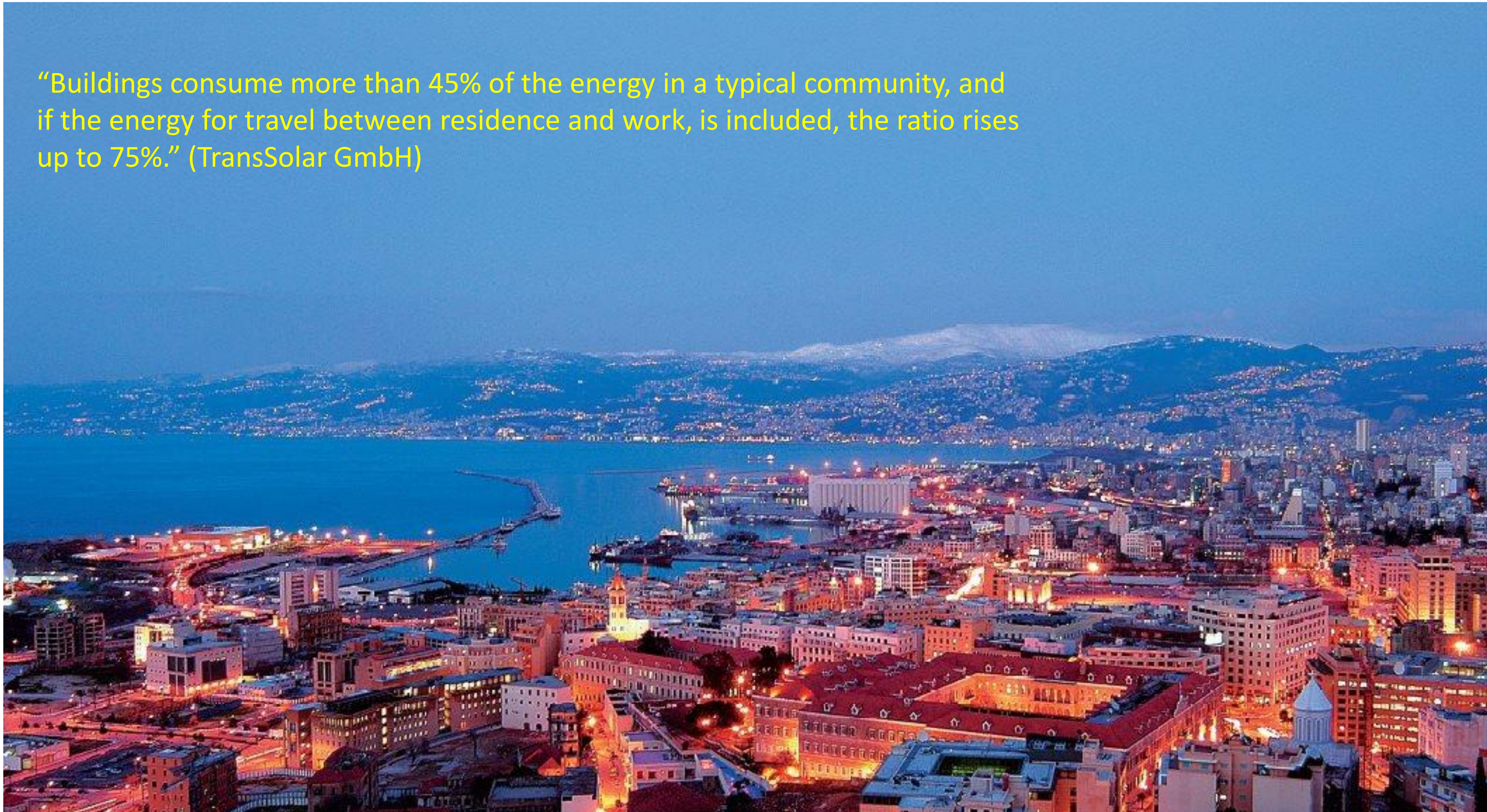
Transsolar academy

Applying Klima Engineering in an existing school facility in Bekka Valley, Lebanon.

Improving Air Quality and Thermal Comfort through Sustainable and Energy Optimized Measures

By Fadi Charaf
Mentor: Peter Voit
15/09/2014



"Buildings consume more than 45% of the energy in a typical community, and if the energy for travel between residence and work, is included, the ratio rises up to 75%." (TransSolar GmbH)

Lebanon

Population: 4 Millions

Climatic Conditions: Mediterranean

Area: 10,452 km2

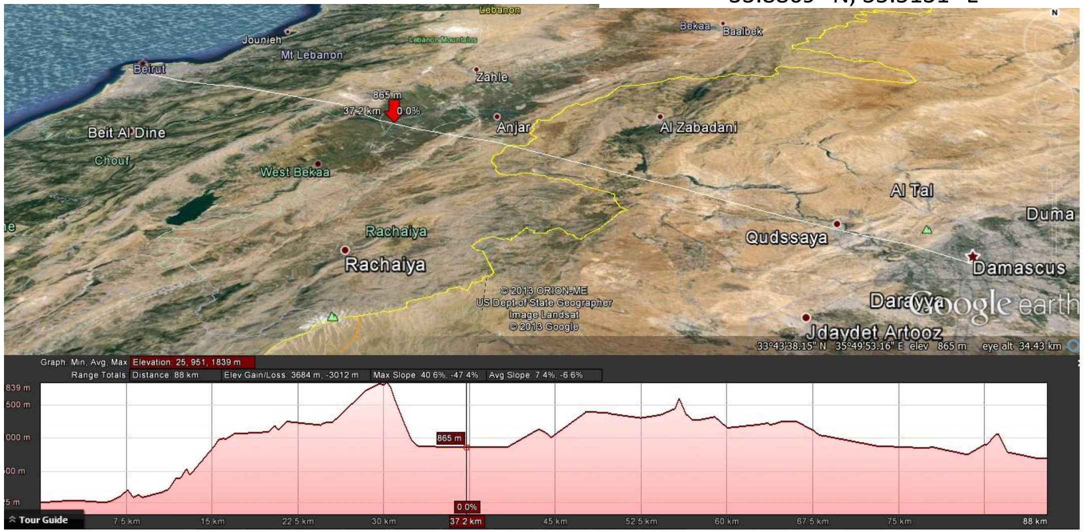
33.8869° N, 35.5131° E

Tri-Arch

Roman Temples 100 BC

Modernism

Terrain Profile



Climate Analysis

The Bekaa valley is an elevated inland plateau (800 m) with different climatic characteristics over the year which includes both a hot arid summer season and a cold winter season.

Outdoor Air Temperature

Minimum Temperature: - 5 °C

MaximumTemperature: 40 °C

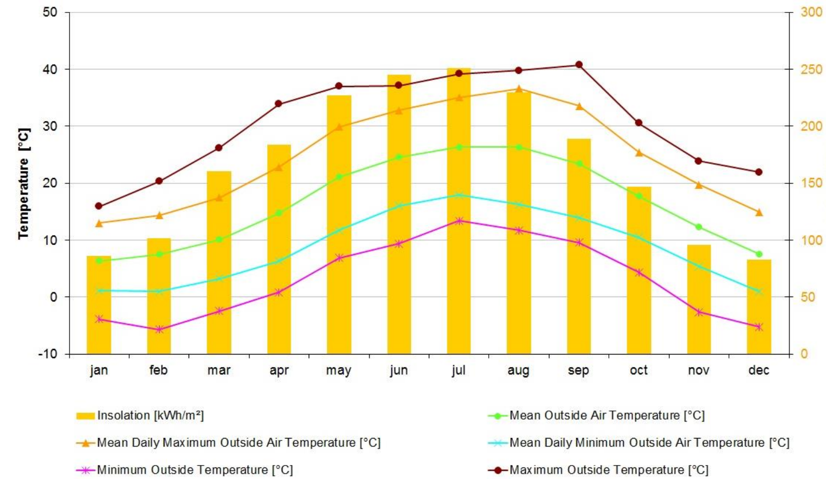
Mean Temperature: 16 °C

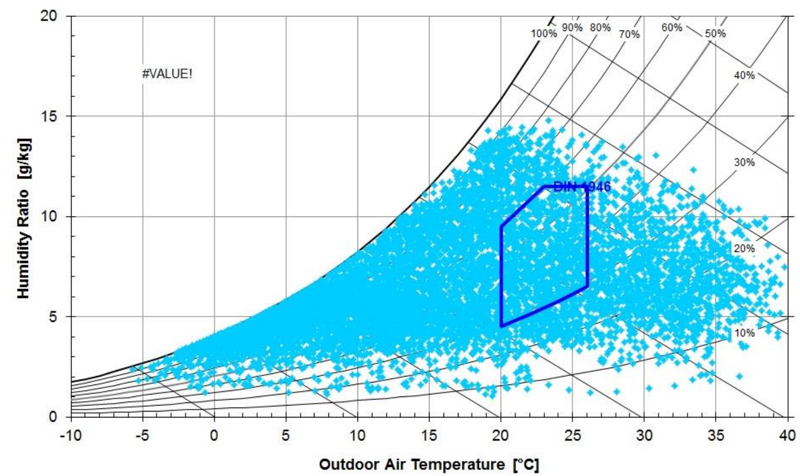
Humidity

90% of hours between 7am and 7pm, fall within the recommended humidity threshold of 12 g/kg. Maximum reached absolute humidity is 14 g/kg.

Insolation

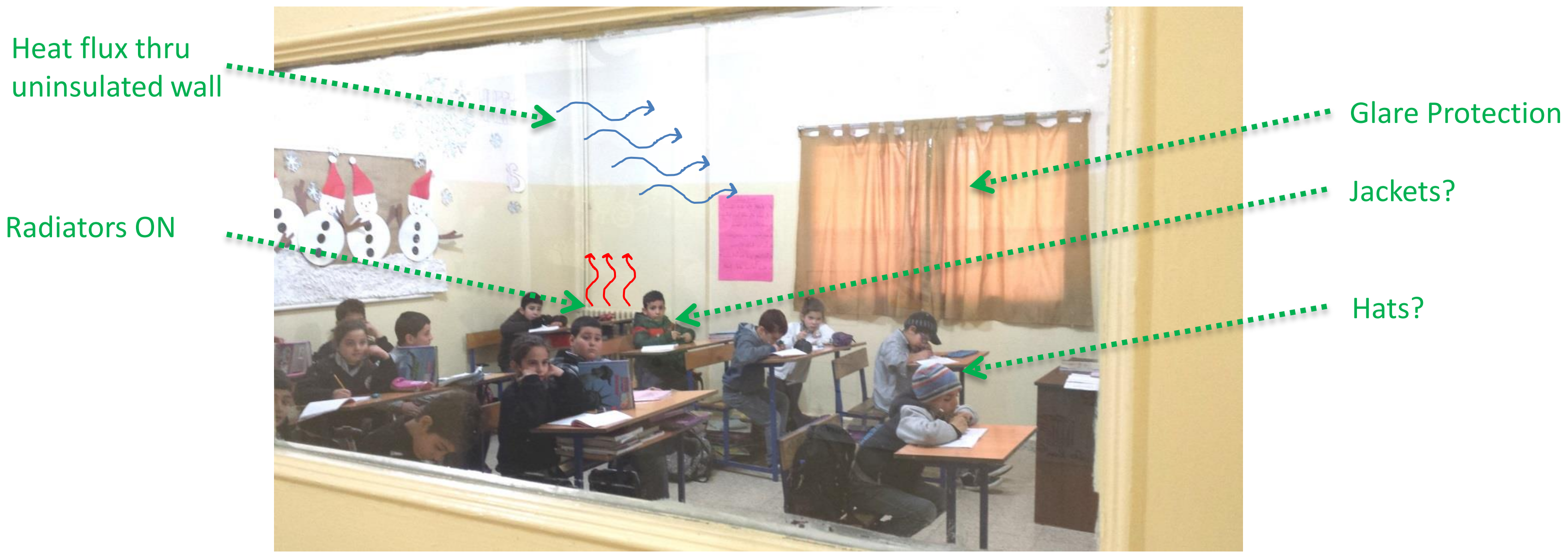
High average yearly solar insolation of about 1800 kWh/m2.





Problem ???

Low thermal comfort and bad air quality during winter time as a result of low and improper heating technique and absence of ventilation.



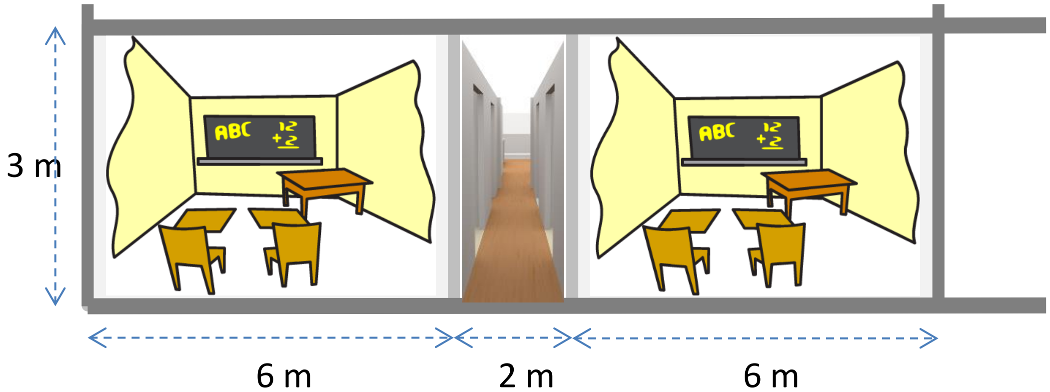
Agenda

- Analysis:
  - Analyzing Existing Conditions
  - Model Setup for Simulation
  - Codes and Regulations
- Interventions:
  - Improved Conditions
  - Passive Strategies
  - Active Strategies
- Feasibilty:
  - Cost Estimation and LCA
- Conclusion and Recommendation

Occupancy

Facility Occupancy
From September till late June
8:00 till 14:30
Occupancy= 20 persons/ 36m2
1.8 m2/ person

Main Concern/ First Impression
Dominated by heating, while cooling can be totally achieved by passive strategies
Tuition Fees around 2500 euros/ year

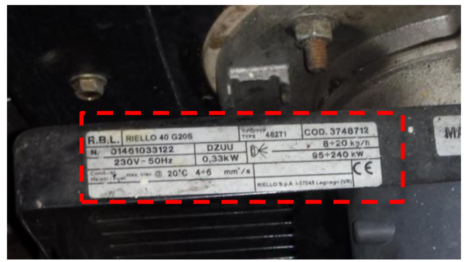


Trnsys Model

Site Visit

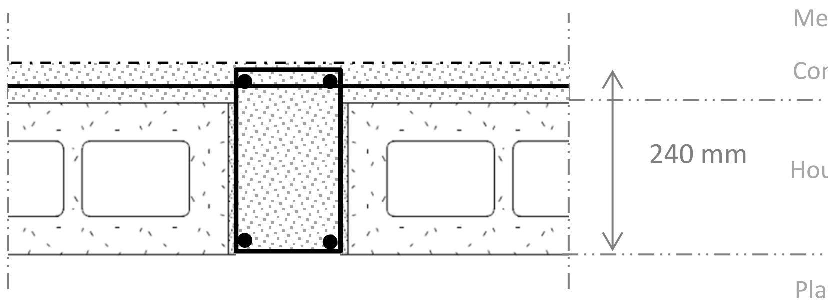
28.01.2014

2 photos per slide from site visite, boiler not necessary

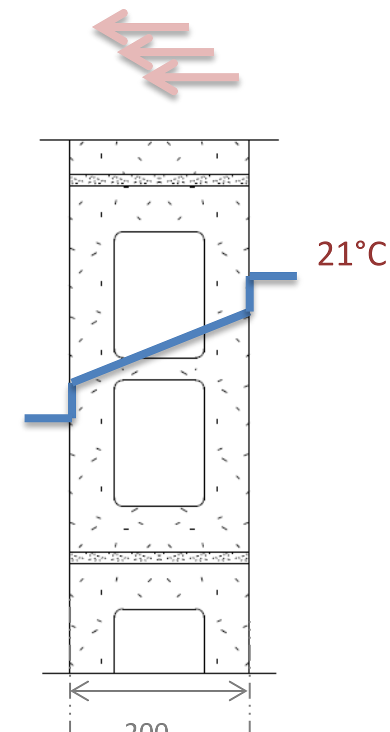


Existing Building Envelope

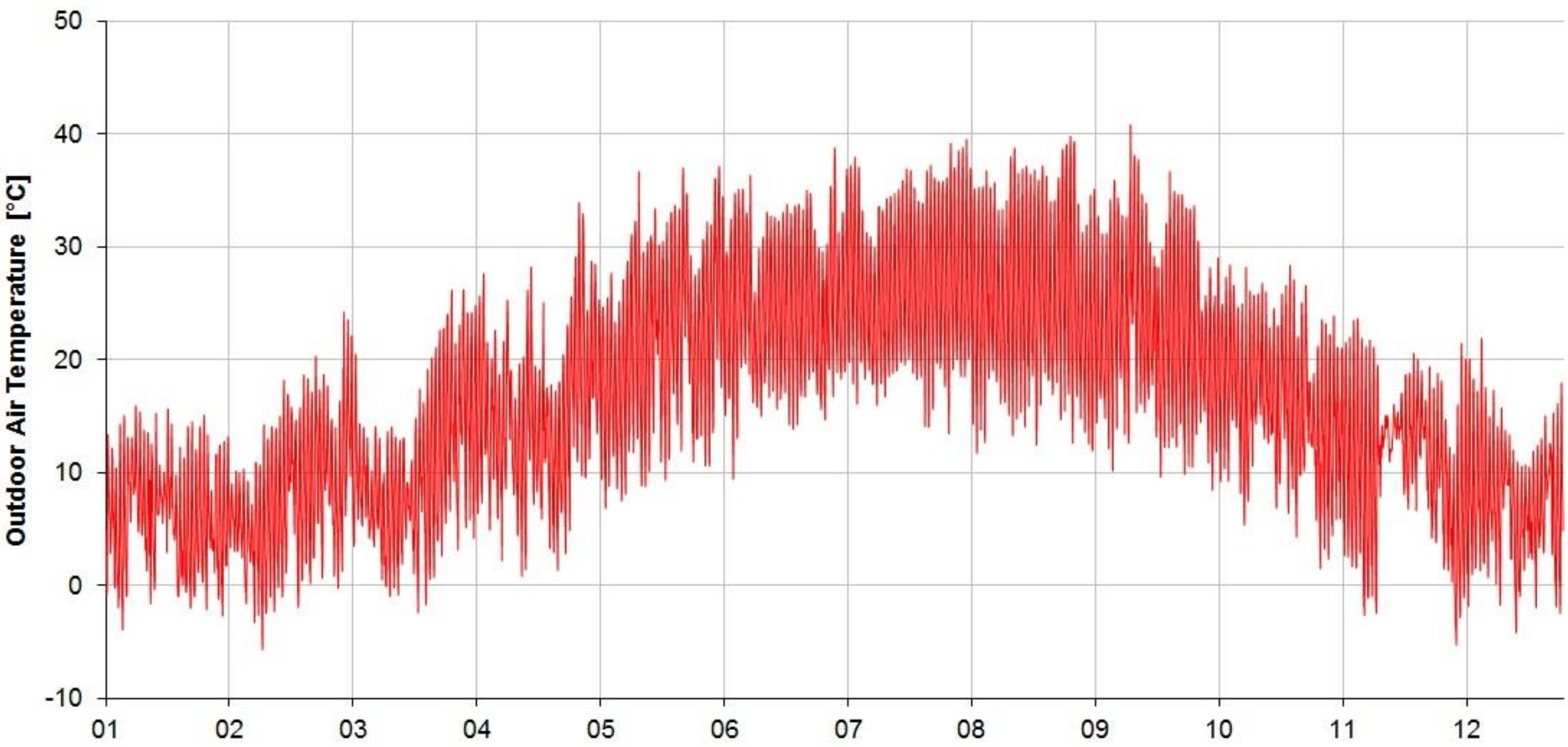
Roof Section



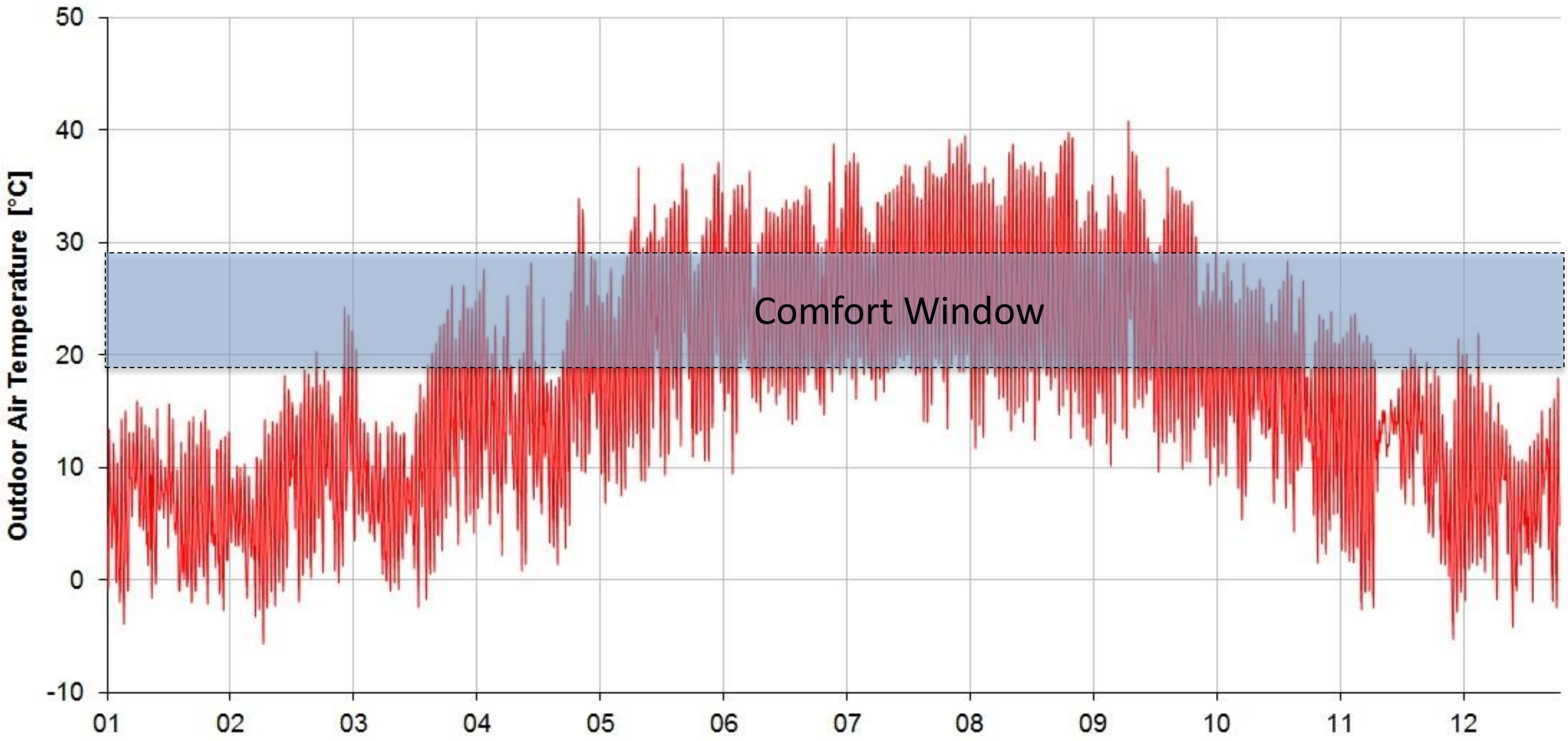
Wall Section



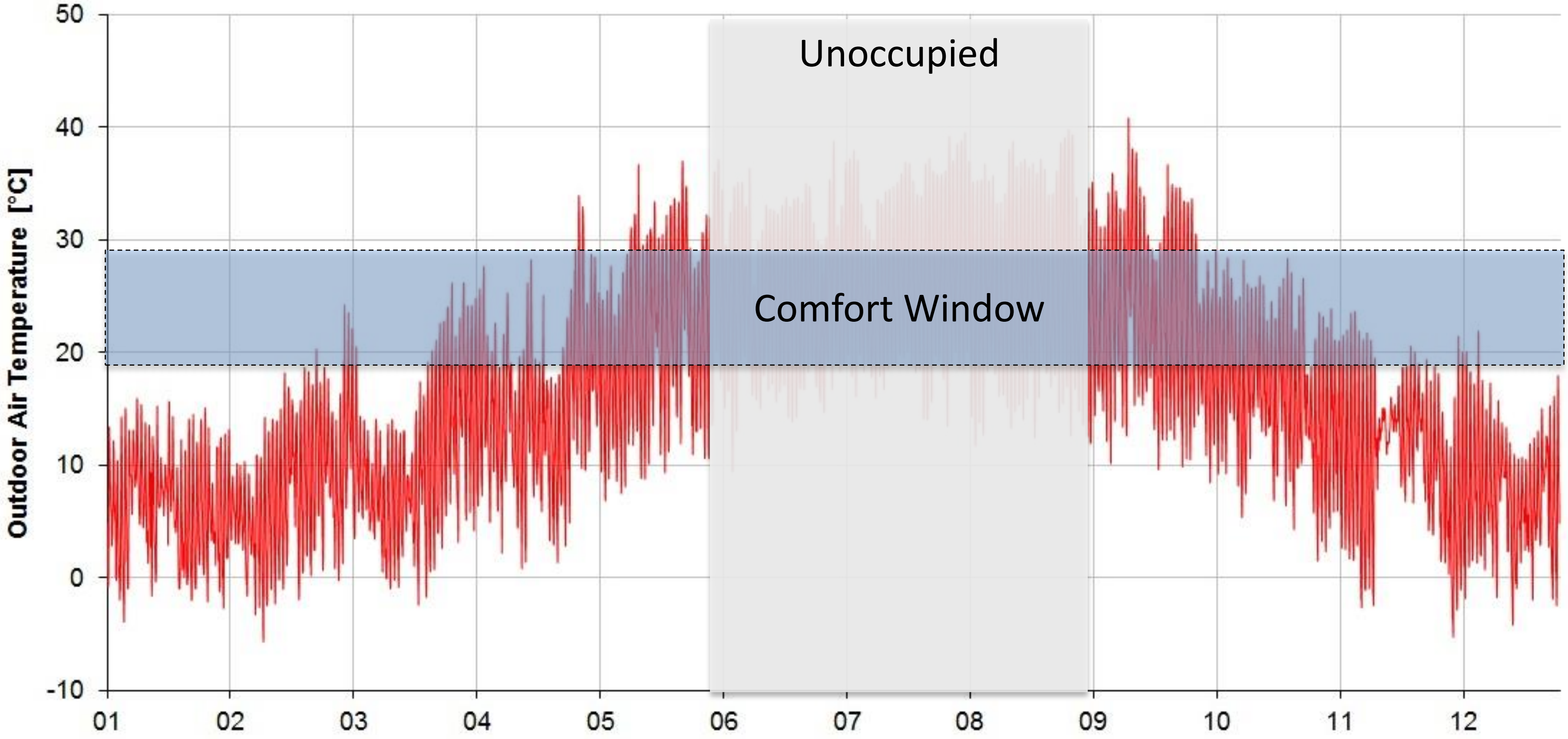
Ambient Temperature



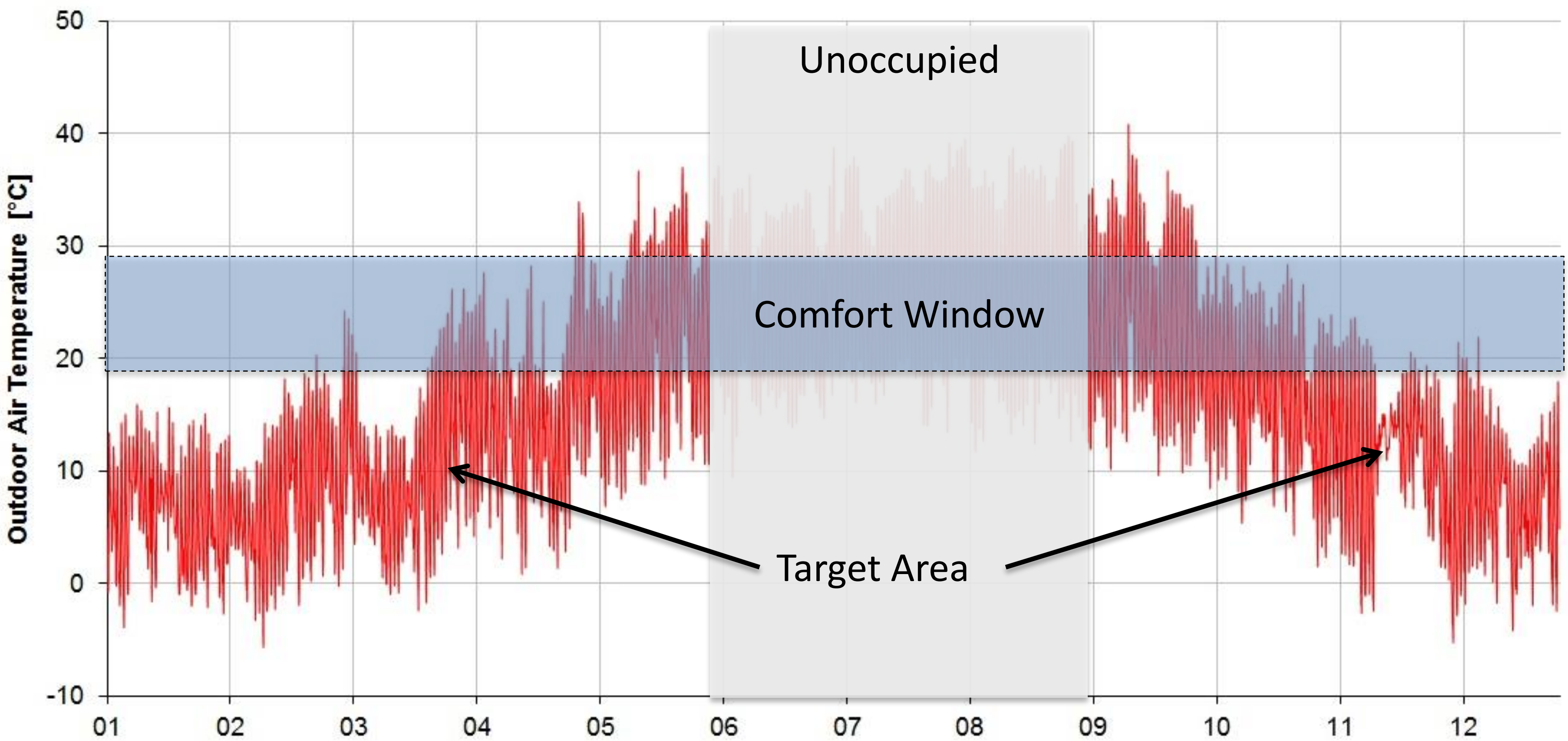
Annual Comfort



Annual Comfort



Annual Comfort



Target Level Assessment

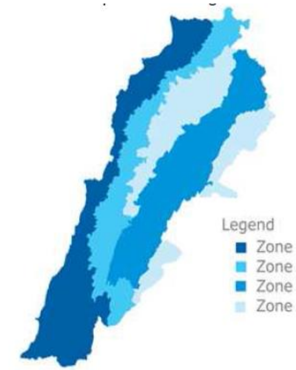
✓DIN 15251

✓ASHRAE 62.1

✓THERMAL STANDARD FOR BUILDINGS IN LEBANON

Table 2: General characteristics of climate zones and sub-zones

Climatic Zone	Climatic Sub-zone	Winter	Summer	Daily Gap
1 Coastal	1A Altitude < 400 m	Warm and short	Hot and humid	Small all year
	1B Altitude > 400 m	Cold and long increasing with altitude	Hot and humid with maximum daily temperatures differing slightly from 1A	
2 Western Mid Mountain	No Sub-zone	Cold and long increasing with altitude	Cool and Moderate summer	More pronounced than the daily gap of zone 1
3 Inland Plateau	No Sub-zone	Colder and longer than the winter at same altitudes in zones 1 & 2 (min temperatures lower than zones 1 & 2)	Hot and dry summer, but cool at night. The min temperatures are lower than zones 1 & 2 and the max temperatures are higher. Very low humidity.	In summer the daily gap is high and varies according to the year.
4 High Mountain	No Sub-zone	Long and rigorous	Cool	Moderate to high in Eastern Mountain



Building Envelop

Table 3: Reference Thermal Transmittance Values per Component U-ref (W/m^2.K) vs. climatic zone

Climatic Zone	Building category	U-value Roof	U-value Wall	U-value Window & Skylight	U-value Ground Floor Exposed*	Semi-exposed**
1 Coastal	1 Residential	0.71	1.60	5.80	1.70	2.00
	2 N Residential	0.71	1.26	5.80	1.70	2.00
2 Mid Mountain	1 Residential	0.63	0,77	4.00	0.77	1.20
	2 N Residential	0.55	0,65	3.30	0.70	1.20
3 Inland Plateau	1 Residential	0.63	0,77	4.00	0.77	1.20
	2 N Residential	0.55	0,65	3.30	0.70	1.20
4 High Mountain	1 Residential	0.55	0.57	3.30	0.66	1.00
	2 N Residential	0.55	0.57	2.60	0.66	1.00

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft^2	L/s·m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1

- Temperature

Class A: Heating: 21°C ; Cooling:25°C

Range 18 °C < Top < 28°C

- Indoor Air Quality

ASHRAE 60.1: 5 L/s/pseron *20 persons= 360m3/h or 3.3 ACH

Remove graphs

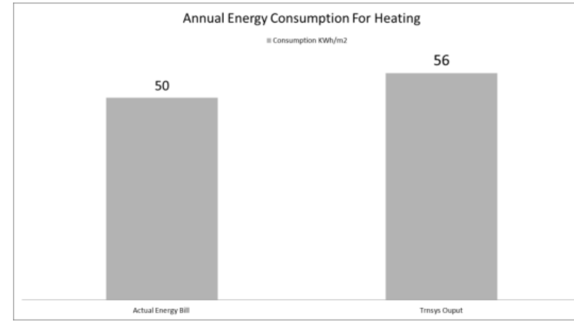
ShoeBox Model - Trnsys

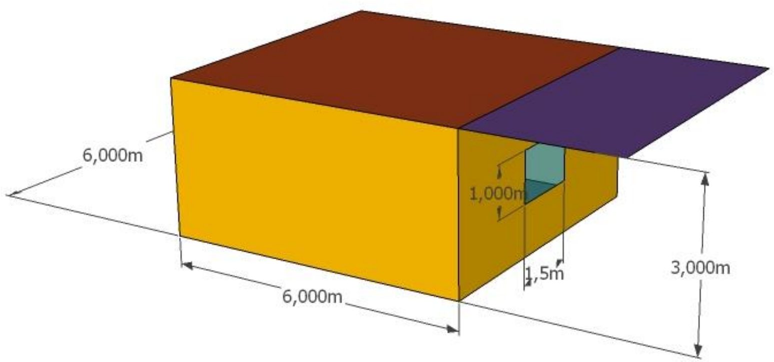
Infiltration 0.3 ACH (operation) + 0.1 ACH

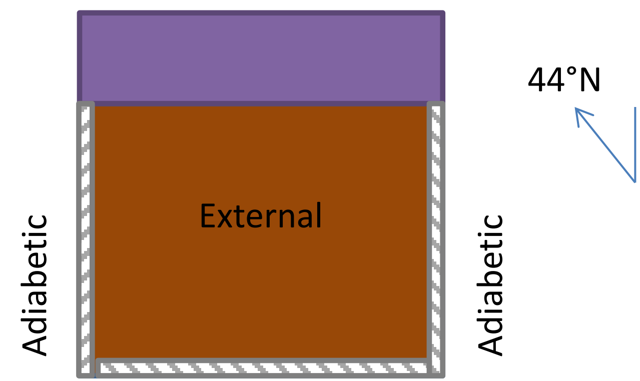
Gains 20 Students seated (100 Watts – Sensible + Latent)

Shoebox Dimensions (6 × 6 × 3m typical measured classroom)

Operation Mode: from 07:00 till 14:00 (except for Weekend)

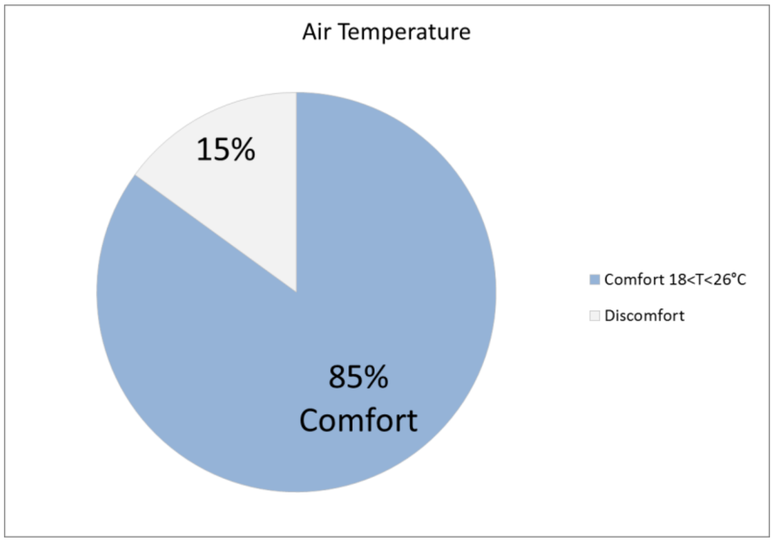




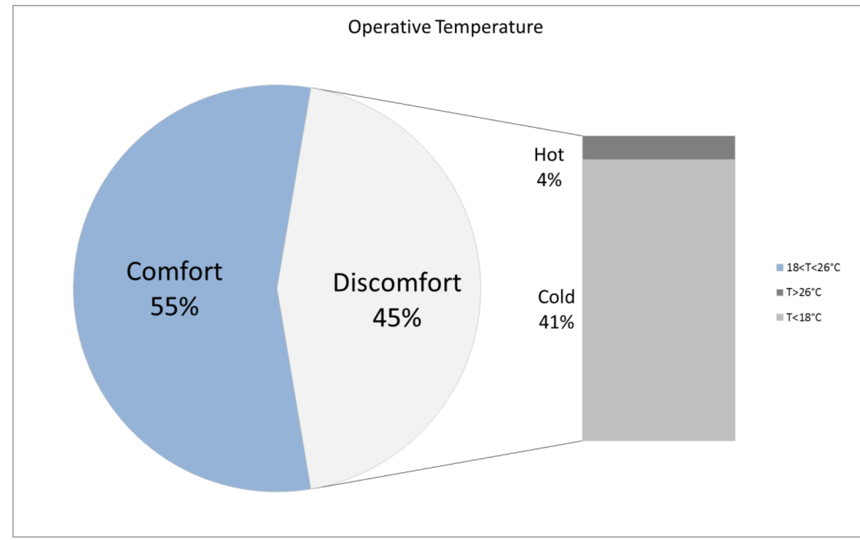


Existing Conditions (including Heating)

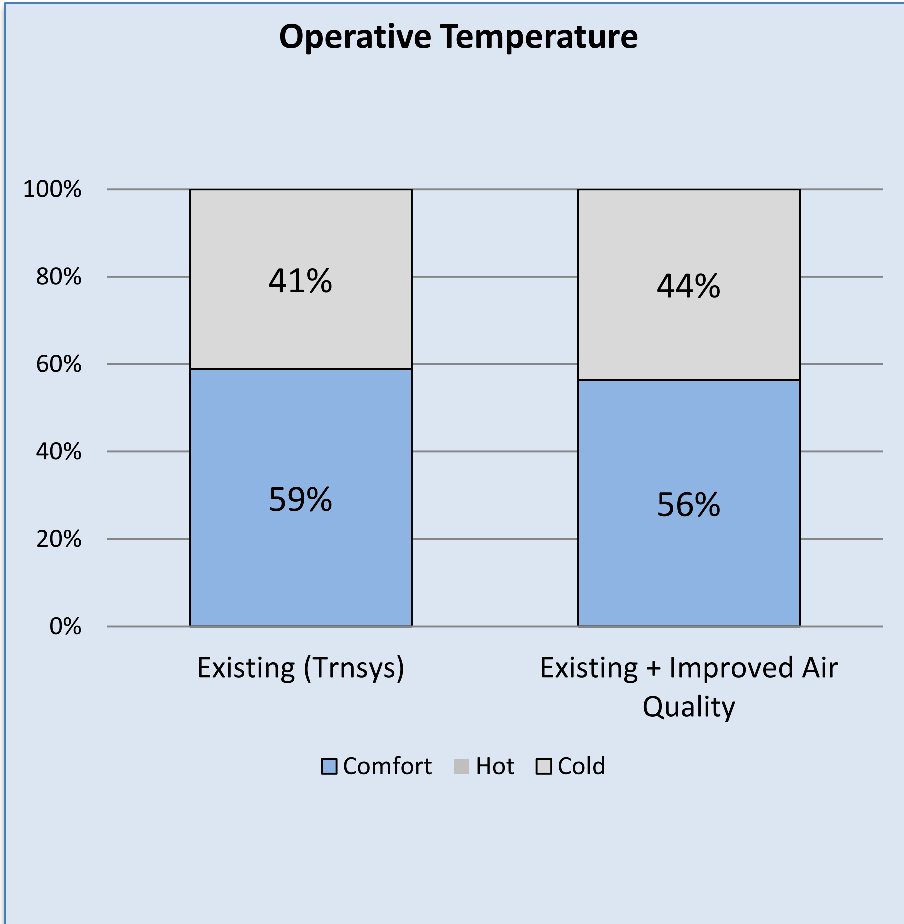
Air

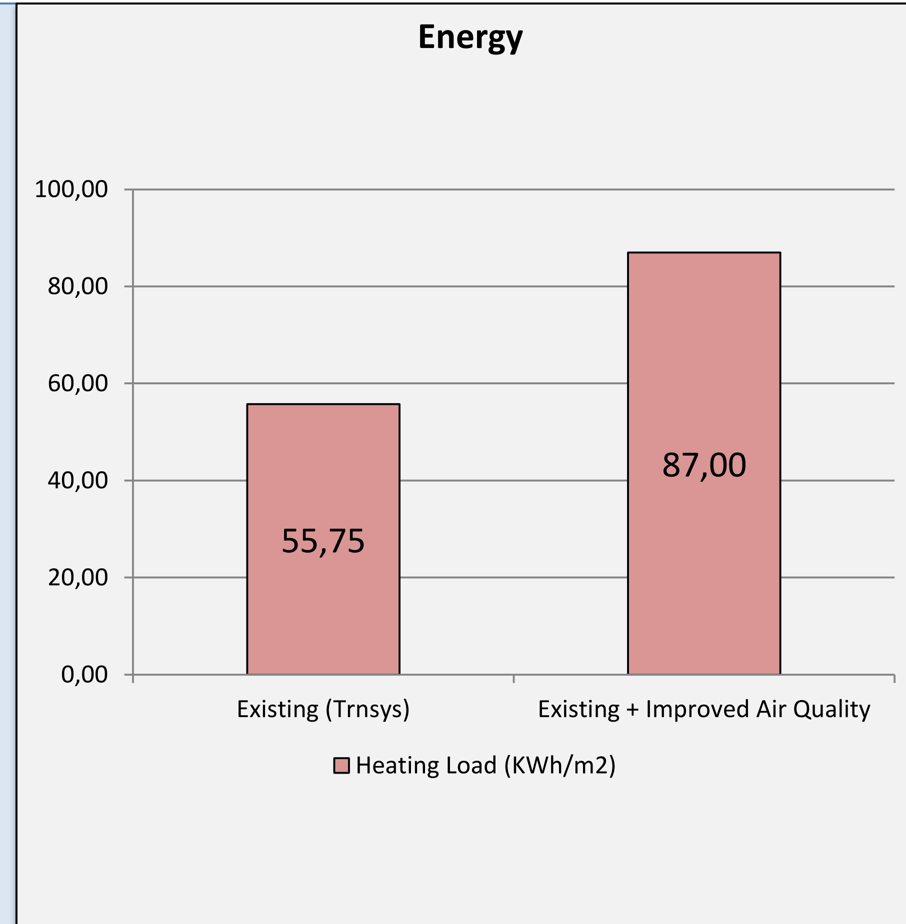


Perceived



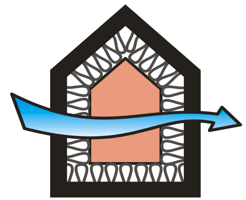
Improved Air Quality + Heating



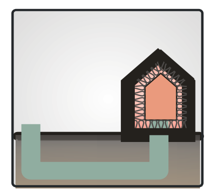


Passive Strategies

– Insulated – Reference Case



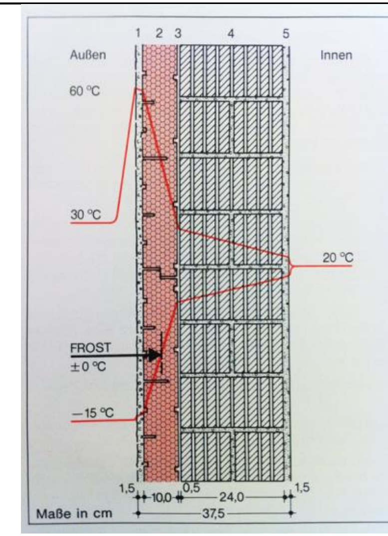
– Ground Duct + Insulation



Passive Strategies

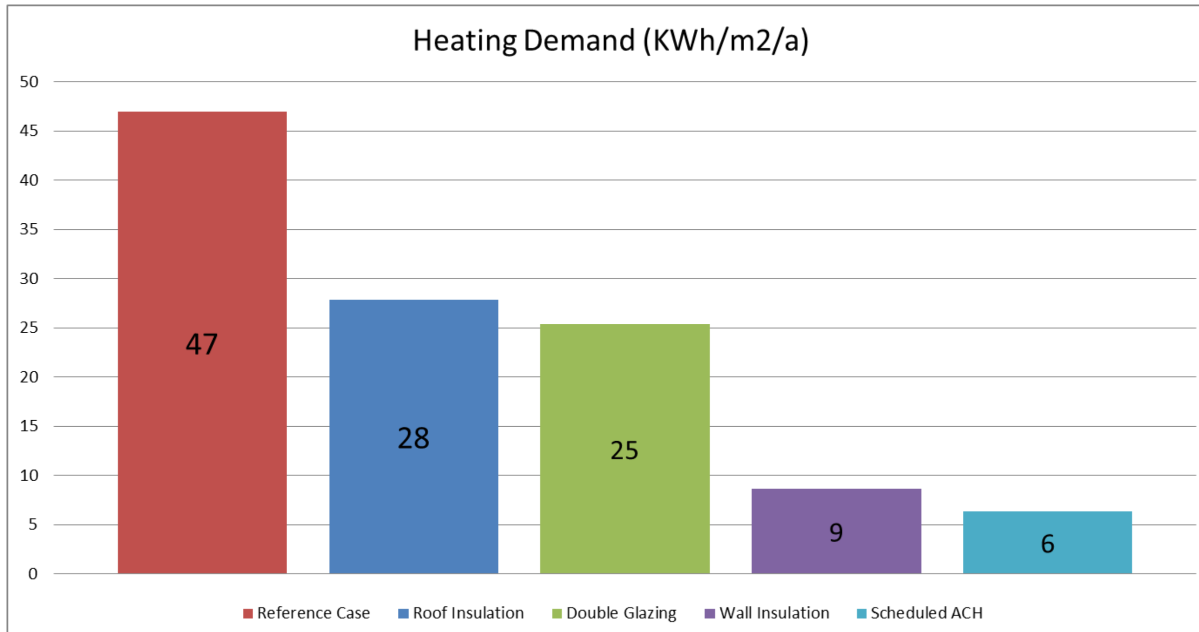
– Insulated – Reference Case

- Type EPS W040
- Thickness:
  - Walls: 10 cm
  - Roof 15 cm

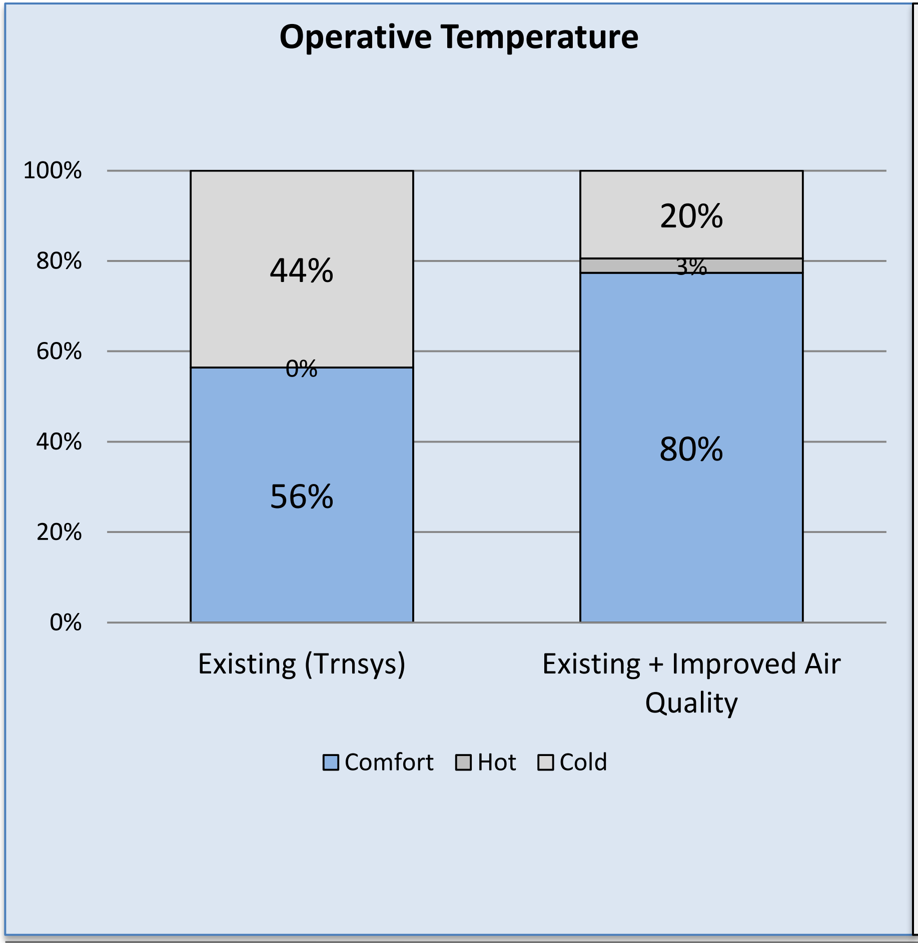


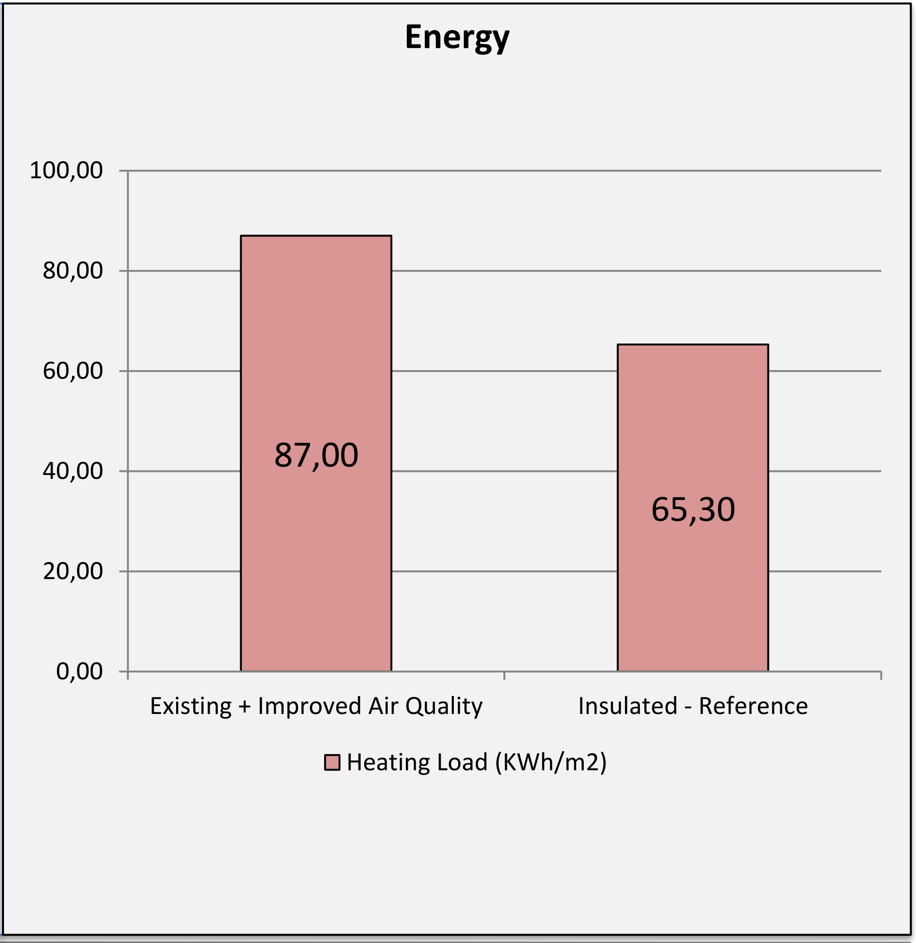
Insulated – Reference Case

The effect of each insulated element on annual heating load in the absence of proper ventilation



Insulation – Reference Case

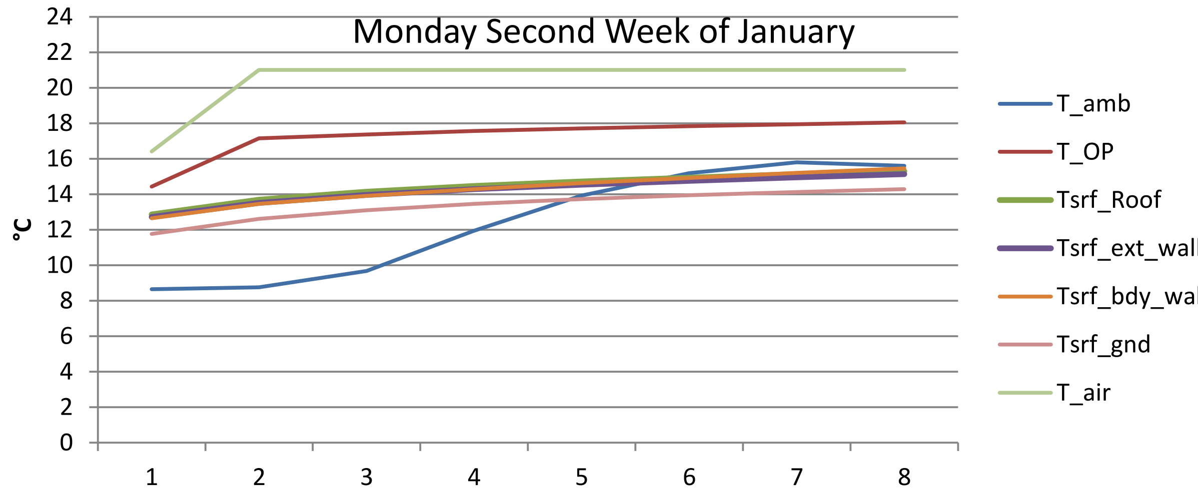


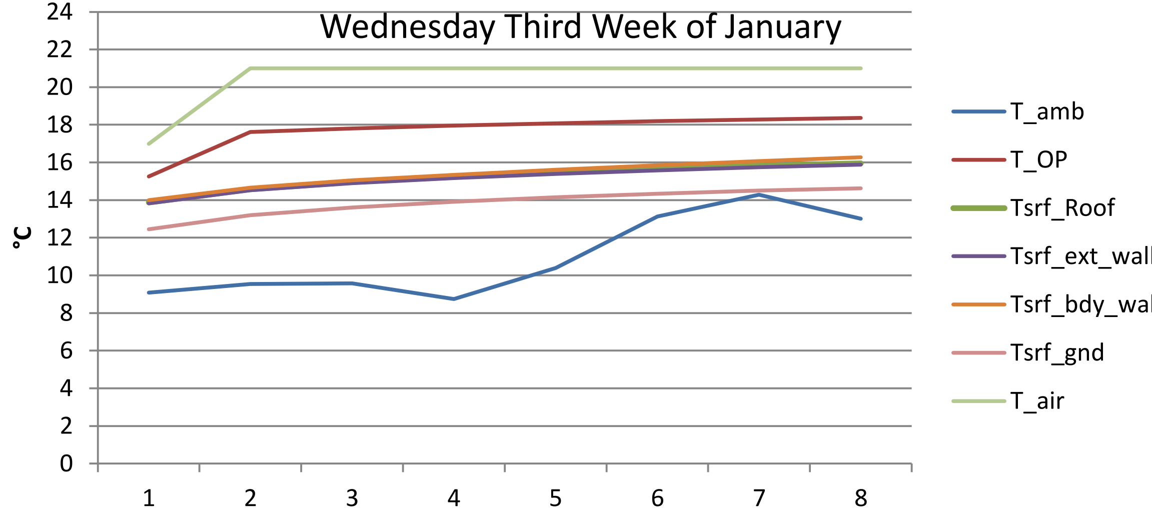


Insulated – Reference Case

Thermal Mass Heat Storage over the day

- Monday colder surfaces stored from weekend
- Wednesday hotter surfaces from the day before





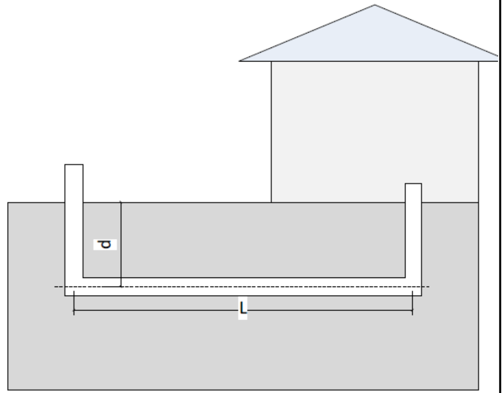
Passive Strategies

– Insulated – Reference Case

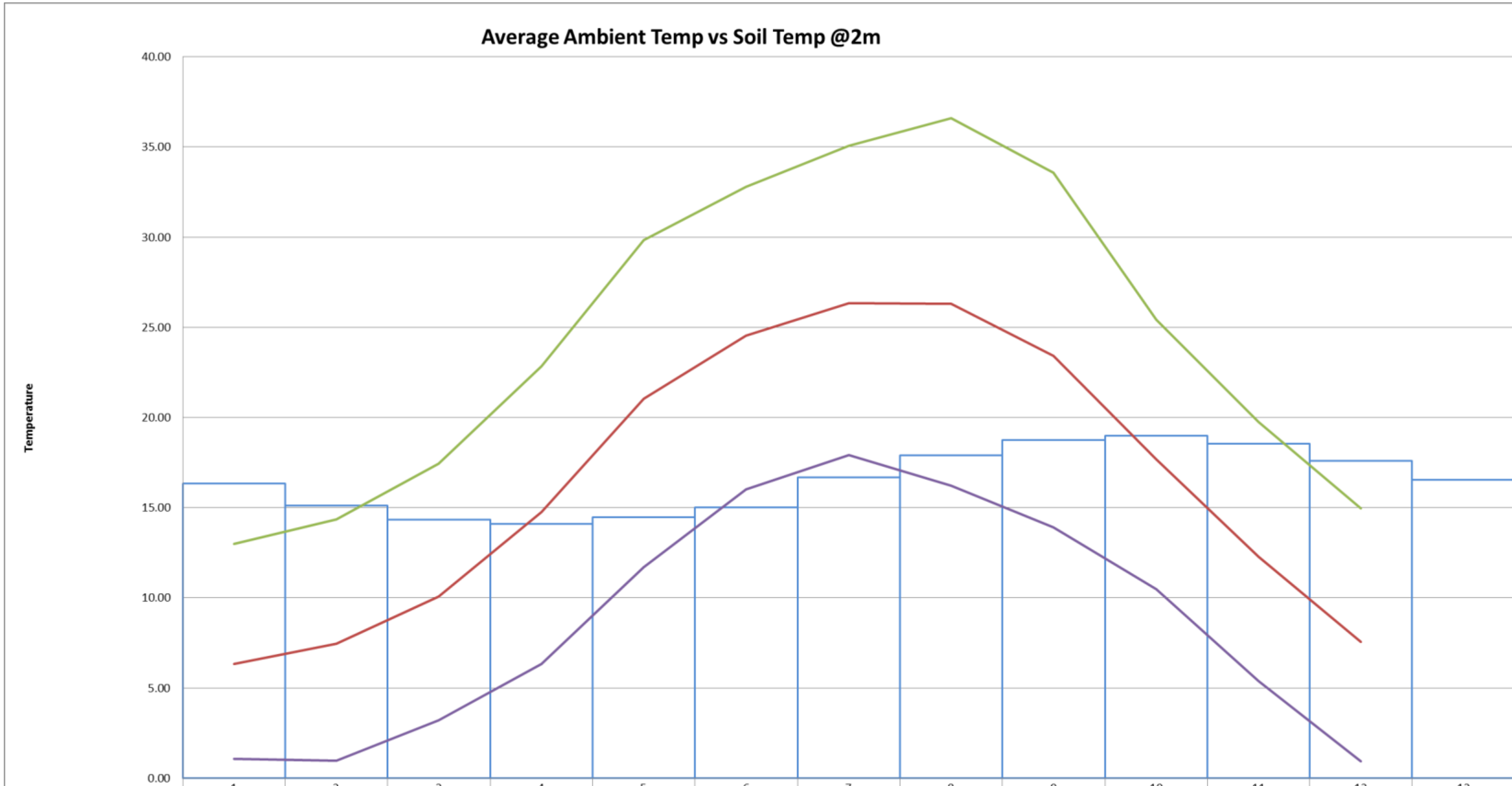
– Ground Ducts + Insulation

- Insulation:
  - Type EPS (0.04 W/mK)
  - Thickness:
    - Walls: 10 cm
    - Roof 15 cm

- Ground Ducts:
  - Reinforced Concrete Pipes
  - Length 100 m, Diameter 1 m, Thickness 10cm

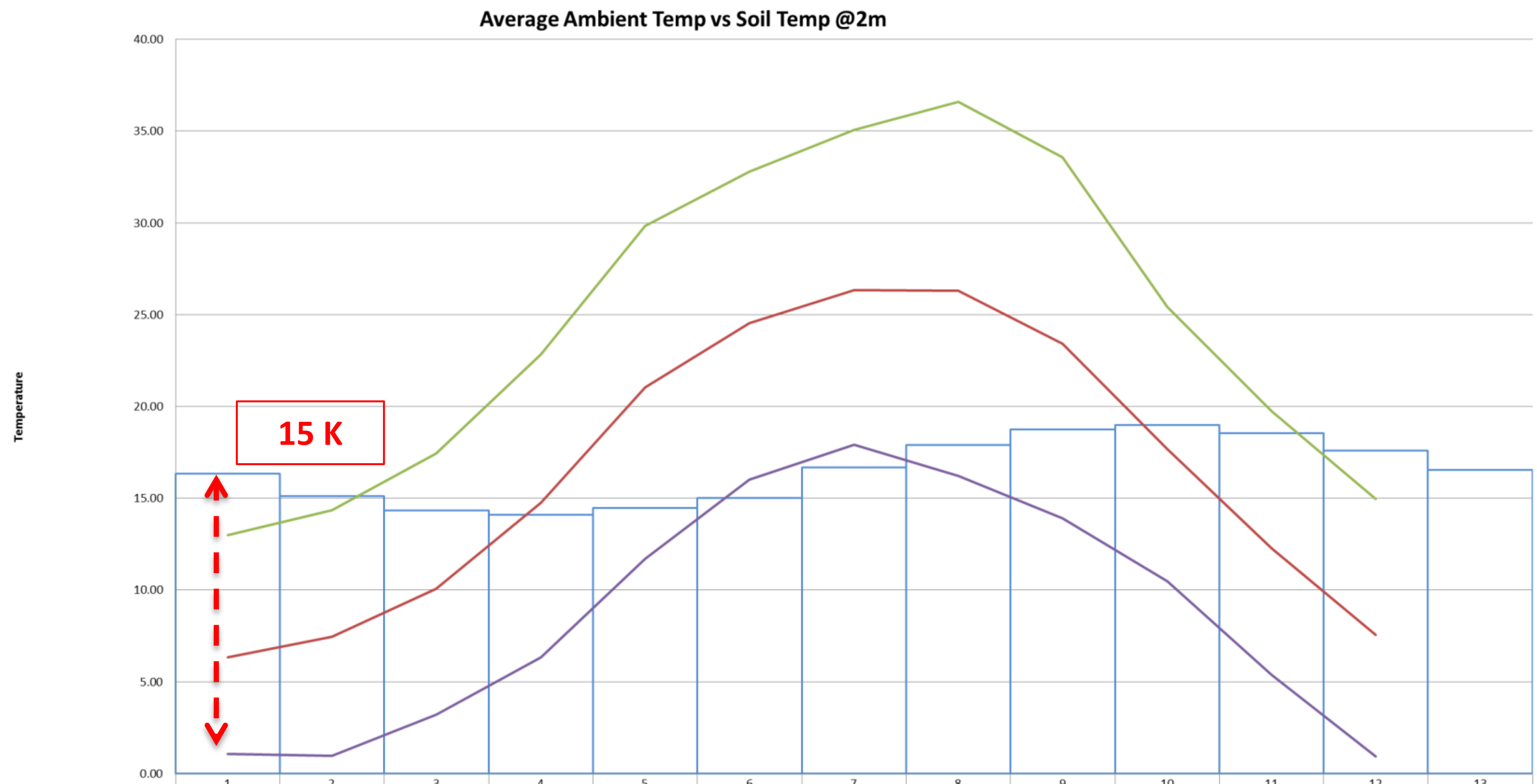


Ground Ducts + Insulation



	1	2	3	4	5	6	7	8	9	10	11	12	13
Soil @ 2 m	16.32	15.11	14.34	14.08	14.47	15.00	16.66	17.88	18.73	18.96	18.54	17.59	16.52
Average Ambient Temp	6.33	7.46	10.05	14.74	21.04	24.53	26.33	26.30	23.42	17.67	12.27	7.54	
Mean Max temp	12.98	14.34	17.43	22.82	29.83	32.80	35.06	36.61	33.56	25.41	19.74	14.95	
Mean Min temp	1.06	0.96	3.19	6.34	11.71	16.02	17.90	16.22	13.90	10.48	5.38	0.94	

Ground Ducts + Insulation



	1	2	3	4	5	6	7	8	9	10	11	12	13
Soil @ 2 m	16.32	15.11	14.34	14.08	14.47	15.00	16.66	17.88	18.73	18.96	18.54	17.59	16.52
Average Ambient Temp	6.33	7.46	10.05	14.74	21.04	24.53	26.33	26.30	23.42	17.67	12.27	7.54	
Mean Max temp	12.98	14.34	17.43	22.82	29.83	32.80	35.06	36.61	33.56	25.41	19.74	14.95	
Mean Min temp	1.06	0.96	3.19	6.34	11.71	16.02	17.90	16.22	13.90	10.48	5.38	0.94	

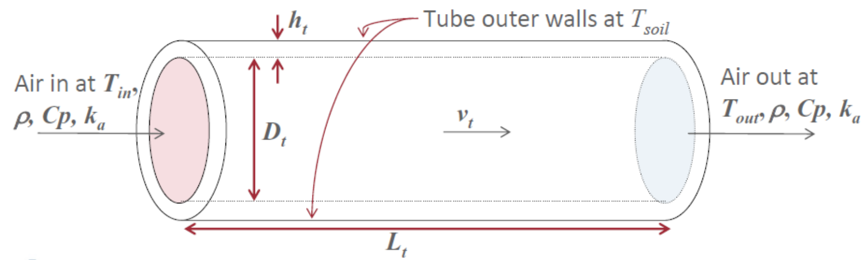
Ground Ducts + Insulation

Efficiency of Heat Recovery 75%

Operation @ T duct > Tamb

Assumption: Twall= T soil

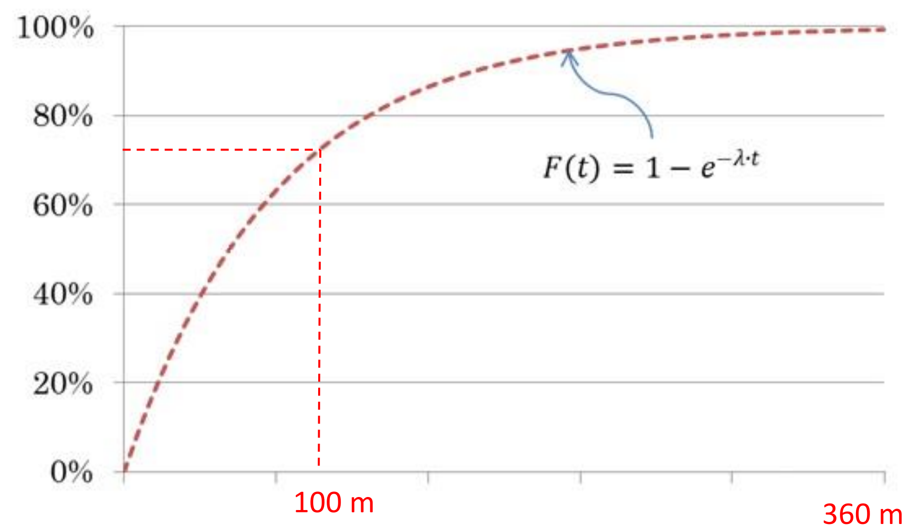
Neglect the Resistance of Wall (10cm concrete)



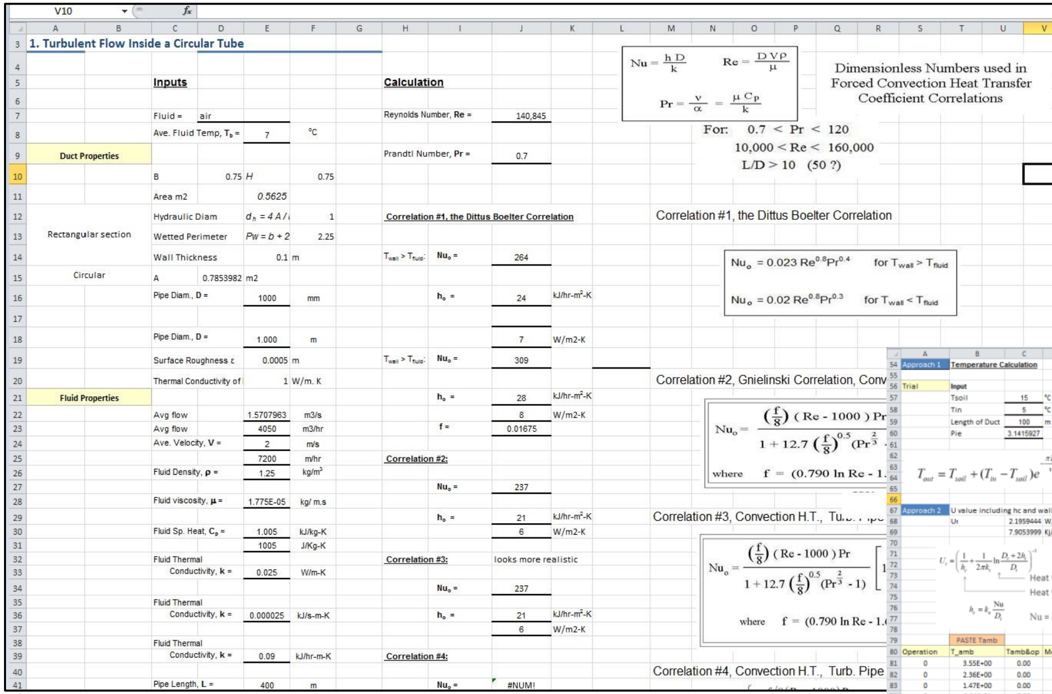
$$Nu_o = \frac{\left(\frac{f}{8}\right)(Re - 1000)\,Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}\left[1 + \left(\frac{D}{L}\right)^{\frac{2}{3}}\right]$$

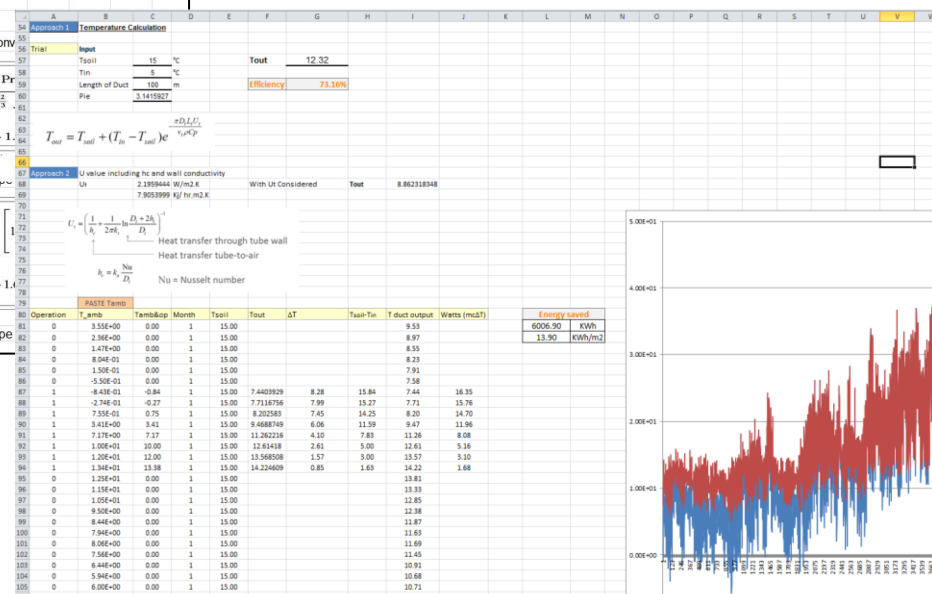
where $f = (0.790 \ln Re - 1.64)^{-2}$

$$T_{out} = T_{soil} + (T_{in} - T_{soil})e^{-\frac{\pi D_t L_t U_t}{v_t \rho Cp}}$$

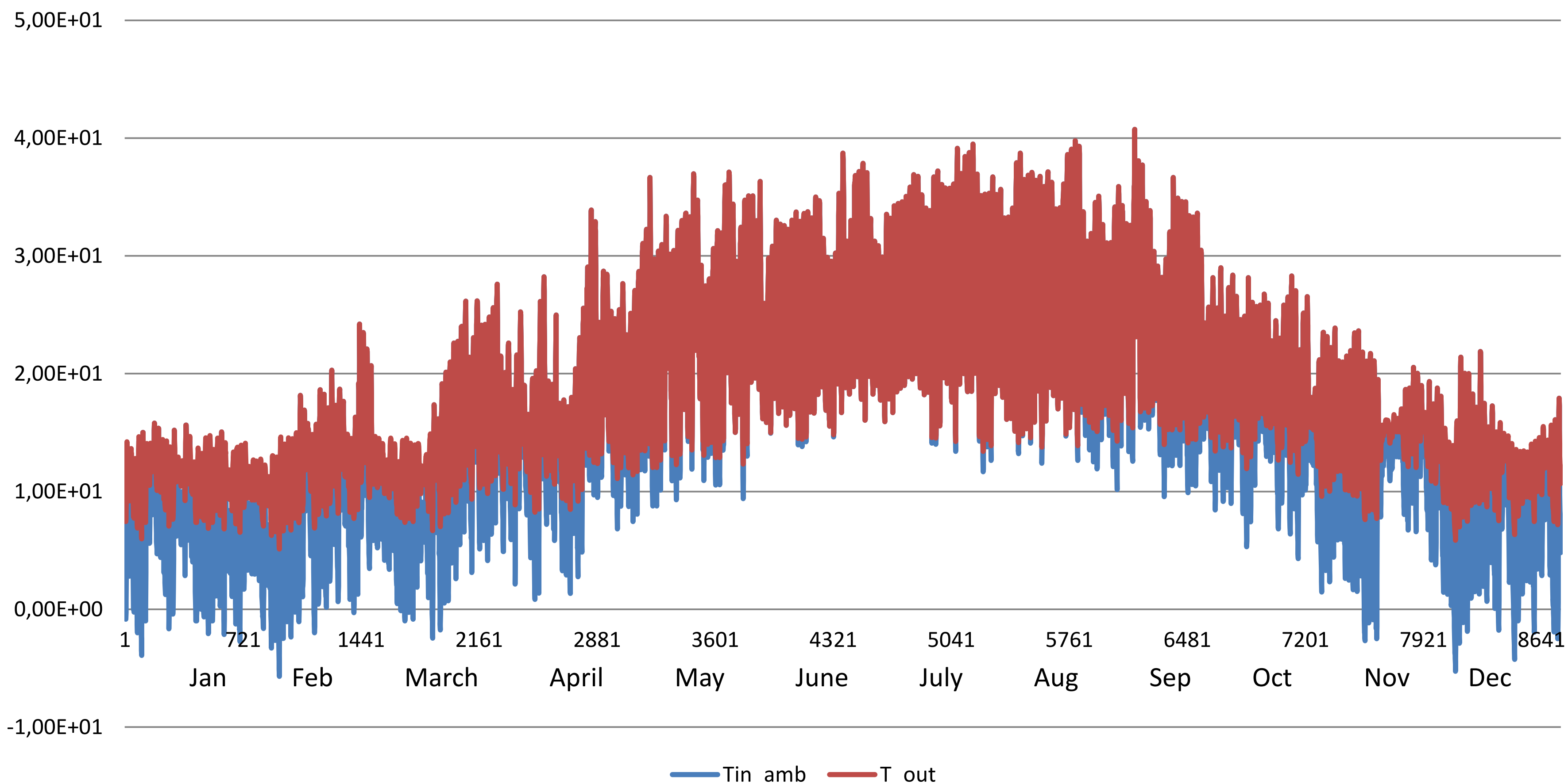


Tool for Ground Duct Heat Recovery

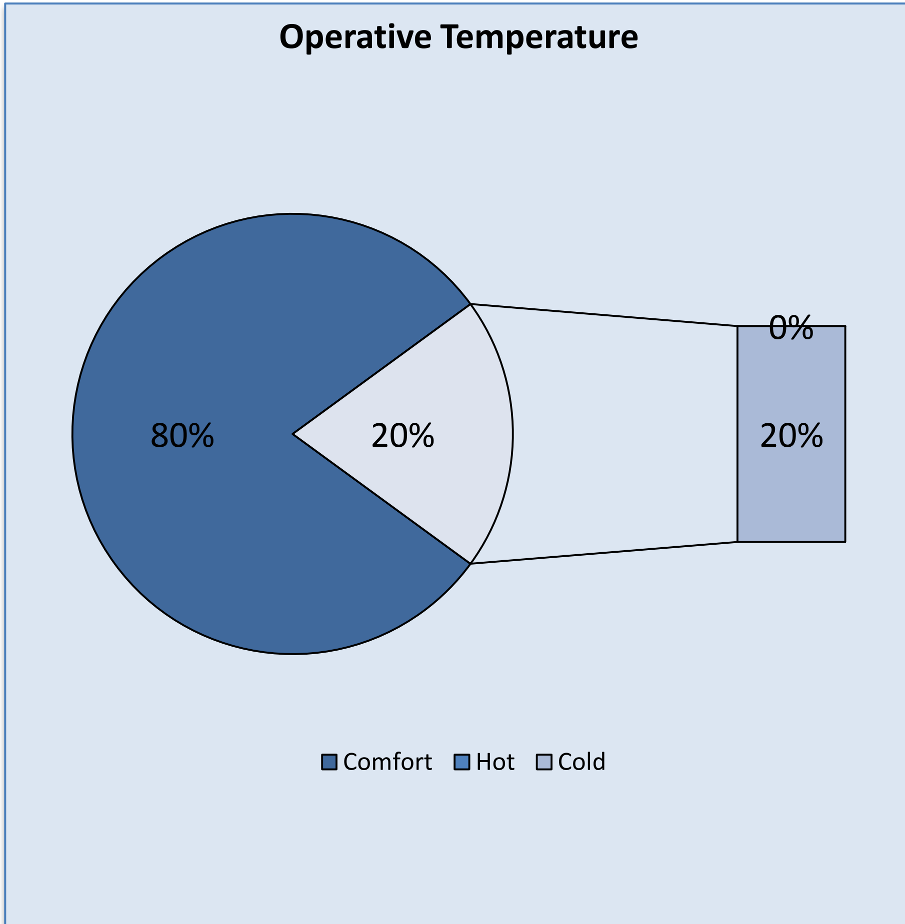


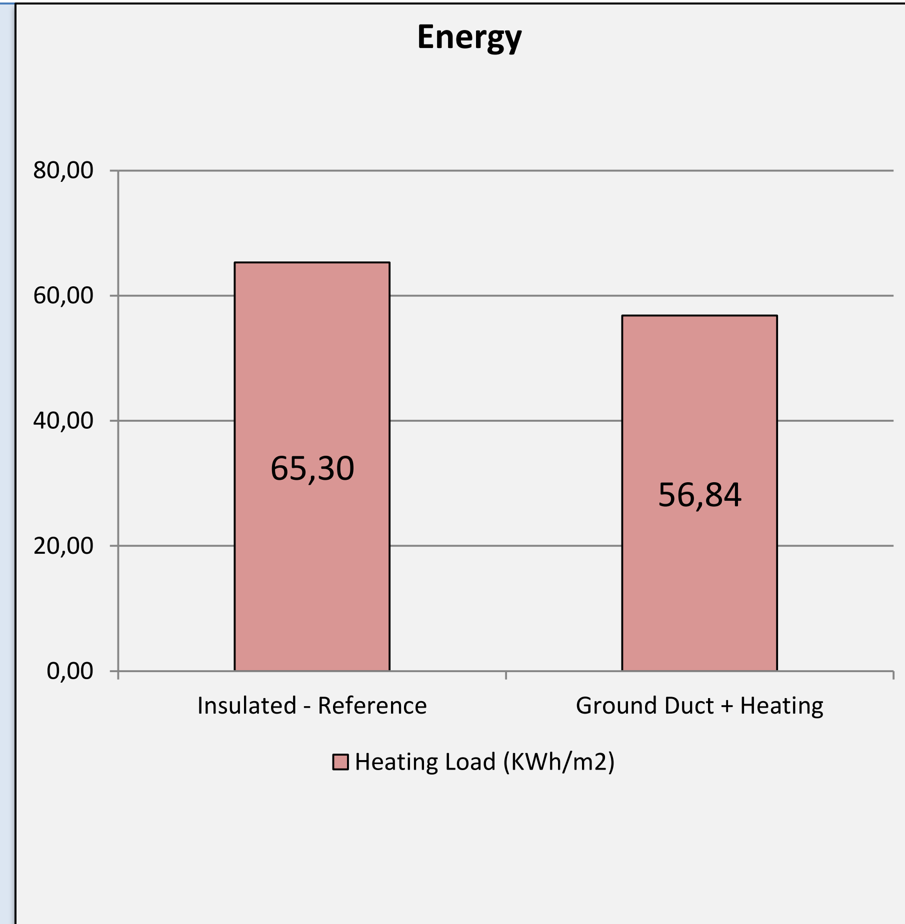


Ground Ducts + Insulation



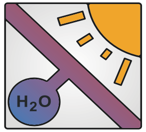
Ground Ducts + Insulation



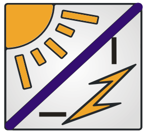


Active Strategies

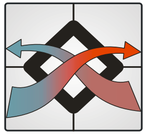
– Solar Thermal Collector



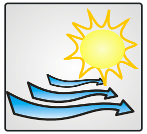
– PV + Heat pump



– AHU



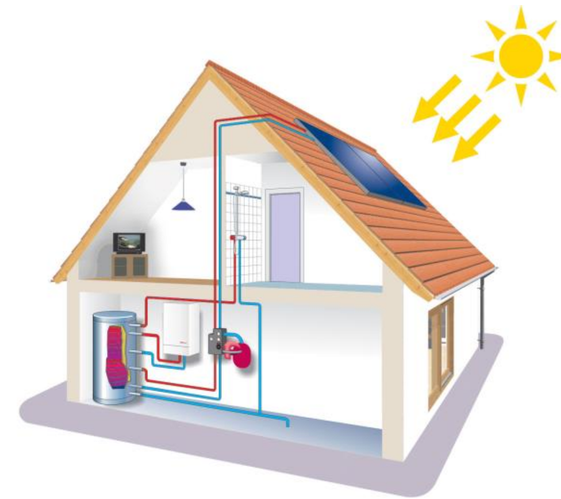
– Solar Air Collector

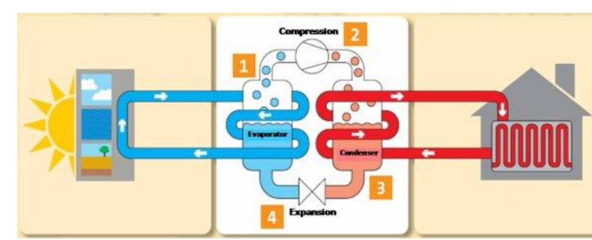


Active Strategies

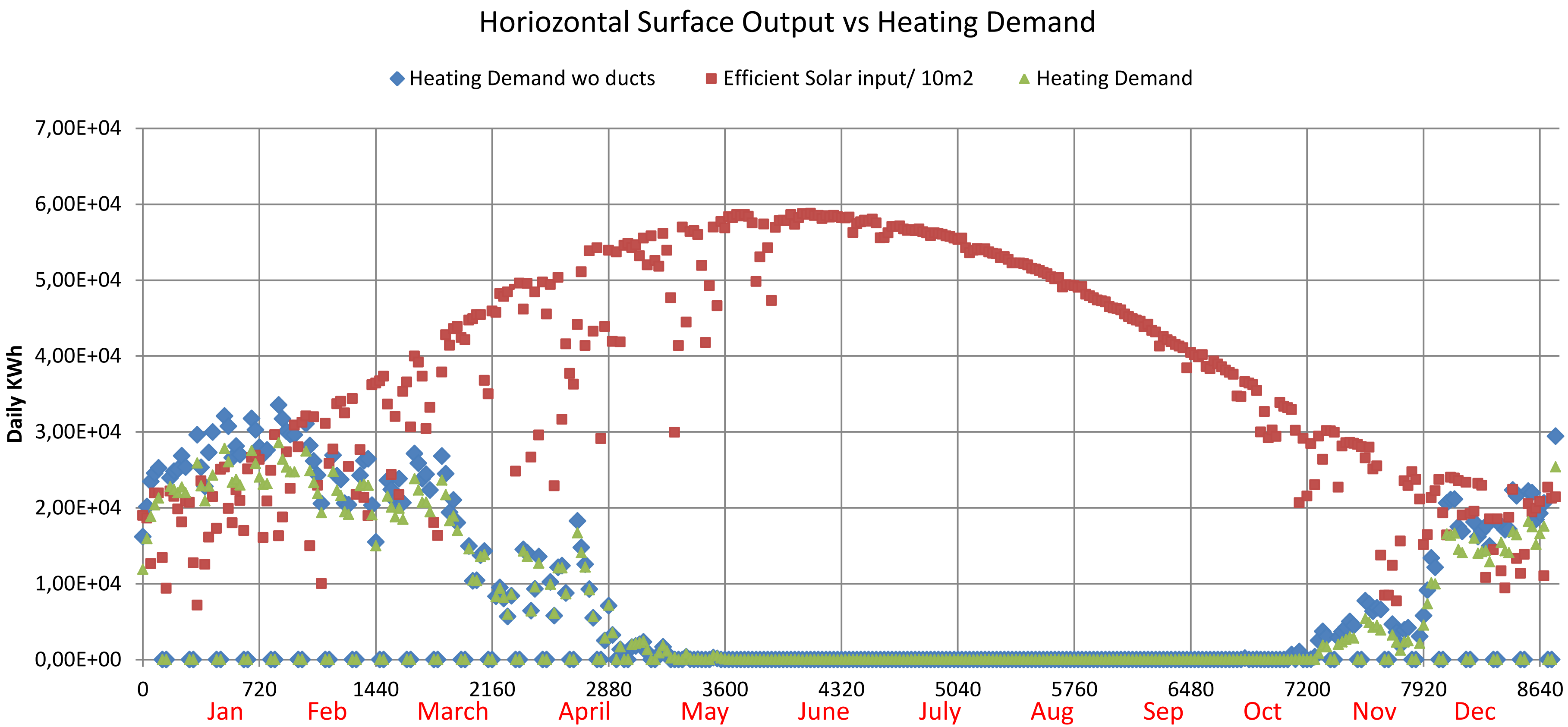
- Solar Thermal Collector
- PV + Heat pump
- AHU
- Solar Air Collector

- Radiator Connected to Solar Thermal Plant 10m2.
- Heat output is related to the average montinored demand during heating season.
- Boiler Set to 70°C





Solar Thermal - Primary Investigation



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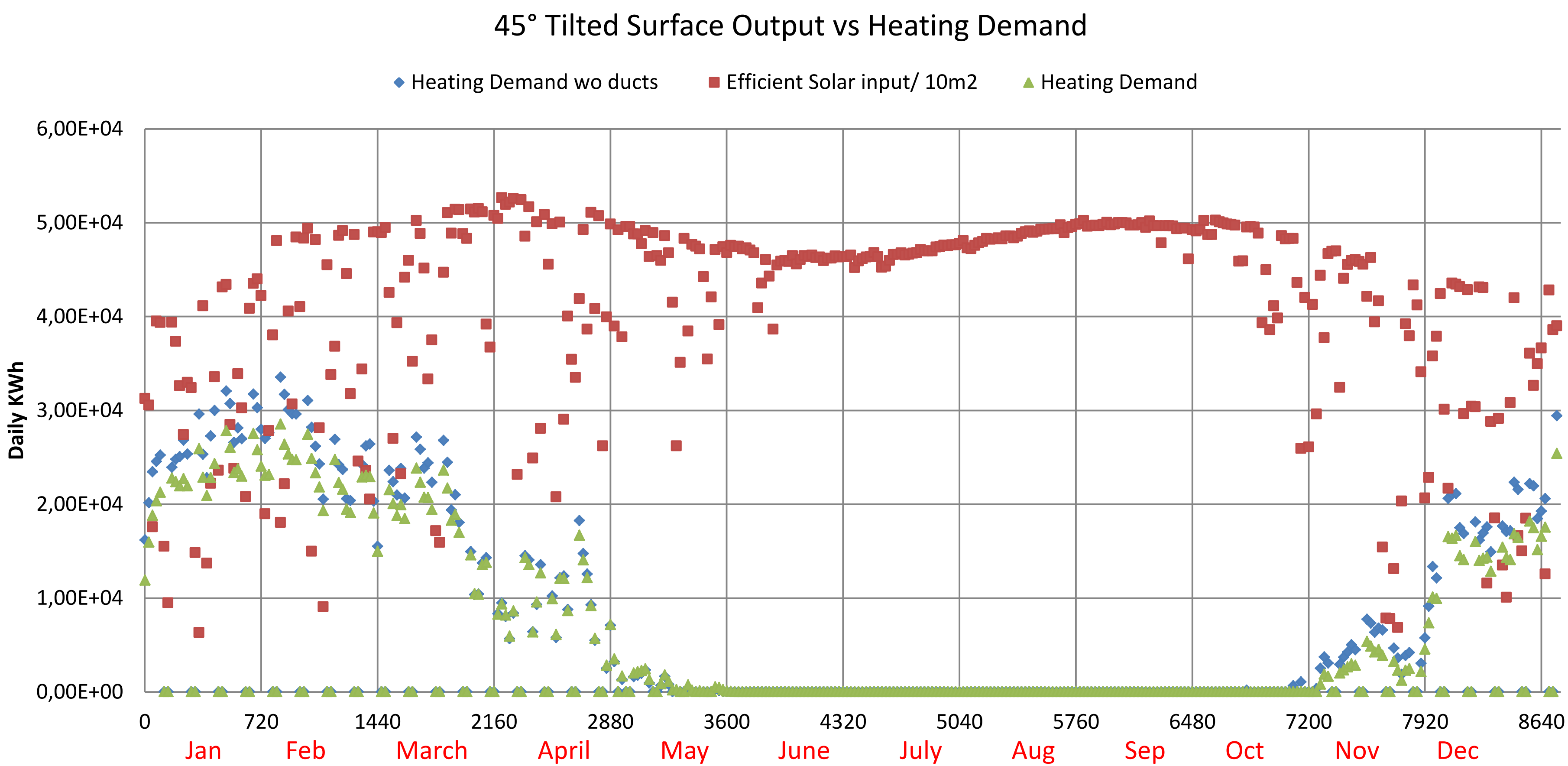

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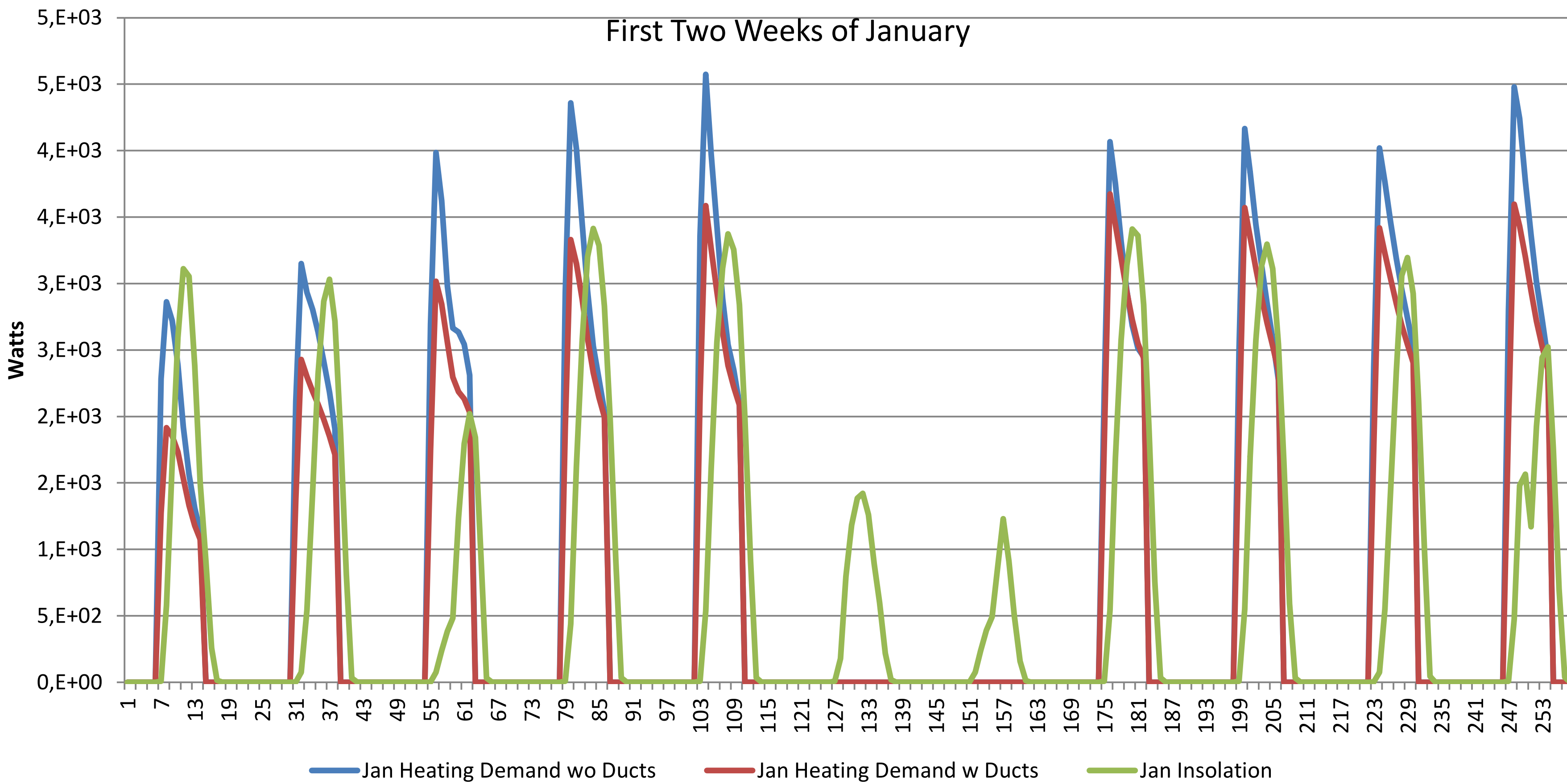
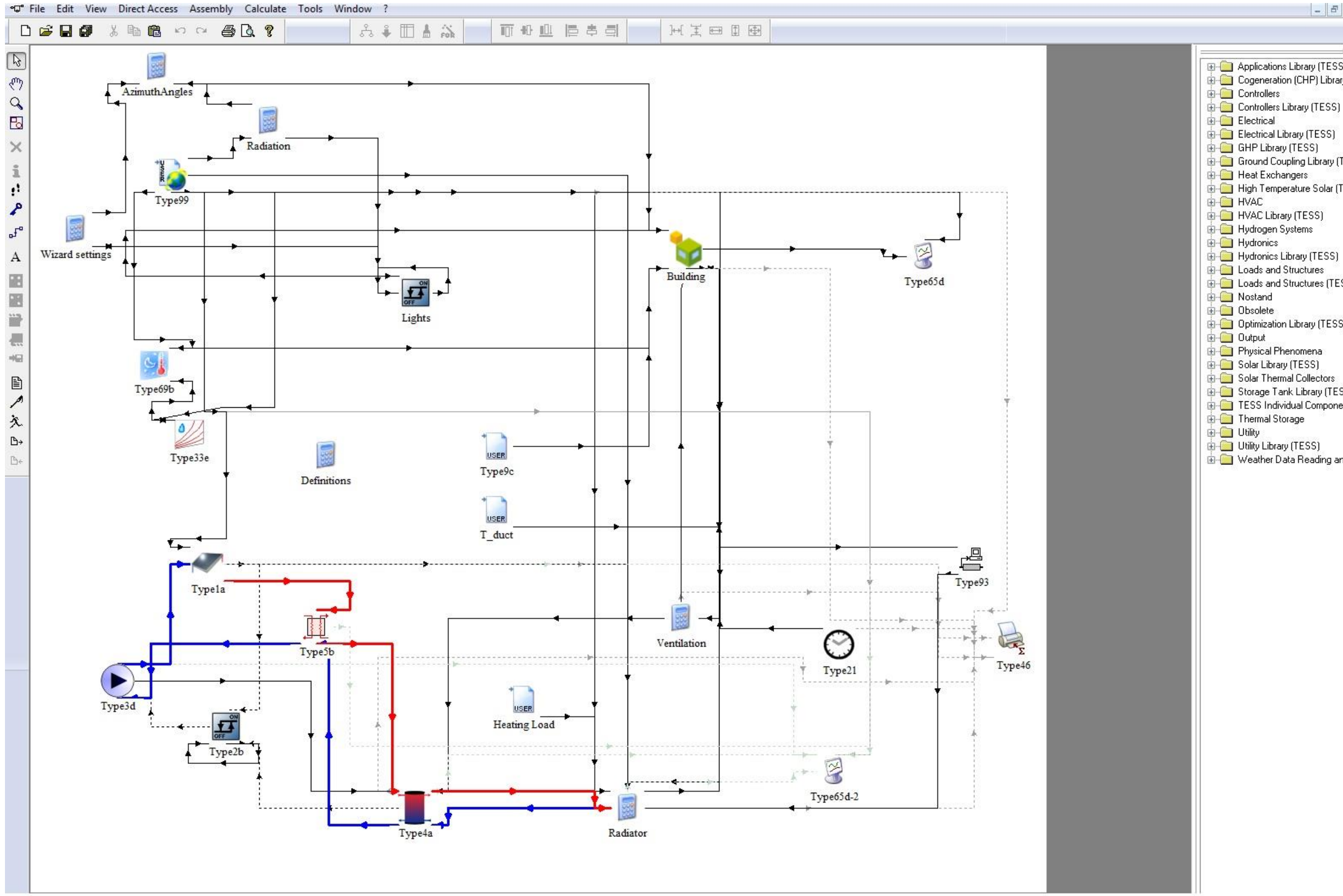
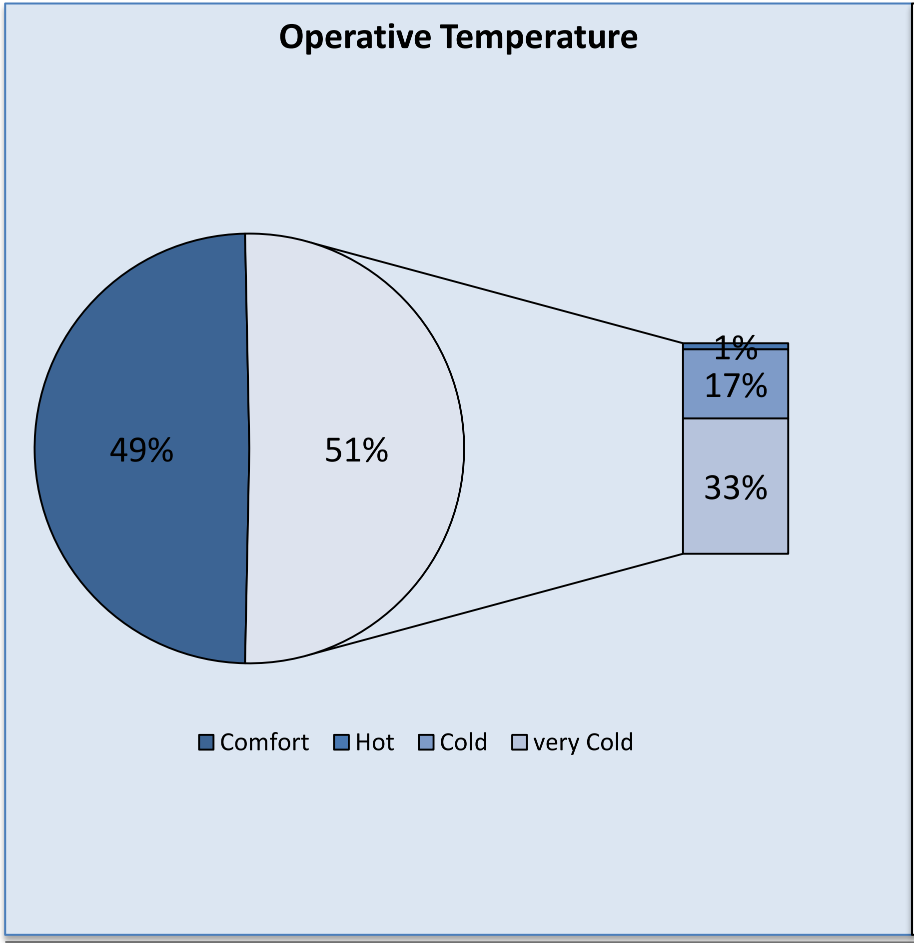


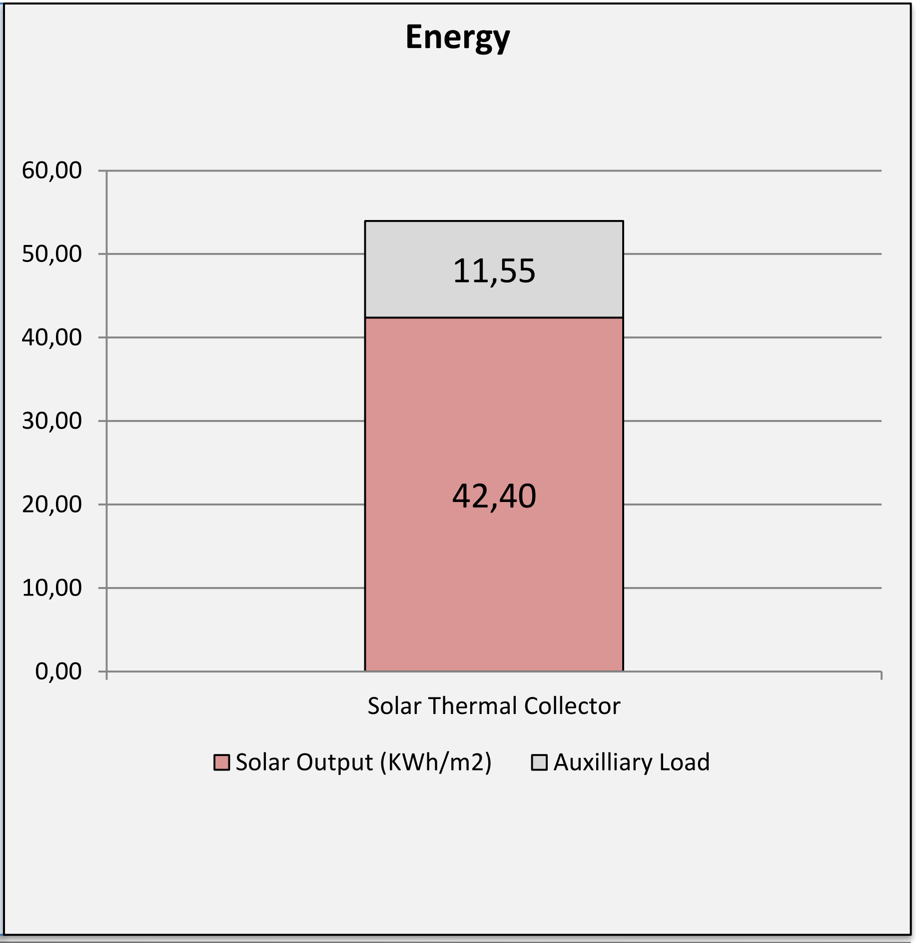
Solar Thermal

Snapshot- Trnsys Setup



Solar Thermal Collector

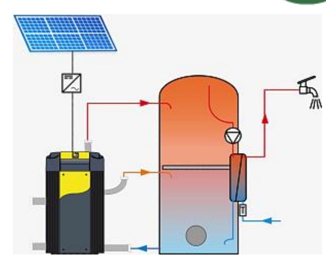




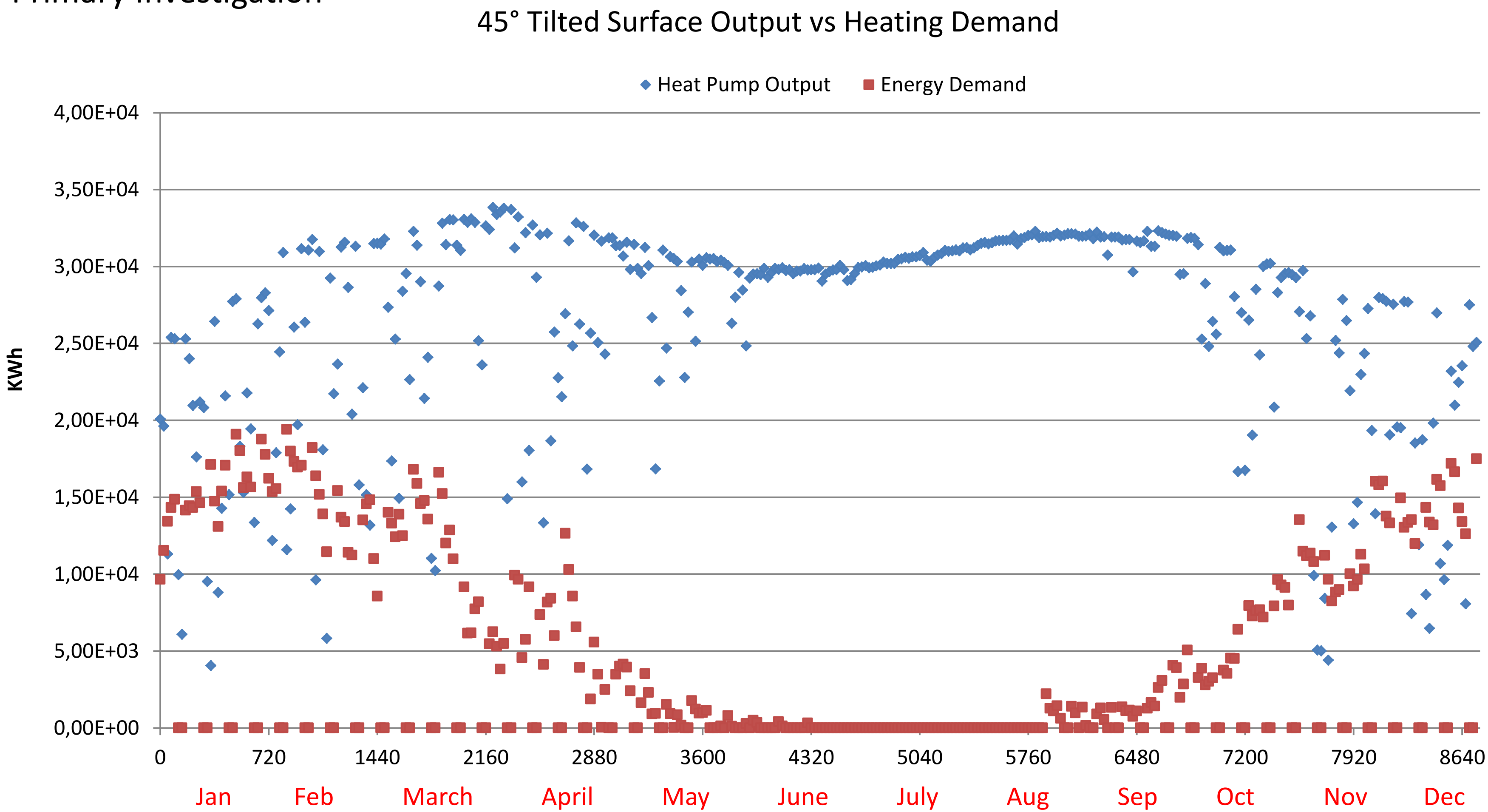
Active Strategies

- Solar Thermal Collector
- PV + Heat pump
- AHU
- Solar Air Collector

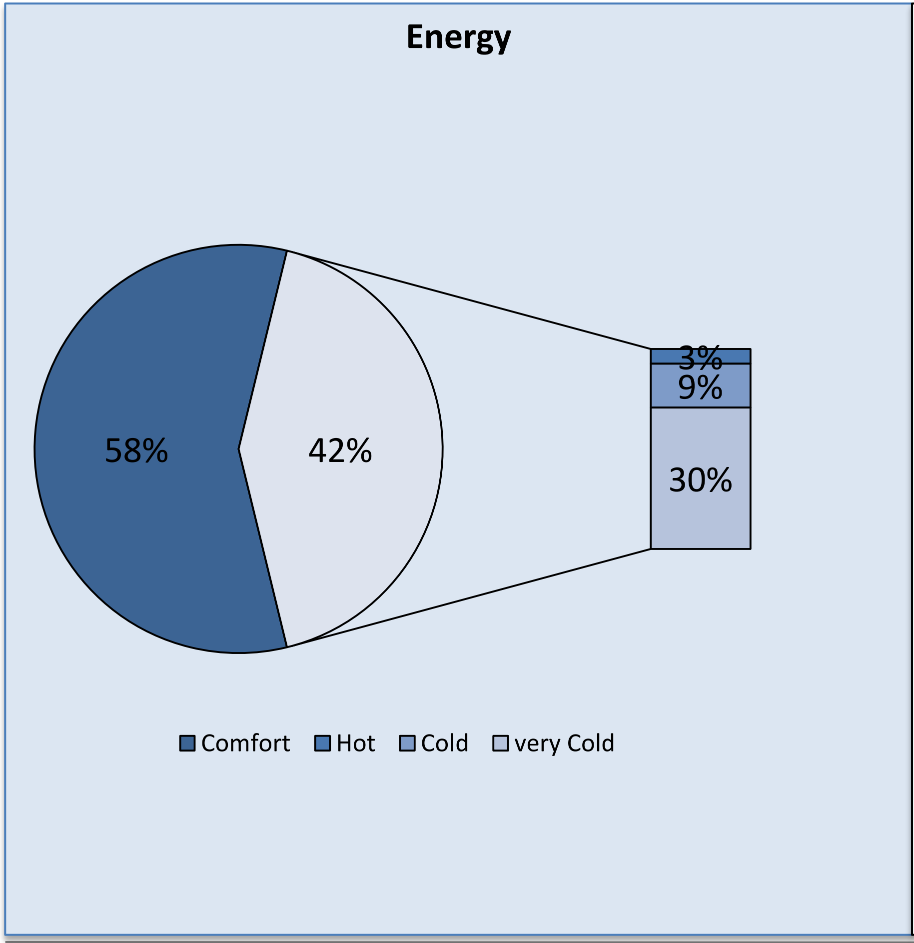
- PV peak 150 Wp/m2, efficiency 15%
- PV Area 10 m2/Class – 36m2
- Heat Pump 5KWp as per heat load, COP 3
- Q_heatpump*le(Tamb,24)*le(T_air,21)

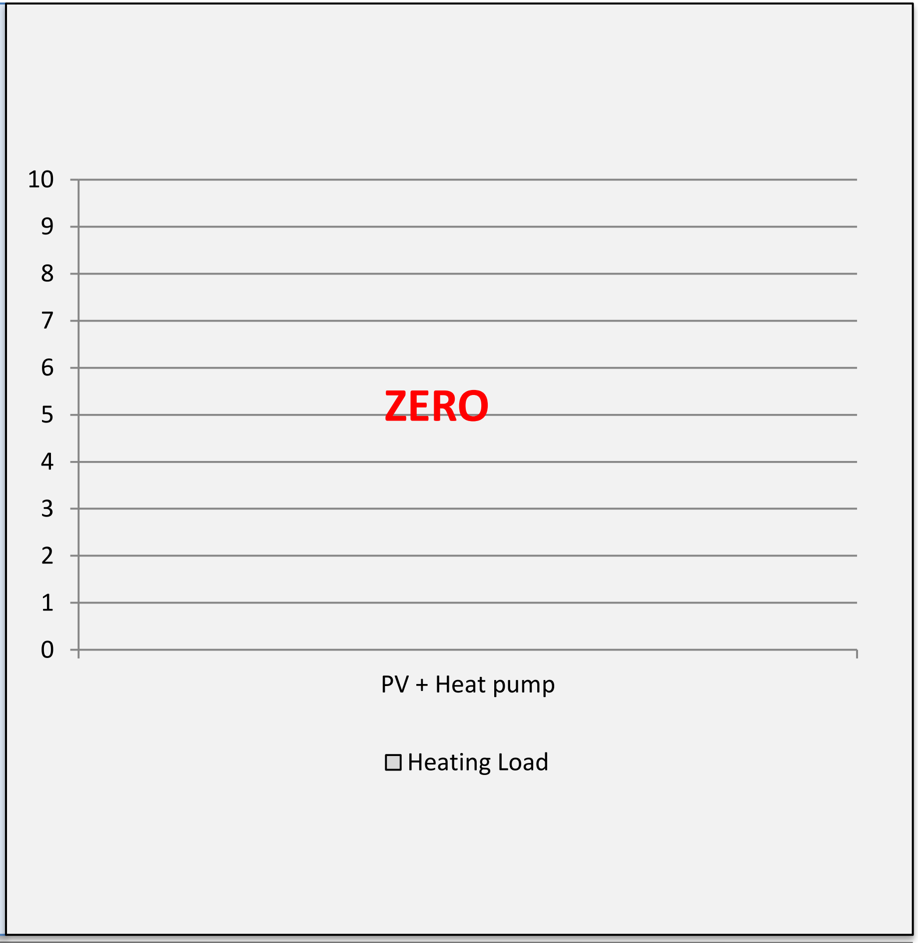


Primary Investigation



PV + Heat Pump

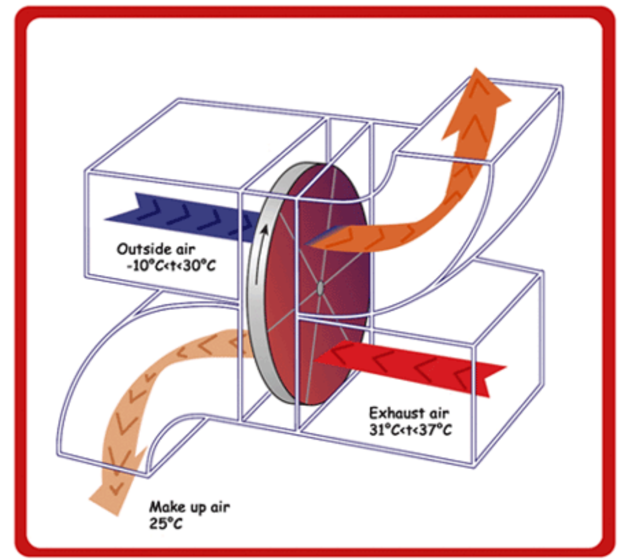

Energy
58%
42%
3%
9%
30%
Comfort
Hot
Cold
very Cold


10
9
8
7
6
5
4
3
2
1
0
ZERO
PV + Heat pump
Heating Load

Active Strategies

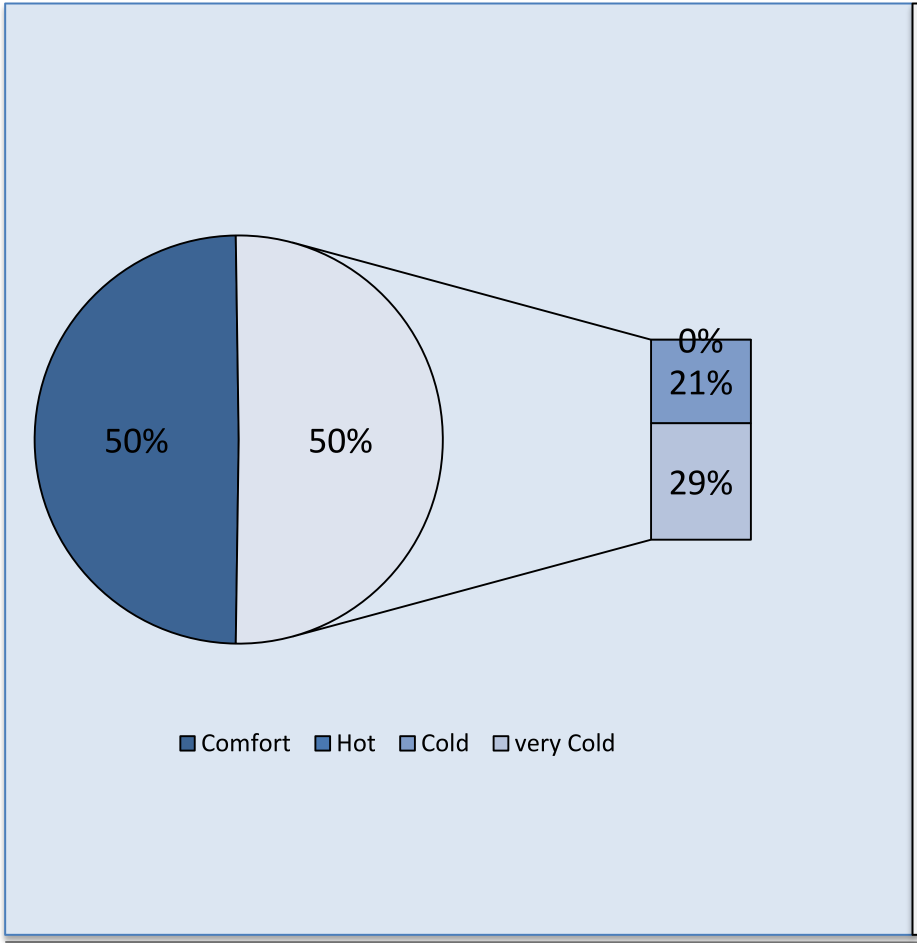
- Solar Thermal Collector
- PV + Heat pump
- AHU
- Solar Air Collector

- Set Temperature AHU= 21 for T_{amb}<21
- Heat Recovery= 70% for T_{amb}< 21

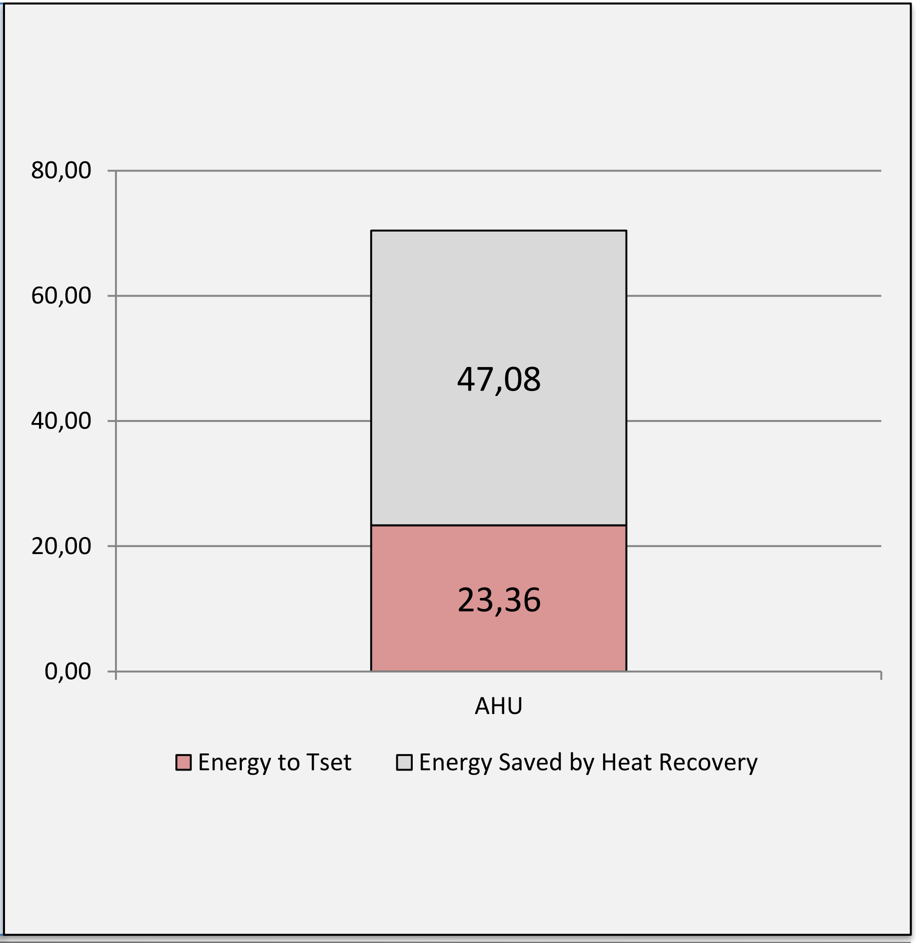


A diagram of a rotary heat exchanger, or "heat wheel" (From Uptime Technology BV)

AHU



50%
50%
0%
21%
29%
Comfort
Hot
Cold
very Cold

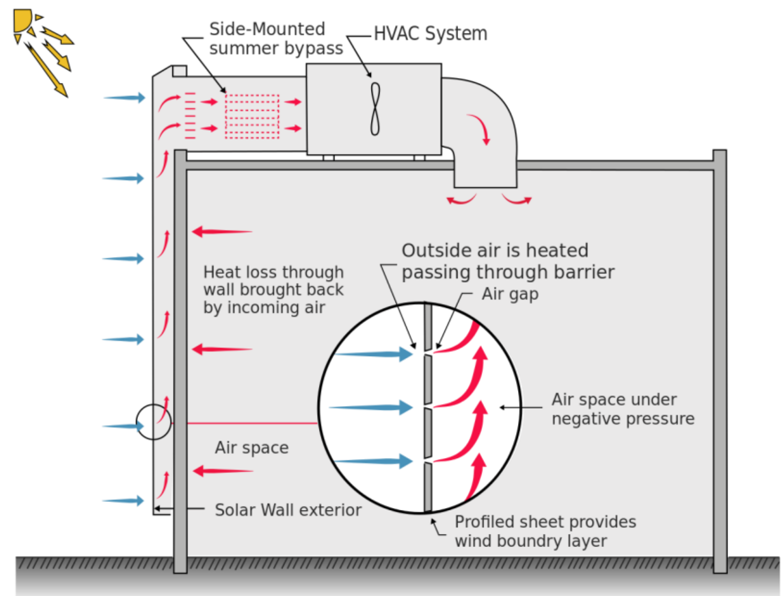


80,00
60,00
40,00
20,00
0,00
47,08
23,36
AHU
Energy to Tset
Energy Saved by Heat Recovery

Active Strategies

- Solar Thermal Collector
- PV + Heat pump
- AHU
- Solar Air Collector

- Vertical Insolation south oriented
- Solar air heat source



Solar Air Collector

Primary Investigation

- Type 1 Glazed
- Efficiency 70%
- Vertical Setup – Directed to South

- T_out = (((n*G)/(Cp*m_flow))+T_amb)* le(T_amb,24) + gt(T_amb,24)*T_amb

From these (and in accordance with equations IV.1.1 and IV.1.3) the following relations can be derived:

$$\dot{Q}_u = \eta G \qquad \text{(IV.1.4.)}$$

and

$$\Delta T = (T_o - T_i) = \frac{\dot{Q}_u}{\dot{m}C_p} = \frac{\eta G}{\dot{m}C_p} \qquad \text{(IV.1.5.)}$$

where A_c is chosen to be 1 for the normalized situation (per m²)

Flat-plate air collectors

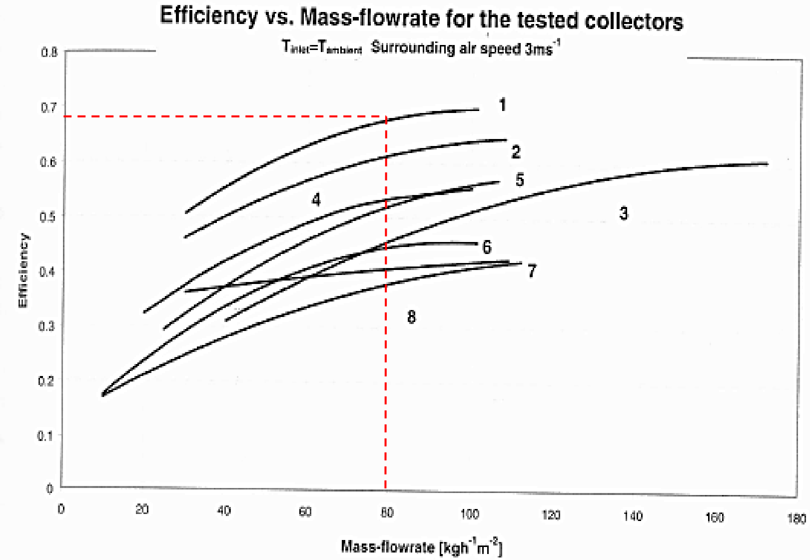
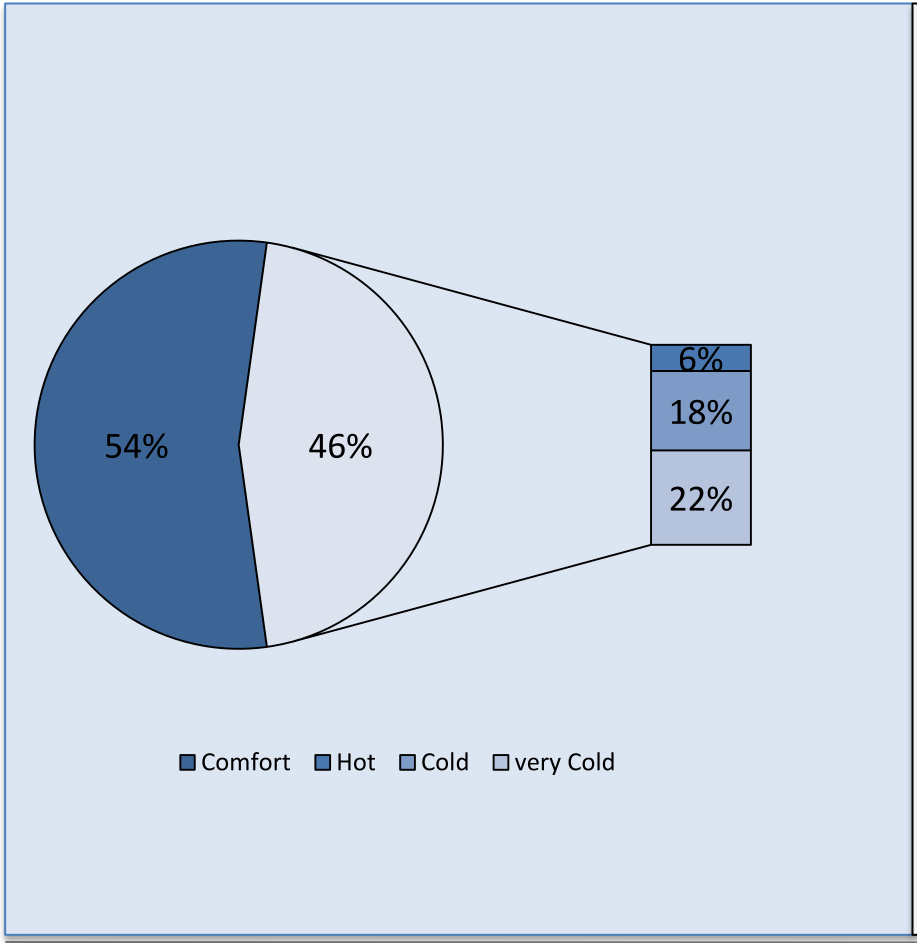
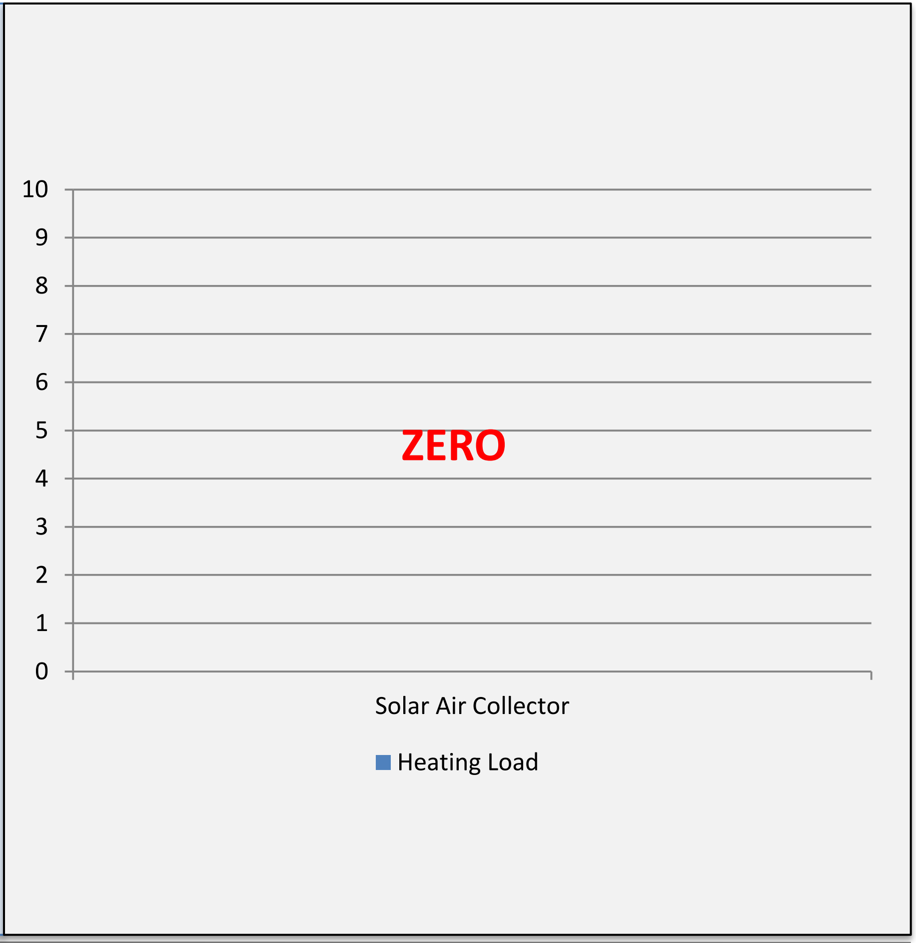


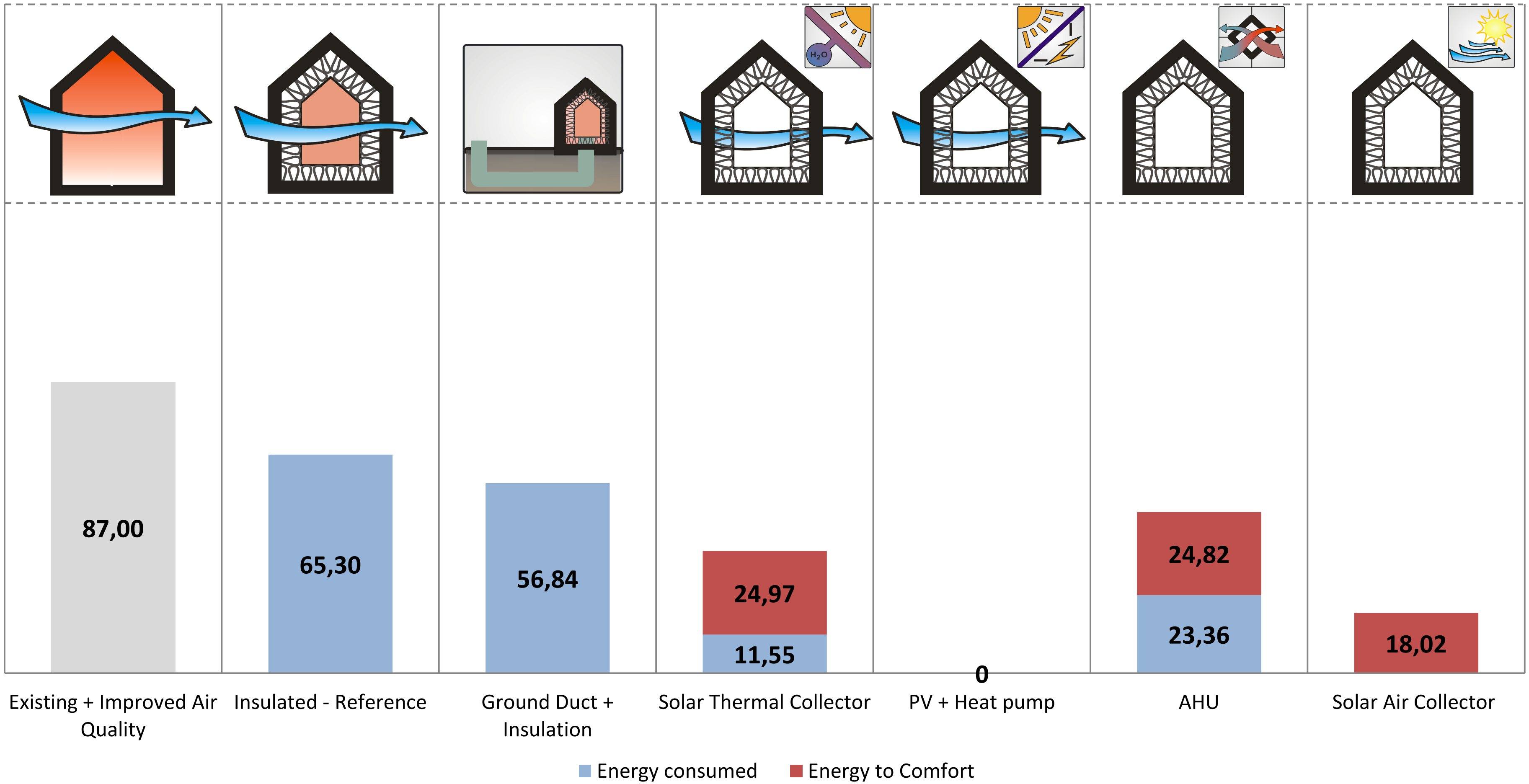
Figure IV.1.4. Efficiency versus mass-flow rate for selected collectors on the market
1 glazed collector (iron-poor), aluminum absorber with U-profiles, selective coating, underflow
2 glazed collector, black textile absorber
3 unglazed perforated trapezoid absorber panel, aluminum, anthracite, strongly dependent on wind (curve for 3ms⁻¹)
4 glazed plane absorber, black painted, facade element, underflow
5 glazed, rippled absorber, air flow on both sides
6 glazed plane absorber, black painted, facade element, air flow on both sides
7 glazed site-built collector, selective absorber, trapezoid profile, underflow
8 glazed plane absorber, black painted, facade element, underflow

Solar Air Collector

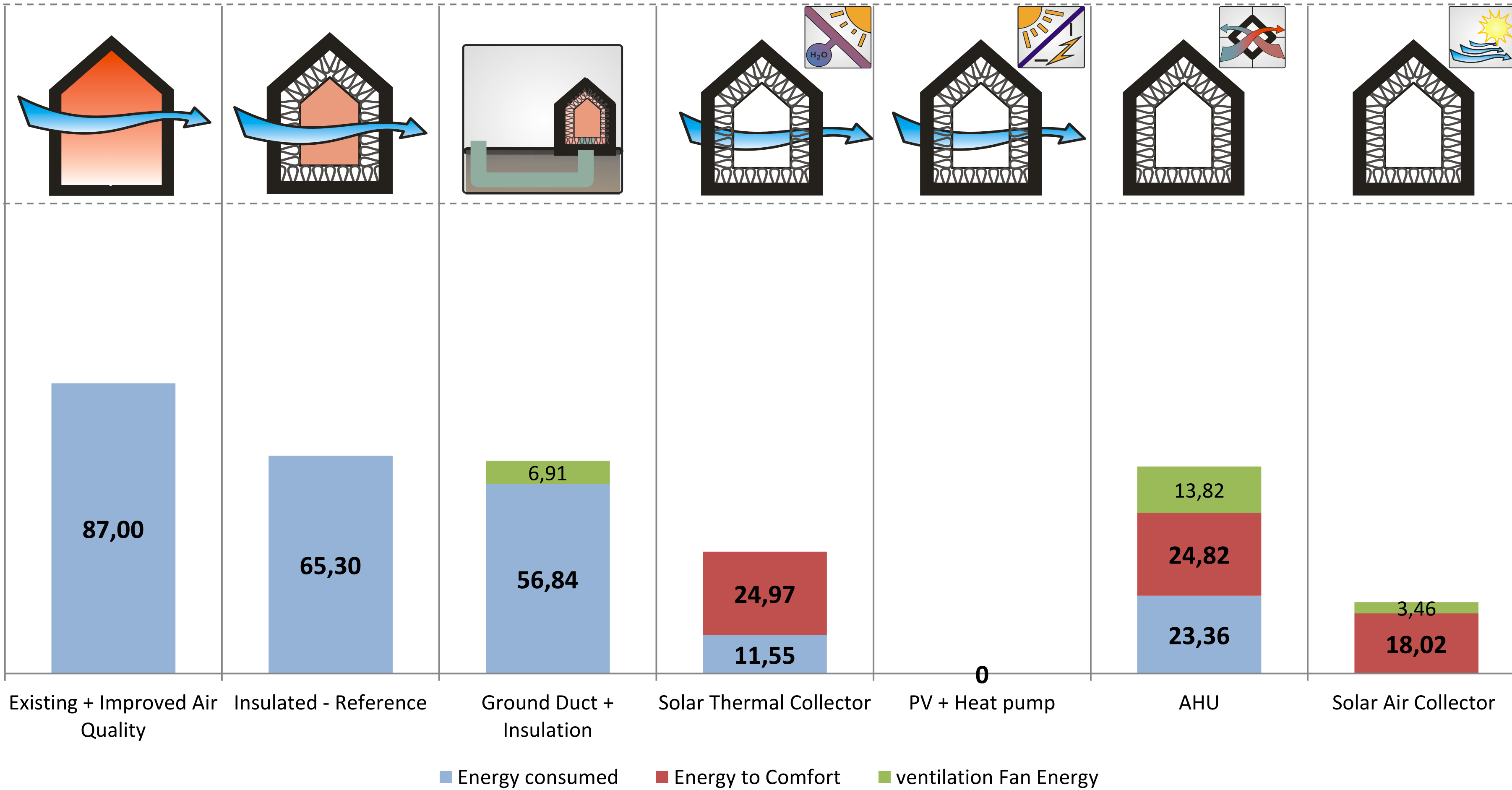




Heating Load



Heating Load + Electric Fan Power



LCA and Cost Estimation

– Capital Investment

– Return Period

	Heating Load/m2	Energy Saved	Electric Required/m2	Cost of system/ unit	Ancillary Costs	Unit	Desription
Existing (Trnsys)	55.75						
Existing + Improved Air Quality	87.00	0.00	0.00				
Insulated - Reference	65.30	21.70	0.00	10-13.5	5.00		Insulation + Plaster
Ground Duct	56.84	30.16	6.91	3298.67	9640.00	12 Classes - 432 m2	100 m duct/12 classes
Solar Thermal Collector	36.51	50.49	0.00	5666.67	1000.00	1 Class - 36 m2	10 m2 Panel-1 m3 tank/class
PV + Heat pump	0.00	87.00	0.00	2300.00	2500.00	1 Class - 36 m2	10 m2 PV + 5KWp Heat Pump
AHU	48.19	38.82	13.82	2160.00	0.00	12 Classes - 432 m2	4000 m3/h/ 12 classes
Solar Air Collector - Type 1	18.02	68.99	3.46	840.00	500.00	1 Class - 36 m2	5.6 m2 Type 1

	Effective Cost $/m2	Total Costs	Total Cost $/m2 (Bldg)	Cost of Energy Saved	Payback Time	Life Cycle	Feasibility
Insulated - Reference	$30.13	$54,243	$19	$4,395	10.23	30-40	Yes
Ground Duct	$29	$105,997.34	$37.86	$4,465	17.02	30-40	No
Solar Thermal Collector	$185	$387,575.98	$138	$10,224	23.53	15-20	No
PV + Heat pump	$133	$294,242.65	$105	$17,618	13.05	15-20	No
AHU	$60	$162,242.65	$57.94	$4,576	22.52	15-20	No
Solar Air Collector - Type 1	$37	$121,243	$43	$13,148	8.01	15-20	Yes
Interest	*0.04*						

years	Insulated - Reference	Ground Duct	Solar Thermal Collector	PV + Heat pump	AHU	Solar Air Collector - Type 1
1	-$47,931	-$97,627	-$362,838	-$265,986	-$151,603	-$103,937
2	-$41,862	-$89,579	-$339,052	-$238,815	-$141,373	-$87,297
3	-$36,026	-$81,841	-$316,181	-$212,690	-$131,536	-$71,296
4	-$30,415	-$74,400	-$294,189	-$187,570	-$122,077	-$55,911
5	-$25,020	-$67,245	-$273,044	-$163,415	-$112,982	-$41,118
6	-$19,832	-$60,366	-$252,711	-$140,190	-$104,237	-$26,894
7	-$14,844	-$53,751	-$233,161	-$117,858	-$95,829	-$13,217
8	-$10,047	-$47,390	-$214,362	-$96,385	-$87,743	-$66
9	-$5,435	-$41,275	-$196,287	-$75,738	-$79,969	$12,579
10	-$1,001	-$35,394	-$178,907	-$55,885	-$72,494	$24,738
11	$3,263	-$29,740	-$162,195	-$36,795	-$65,306	$36,429
12	$7,363	-$24,303	-$146,126	-$18,440	-$58,395	$47,671
13	$11,305	-$19,075	-$130,675	-$791	-$51,749	$58,480
14	$15,096	-$14,048	-$115,818	$16,180	-$45,359	$68,874
15	$18,741	-$9,214	-$101,533	$32,497	-$39,215	$78,867
16	$22,246	-$4,567	-$87,797	$48,187	-$33,307	$88,477
17	$25,615	-$98	-$74,589	$63,274	-$27,627	$97,716
18	$28,856	$4,199	-$61,890	$77,781	-$22,165	$106,601
19	$31,971	$8,330	-$49,678	$91,729	-$16,913	$115,143

Recommendation and Future Steps

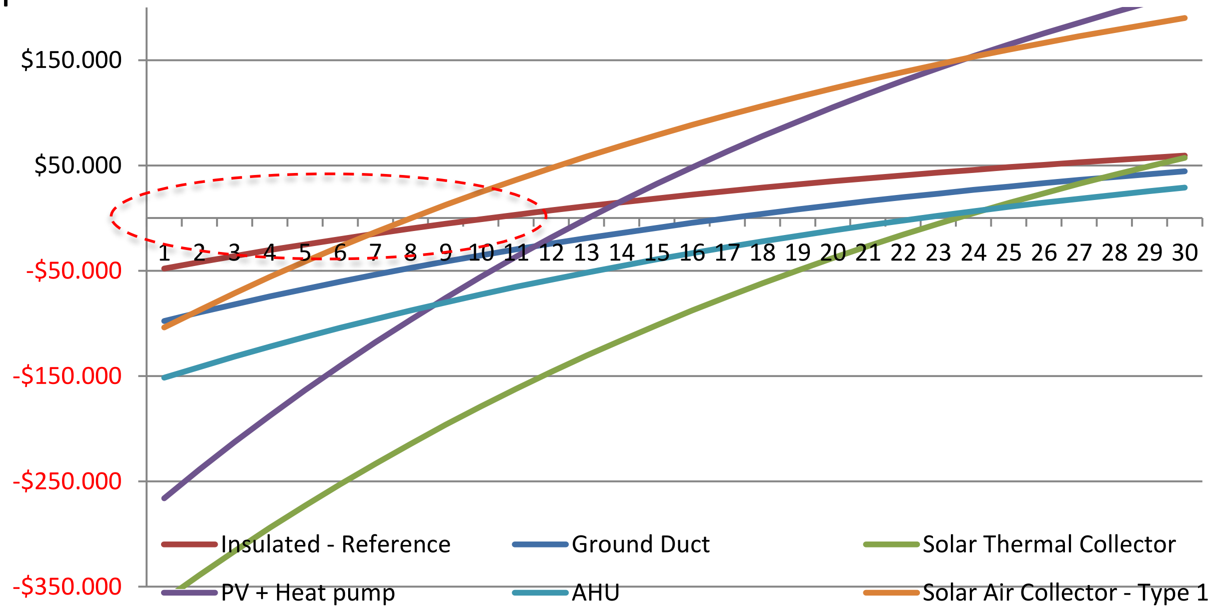
Which Investment is sexy?

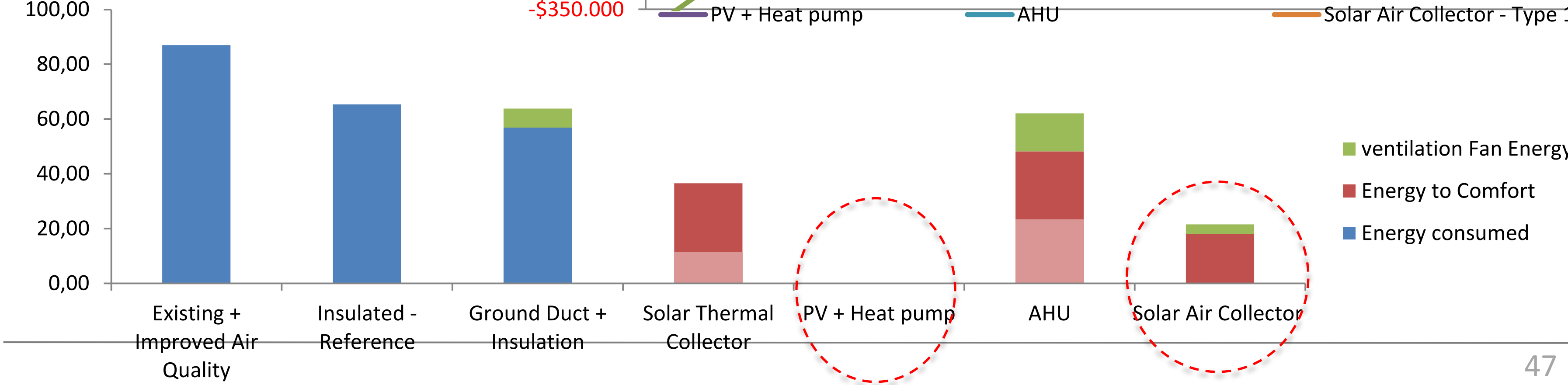
Solar Air Collector ✓
Total Cost + Insulation
120,000 $ or 92,000 euros

PV + Heat Pump
295,000 $ or 227,000 euros

Life Cycle

Technical System: 15-25 years
Insulation: 30-40 years





Solar Air Collector

Solar Air Collector

Advantages

- No need to change the system
- Decentralized
- Aesthetic enhancement to the Facade (Simple system but looks fancy)
- Low Cost
- Easy to Implement
- Can be coupled with existing radiator system to meet comfort
- Low Maintenance
- Clean and Easy source of energy
- Less space needed with respect to other systems only 5.6 m2/ class

Future Steps

- Present the results to the school
- Hope that they are smart enough to adopt the recommended scheme

THANK YOU

TransSolar GmbH

Special Thanks

Peter Voit

Christian Degenhardt

Jochen Lam

Monika Schulz

Matthias Schuler