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RESEARCH REPORT No. 2

VENTILATION MODELS AND METHODS FOR PASSIVE HOUSES

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SUMMARY

LIST OF NOTATIONS

F	volumetric gravitational force, N/m^3
g	transmission factor of solar radiation, %
h	height work plan, m
n_a	refresh rate, h^{-1}
p	pressure, N/m^2, Pa
Q_e	exhaust air flow, m^3/h
Q_i	inlet air flow, m^3/h
$Q_{h,an}$	annual energy demand for heating, KWh/m^2 a
$Q_{pr,an}$	annual primary energy, KWh/m^2 a
S_u	useful surface, m^2
T_i	inside air temperature, K
T_{20}	inlet air temperature, K
u	air inlet velocity, m/s
U_{op}	envelope transmittance, W/m^{2}K
U_{win}	window transmittance, W/m^{2}K
U_{fl}	floor transmittance, W/m^{2}K
v_0	air layer limit velocity, m/s
$v_{1,2,3}$	air inlet velocity, m/s
$V_{1,a,dom}$	simulation domain volume without furniture, m^3
$V_{2,a,dom}$	simulation domain volume with furniture, m^3
μ	dynamic viscosity, Ns/m^2
ρ	density, kg/m^3
v	kinematic viscosity, m^2/s
Δt	difference temperature, K
λ	thermal conductivity, W/mK

LIST OF INDEXES

a	air
an	annual
dom	domain
e	exhaust
fl	floor
g	glazing
h	heat
i	inlet/inside
op	opaque envelope
pr	primary
rec	recovery
win	window

LIST OF ABBREVIATIONS

COV	Volatile organic compounds
CO_2	Carbon dioxide
CFD	Computational fluid dynamics
EPS	Expanded polystyrene
MV	Mechanical ventilation
MVHR	Mechanical ventilation with heat recovery
PHI	Passive House Institute
PVC	Polyvinyl chloride
SGG	Saint Gobain glass

INTRODUCTION

In the modern world in which he lives and works daily, man is in constant interaction with the environment. Under the diverse action of psychological and psychological physiological sources, he is constantly looking for complex technological solutions to "secure" the quality of the environment in which he develops his creative abilities.

Quality environment in which people operate complex has an influence on them, both in terms of hygiene and health and labor productivity.

The quality of the environment is appreciated by the thermal comfort parameters, chemical composition and air purity, as well as by other factors such as lighting levels, noise levels, air ionization degree, aesthetics, etc.

The nature and quantity of releases harmful, their propagation constructive system of the premises, the values that are prescribed parameters of indoor air for reasons of comfort or technology, the allowable limits that have low concentrations of various harmful substances released, plus many or with an important economic considerations have led to the use for a wide range of ventilation and air conditioning.

The concern to ensure the microclimate conditions appropriate to the specific work done by people or the nature of the technological process is a major requirement in the development of ventilation and air conditioning worldwide.

In the context of the requirements of the directives of the European organisms on the energy efficiency of buildings, which for residential buildings has become mandatory since the beginning of the current year, it is necessary to adopt ventilation solutions and strategies that meet these requirements.

Considering the criteria for assessing the energy performance of passive houses, ventilation is one of the centers of gravity of their meeting both as to ensure flow of fresh air to meet the quality requirements of indoor air hygiene and health of occupants and stability hygro-thermal treatment of the construction, and managing the contributions effectively the heat generated by the "sources" in the environment, (Van Dijken, 2011).

The systematic research has shown that passive houses for distribution of the fresh air in all working areas and a sufficient volume of air extracted in rooms with high moisture content is the most suitable ventilation system with heat recovery, thus providing fresh air to the living, working and sleeping rooms, (Passipedia, 2018).

These ventilation systems have very efficient heat recovery units that have been specifically developed for use in passive houses. This equipment has a distinct separation between the outlet and the fresh air flow, and requires only a small amount of power to operate, being extremely silent. Using efficient heat recovery, heat loss through ventilation will be negligible; between 2 and 7 kWh/(m^2a) (pre-condition for a passive house), (Passipedia, 2018).

Therefore, this type of fresh air heating is intended for space buildings with very low energy requirements (heat) - a defining condition for a passive house, (Feist, 2000).

The present paper focuses in the chapter I on the basic notions regarding the factors and conditions that influence the ventilation of the living quarters, the main types of ventilation systems with specific peculiarities.

In Chapter II are presented the models and methods of ventilation specific to passive houses, based on the concerns of scientific environments at international and national level.

Chapter III presents the results achieved in numerical simulations supported through a specialized application COMSOL MULTIPHISYCS on how to achieve centralized ventilation controlled for a range of board in a pre-certified passive house.

1. VENTILATION SYSTEMS

Ventilation systems are designed to provide thermal comfort indoors and maintain indoor air quality limits allowed on the whole life cycle of built space in order to maintain health occupants regardless of variation of meteorological factors, recesses and heat gains inside.

Ventilation is the introduction of the air from the outside, which is considered fresh (supply air/air discharged), having the role to retrieve the emissions in excess (gas, dust and fumes), humidity, and excess heat (by the intake air / air absorbed) and to evacuate to the outside (the air discharged), (***, 2010).

1.1 Sources of indoor air pollution

The factors that cause air pollution in the rooms the result of human metabolism, domestic activities and maintenance form a complex of several types of pollution agents, which together with excessive humidity are decisive factors for people's health.

Pollutants of indoor air can be classified according to the nature of the pollutant physical, chemical or biological and their origin their source of production, (***, 2010).

Table 1 summarizes the main pollutants that can be found in the living environment.

Table 1:The main agents of indoor air pollutants and their sources of production

Pollutants	Sources of production
SO_2, SPM/RSP (small particles / breathable particles)	Combustion processes, cigarette smoke, vapor condensation, dust particles in suspension
O_3	Photochemical reactions
Pollen	Trees, plants
P_b, M_n	Road traffic (exhaust)
P_b, C_d	Industrial emissions

COV, HAP (Volatile Organic Compounds, Polycyclic Aromatic Hydrocarbons)	Petrochemical solvents, vaporization of unfired fuels
NO_x, CO	Combustion of fuels
CO_2	Combustion of fuels, human metabolism (respiration)
Water vapor	Domestic activities (cooking, washing), evaporation from free water surfaces, human breathing
COV (Volatile Organic Compounds)	Volatilization, combustion of fuels, varnishes and paints, pesticides, insecticides, fungicides Adhesive materials, solvents, cosmetics, cooking
Spores	Mushrooms, molds
Radon	Soil, building materials, underground water
HCHO (Formaldehyde)	Insulating foams, finishing materials, cigarette smoke
Asbestos	Fireproofing materials, thermal insulation materials
NH_3	Cleaning products, domestic activities
HAP (arsenic, nicotine, acrolein)	Cigarette smoke
Hg	Fungicides, paints, leaks of non-sealed containers
Aerosols (dust)	Dust inside the house
Allergens	Dust inside the house, pet
Micro-organisms (microbes, viruses, bacteria)	Human / animal infections and airborne transport

1.2 Quality requirements of the indoor air

The indoor air quality of the occupied spaces, according to the provisions of the indicative normative I5/2010, shall be obligatory, by ventilation according to the purpose of the building, by the activity in the rooms, of the type of pollution sources presented above, (***, 2010).

1.2.1 Indoor air quality categories

According to the provisions of the Normative for design, execution and operation of ventilation and air-conditioning installations, indicative I5 - 2010, for the occupied spaces within the residential buildings are established four indoor air quality categories, presented in Table 2, (***, 2010).

Table 2: Indoor air quality categories (from SR EN 13779:2007)

Indoor air quality class	Description
IDA 1	High indoor air quality
IDA 2	Average indoor air quality
IDA 3	Moderate indoor air quality
IDA4	Low indoor air quality

For civil buildings where the main source of pollution is biofuel emitted by humans, the air quality in non-smoking areas is classified as the in-built carbon dioxide concentration above the outdoor concentration according to Table 3.

Table 3: Indoor air quality categories, based on CO_2 concentration above the level in the outdoor air (from SR EN 13779: 2007)

Category	CO_2 level above the level of the outside air, in ppm	
	Typical domain	Value through lack
IDA 1	≤ 400	350
IDA 2	400-600	500
IDA 3	600-1000	800
IDA 4	≥ 1000	1200

1.3 Classification criteria for ventilation systems

In according to Norm I5/2010, (***, 2010). ventilation systems can be classified based on the following criteria, (***, 2010).:

- energy source for air circulation;
- volume of ventilated space;
- Indoor / outdoor pressure regime;
- air exchange mode;
- the position of the inlet and outlet holes;
- the complexity of air treatment according to technological or comfort requirements

1.3.1 Energy source for air circulation

After the mode of air circulation in the room we have:

- *natural ventilation systems* - air circulation is made naturally through openings practiced in building elements, generated by the combination of wind speed or pressure difference due to temperature difference:
  - *unorganized*: - air penetration is achieved through leaks or joints between rooms or through uncontrolled openings of doors and windows (living quarters, offices, warehouses, small mechanical workshops;
  - *organized*: - air penetration/evacuation is accomplished by specially designed and dimensioned openings, which are located at certain heights for this purpose, windows, skylights, kitchen ventilation basins, bathrooms, industrial buildings that can be closed or opened as needed.
- *mechanical ventilation systems - air circulation is forced by fans:*
  - *simple* - requires only input and exhaust air often intermittent operation;
  - *combined* - also involves the treatment of the introduced air (by simple heating or cooling, drying or humidification processes, heat recovery) in order to limit the increase of the indoor air temperature during the summer period and to maintain an approximately constant temperature during the winter period.
- *mixed ventilation systems (hybrid):*
  - *mechanical introduction and natural evacuation;*
  - natural introduction (compensation) and mechanical evacuation.

1.3.2 Number of mechanical ventilation circuits

After the number of mechanical ventilation circuits there are:

- *mechanical ventilation systems - single-circuit (mono flow)*
  - insertion or evacuation by mechanical means
- *mechanical ventilation systems - double-circuit (double flow)*
  - insertion and evacuation by mechanical means

1.3.3 Internal - external pressure regime

The pressure difference between the inside and the outside of the ventilated room can generate:

- *overpressure ventilation systems* - supply air flow is greater than that of the exhaust air flow, the excess air flow being discharged naturally, specific to mixed ventilation systems with mechanical introduction and natural evacuation, rooms with insignificant releases of pollutants (conventionally clean rooms), rooms in the residential sector (living rooms, bedrooms) or non-residential offices, shops, classrooms, movie theaters;
- *under pressure ventilation systems* - supply air flow is smaller than that of the exhaust air flow, specific to mixed ventilation systems with natural introduction and mechanical evacuation, for dirty or wet rooms: toilets and kitchens for residential buildings and production halls for industrial buildings.
- *balanced ventilation systems* - the intake and exhaust air flows are equal.

1.3.4 Volume of ventilated space

Mechanical ventilation is diversified by:

- *general mechanical ventilation* – characteristic of rooms with general exhaust emissions and creates a uniform distribution of air in the ventilated space, in industrial, social - cultural, commercial, administrative buildings;
  - *local mechanical ventilation* - required for:
    - recesses concentrates pollutants acting on the source release, sucking air around the source of release of pollutant, taking harmful substances before they enter the room (ovens, tables welding bathrooms industrial galvanizing, pickling, grinders, machines
    - providing protection areas by creating air jets either at public entrances or for protecting people in the proximity of high temperature surfaces.

- *combined mechanical ventilation system* – is achieved by simultaneous local ventilation (to evacuate the locally produced emissions) and general (in order to ensure the quality of the ambient air).

1.3.5 Complexity of the thermodynamic air treatment

Depending on the complexity of the air treatment, we have:

- *simple ventilation* - no thermodynamic treatment (air filtering from outside with air filters)
- *ventilation with thermodynamic treatment* of the introduced air, which may be:
  - heated or cooled with heating or cooling batteries,
  - humidified or dry with cooling batteries, spraying with fine drops of water or steam.

1.4 Ventilation of residential buildings

To ensure the indoor air quality requirements and the hygro-thermal stability of buildings, residential buildings can be:

- ventilated by natural
- mechanical ventilation.

1.4.1 Natural ventilation

It's the simplest way of ventilating. The natural ventilation is realized by air circulation, through different openings practiced in building elements of buildings, under the effect of wind or natural draft (without mechanical action), (***, 2010).

Air freshening is done by opening the windows or through the permeability of construction elements to the passage of air; the air flow introduced will be minimal to eliminate heat losses through the exhaust air.

Natural ventilation systems are based on pressure differences to move clean air through buildings. Differences in pressure can be caused by the wind or the buoyancy effect created by temperature differences or moisture differences. In both cases, the quality of ventilation will depend critically on the size and location of the openings in the building elements. It is useful for a natural ventilation system to be thought of as a circuit, equally considering supplying and exhausting the air.

Natural ventilation is based on one of the following schemes, Figure 1.1.

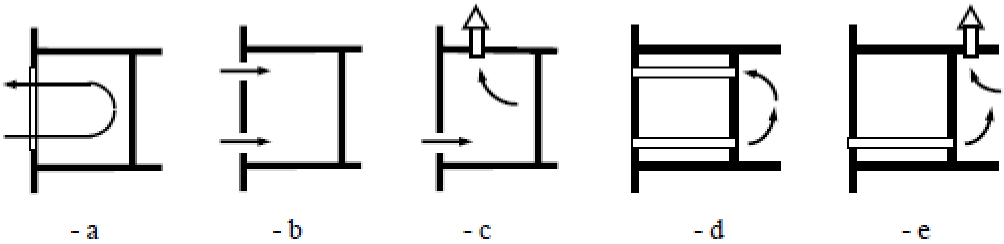


Figure 1: Methods of realizing natural ventilation

These can be:

a) ventilation by opening the windows - the air flow is random and intermittent,

b) ventilation through openings in the front of the enclosure - uncomfortable system of air flow is random and intermittently dependent on external atmospheric, conditions,

c) ventilation through the hole in the façade associated with vertical piping - uncomfortable system but can be improved if the air inlet is self-adjustable,

d) ventilation through horizontal tubing - it is difficult to lose loads through the tubing,

e) horizontal duct ventilation associated with vertical tubing - the best method ensuring correct ventilation.

1.4.2 Mechanical ventilation

Allows general and permanent ventilation with a fresh and stable air flow independent of atmospheric conditions, (***, 2010).

The main types of mechanical ventilation are:

1.4.2.1 Mechanical ventilation simple flow

In the case of the simple flow ventilation system, shown in Figure 1.2, the mode of ventilation is done as follows:

- fresh air is introduced exclusively into the main compartments (bedroom, living room) through self-adjusting inlet grilles with the role of attenuation of wind effects and constantly maintaining input flows,
- vicious air is discharged through the extraction holes located in the polluted premises (kitchens, bathrooms, toilets).

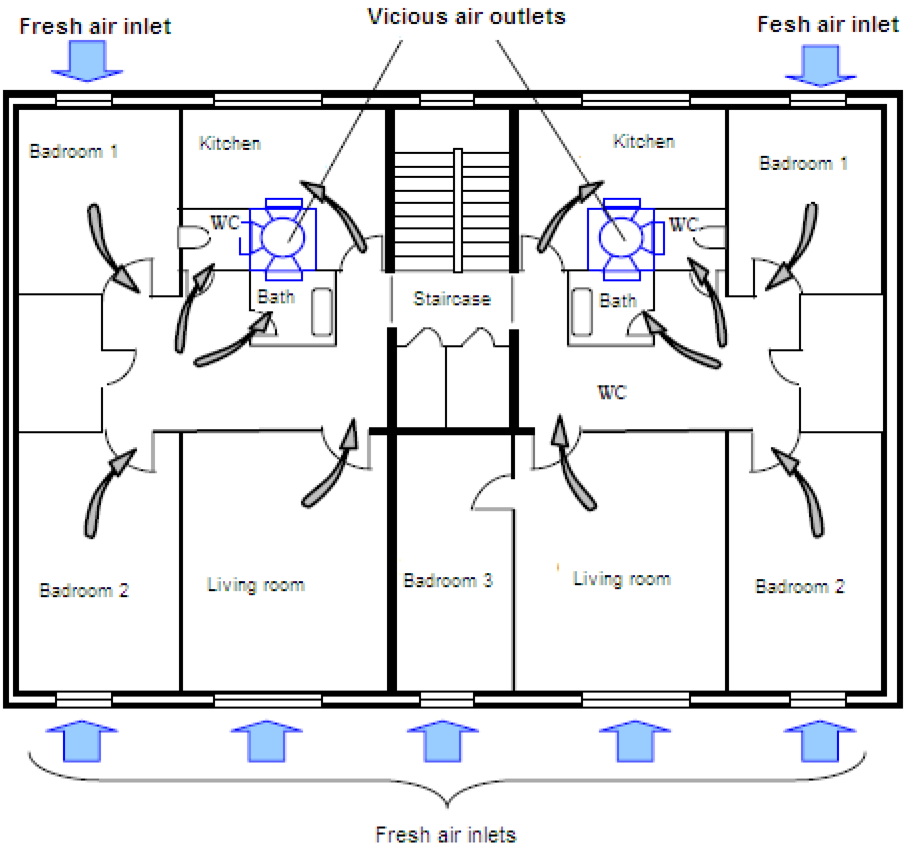


Figure 1.2: Schematic diagram of mechanical ventilation simple flow

For individual dwellings, the vicious air extractor is located in the bridge of the house or in the attic. In the case of collective dwellings (blocks) these chambers are placed directly or in specially arranged premises on the block terrace.

1.4.2.2 Mechanical ventilation double flow

It is the ventilation mode that satisfies the comfort level to the highest degree, providing various thermodynamic functions (heating, cooling, air conditioning).

This type of ventilation system, presented in the schematic diagram of Figure 1.3, is characterized by:

- input circuits of fresh air and exhaust air are parallel and serve multiple premises;
- the diffusion of air through the air inlets are placed in the wall or ceiling and connected to an air supply circuit by a pipe end provided with a flow control device,
- at the exit of the air inlet circuit, heating batteries are mounted on the air flow path of the diffusion zone (for recover heat from the exhaust air) or cooling (Δt = 8-13˚C, involving the doubling air flows and avoidance of cold air currents),

- in the case of office buildings and hotels, the batteries are mounted in expansion boxes fitted with flow control and terminal battery heating or cooling,
- the air humidity control is done through the ventilation system.

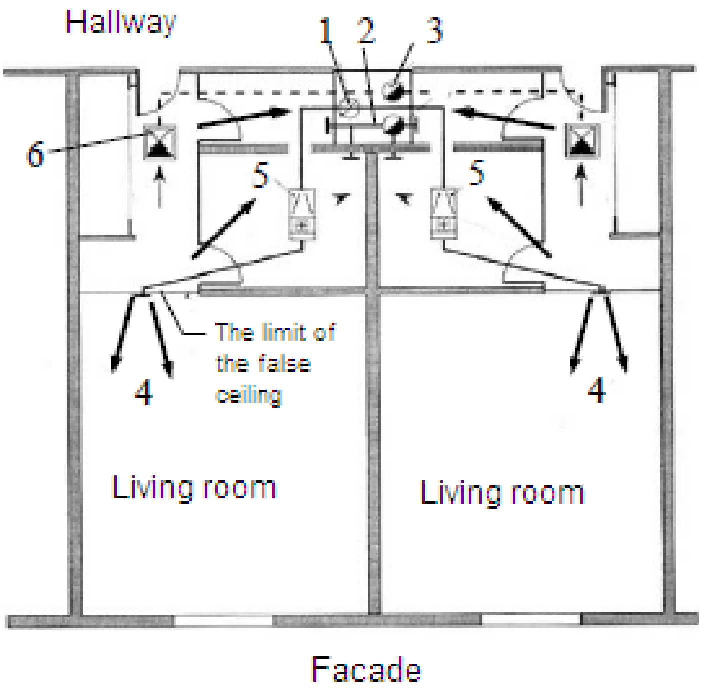


Figure 1.3: The principle of mechanical ventilation double flow (air conditioning)

1- fresh air inlet and recirculated air, 2 - sanitary extraction, 3 – comfort air extraction, 4 – diffusion, 5 - expansion boxes (with heat battery and variable air flow), 6 - take over comfort air

2. VENTILATION MODELS AND METHODS FOR PASSIVE HOUSES

Passive houses are constructive entities that, according to the design and execution criteria, require a series of structural and functional requirements for the validation and certification of energy performance. In addition to the requirements of orientation, shape, removal of thermal bridges, opaque envelope elements and energy-efficient glazing, elimination of infiltration between the tire elements, ventilation system is an essential condition, on the one hand to ensure the occupants' comfort and on the other hand for the preservation of thermal energy from the processes and domestic activities carried out by them, (Feist, 2005).

The methods of ventilation of passive houses are: passive (natural) and mechanical.

2.1 Passive ventilation methods

Ventilation systems based on passive ventilation methods specific to low energy houses, in this case passive houses, are:

- windcatcher natural ventilation system,
- adjustable ventilation systems.

2.1.1 Windcatcher natural ventilation system

The Windcatcher ventilation system is the most effective method of natural ventilation of buildings by capturing the predominant wind from any direction. Windcatcher system captures the fresh air on the roof and leads to the interior through the ventilation channels divided, specially designed for the simultaneous exhausting of exhaust air, regardless of the direction of air currents outside, Figure 1.4, realizing natural ventilation without energy consumption, (Jomehzadeha, 2017).

The temperature difference between outside and inside causes a difference in density and pressure. Due to this phenomenon, under normal atmospheric conditions, the indoor (heated) air rises to the ceiling and causes in interior to drop pressure, allowing fresh (cold) air to enter the room and push out the exhaust air, making natural ventilation.

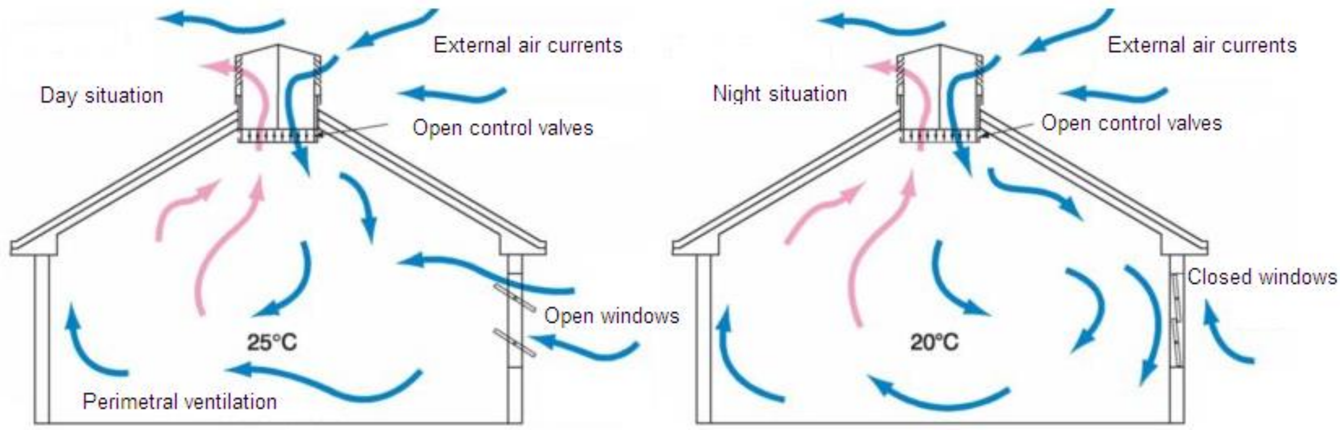


Figure 1.4: Windcatcher system. Circulation of airflows for day/night situations

Windcatcher systems have intelligent control system by means of air flow control valves controlled by the temperature and CO_2 sensors, adjusting the air flow rate according to these parameters. The systems can be controlled individually or by a central control panel which controls the automatic opening / closing of the control flaps depending on the date, time, and the signals received from the room sensors. Mural controllers offer the possibility of manual intervention by users at any time to meet their preferences, (KHAN, 2008).

One of the most important aspects of the natural ventilation strategy is night room cooling, called "night free cooling". Adjustment flaps can be programmed to open completely at a specific time of the night to allow cold and fresh air to enter the room with maximum flow. At a certain hour of the morning, they are programmed to close in order not to lower the indoor temperature below a limit value. Thus, users will find the well-ventilated interior space at an ideal temperature. The entire process is carried out without energy and the building safely.

WINDCATCHER systems have innovative technology that allows the ventilation flow to be controlled at roof level and prevents infiltration of rainwater and snow inside the ventilation system. It contains an external set of static grids and an internal set of active grids that are lowered or raised to vary the opening surface according to the control strategy. Active grids can be opened to allow maximum flow ventilation or can be completely closed to control rain sensor to prevent ingress of rain or snow.

Advantages of the Windcatcher natural ventilation system are:

- zero energy by using outdoor air currents, free and inexhaustible source,
- effective capture of fresh air regardless of direction of outdoor airflow,

- free night cooling by programming control valves to operate during the night so that occupants morning to find enough inside space ventilated and an ideal temperatures;
- permanent ventilation of the inside space in complete safety, without any risk of intrusion;
- efficient operation indifferent if the windows are closed or open;
- control and total protection against rain and snow;
- comfortable airflow speeds inside, ensuring occupant protection and health;
- removal of SBS syndrome (sick building syndrome) specific to the climate;
- multiple possibilities for automatic and manual control;
- possibility of integration with natural lighting in a single system, that realized simultaneously natural ventilation to the inside.

2.1.2 Adjustable hygro ventilation system

The basic criteria for evaluation indoor air quality are:

- CO_2 level - low interest rate from economic reasons,
- hygrometric - extract air flow depends on the degree of humidity from air (the humidity level notified); specialized measuring sensors which control the air extraction system.

Hygro-adjustable ventilation system is based on the principle of transit control section that controlling the air flow by turning the air intake grilles for fresh air and exhaust the polluted air by means of detection and control elements (sensors). In other words, the principle of this type of ventilation is to establish the dependence between the air flow input and one or more parameters that characterize the ambient air status of the enclosure that reflects the occupancy degree and the type of activity that takes place in this space. This system allows continuous and proportional adaptation of the fresh air flow rate depending on these pollutants to effectively eliminate them, (Lu, 2011).

This system optimizes air flow, which is directed with preference to living rooms, leading to a fresh air in these spaces, preserving the energy stored in unoccupied rooms, (Nassif, 2012). In Figure 1.5 are presents distributions air flow for ventilation hygro adjustable controlled for day and night periods.

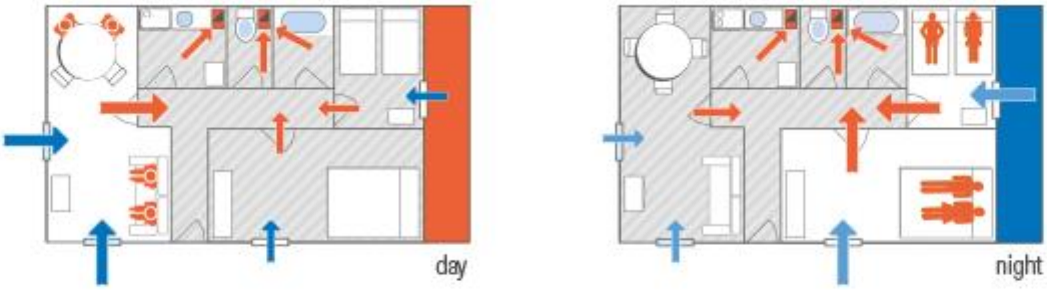


Figure 1.5: Circulation of airflows in the building for day and night periods

Controlling air flows by actuating the hygro-adjustable grid flaps can be done by means of sensors that can react to different pollutants:

- sensitive hygro - air flow is controlled according to the relative humidity near the area where the grid is mounted,
- manually or remotely, at the user's request to eliminate moisture or unpleasant odors,
- presence detector - automatic flow increase when there is a presence of person in the room,
- CO_2 or VOC sensors - Airflow control based on CO_2 or volatile organic compounds (VOC).

Advantages of hygro-adjustable ventilation system, (Zuckera, 2017):

- ensure indoor air quality,
- reduce the risk of condensation,
- reduce energy losses through ventilation,
- reduce and controls energy consumption for heating.

2.2 Mechanical ventilation methods with heat recovery

Mechanical ventilation systems with heat recovery are of two types, (***, 2010):

- *decentralized*: serving a single room; is mounted in the exterior wall of the respective room, with:

  - <u>*one flow*</u>: (ceramic recovery, alternating flux), relative recently appeared, highly performing and reliable: have a single fan and a single tube that crosses the wall; the fan changes its alternate meaning over a certain time interval (tens of seconds); for 70 seconds he removes warm and vicious air by heating the built-in heat exchanger; then another 70s will draw fresh air out through the same heat exchanger, which will cool out yielding the heat of the introduced air;

- <u>double flow</u>: implies the existence of two fresh air intake ways and fully-equipped vicious air outlet and a cross-flow heat exchanger, for sensible and latent heat recovery from exhaust air and transfer them to fresh air introduced.

- *centralized*: serve the whole building; have a HRVU (Heat Recovery Ventilation Unit) located in a bridge, cellar, or a technical room and a network of exhaust/intake air channels; in general, require the evacuation of vicious air from "wet" rooms (from bathrooms and kitchens) to the ceiling, and the fresh air intake is done in the rooms occupied by the bottom; requires door transfer grids or transfer color for air circulation between rooms.

2.2.1 Single flow decentralized mechanical ventilation system

The single-flow mechanical ventilation system has as a principle the operation of a flow of air through a ceramic heat exchanger through which an alternating air flow circulates by alternately changing the rotation direction of the fan over a period of time (tens of seconds). In a defined time interval, the ventilator will extract and evacuate the hot air and stale, which will give the heat of the heat exchanger built-in, and will draw fresh air filtered from the outside will pass through the same heat exchanger, and which will be cooled by yielding the accumulated heat to the fresh air introduced, (Kim, 2015).

Control of the air flow by adjusting the fan speed is achieved by means of information received from sensors of temperature, humidity and light, the environmental conditions. Due to the reverse flow of air generated by alternately change the direction of rotation of the fan, to ensure frost protection system does not require the presence of an additional protective element (electric resistance), being very efficient at temperatures of -20 °C, (Manz, 2000).

In Figure 1.6 are presents the components of this decentralized mechanical ventilation system.

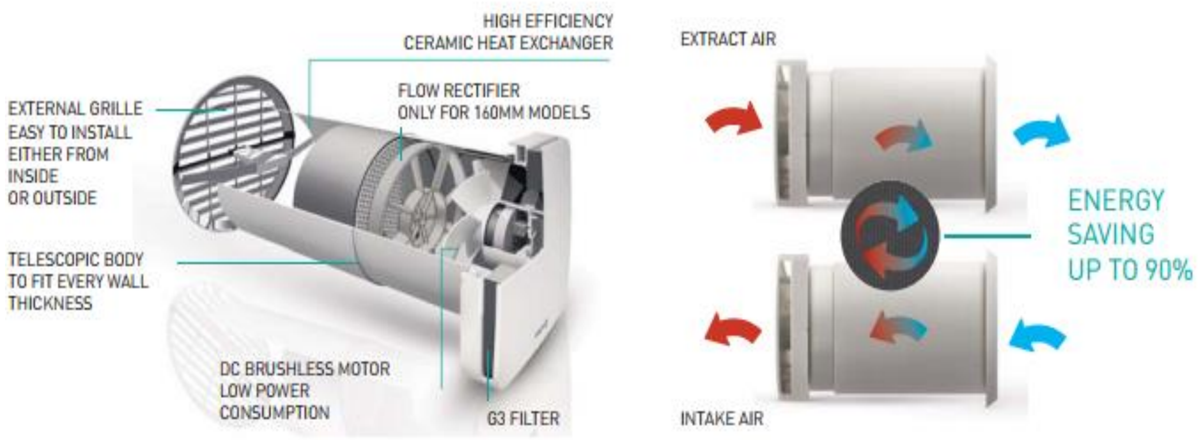


Figure 1.6: Single flow decentralized mechanical ventilation with heat recovery

2.2.2 Double flow decentralized mechanical ventilation system

The dual-flow decentralized ventilation system provides a local room ventilation, serving a single room, through circulation the flows of air introduced / discharged into overpressure. Thus the fresh air flow rate is higher by 8-10% than the extraction and exhaust air flow rate.

The ventilation system has built-in a countercurrent heat exchanger through which the exhaust air from the room gives off the heat of cold air and freshly taken from the outside, through the walls of the heat exchanger, keeping a room temperature regime while maintaining an optimal humidity level. The system works without filters with potential for contamination.

Given the very high thermal conductivity of copper of 399 W/mK, the heat recovery can be a heat recovery yield of 92%, achieving substantial energy savings of 30% in winter and 70% in summer.

For the cold season, the system can also preheat the introduced air through an integrated electric receiver within the recovery. Due to the natural antiseptic properties of copper (similar to silver) within the heat exchanger creates an environment that provides air decontamination, where viruses, bacteria and microbes lose their viability.

In Figure 1.7 is presented the mode how is realized of the circulation airflows introduced / evacuated inside the heat recovery unit.

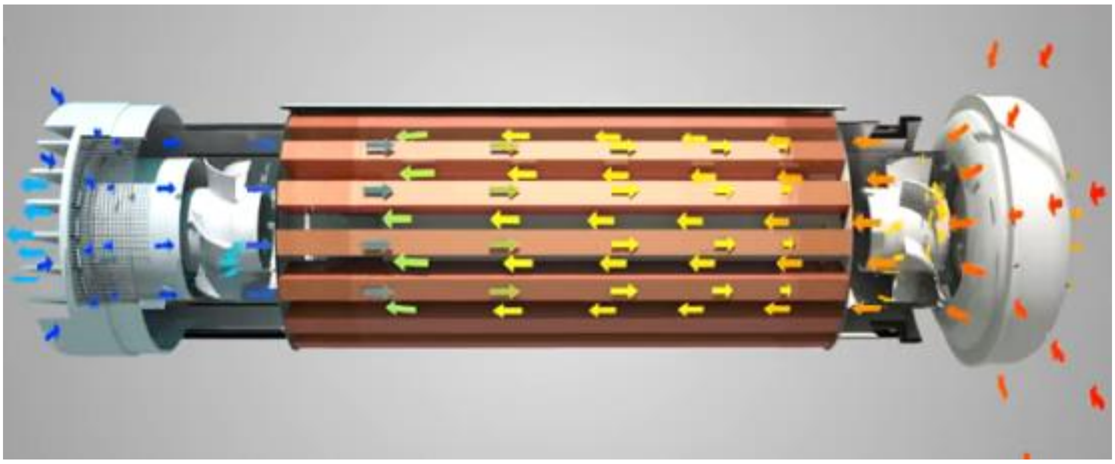


Figure 1.7: Circulation of airflows within the heat recovery unit

In Figure 1.8 is shown how to realize the circulation of introduced / evacuated airflows into the ventilated room.

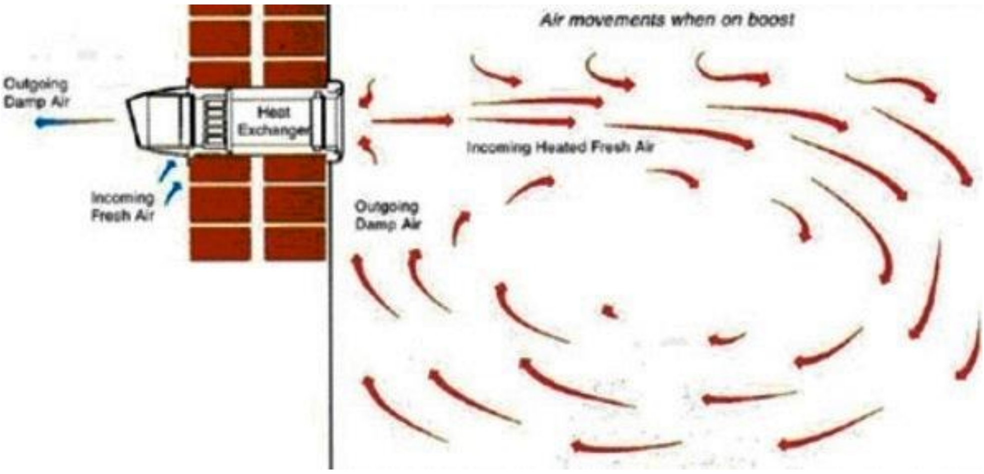


Figure 1.8: Circulation of air flows in ventilated space

2.2.3 Double flow centralized-controlled ventilation

Improved air tightness systems and mechanical ventilation systems are considered vital elements of low energy strategy in passive houses. Mechanical ventilation (MV) has become part of the thermal energy optimization model due to its ability to provide the recommended air change levels without depending on the daily active control of residents or uncontrolled air leakage. Double mechanical ventilation systems with heat recovery flow on the one hand ensures the evacuation of stale air and the other the introduction of a continuous flow of fresh air for improving the quality of the indoor air at the same time with the recovery of the heat from the waste-exhaust air and its transfer to the fresh air introduced into the room, (Jensen, 2008).

Also, the continuous introduction of fresh air ensures the air and microclimate conditions corresponding to human activity, and prevents too high a concentration of pollutants (CO_2, VOC, etc.). Ventilation also allows the avoidance of humidity problems that can lead to occupant health damage and condensation degradation of building elements. The advantage of using a ventilation system is the daily comfort, the fresh air that is permanently introduced inside, the rapid dissipation of odors, the much lower dust concentration, (Kamendere, 2015).

Avoiding the opening of the ventilation windows also allows the noise level to be reduced from the outside of the building (traffic in particular). During the warm season, ventilation directly contributes to dissipating the heat that accumulates during the day inside the building.

The double-flow mechanical ventilation system with heat recovery is presented in Figure 1.9.

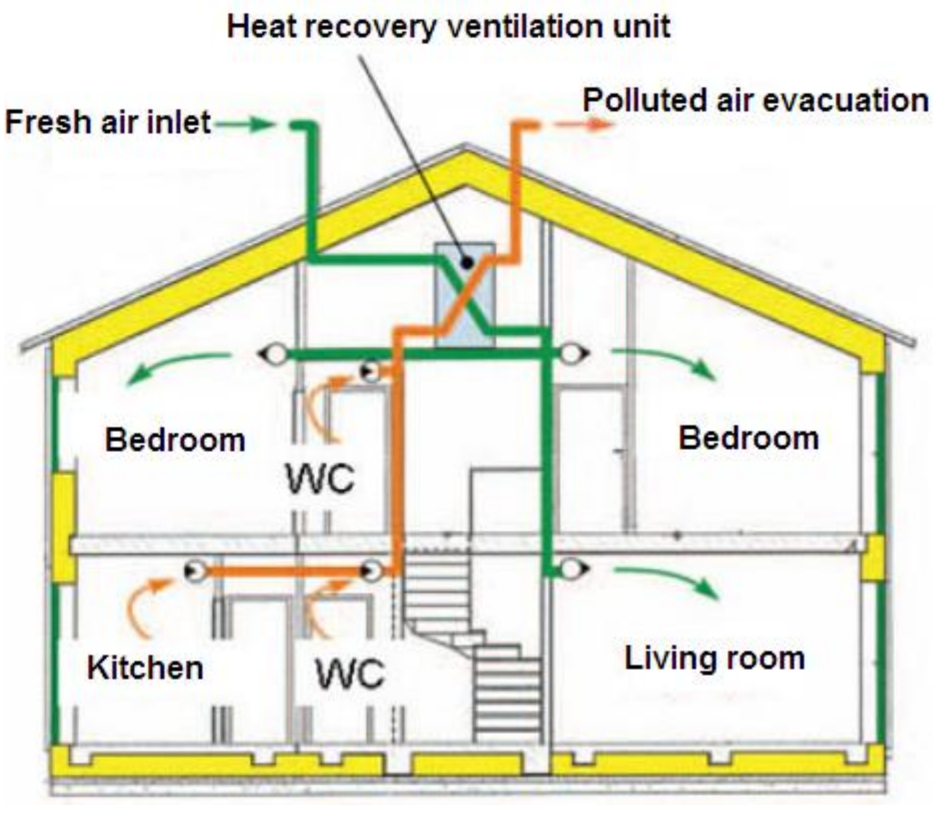


Figure 1.9: Schematic diagram of double-flow mechanical ventilation (with heat recovery)

To control the direction of air movement, fresh air supply will be made into "dry" rooms (living rooms, bedrooms), while evacuation of vicious air will occur where air pollution is more present, in wet areas (kitchen, bathroom, toilets) or service hallways.

Between the inlet doors and the exhaust devices, the air circulates through the "transfer openings" (grids) positioned at the doors or walls, Figure 2.0.

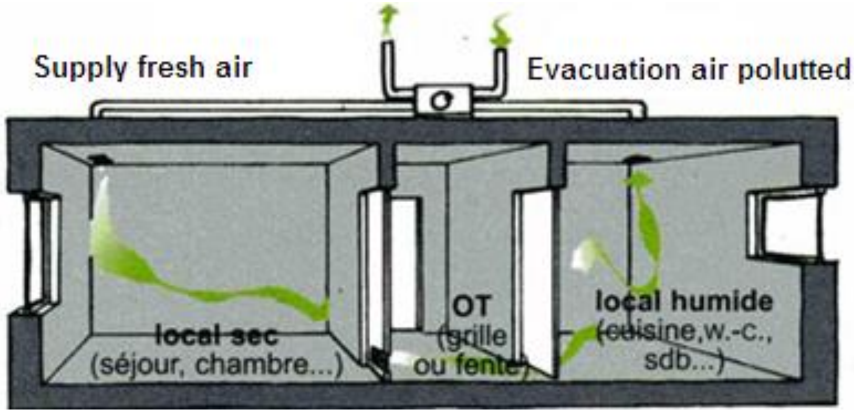


Figure 2.0: Circulation of air flows inside the building
(double-flow mechanical ventilation heat recovery unit)

The pressure difference between dry areas in overpressure and wet areas in depression ensures a constant airflow in the desired air circulation direction. Avoid unpleasant smells being taken from the kitchen or from the bathroom to the dining room or bedrooms.

In generally, the recommended heat recovery is a plate heat exchanger (countercurrent), fig. 2.1, the efficiency of the heat recovery device must be between 80 - 95%.

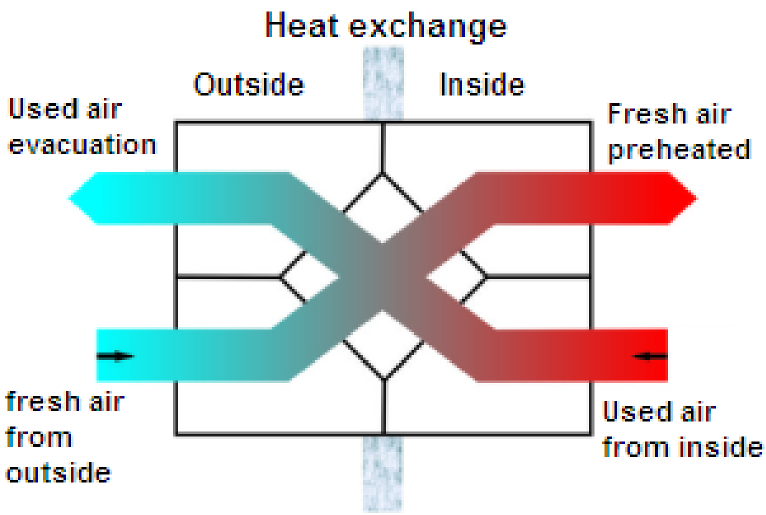


Figure 2.1: The schematic diagram of the heat recovery

For energy efficiency of the entire complex system of centralized ventilation and production of passive house utilities, it can integrate various equipment based on various technologies to exploit renewable energy sources (heat pumps, solar panels, photovoltaic panels), for heating / cooling passive/active with thermal energy storage (buffers), usually using domestic hot water working agent, or systems that have components transfer stored energy from renewable with massive environments with high thermal properties such as system "Canadian well" mainly used for passive cooling.

Figure 2.2 presents the schematic diagram of such an integrated complex system of centralized ventilation and production of passive house specific utilities.

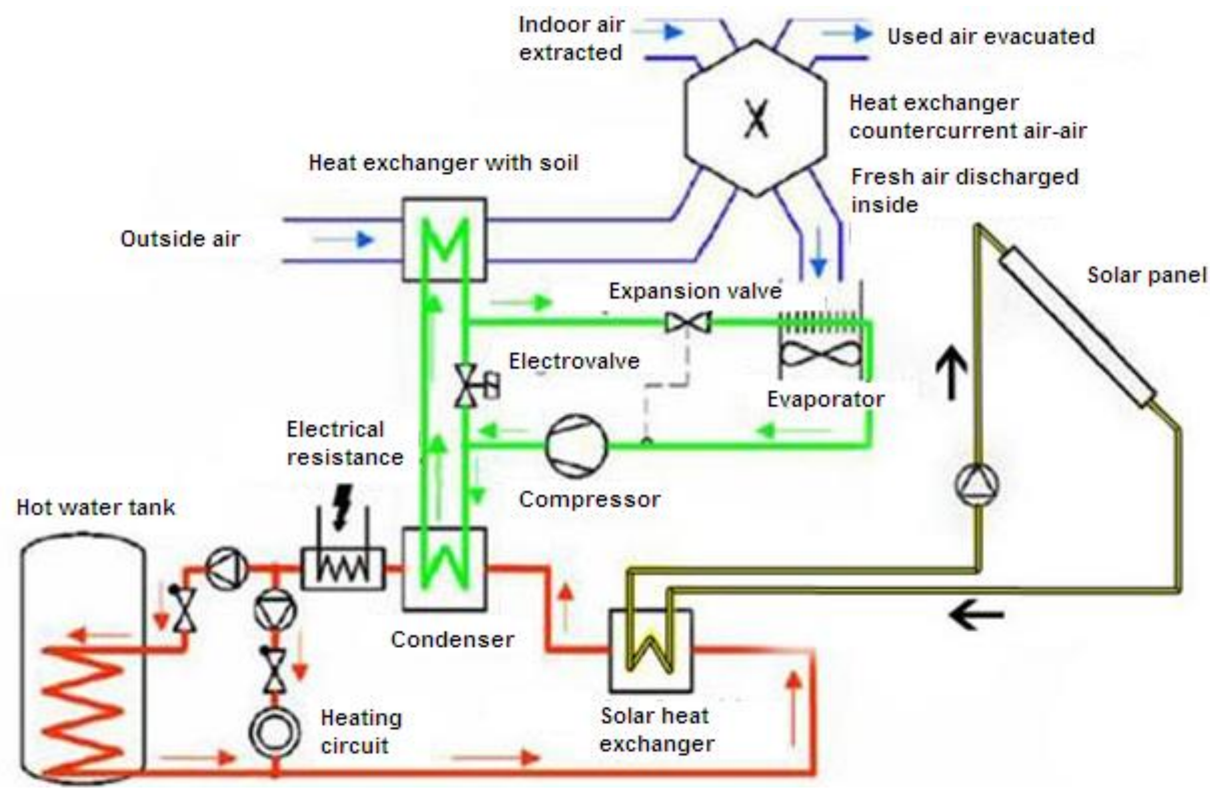


Figure 2.2: The schematic diagram of the integrated system of passive house installations

3. CASE STUDY

In the case studied, was analyzed the distribution of air currents having as object a single-family dwelling located in Cluj Napoca, street, Vânătorului, no. 31, Figure 2.3., which was obtained in advance precertification by passive house after preliminary tests conducted by specialists PHI (Passive House Institute- Darmstadt, Germany), at this moment in the phase of working.

Figure 2.3: Situation plan for the analyzed property

Considering the quality of the passive pre-certified house of the real estate in the case study it was proposed to follow the way of realization of centralized controlled ventilation more precisely the distribution of fresh air flows and evacuated exhaust air through a CFD simulation (Computational Fluid Dynamics), through the specialized software COMSOL MULTIPHISYCS.

3.1 Building description and facilities

The building is an individual dwelling with the useful surface $S_u = 276m^2$. In terms of constructive although initially was provided in draft resistance concrete structure was adopted constructive solution made of polystyrene formwork filled with concrete monolith. At the exterior finish of the building were used materials with different textures, thus: to ground floor dominate stone and plywood, upstairs walls facing south and north are covered with wooden rods placed horizontally, and aluminum-painted carpeting in anthracite gray appear as small accents on the facades.

The large glazed surfaces, which are mostly oriented to the south, ensure both the required solar input and natural light, while reducing visual barrier between inside and outside. The reduced number of gaps on the main façade from the north reduces heat loss and gives privacy to the occupants.

In the cross section of the building, in Figure 2.4, can be seen the characteristic parameters of building envelope components, as follows:

- *exterior walls* **-** stratification: decorative plaster 5 mm, EPS QL Panel 108 mm, EPS QL Plus panel 102 mm, 150 mm reinforced concrete diaphragm, EPS QL Panel 57 mm, 10 mm clay plaster, U_{op} = 0.128W/m^{2}K,
- *floor* - stratification parquet 8 mm, 5 mm layer picture, Dig Army 50 mm, 50 mm EPS, piece with reinforced concrete formwork elements EPS, mineral wool 50 mm, 12.5 mm plasterboard floor, U_{fl} = 0.125 W/m^{2}K,
- *frame* - PVC Rehau Geneo PHZ, U_f=0,79 W/m^{2}K
- *glazing*: SGG 4+20+4+20+4 cu Argon 90%, U_g =0.51 W/m^{2}K, g = 50%.

In order to establish the energy performance of the building, preliminary tests by PHI experts showed that the annual energy demand for heating is $Q_{h,an}$ = 12 kWh/m^2 a, and the required annual primary energy is $Q_{pr,an}$ = 58 kWh/m^{2}a.

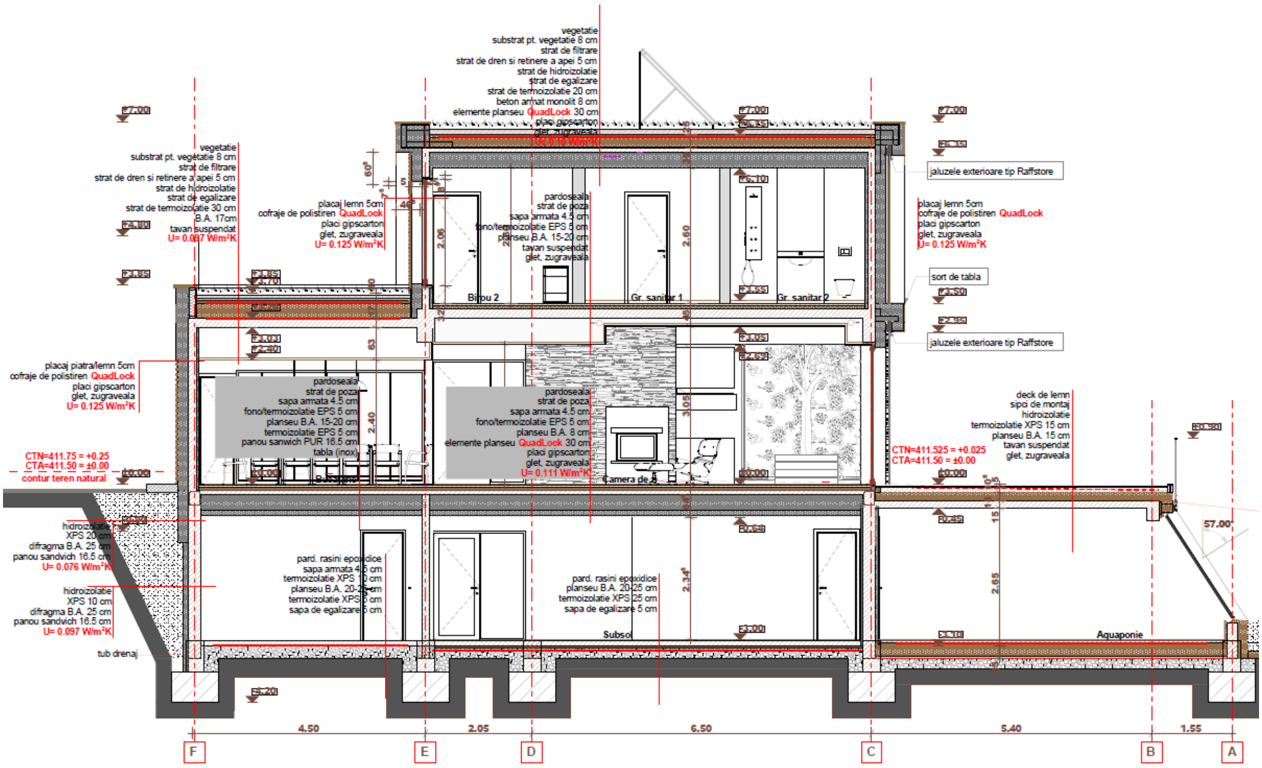


Figure 2.4: Characteristic section of the building

In winter, the demand for heating the passive house will be achieved by means of a fireplace located in the living room with an air-to-air heat exchanger and during the transit and summer periods the demand for domestic hot water with the help of the solar panels placed on the green roof. Hot water will be stored in two hot water tanks located at the basement.

The heat recovery ventilation system, Figure 2.5, will provide fresh air that will be preheated both in summer and in winter by means of a closed loop geothermal collector.

The closed-loop geothermal collector system is a horizontal serpentine made of a polyethylene pipe located at a depth of approximately 4 meters connected to the heat exchanger ventilation system.

Figure 2.5. Integrated installation system

The ventilation system has the following features:

- volume flow rate of the air ventilation unit: 50-320m^3/h,
- recovery rate - heat exchanger: 84% > 80%,
- electricity demand: 0.31Wh/m3 < 0.45Wh/m^3,
- noise level 28dB(A) < 30dB(A).

3.2 Domain of simulation

In order to facilitate the running of the application, a computing/work area was selected from the passive house architecture plan, located on the ground floor of the building, which is the domain of simulation, shown in the Figure 2.6, resulting in two distinct situations for which the volume of the simulation domain analyzed is:

- without furniture, $V_{1,dom}$ = 278mc;
- with the furniture proposed by the architect, $V_{2,dom}$ = 271mc

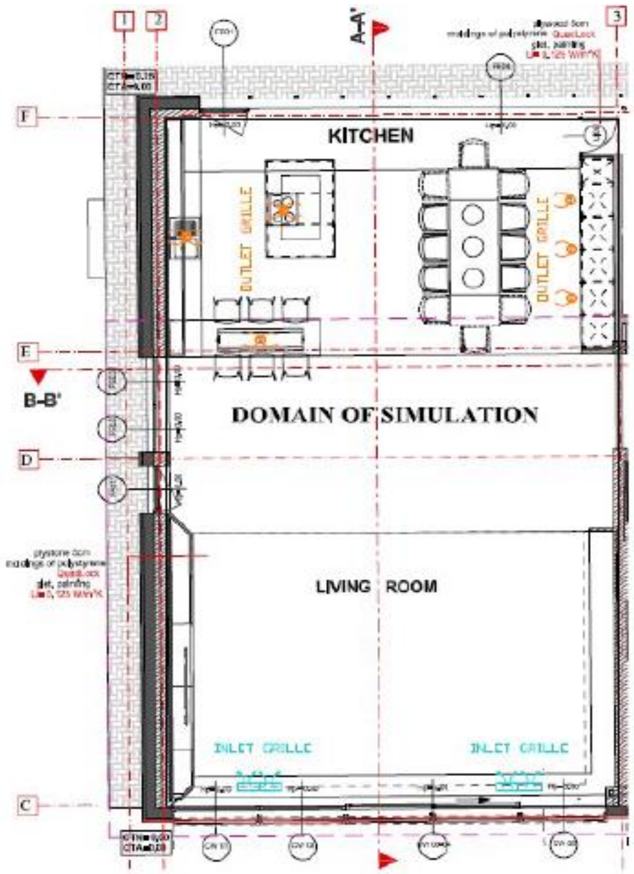


Figure 2.6: The domain of simulation

Prior to running the numerical simulation, were determined the thermo physical properties of the fluid environment of the computing domain, considered dry air, with the following parameters:

- temperature, T_{20}=293,15 K,
- density, ρ_{air}=1,205 Kg/m^3,
- kinematic viscosity, v_{20}=18,12 m^2/s,
- dynamic viscosity, μ_{20}=15.1 Ns/m^2,
- pressure, p=101325 N/m^2

3.3 Conditions of uniqueness

Limit conditions have also been set as follows:

- NO SLIP – air adherent to wall, v_0 = 0 m/s,
- refresh rate of air, n_a=0.6 h^{-1},
- exhaust grilles were considered open boundary,
- the inlet volume flow is equal to the outlet volume flow – balanced ventilation, (Q_i=Q_e, m^3/h),

- NO SLIP – the air layer is in contact with the surface of the wall – is

For this study inlet boundary conditions, we simulated three cases, imposing three values of the inlet speed:

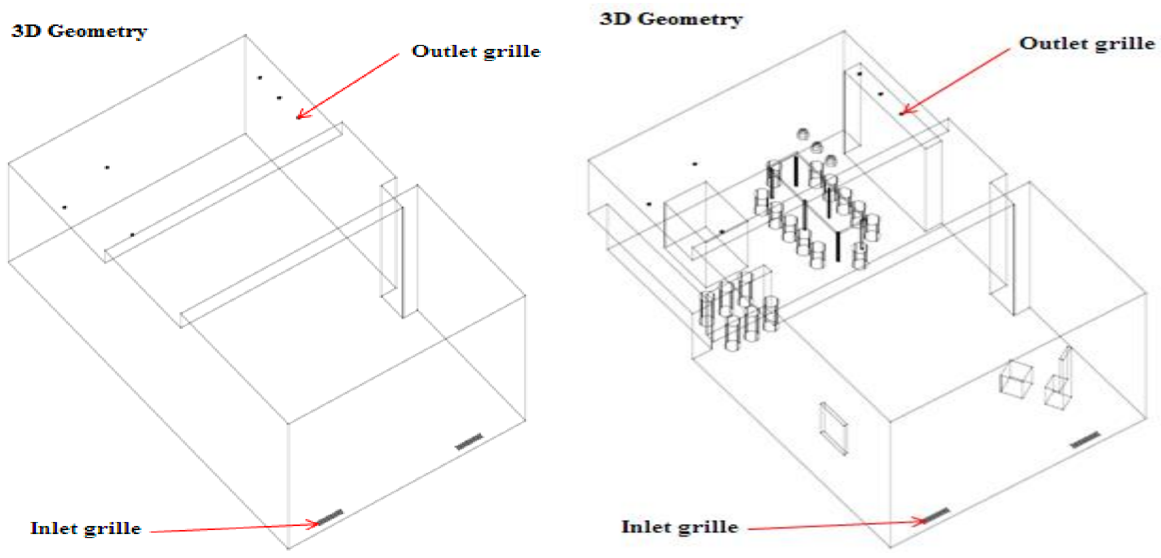
- Case 1 – (v_1 = 0.1m/s, Q_i= 86 m^3/h),
- Case 2 – (v_2 = 0.2m/s, Q_i= 172 m^3/h),
- Case 3 – (v_3 = 0.5m/s, Q_i= 430 m^3/h)

3.4 Simulation of model

Based on the data taken from the site and the architecture of the passive house, was defined the geometry of the model (study) subjected to the simulation, resulting in the AUTOCAD application construction of the models from Figure 2.7.

In the computational domain, the locations of the fresh air intake and exhaust air were placed according to the data taken from the site as follows:

- fresh air inlet grilles are positioned in the finishing layer of the living room floor at a distance of 30 cm from the wall, located on the south side of the building,
- the outlet air grilles are positioned in the kitchen space above the food preparation equipment (stove/electric hob), where significant releases of CO_2, VOC, and high relative humidity occur above the dishwasher and meal places areas.



a) b)

Figure 2.7: 3D Simulation model

a) without furniture, b) with furniture

3.5 Generating nodal network

Numerical modeling and numerical simulation of air flow through the simulation domain was achieved using the COMSOL MULTYPHISICS application, version 3.5a, Figure 2.8.

Figure 2.8: COMSOL MULTYPHISICS software, version 3.5a

This application provides easy to use interfaces, algorithms for the efficient calculation, possibility of controlling the generation of complete nodal network and development environment for modeling the physical account for completely described of the coupled differential equations, (***, 2018).

The model is built quickly due to a large number of predefined physical interfaces, from fluid flow and heat transfer to mechanical and electromagnetic analysis. Material properties, sources and boundary conditions can be freely defined as variable functions.

In the case study, in order to simulate the flow of air within the simulation domain, for the realization of the nodal network was used the turbulence module k-Ɛ, which has as equation of movement the Navier-Stokes, of the form equation 1, (***, 2006).

$$\rho\frac{\partial u}{\partial t} - \eta\nabla^2 \mathrm{u} + \rho(u * \nabla)\mathrm{u} + \nabla_p = F, \nabla * u = 0 \quad (1)$$

where: η – dynamic viscosity, Ns/m^2,

ρ – density, kg/m^3,

u – velocity, m/s,

p – pressure, N/m^2,

F – volumetric – gravitational force, N/m^3

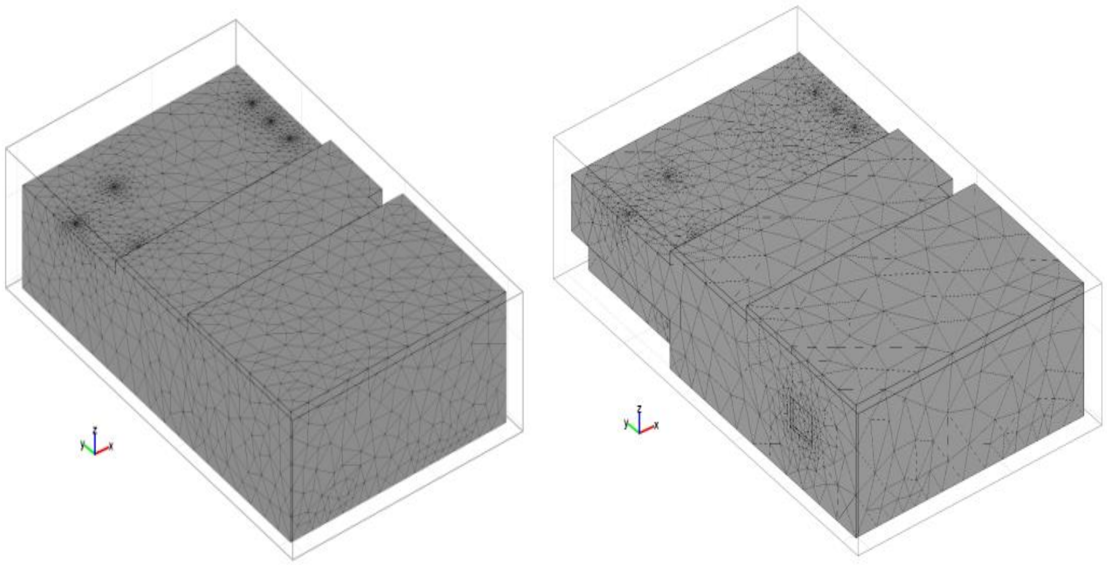
Preliminary to the computerized simulation of the flow of the working fluid, the simplifying working hypotheses were established, as follows:

- stationary regime,
- Newtonian incompressible fluid (speeds, low pressures - no compressibility factor),
- mass forces are neglected (there are no pressure differences determined by the gravitational field
- constant temperature,
- isothermal jet, (the introduced air has the same temperature as indoor air, $T_{20} = T_i$),
- adiabatic system (there is no heat transfer but just impulse),
- no internal heat sources.

3.6 Discretization of the simulation domain

For the discretion of the simulation domain, the finite element method was adopted, characterized by the fact that a certain virtual domain is subdivided into a number of finite elements, subdomains of variable size and shape that are interconnected by a discrete number of nodes.

The mode of dividing the simulation domain is uneven, the finite elements of the nodal network having the form of linear tetrahedron, it has a higher density of nodal network elements near the delimiting areas of the simulation domain, as shown in Figure 2.9.



a) b)

Figure 2.9. 3D Nodal network of simulation domain

a) without furniture, b) with furniture

After meshing the computational domain, a finite number of elements resulted, as follows:

- 24089 elements – in the case without furniture,
- 34497 elements – in the case with furniture.

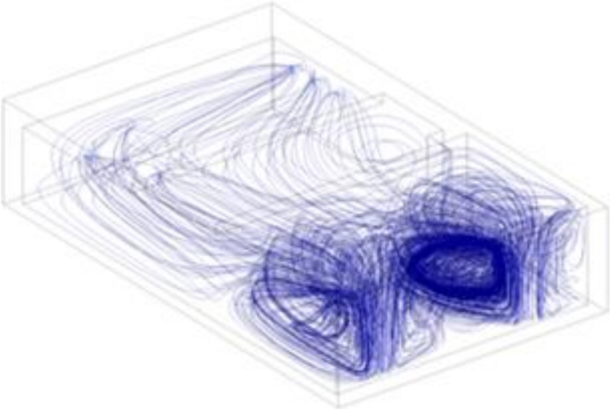
3.7 Results and discussions

By means of computerized simulation on the behavior of the working fluid through the simulation field for the two analyzed situations, with or without the presence of the furniture, under the conditions of the fresh air jet velocities introduced with the imposed values of 0.1, 0.2, 0.5 m/s, the behavior of the air flow was materialized through the below aspects:

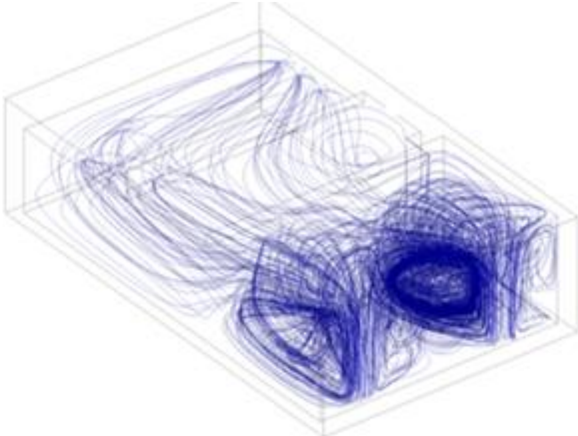
- **qualitative** distribution: the stream lines and the velocity vector,
- **quantitative** distribution: velocity contours.

The qualitative highlights of the flow of the working fluid through the distribution of the current lines, without the presence of the furniture, is shown in Figure 2.10.

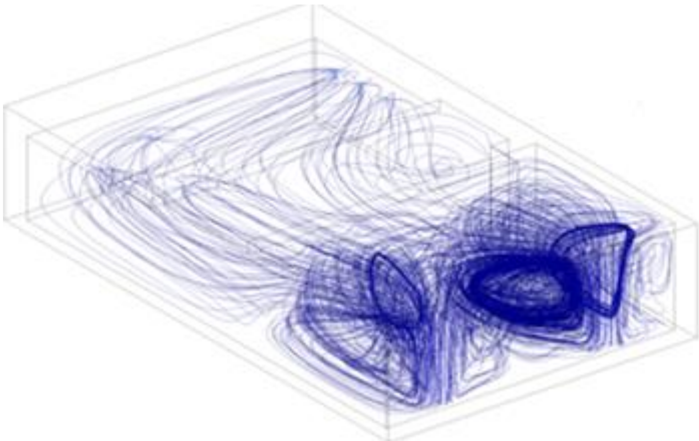
When fresh air is introduced, it can be noticed that a turbulent air movement is generated in the adjacent area of the inlet grids, generated by passing the air jet at a rate of 0.1, 0.2, 0.5 m/s through the inlet grids. Upon exiting the turbulence zone, the air streams uniformly "wash" the other two sections of the simulation domain, freely orienting towards the suction and exhaust air grids.



a)



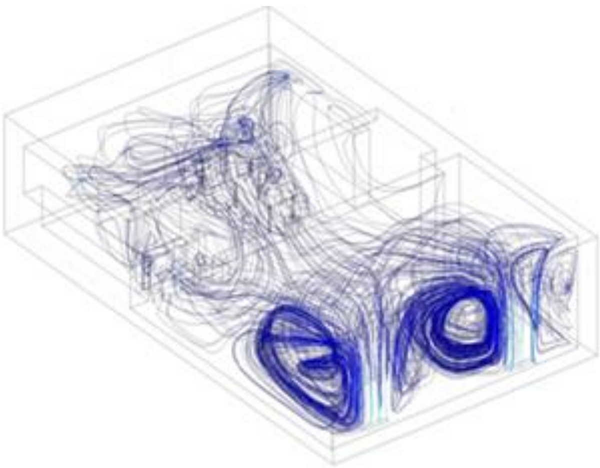
b)



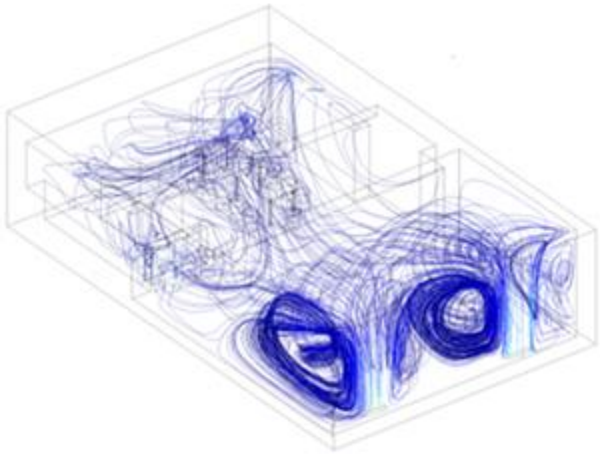
c)

Figure 2.10: Distribution of stream lines, without furniture
a) v_1 =0.1m/s, b) v_2 =0.2m/s, b) v_3 =0.5m/s

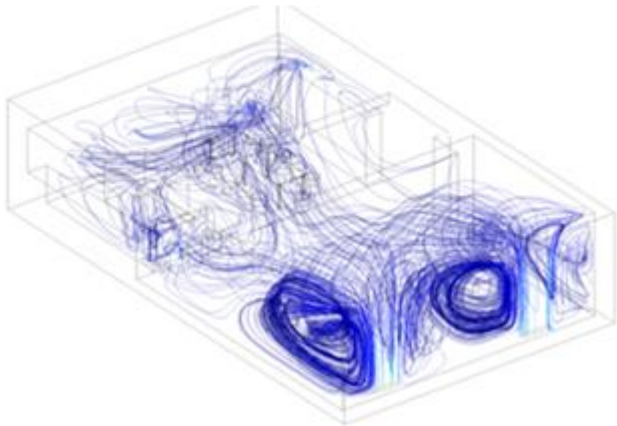
In the presence of the furniture proposed by the designer, the distribution of air currents materialized by the distribution of current lines shows as in Figure 2.11.



a) .



b)



c)

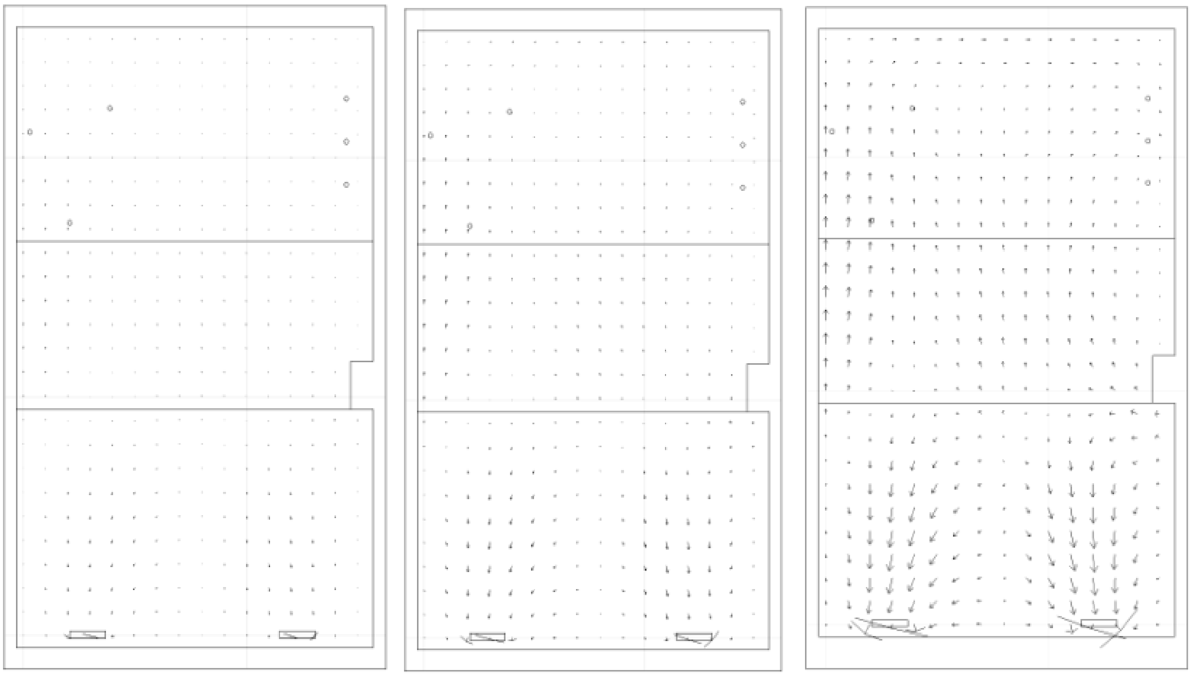
Figure 2.11: Distribution of stream lines, with furniture

a) v_1 =0.1m/s, b) v_2 =0.2m/s, b) v_3 =0.5m/s

In this case it is observed that in the area of the inlet grids the turbulence of the configuration air currents is slightly different in intensity from the previous case, and it can be noticed that in the kitchen area there is an uneven distribution of the stream lines due to the presence of the furniture in this space.

The second aspect of qualitative evaluation of the flow of working fluid through the simulation field, presented for the two variants analyzed (with or without furniture) considering two characteristic horizontal sections, located at 0,8m and 1, 2m from the floor.

In the images presented in Figure 2.12 it is observed that in the horizontal section located at 0.8 m from the floor, which coincides with a work plan specific to the activities performed by the occupants in the seated position, when the speed of fresh air is increased the velocity vectors are becoming more and more visible, occupying the whole analyzed space.

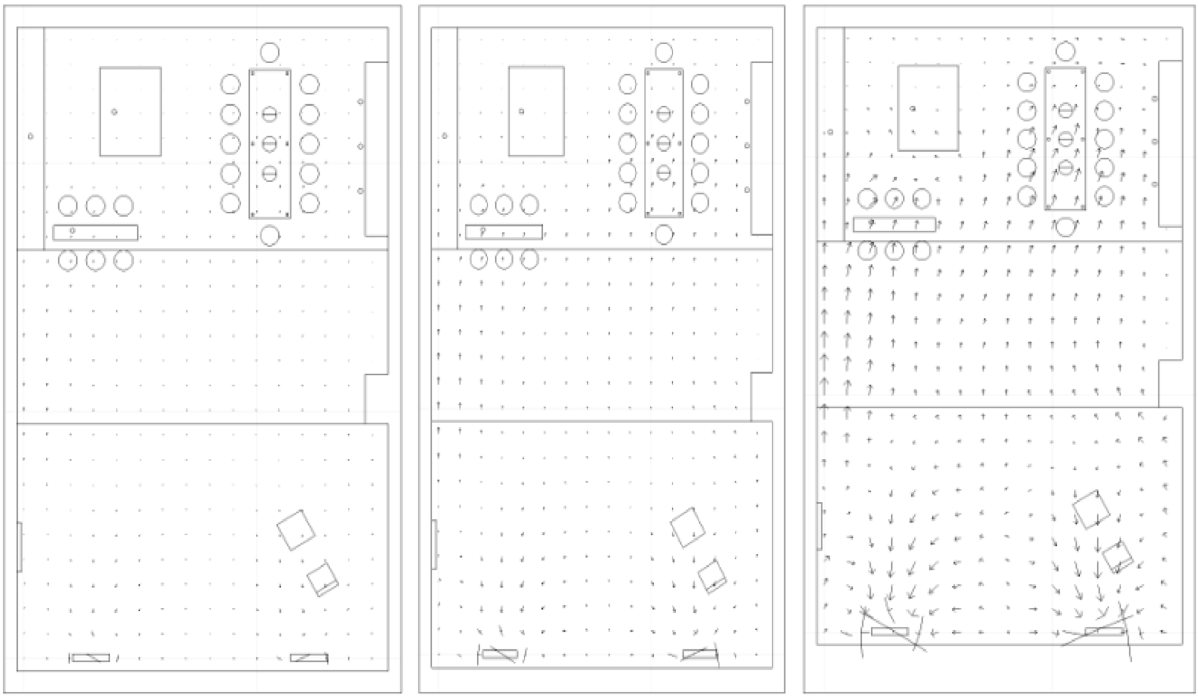


a) . b) c)

Figure 2.12: Distribution of velocity vectors, without furniture

a) ($v1$=0.1m/s, h=0.8m), b) (v_2=0.2m/s, h=0.8m), c) (v_3=0.5m/s, h=0.8m)

The situations in which, for the same characteristic section, the furniture is also introduced in the analyzed space are presented in Figure 2.13.

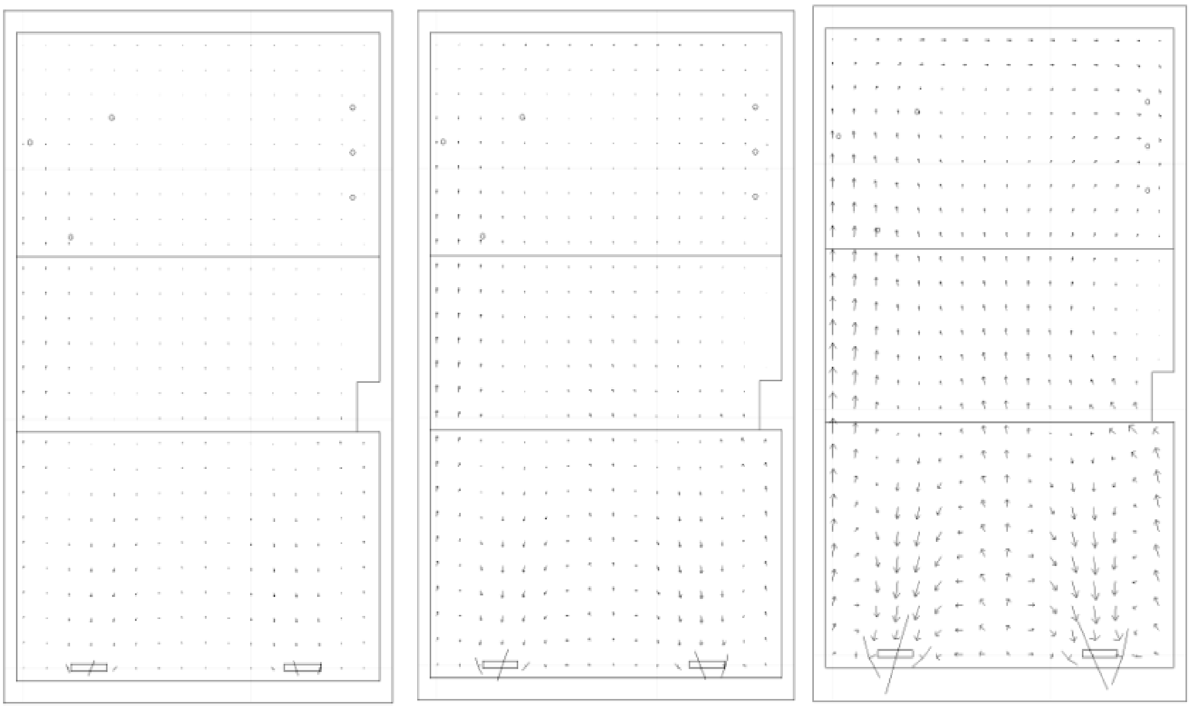


a) b) c)

Figure 2.13: Distribution of velocity vectors, with furniture
a) (v1=0.1m/s, h=0.8m), b) (v_2=0.2m/s, h=0.8m), c) (v_3=0.5m/s, h=0.8m)

Compared to the previous cases presented in Figure 2.12, it is observed the appearance of areas located near the furniture objects in the kitchen, in which the velocity vectors change their direction as a result of meeting these obstacles

If we consider the horizontal section feature located at 1.2m from the floor, which coincides with a work plan specific to the activities of the occupants in the standing position, the distribution of the velocity vectors is shown as in Figure 2.14.



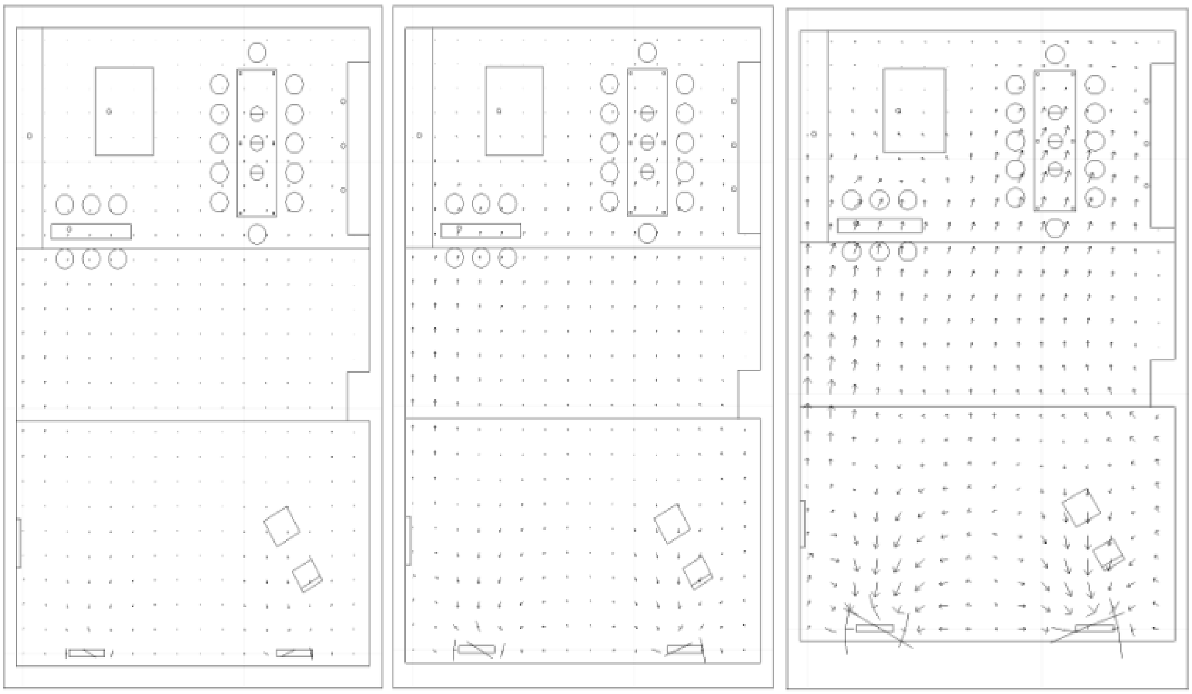
a) b). c)

Figure 2.14: Distribution of velocity vectors, without furniture

a) (v_1=0.1m/s, h=1.2m), b) (v_2=0.2m/s, h=1.2m), c) (v_3=0.5m/s, h=1.2m)

In this case we can remark in comparison with the characteristic elements presented in Figure 2.12, that for this characteristic section we have no significant differences, velocity vectors maintaining their characteristics.

In the situation of introducing the furniture in the analyzed space, the distribution of the velocity vectors will look like in Figure. 2.15.



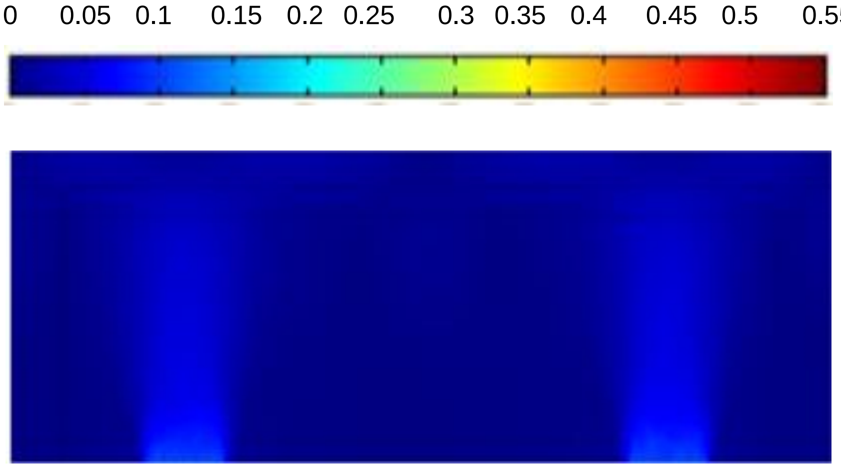
a) b) c)

Figure 2.15: Distribution of velocity vectors, with furniture
a) (v_1=0.1m/s, h=1.2m), b) (v_2=0.2m/s, h=1.2m), c) (v_3=0.5m/s, h=1.2m)

In this case, compared to the previous case shown in Figure 2.13, not observed major differences, velocity vectors maintain their spatial characteristics in areas next to the furniture in the kitchen.

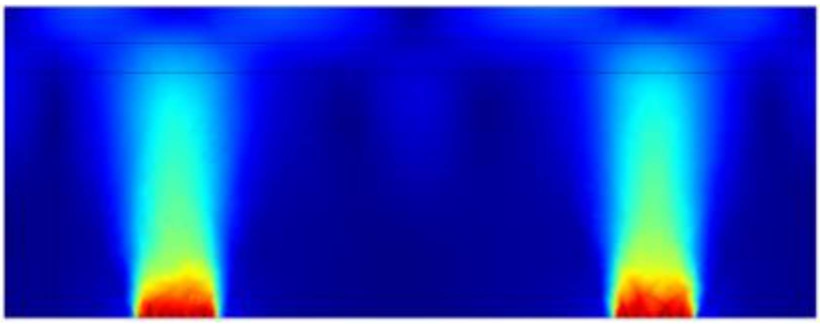
The third aspect of quantitative evaluation of the flow of working fluid through the simulation field it is highlighted by the distribution of the velocity contours, analyzed for the two variants (with or without furniture), for the same speeds of fresh air introduction (v_1 = 0.1 m/s, v_2 = 0.2 m/s, v_3 = 0.5 m/s), considering two axial reference planes corresponding to the grids for the introduction of the fresh air and the evacuation of the vicious air.

The distribution of the velocity contours in the variant without furniture, specific to the speeds of introduction of the fresh air, in the axial plane corresponding to the inlet grids is shown in Figure 2.16.



a)

b)



c)

Figure 2.16: Distribution of air currents velocity contours, inlet grids, without furniture a) v_1 =0.1m/s,b) v_2 =0.2m/s, b) v_3 =0.5m/s

In the images presented in Figure 2.16 it can be observed that when the fresh air is introduced in the axial vertical plane on the input grids a distribution of air velocity contours is born, which increases with the speed air introduction.

In the presence of the furniture in the simulation field, Figure. 2.17, it is observed that the contours (fields) of speeds have a lower "amplitude" than in the variant without furniture.

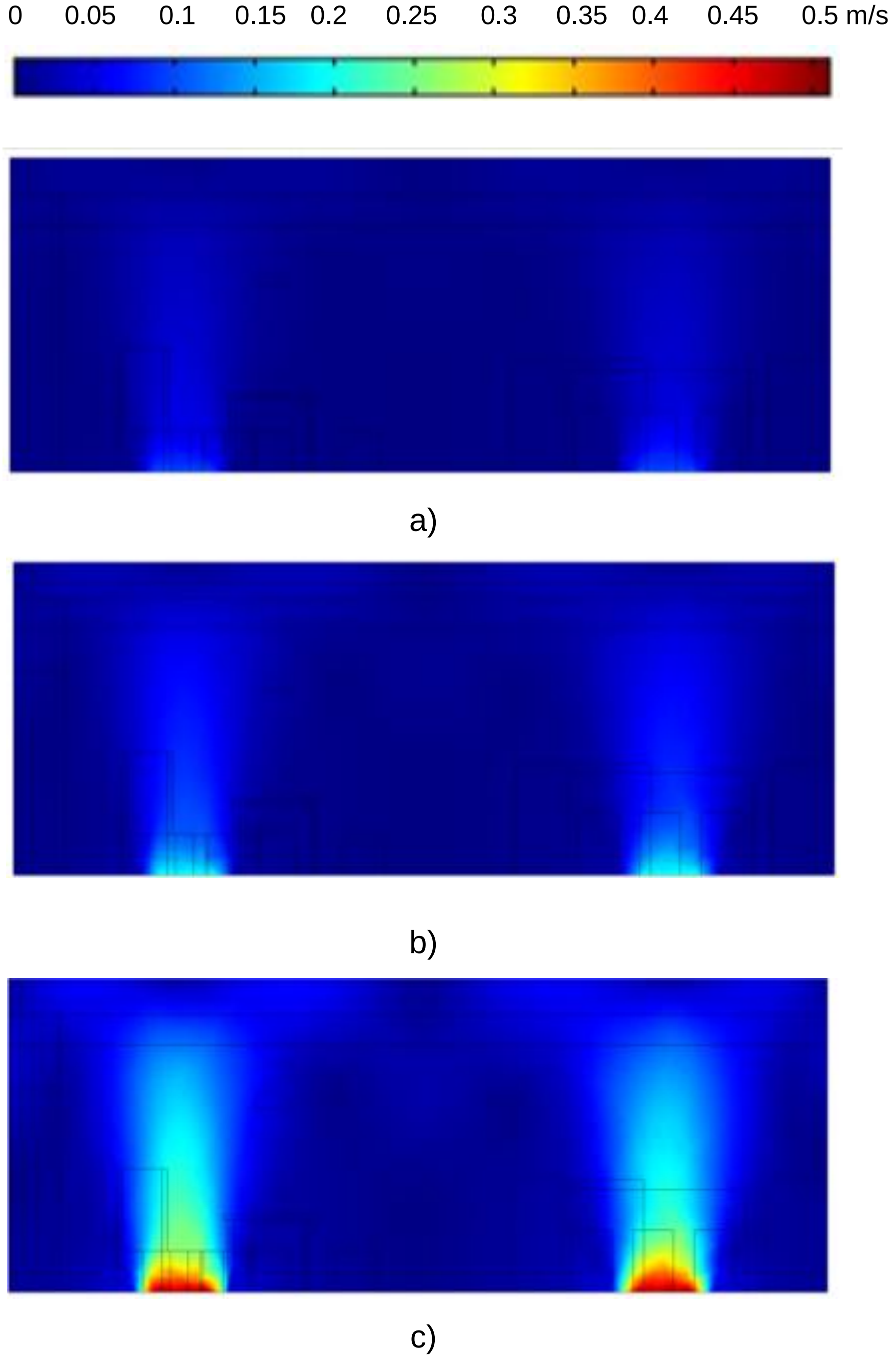
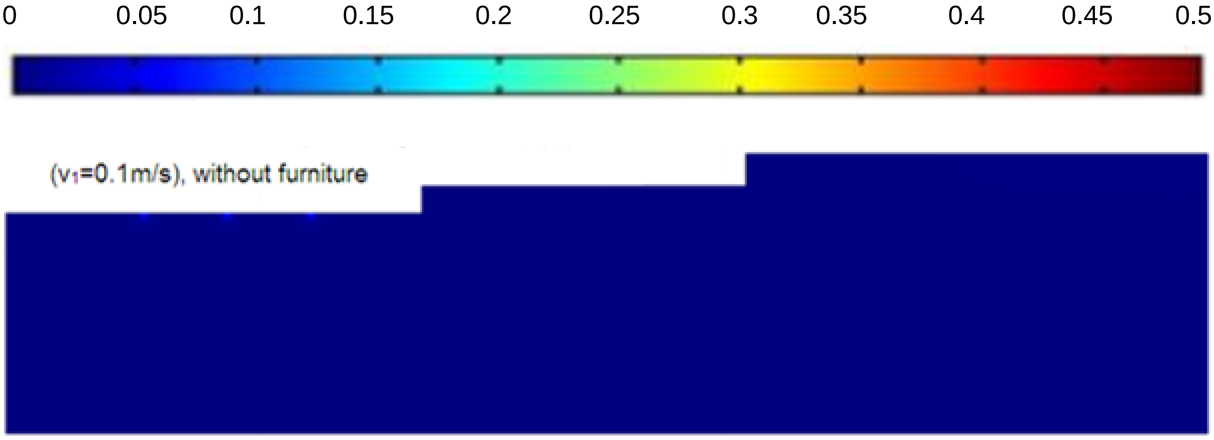


Figure 2.17: Distribution of air currents velocity contours, inlet grids, with furniture
a) v_1 =0.1m/s, b) v_2 =0.2m/s, b) v_3 =0.5m/s

In the axial plane corresponding to the exhaust grilles distribution of velocity contours in the version without furniture, which is born under the conditions of the three speeds of fresh air will be present as in the Figure 2.18.



a)

b)

c)

Figure 2.18:Distribution of air currents velocity contours, outlet grids, without furniture a) v_1 =0.1m/s, b) v_2 =0.2m/s, b) v_3 =0.5m/s

In the case of the outlet grids, it is found that with the increase of the speed fresh air introduction a slight variation of the velocity contours is observed at the outlet grids.

In the presence of the furniture in the simulation field, the distribution of the velocity contours at the level of the outlet grilles is presented as in the Figure 2.19.

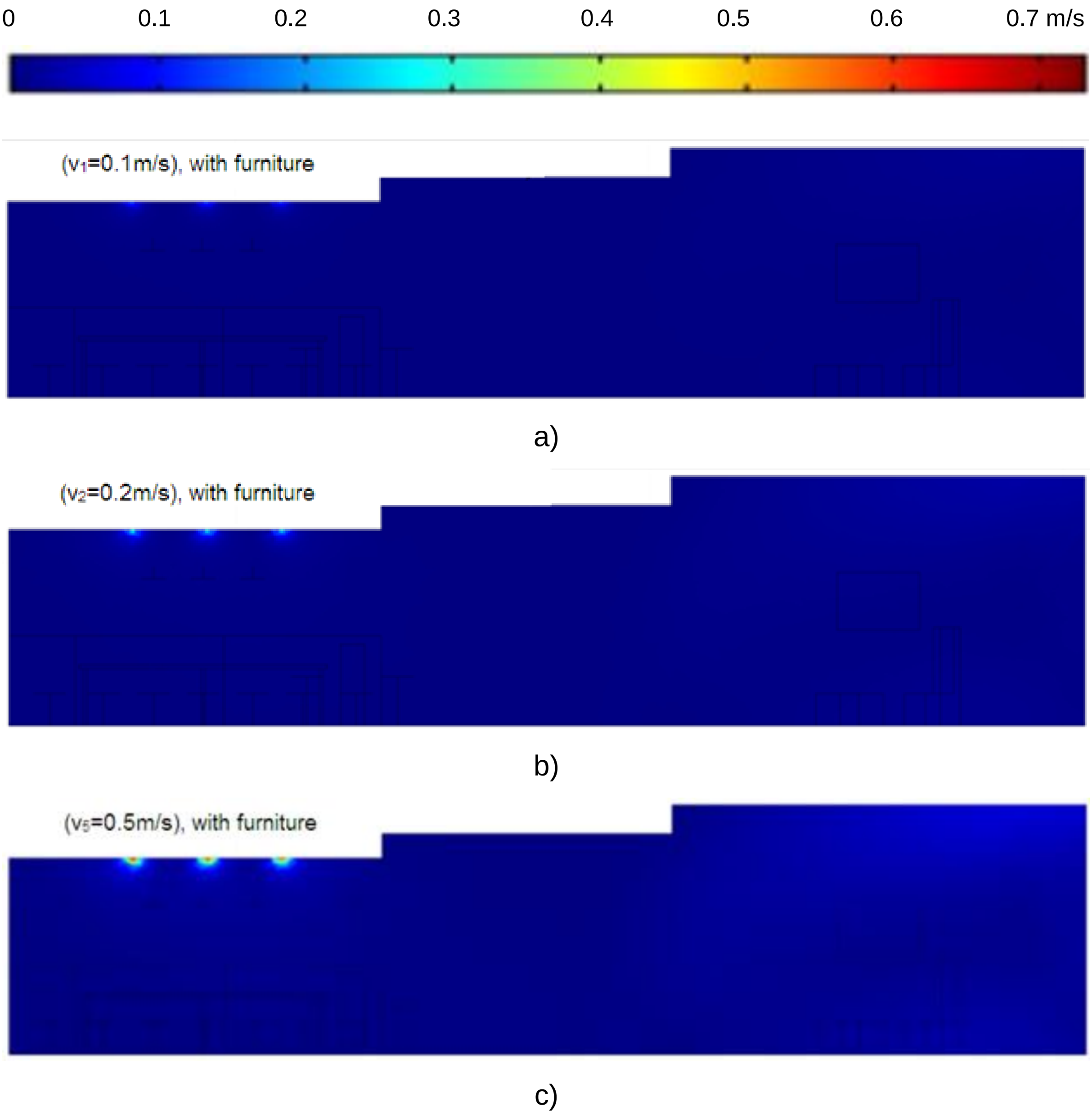


Figure 2.19: Distribution of air currents velocity contours, outlet grids, with furniture a) v_1 =0.1m/s, b) v_2 =0.2m/s, b) v_3 =0.5m/s

In this case the distribution of the velocity contours of the air currents becomes better contoured, noting the fact that in the section of the outlet grids you can find peaks of velocity values is higher than those of introduction, due to the presence of furniture in the area of outlet grids.

3.8 Conclusions

Following the case study on modeling and simulation of air movement in the working area (calculation), evaluated qualitatively by means of: the distribution of the stream lines and the velocity vector and quantitatively by means of the velocity contours can be drawn the following conclusions:

- the presence of the furniture has an insignificant influence for the qualitative distribution of speeds,
- in the occupied zone air speed within the limits provided for by standards of occupant comfort,
- the comfort of the occupants is not affected by the higher values of air speed which can be meet in the inlet grids area or the velocity peaks present in the area of the outlet grids.

3.9 Perspectives

The distribution of air currents will be studied taking into account the following aspects:

- the heat transfer phenomena,
- the boundary conditions will be restored,
- will determine heat loss through the building envelope,
- the internal heat sources will be established,
- the heat exchanger and the auxiliary heating source will be considered.

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