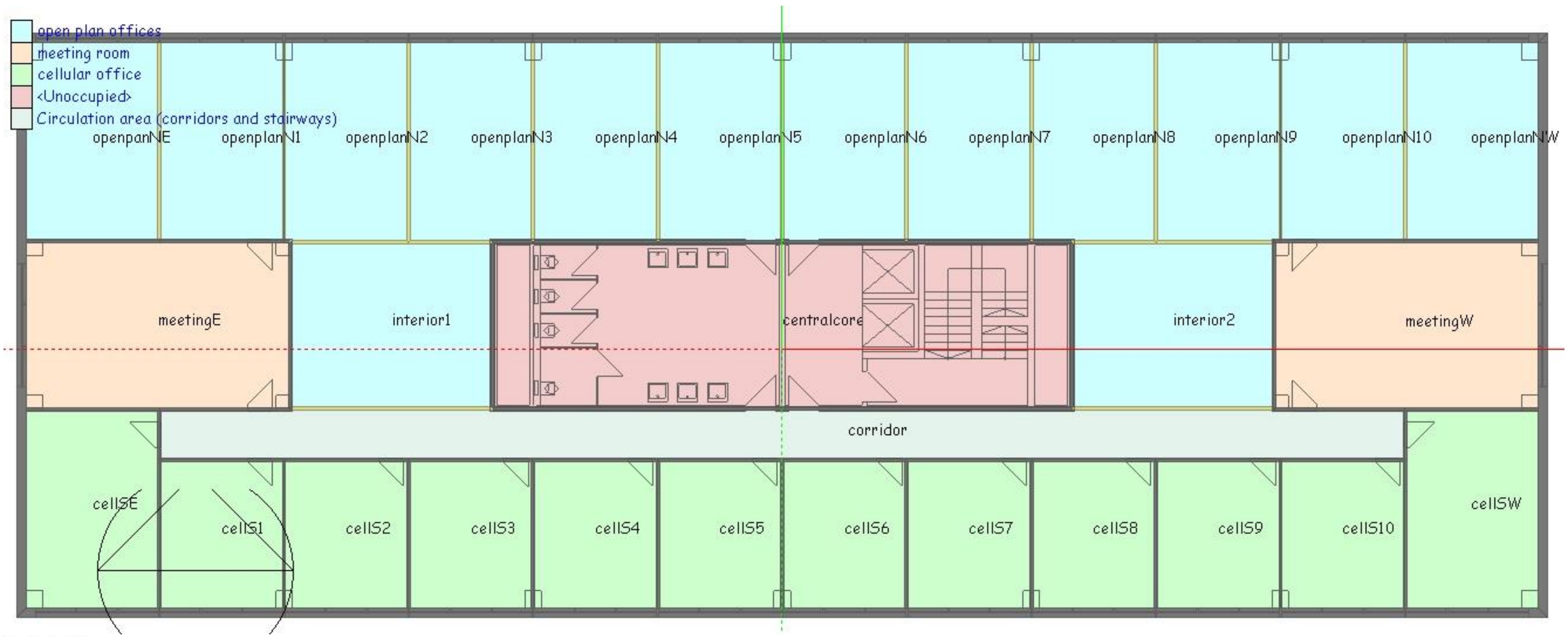
Established in the Owner's Project Requirements (OPR).



Occupancy

Heating&Cooling Demands

Thermal zones in the building model and also to be considered in the HVAC system design.



Thermal Zoning

Heating&Cooling Demands

Owner Project Requirements

Zone Loads calculated using a dynamic building simulation software.

1	2	3	4	5	6.1	6.2	6.3	7.1	7.2	8.1	8.2	9.1	9.2	10.1	10.2
Compartment	**referènce**	**area**	**height**	**volume**	**n.º of people**			**lighting**		**equipment**		**internal gains sensible**		**zone loads sensible**	
	-	m2	m	m3	p	m2/p	p/m2	W	W/m2	W	W/m2	W	W/m2	W	W/m2
cellular office South	cellS	16,5	2,8	46	1	16,5	0,06	198	12	115	7	383	23	800	48
cellular office SE	cellSE	23,5	2,8	66	2	11,8	0,09	282	12	230	10	652	28	1.200	51
cellular office SW	cellSW	23,5	2,8	66	2	11,8	0,09	282	12	230	10	652	28	1.200	51
openplan office N	openplanN	22,5	2,8	63	4	5,6	0,18	270	12	460	21	1.010	45	1.500	67
openplan office NE	openplanNE	23,5	2,8	66	4	5,9	0,17	282	12	460	20	1.022	43	1.800	77
openplan office NW	openplanNW	23,5	2,8	66	4	5,9	0,17	282	12	460	20	1.022	43	1.800	77
meeting room E	meetingE	39,5	2,8	111	10	4,0	0,25	474	12	1.150	30	2.324	59	3.000	76
meeting room W	meetingW	39,5	2,8	111	10	4,0	0,25	474	12	1.150	30	2.324	59	3.000	76
interior zone	interior	31,0	2,8	87	4	7,8	0,13	372	12	460	15	1.112	36	1.400	45

Contents of Training

PART I: CHILLED BEAM TECHNOLOGY

- PERFORMANCE AND BENEFITS OF CHILLED BEAM SYSTEM
- FLEXIBILITY AND CONTROL ZONE
- ROOM CONTROL
- THE OVERALL SYSTEM CONCEPT
- THERMAL COMFORT AND ENERGY CONSUMPION
- INSTALLATION AND COMMISSIONING
- nZEB CASE-STUDY BUILDINGS

PART II: CHILLED BEAM DESIGN EXAMPLE

- HEATING&COOLING DEMANDS
- **PRIMARY AIR CALCULATION & BEAM SPECIFICATION**
- BEAM SELECTION IN ONE ROOM MODULE
- CONCEPT DESIGN OF A FLOOR LAYOUT
- CHILLED WATER SYSTEM DESIGN
- PRIMARY AIR HANDLING UNIT DESIGN

Primary Air Calculation & Beam Specification

Primary air flow has the following functions and corresponding requirements;

Function	Goal	Requirements
Ventilation	•Comfort •Health	•Local code, •Owner Project Requirements
Indoor air dehumidification	•Comfort •Condensation control	•Indoor air humidity inside comfort range •Indoor air dewpoint equal or under chilled water temperature supplied to the beams
Space cooling	•Comfort	•Indoor air temperature inside comfort range

Primary air flow rate needed for each of the three functions must be calculated. Design primary air flow is the highest value of the three.

Ideally primary air flow rate should be as close as possible to the air flow calculated to comply with the ventilation requirements.

Primary Air Calculation & Beam Specification

Primary air flow needed for **ventilation**;

Calculation according to EN15251 – category2

description	symbol	value	units	formula/source
floor area	A	16,5	m2	
ceiling height	h	2,8	m	
volume	Vol	46	m3	A x h
occupancy	NP	1	-	
ventilation per person	Rp	7,0	l / s.p	EN 15251 - category 2
ventilation unit area	Ra	0,70	l / s.m2	EN 15251 - category 2 ; low polluting
ventilation requirement	**V1**	**19**	**l/s**	EN15251 : 2007 (Rp x NP + Ra x A)
Air Changes per Hour	ACH	1,4	/h	V1 x 3,6 / Vol

Calculation according to ASHRAE 62.1

description	symbol	value	units	formula/source
occupancy	NP	1	-	
ventilation per person	Rp	2,4	l / s.p	ANSI/ASHRAE 62.1
ventilation unit area	Ra	0,30	l / s.m2	ANSI/ASHRAE 62.1
ventilation requirement	**V1**	**7,4**	**l/s**	ANSI/ASHRAE 62.1 ; (Rp x NP + Ra x A)
Air Changes per Hour	ACH	0,6	/h	V1 x 3,6 / Vol

Primary Air Calculation & Beam Specification

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description	symbol	value	units	formula/s
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Very different requirements from different standards

Calculation according to ASHRAE 62.1

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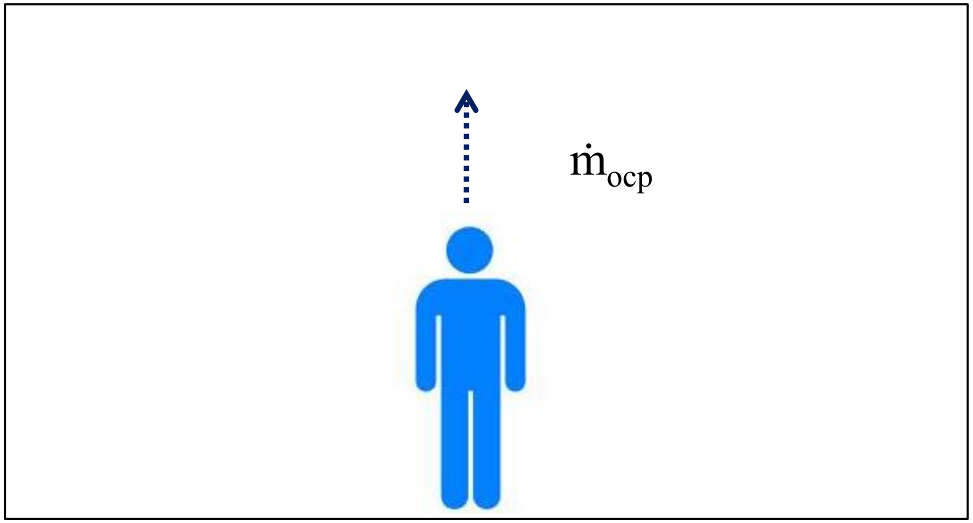
Air Changes per Hour	ACH	0,6	/h	V1 x 3,6 / Vol

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

The main water vapour addition to the indoor air is generated by the occupant´s metabolism.



Primary Air Calculation & Beam Specification

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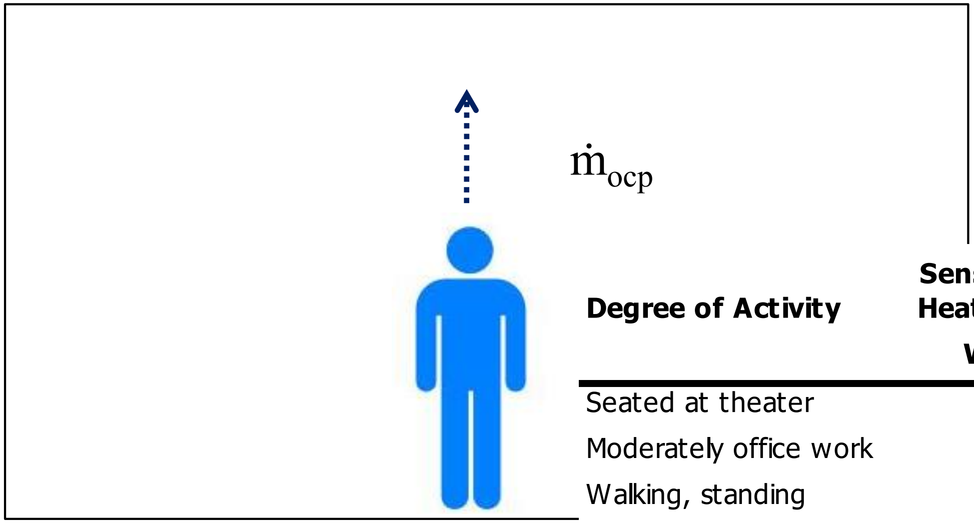

Degree of Activity	Sensible Heat (1)	Latent Heat (1)	water vapour generation	
	W	W	g/s	g/h
Seated at theater	70	35	0,014	50
Moderately office work	75	55	0,022	79
Walking, standing	75	70	0,028	101
Light bench work	80	140	0,056	202
Moderate dancing	90	160	0,064	230
light machine work	110	185	0,074	266
Heavy work	170	255	0,102	367
Athletics	210	315	0,126	454

(1) from ASHRAE Handbook of Fundamentals

Primary Air Calculation & Beam Specification

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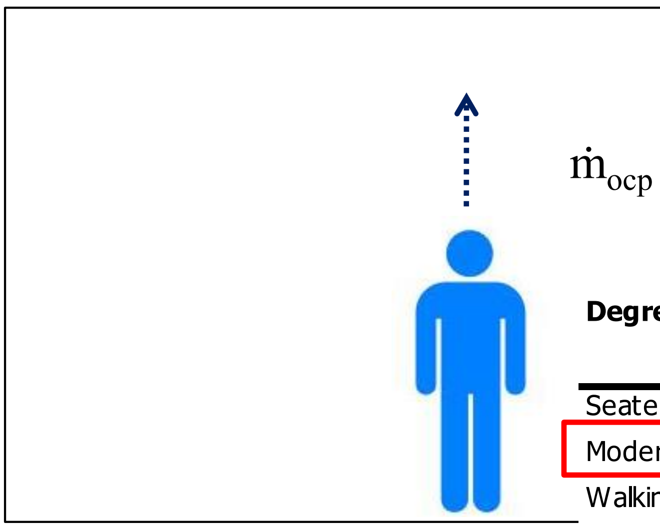

Degree of Activity	Sensible Heat (1) W	Latent Heat (1) W	water vapour generation g/s	water vapour generation g/h
Seated at theater	70	35	0,014	50
Moderately office work	75	55	0,022	79
Walking, standing	75	70	0,028	101
Light bench work	80	140	0,056	202
Moderate dancing	90	160	0,064	230
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Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

The main water vapour addition to the indoor air is generated by the occupant´s metabolism.

$$\dot{m}_{ocp} = N \bullet 0{,}022 g/s$$

N – number of people

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Seated at theater	70	35	0,014	50
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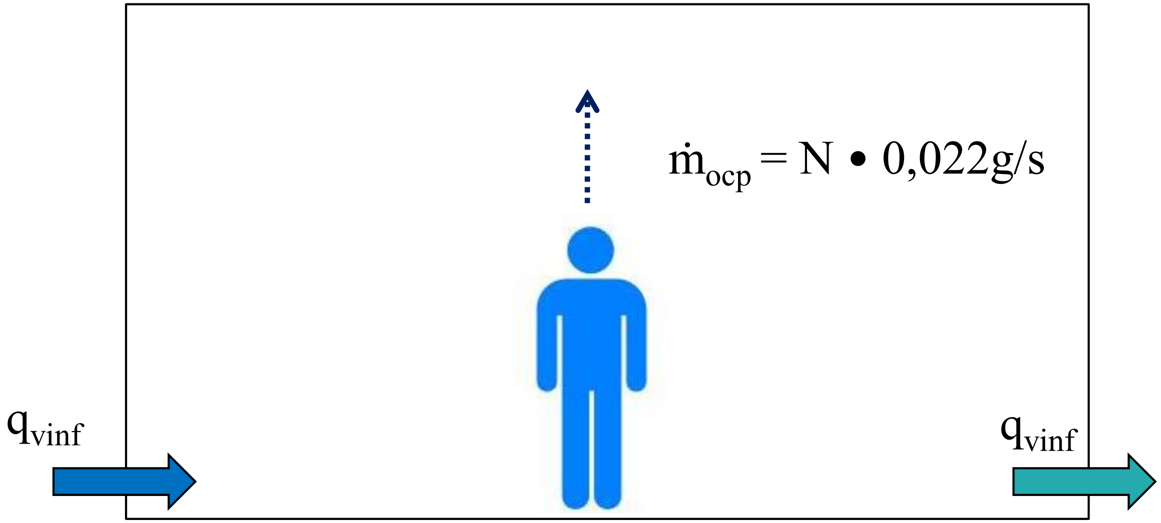
Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

The second water vapour addition to the indoor air results from infiltrations of outdoor air through the building envelope.



Whenever indoor pressure is lower than outdoor pressure, outdoor air will enter the room through the envelope

Infiltration air entering the building shall leave the building, through the envelope or through the HVAC system, at the indoor humidity ratio

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

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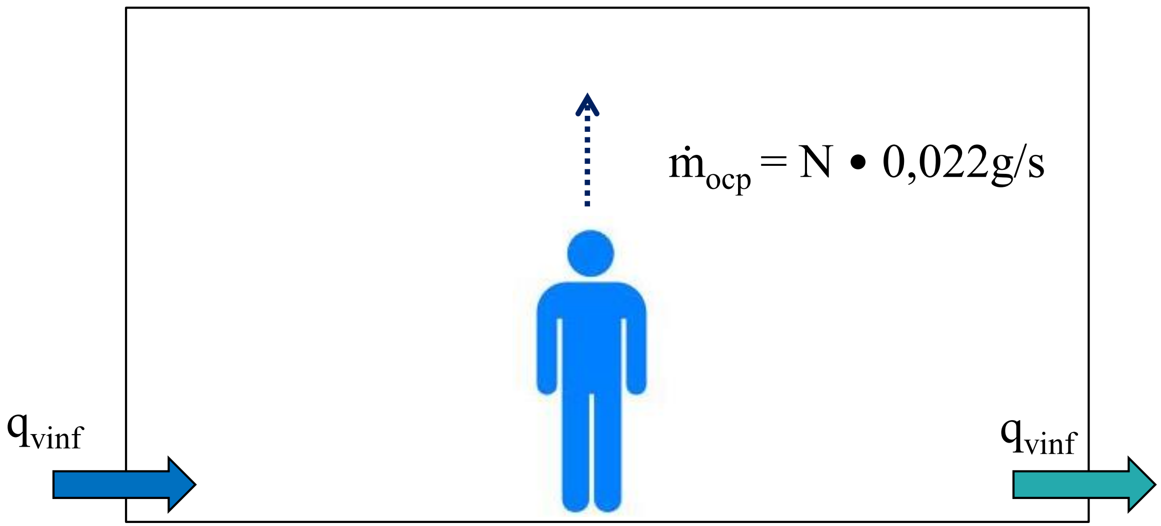


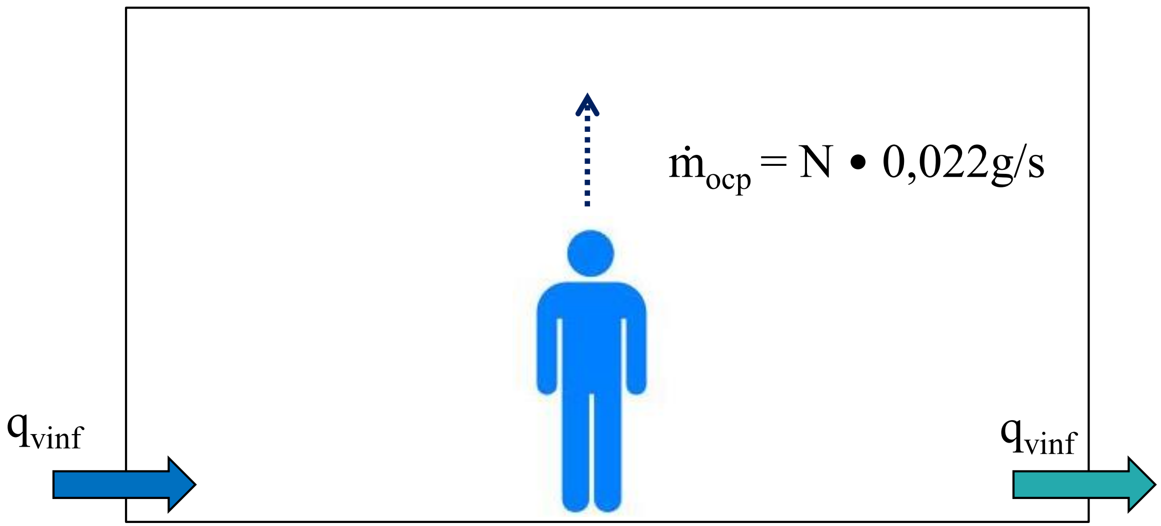
$$\dot{m}_{inf} = q_{vinf} \bullet \rho \bullet (HR_{ODA} - HR_{IDA})$$

q_{vinf}	(m^3/s)	infiltration air flow	HR_{ODA}	(g/Kg)	outdoor air humidity ratio
ρ	(Kg/m^3)	air density (1,2)	HR_{IDA}	(g/Kg)	indoor air humidity ratio

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

The total water vapour addition to the indoor air is the sum of both sources;



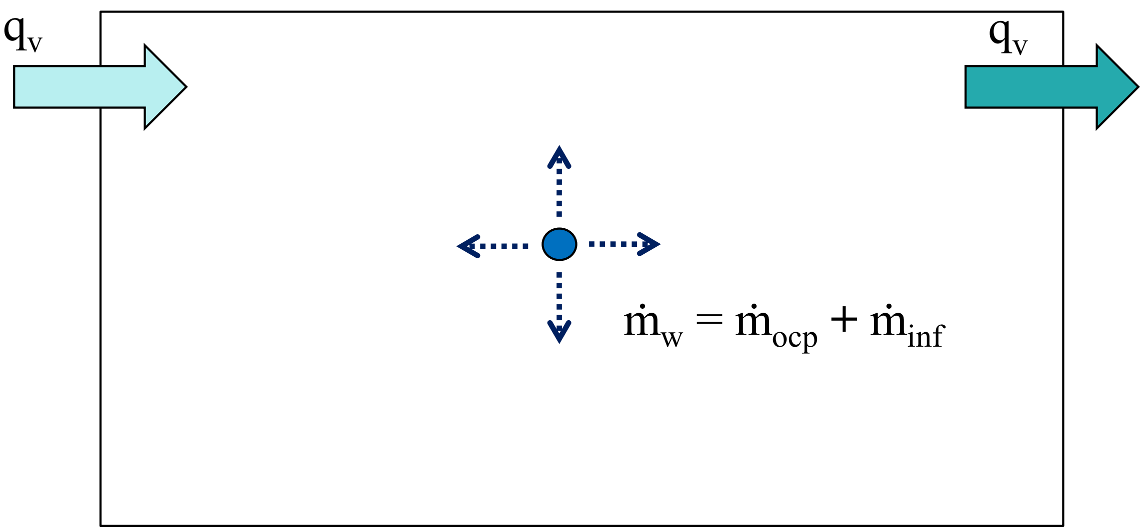
$$\dot{m}_{inf} = q_{vinf} \bullet \rho \bullet (HR_{ODA} - HR_{IDA})$$

$$\dot{m}_{w} = \dot{m}_{ocp} + \dot{m}_{inf}$$

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Knowing the strenght of the sources, the required indoor air humidity ratio and the primary air humidity ratio the primary air flow needed for dehumidification can be determined.



Mass balance equation applied to the room control volume;

$$q_v \cdot \rho \cdot HR_{IDA} = \dot{m}_w + q_v \cdot \rho \cdot HR_{SUP} \longrightarrow q_v = \dot{m}_w \; / \; [\, \rho \cdot (HR_{IDA} - HR_{SUP}) \,]$$

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Since the dynamic load calculation software delivers the value of the design latent load of the space (L_{LAT}) the strenght of the water vapour sources can easily be aproximated by using the following formula;

$$\dot{m}_w = L_{LAT} / 2.500$$

$\dot{m}_w$	(g/s)	;	mass flow of water vapour added to the space
L_{LAT}	(W)	;	latent space load (from load calculation)
2.500	(KJ/Kg)	;	approximate heat content of vapour in indoor air at 24ºC & 50%RH less the heat content of water at 10ºC. *Note. A common design condition for the space is 50% rh at 24°C, and 10°C is normal condensate temperature from cooling and dehumidifying coils.*

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

First step, choose the design indoor air and primary air humidity ratio;

Second step, calculate the strenght of the water vapour sources;

$$\dot{m}_w = \dot{m}_{ocp} + \dot{m}_{inf}$$

Third step, calculate the needed primary air flow for dehumidification;

$$q_v = \dot{m}_w \ / \ [\ \rho \bullet (HR_{IDA} - HR_{SUP})\ ]$$

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Choice of the design indoor air dew point temperature, **DP_{IDA}**;

DP_{IDA} must be such that indoor air relative humidity falls inside the comfort range specified in the OPR; 30% < RH_{IDA} < 60%.

	Dry bulb	RH	DewPoint
High limit	25ºC	60%	16,7ºC
Low limit	25ºC	30%	6,2ºC

$$6{,}2^{o}C < DP_{IDA} < 16{,}7^{o}C$$

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Choice of the design indoor air dew point temperature, **DP_{IDA}**;

In order to <u>prevent condensation</u>, DP_{IDA} must be equal to or smaller than the chilled water temperature supplied to the beams, CWT_{IN}.

$$DP_{IDA} = CWT_{IN} - dT$$

dT; safety temperature difference

The safety temperature difference, dT, is typically between 0ºC and 1ºC. It's value has a big influence on the dimensioning of the primary air flow and should be kept as small as possible.

Primary Air Calculation & Beam Specification

Safety factors included in the calculation

The formation, and subsequent falling, of water droplets on the coil surface lags the onset of conditions that could cause condensation.

A rule of thumb from mock-up tests, which have forced condensation to form on the beam's coil surface, showed the **first visible droplet** on the inlet cold pipe to the coil was detected at approximately **2ºC** below the indoor air dew point (DP).

Primary Air Calculation & Beam Specification

Safety factors included in the calculation

Dehumidification air flow is usually calculated using steady state conditions.

The consideration of dynamic effects accounting for building and furniture absorption of water vapor results in a lower calculated dehumidification air flow.

Not considering the dynamic effects in the water vapor mass balance results in a conservative calculation, ie, the calculated air flow includes a safety margin.

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Choice of the design indoor air dew point temperature, **DP_{IDA}**;

The bigger the DP_{IDA} the smaller the needed air flow for dehumidification.

In this example we choose, **DP_{IDA} = 16ºC**

description	symbol	value	units	formula/source
IDA design condition cooling	DB_{IDA}	**25,0**	ºC	**Owner Projet Requirements**
IDA design condition cooling	DP_{IDA}	16,0	ºC	CWTin - dT
IDA design condition cooling	HR_{IDA}	11,4	g/kg	psychart
IDA design condition cooling	RH_{IDA}	57,5	%	psychart

Primary Air Calculation & Beam Specification

Primary air flow needed for **dehumidification**;

Choice of the design primary air dew point temperature, $\mathbf{DP_{SUP}}$;

The choice of the primary air dew point greatly affects the size of the needed air flow for dehumidification and also the technological solution of the primary air handling unit (AHU).

In this example we choose, $\mathbf{DP_{SUP} = 13^oC}$.

Since we choose a primary air dry bulb temperature of 14ºC, the primary air supply dew point temperature can be obtained using a simple conventional AHU configuration without significant energy use for reheat in the dehumidifying process.

Primary Air Calculation & Beam Specification

All the calculations can be organized in a spreadsheet and performed in a very productive way.

The first two parts regard the outdoor air, ODA, and indoor air, IDA, design conditions.

	nun	description	symbol	cellS	units	formula/source
ODA design dondition	1	location	-	**Lisbon**	-	
	2	ODA design condition cooling	DB_{ODA1}	**32,1**	ºC	**ASHRAE Fundamentals 1% criteria**
	3	ODA design condition cooling	$MCWB_{ODA1}$	**19,7**	ºC	**ASHRAE Fundamentals 1% criteria**
	4	ODA design condition cooling	HR_{ODA1}	**9,3**	g/kg	**ASHRAE Fundamentals 1% criteria**
	5	ODA design condition dehumid	DP_{ODA2}	**20,0**	ºC	**ASHRAE Fundamentals 1% criteria**
	6	ODA design condition dehumid	$MCDB_{ODA2}$	**22,7**	ºC	**ASHRAE Fundamentals 1% criteria**
	7	ODA design condition dehumid	HR_{ODA2}	14,8	g/kg	**ASHRAE Fundamentals 1% criteria**
	8	ODA design condition heating	DB_{ODA3}	**5,8**	ºC	**ASHRAE Fundamentals 1% criteria**
IDA design conditions	9	IDA design condition cooling	DB_{IDA}	**25,0**	ºC	**Owner Projet Requirements**
	10	IDA design condition cooling	DP_{IDA}	16,0	ºC	CWTin - dT
	11	IDA design condition cooling	HR_{IDA}	11,4	g/kg	psychart
	12	IDA design condition cooling	RH_{IDA}	57,5	%	psychart

Note. In this spreadsheet the values in red+bold are required inputs, the values in black+normal are automatically calculated based on the inputed values.

Primary Air Calculation & Beam Specification

The third and fourth parts regard the room dimensions and the calculation of the primary air flow required for ventilation.

	num	description	symbol	cellS	units	formula/source
dimensions	13	floor area	A	**16,5**	m2	
	14	ceiling height	h	**2,8**	m	
	15	volume	Vol	46	m3	A x h
ventilation	16	occupancy	NP	**1**	-	
	17	**ventilation requirement**	**V1**	**19**	**l/s**	**EN15251 : 2007 (Rp x NP + Ra x A)**
	18	Air Changes per Hour	ACH	1,4	/h	V x 3,6 / Vol
	19	ventilation per person	Rp	**7,0**	l / s.p	**EN 15251 - category 2**
	20	ventilation unit area	Ra	**0,70**	l / s.m2	**EN 15251 - category 2 ; low polluting**

Primary Air Calculation & Beam Specification

The final parts regard the calculation of the air flow needed for dehumidification and the beam selection data.

	nun	description	symbol	cellS	units	formula/source
occupancy load	21	occupant load, sens/p	OCP_S	75	W	ASHRAE Fundamentals
	22	occupant load, lat/p	OCP_L	55	W	ASHRAE Fundamentals
infiltration	23	infiltration airflow	INF	3,9	l/s	ACH_{INF} x Vol / 3,6
	24	infiltration air Changes per Hour	ACH_{INF}	0,3	/h	
loads	25	sensible load (clg design cdts)	L_{SENS}	800	W	from loads calcuation
	26	latent load (dehumd.dsg cdts)	L_{LAT}	94	W	NP x OCP_L + (INF/1000) x 1,2 x 2.500 x (HR_{ODA2} - HR_{IDA})
	27	**airflow for dehumidification**	**V2**	**15**	**l/s**	1000 x L_{LAT} / [1,2 x 2500 x (HR_{IDA} - HR_{SUP})]
Beam selection data	28	Beam chilled water temp. in	CWTin	16,0	ºC	
	29	Safety temperature difference	dT	0,0	ºC	CWTin - DP_{IDA}
	30	**primary airflow**	**V**	**19**	**l/s**	max (V1 ; V2)
	31	primary air temperature	DB_{SUP}	14,0	ºC	
	32	primary air dew point	DP_{SUP}	13,0	ºC	psychart
	33	primary air relative humidity	RH_{SUP}	94	%	psychart
	34	primary air humidity ratio	HR_{SUP}	9,4	g/kg	psychart
	35	cooling by air (primary airflow)	Cair	245	W	V x 1,2 x (DB_{IDA} - DB_{SUP})
	36	cooling by water (water coil)	C_W	555	W	L_{SENS} - Cair
	37	cooling by water (water coil)	C_W	69%	%	C_W / L_{SENS}

Primary Air Calculation & Beam Specification

	nun	description	symbol	cellS	cellSE	openplanN	openplanNE	meetingE	interior1	units	formula/source
ODA design dondition	1	location	-	Lisbon	Lisbon	Lisbon	Lisbon	Lisbon	Lisbon	-	
	2	ODA design condition cooling	DB_{ODA1}	32,1	32,1	32,1	32,1	32,1	32,1	ºC	ASHRAE Fundamentals 1% criteria
	3	ODA design condition cooling	$MCWB_{ODA1}$	19,7	19,7	19,7	19,7	19,7	19,7	ºC	ASHRAE Fundamentals 1% criteria
	4	ODA design condition cooling	HR_{ODA1}	9,3	9,3	9,3	9,3	9,3	9,3	g/kg	ASHRAE Fundamentals 1% criteria
	5	ODA design condition dehumid	DP_{ODA2}	20,0	20,0	20,0	20,0	20,0	20,0	ºC	ASHRAE Fundamentals 1% criteria
	6	ODA design condition dehumid	$MCDB_{ODA2}$	22,7	22,7	22,7	22,7	22,7	22,7	ºC	ASHRAE Fundamentals 1% criteria
	7	ODA design condition dehumid	HR_{ODA2}	14,8	14,8	14,8	14,8	14,8	14,8	g/kg	ASHRAE Fundamentals 1% criteria
	8	ODA design condition heating	DB_{ODA3}	5,8	5,8	5,8	5,8	5,8	5,8	ºC	ASHRAE Fundamentals 1% criteria
IDA design conditions	9	IDA design condition cooling	DB_{IDA}	25,0	25,0	25,0	25,0	25,0	25,0	ºC	Owner Projet Requirements
	10	IDA design condition cooling	DP_{IDA}	16,0	16,0	16,0	16,0	16,0	16,0	ºC	CWTin - dT
	11	IDA design condition cooling	HR_{IDA}	11,4	11,4	11,4	11,4	11,4	11,4	g/kg	psychart
	12	IDA design condition cooling	RH_{IDA}	57,5	57,5	57,5	57,5	57,5	57,5	%	psychart
dimensions	13	floor area	A	16,5	23,5	23,5	23,5	39,5	31,0	m2	
	14	ceiling height	h	2,8	2,8	2,8	2,8	2,8	2,8	m	
	15	volume	Vol	46	66	66	66	111	87	m3	A x h
ventilation	16	occupancy	NP	1	2	4	4	10	4	-	
	17	**ventilation requirement**	**V1**	**19**	**30**	**44**	**44**	**98**	**50**	**l/s**	EN15251 : 2007 (Rp x NP + Ra x A)
	18	Air Changes per Hour	ACH	1,4	1,7	2,4	2,4	3,2	2,1	/h	V x 3,6 / Vol
	19	ventilation per person	Rp	7,0	7,0	7,0	7,0	7,0	7,0	l / s.p	EN 15251 - category 2
	20	ventilation unit area	Ra	0,70	0,70	0,70	0,70	0,70	0,70	l / s.m2	EN 15251 - category 2 ; low polluting
occupancy	21	occupant load, sens/p	OCP_S	75	75	75	75	75	75	W	ASHRAE Fundamentals
	22	occupant load, lat/p	OCP_L	55	55	55	55	55	55	W	ASHRAE Fundamentals
infiltration	23	infiltration airflow	INF	3,9	5,5	5,5	5,5	9,2	0,0	l/s	ACH_{INF} x Vol / 3,6
	24	infiltration air Changes per Hour	ACH_{INF}	0,3	0,3	0,3	0,3	0,3	0,0	/h	
loads	25	sensible load (clg design cdts)	L_{SENS}	800	1.200	1.500	1.800	3.000	1.400	W	from loads calcuation
	26	latent load (dehumd.dsg cdts)	L_{LAT}	94	165	275	275	643	220	W	NP x OCP_L + (INF/1000) x 1,2 x 2.500 x (HR_{ODA2} - HR_{IDA})
	27	**airflow for dehumidification**	**V2**	**15**	**27**	**45**	**45**	**105**	**36**	**l/s**	1000 x L_{LAT} / [1,2 x 2500 x (HR_{IDA} - HR_{SUP})]
Beam selection data	28	Beam chilled water temp. in	CWTin	16,0	16,0	16,0	16,0	16,0	16,0	ºC	
	29	Safety temperature difference	dT	0,0	0,0	0,0	0,0	0,0	0,0	ºC	CWTin - DP_{IDA}
	30	**primary airflow**	**V**	**19**	**30**	**45**	**45**	**105**	**50**	**l/s**	max (V1 ; V2)
	31	primary air temperature	DB_{SUP}	14,0	14,0	14,0	14,0	14,0	14,0	ºC	
	32	primary air dew point	DP_{SUP}	13,0	13,0	13,0	13,0	13,0	13,0	ºC	psychart
	33	primary air relative humidity	RH_{SUP}	94	94	94	94	94	94	%	psychart
	34	primary air humidity ratio	HR_{SUP}	9,4	9,4	9,4	9,4	9,4	9,4	g/kg	psychart
	35	cooling by air (primary airflow)	Cair	245	402	593	593	1.386	656	W	V x 1,2 x (DB_{IDA} - DB_{SUP})
	36	cooling by water (water coil)	C_W	555	798	907	1.207	1.614	744	W	L_{SENS} - Cair
	37	cooling by water (water coil)	C_W	69%	67%	60%	67%	54%	53%	%	C_W / L_{SENS}

Primary Air Calculation & Beam Specification

reference	Floor plan	reference in the floor plan	type of space	total cooling load (kW)	sensible cooling load (kW)	latent cooling load (kW)	ventilation effectiveness	type of building	metabolism	EN15251, air flow people (l/s)	EN15251, air flow blding (l/s)	EN15251, air flow (l/s)	Code, air flow people (l/s)	Code, air flow blding (l/s)	Code, air flow (l/s)	**Ventilation air flow (l/s)**	primary air, DB temp (ºC)	primary air, DP temp (ºC)	primary air, Humidity ratio (g/kg)	indoor air, DP temp (ºC)	indoor air, Humidity ratio (g/kg)	indoor air, rel. humidity (%)	**dehumidification air flow (l/s)**	**primary air flow** ventilation&dehumid **(l/s)**	beam type	beam quantities	primary air / beam (l/s)	**primary air flow** beam selection **(l/s)**	primary air cooling (kW)	primary air cooling (%)
2	3	4	5	212	22	23	24	25	28	26	27	29	30	31	32	33	34	35	36	37	38	39	40	41	46	46.	46.	46.1	46.2	46.3
11.19	11	19	1	2,17	1,98	0,19	1,0	LP	1,20	14	11	25	13	13	13	25	15,5	10,0	7,7	14,0	10,0	53,5	27	27	2	4	19	76	0,775	39%
12.1	12	1	1	2,77	2,54	0,24	1,0	LP	1,20	7	15	22	7	18	18	22	15,5	10,0	7,7	14,0	10,0	53,5	33	33	2	5	19	95	0,969	38%
14.22	14	22	1	2,41	2,19	0,21	1,0	LP	1,20	7	12	19	7	15	15	19	15,5	10,0	7,7	14,0	10,0	53,5	30	30	2	4	19	76	0,775	35%
14.26	14	26	1	6,68	6,13	0,55	1,0	LP	1,20	28	32	60	27	37	37	60	15,5	10,0	7,7	14,0	10,0	53,5	77	77	2	11	19	209	2,132	35%
13.1	13	1	1	3,70	3,39	0,32	1,0	LP	1,20	7	21	28	7	24	24	28	15,5	10,0	7,7	14,0	10,0	53,5	45	45	2	6	19	114	1,163	34%
14.36	14	36	1	0,85	0,71	0,14	1,0	LP	1,20	14	9	23	13	11	13	23	15,5	10,0	7,7	14,0	10,0	53,5	20	23	6	1	24	24	0,240	34%
14.38	14	38	1	1,95	1,79	0,16	1,0	LP	1,20	14	9	23	13	11	13	23	15,5	10,0	7,7	14,0	10,0	53,5	22	23	2	3	19	57	0,581	32%
15.1	15	1	1	18,98	17,21	1,77	1,0	LP	1,20	63	117	180	60	139	139	180	15,5	10,0	7,7	14,0	10,0	53,5	251	251	1	12	44	528	5,386	31%
14.12	14	12	1	5,26	4,38	0,88	1,0	LP	1,20	35	58	93	33	69	69	93	15,5	10,0	7,7	14,0	10,0	53,5	124	124	1	3	44	132	1,346	31%
13.24	13	24	1	3,85	3,51	0,34	1,0	LP	1,20	49	20	69	47	23	47	69	15,5	10,0	7,7	14,0	10,0	53,5	48	69	2	5	19	95	0,969	28%
11.16	11	16	1	2,35	2,16	0,19	1,0	LP	1,20	7	11	18	7	13	13	18	15,5	10,0	7,7	14,0	10,0	53,5	27	27	2	3	19	57	0,581	27%
10.11	10	11	1	2,41	2,21	0,19	1,0	LP	1,20	7	11	18	7	14	14	18	15,5	10,0	7,7	14,0	10,0	53,5	28	28	2	3	19	57	0,581	26%
12.12	12	12	1	3,24	2,98	0,26	1,0	LP	1,20	7	15	22	7	18	18	22	15,5	10,0	7,7	14,0	10,0	53,5	37	37	2	4	19	76	0,775	26%
13.17	13	17	1	3,31	3,04	0,27	1,0	LP	1,20	14	16	30	13	19	19	30	15,5	10,0	7,7	14,0	10,0	53,5	38	38	2	4	19	76	0,775	26%
11.15	11	15	1	5,82	5,35	0,47	1,0	LP	1,20	28	28	56	27	33	33	56	15,5	10,0	7,7	14,0	10,0	53,5	67	67	2	7	19	133	1,357	25%
13.18	13	18	1	1,70	1,56	0,14	1,0	LP	1,20	7	8	15	7	10	10	15	15,5	10,0	7,7	14,0	10,0	53,5	19	19	2	2	19	38	0,388	25%
13.10	13	10	1	3,45	3,18	0,28	1,0	LP	1,20	21	16	37	20	19	20	37	15,5	10,0	7,7	14,0	10,0	53,5	39	39	2	4	19	76	0,775	24%
15.7	15	7	1	2,05	1,92	0,13	1,0	LP	1,20	7	7	14	7	8	8	14	15,5	10,0	7,7	14,0	10,0	53,5	18	18	1	1	44	44	0,449	23%
12.4	12	4	1	3,73	3,43	0,30	1,0	LP	1,20	21	18	39	20	21	21	39	15,5	10,0	7,7	14,0	10,0	53,5	43	43	2	4	19	76	0,775	23%
15.2	15	2	1	11,91	10,62	1,29	1,0	LP	1,20	63	93	156	60	110	110	156	15,5	10,0	7,7	14,0	10,0	53,5	183	183	1	5	44	220	2,244	21%
11.23	11	23	1	13,37	12,28	1,09	1,0	LP	1,20	112	63	175	107	75	107	175	15,5	10,0	7,7	14,0	10,0	53,5	155	175	2	13	19	247	2,519	21%
14.37	14	37	1	2,11	1,94	0,17	1,0	LP	1,20	14	10	24	13	12	13	24	15,5	10,0	7,7	14,0	10,0	53,5	24	24	2	2	19	38	0,388	20%
14.10	14	10	1	3,19	2,93	0,26	1,0	LP	1,20	21	17	38	20	20	20	38	15,5	10,0	7,7	14,0	10,0	53,5	37	38	2	3	19	57	0,581	20%
13.33	13	33	1	6,78	6,24	0,55	1,0	LP	1,20	42	32	74	40	38	40	74	15,5	10,0	7,7	14,0	10,0	53,5	78	78	2	6	19	114	1,163	19%
13.9	13	9	1	5,87	5,40	0,47	1,0	LP	1,20	21	28	49	20	33	33	49	15,5	10,0	7,7	14,0	10,0	53,5	67	67	2	5	19	95	0,969	18%
14.4	14	4	1	2,31	2,18	0,13	1,0	LP	1,20	7	13	20	7	15	15	20	15,5	10,0	7,7	14,0	10,0	53,5	19	20	2	2	19	38	0,388	18%
11.17	11	17	1	3,71	3,41	0,30	1,0	LP	1,20	7	18	25	7	21	21	25	15,5	10,0	7,7	14,0	10,0	53,5	42	42	2	3	19	57	0,581	17%
																								1.647				2.905		27%

This example is from a <u>real building</u> job. It was a <u>renovation</u> of a building with a very <u>low quality envelope</u>. This example also shows that, even with relatively high sensible loads, it is possible to have a good beam selection, ie, cooling by water > 65%.

Primary Air Calculation & Beam Specification

The use of the spreadsheet facilitates the exercise of trying different base conditions and optimizing the key design parameters, namely;

- CWT_{IN} , chilled water temperature supplied to the beams,
- dT, safety temperature difference,
- DP_{IDA}, indoor air dew point temperature,
- DP_{SUP}, primary air dew point,
- DB_{SUP}, primary air dry bulb temperature.

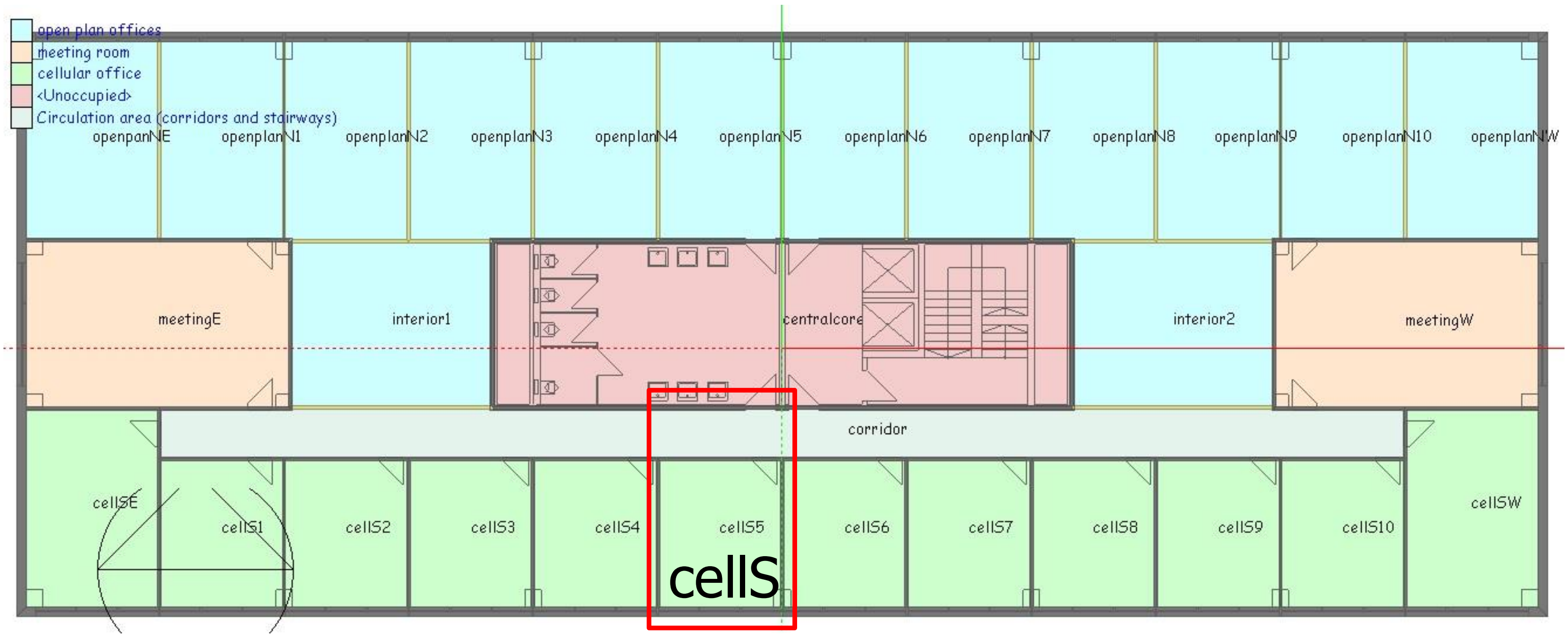
The actual beam selection may require the adjustment of some of the parameters and also reveal the need to increase the primary air flow in order to get to the required sensible cooling capacity in the room.

In any case the beam selection should maximize the amount of cooling done by the water coil. A good beam selection should have over 65% cooling done by the water coil.

Contents of Training

Beam selection in one room module

Beam selection for module cellS.



Beam selection in one room module

The parameters required to perform the beam selection are the following;

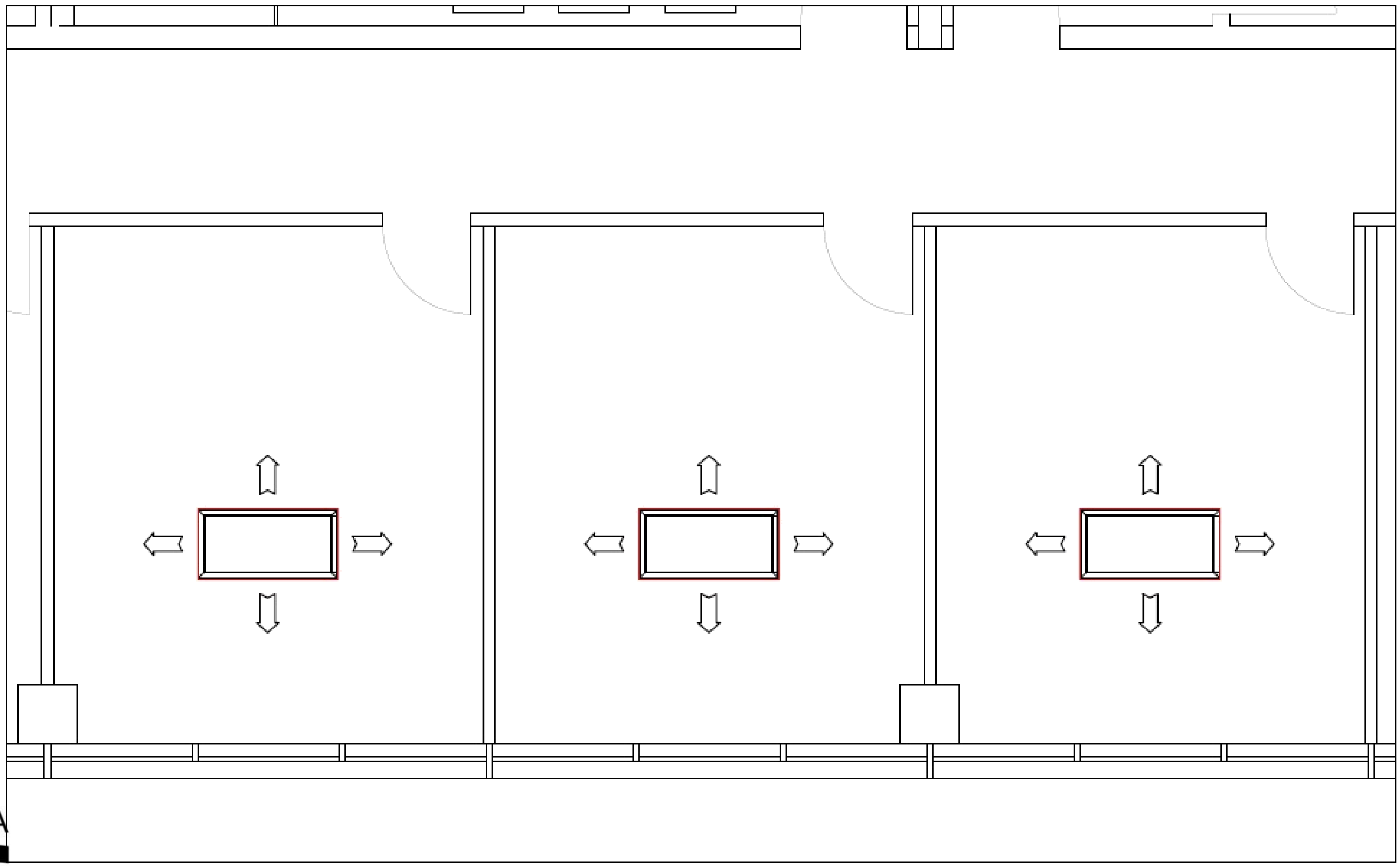
Beam selection data
Module CellS

description	symbol	operator	value	units
IDA design condition cooling	DB_{IDA}	=	25,0	ºC
Beam chilled w ater temp. in	CWTin	≥	16,0	ºC
Beam chilled w ater temp. iout	CWTout	≥	18,0	ºC
pressure drop, w ater	Pd_w	≤	20	kPa
primary airflow	V	=	19	l/s
primary air temperature	DB_{SUP}	=	14,0	ºC
pressure drop, air	Pd_{air}	≤	120	Pa
cooling by air	Cair	=	245	W
cooling by w ater	C_W	≥	555	W
cooling by w ater	C_W	≥	69%	%

These are the fundamental parameters to specify. Other parameters should also be included in the beam specifications, for example; noise, beam type, dimensions, air distribution, materials, accessories, etc.

Beam selection in one room module

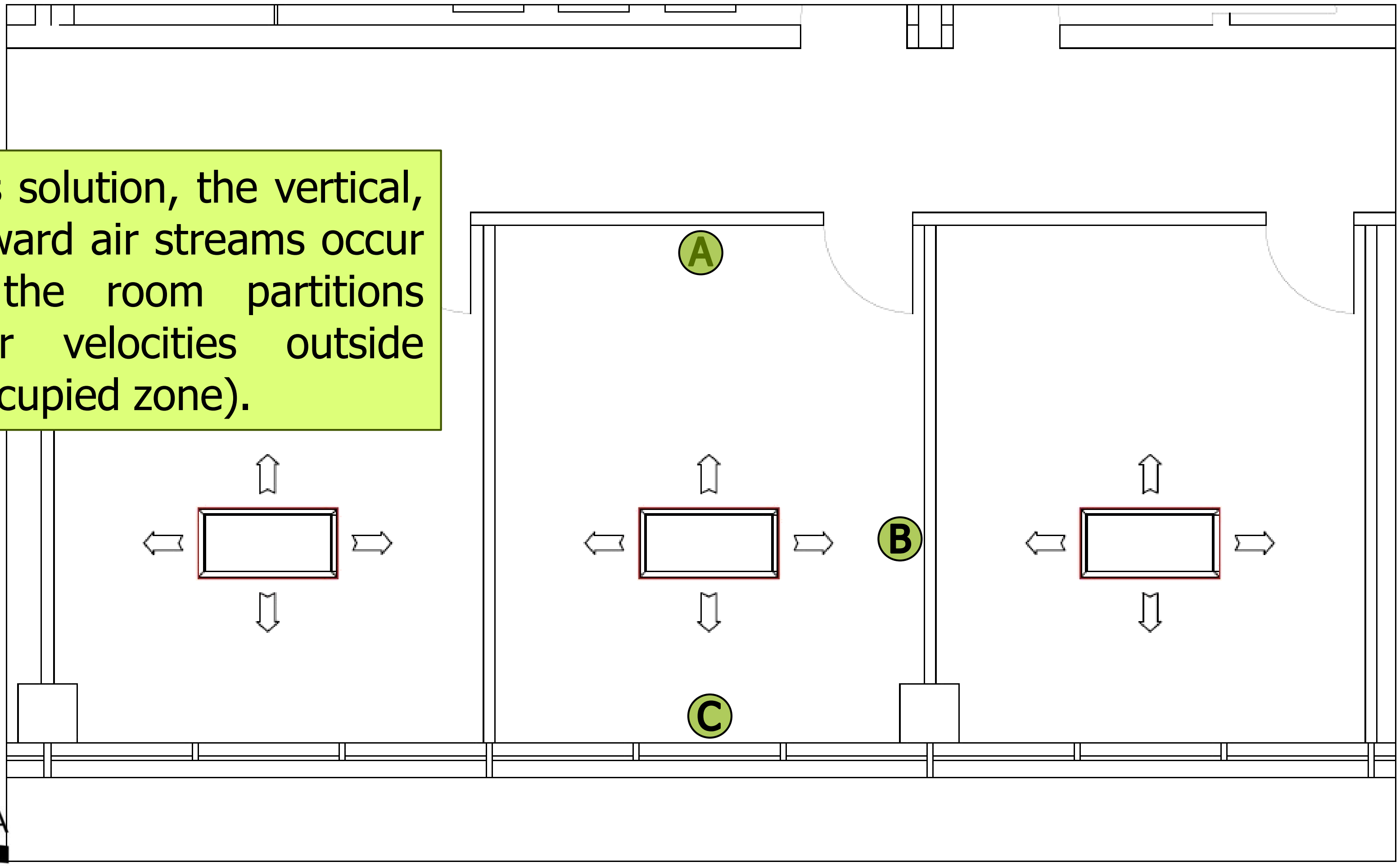
Layout for cellular offices, module cellS, four way beam layout;



Beam selection in one room module

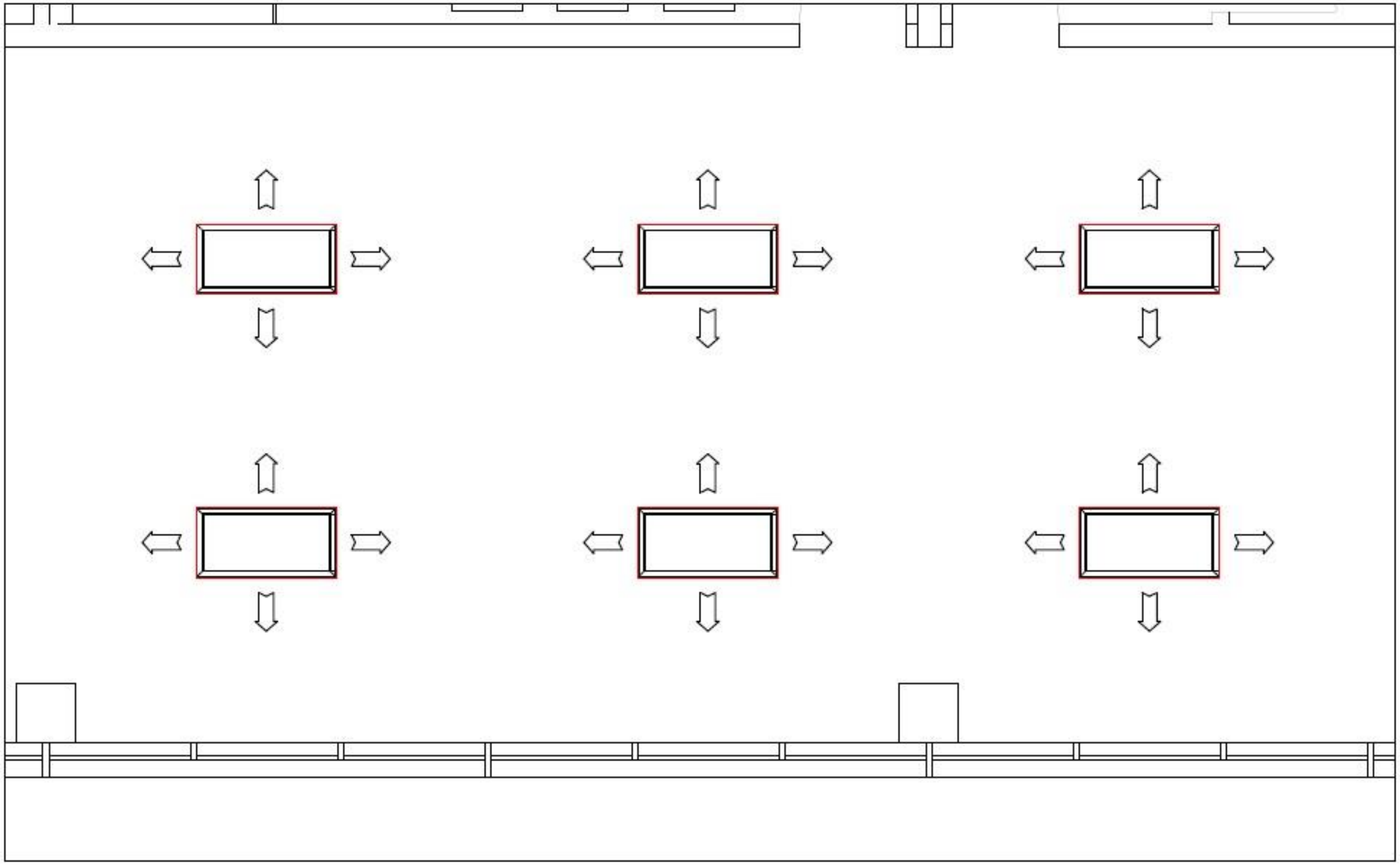
Air velocity must be checked at the critical points; A, B and C.

In this solution, the vertical, downward air streams occur near the room partitions (higher velocities outside the occupied zone).



Beam selection in one room module

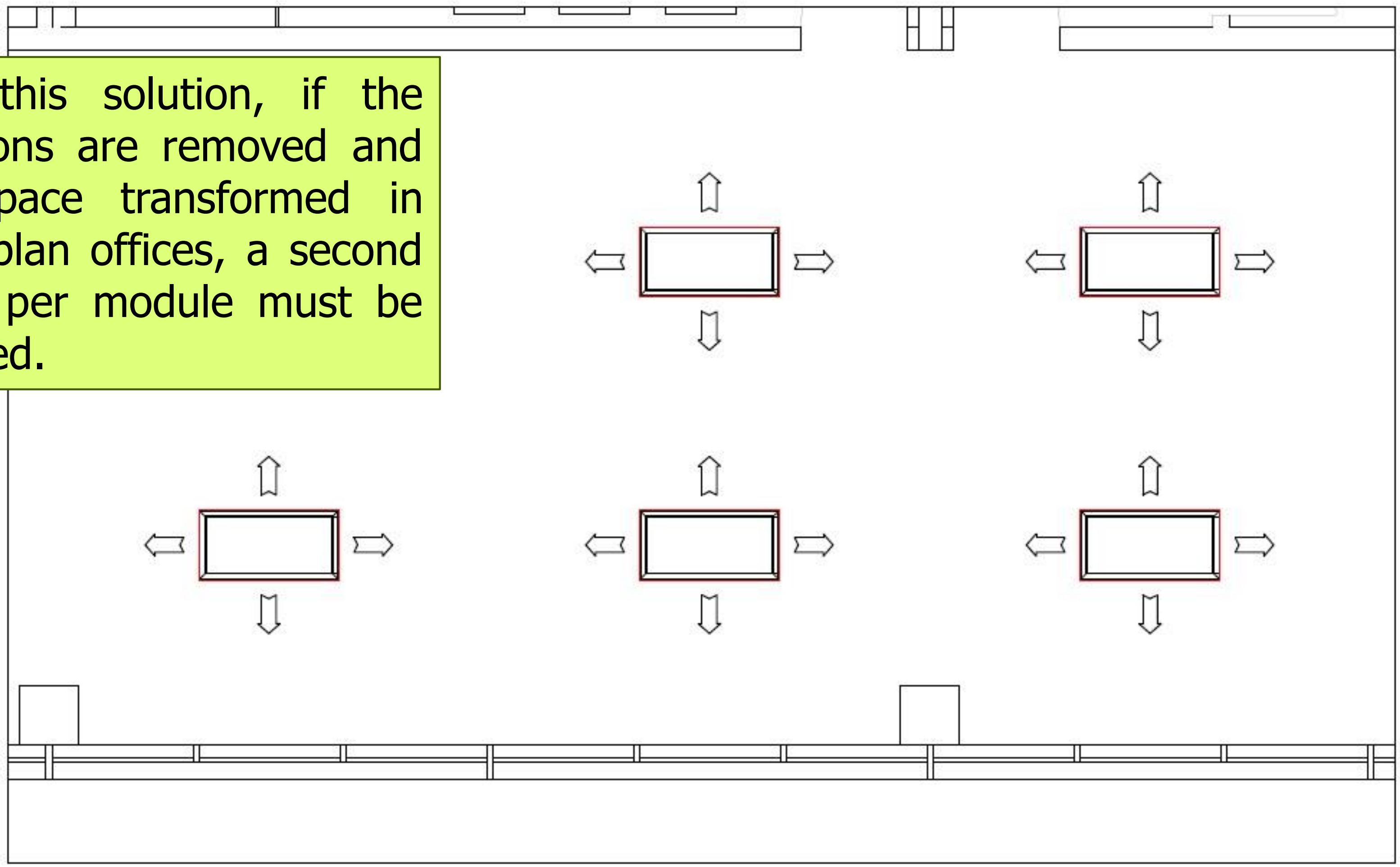
Layout for open plan offices, module openplanS, four way beam layout;



Beam selection in one room module

Layout for open plan offices, module openplanS, <u>four way beam</u> layout;

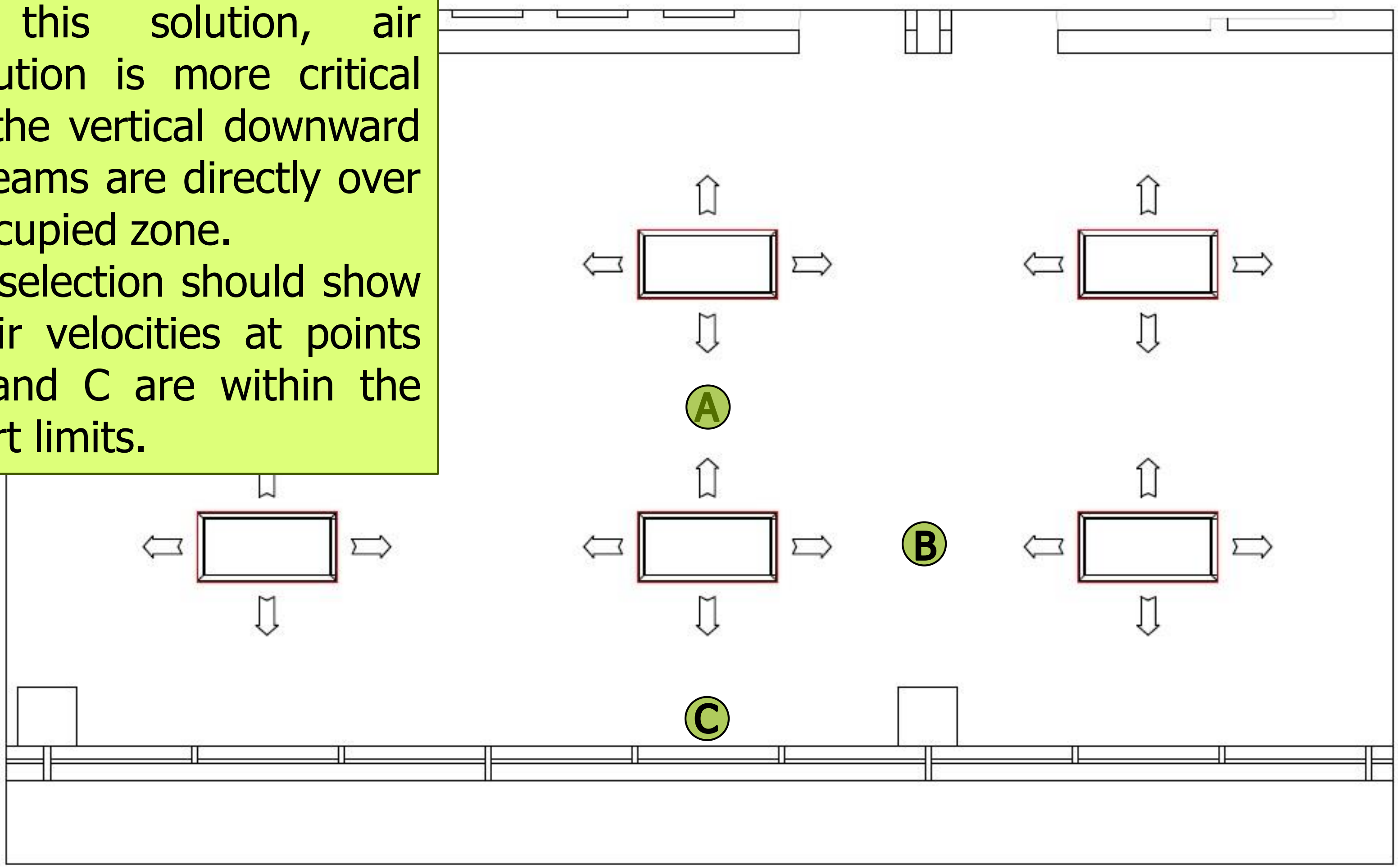
With this solution, if the partitions are removed and the space transformed in open plan offices, a second beam per module must be installed.



Beam selection in one room module

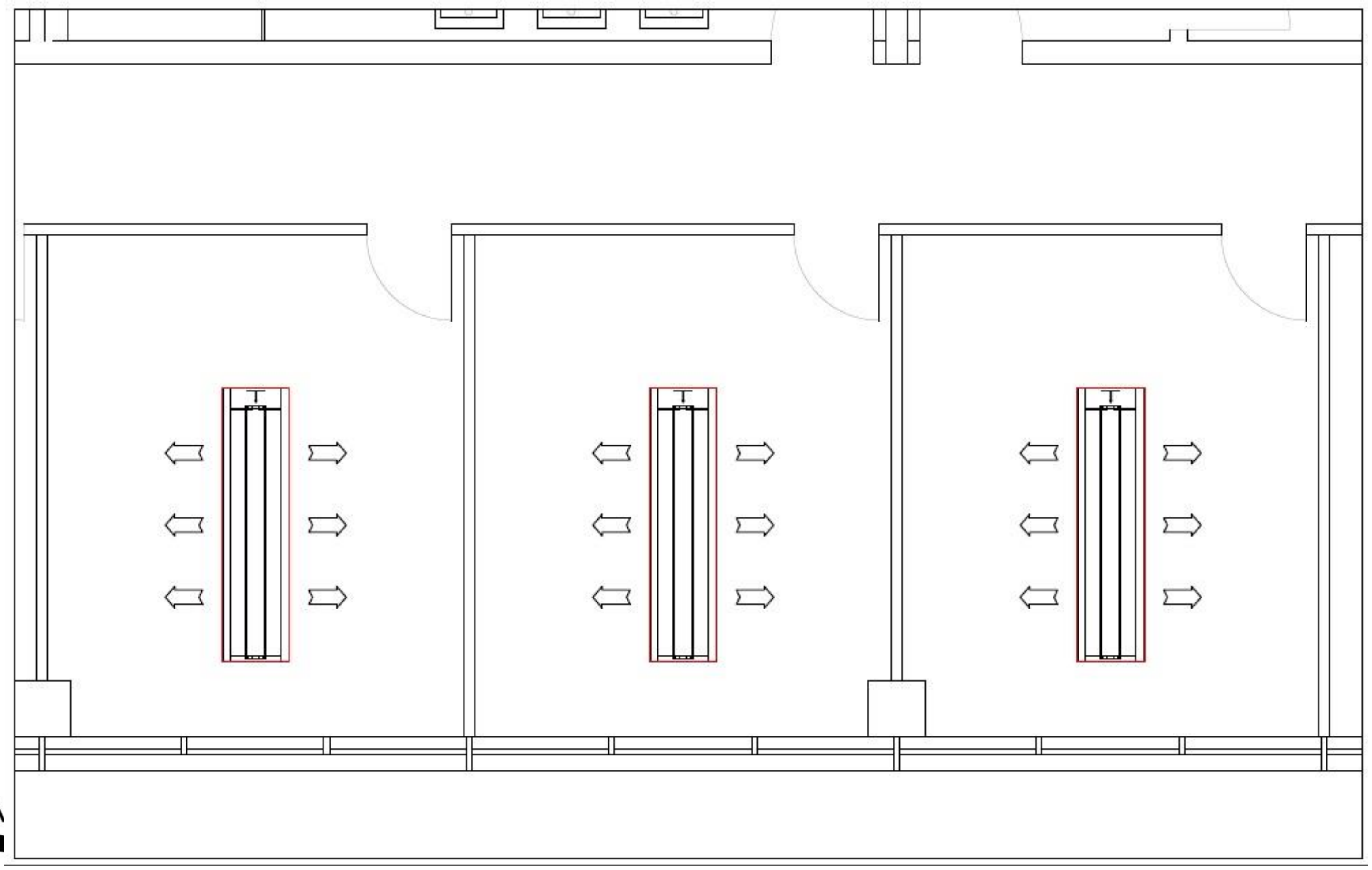
Air velocity must be checked at the critical points; A, B and C.

With this solution, air distribution is more critical since the vertical downward air streams are directly over the occupied zone.
Beam selection should show that air velocities at points A, B and C are within the comfort limits.



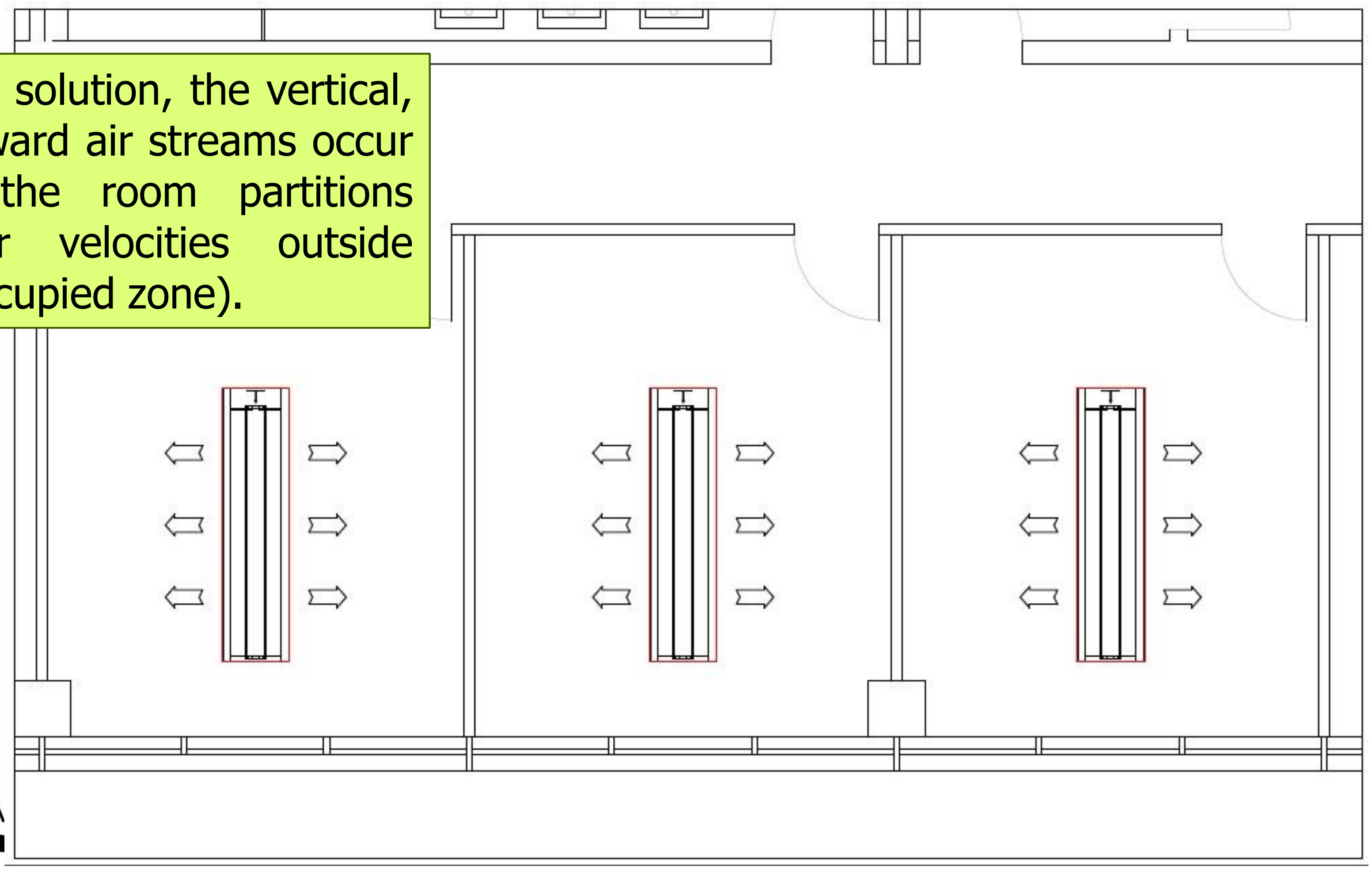
Beam selection in one room module

Layout for cellular offices, module cellS, two way beam layout;



Beam selection in one room module

Layout for cellular offices, module cellS, two way beam layout;

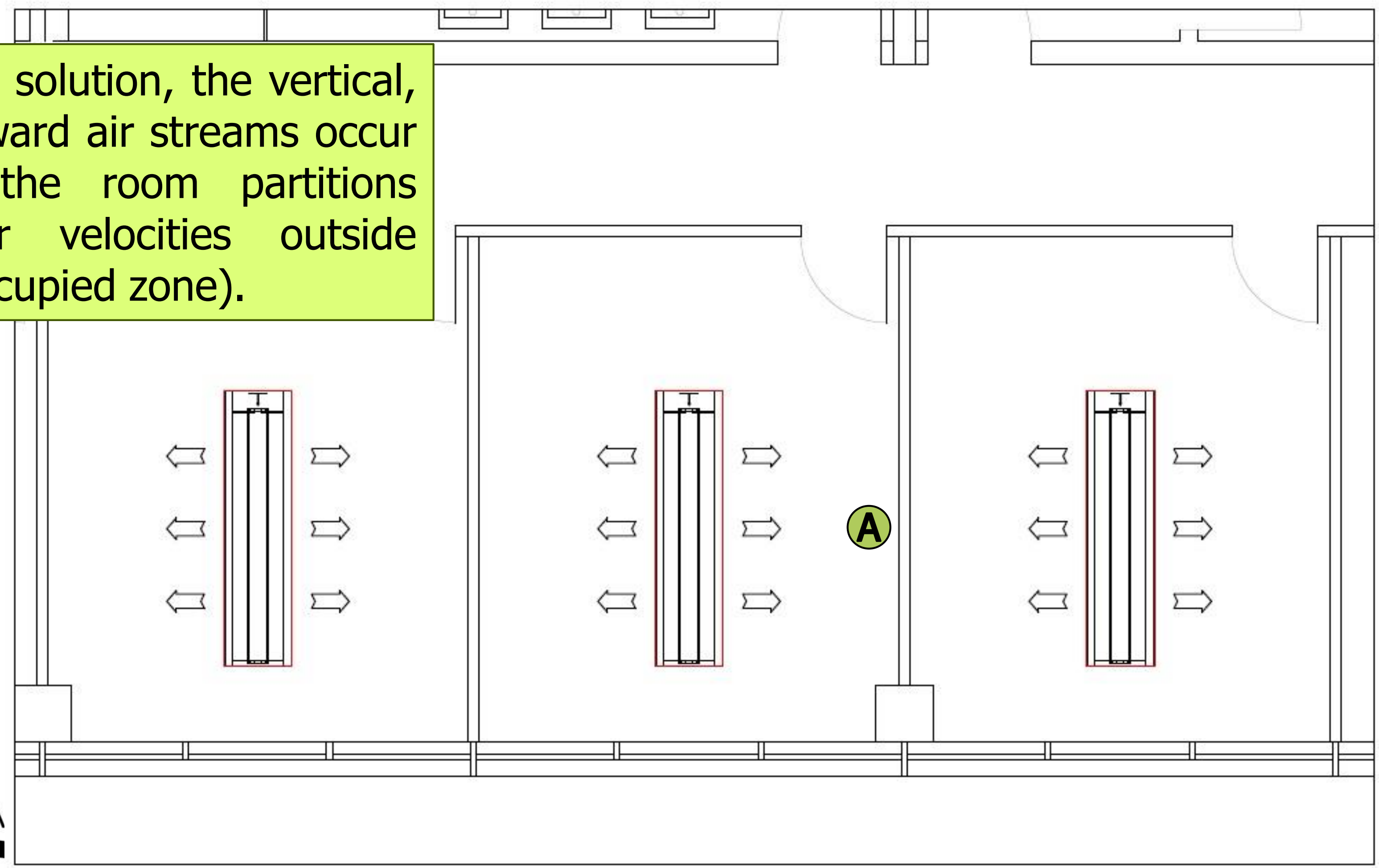


In this solution, the vertical, downward air streams occur near the room partitions (higher velocities outside the occupied zone).

Beam selection in one room module

Layout for cellular offices, module cellS, two way beam layout;

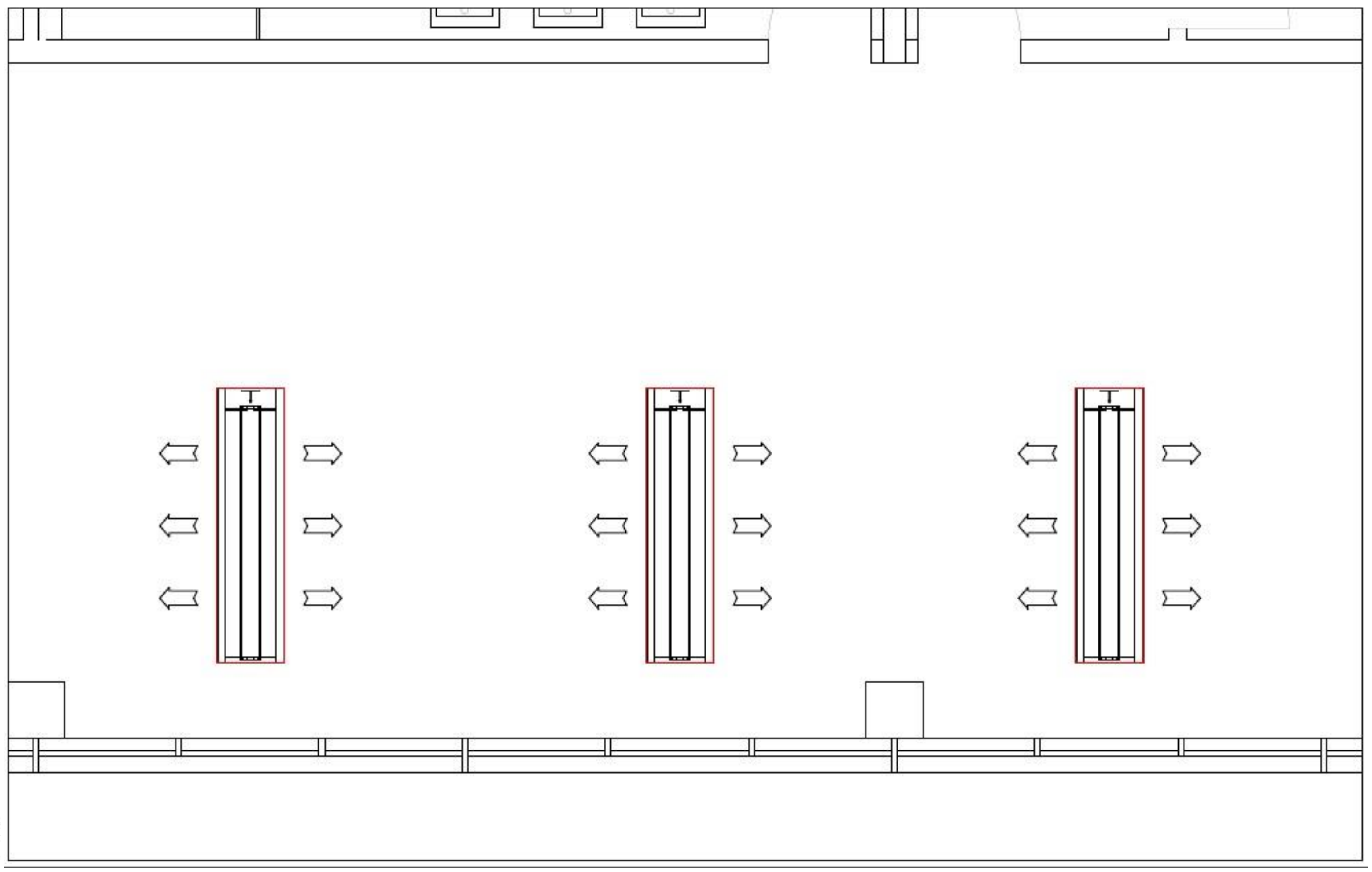
In this solution, the vertical, downward air streams occur near the room partitions (higher velocities outside the occupied zone).



REHVA

Beam selection in one room module

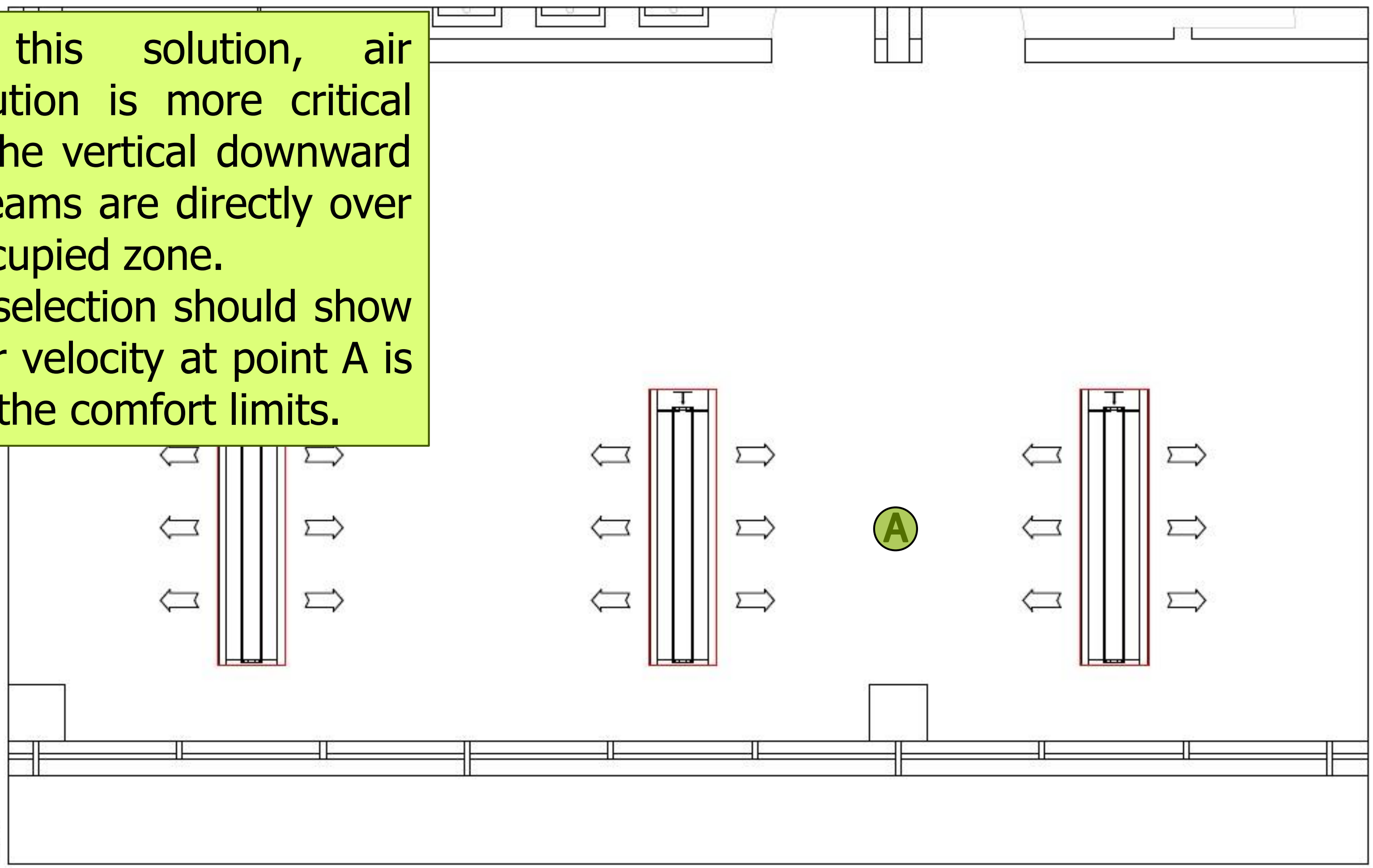
Layout for open plan offices, module cellS, <u>two way beam </u>layout;



Beam selection in one room module

Layout for open plan offices, module cellS, two way beam layout;

With this solution, air distribution is more critical since the vertical downward air streams are directly over the occupied zone.
Beam selection should show that air velocity at point A is within the comfort limits.



Contents of Training

PART I: CHILLED BEAM TECHNOLOGY

- PERFORMANCE AND BENEFITS OF CHILLED BEAM SYSTEM
- FLEXIBILITY AND CONTROL ZONE
- ROOM CONTROL
- THE OVERALL SYSTEM CONCEPT
- THERMAL COMFORT AND ENERGY CONSUMPION
- INSTALLATION AND COMMISSIONING
- nZEB CASE-STUDY BUILDINGS

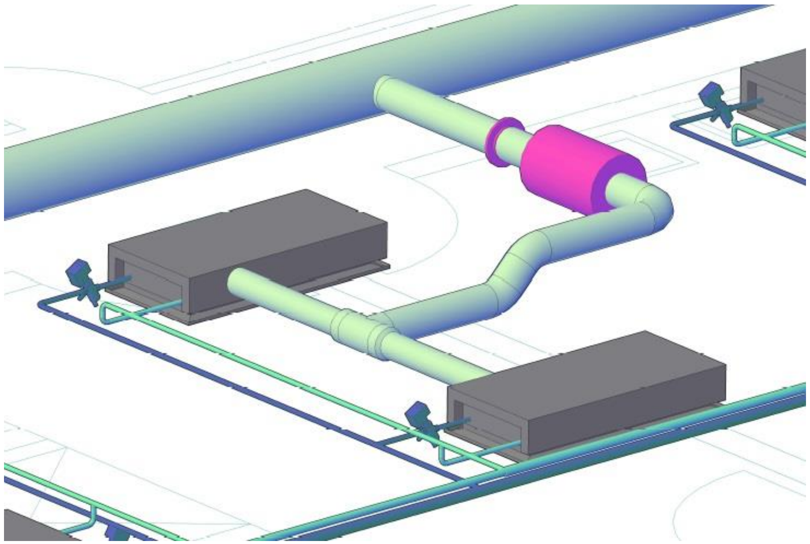
PART II: CHILLED BEAM DESIGN EXAMPLE

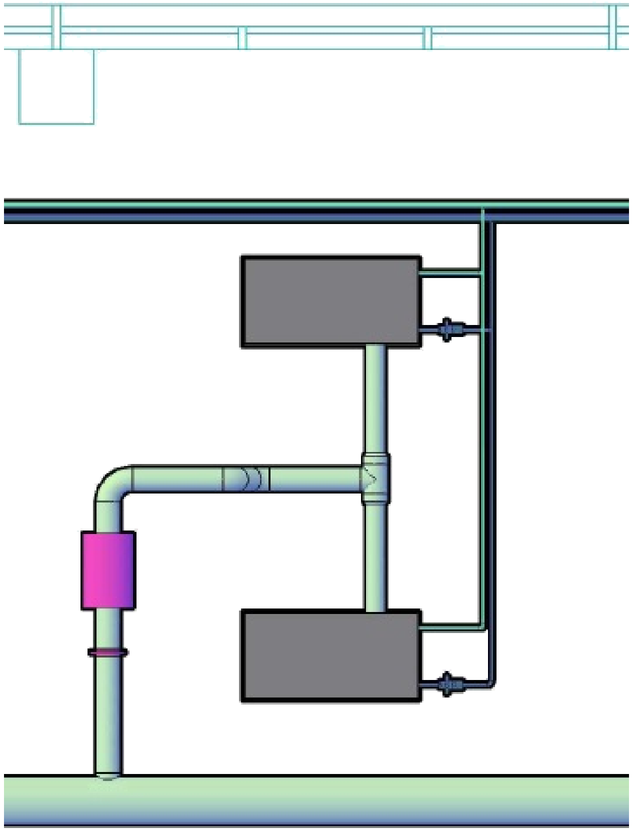
- HEATING&COOLING DEMANDS
- PRIMARY AIR CALCULATION & BEAM SPECIFICATION
- BEAM SELECTION IN ONE ROOM MODULE
- **CONCEPT DESIGN OF A FLOOR LAYOUT**
- CHILLED WATER SYSTEM DESIGN
- PRIMARY AIR HANDLING UNIT DESIGN

Design of the floor layout

Four way beam solution, beam, ducting and piping layout in one module.

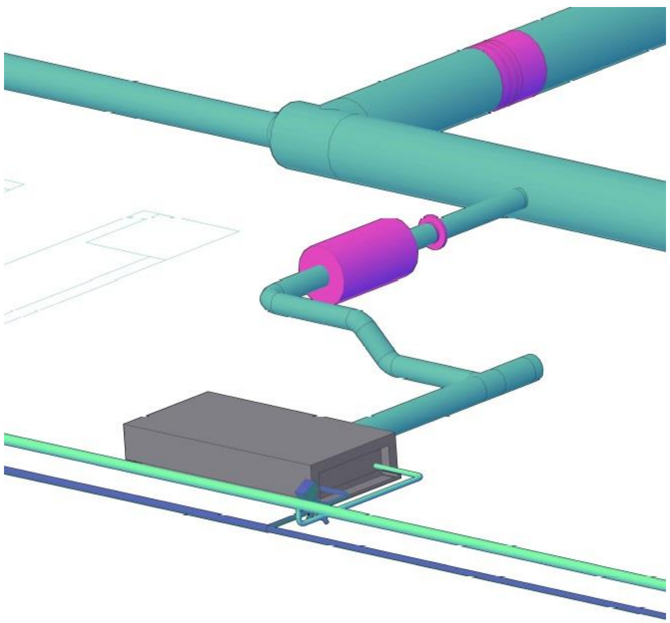
Beam layout, ducting and piping are conceived so that no changes are needed in the case of module compartmentation.

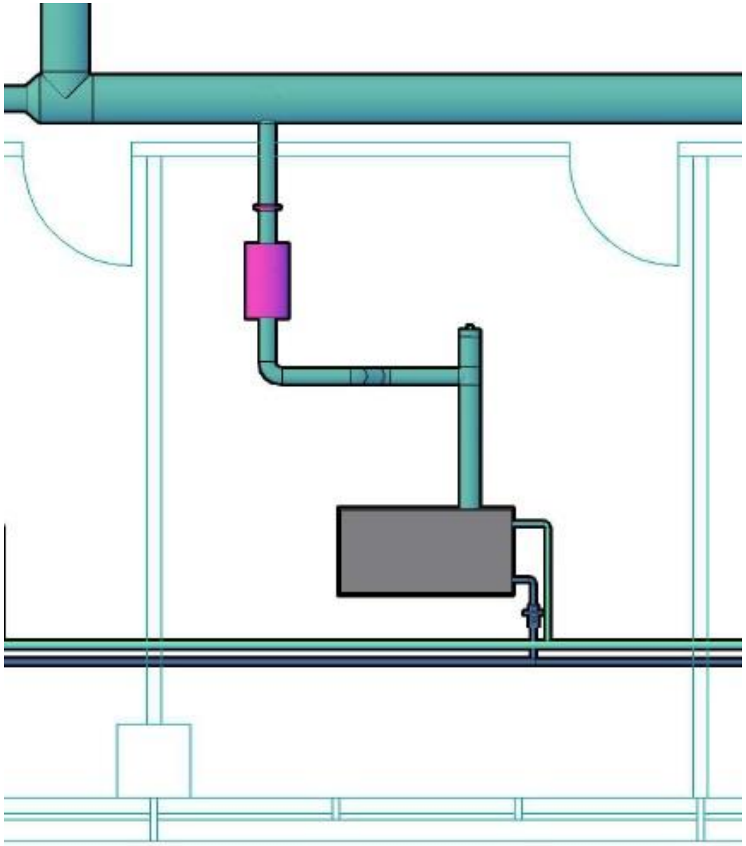




Design of the floor layout

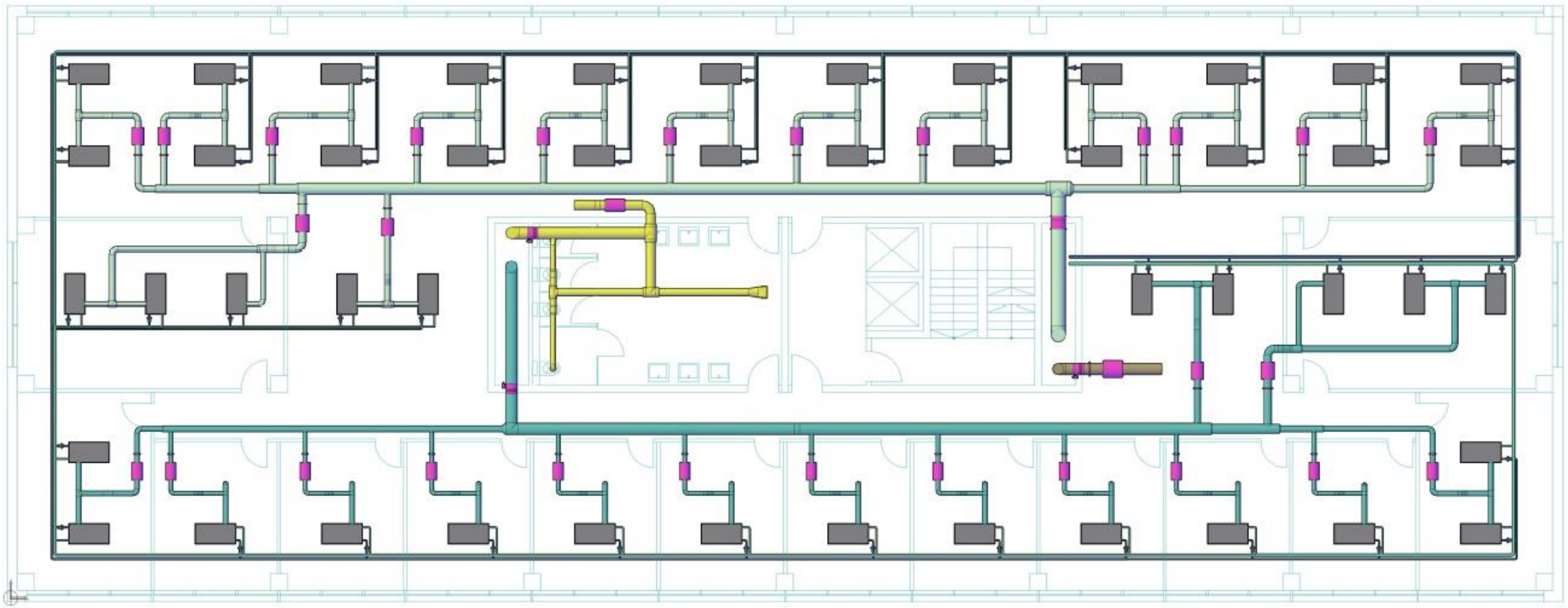
Four way beam solution, beam, ducting and piping layout in one module. Cellular office with low loads. One beam installed and infrastructure prepared for the installation of a second beam.





Design of the floor layout

Four way beam solution, beam, ducting and piping layout.



Duct network in the corridors.

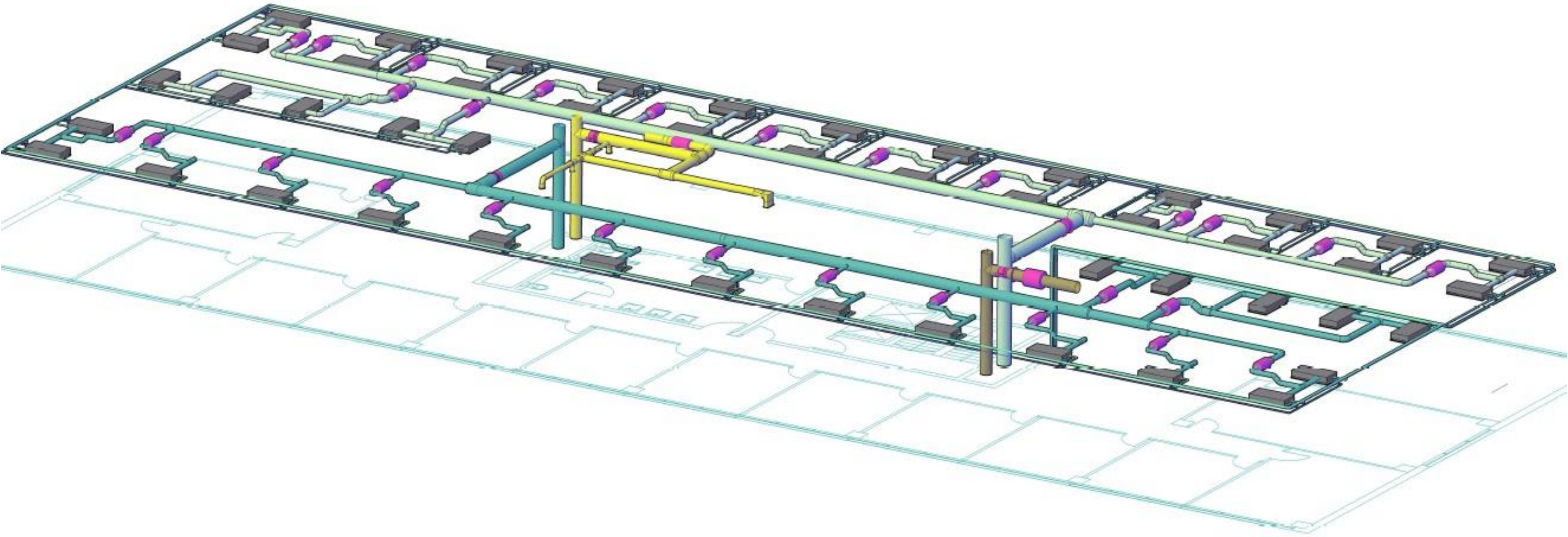
Piping ring in the perimeter minimizing crossings.

Ducted primary air to the beams, extract air unducted through the corridors using transfer air devices (with sound attenuation) in the room partitions.

REHVA

Design of the floor layout

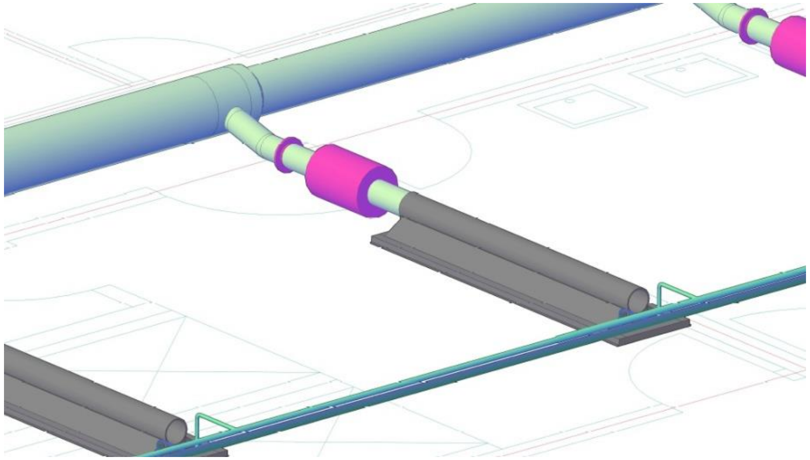
Four way beam solution, beam, ducting and piping layout.

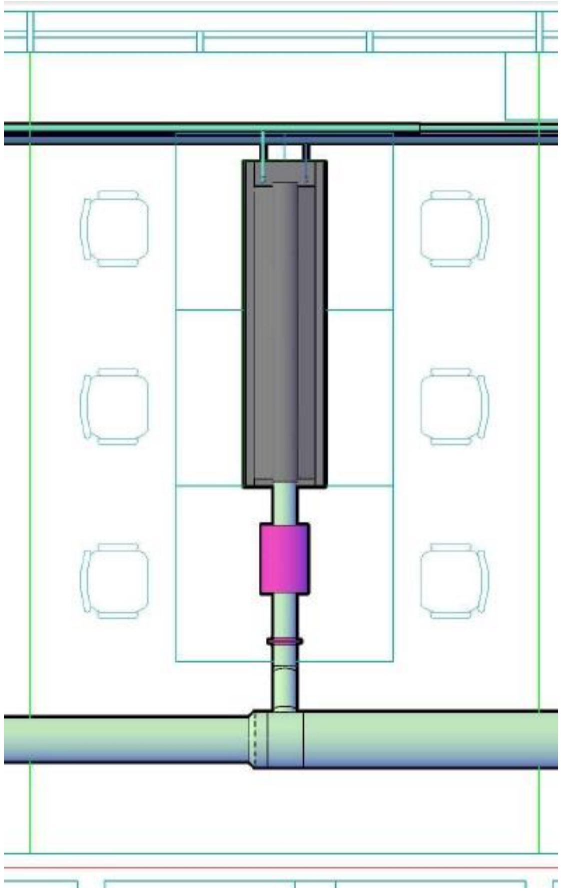


Design of the floor layout

Two way beam solution, beam, ducting and piping layout in one module.

Beam layout, ducting and piping are conceived so that no changes are needed in the case of module compartmentation.

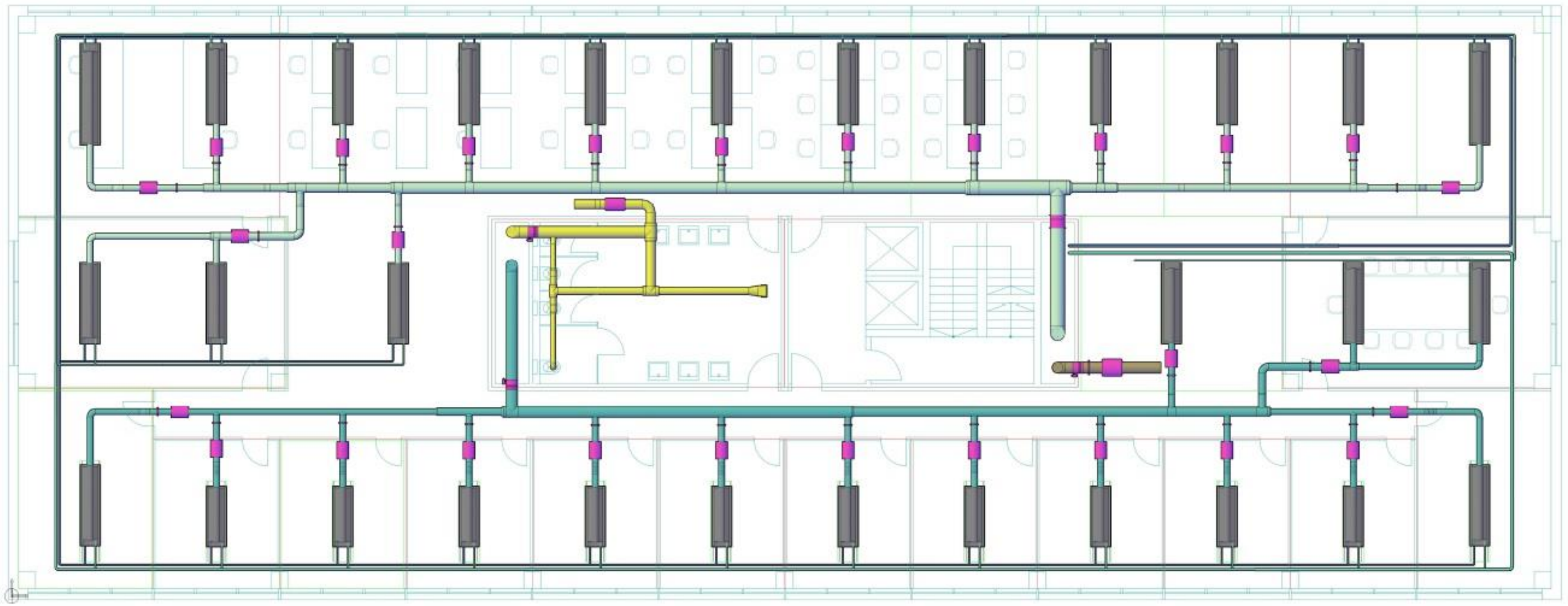




In this solution the beams are selected for the high density loads. Low density loads are managed by blanking beam nozzles.

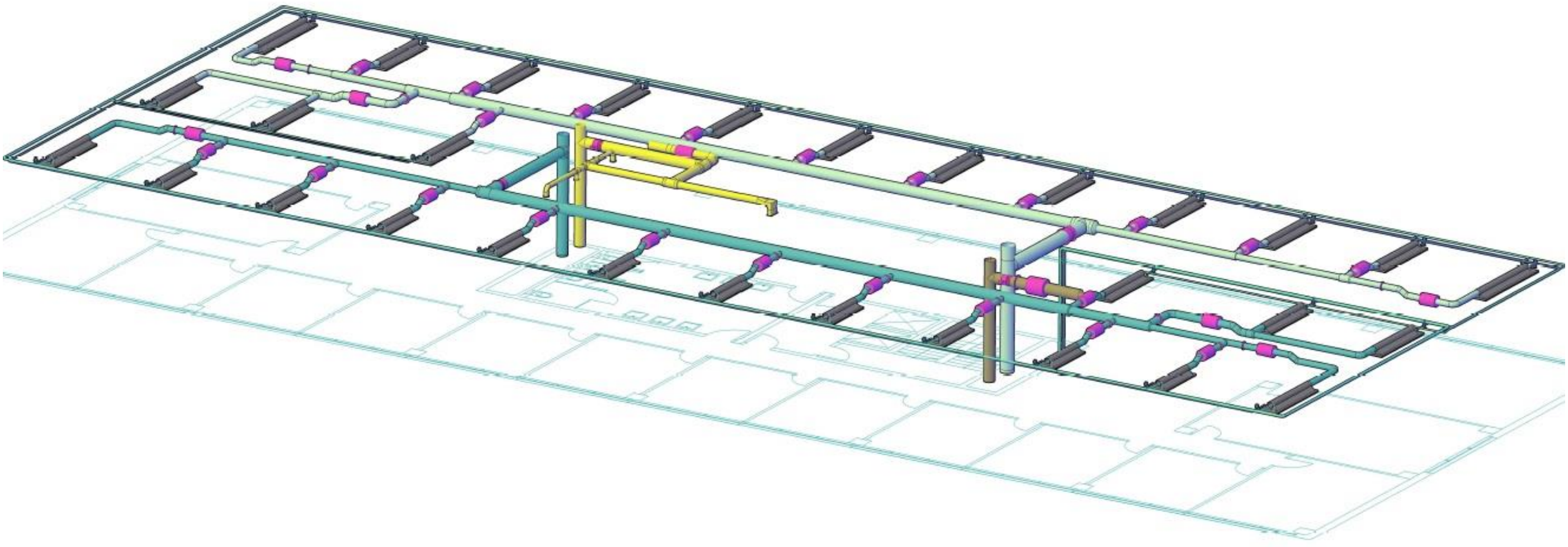
Design of the floor layout

<u>Two way beam</u> solution, beam, ducting and piping layout.



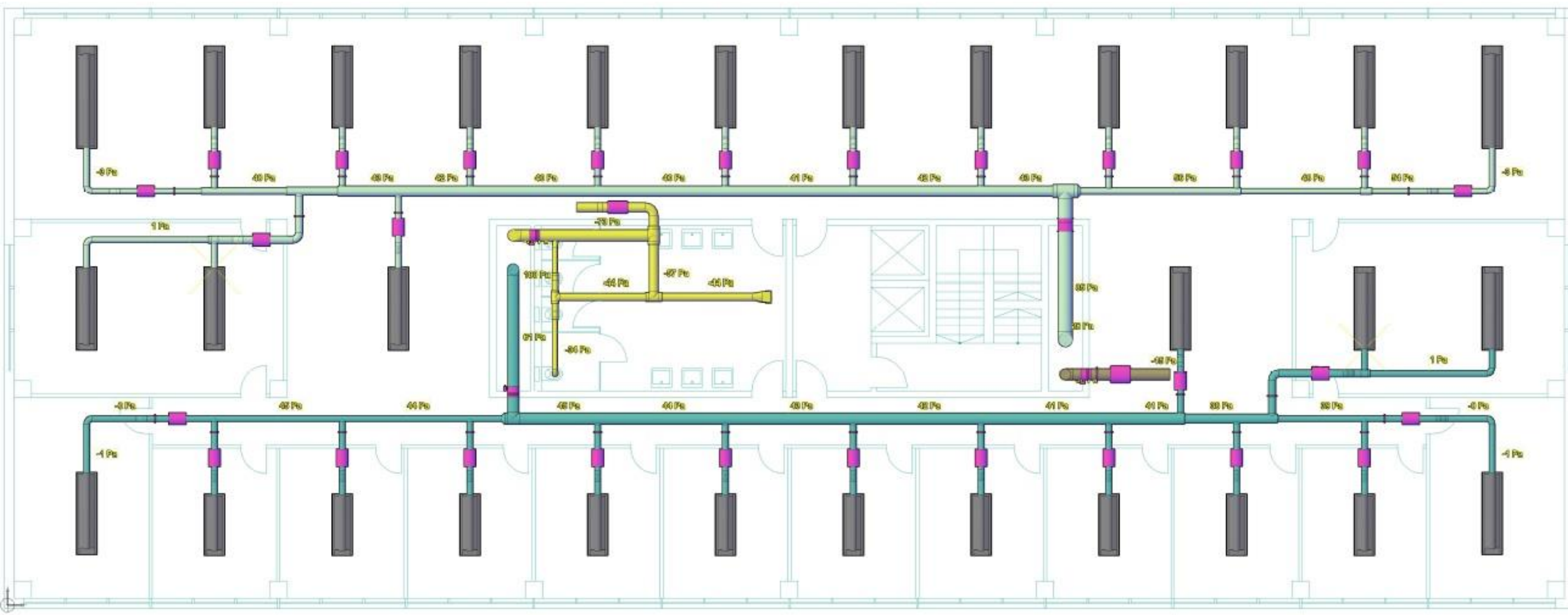
Design of the floor layout

Two way beam solution, beam, ducting and piping layout.



Design of the floor layout

Duct sizing for pressure equalization



Duct is iteratively sized in order to optimize static pressure equalization between all duct branches to the beams.

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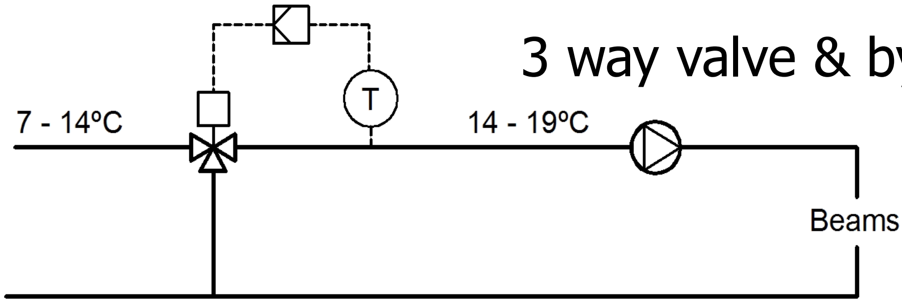
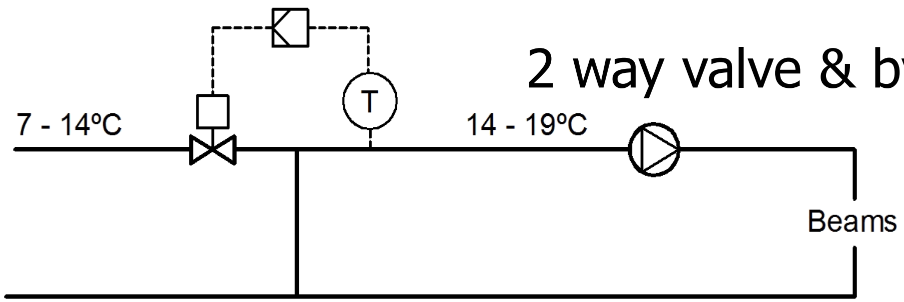
- PRIMARY AIR HANDLING UNIT DESIGN

Chilled water system design

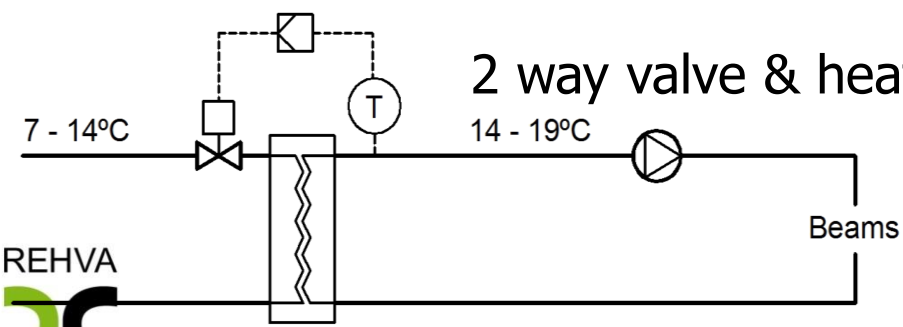
3 way valve & bypass



2 way valve & bypass



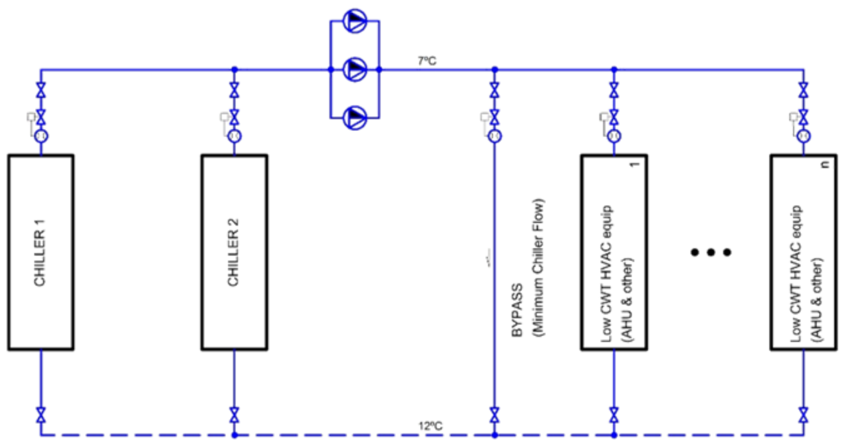
2 way valve & heatexchanger



Quality chilled water temperature control is necessary to prevent condensation risk, maintaining chilled water temperature at or above indoor air dewpoint.

Chilled water system design

Conventional system. Only low temperature HVAC units.

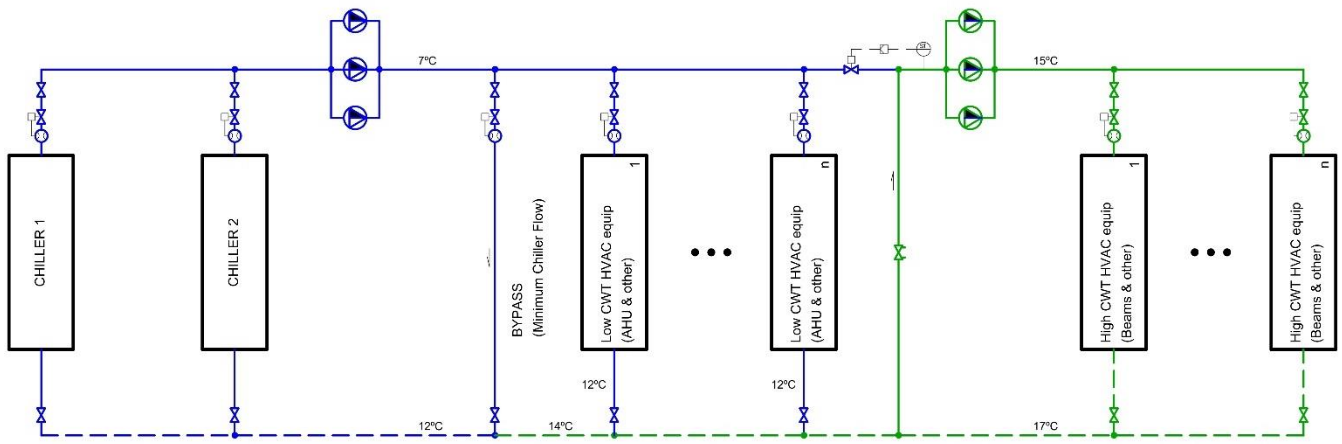


Most common system, operating with chilled water leaving ar 7ºC and,(hopeffully) returning at 12.ºC. Usually return water temperatures are much lower than 12ºC decreasing chiller efficiency.

Chilled water system design

Beam system, low and high temperature HVAC units.

Mixing system.



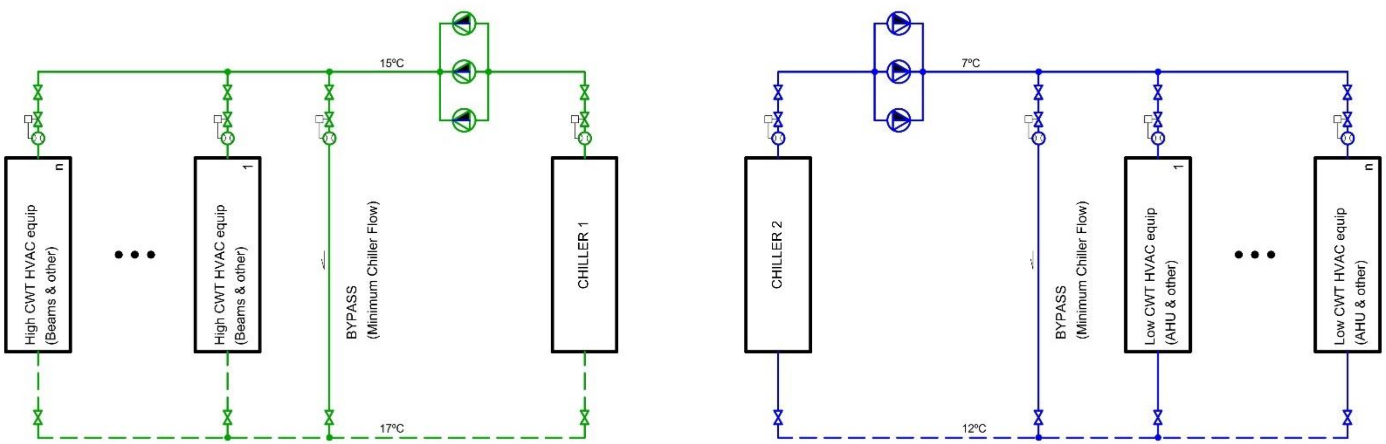
Most common beam water system. Chillers produce 7ºC chilled water. Beam water circuit uses a mixing system.

Chiller efficiency is increased due to the higher return water temperature.

Chilled water system design

Dedicated separated chillers for beams and for AHUs.

Two independent systems.



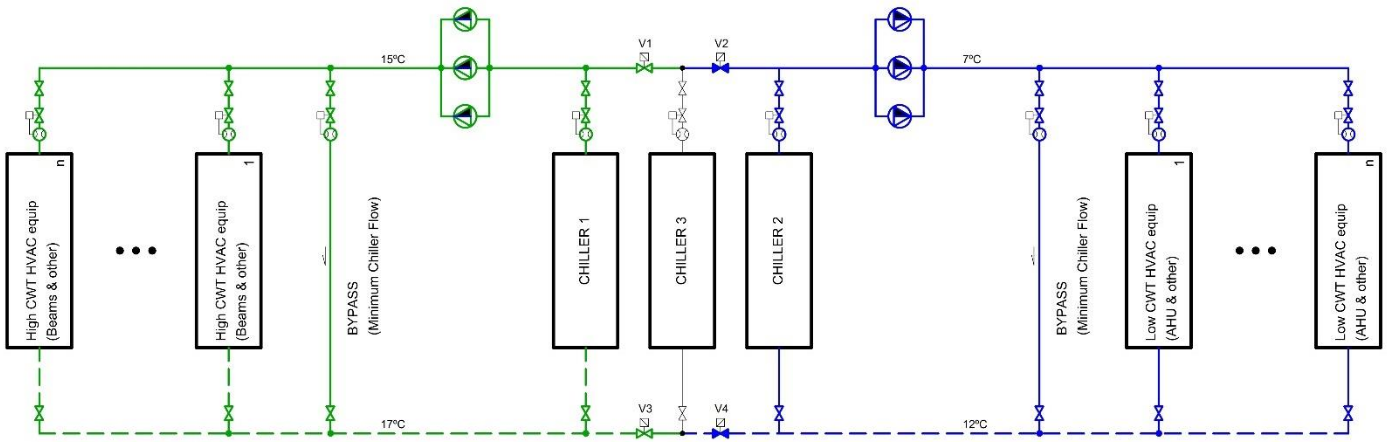
Best efficiency solution. Beam system is served by dedicated Chillers producing 15ºC coolled water. Simple and reliable solution.

A complete separation reduces redundancy.

Chilled water system design

Dedicated separated chillers for beams and for AHUs.

Redundant chiller, N+1, serves both systems.

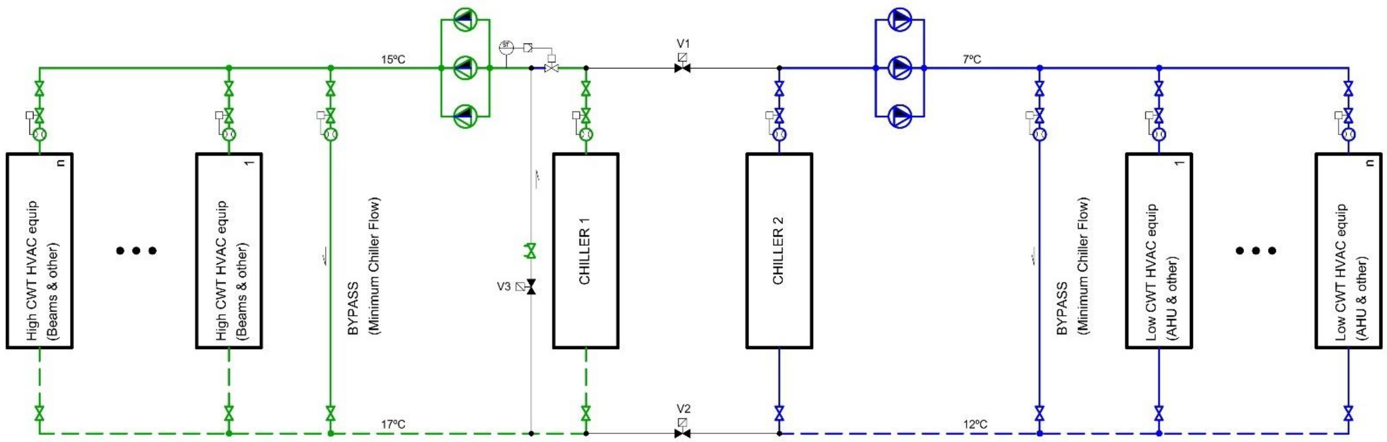


Redundancy can be created by hydraulically connecting both systems. A redundant chiller for both systems can be installed.

Very simple and reliable solution.

Chilled water system design

Dedicated separated chillers for beams and for AHUs.
Two independent systems with emergency conection.
Normal operation.



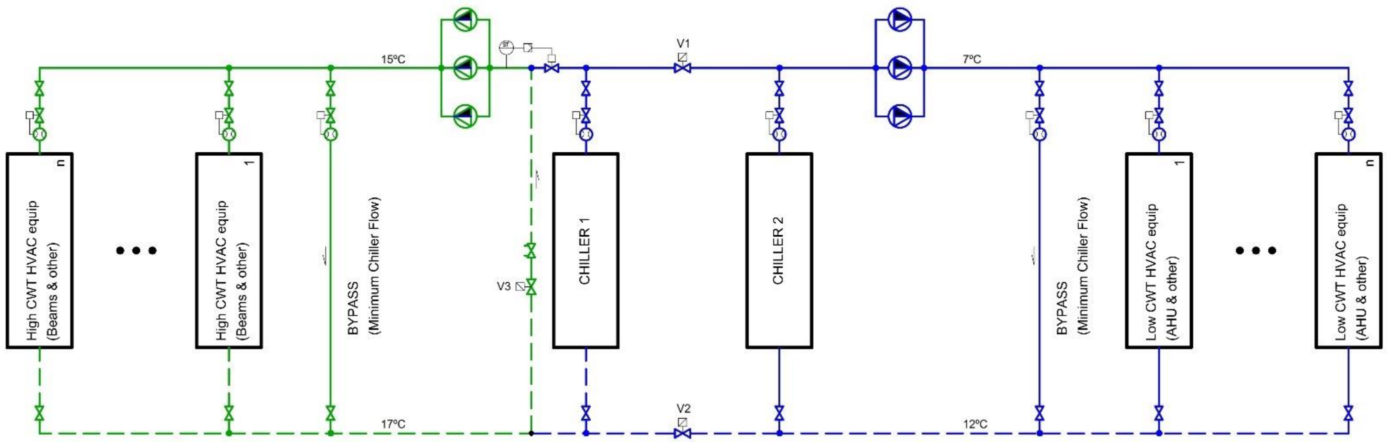
Redundancy can be created by hydraulically connecting both systems without adding an extra chiller.

Chilled water system design

Dedicated separated chillers for beams and for AHUs.

Two independent systems with emergency conection.

Energency operation.



In case of faillure of one chiller the operating chiller produces water at 7ºC and the beam water circuit operates in the mixing mode.

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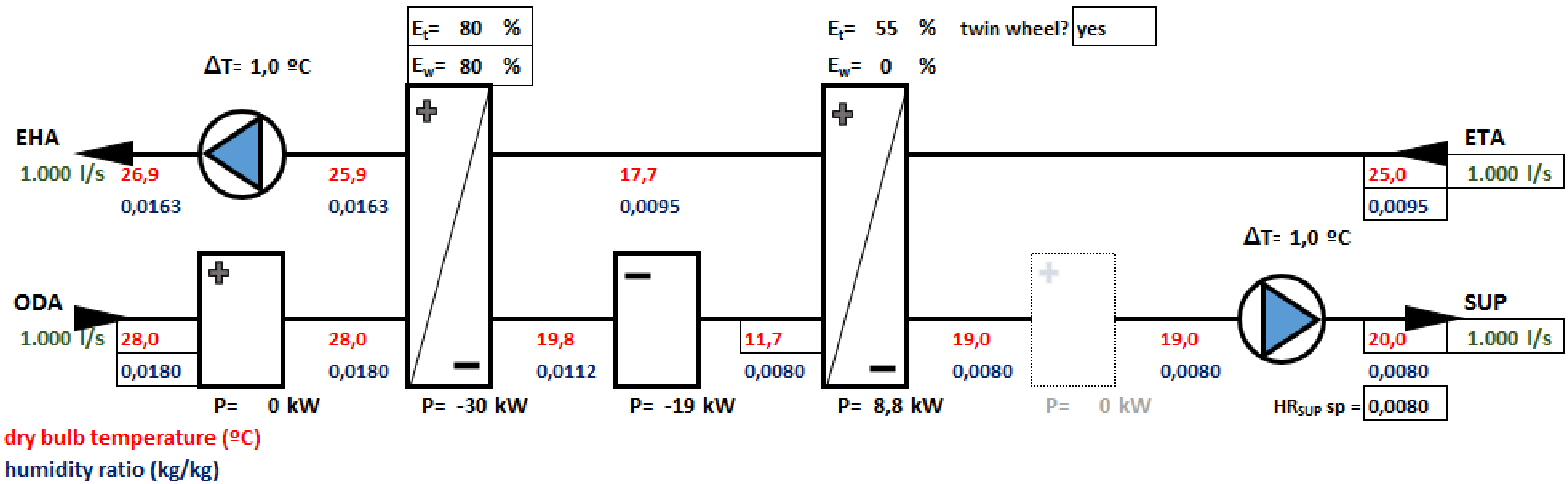
Primary Air Handling Unit Design

AHU - Twin Whell

Design Day, dehumidification



Very eficient sollution for extreme climates.

Minimizes zone reheat and AHU termal energy consumption. <u>Increses AHU fan energy consumption</u>.

Primary Air Handling Unit Design

Energy used to supply 1.000W cooling

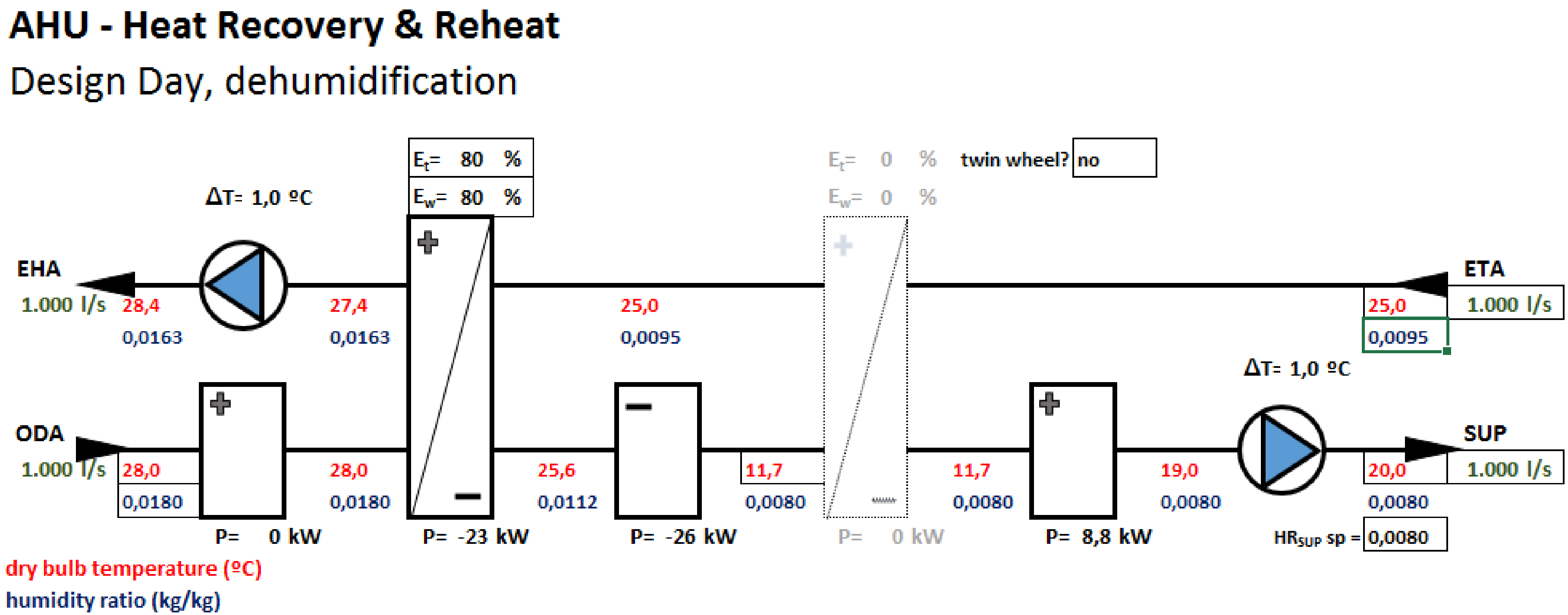
description	symbol	cooling with water	cooling with air	units	formula/source
density	ρ	1.000	1,2	kg/m3	
specific heat	cp	4,2	1,0	kJ/kg.K	
delta T	∆T	2	10	K	current value
cooling per (l/s)	cap	8,4	0,012	kW	ρ . cp . ∆T / 1000
flow per kW cooling	q	0,12	83,33	l/s	1 / cap
fan/pump pressure	P	200	1,5	kPa	current value
fan/pump efficiency (global)	η	0,55	0,55	-	current value
fan/pump power per kW cooling	**E**	**43**	**227**	**W / kWclg**	q . P / η

Air requires around 5 times more energy to supply the same cooling capacity

Adds 23% to the sensible cooling load

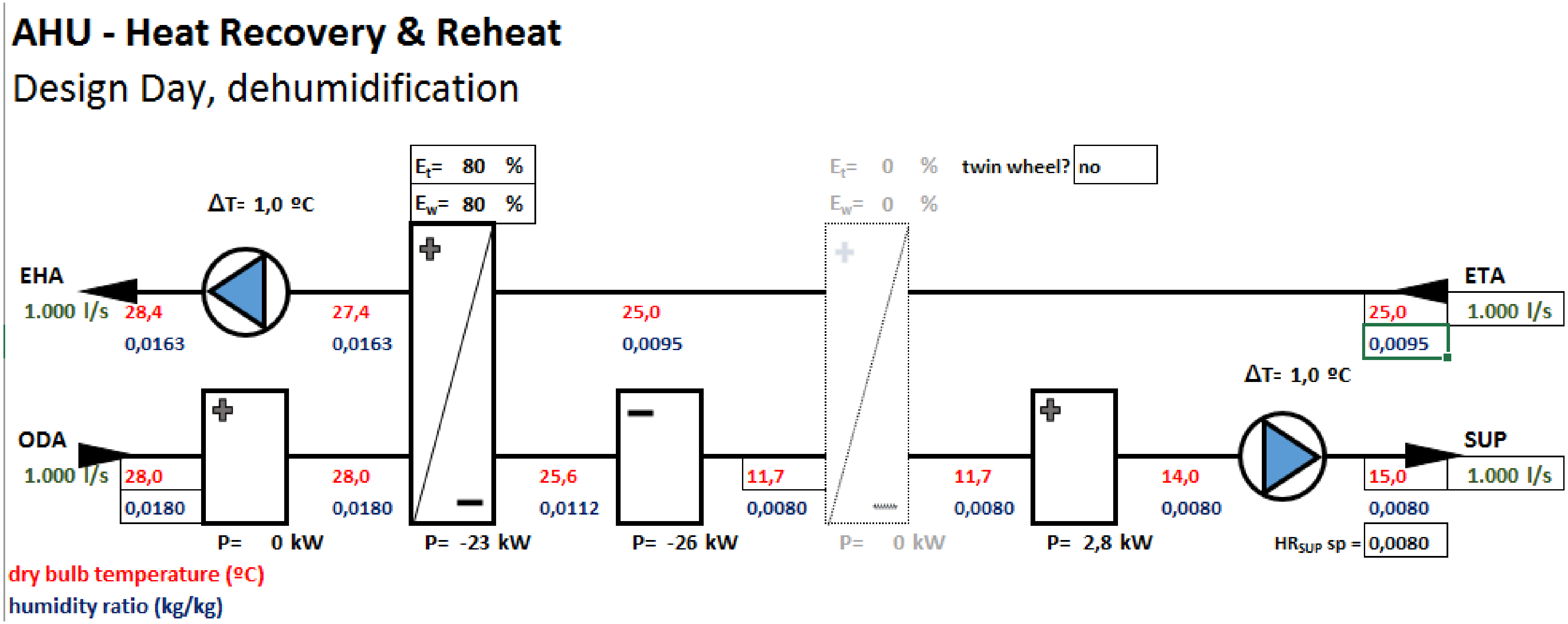
Be very carefull with AHU configuration in order to minimize pressure drop and fan energy

Primary Air Handling Unit Design



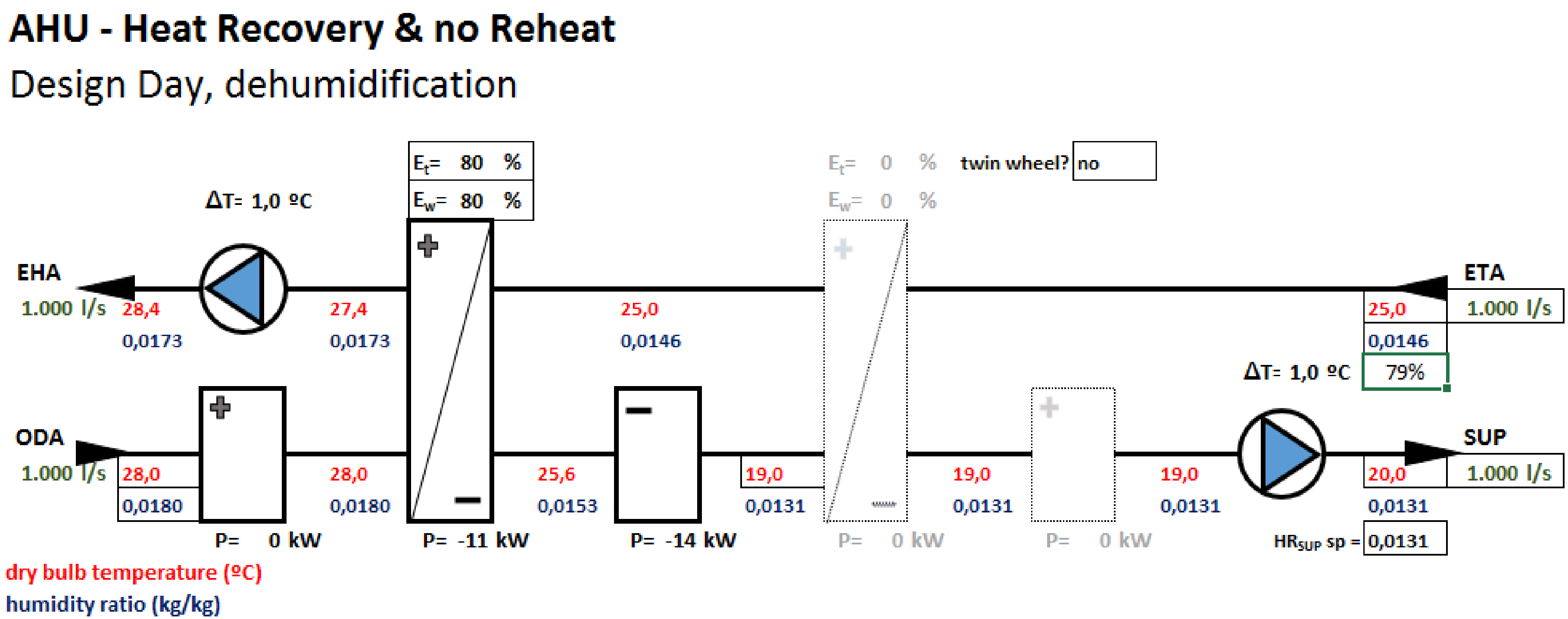
Very simple sollution and eficient for moderate climates. Efficiency is maximized when reheat is done using reclaim heat.

Primary Air Handling Unit Design



In warm days, supply air temperature can be lowered, minimizing reheat energy at the AHU.

Primary Air Handling Unit Design

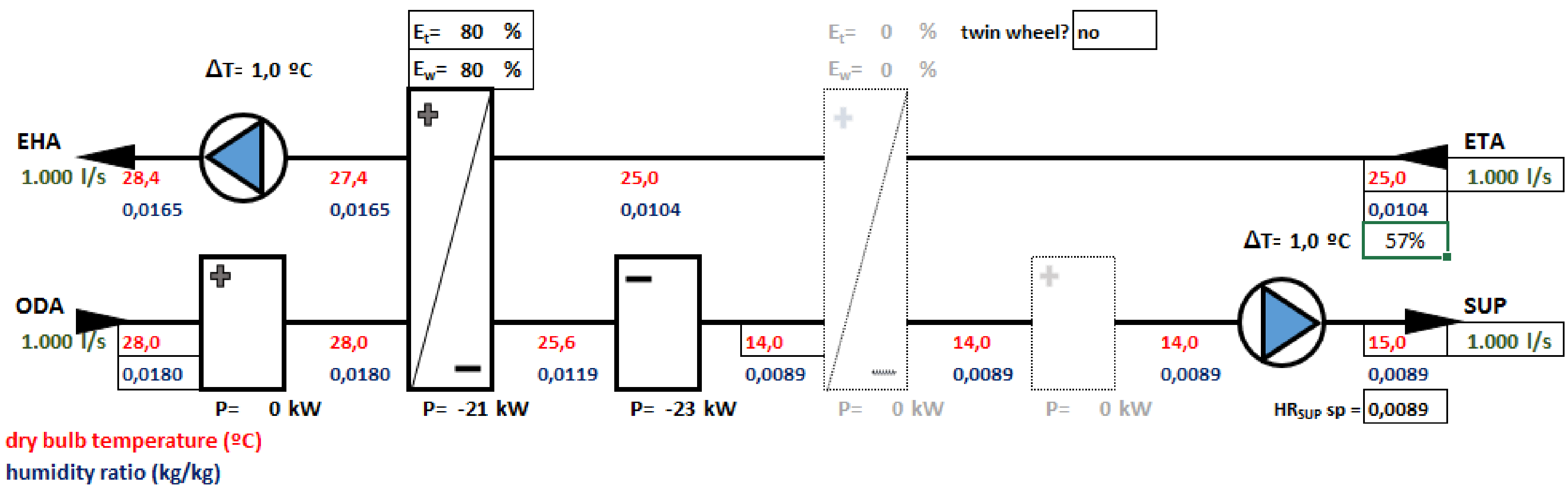


Most common solution. If operated with high supply air temperature, condensation shall occur. These systems must always operate with a low supply air temperature.

Primary Air Handling Unit Design

AHU - Heat Recovery & no Reheat

Design Day, dehumidification

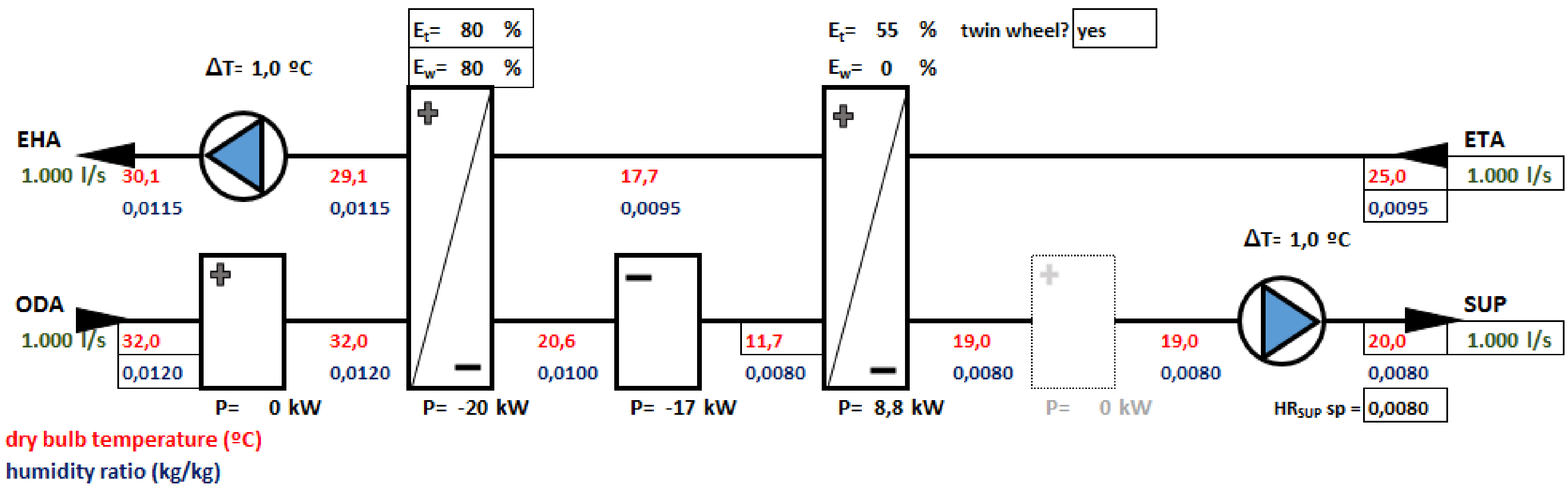


Supplying air at 15ºC, instead of 20ºC, signifficant air dehumidification is performed, although not controlled.

Primary Air Handling Unit Design

AHU - Twin Whell

Design Day, cooling



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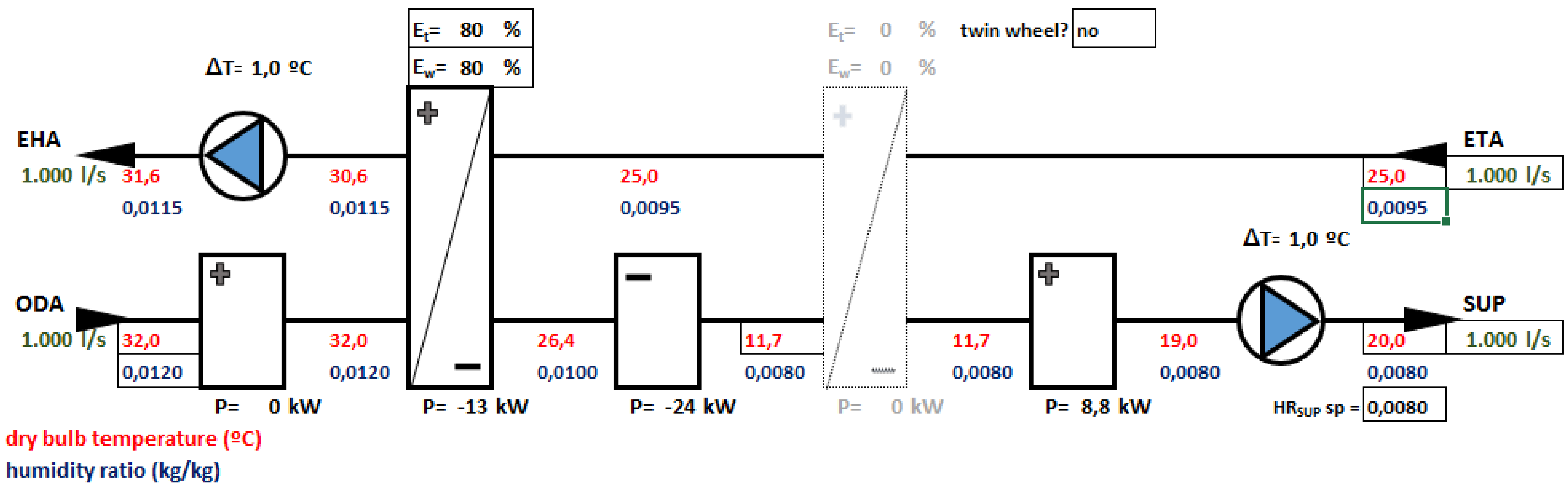
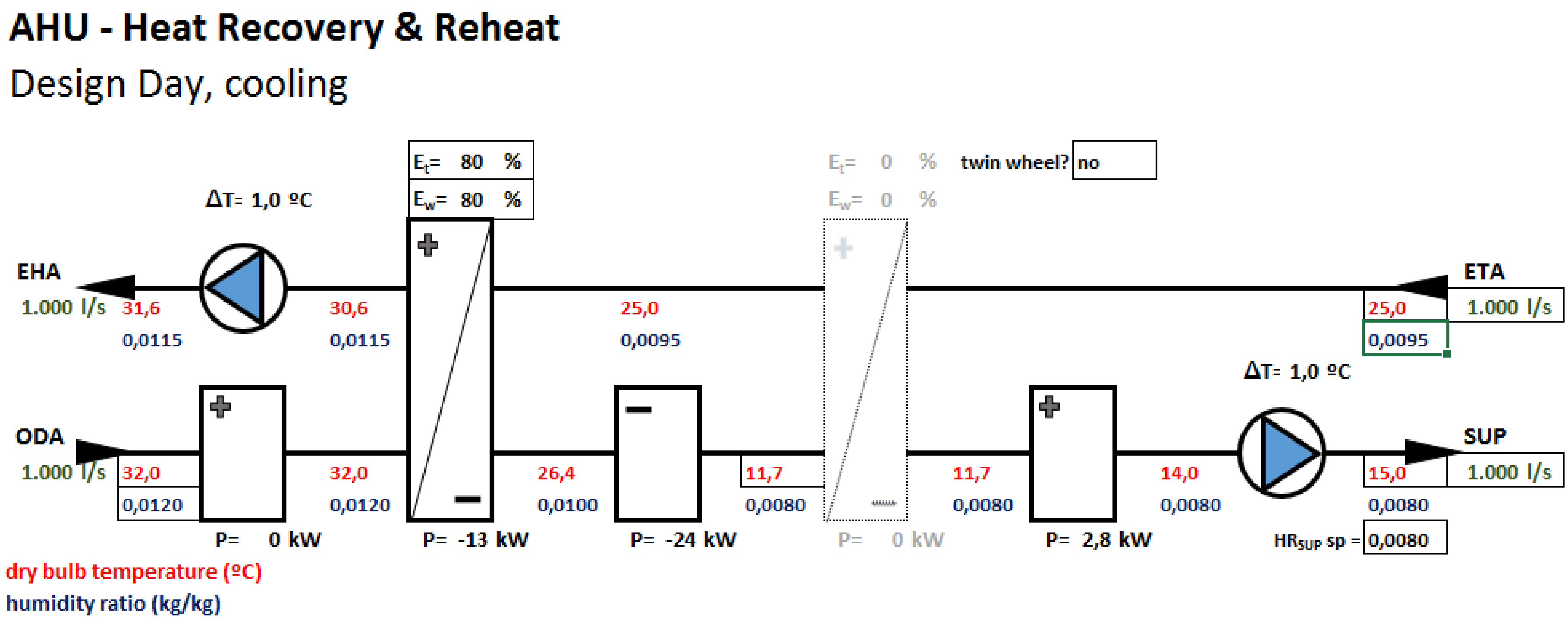
Primary Air Handling Unit Design

AHU - Heat Recovery & Reheat

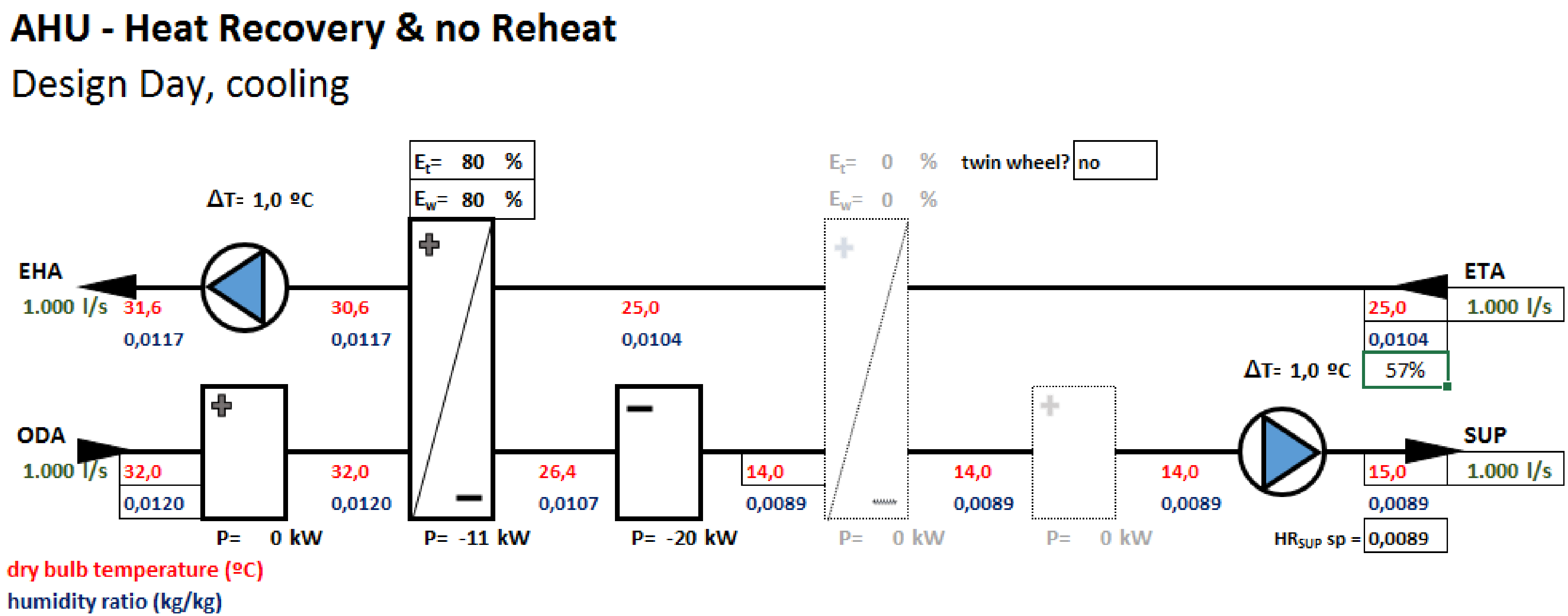
Design Day, cooling



Primary Air Handling Unit Design



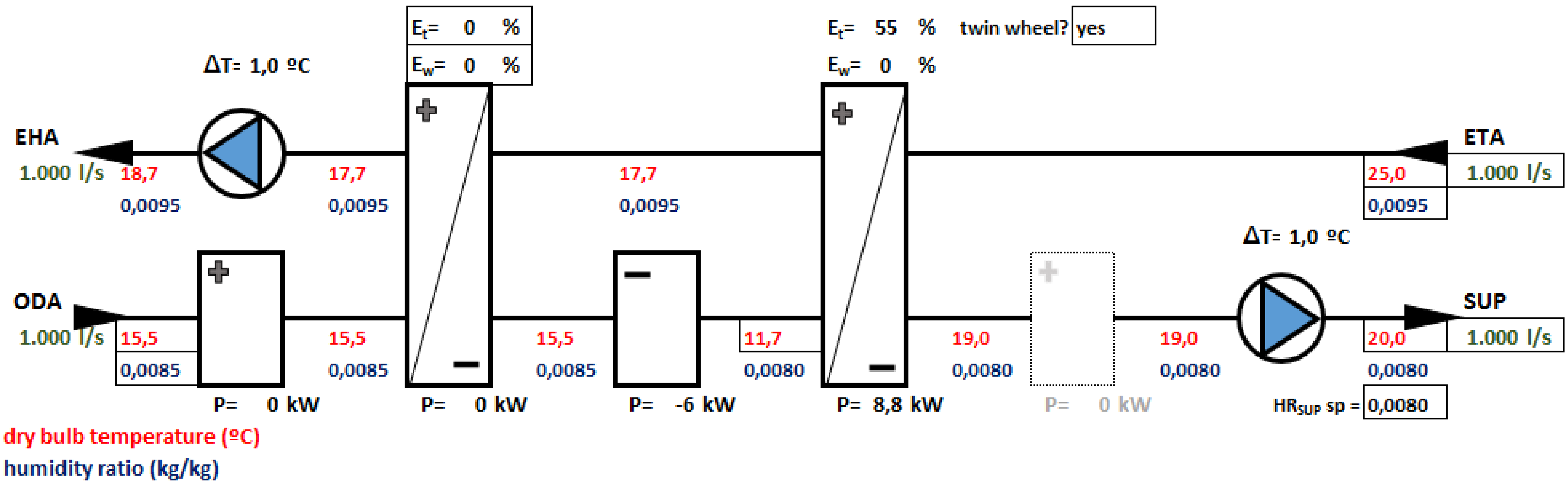
Primary Air Handling Unit Design



Primary Air Handling Unit Design

AHU - Twin Whell

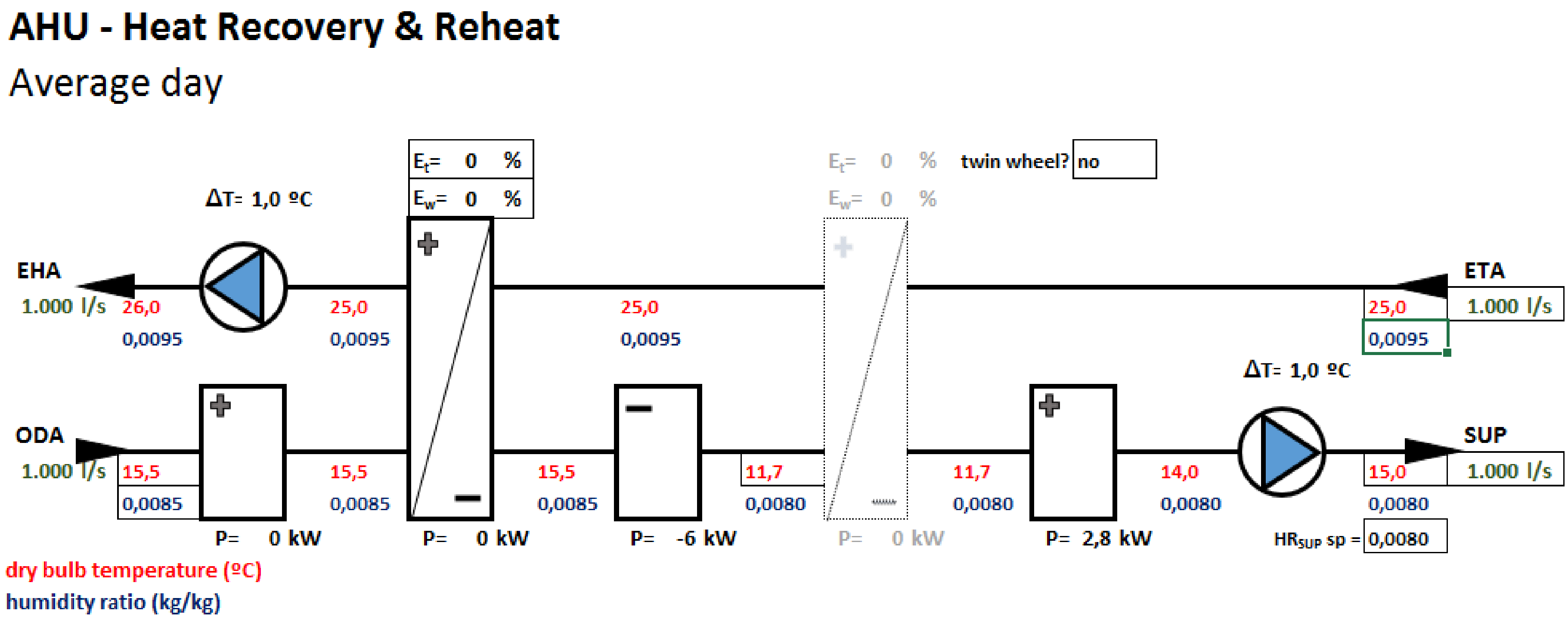
Average day



S.

REHVA

Primary Air Handling Unit Design

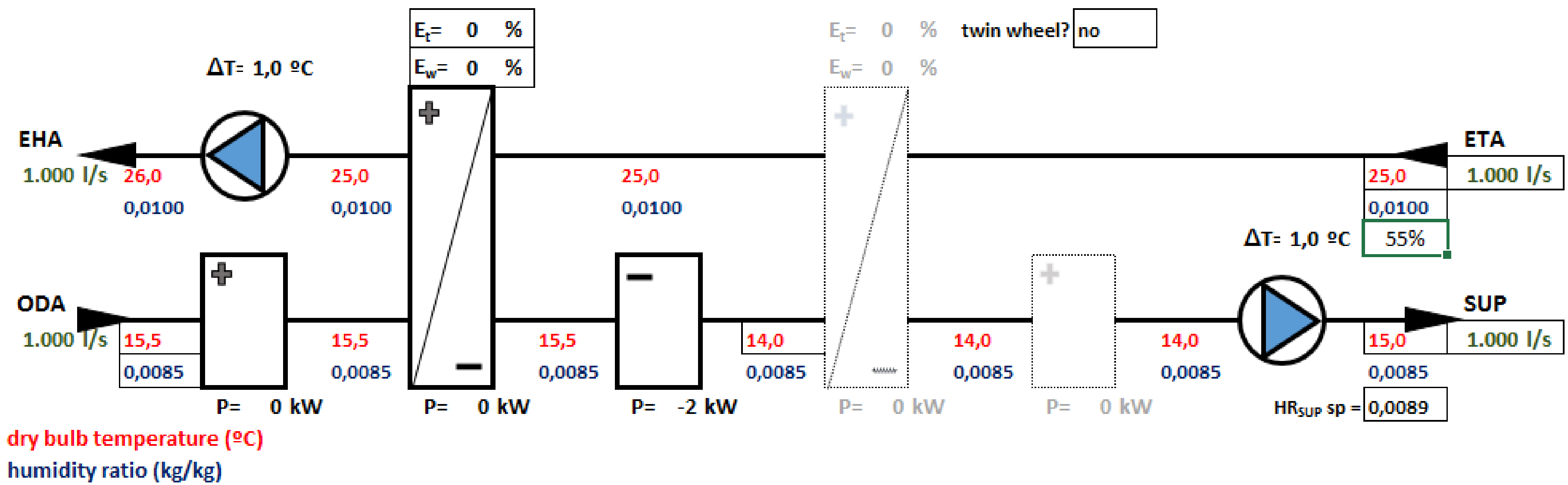


In an average day this solution uses an ammount of thermal energy close to the one used by the twin whell solution.

Primary Air Handling Unit Design

AHU - Heat Recovery & no Reheat

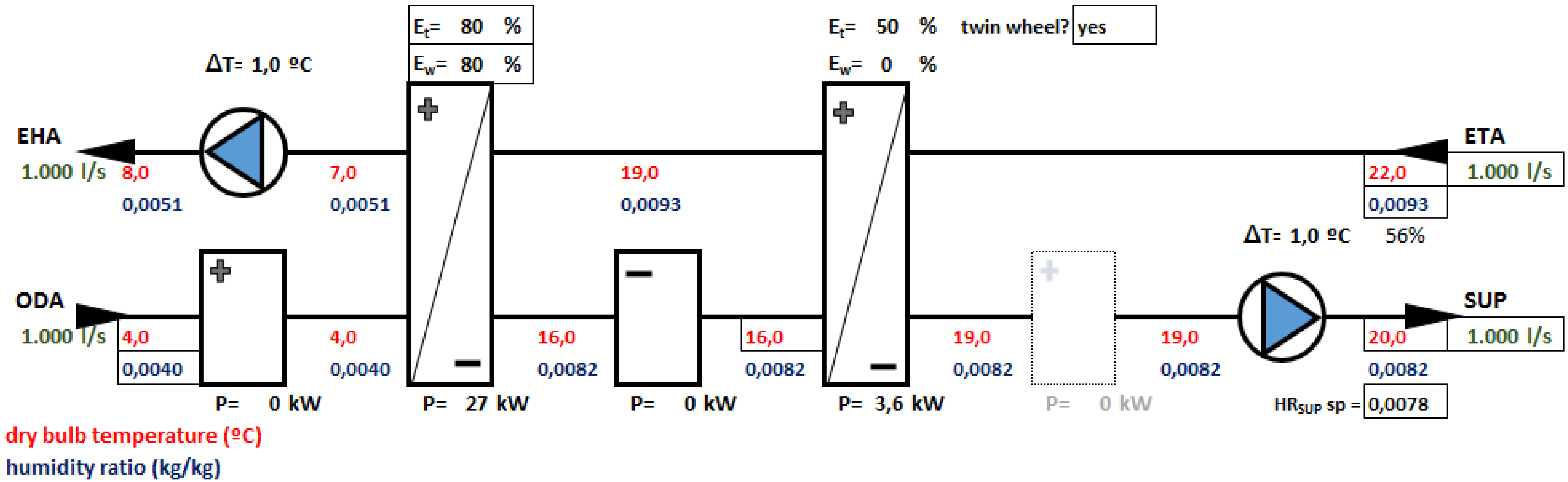
Average day



Primary Air Handling Unit Design

AHU - Twin Whell

Winter day



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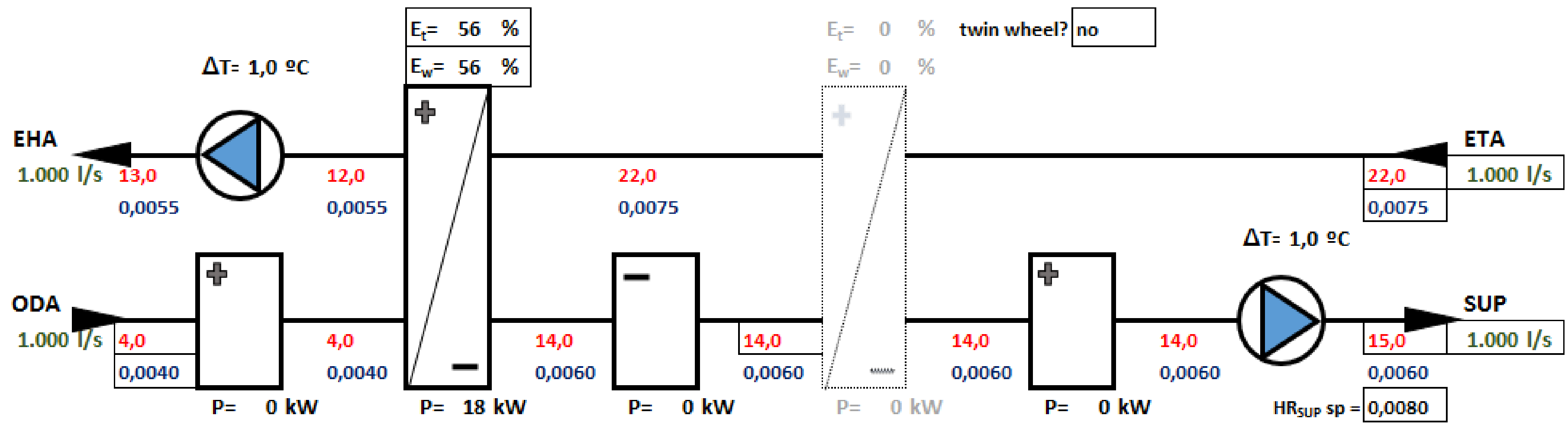
Primary Air Handling Unit Design

AHU - Heat Recovery & Reheat

Winter day



dry bulb temperature (ºC)

humidity ratio (kg/kg)

In a winter day neither system uses termal energy at the AHU level.

Primary Air Handling Unit Design

“No suit fits all”, ie, there is not an AHU solution that is the best for each and every case.

Weather as a determinant influence.

Detailled building energy simulation should always be performed to optimize the solution.

REHVA

Federation of European Heating and Air-conditioning Associations

Address:
Washington street 40
B-1050 Brussels
Belgium

- www.rehva.eu
- info@rehva.eu
- Tel: +32 2 514 11 71
- Fax: +32 2 512 90 62