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"GHEORGHE ASACHI" TECHNICAL UNIVERSITY OF IASI

Use of renewable energy to increase the energy efficiency in buildings

Thermal energy storage

Lecturer. Phd. Marius Balan

Yerevan, April 17-19

Introduction in thermal energy storage

Thermal energy storage (TES) systems can store heat or cold to be used later under varying conditions such as temperature, place or power.

Introduction in thermal energy storage

There are basically three types of thermal storage devices being investigated at present by the international players:

- Specific (sensible) heat storage
- Latent heat storage (phase change materials)
- Thermochemical heat storage

The principal gain from thermal storage is that heat and cold may be moved in space and time to allow utilization of thermal energy that would otherwise be lost because it was available at the wrong place at the wrong time.

Thermal energy storage systems themselves do not save energy. However, energy storage applications for energy conservation enable the introduction of more efficient, integrated energy systems.

Introduction in thermal energy storage

Thermal energy storage can consequently serve at least five different purposes:

· Energy conservation use of new renewable energy sources.

· Peak saving both in electric grids and district heating systems.

· Power conservation by running energy conversion machines, for instance cogenerating plants and heat pumps, on full (optimal) load instead of part load. This reduces power demand and increases efficiency.

· Reduced emissions of greenhouse gases.

· Freeing high quality electric energy for industrial value adding purposes.

Introduction in thermal energy storage

The main technological concepts for thermal energy storage (heat/cold) are:

- Underground thermal energy storage
- Water tanks above ground
- Rock filled storage with air circulation
- Phase change materials
- Thermochemical storage

Most heat storage concepts with the exception of PCM and chemical storage have one basic challenge in common. When heat or cold is charged into or discharged from the store, there will be temperature differences in different parts of the storage volume.

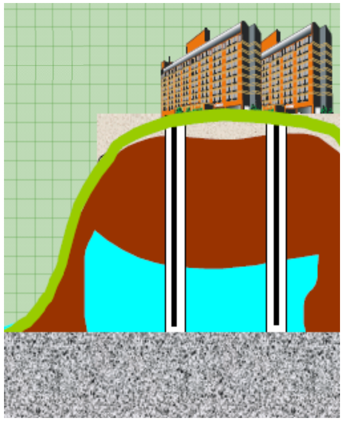
Long term energy storage systems

The problem of **interseasonal storage** of heat has raised the interest of specialists as a result of a set of factors, like :

- *the **energy situation** of the last decades, but also the perspective from the point of view of the end of the 20th century and the beginning of the 21st century;*
- *the need of **thermal energy storage** for longer periods of time, especially for countries at less-favored latitudes;*
- *the occurrence in some countries of an **energy surplus during the warm season** of the year, the consumption of which can be **transferred in the cold season** through appropriate storage systems.*

Long term energy storage systems

ATES



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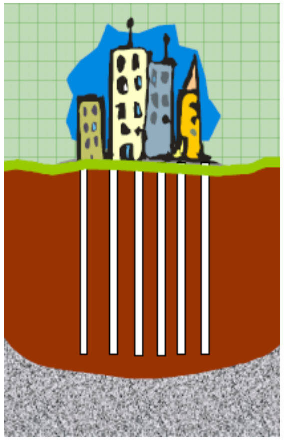

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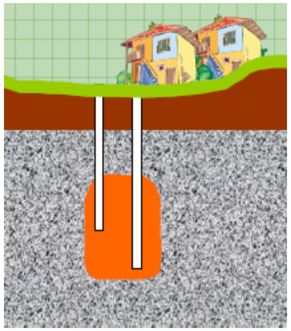

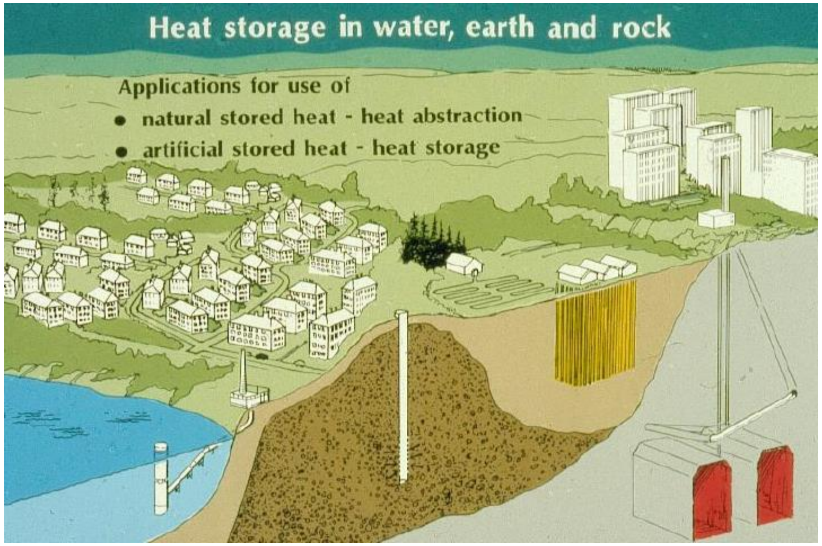

Long term energy storage systems

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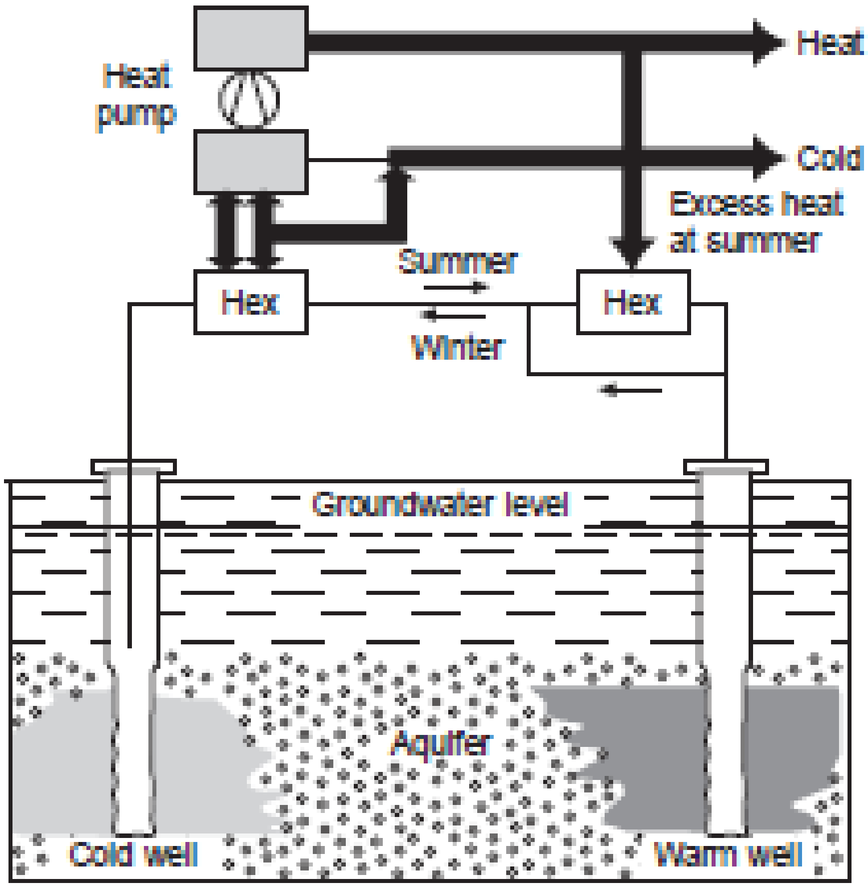

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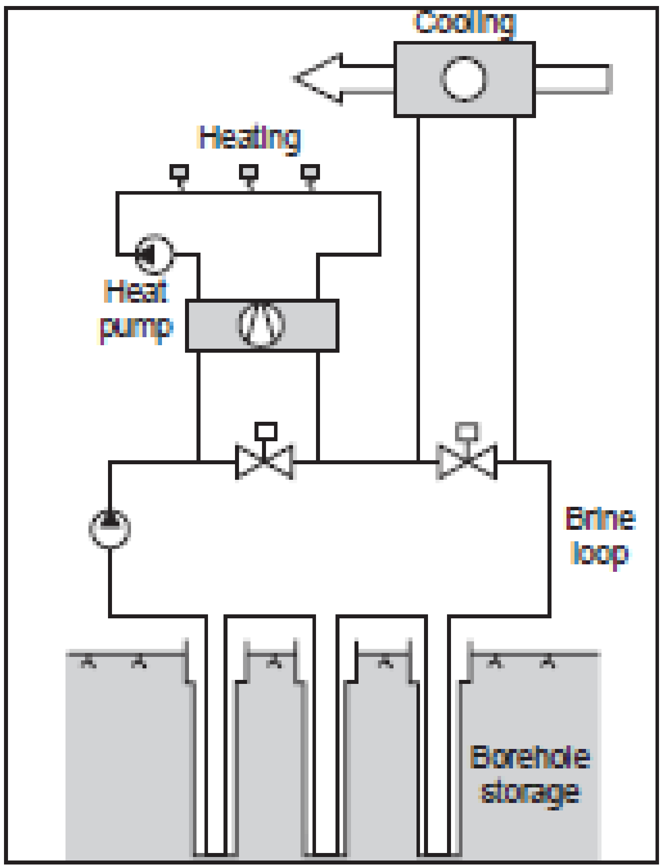

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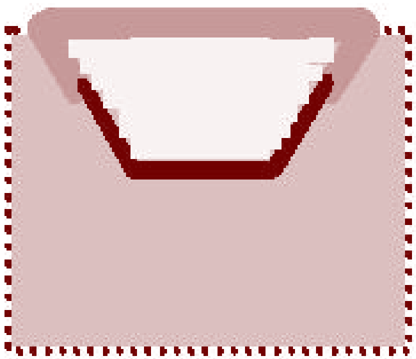
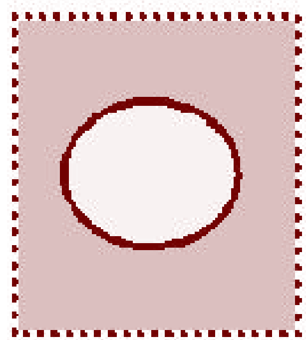
Long term energy storage systems

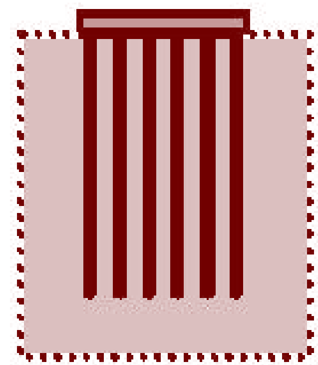
1. Partly insulated earth pit



2. Rock cavern

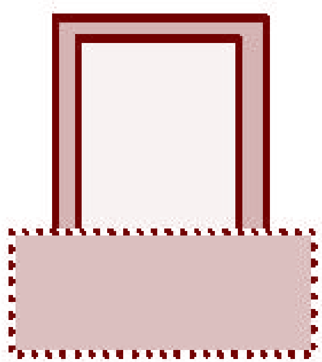


3. Vertical pipes in ground

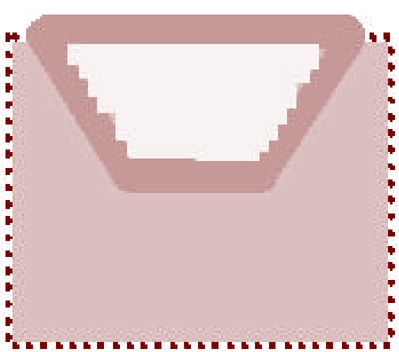


4. Aquifer

5. On-ground water tank



6. Insulated earth pit



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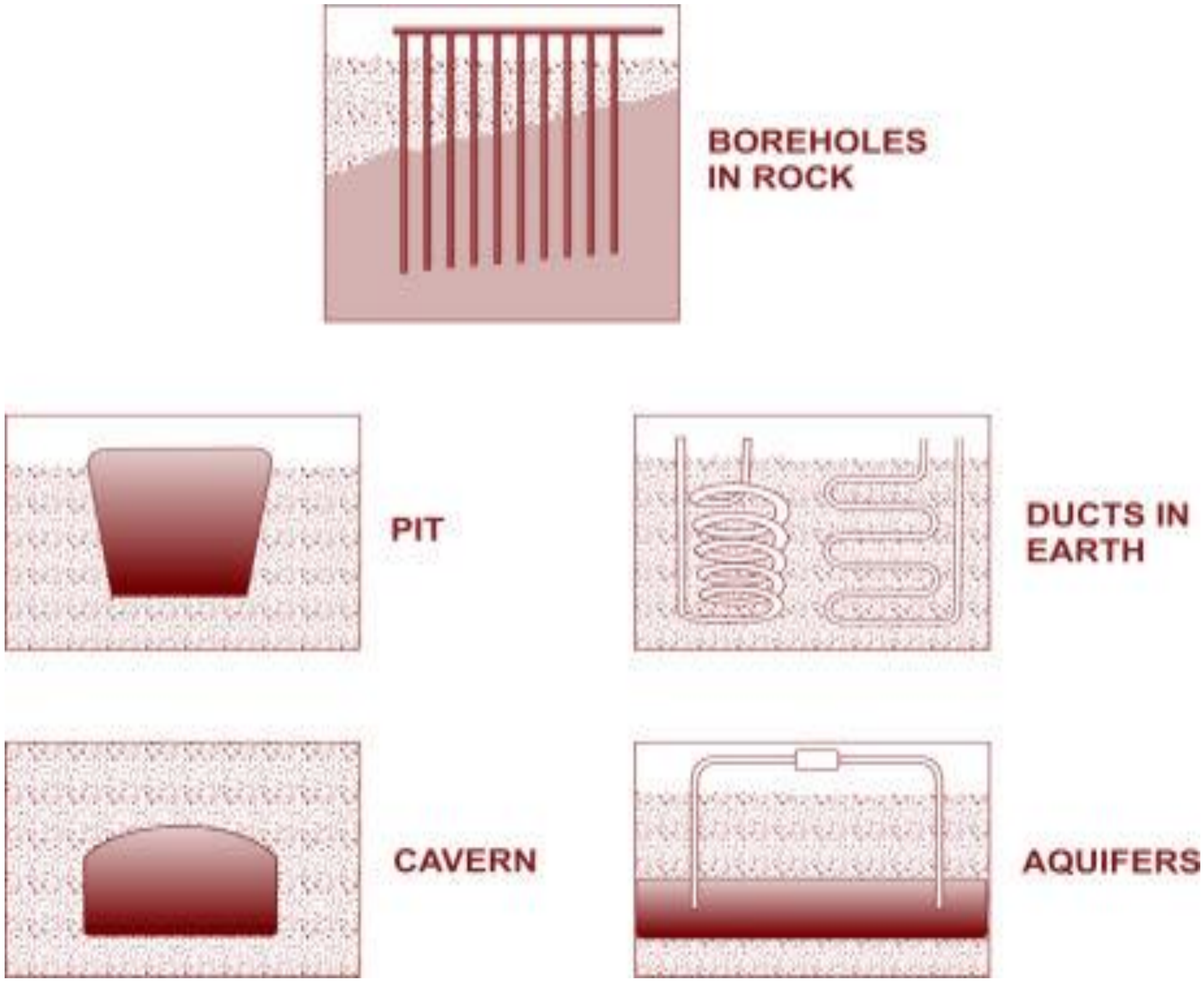
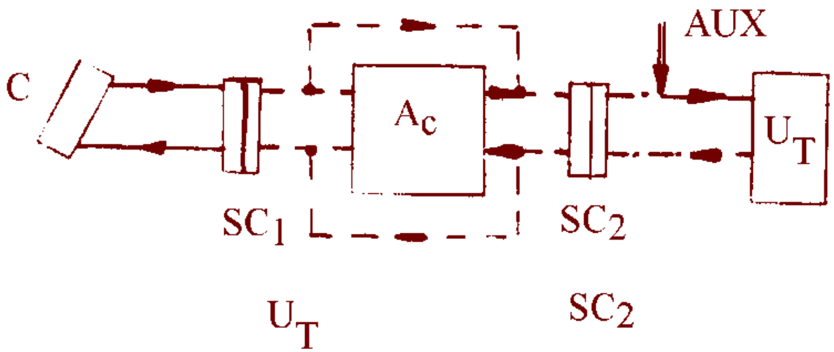
Long term energy storage systems



Long term energy storage in water in on-ground tanks

Of all the liquids used as storage materials, water is practically the most used



Block Diagram

Where:

- C - solar collectors
- SC - heat exchanger
- Ac - thermal accumulator
- UT - the user of the stored heat
- AUX - auxiliary thermal source

Long term energy storage in water in on-ground tanks

- **The typical example** for the use of on-ground tanks for long-term storage of heat is the experimental plant in Ingelstad, SWEDEN.

- The subject of the experiment was to provide a **50% annual heat requirement** for a group of **52 individual family homes**.
- The storage temperature varies between 40 ° C and 70 ° C.
- Heat agent is supplied by solar collectors (1425 m^2).
- The storage tank has a **volume of 5000 m^3**.

Long term energy storage in water in on-ground tanks

Project: U.K. National,

The project covers the heating requirement for **100 houses** with a total living area of **8000 m^2.**

The storage system is an insulated steel tank, located on the surface of the soil, with a volume of **7000 m^3.**

The water storage temperature varies between 25 and 80 ° C.

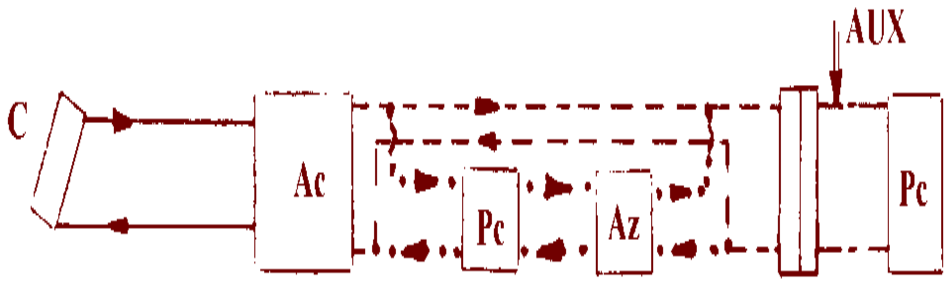
The capture area is **3600 m^2**, represented by solar collectors on 30 ° sloped drafts.

Long term energy storage in water in on-ground tanks

Project: WOLFSBURG - GLOCKENBERG, GERMANY

- The stand is designed to serve **23 homes** located near Hanover, connected to a low-temperature energy network.
- It is intended to provide **100% heating and 75% domestic hot water.**
- The volume of the steel tank is **3000 m^3**.
- The maximum water temperature in the tank was set at 95 ° C.

Long term energy storage in water in underground tanks



Block Diagram

Where:

- C - solar collectors
- PC - heat pump
- Ac - thermal storage
- UT - user of stored heat
- AUX - auxiliary thermal source
- Az-daily storage

Long term energy storage in water in underground tanks

- The scheme shown in the previous figure corresponds to the experimental installation in LAMBOHOV, Sweden
- At this facility, which was commissioned in 1980, the specific objective was to test a solar heating system with a long-term heat tank that uses the solar energy captured from panels installed on **55 homes**, storing energy in summer to use it in the winter.
- Water is used as a storage medium and as a transport medium. The tank has a volume of about **10.000 m^3**.

Long term energy storage in water in underground tanks

- The water tank is a **rock-cut well** with insulated walls.
- The thermal insulation is made with a lightly sintered cement with clay granules. It lies between the surface of the wall and the rock. The bottom of the insulation consists of compressed clay granules.
- Insulation thickness is 1.2 m.
- At the top, the insulation consists of 40 cm expanded polyurethane bricks that float.
- The tank is lined with a rubber foil, which is also used under the top insulation.

Long term energy storage in water in underground tanks

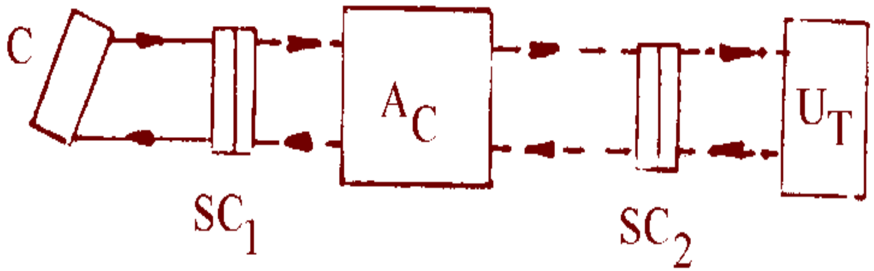
Project: CHARLESTOWN, USA

In the 1950s, **two underground tanks** with a total volume of **5700 m^3** were built to store oil products.

Introducing in circuit and heat pumps, will cover an annual thermal load of about **2000 MWh.**

The surface of the solar collectors is **2300 m^2** and must cover about 60% of the energy requirement.

Long term energy storage in water in natural underground cavities



Project: LYCKEBO, SWEDEN

Large-scale program to provide heating for domestic hot water and hot water, **550 homes** in a residential area under construction, all-energy from the sun.

The storage is made in the water in a natural cave with a volume of about **100000 m³**.

A capture area of **4320 m²**

Because no heat pumps are used in the system, the water storage temperature is relatively high: between **45 and 95 °C.**

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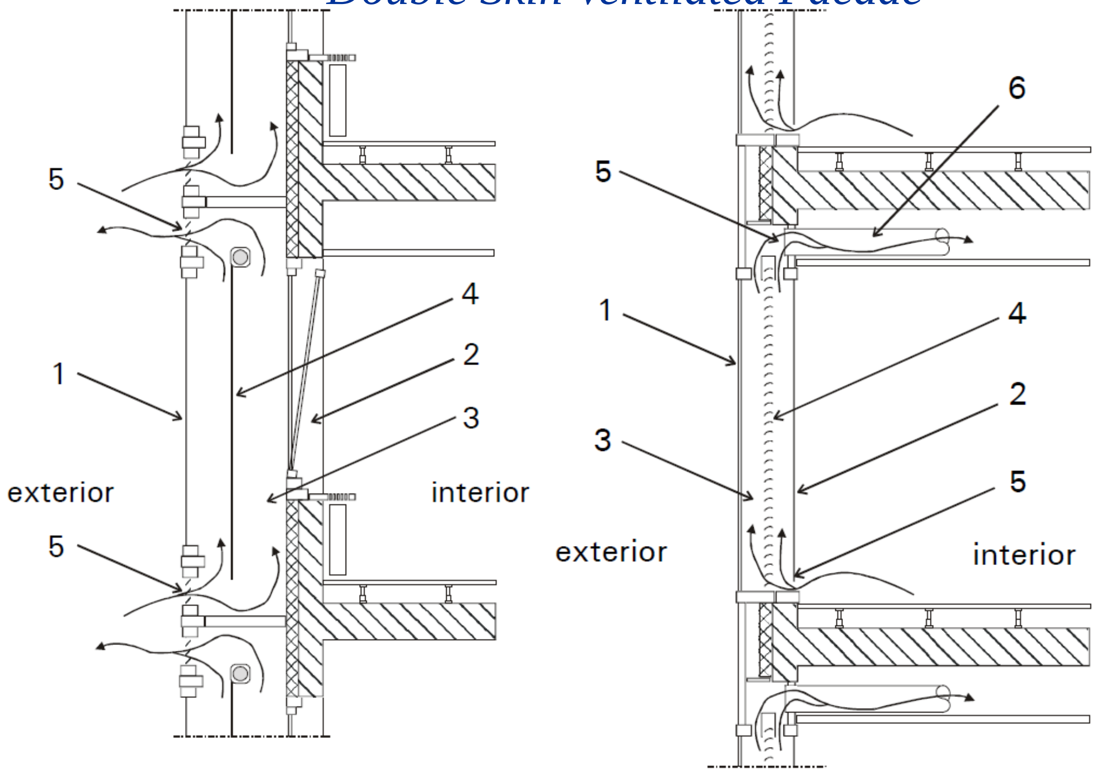
Double Skin Ventilated Facade

Concept of double skin facade

- **Double skin facades** (DSF) are building envelopes composed of **two layers** of glass separated by a ventilated air **channel.**

Double Skin Ventilated Facade

1 –exterior glazing;
2 –interior glazing;
3 –air channel;
4 – solar protection;
5 – inlet section;
6 – outlet section.

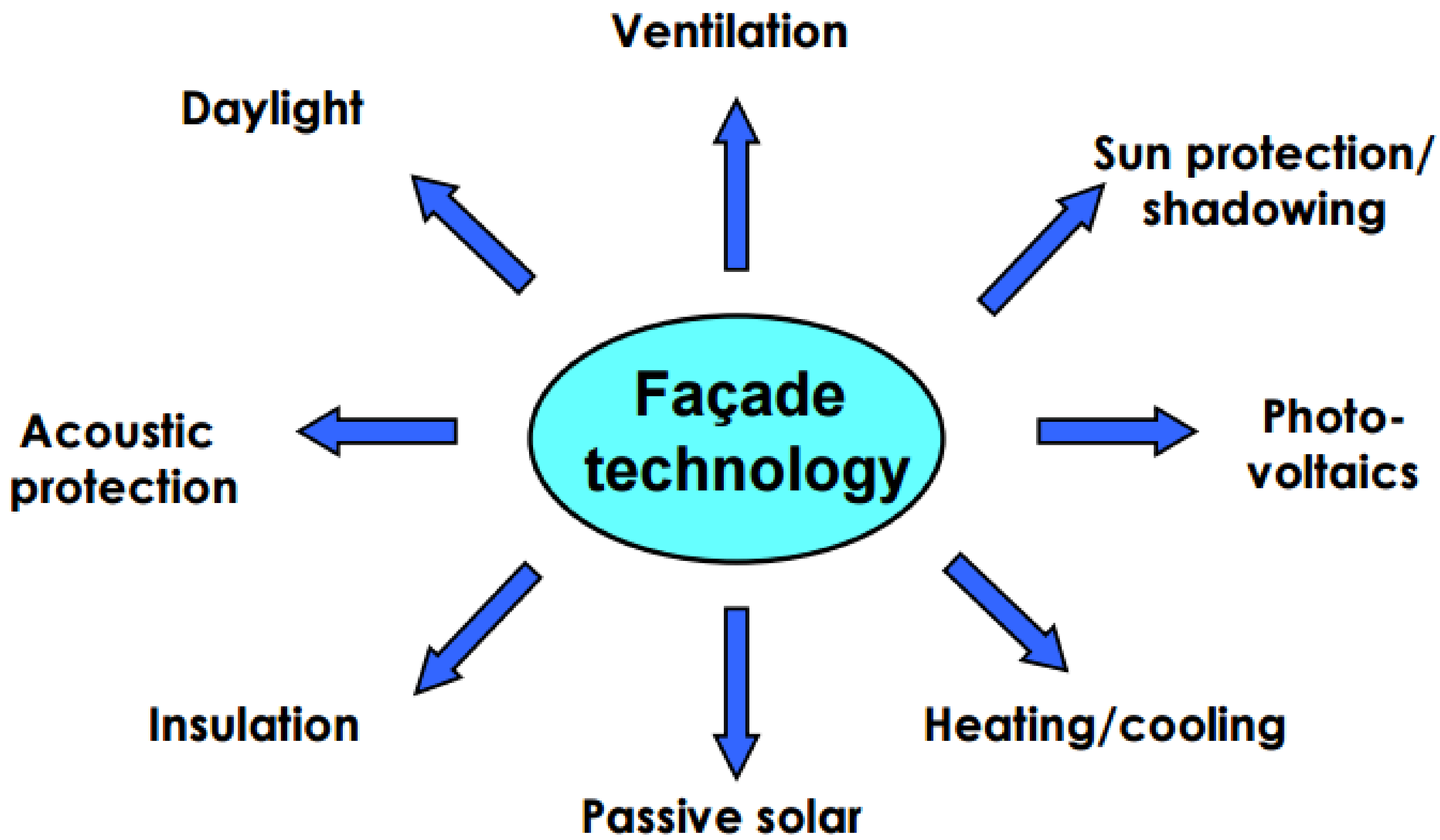


a) natural ventilation b) mechanical ventilation

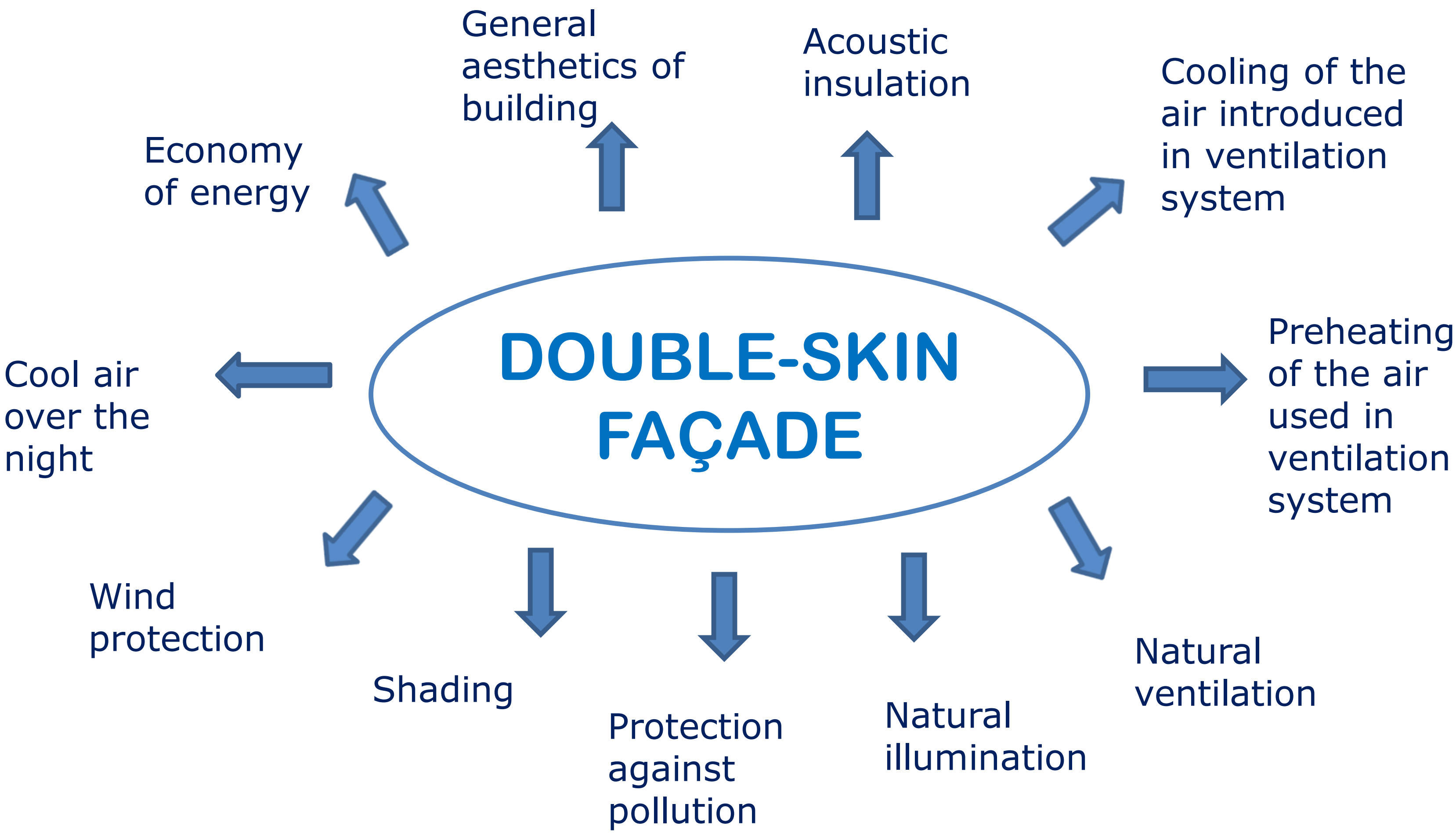
Different definitions of double-skin façade:

- active/passive façade, [BBRI], (2002);
- twin skin, Arons, (2001);
- pair of glass skins separated by an air corridor, Uuttu, (2001);
- an additional building envelope installed over the existing façade, Claessens and DeHerde.

- **Possible integrated functions**



Advantages of DSF



Disadvantages of DSF

DOUBLE-SKIN FAÇADE

- The moving of the air can generate noise
- The investment costs are higher
- Different distribution of air and temperature in rooms
- Additional costs for maintaining the glass
- Reduce area of exploitation
- Dust deposits
- The possibility of germs appearance

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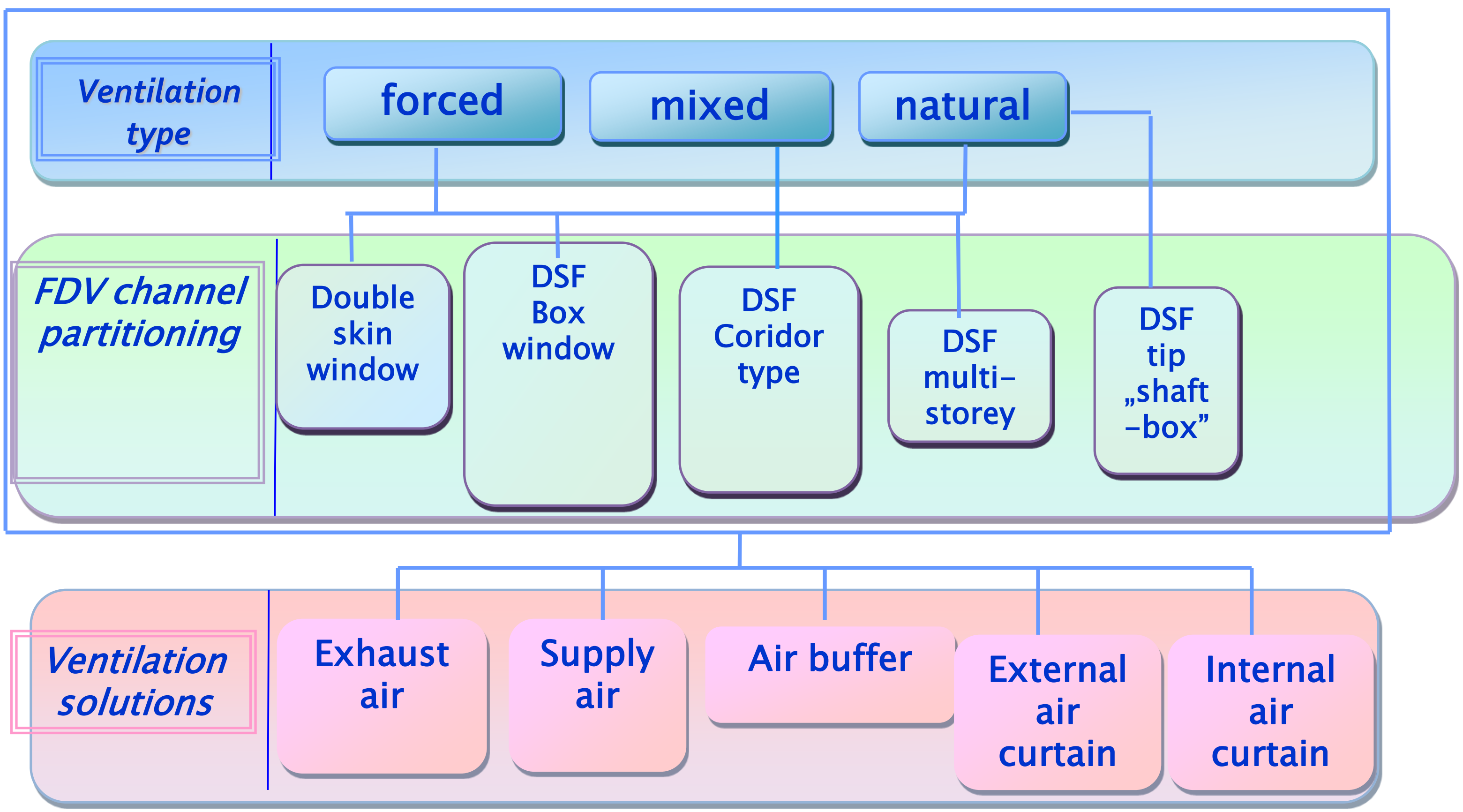
Classification of DSF

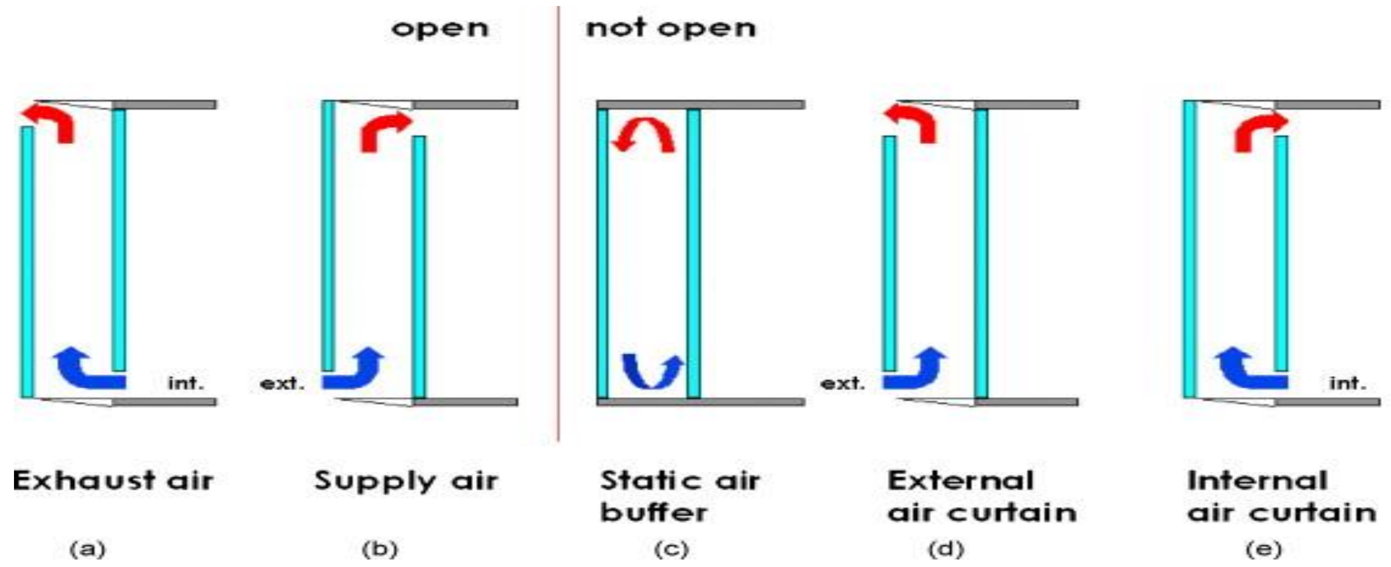


Classification of DSF

- depending on the communication of interior air with exterior air:

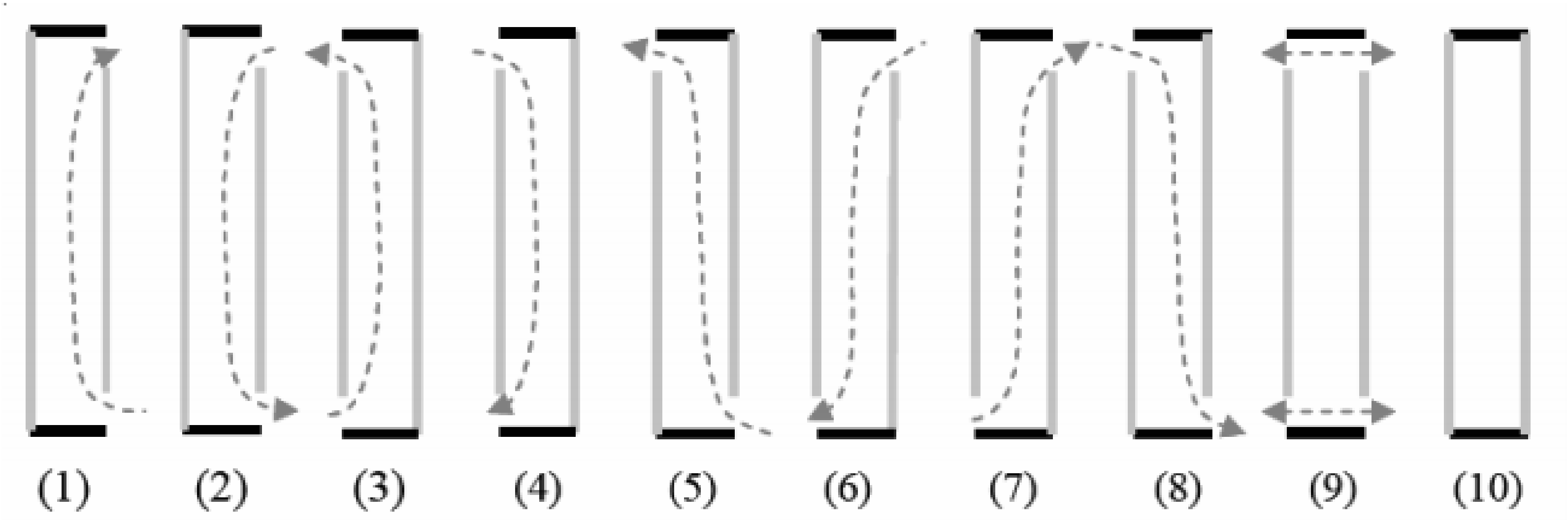
➢ **open**;

➢ **not open**.



Classification of DSF

- depending on the communication of interior air with exterior air:



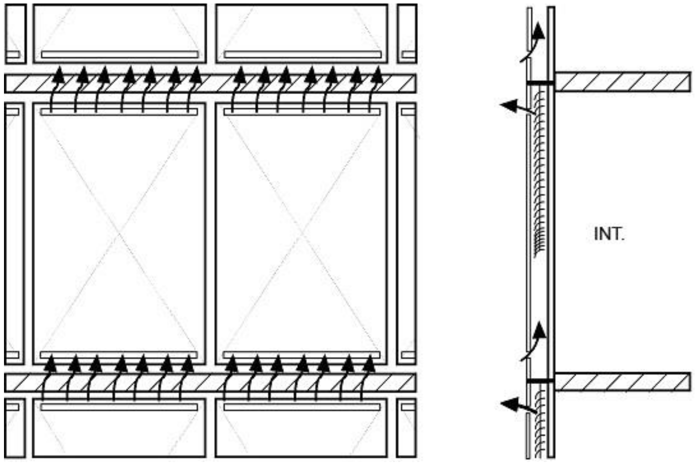
Ten air flow regimes, Park, et al. (2003).

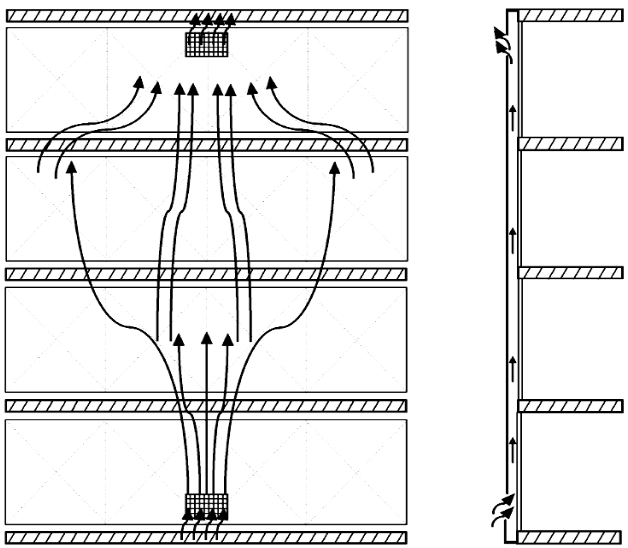
http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

Classification of DSF

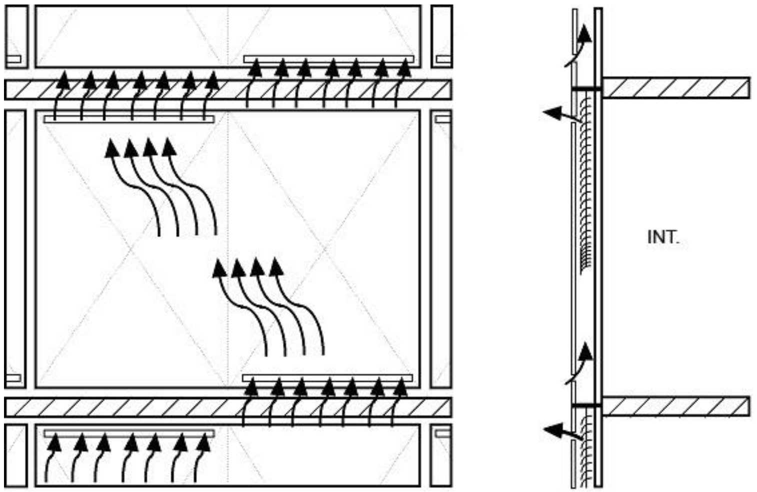
Location of the channel openings

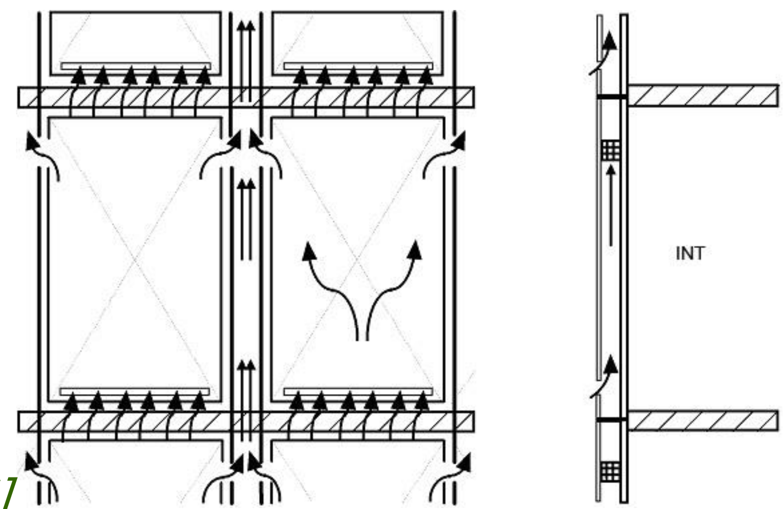
On the same direction





Other locations

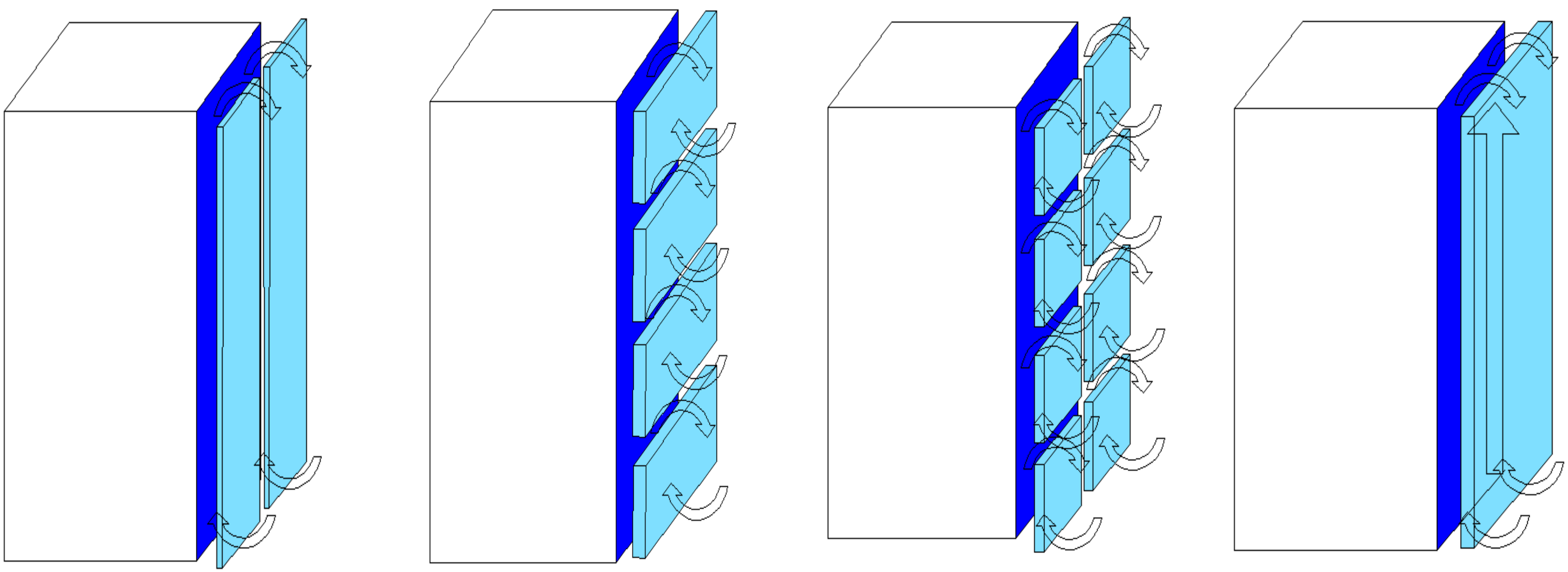




[Safer, 2006]

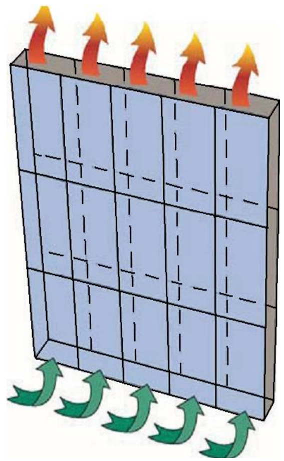
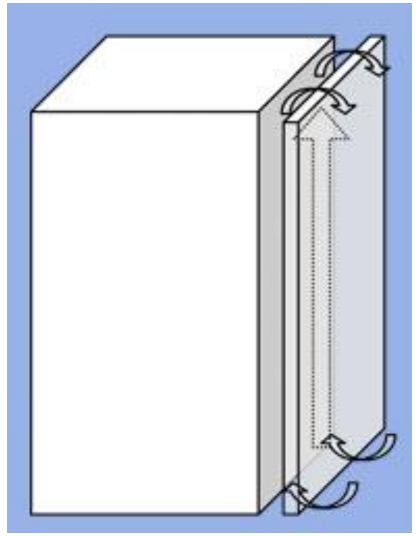
Classification of DSF

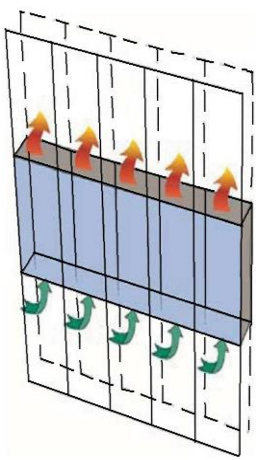
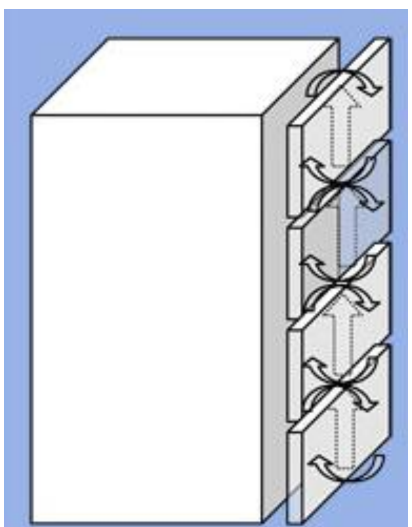
- Ventilation solutions



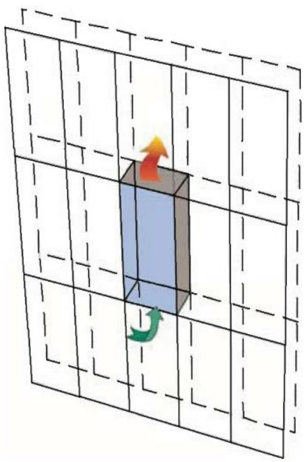
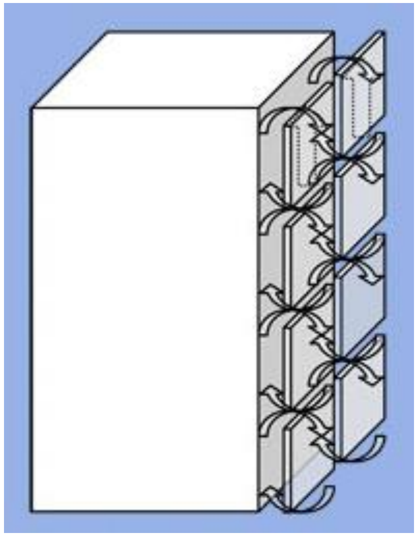
a) Shaft box b) Corridor façade c) Box-window d) Multi storey

Multi storey

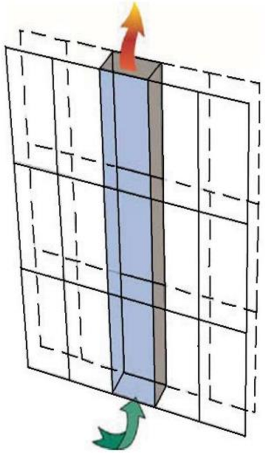
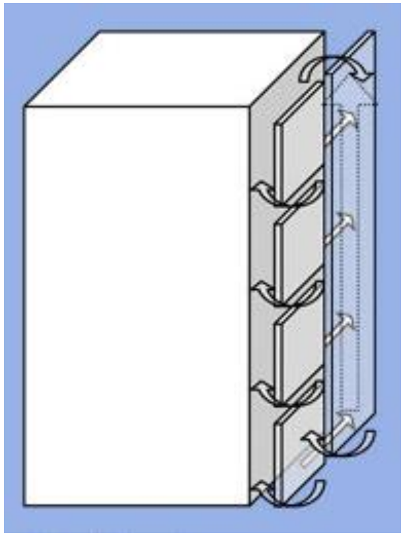




Corridor façade

Box-window

Shaft box

Classification of DSF

- depending on the **thickness** of the channel:

- ➢ inaccessible (a) ->(0...50 cm);
- ➢ accessible (b) -> (50...200 cm);
- ➢ atriums (c) -> (over 200 cm).

a)

b)

c)

Classification of DSF

- depending on solar protections:


Vertical blinds


Venetian blinds

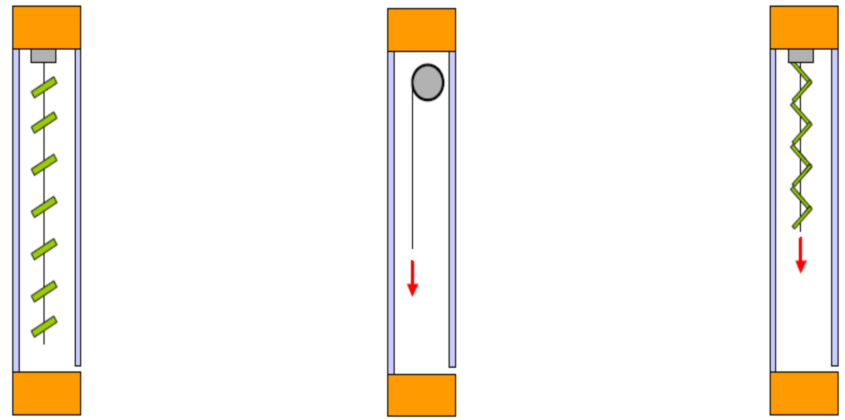

Exterior roller blinds

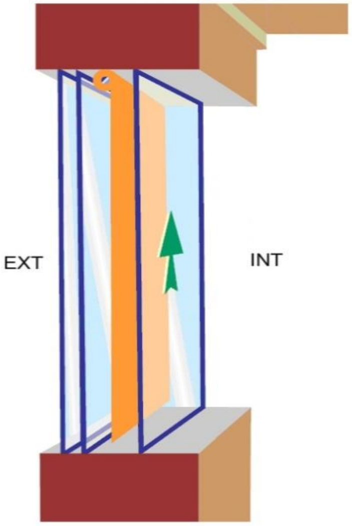

Exterior solar protection (cover type)

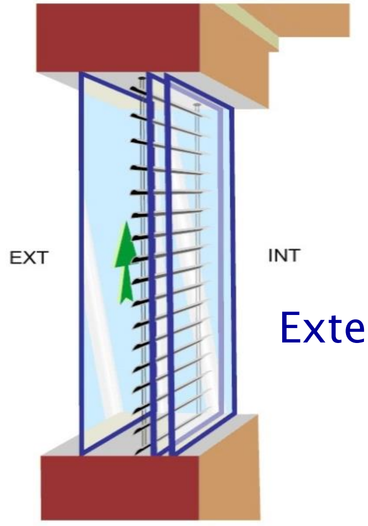

Interior roller blinds

Solar protections location

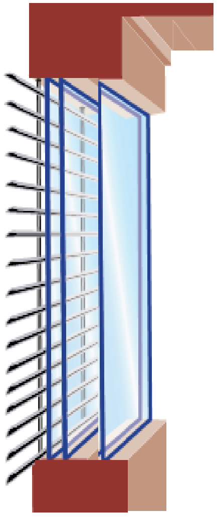
Inside the DSF channel

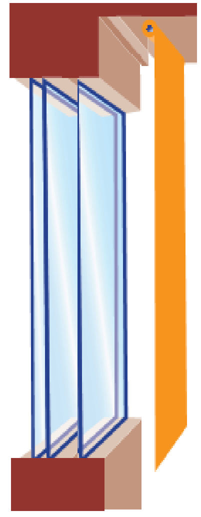






Exterior





Interior

Types of glazing

INTERIOR

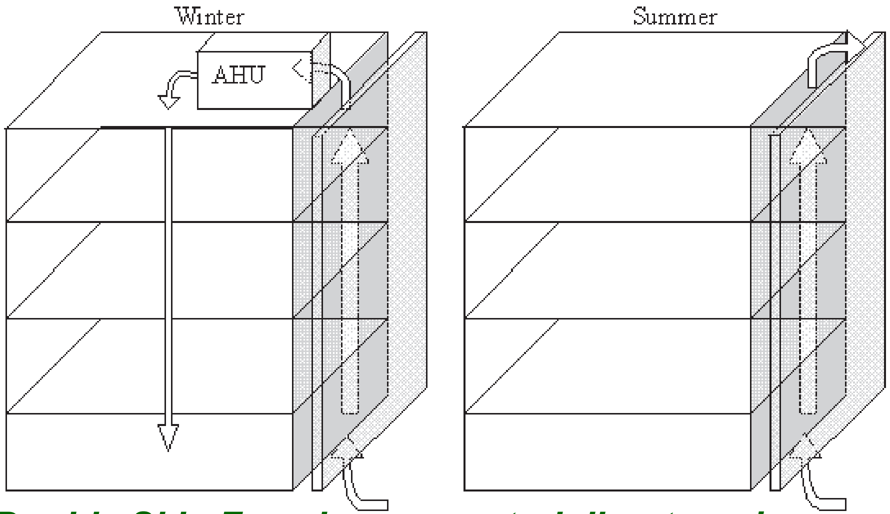
double or triple glazing with air, argon or krypton

EXTERIOR

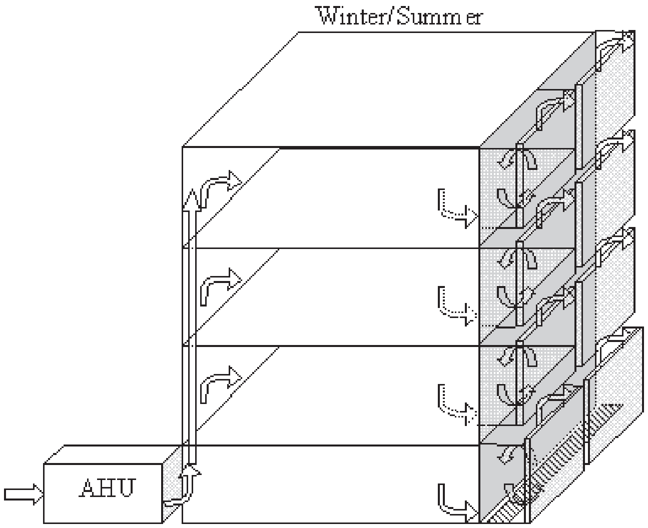
single or double glazing with safety glass, laminated etc.

- low emissivity coated glass (Low E)
- laminated glass
- safety glass
- spectrally selective glass or colored
- angular selective solar control glass
- self-cleaning glass
- self-cleaning windows and solar control properties.

STRATEGIES FOR OPERATION OF DOUBLE SKIN FACADE



Double Skin Façade as a central direct pre-heater of the supply air



Double Skin Façade as an exhaust duct.

http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

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STRATEGIES FOR OPERATION OF DOUBLE SKIN FACADE

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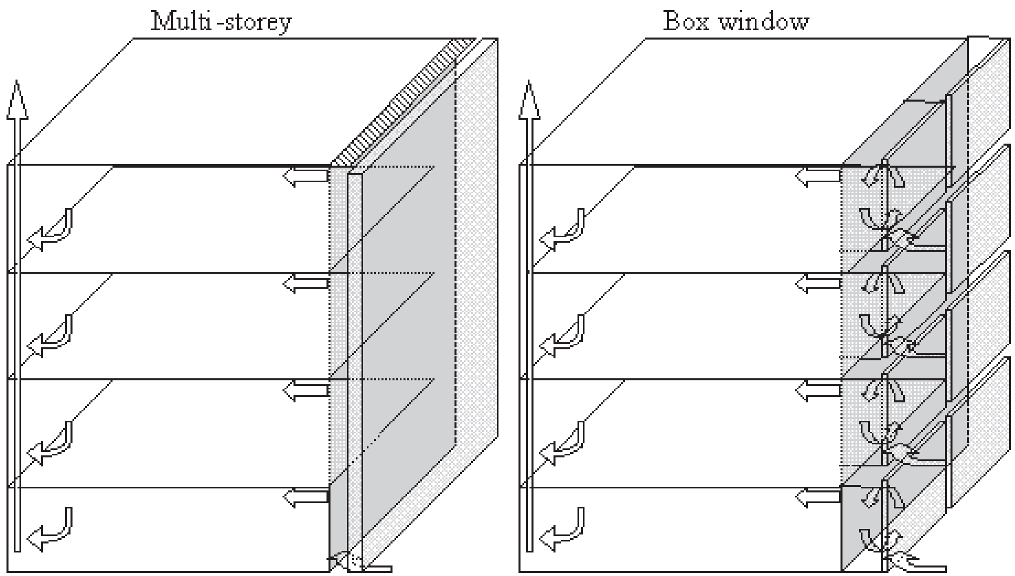
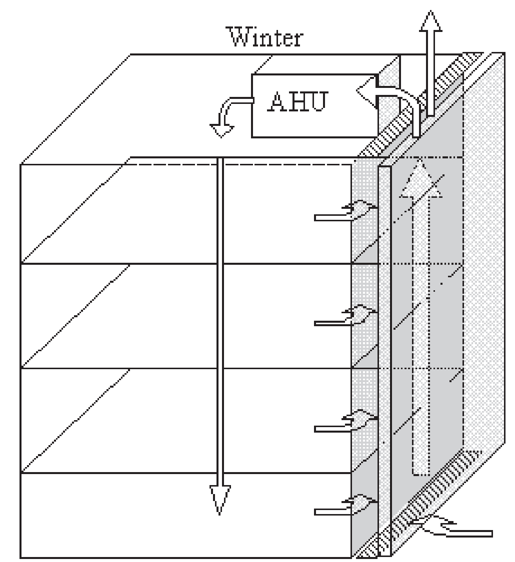


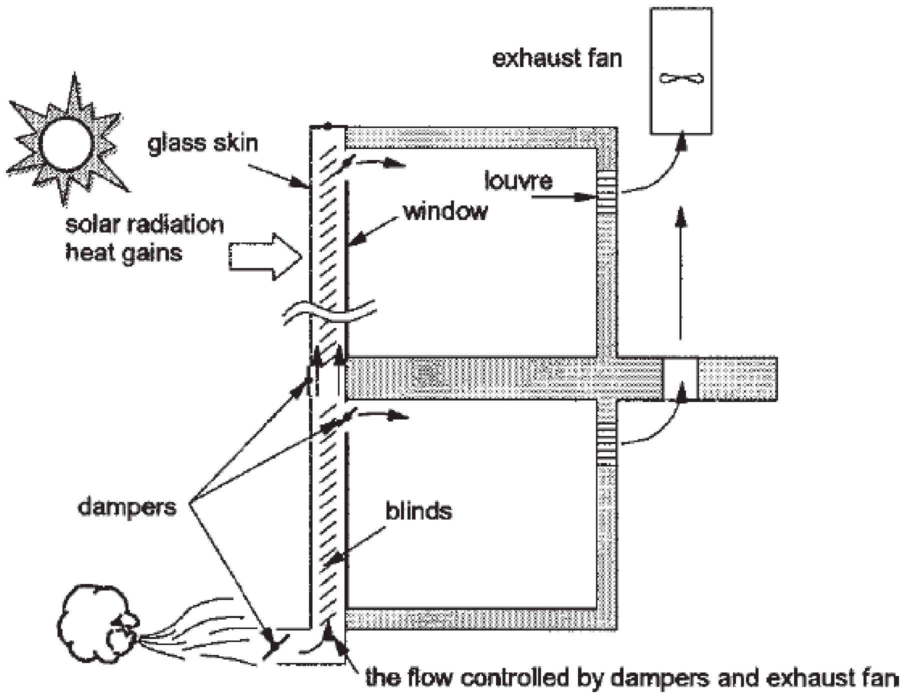
Double Skin Façade as an individual supply of the preheated air



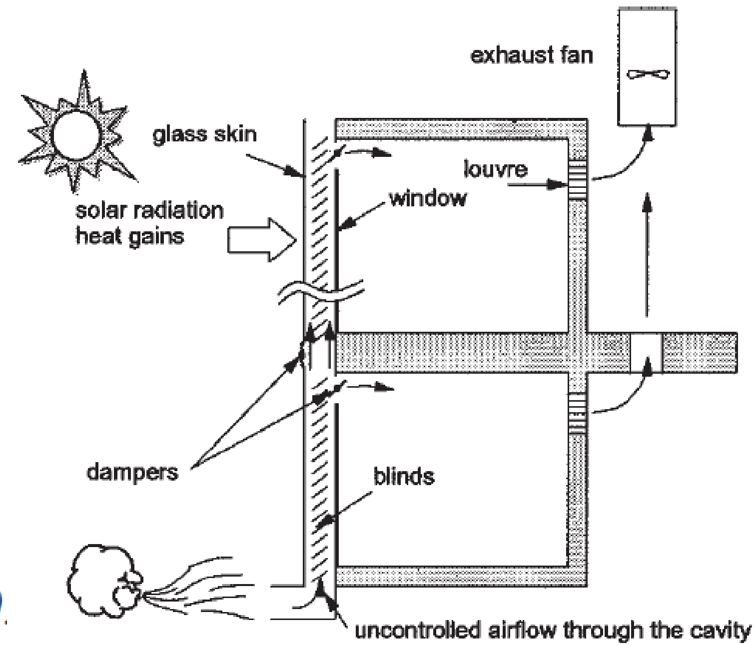
Double Skin Façade as a central exhaust duct for the ventilation system.

http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

Coupling Double Skin Facades and HVAC-Examples

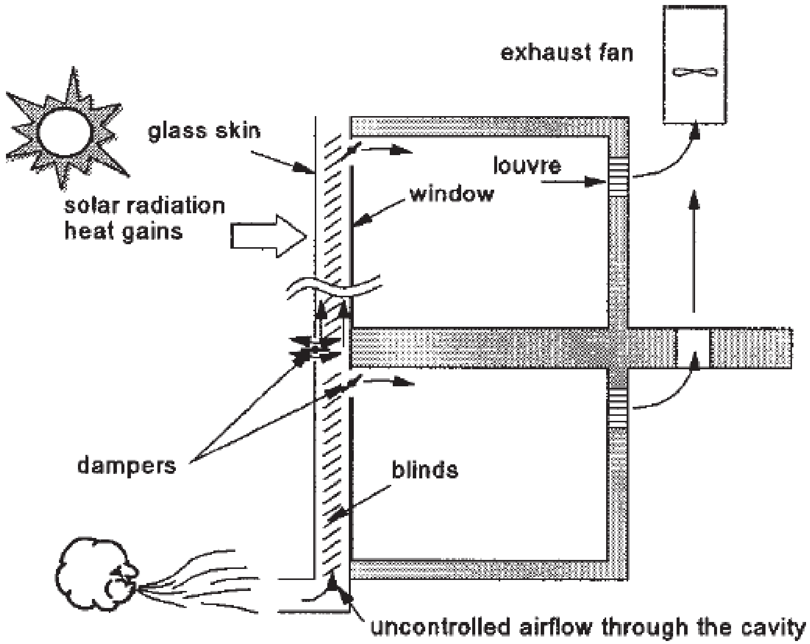


Controlled air flow in the cavity (Stec et al, 2000).

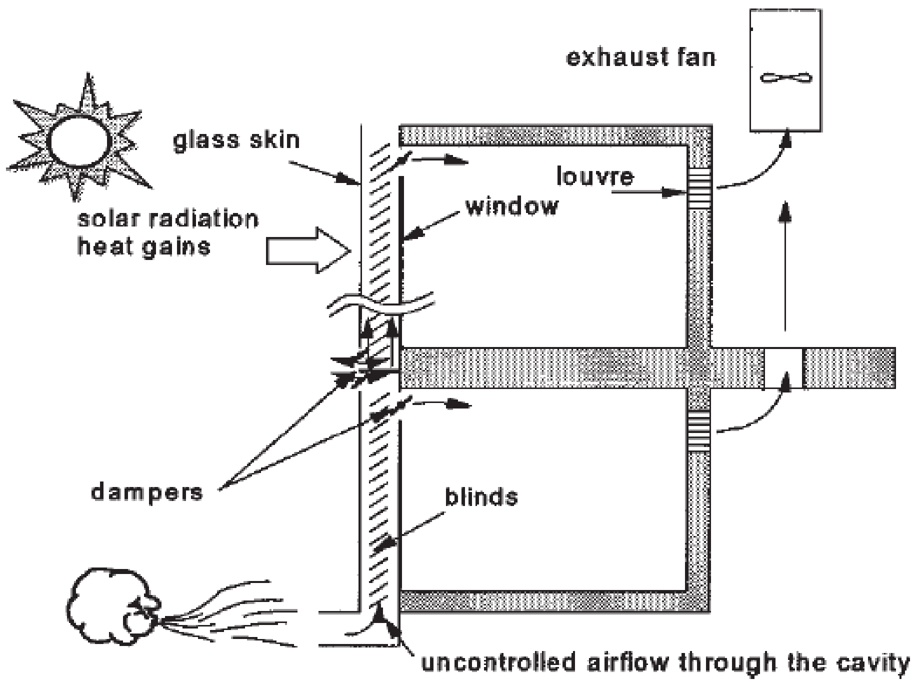


Uncontrolled air flow in the cavity (Stec et al, 2000).

Coupling Double Skin Facades and HVAC-Examples

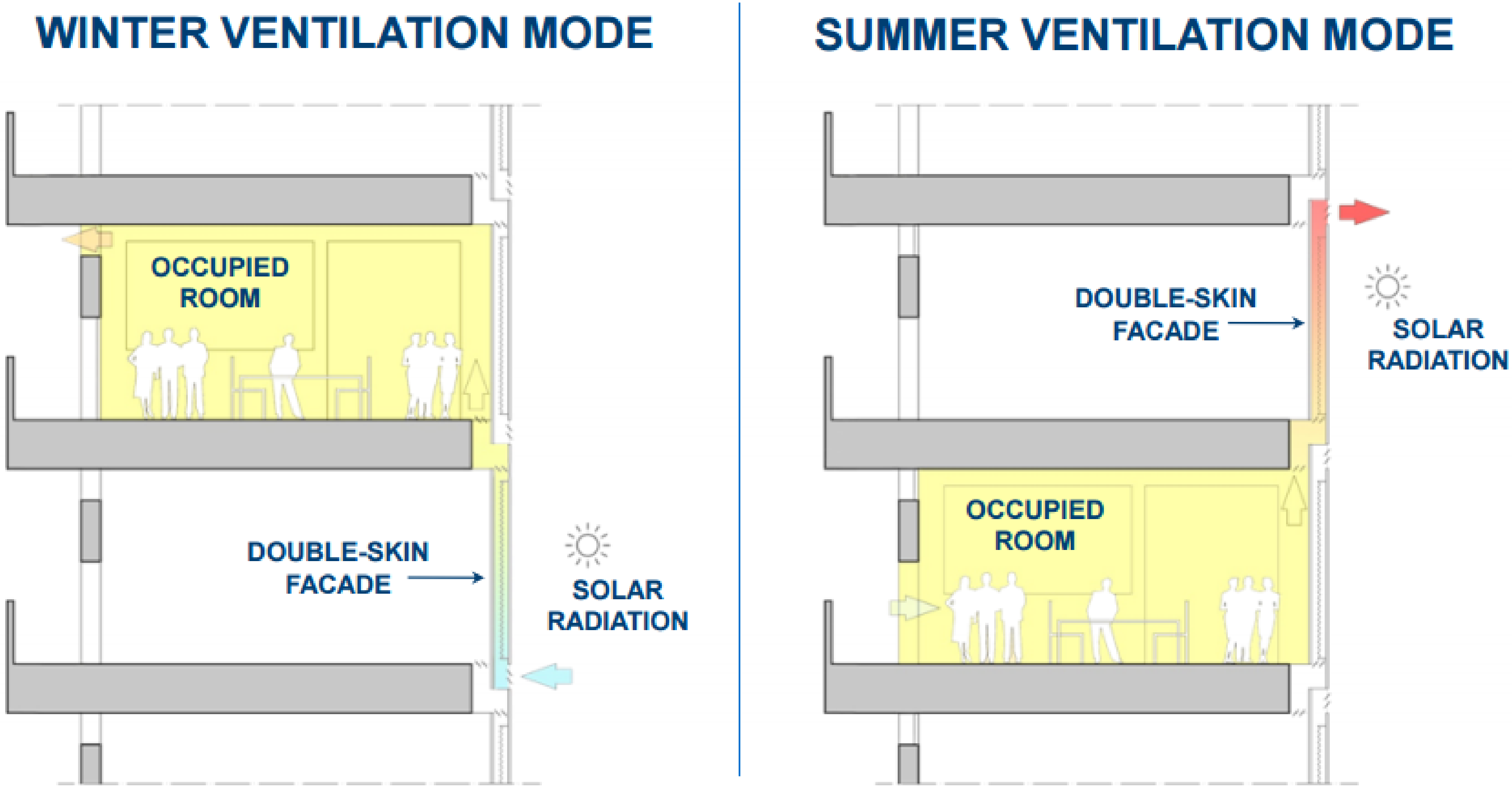


Open junctions in each floor (Stec et al, 2000).



Each storey is separated (Stec et al, 2000).

Optimised ventilation in different seasons or climates



http://www.breathingbuildings.com/media/129499/2%20nicola%20mingotti.pdf

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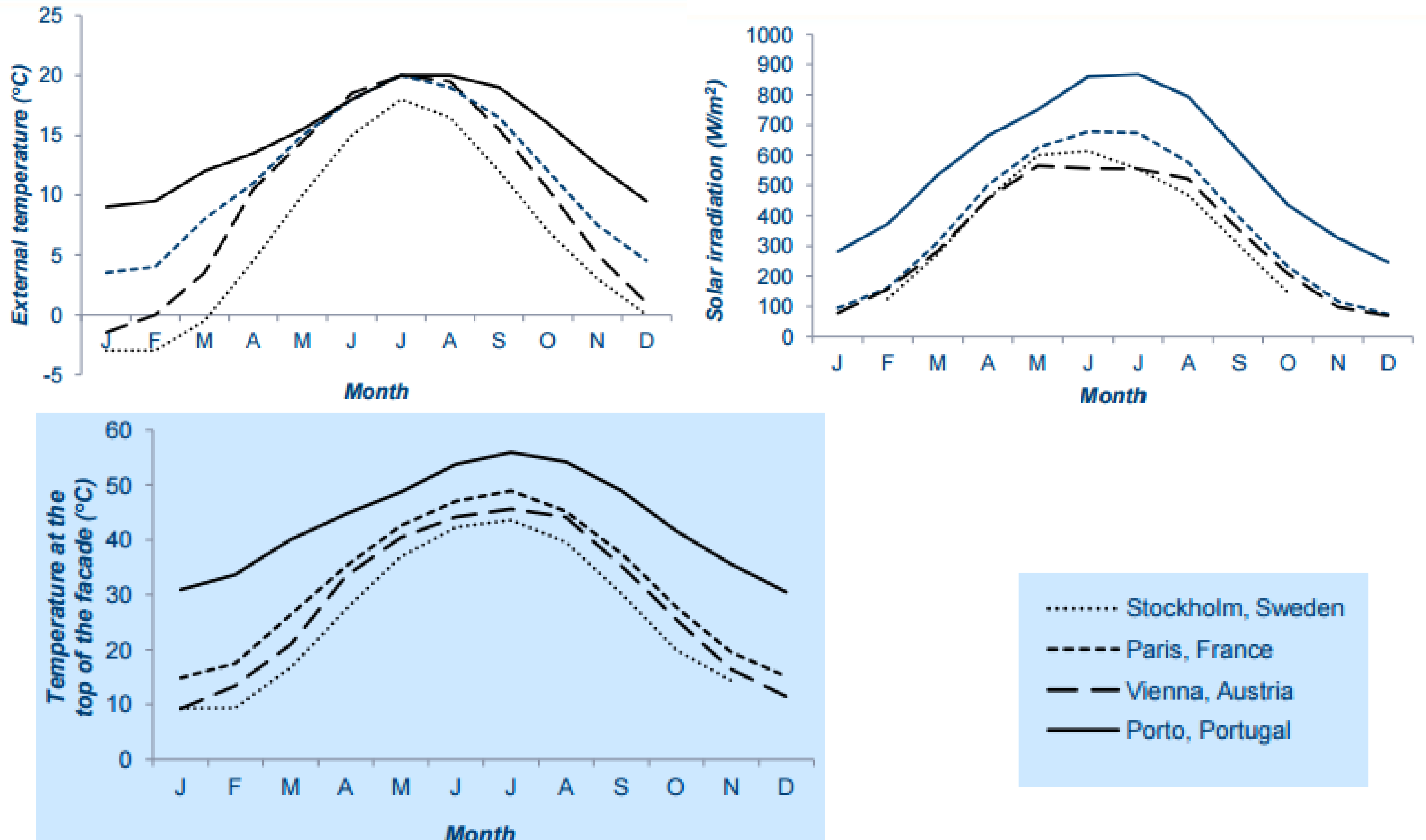
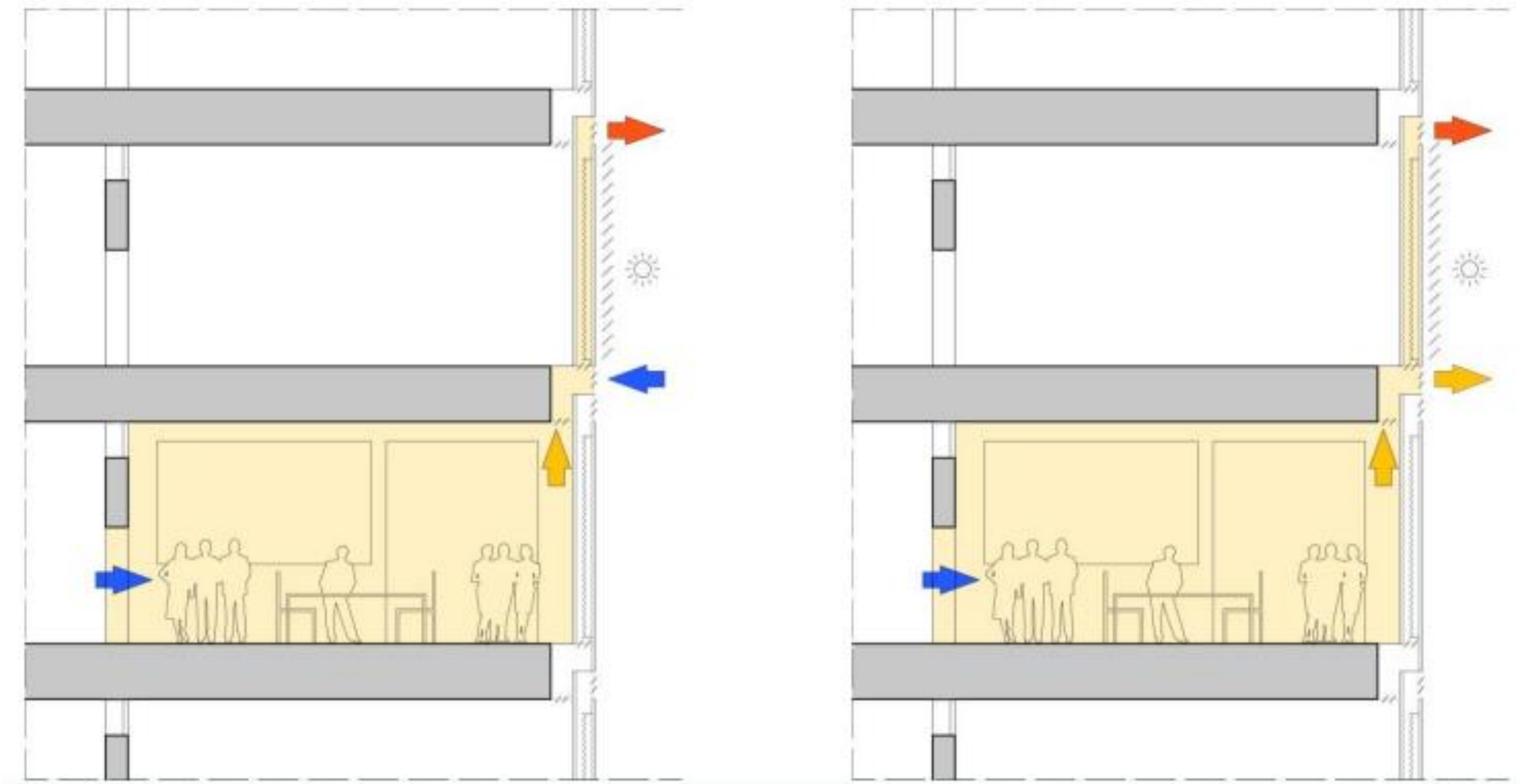
Warm-season facade overheating



http://www.breathingbuildings.com/media/129499/2%20nicola%20mingotti.pdf

THE ADDITION OF EXTRA VENTS IN THE FACADE LEADS TO MULTIPLE VENTILATION REGIMES



http://www.breathingbuildings.com/media/129499/2%20nicola%20mingotti.pdf

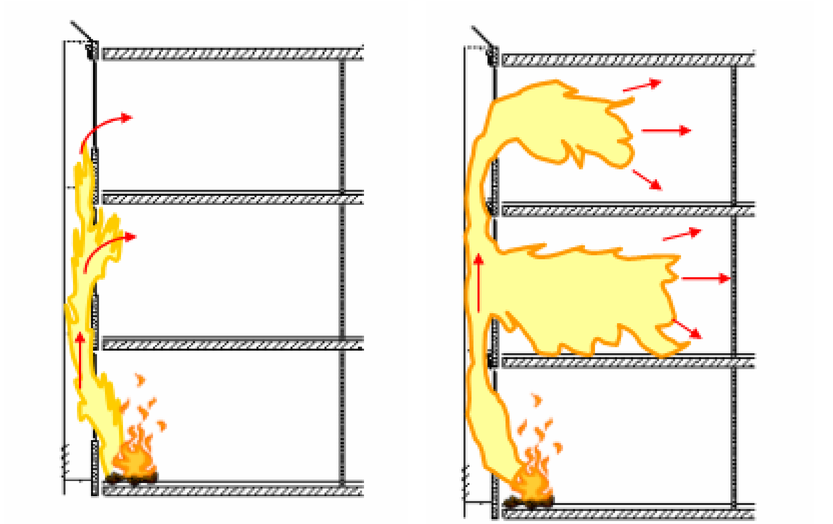
Performance and quality demands of DSF

MECHANICAL RESISTANCE AND STABILITY

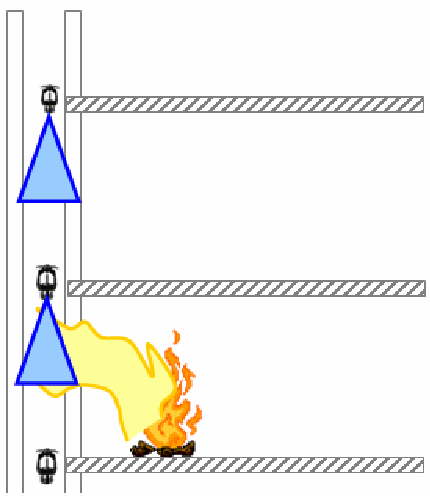
- evaluation of resistance to various types of loads: permanent (including its own weight) and operating load coming from wind action, particularly on the stability of glass (or panel);

FIRE SAFETY

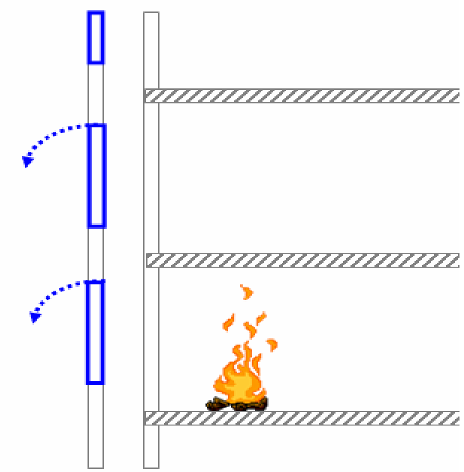
- evaluation issues: reaction to fire, fire resistance, fire spread;



Fire propagation and penetration in a DSF [Martin Y., Loncour X, 2004]



Automatic firefighting system



Facades provided with automatic openings fire

Performance and quality demands of DSF

HYGIENE, HEALTH AND ENVIRONMENT

Evaluation issues:
- air permeability
- waterproof

SAFETY IN EXPLOITATION

Evaluation issues:
- shock resistance
- thermal shock

PROTECTION AGAINST NOISE

It depends on:
- Layers of glass configuration
- Inlet and outlet opening size
- The depth of the cavity between glass layers

ENERGY SAVING AND THERMAL INSULATION

Assessment requirements for:
- components
- building
- Installations and systems ventilation and air conditioning

- sizing of heating
- determination of energy demands for heating / cooling of the building
- evaluation of thermal comfort in winter / summer
- risk evaluation of the air condensation inside façade
- evaluating the risk of glazing thermal
- shock

Costs and Investments

Investments (in Central Europe)
• Standard façade 300 to 500 Euro/ m^2
• Double Skin Standard **600** to **800 Euro**/ m^2
• Double Skin with adjustable air in and outlet 700 to 1000 Euro/ m^2
• Double Skin with openable exterior sashes 800 to 1300 Euro/ m^2

Running Costs (in Central Europe)
• Standard façade 2.5 to 3.5 Euro/ m^2 and cleaning operation
• Double Skin façade **4** to **7.5 Euro**/ m^2 and cleaning operation".

http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

Examples of Office Buildings with Double Skin Façade

City Gate Dusseldorf Germany - 1998

The façade is a corridor type. The intermediate space between the two skins is closed at the level of each floor.

The solar blinds are situated near the outer glazing layer.

The first years of operation show that the building can be naturally ventilated for roughly 70-75% of the year.

Examples of Office Buildings with Double Skin Façade

Headquarters of Commerzbank, Frankfurt

It consists of a three storey sealed outer skin, a continuous cavity and an inner façade with operable windows

Two variations on the principle of the “buffer zone” for natural ventilation of the offices were used: as a double skin façade and as a winter garden.

http://www.ecbcs.org/docs/Annex_43_Task34-Double_Skin_Facades_A_Literature_Review.pdf

Examples of Office Buildings with Double Skin Façade

Debis headquarters, Berlin



Façade Type: Corridor façade

During the summer, the exterior glass louvers are tilted to allow for outside air exchange.

The users can open the interior windows for natural ventilation. Night-time cooling of the building's thermal mass is automated. During the winter, the exterior louvers are closed. The user can open the internal windows to admit to the warm air on sufficiently sunny days

Examples of Office Buildings with Double Skin Façade

Galleries Lafayette, Berlin

Façade Type: Storey high type (horizontally divided cavity)

The façade enables natural ventilation of the offices for most of the year. If the outside temperature is too low or too high, a mechanical ventilation system is switched on.

Perforated louvre blinds of stainless steel are fitted as solar control in the 200 mm wide cavity

The inlet and outlet vents are placed at each floor

Examples of building equipped with DSF

The Gherkin, London

The Quartier de Spectacles, Montreal

Energy performance indicators specific to DSF

The dynamic insulation efficiency ϵ (–), as defined by Corgnati *et al.* (2007).

$$\varepsilon = \frac{\dot{Q}_R}{\dot{Q}_{IN}}$$

This represents the amount of the **total thermal load that heats the façade** Q_R which is removed by the ventilation air, with respect the **total heat flux** Q_{IN}, through the external glazed pane of the double-skin façade.

The dynamic insulation efficiency is therefore a parameter that represents the performance of the ventilated façade during summer and the mid-seasons, when the HVAC system is in cooling mode.

Energy performance indicators specific to DSF

The **pre-heating efficiency** η **(-)**, as defined by Di Maio and van Passen (2001):

$$\eta = \frac{T_{exh} - T_{inlet}}{T_i - T_o}$$

Texh is the temperature of the air extracted from the façade,
Tinlet is the temperature of the air entering the façade,
Ti is the temperature of the indoor air and
To is the temperature of the outdoor air.

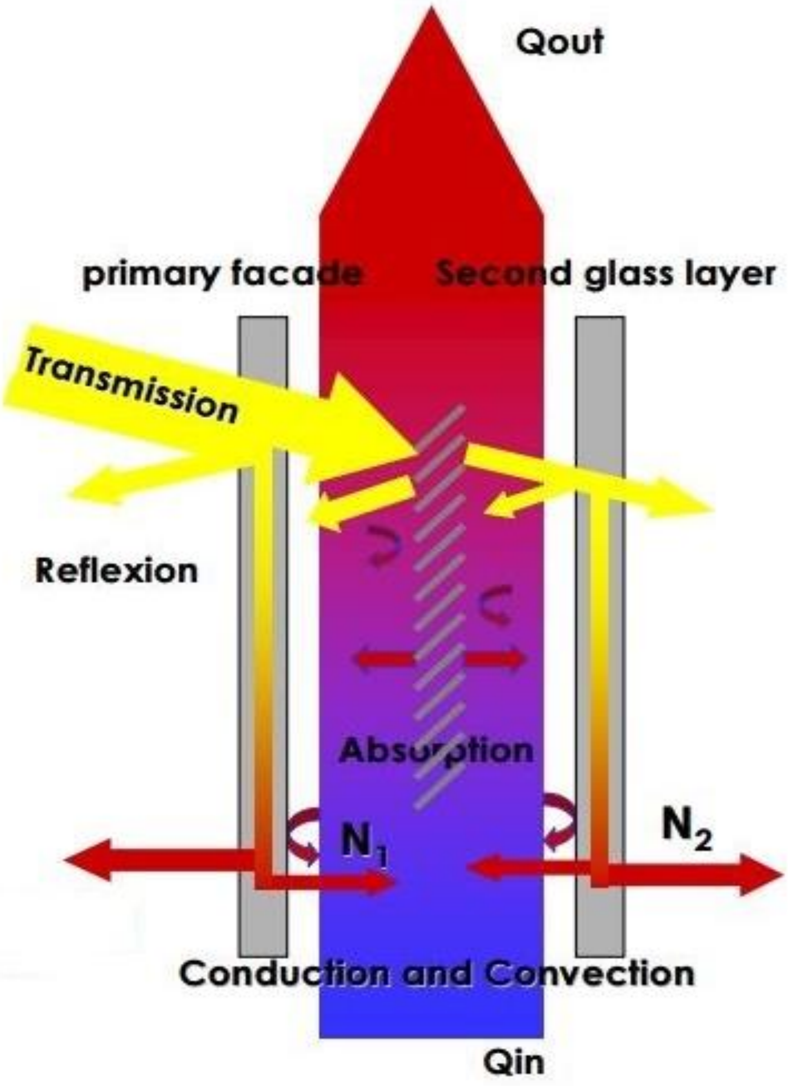
The pre-heating efficiency is therefore a parameter that represents the performance of the façade in winter and in the mid-seasons, when the HVAC system is in heating mode and $Ti > To$.

When $\eta > 1$, the façade is able to completely recover the ventilation losses; when $0 > \eta > 1$, the façade is able to partly pre-heat the ventilation air; when $\eta < 0$, the façade does not recover energy.

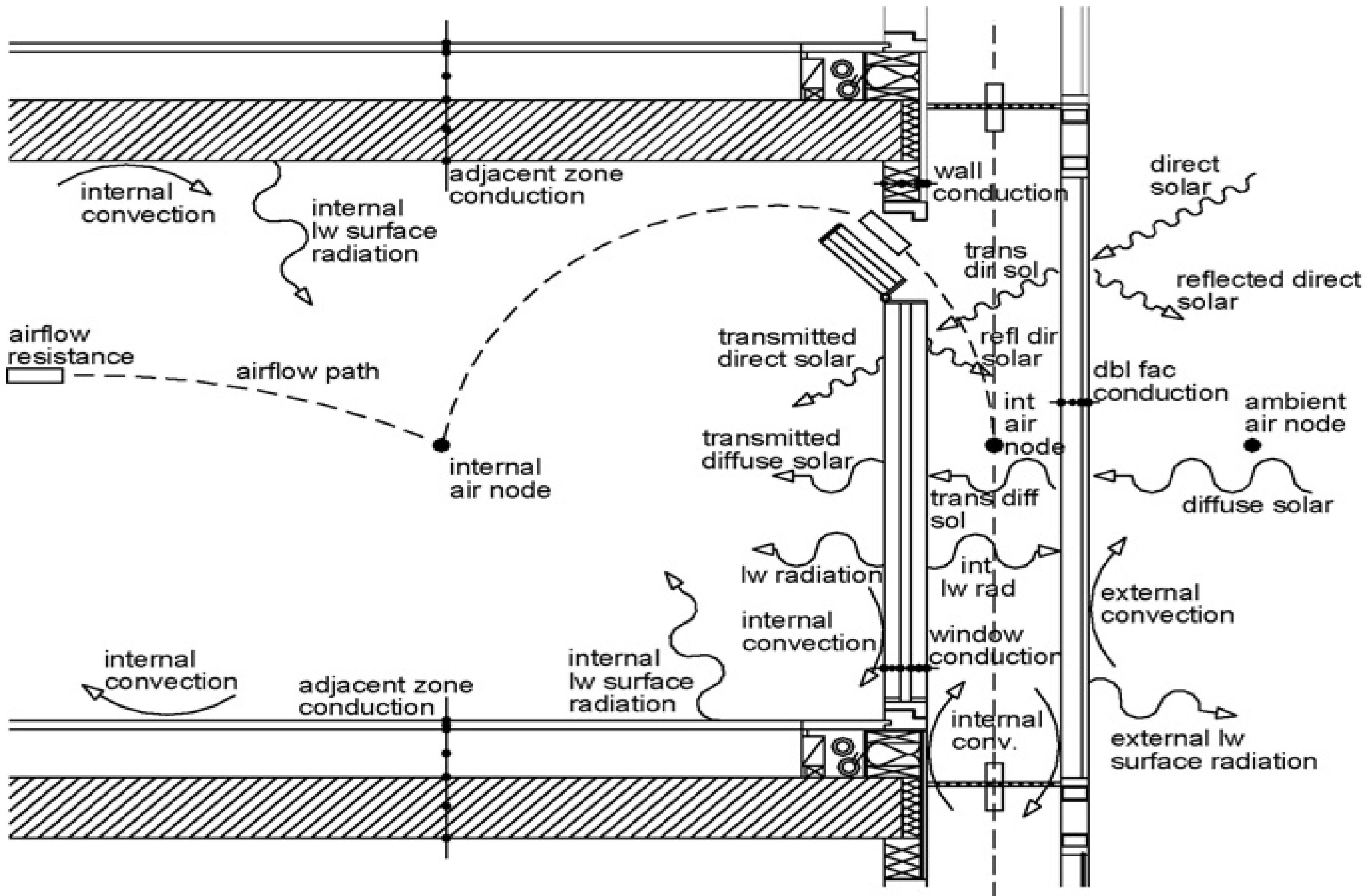
Thermodynamic Study of Double Skin Ventilated Facade

Heat transfer

- **Radiation**
- $Q_{12} = \sigma A_1 \Phi_{12} (T_1^4 - T_2^4)$
- **Conduction**
- $Q = \lambda A (T_1 - T_2) / t$
- **Convection**
- $Q = h_c \; A \; \Delta T$



The heat transfer for a double-skin façade



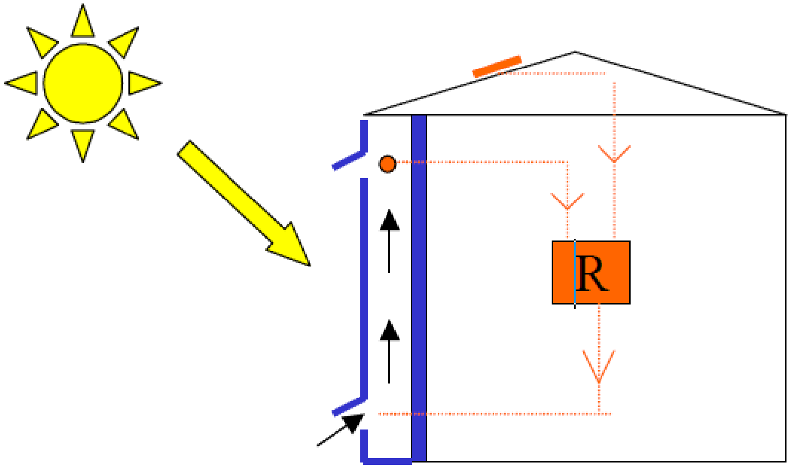
Thermodynamic Study of Double Skin Ventilated Facade

- Experimental simulation of DSF
  - "In situ" conditions
  - Laboratory conditions
- Numerical modeling of DSF
  - Ansys-Fluent

Numerical modeling for Buildings with DSF

Software requirements:

- Simulation of external environment;
- Simulation of DSF: glass layers, shading devices, natural or mechanical ventilation etc.
- Simulation of the interior chamber : connection between DSF and HVAC system,
- accurate modeling of systems and control strategies.



FDV modeling

Numerical modeling for Buildings with DSF

=> There is **NO** perfect software, each program having its limitations

There are two possibilities for the use of software :

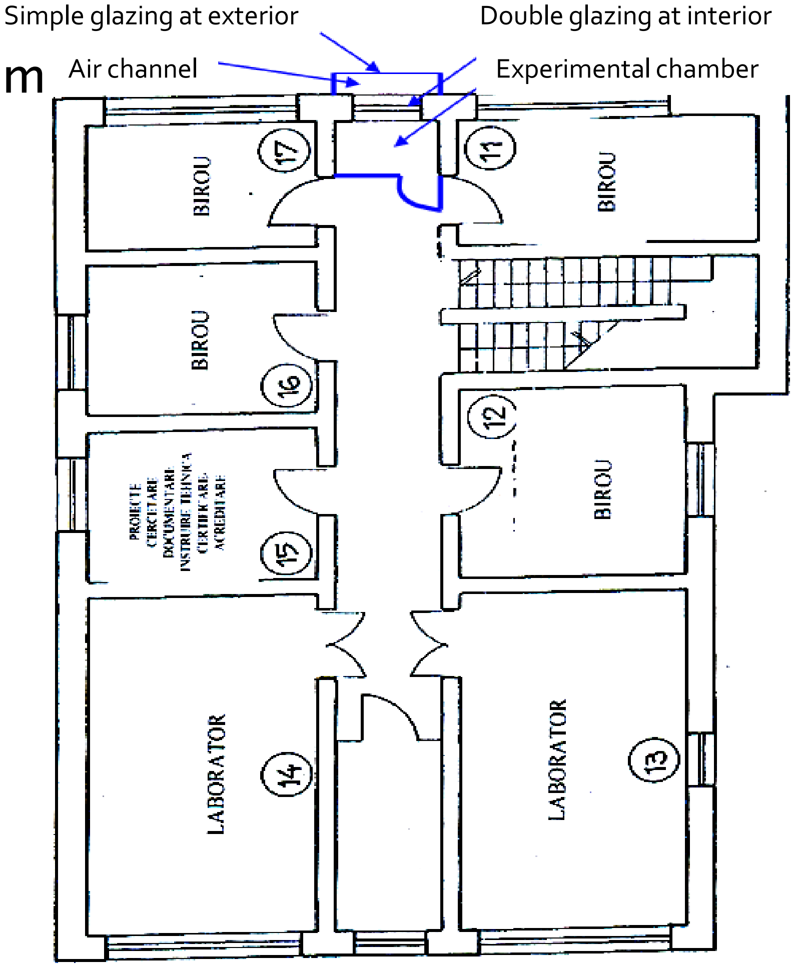
- CFD (computational fluid dynamics) simulation – softwares for simulation of heat transfer and fluid flow;

- programs coupled with energy balance air flow.

CFD Simulations: – have the potential to deliver accurate results;
– it is often necessary to validate the model;
– practical implementation is sometimes difficult.

Experimental simulation of DSF - “In situ” conditions

National Institute for Research and Development in Constructions, Urbanism and Sustainable Spatial Development URBAN-INCERC, Iasi branch



View from inside - door of the experimental chamber

Metallic frame for DSF windows

Outlet opening of DSF

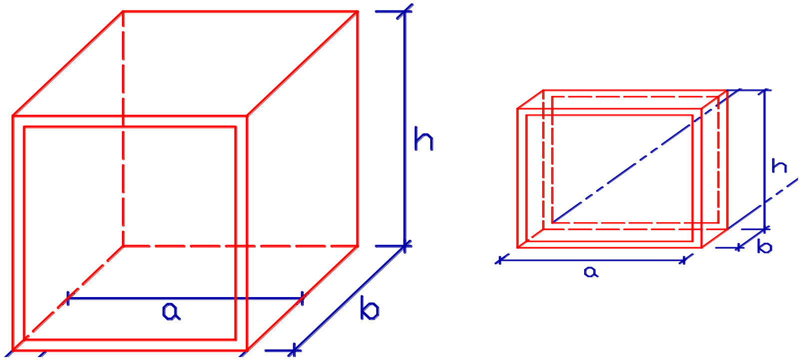
Metallic frame

Construction of "in-situ" DSF

Floor of DSF

Construction of DSF - “in-situ” conditions

Dimensions of DSF and interior chamber



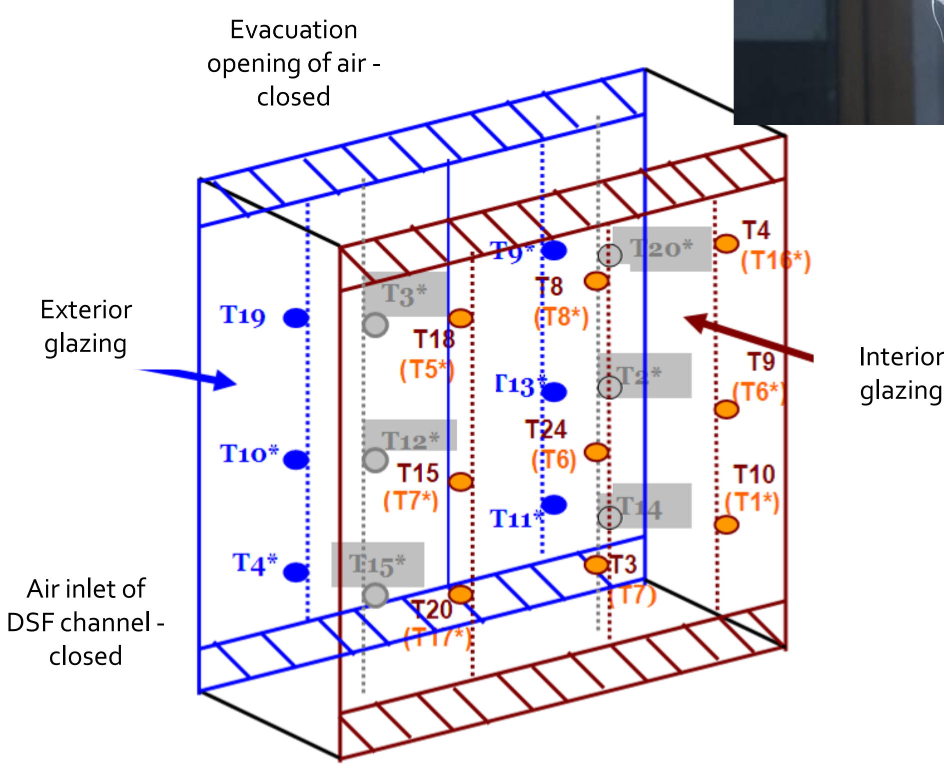
Area	*a, mm*	*b, mm*	*h, mm*
Ventilated facade	2000	400	2800
Interior chamber	2000	1750	2800

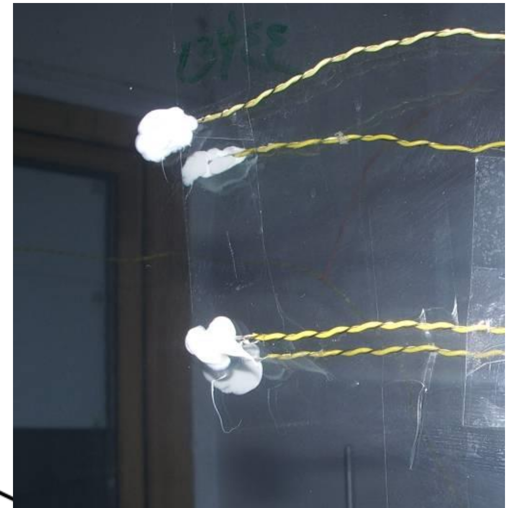
Measured parameters:

- **Air temperature : to interior chamber**
- **Air temperature in façade channel**
- **Temperature of exterior and interior channel glazing**
- **Air humidity**
- **Solar radiation**

Location of thermocouples for temperature measurements:

- Air inside the channel
- On the glazing surfaces





Acquisition station for temperatures

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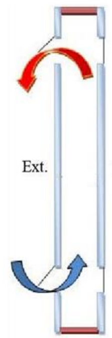
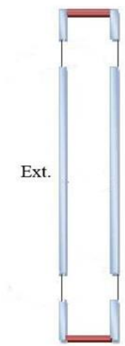
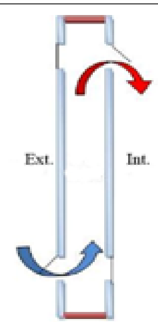
MEASUREMENTS IN SEASON CONDITIONS

	Regim de temperatură	Ventilare exterioară	Etapă măsurări	Perioada	Condiții testare
Summer conditions	$T_e > T_i$		SET 1	06/07/2012 - 13/07/2012	Convecție naturală - deschideri la partea inferioară și superioară a fațadei exterioare
			SET 2	14/07/2012 - 20/07/2012	Convecție forțată - ventilatoare amplasate în deschiderea superioară a fațadei exterioare
			SET 3	21/07/2012 - 27/07/2012	Convecție naturală - deschidere la partea inferioară a fațadei exterioare și la partea superioară a canalului de aer
Autumn – winter conditions	$T_i > T_e$		SET 4	**27/10/2012 - 02/11/2012**	**Fațadă etanșă** - obturarea tuturor deschiderilor din fațadele vitrate interioară și exterioară - cameră experimentală necondiționată
			SET 5	**24/11/2012 - 30/11/2012**	**Fațadă etanșă** - obturarea tuturor deschiderilor din fațadele vitrate interioară și exterioară - cameră experimentală condiționată
Winter – spring conditions	$T_i > T_e$		SET 6	**1/03/2013 – 16/03/2013**	**Convecţie forţată** -deschideri la partea inferioara a fatadei exterioare si superioara a fatadei interioare

Experimental results

Autumn – winter conditions:
- ***Ti > Te***
- ***Closed channel***

Conclusions:

- ***High values for air humidity***
- ***DSF assure partial or integral the energy for heating for interior chamber, function of the presence or not of the solar radiation.***

Recomandation:
- The need of the BMS (building monitoring system) to open/close the openings of the DSF channel in function of the heating / cooling of the interior spaces.

View from air channel

View from interior chamber

Condensation phenomena at exterior glazing, inside the channel

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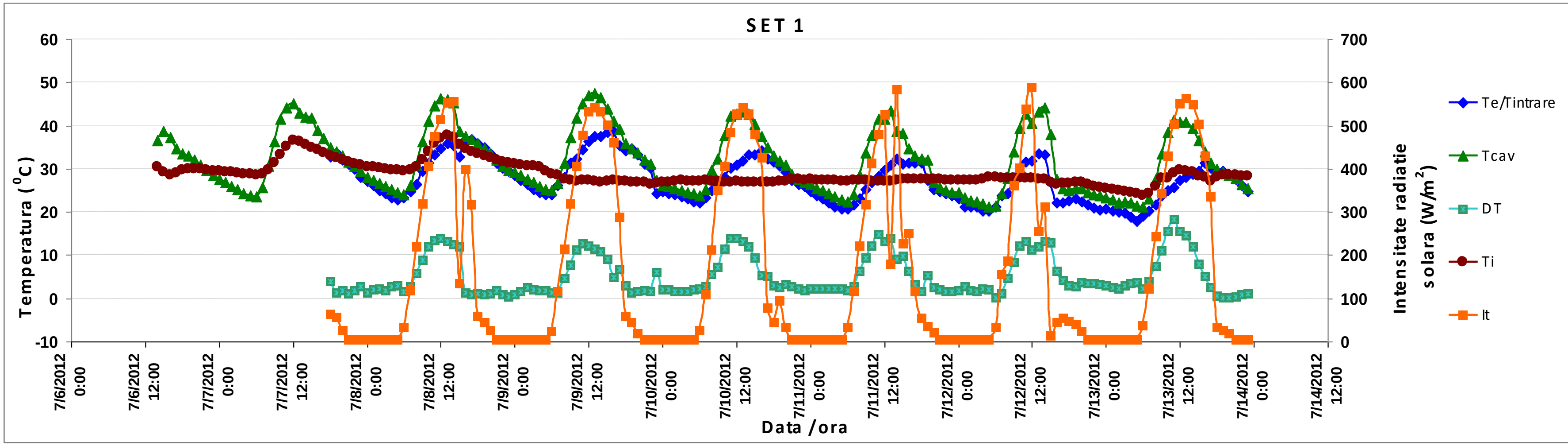
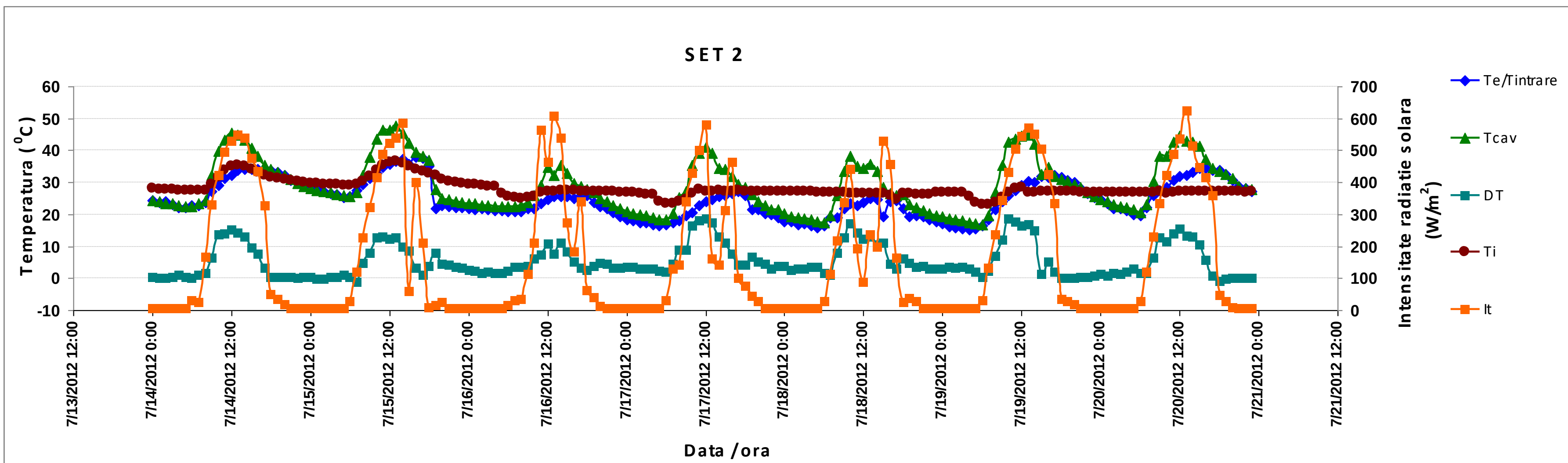
Experimental results - measurements in summer conditions

Average air temperature variation function of solar radiation intensity





Exterior temperature (T_e), Temperature inside the experimental chamber (T_i), Average temperature of the channel (T_{cav}), Diference of temperature from inlet and outlet of the channel (DT), solar radiation (It).

Energetic model

- Establishment of parameters which define the functioning state of the building:
  - -project location;
  - -fuel type;
  - -comfort temperatures in summer/winter season etc;

Combustibil			Debit combustibil 1
Debit combustibil			Energie electrică
Consum de combustibil - unitate			MWh
Preţ combustibil - unitate			ROL/kWh
Tarif combustibil			0,600

Orar	Unitate		Orar 1
Descriere			24/7
Temperatură - încălzire spaţiu	°C		21,0
Temperatură - răcire spaţiu	°C		25,0
Temperatură - neocupată	+/-°C		
Rata de ocupare - zilnică			o/zi
Luni			24
Marţi			24
Miercuri			24
Joi			24
Vineri			24
Sâmbătă			24
Duminică			24
Rata de ocupare - anuală	oră/an		8.760
	%		100%
Temperatură de tranziţie pentru încălzire/răcire	°C	16,0	
Durata sezonului de încălzire	zi	212	
Durata sezonului de răcire	zi	153	

- RETScreen compute the period of the heating / cooling season

Economic model

- Establishment of the electrical energy consumption for heating / cooling;

- Reduction of the energy consumption in case of DSF of 22,4 %

Verificarea proiectului Debit combustibil	Consum de combustibil - unitate	Consum de combustibil - istoric	Consumul de combustibil Caz de referință	Consum de combustibil - variație
Energie electrică	MWh		6,7	

Consumul de combustibil	Încălzire GJ	Răcire GJ	Energie electrică GJ	Total GJ
Consum de combustibil - caz de bază	19	5		24
Consum de combustibil - caz propus	15	4		19
Combustibil economisit	4	1		5
Combustibil economisit - %	21,6%	25,0%		22,4%

Punct de referință		
Unitate de energie	kWh	
Unitate de referință	m²	1

Punct de referință Consumul de combustibil	Încălzire kWh/m²	Răcire kWh/m²	Energie electrică kWh/m²	Total kWh/m²
Consum de combustibil - caz de bază	5.271	1.460		6.731
Consum de combustibil - caz propus	4.130	1.095		5.225
Combustibil economisit	1.141	365		1.506

Analysis of greenhous gas emission

Annual reduction of greenhouse gas emission of

0,8t CO_2/year respectively

40t CO_2/50 ani ;

Sumar pentru reducerile emisiilor de GES

	Emisii de GES caz de referinţă tCO2	Emisii de GES caz propus tCO2
Proiect de măsuri de eficienţă energetică	3,6	2,8
Reducerea anuală netă a emisiilor de GES	0,8	tCO2
Reducere GES netă	tCO2/an	1
Reducere GES netă - 50 ani	tCO2	40

Financial analysis

In the software are introduced:

The original costs - price façade;

The annual costs - fuel prices, maintenance costs;

Duration of the project life;

Paramerii financiari		
General		
Valoare indexare combustibil	%	0,0%
Rata inflației	%	4,0%
Valoare discount	%	
Durată viață proiect	an	50

Costuri inițiale

Măsuri de eficiență energetică	100,0%	ROL	5.000
Echilibrare sistem și diverse	0,0%	ROL	0
Costuri totale inițiale	**100,0%**	**ROL**	**5.000**

Costuri anuale și plată datorii		
Exploatare și întreținere	ROL	50
Cost combustibil - caz propus	ROL	3.135
Costuri anuale totale	**ROL**	**3.185**

It follows a series of parameters that highlight viability for the case of DSF :

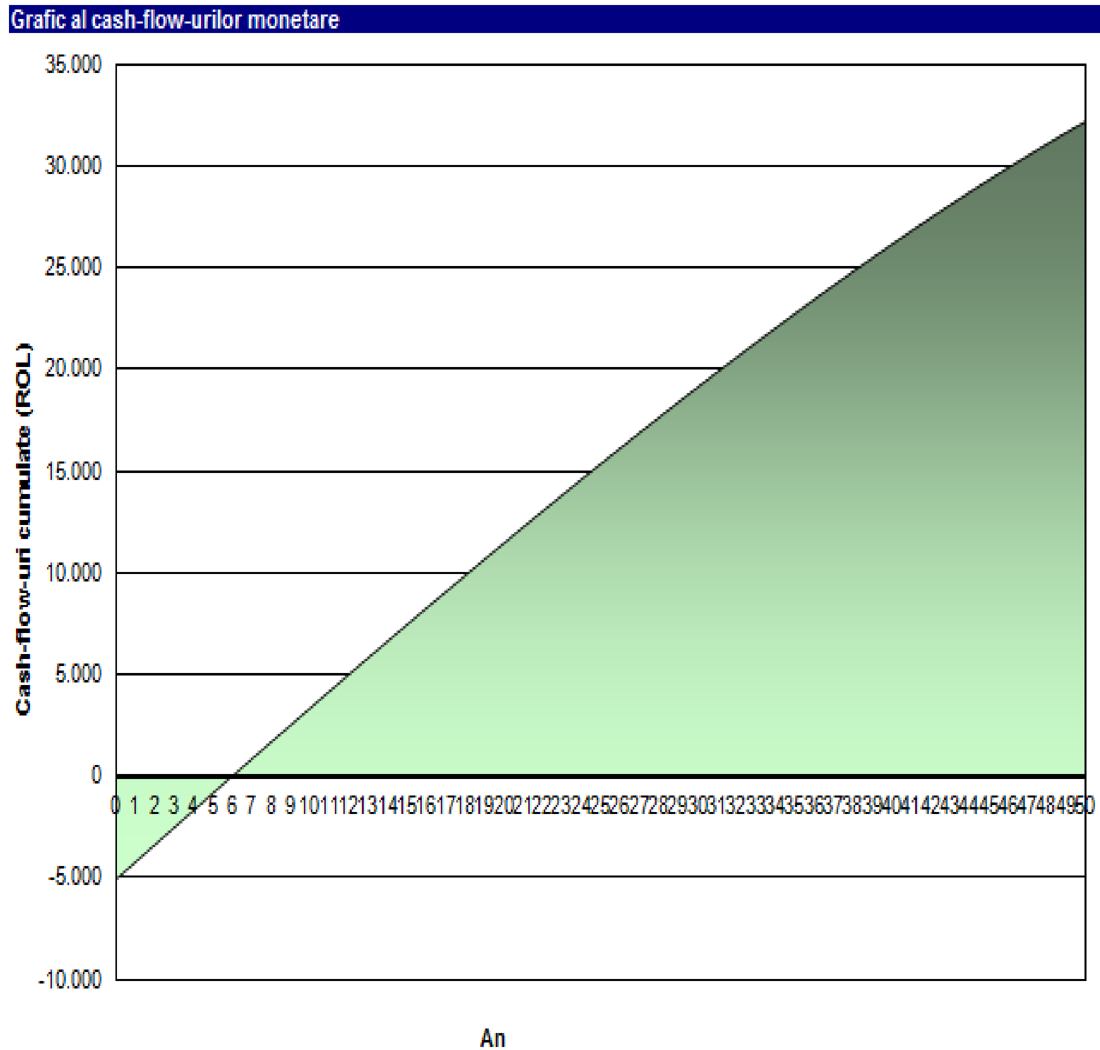
-rate of return> 5%;

-present positive net value ;

-Report cost-benefit

Investment payback

Viabilitate financiară		
RIR după impozit - cap. proprii	%	16,7%
RIR înainte impozit-active	%	16,7%
RIR după impozit-cap. proprii	%	16,7%
RIR după impozit-active	%	16,7%
Per. amortizare simplă	an	5,9
Rentabilitate cap. proprii	an	5,9
Val. actualizată netă (VAN)	ROL	32.236
Economii anuale în durata de viață	ROL/an	645
Raport cost-beneficiu (C-B)		7,45

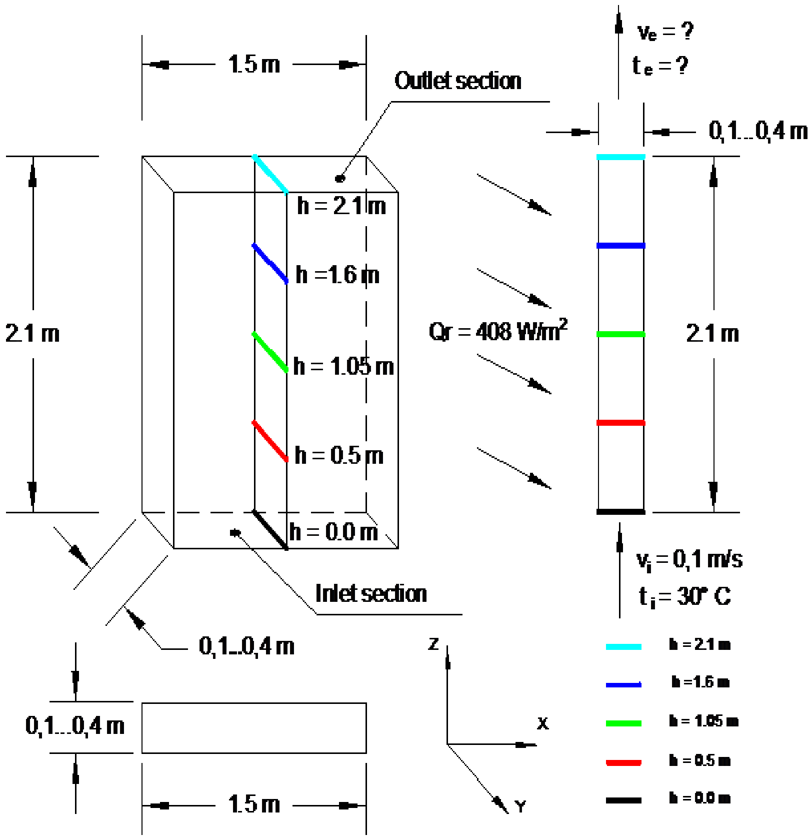


The influence of different widths of the channel on thermodynamic behavior of DSF

Objectives of the study

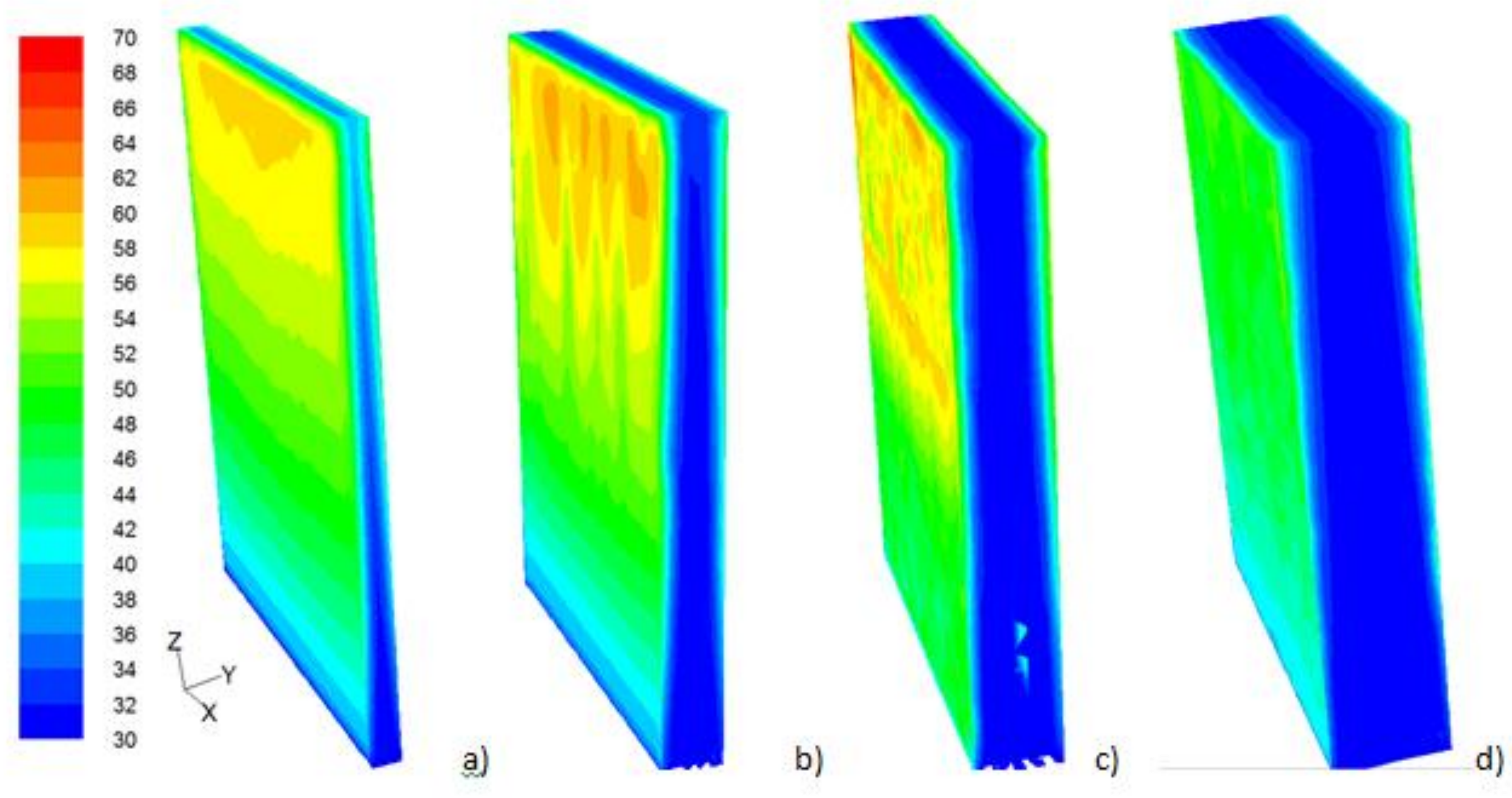
- Realize a numerical analysis of thermodynamic behavior of ventilated inaccessible façades, by modeling solar radiation.
- Comparative study of results when the thickness of the façade is variable (0.1 m to 0.4 m).

Case description



- façade geometry: H=2.1 m, L=1.5 m
- constant heat flux of solar radiation: Q_r = 408 W/m²
- air temperature and velocity at inlet: T_i = 30 °C, v_i = 0.1 m/s;
- glazing properties : thickness of 6 mm; absorption, reflection and transmission coefficients: α = 0.07 , ρ = 0.08 , τ = 0.85;
- exterior ventilation system with ascendant air circulation, between inlet and outlet sections.

Numerical results

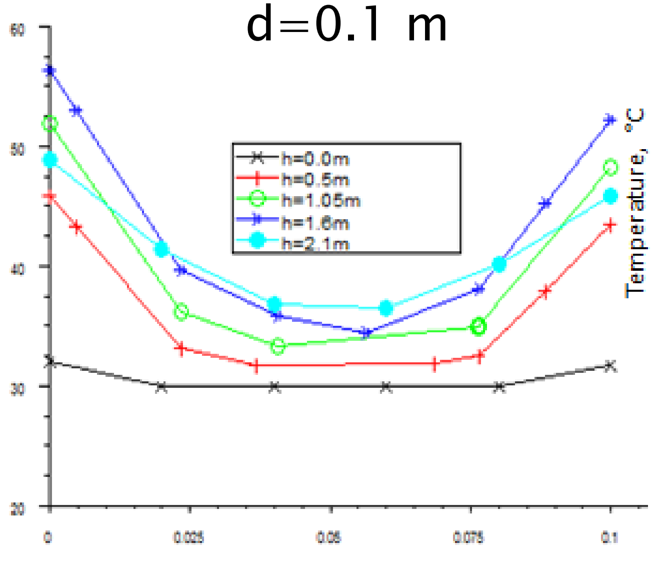


Temperature range: a) d = 0.1 m; b) d = 0.2 m; c) d = 0.3 m; d) d = 0.4 m

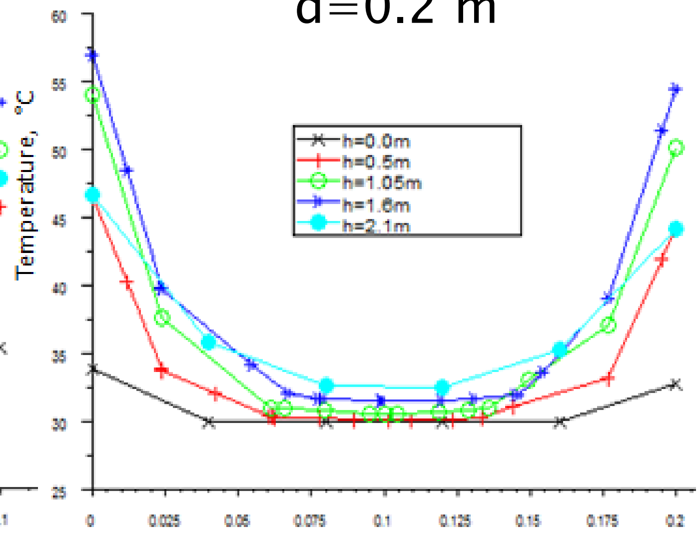
With the increasing of the section, the air from the middle area is less influenced by the heat transfer.

Temperature profiles inside the channel along y axis:

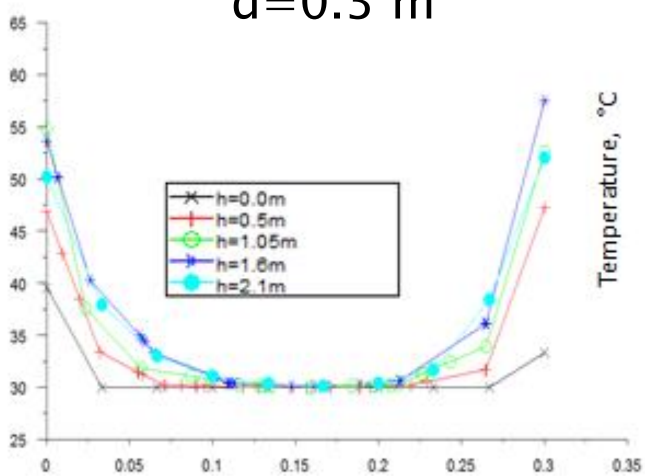
d=0.1 m



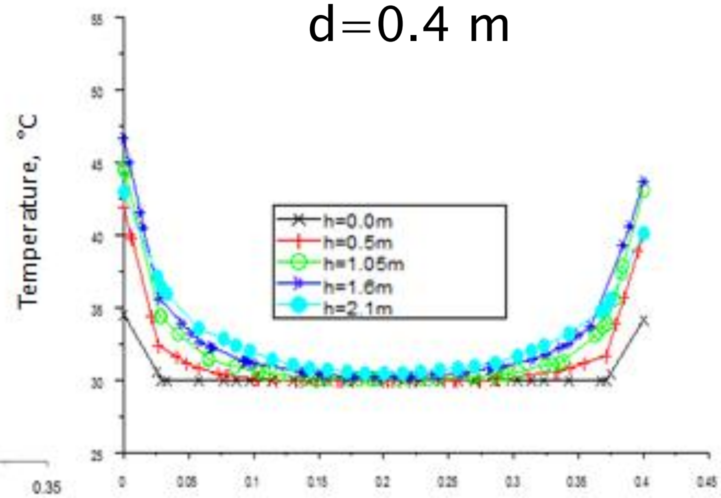
d=0.2 m



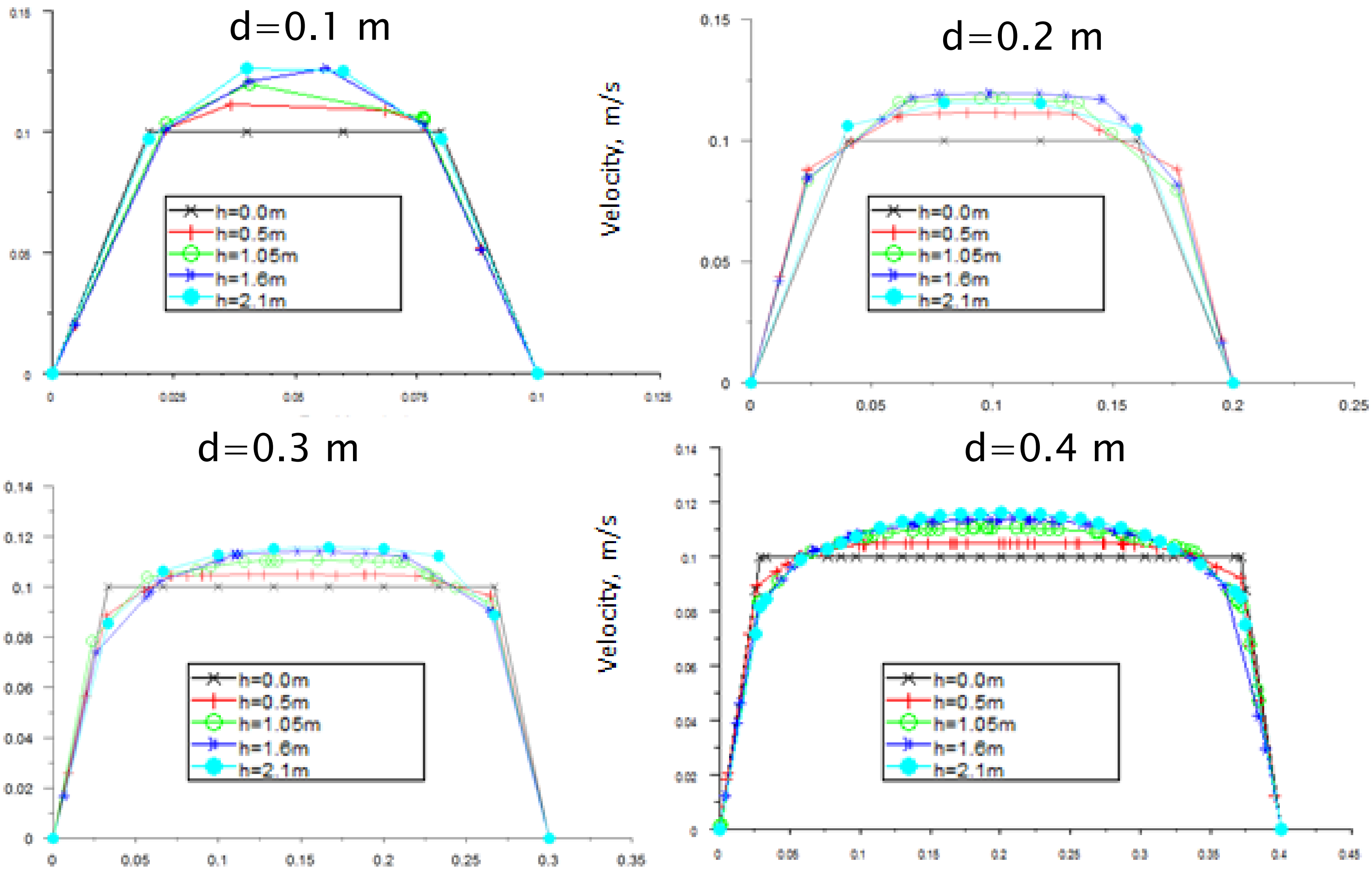
d=0.3 m



d=0.4 m



Velocity profiles inside the channel along y axis



Conclusions

- the heat transfered to the interior air is achieved indirectly;
- the heat is absorbed by the layers of the glass, and after that it is transferred by forced convection to the air;
- the heat transferred to the air and the velocities for small thickness of channel are higher;
- once the width of the channel is enlarged, the distribution of velocities becomes uniform in the central area;
- lower temperatures in DSF channel were registered for 30 cm thickness of the channel

IMPROVEMENT OF ENERGY PERFORMANCE OF A DOUBLE SKIN VENTILATED FAÇADE USING

EAHX and heat pipes

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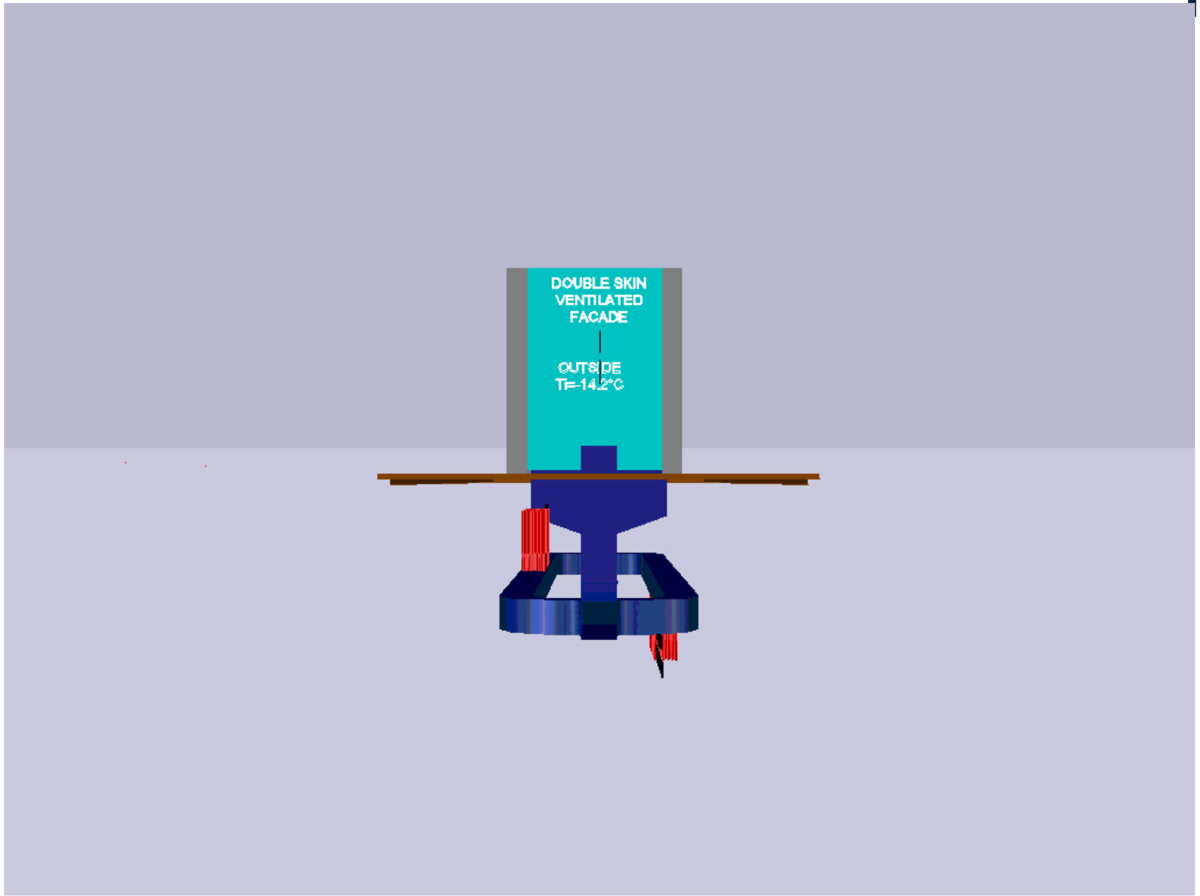
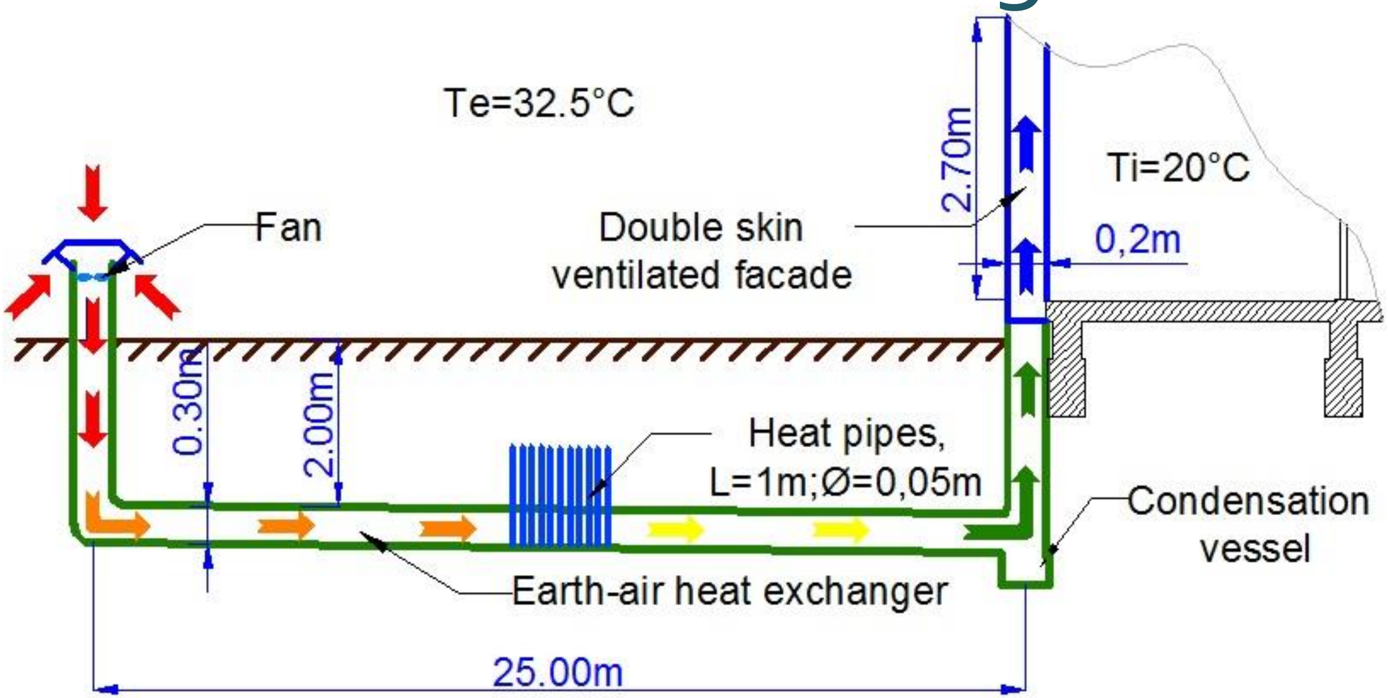
- low energy consumption
- use of renewable energy
- improvement of thermal comfort
- improving the double skin ventilated façade using accessible and low-cost solution

Double skin ventilated façades improved with EAHX and heat pipes

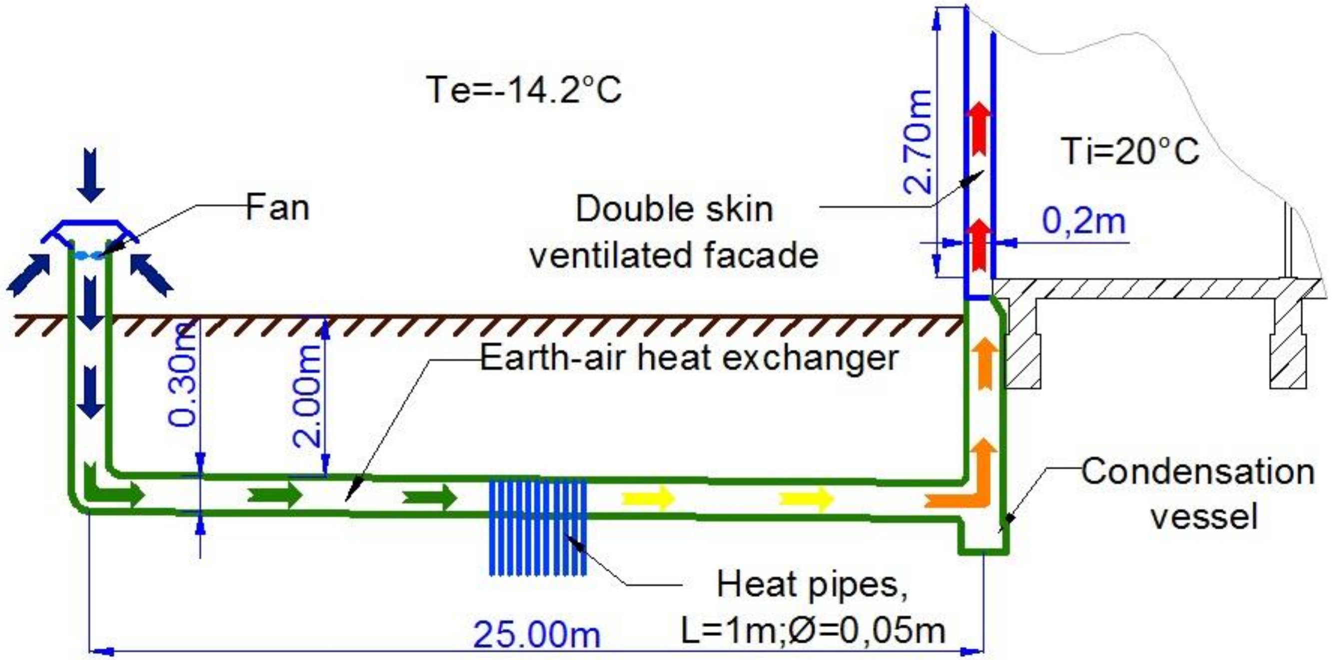


Double skin ventilated façades improved with EAHX and heat pipes

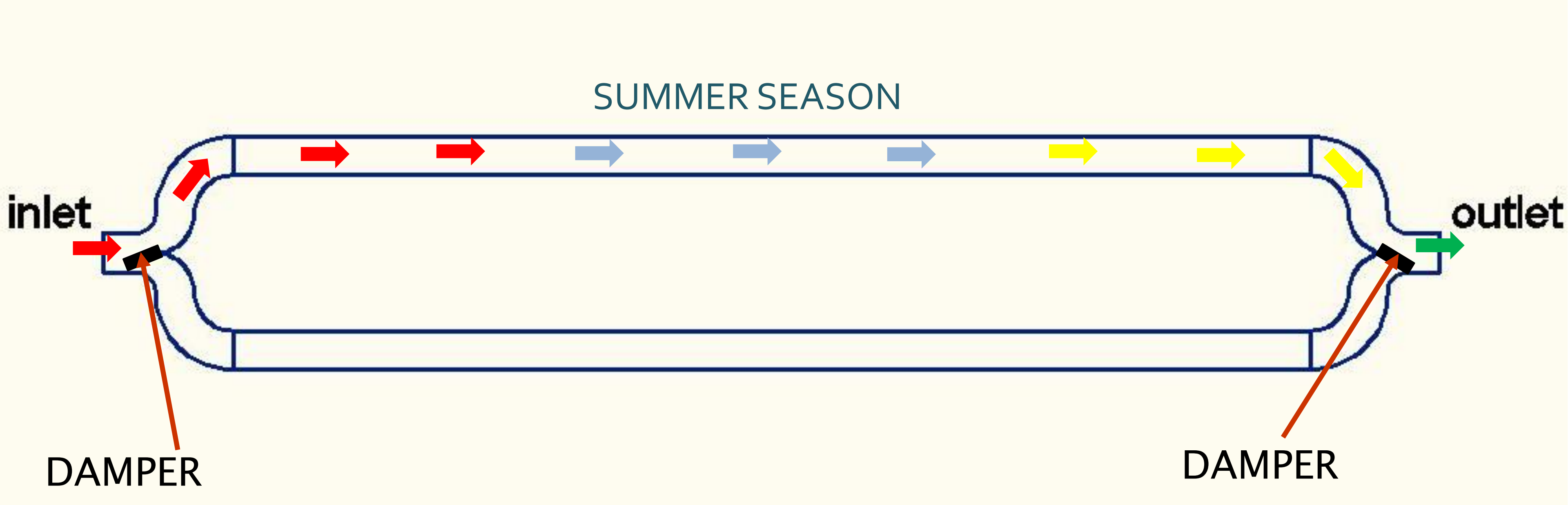
summer design



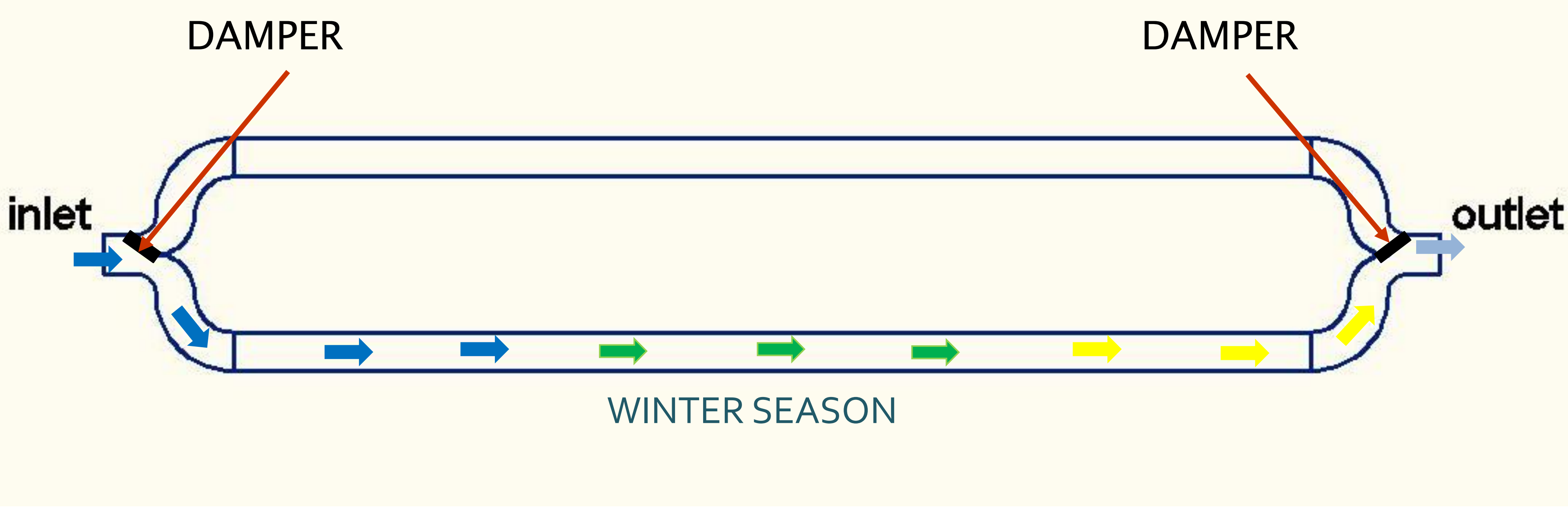
Double skin ventilated façades improved with EAHX and heat pipes winter design



Damper position

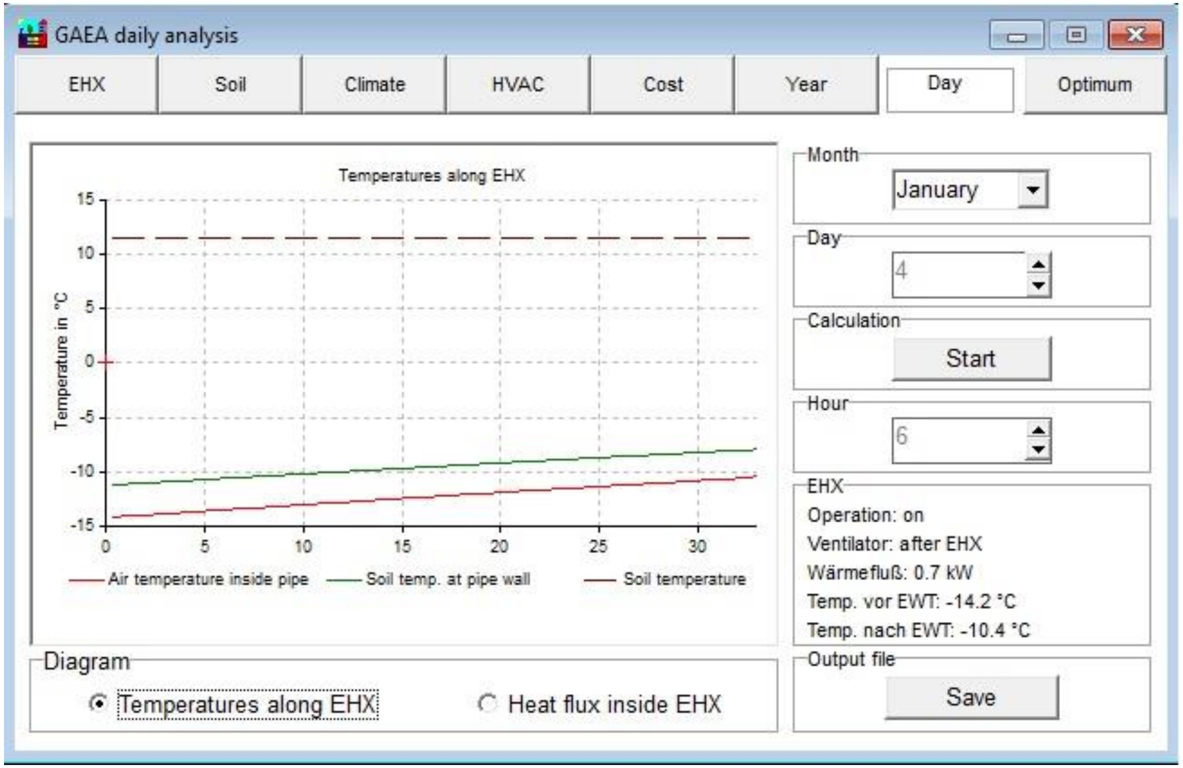


Damper position



Temperature determination from EAHX

winter season - coolest day



1st case

$T_{\text{inlet EAHX}} = -14,2$ [°C]

$T_{\text{outlet EAHX}} = -11,2$ [°C]

ΔT = 3 [°C]

2nd case

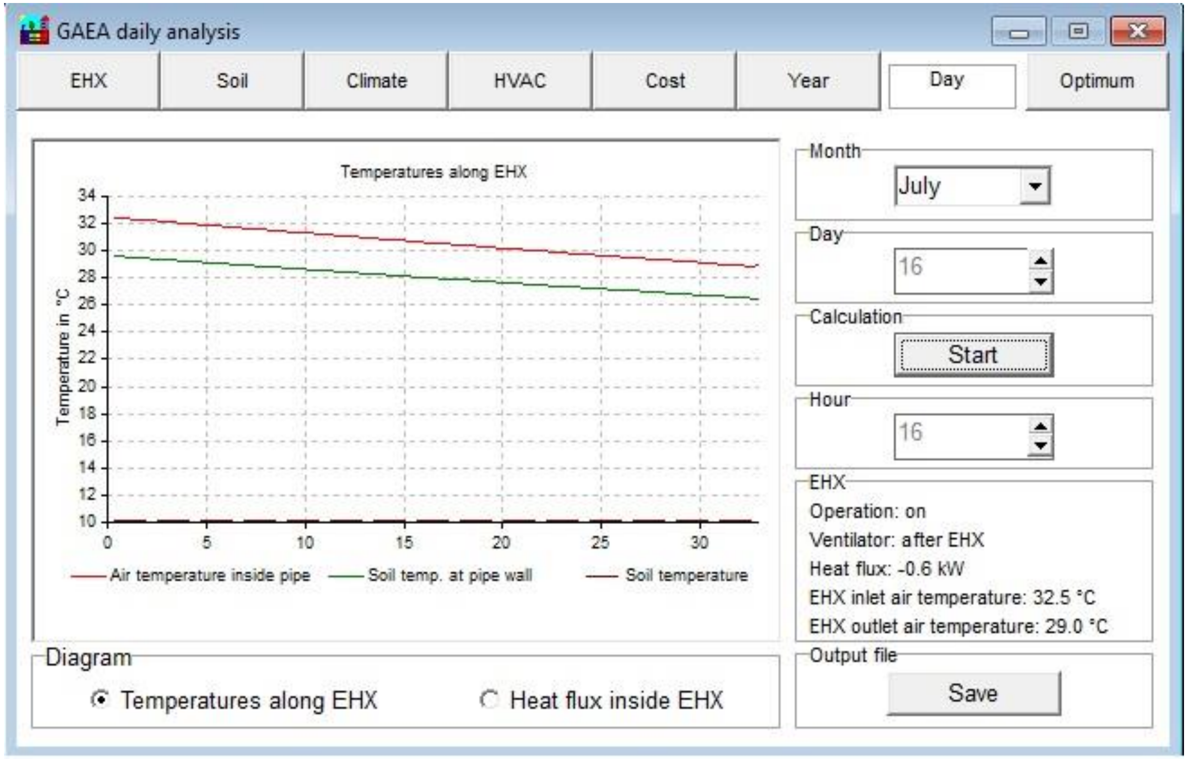
$T_{\text{inlet EAHX+HP}} = -14,2$ [°C]

$T_{\text{outlet EAHX+HP}} = -10,4$ [°C]

ΔT = 3,8 [°C]

Temperature determination from EAHX

summer season - warmest day



1st case

$T_{\text{inlet EAHX}}$ = 32,5 [ºC]

$T_{\text{outlet EAHX}}$ = 29,8 [ºC]

ΔT = 2,7 [ºC]

2nd case

$T_{\text{inlet EAHX+HP}}$ = 32,5 [ºC]

$T_{\text{outlet EAHX+HP}}$ = 29 [ºC]

ΔT = 3,5 [ºC]

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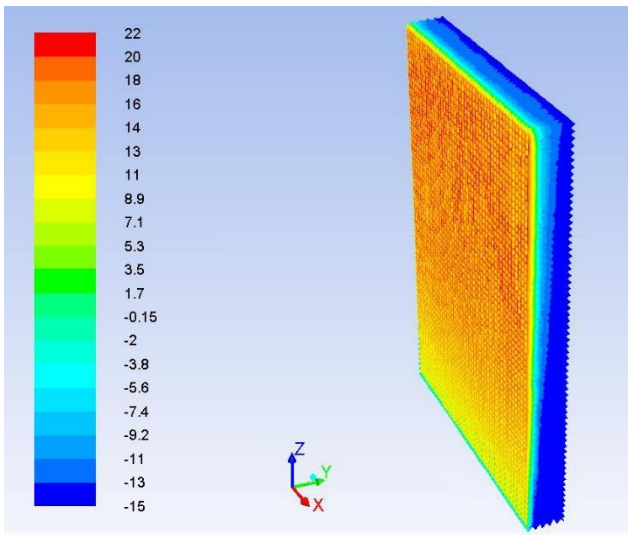
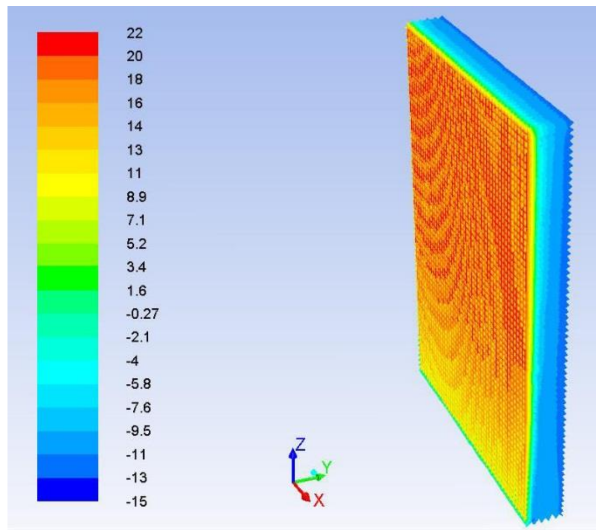
Numerical results

Temperature spectrums winter season

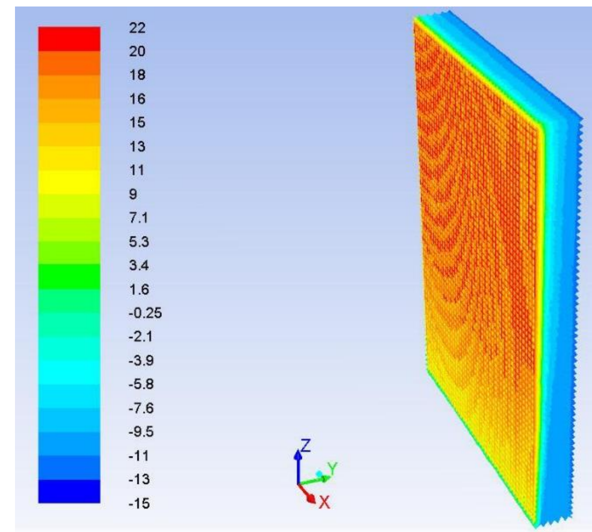
Basic case	1st case	2nd case



Double skin ventilated façade $T_{air,\ inlet}$ *= -14,2 [ºC]*
$T_{air,\ outlet}$ *= -12,8 [ºC]*



Double skin ventilated façade and earth-air heat exchangers
$T_{air,\ inlet}$ *= -11,2 [ºC],*
$T_{air,\ outlet}$ *= - 9,48 [ºC]*



Double skin ventilated façade and earth-air heat exchangers improved with heat pipes ,
$T_{air,\ inlet}$ *= -10,4 [ºC]*
$T_{air,\ outlet}$ *= -8,7 [ºC]*

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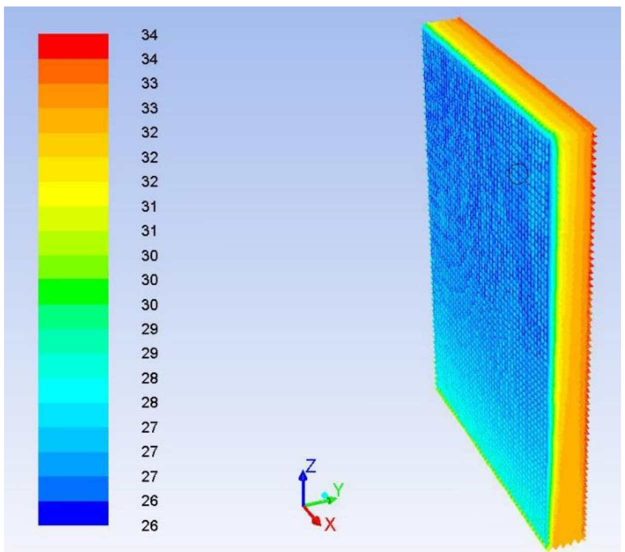
Numerical results

Temperature spectrums summer season

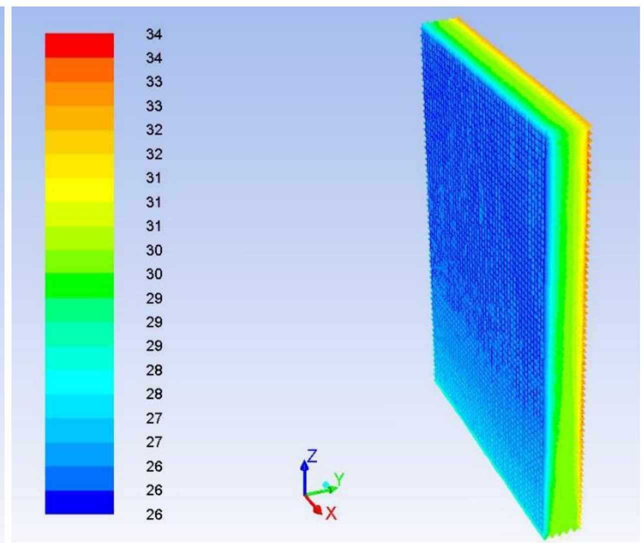
Basic case



Double skin ventilated façade $T_{air, inlet} = 32{,}5\ [^oC]$

$T_{air, outlet} = 32{,}3\ [^oC]$

1st case

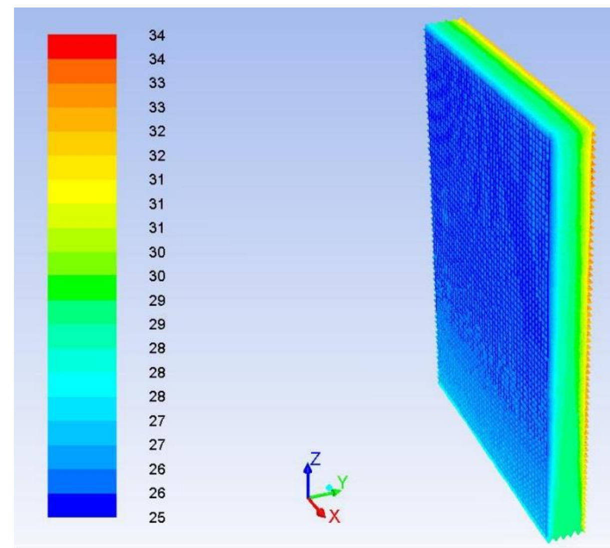


Double skin ventilated façade and earth-air heat exchangers

$T_{air, inlet} = 29{,}8\ [^oC]$,

$T_{air, outlet} = 29{,}9\ [^oC]$

2nd case



Double skin ventilated façade and earth-air heat exchangers improved with heat pipes ,

$T_{air, inlet} = 28{,}9\ [^oC]$

$T_{air, outlet} = 29{,}1\ [^oC]$

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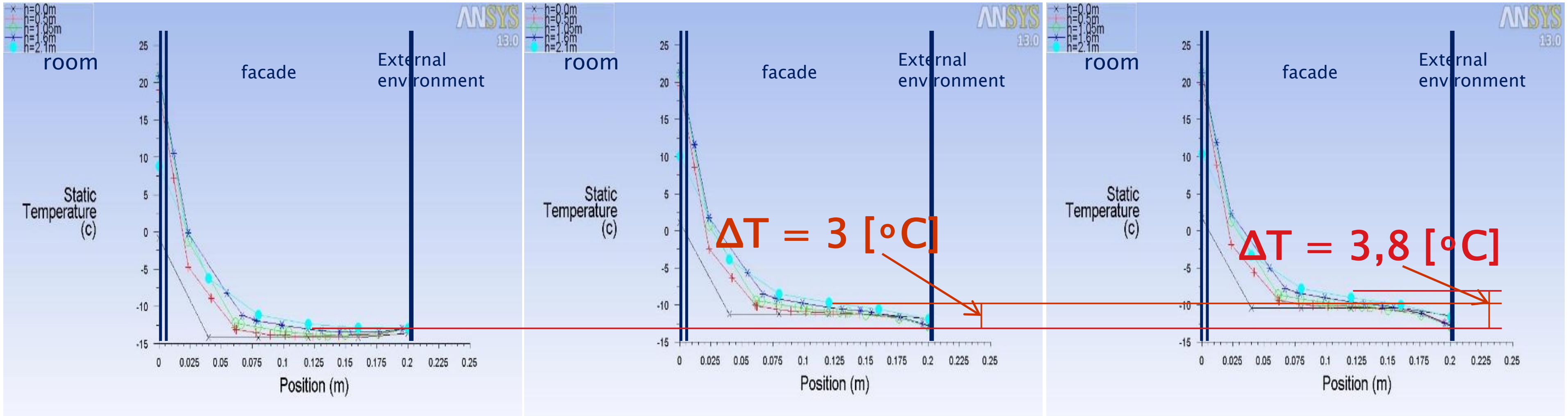
Numerical results

Temperature profiles winter season

Basic case | **1st case** | **2nd case**



Double skin ventilated façade $T_{air,\ inlet}$ *= -14,2 [ºC]*
$T_{air,\ outlet}$ *= -12,8 [ºC]*

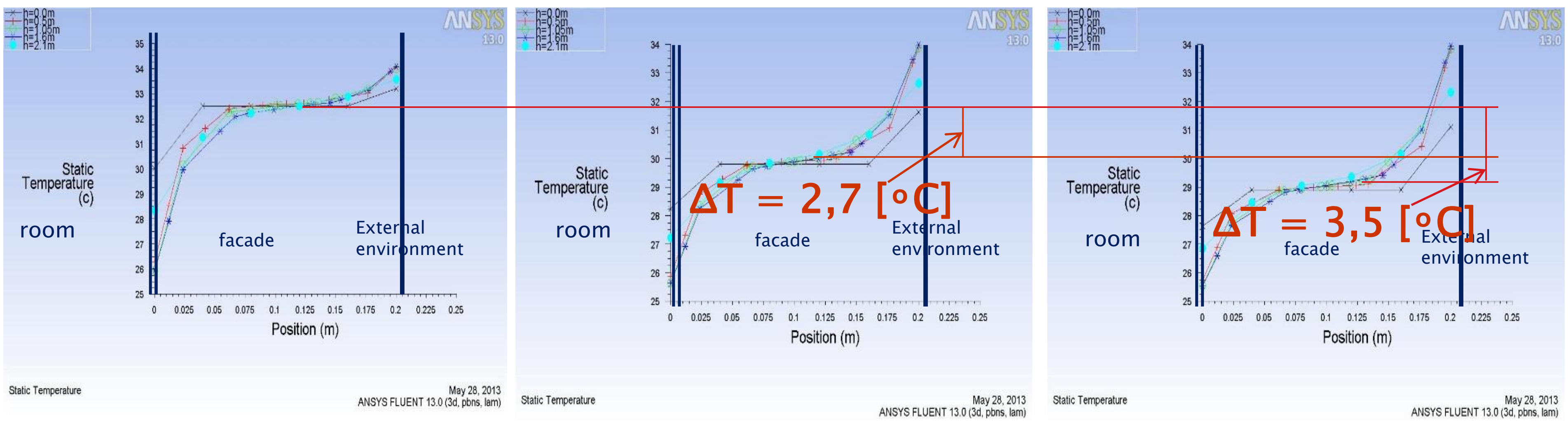
Double skin ventilated façade and earth-air heat exchangers
$T_{air,\ inlet}$ *= -11,2 [ºC],*
$T_{air,\ outlet}$ *= - 9,48 [ºC]*

Double skin ventilated façade and earth-air heat exchangers improved with heat pipes ,
$T_{air,\ inlet}$ *= -10,4 [ºC]*
$T_{air,\ outlet}$ *= -8,7 [ºC]*

Numerical results

Temperature profiles summer season

Basic case	1^{st} case	2^{nd} case

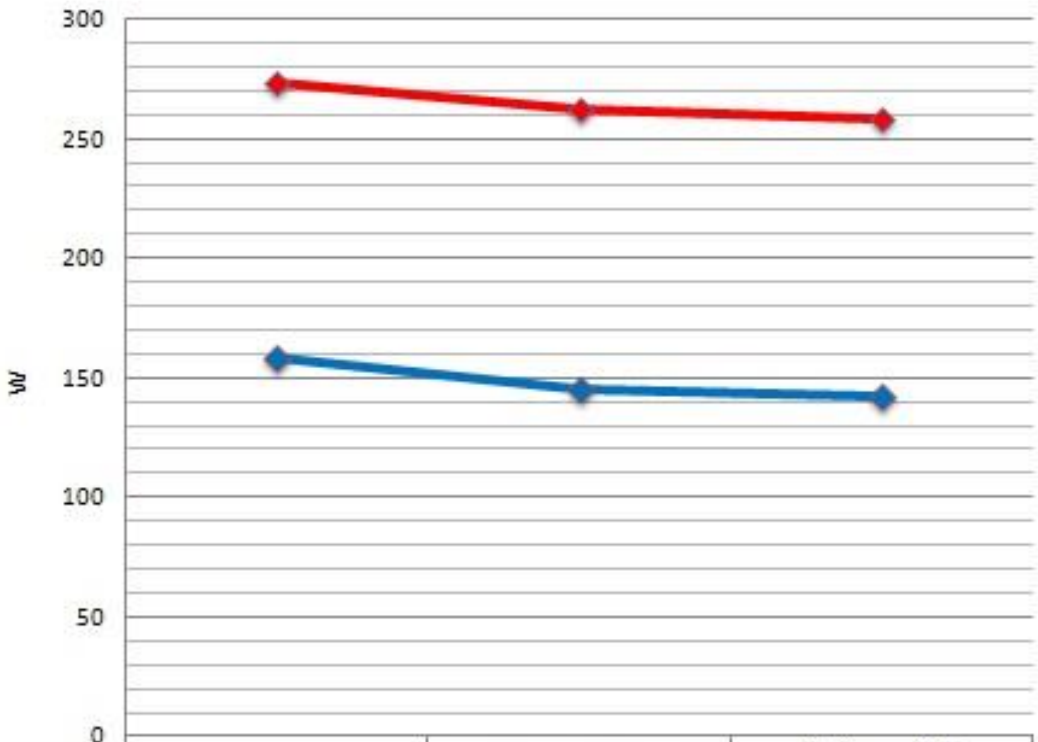


Double skin ventilated façade $T_{air,\ inlet}$ = -14,2 [ºC]
$T_{air,\ outlet}$ = -12,8 [ºC]

Double skin ventilated façade and earth-air heat exchangers
$T_{air,\ inlet}$ = -11,2 [ºC],
$T_{air,\ outlet}$ = - 9,48 [ºC]

Double skin ventilated façade and earth-air heat exchangers improved with heat pipes ,
$T_{air,\ inlet}$ = -10,4 [ºC]
$T_{air,\ outlet}$ = -8,7 [ºC]

The improvement of double skin ventilated facade



	basic DSF	1st case: DSF improved with EAHX	2nd case: DSF improved with EAHX and heat pipes
heat gains (summer)	273.78	262.34	258.61
heat loses (winter)	158.18	145.63	142.27

Energy saving 1st case

Summer 5%

Winter 8%

Energy saving 2nd case

Summer 6%

Winter 11%

Conclusions

- ✓ the double skin ventilated facade was improved using EAHX and heat pipes with **11%** in winter season and **6%** in summer season;

- ✓ the energy consumption was reduced through the decreasing of heat loss with **5 W/m²** in winter and heat gains reduced with **4,7 W/m²** in summer.

Improvement of the indoor climate conditions inside orthodox churches

Opportunity of the study:

- No normative regulations in Romania on HVAC system of churches (EN 15759-1 in draft)

- Over the time, solutions for heating and ventilation were arbitrary chosen

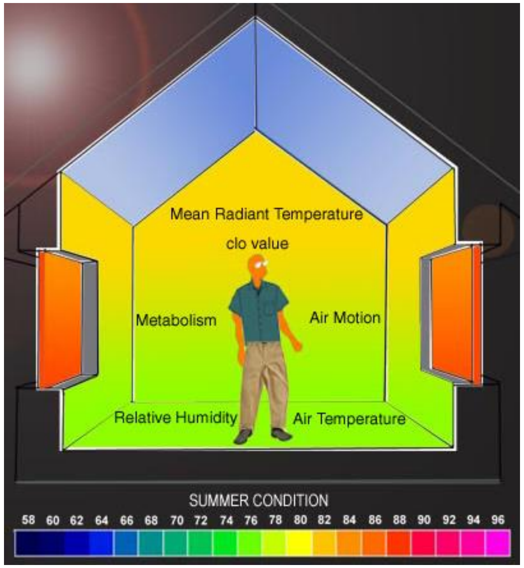
- Improve the indoor climate conditions inside the places of worship
- Comparative study of thermal and ventilation systems usually used in churches
- Protect the icons and paintings against damage (condensation and high temperature gradients)

Comfort in occupational zone:

- Air temperature;
- Surface temperatures;
- Relative humidity;
- Air movements.

THE INDOOR CLIMATE

- Subjective parameter;
- Depends on clothing, activity and duration of stay in the building;
- Typical range: 12-15 degrees C;
- Relative humidity: very high >80% and very low <30%.



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Conservation of religious artworks

- Require indoor climate that minimizes ageing and degradation;
- For materials the most important parameter is relative humidity;
- A solution that is too expensive is useless.

distemper paint damaged by dry interior climate

distemper paint damaged by humidity

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HVAC systems in Romanian churches

Source subsystem

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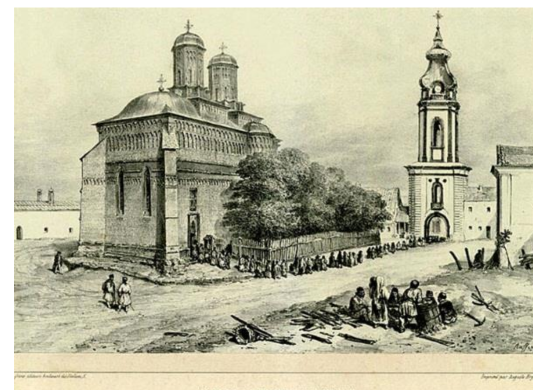
HVAC systems in Romanian churches

Consumer subsystem

Three Holy Hierarchs Monastery in Iasi

- Built between 1635 and 1639;
- Capital restoration in the 1880s includes a hot air central heating, partially functional nowadays;
- Solution by the Engineering Office of F.R. Richnowsky of Lemberg between 1885 and 1886.



The Three Holy Hierarchs Monastery after the last restoration

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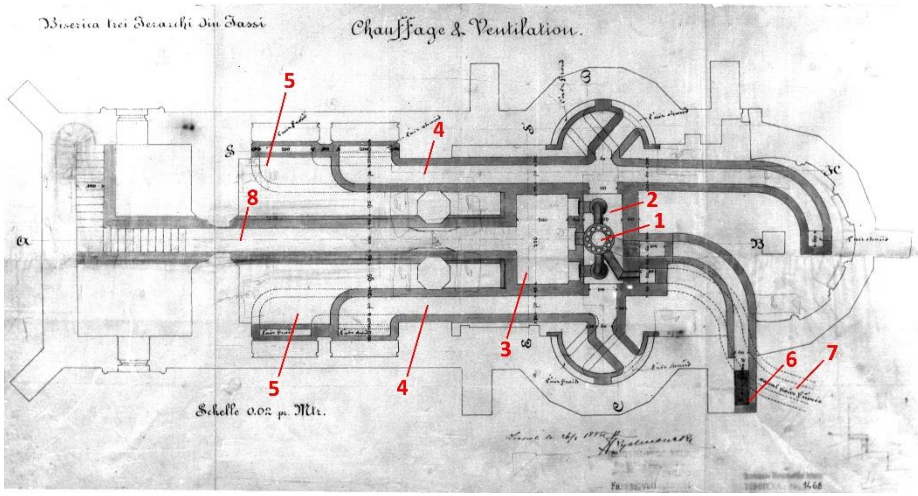
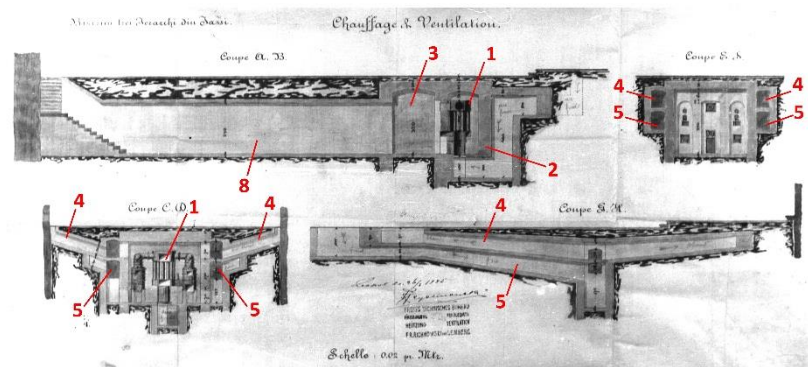
Three Holy Hierarchs Monastery in Iasi

Plan and sections for heating solution designed in 1885-1886



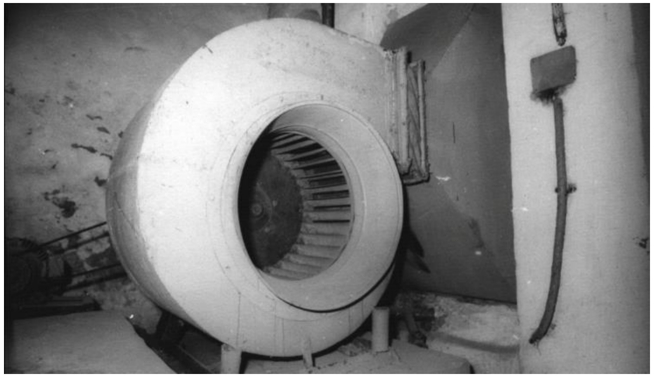


- thermal source: wood stove;
- gravitational circulation;
- first Romanian church using air heating solution.

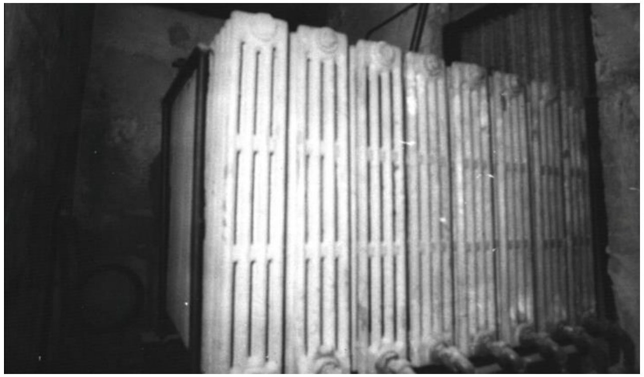
1 - thermal source, 2 - room air distribution, 3 - air collection chamber, 4 - input channel and vents; 5 – suction channels and vents, 6 - the chimney, 7 - air intake, 8 - gallery

Three Holy Hierarchs Monastery in Iasi

- 1960 – the heating system was modified to allow forced convection inside the church;
- Air circulation – gravitational or in forced convection using a single centrifugal fan;
- The heating regime – depends on the parameters coming from de the heating station.



Centrifugal fan



Heating coil

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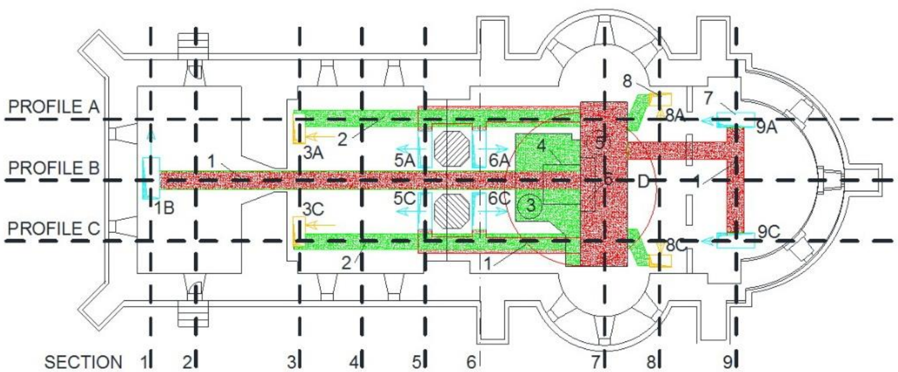
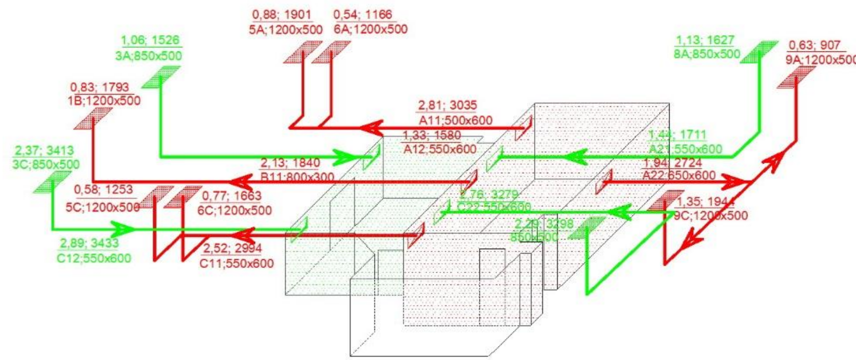
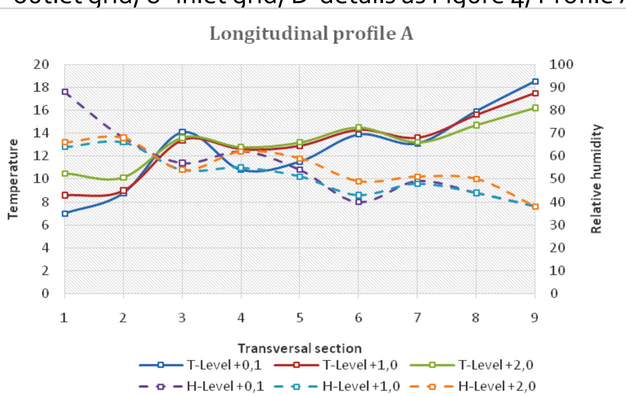
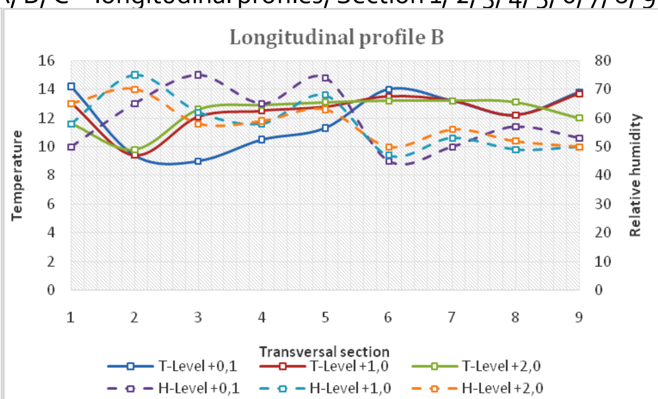
Plan of the air channels under the floor, designed in 1993

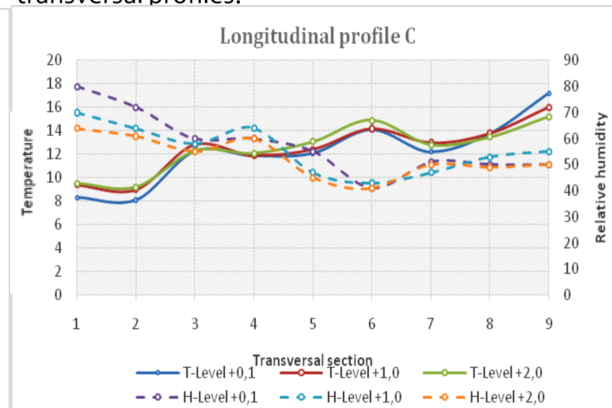




1-hot air channel; 2-recirculated air channel; 3- aspiration chamber, 4-inlet fan; 5- pressure side chamber; 6- water heating coil; 7-outlet grid; 8- inlet grid; D-details as Figure 4, Profile A, B, C – longitudinal profiles; Section 1, 2, 3, 4, 5, 6, 7, 8, 9 - transversal profiles.

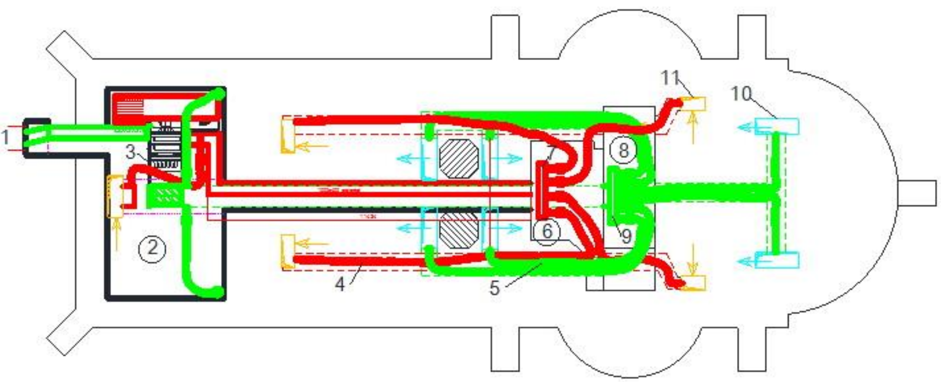






Three Holy Hierarchs Monastery in Iasi

Hot air heating system – nowadays



- *1-fresh air intake channel; 2-basement of porch; 3- air handling unit*
- *4-flexible pipe connected to the suction grid; 5- flexible pipe connected to the outlet grid; 6- suction chamber; 7- exhaust air collector; 8- pressure side chamber; 9- treated air collector; 10-outlet grid; 11-suction grid*

TUIASI

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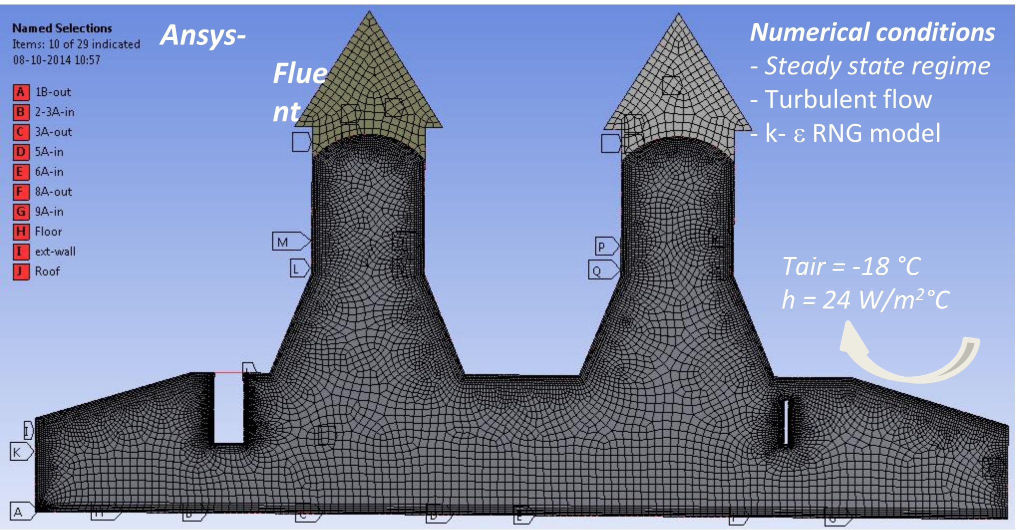
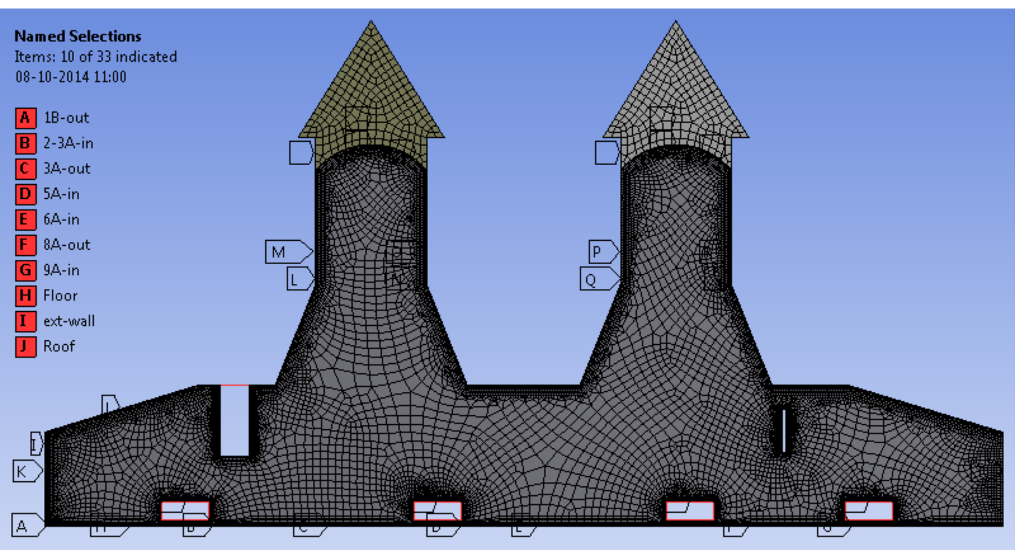
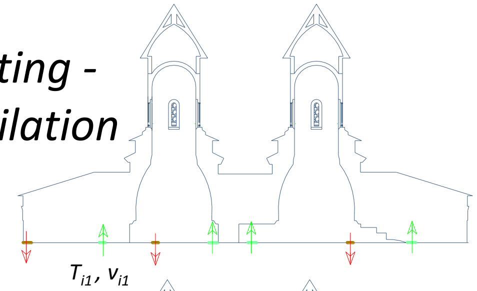
MARUEEB





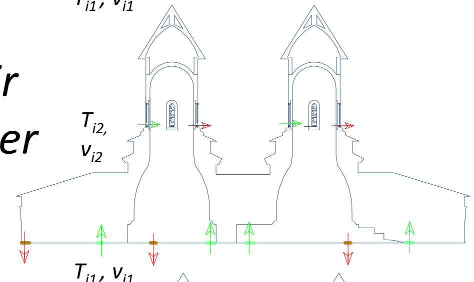
Base Case - Air heating - without tower ventilation

T_{i1} = 15 °C
v_{i1} = 0,5m/s



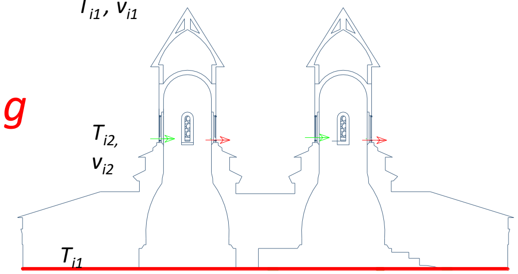
Proposed Case - Air heating - with tower ventilation

T_{i1} = 15 °C, v_{i1} = 0,5m/s
T_{i2} = 15 °C, v_{i2} = 1m/s



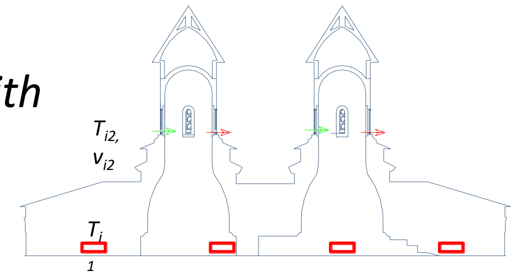
Under floor heating – with tower ventilation

T_{i1} = 32 °C
T_{i2} = 15 °C, v_{i2} = 1m/s



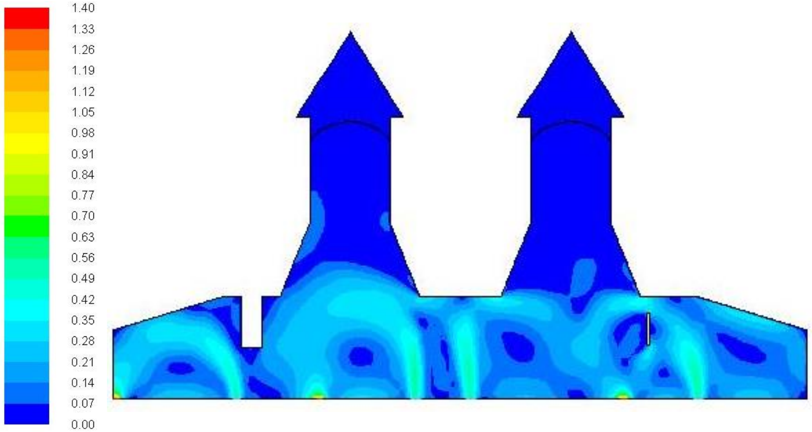
Static heaters – with tower ventilation

T_{i1} = 70 °C
T_{i2} = 15 °C, v_{i2} = 1m/s

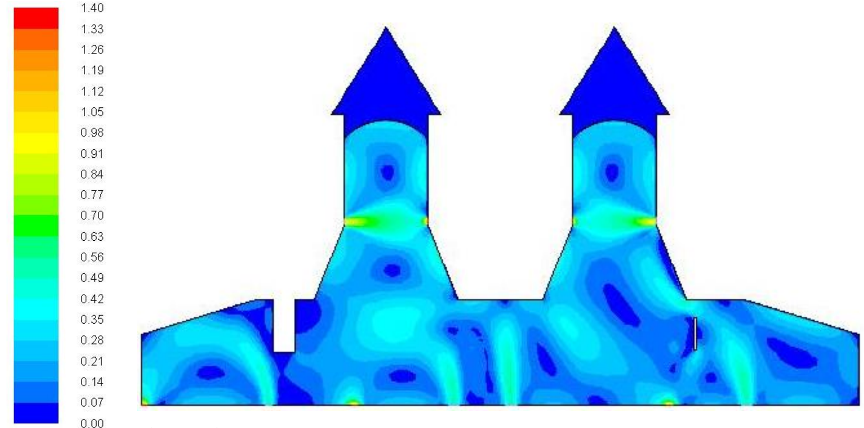


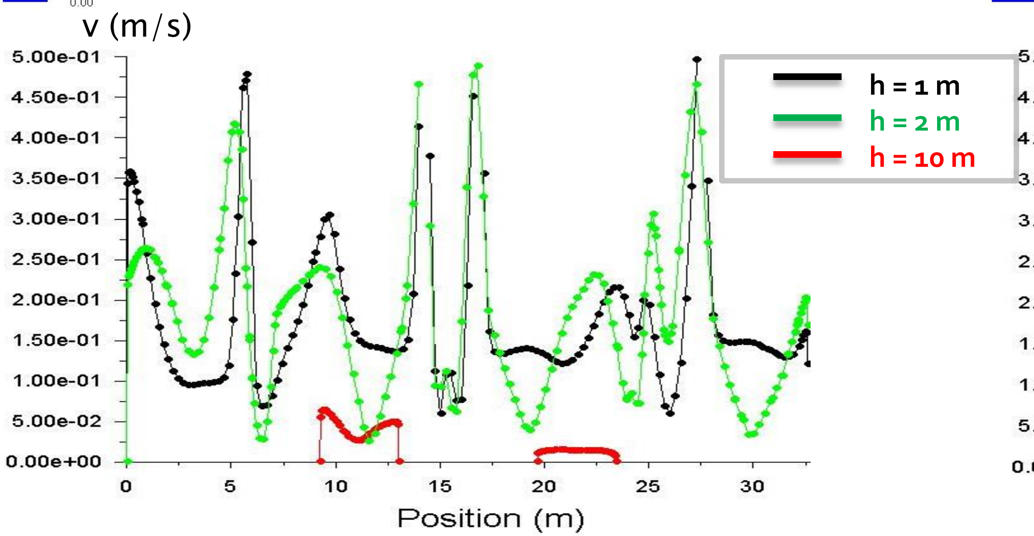
Improve air circulation in tower - Velocities (m/s)

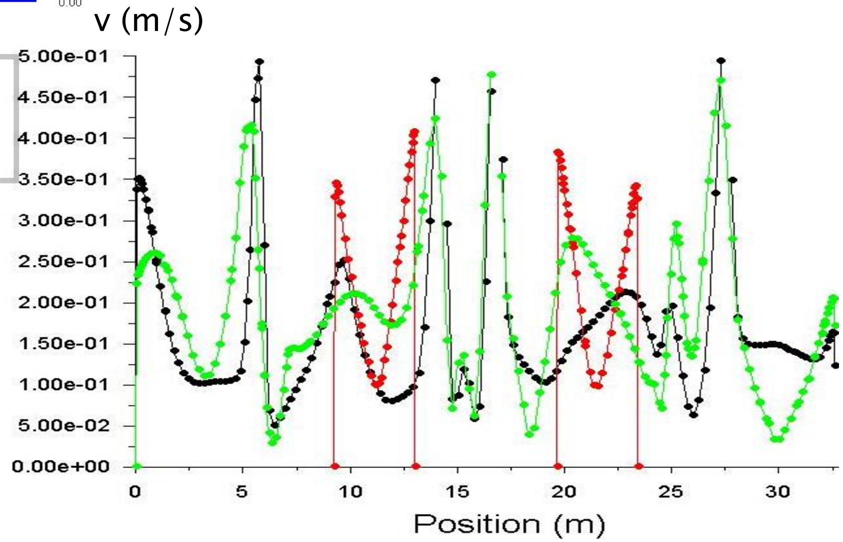
Base case: air heating system - without tower ventilation



Proposed air heating system - with tower ventilation

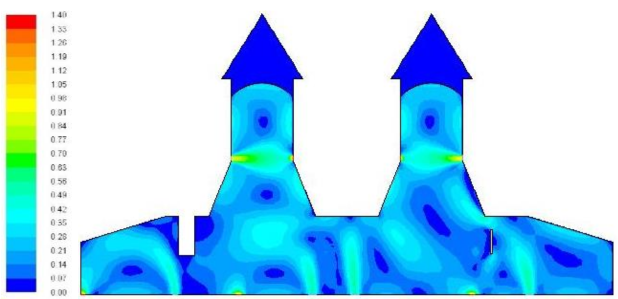


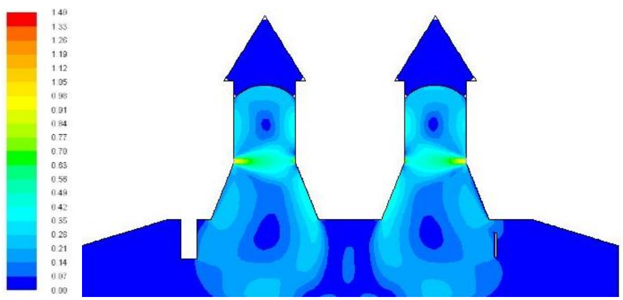


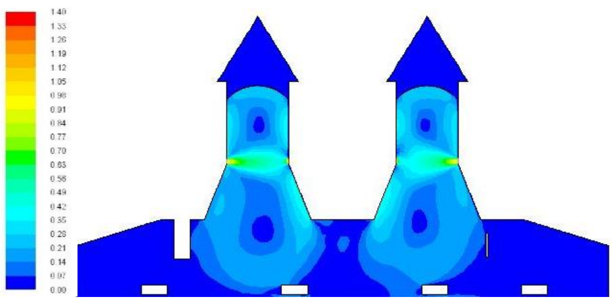


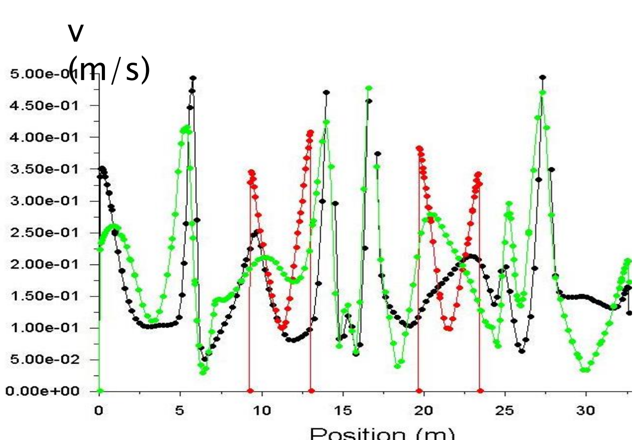
Comparative results in case of using tower ventilation - Velocities (m/s)

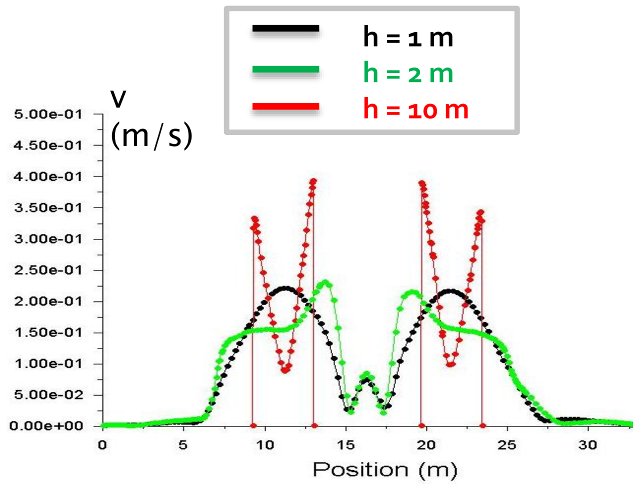
Air heating	*Under floor heating*	*Static heaters*

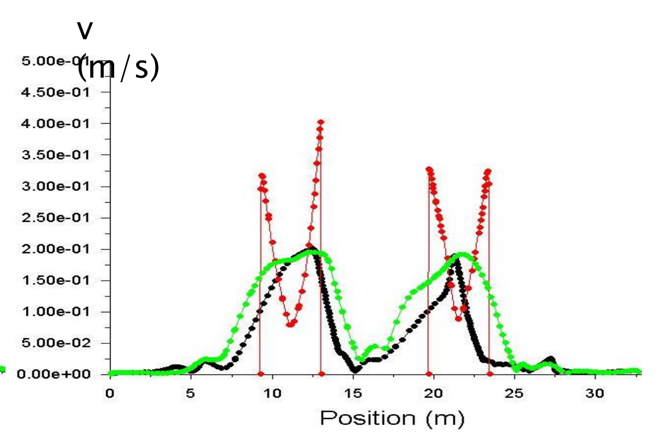




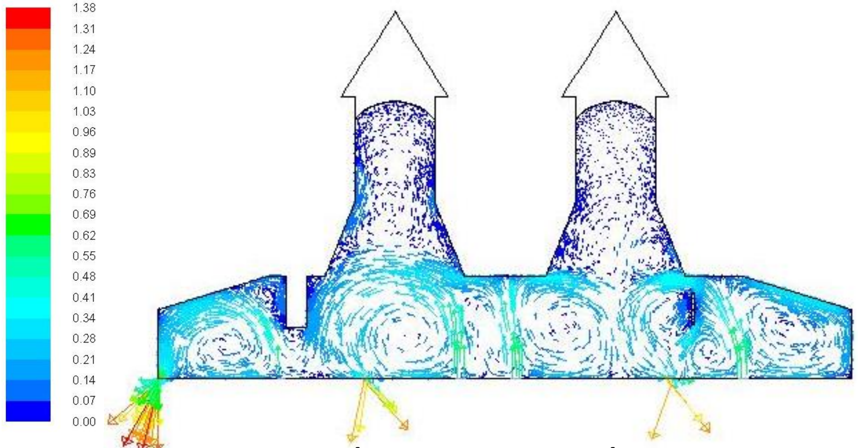




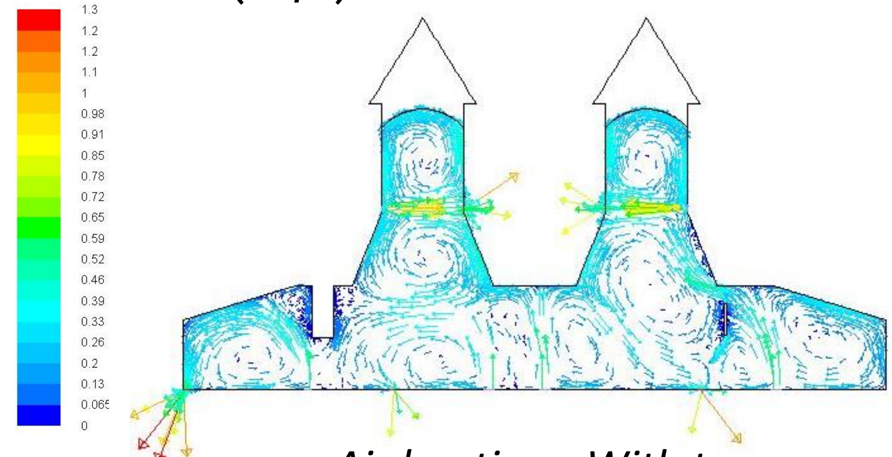




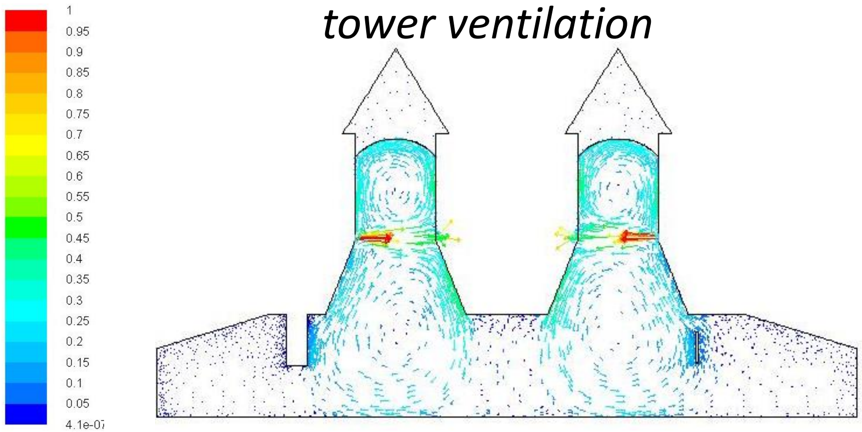
Vectors of velocities (m/s)



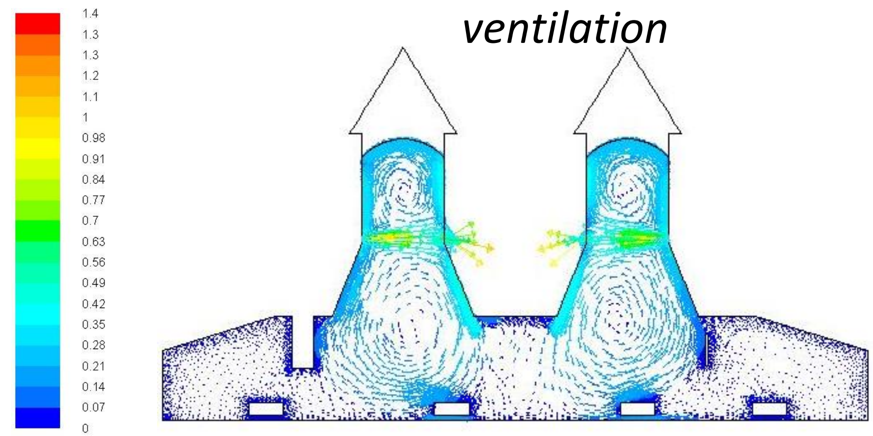
Air heating - Without tower ventilation



Air heating - With tower ventilation

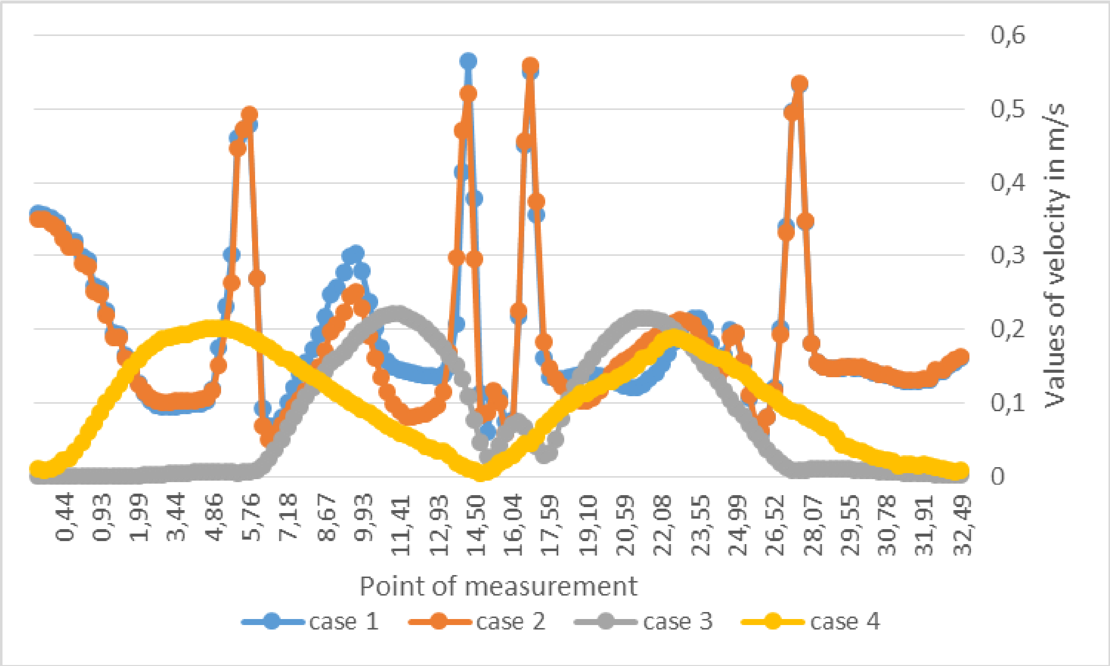


Under floor heating – with tower ventilation



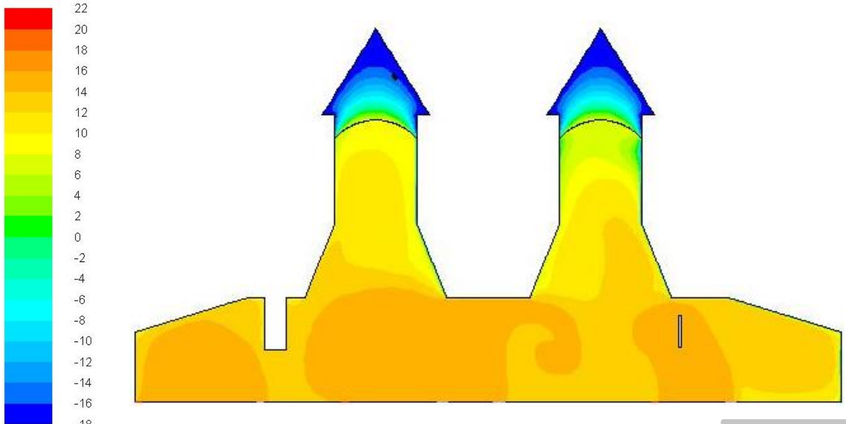
Static heaters – with tower ventilation

Profiles of velocity at 1 m of the floor

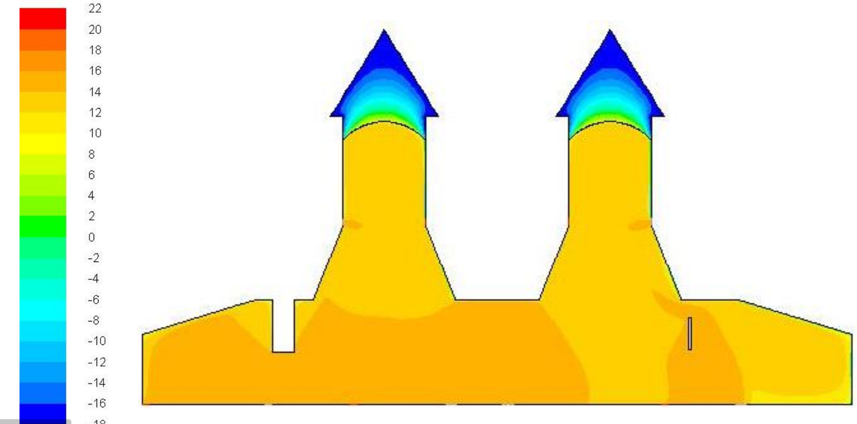


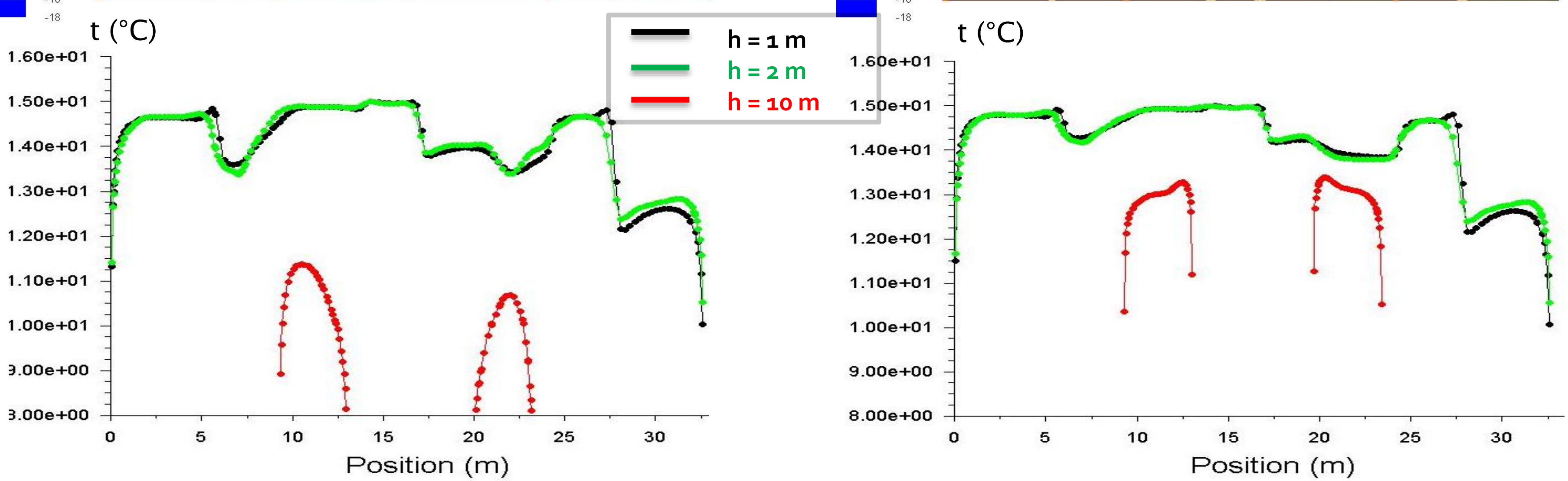
Improve air circulation in tower - Temperatures (°C)

Base case: air heating system - without tower ventilation



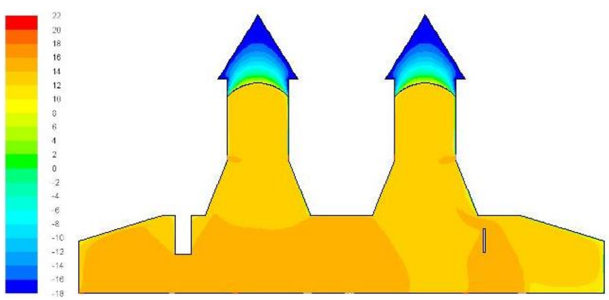
Proposed air heating system - with tower ventilation

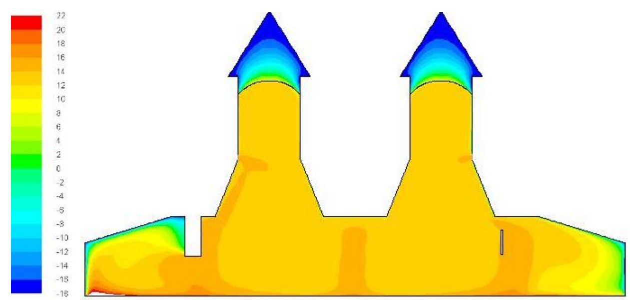


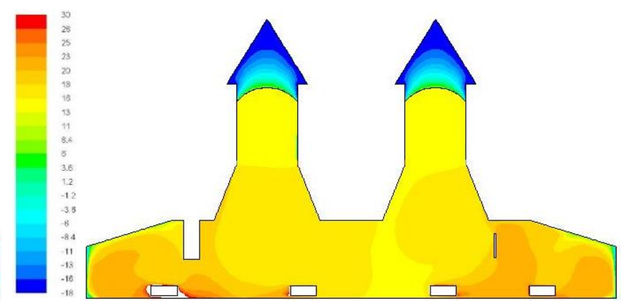


Comparative results in case of using tower ventilation - Temperatures (°C)

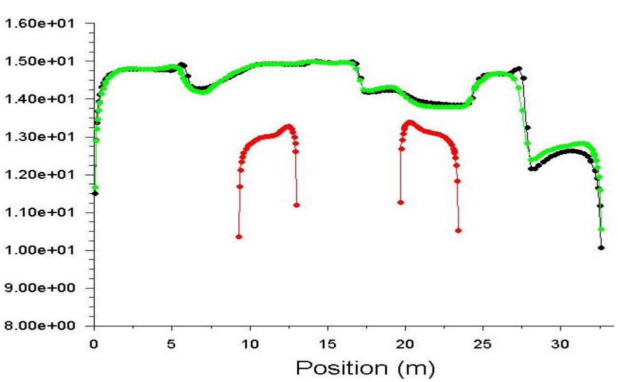
Air heating | *Under floor heating* | *Static heaters*

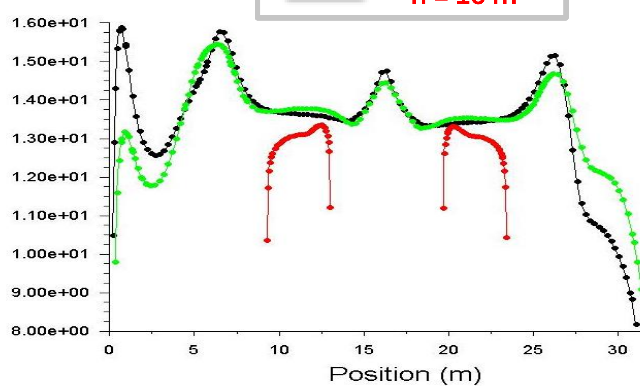


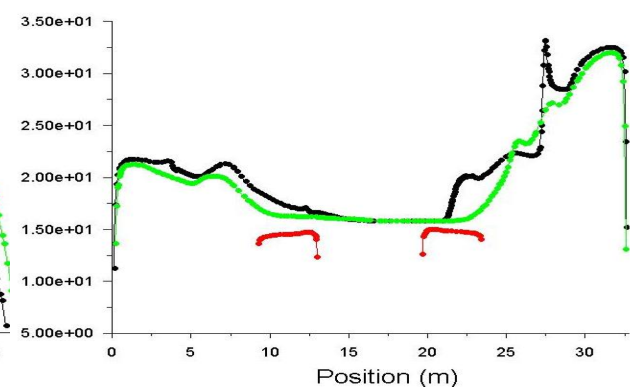




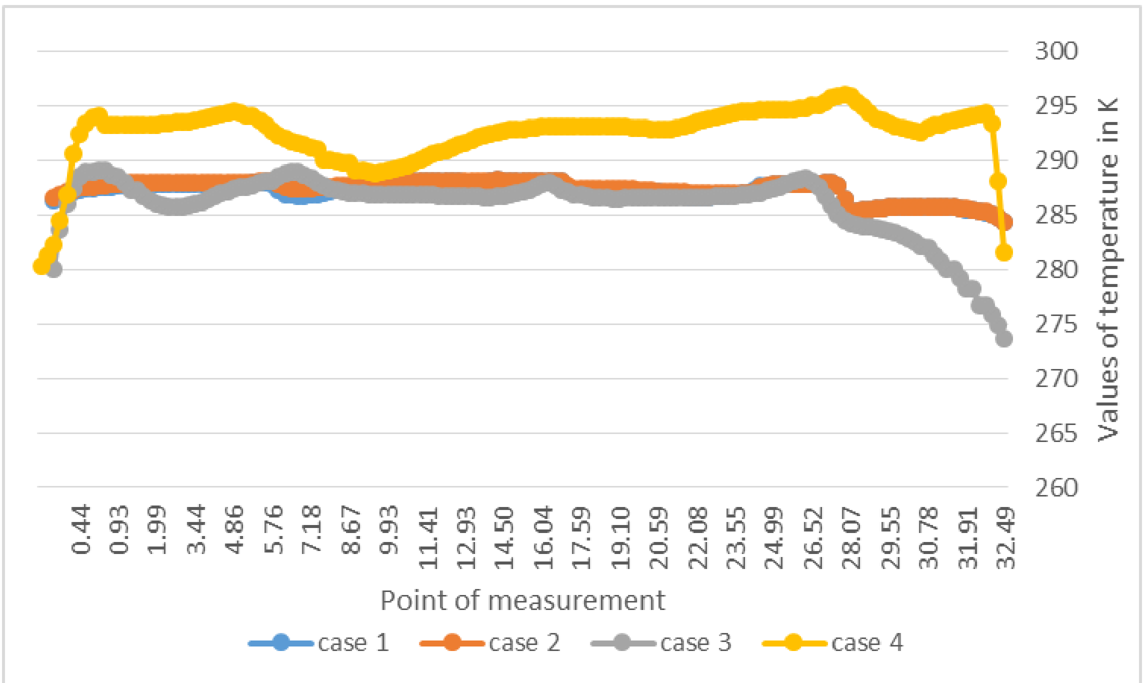
h = 1 m
h = 2 m
h = 10 m







Profiles of temperature at 1 m of the floor



Conclusions

- the solution of local ventilation in towers enhanced the evacuation of humidity and reduce the risk of condesation;
- in ocupational zone, the use of ventilation in towers does not affect the distribution of temperatures and velocities;
- with under floor heating system and static heaters, the use of ventilation in towers generates two recirculations of air below them which creates a gradient of temperatures raising towards the sides of the church;
- case 2 with heating air ventilation is the most appropriate for keeping the comfort parameters in the occupational zone.

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Thank you!