A HOUSE IN TANZANIA TO MEET GOD.
NATURAL VENTILATION

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Abstract *In this paper it is presented a method of calculation for the design, sizing and verification of natural ventilation for the "St. Maria del Carmelo" in Dar es Salaam – Tanzania, a house to meet God.*

A wind tower is adjacent to the bell tower and is called to collect the wind to enter into an underground pipeline. There are two principles that govern the dynamics of natural ventilation: 1. the hot air, being less dense than cold air, tends to rise, thus generating the "chimney effect"; 2. the circulation of the wind around and above the building that creates a pressure difference. Another factor that causes current of air is the temperature, the more it increases more and the gas expands decreasing its density.

So if the day is captured the cooler air and faster at a height higher than that of the soil, the latter being then channeled into an underground conduit, through which disperses heat still decreasing its temperature, then when this air will enter the church in touch with people, it will tend to heat up quickly, thus leading to the chimney effect, flowing so naturally by the openings at the highest altitudes of the structure.

This phenomenon is even more accentuated by the presence of the solar chimney placed on top of the roof which causes a greater pressure difference between the air captured and the one that enters the environment.

The study of the natural ventilation system, first shown, it was particularly complex due to the large volume of the church (designed for 2,000 faithful) and the local weather conditions.

In the paper, after a brief presentation of the architectural design of the church, the basic criteria are discussed for the design of this particular ventilation system.

1. INTRODUCTION

The objective of this study was to obtain a general method of calculation for the design, sizing and verification of natural ventilation provided for the "St. Maria del Carmelo's Church" in Dar es Salaam - Tanzania.

The study started in research, on the territory of this economic capital of Tanzania, other buildings in which elements were present plant to be connected to the criterion of natural ventilation.

In the various forms of architecture found in Dar there are, fortunately, examples of new technologies aimed also building energy efficiency following. Indeed, in the church of St. Peter (Fig. 1) built by the architect. H.L. Shah in 2005 we found the attention to the design of specific openings of the church, in order to promote natural ventilation by using only the transverse motion of the winds in the region.

Figure 1. St. Peter's Church, Dar es Salaam, Tanzania, 2005

Other such examples are the National Museum (Fig. 2) of the office French & Hastings (2008) and the National Bank of Tanzania (Fig. 3) built by Arch. H.L. Shah (2008), where you can enjoy the study of shading and ventilation tower.

In the following they are described the operating principles of fire effect on which it was based on both the construction of the tower which catches the wind, built near the church tower, is for the entire system that serves the entire structure on its three different levels (Basement, Ground and Matroneum, 2184 seats).

In particular, the principles that govern the dynamics of natural ventilation are two: 1. The hot air, being less dense than cold air, tends to rise, thus generating the so-called "chimney effect"; 2. The circulation of the wind around and above the building that creates a pressure difference. Another factor that causes current of air is the temperature, the more it increases more and the gas expands decreasing its density.

So, if the day is captured the cooler air and faster at a height higher than that of the soil, the latter being then channelled into an underground conduit, through which disperses heat still decreasing its temperature, then when this air will enter the church in touch with people, it will tend to heat up quickly, thus leading to the chimney effect, flowing so naturally by the openings at the highest altitudes of the structure.

Figure 2. Bank of Tanzania – Arch. H.L. Shah – 2008.

This phenomenon is even more apparent thanks to the presence of the solar chimney place on the top cover and from the fan, installed in the tower, which in turn determines a greater pressure difference between the air captured and fed into the environment. This beneficial air flow is reversed by night. The tower, absorbing heat during the day, the issue heats up the air, that cold calling from the rooms through the windows left open.
Finally, in the final chapter discusses the methods of design, selection and testing of air distribution ducts and the fixing and the placement of air diffusers to be included in the project plant of the church, while the eighth chapter focuses attention on systems with ducts sheet metal material used for the construction of that facility, preferred to others due to its excellent thermo physical qualities, ideal present for the climatic conditions in Dar es Salaam.

2. THE CHURCH OF "BIKIRA MARIA WA MLIMA KARMELI"

The Church of "Bikira Maria wa Mlima Karmeli" (Architectural design of Flavia Fascia - Structural design of Renato Iovino) (Fig. 3) develops with a ground floor and with a basement. The church, with a Latin cross plan, was designed to accommodate 2184 worshipers, distributed between the ground floor and the floor of the *matroneo* (Fig. 3 and 4). On the left side of the apsidal area there are the sacristy, and the working chapel on the right; at the entrance there are two staircases that connect the hall of the faithful with the women's gallery and the conference room in the basement (Fig. 5 and 6). The section (Fig. 7) highlights the altimetric development of the church.
The Church presents the reinforced concrete structure and the laminated wood covering (Fig. 8 and 9).
The bell tower supported by the wind tower completes the project. The bell tower and the wind tower are raised from a green area. At the base of the two towers there isthe statue of the Madonna (Fig. 10 and 11).

Figure 3. Render of the Bikira Maria wa Mlima Karmeli- Bunju Area, Kinondoni, Dar Es Salaam, Tanzania

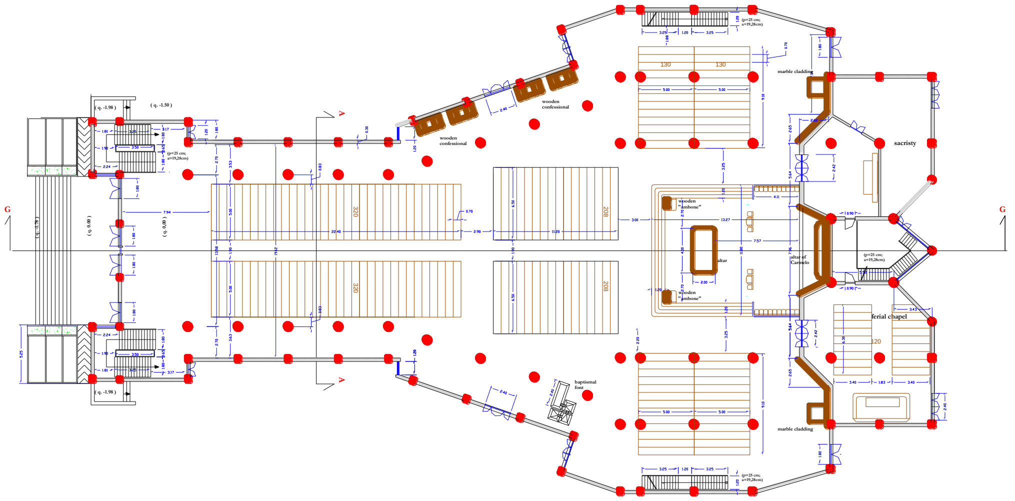


Figure 4. Ground level plan. The faithful hall has 1576 seats, the ferial chapel 120 seats.

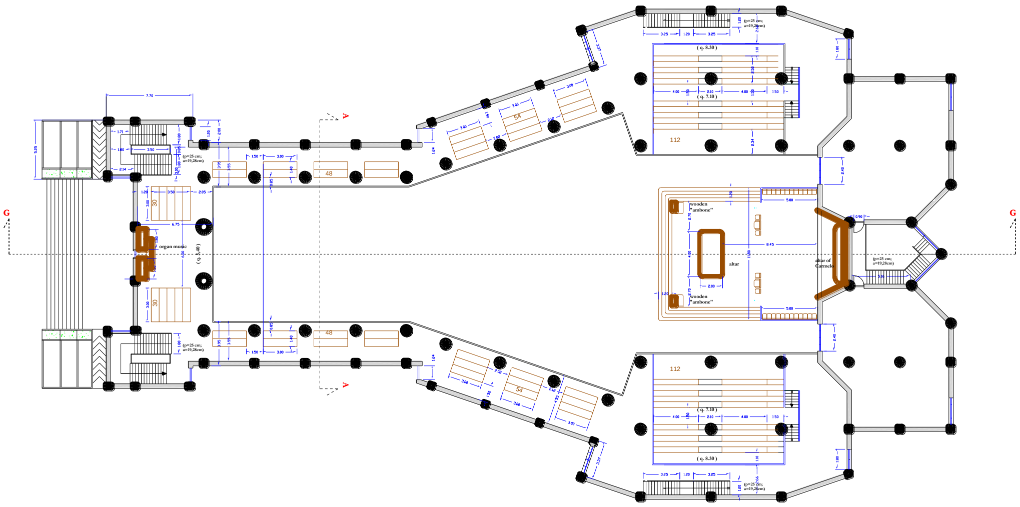


Figure 5. Second level plan – *Matroneum*. The *Matroneum* has 488 seats.

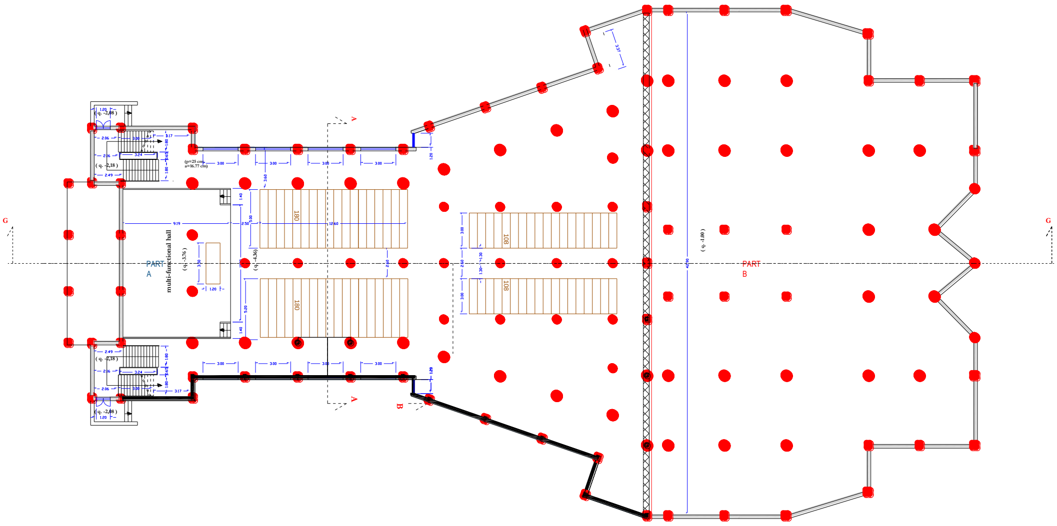


Figure 6. Level – 4,00 m plan. The conference room has 576 seats.

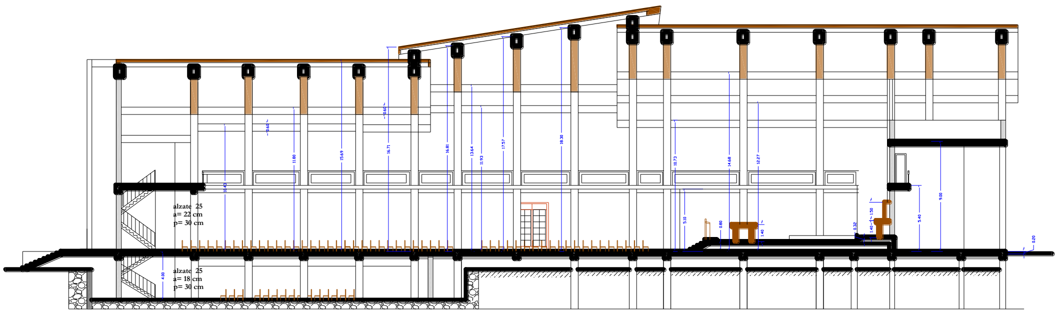


Figure 7. Section G-G

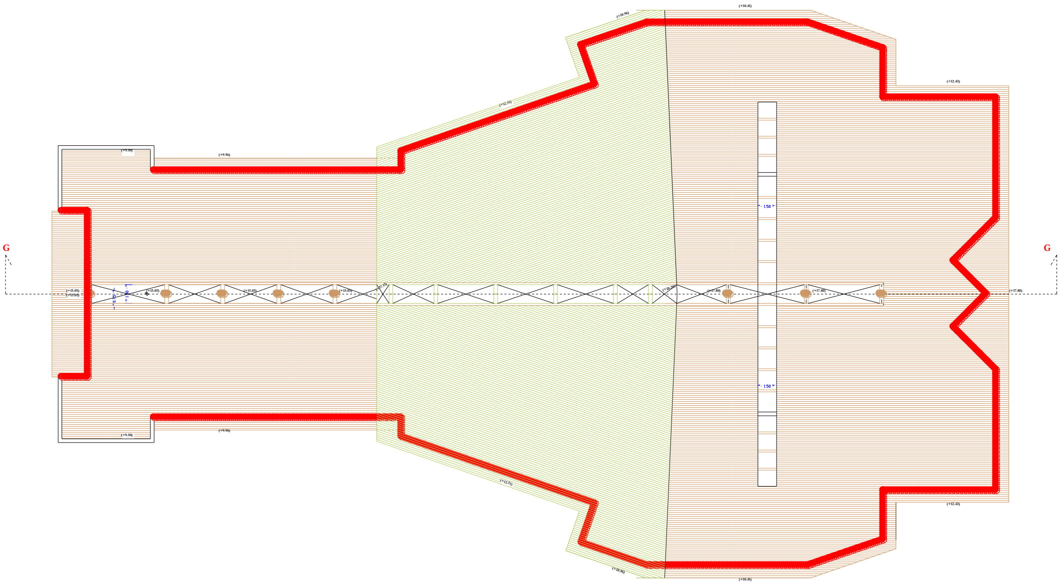
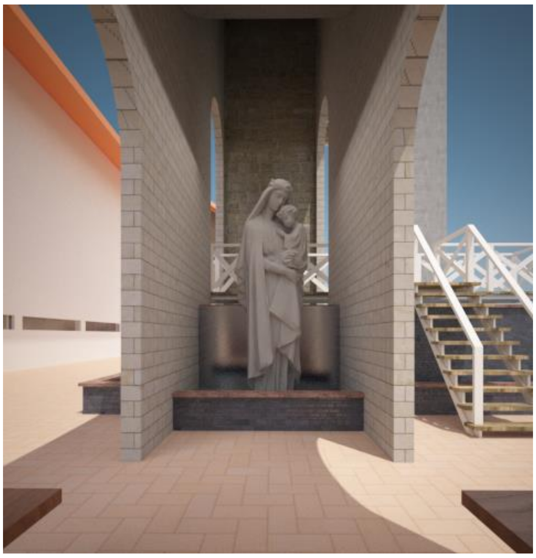


Figure 8. Roof plan. On the top of the roof it develops the stell and glass skylight

Figure 9. Render of the laminated wood covering during assembly



Figures 10 and 11. The bell tower with the wind tower.

3. NATURAL VENTILATION SYSTEMS

Among the natural ventilation systems we mention the *termitarium*, (a complex built in sand, worked by the worker termites within of which the temperature is almost constant for the whole year, thanks to the metabolism of termites and to a network of ventilation ducts, which are open or closed to regulate the flows of air), the *tepee* (traditional tent of the American Indians of the Great Plains, consists of a conical structure of poles of spruce, topped with buffalo skins tanned and oily mixtures prepared with tannin, such as make the skin waterproof.) and the *Qa'a*.

- The Termitarium

The most paradigmatic example is represented by an architecture of the animal world: the nest, a complex built in sand, worked by the worker termites within of which the temperature is

almost constant for the whole year, thanks to the metabolism of termites and to a network of ventilation ducts, which are open or closed to regulate the flows of air.
The ridge, the most exposed to solar radiation, is massive and devoid of cockpits, so as to mitigate the thermal oscillations internal. It is crossed, in addition, from a duct in a position to facilitate air escape vitiated (Fig.12).

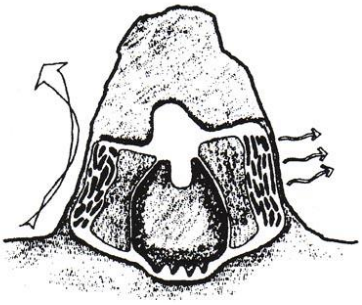


Figure 12. Schematic section of a termite, illustrating the ducts for the ventilation, the thin side walls for the convective cooling and the thermal mass at the top, with solar control

- The Tepee

Examples of application of natural ventilation mechanisms are, instead, the ramparts "light" of the indigenous peoples of different continents, built to adapt to hot and humid climates or for the mobility needs of nomadic peoples. Among these, the most representative is the tepee (the traditional tent of the American Indians of the Great Plains), consists of a conical structure of poles of spruce, topped with buffalo skins tanned and oily mixtures prepared with tannin, such as make the skin waterproof. This casing has two flaps reported, which remain protruding at the top and can be held open, for the release of smoke and for ventilation or closed, by moving the two posts to which they are hung, for repair from the rain and cold. The poles can also be moved to position the opening leeward, in such a way as to favor the release of smoke. In winter, the tent is placed around a circular fence made of twigs, for protection against cold winds. In summer, the skins are raised in the lower part, for ventilate the interior space. Inside, the cabin being lined up to a third of useful, by a layer of tanned leather, fixed so as to create an air gap towards the outer skin.
The latter has the function of maintaining the internal environment dry, even in case of rain, and to increase the thermal draft for the output of the smoke (Fig. 13).

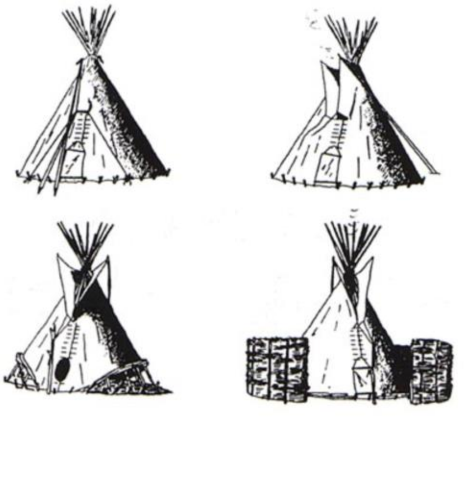


Figure 13. The different mechanisms of microclimate control of North American Indian tepee, a) closed-period cold-, b)-stack effect ventilation to expel smoke-, c) through ventilation, d) barrier protection from cold winds

- The Qa’a

Cooling techniques for natural ventilation are the most advanced in civilization as developed within the Arab or Persian, such as those applied in Qa'a Egyptian and Iranian wind towers. The basic mechanism of both is to capture the wind at the top, where it is faster and more cold, and bring it into the building through vertical pipes that have a shell mass consisting of (in order to prevent the heating of the air) and then expel the vitiated air of the interior compartment through openings at the top. In Qa'a element uptake wind is the place over and possibly to the north, while the opening of extraction is represented by a lantern. Both openings are directly connected with the premises to be cooled and the cycle is continuous, day and night (Fig. 14).
In the tower of the wind, the air element uptake (tower) is usually separated from the local to be cooled and connected to them by a culvert, which further cools the air. The expulsion of hot air is carried through the windows. The air flow is reversed at night, due to the release of heat (absorbed during the day) by the casing of the tower, which heats the air. This is thus designed to rise, drawing colder air from the culvert and, in turn, from living areas, through the windows left open (Fig. 15).

The basic mechanism is to capture the wind. With high towers, in fact, during the day, the colder air is captured and taken through specific vertical channels in a culvert, where it is further cooled. From there the cold air is fed from the windows in the home just as the hot air is expelled.

This beneficial air flow is reversed by night. The casing of the tower, after absorbing heat during the day, the issuing authority, by heating the air. This hot air less dense, tends to rise, drawing cold air from the culvert and living areas through the windows left open.

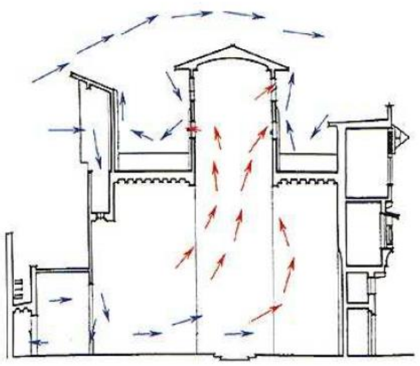


Figure 14. Diagram of the air flows in Qa'a of Othman Katkhuda, Cairo (1350)

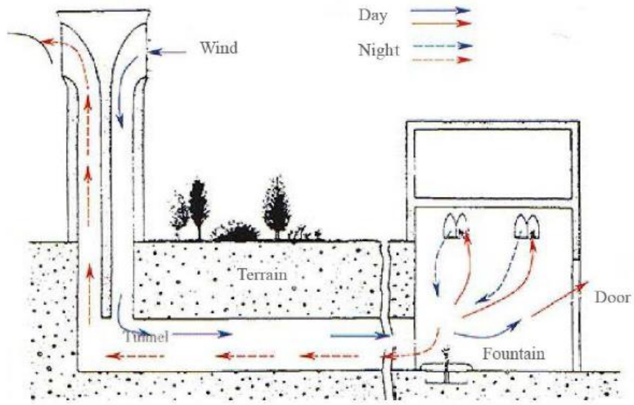


Figure 15. Diagram of the air flows in a tower Iranian associated with an underground conduit

3.1. The natural free-cooling

The natural ventilation depends on the type of force that determines the displacement of the air mass and the transport mechanism of the air itself. Let's examine, in particular, the natural free-cooling.
The cooling can be implemented by means of ventilation, essentially, of three types:

a. Ventilative Cooling Body, VCB (comfort ventilation), produced by the convective exchange between air and skin, owing to the difference in temperature, both of the air speed;
b. Ventilative Cooling Environmental, VCE (free cooling), relative to the lowering of air temperature in a confined environment, following the introduction of colder air from outside;
c. Ventilative Cooling of the Mass, VCM (structural cooling), produced by the convective exchange between the surfaces of building structures (walls, floors, ceilings, etc..) and air at a temperature lower than that of the surfaces.

3.2. Ventilative Cooling Environmental

The ventilative cooling environment, VCE, is generated for introduction into a confined environment of air colder than the inner one, with the aim to bring the latter within the limits of comfort for temperature and relative humidity.
The driving forces of the air flow necessary to induce ventilative cooling are the wind and the chimney effect, integrated with mechanical handling of the air to be activated in case of need, in the passive systems hybrids.
The air flow rate - q_{rva} - necessary for the VCE of a confined space is determined, in steady state, by the following equation:

$$q_{vce} = \frac{H}{c_a \times p \times (t_i - t_e)} \qquad (1)$$

where:

H = heat flux produced within the environment, is equal to: $H = H_i + H_s - H_d$, with
H_s = solar gains
H_i = internal inputs (people and equipment)
H_d = dispersions (W)
ca = specific heat of air (J/kgK)
p = air density (kg/m^3)
t_i, t_e = internal and external air temperature

Based on the above equation, and of other specific formulas for the calculation of the air flow from wind and chimney effect, have been calculated curves of the graphs of Fig. 16 and Fig. 17.
In Fig. 16 shows the curves of correlation between the wind speed (incident perpendicular to a window) and net area on the opening (as % of the surface of the floor), for different values of heat flux removed, in the case of ventilation through-in an environment monozona, with openings of equal area in and out of the flow and temperature difference of 1.7 ° C.
Similar curves are shown in Fig. 17, with reference to the correlation between the height of the thermal chimney (vertical distance between the input level and output of air) and area of the cross section to the flow, in the same hypothesis of size and temperature of Fig. 16.
These curves, as the equation above, are useful only to verify conditions snapshots of the need to limit air flow to the VCE, at the end of the day to determine the potential of ventilation depending on the choices geometric-dimensional relating to the openings. For an effective evaluation of the effectiveness of the VCA, you must use the calculation methods and models

of dynamic, complex and well articulated, referring to periods shorter than the week and times based on weather data.

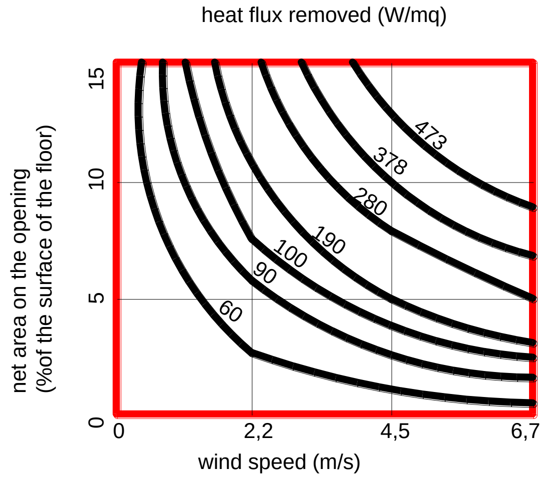


Figure 16. Heat dissipation capacity of VCE with ventilation passing, monozona, in the case of openings of equal length and will ti, te =1.7 °C

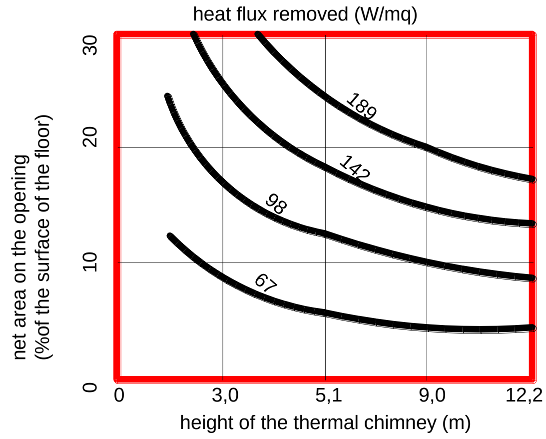


Figure 17. Heat dissipation capacity of VCE with ventilation passing, monozona, for chimney effect, in the case of openings same and will ti, te = 1.7 °C

3.3. Air flow rate

Buildings in the level of air quality and in his spare time is often imposed by law on the basis of its intended use or the rate of local crowding. If it turns out that the real extent of infiltration through the windows for ventilation is less desirable to a conventional value, you have to install a special ventilation system to provide forced air flow environment for complementary external. The air flow rate of ventilation is fixed by one of the following parameters:

- *Vp* [m^3/(h x person)], flow rate of outside air ventilation to be introduced and extracted from the local to each person present;
- *n* [1/h), frequency with which the volume of air of an environment is reciprocated.

The first parameter is applicable when it is known a priori the number of occupants present in a room such as in the case of rooms equipped with fixed seats, seats; the second in the opposite case.
In environments with medium to high crowding index (offices, conference rooms, classrooms, etc..) in the case where the number of people inside is known, the standard UNI 10339 requires the use of the special following Table 1 article reporting on the minimum flow rate of outdoor air per person inside the room (in UNI 10339 expressed through the symbol Q_{op} [10^{-3} m^3/(s for person)] for which from now on $V_p = Q_{op}$).
The flow of outside air V_a is obtained from the product of Q_{op} and the number of people N:

$$V_a = N \times Q_{op} \qquad [2]$$

In some cases, the minimum outside air flow rate of ventilation is calculable by the volumetric flow rate of at least renewal for each m^2 of surface Q_{op} [10^{-3} m^3/(s for person)] (Table 1).

Buildings category	External air flow rate Q_{op} [10^{-3} m^3 / s for person]
HOSPITALS, CLINICS, RETIARMENT HOUSES	11
Germ-free chambers	11
Infectious rooms	11
Medical rooms	8,5
Body therapy	11
Operating room	-
FAIRS, MUSEUMS, LIBRARIES, PLACES OF WORSHIP	
Show rooms, art galleries, museums	6
Libraries	5,5
Book storages	-
Places of worship	6
BAR, RESTEURANTS, DANCING ROOMS	
Bar	11
Bakeries	6
Lunch rooms	10
Kitchens	16,5

Table 1. External air flow rate

For places of public entertainment or meeting, UNI 10339 provides that the effective range, Q_{ope}, is determined as a function of the ratio of the volume V and the number of occupants N (the ratio is therefore expressed in m^3 per person), with the following procedures:

1) for $V/N \leq 15$ m^3/person it has: $Q_{ope} = Q_{op}$ (apply that is the values of Table 1);

2) for $V/N \geq 45$ m^3/person the effective range Q_{ope} is taken as equal to $Q_{op,min}$, as reported in Table 2 as a function of Q_{op};

Q_{op} 10^{-3} [m^3/s for person]	$Q_{op,min}$ 10^{-3} [m^3/s for person]
< 7	4,5
7 ÷ 10	5,5
10 ÷ 12,5	7,0
> 12,5	8,5
$Q_{op,min}$ is the external air flow rate, per person, minimum allowed	

Table 2. external air flow rate per $V/N \leq 45$ m^3/person

3) for $15 < V/N < 45$ m^3/person the effective range Q_{ope} is determined by applying the following formula for linear interpolation:

$$Q_{ope} = Q_{op} - \frac{Q_{op} - Q_{op,min}}{45-15} \left({}^{V}\!/_{N} - 15\right) \quad (3)$$

In summary, for places of public entertainment or meeting the regulations will reduce the flow of outdoor air per person per Table 2 in the presence of high volumes and / or low number of people (V/N ≥ 45 m^3/person), then the value shown in Table 1 on small volumes and / or high number of people (V/N ≤ 15 m^3/person), while for the intermediate situations are prescribed linear interpolation. In Fig. 17 is shown in graphical form as just described.

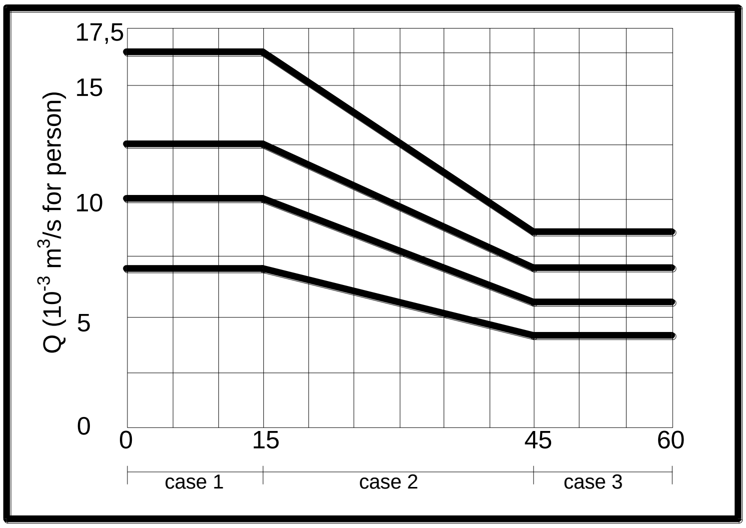


Figure 17. Air flow per person per meetings or dancing rooms.

In the case of the church of "Bikira Maria wa Mlima Karmeli", it results:

- the faithful hall has 1576 seats
- the Matroneum has 488 seats
- the surface of the faithful hall is 1,840.00 m2
- the average height of the faithful hall is 17.00 m
- N = 1576 + 488 = 2064 persons
- V = 1840 x 18.00 = 33.120,00 m3
- V / N = 33120/2064 ≈ 16.00 m3 / person

Therefore, applying [3] we have:

$$Q_{ope} = 6 - \frac{6-4{,}5}{45-15}\left({}^{33120}/_{2064} - 15\right) = 5{,}95 \ [10^{-3}\ m^3/s \text{ for person}]$$

And, som the required airflow is:

V_a = 5,95 x 10^{-3} x 2064 ≈ 12,30 m^3/s

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