ENVIRONMENTALLY FRIENDLY CITIES, Proceedings of PLEA'98, Lisbon, Portugal, June 1998
Pages 475-478

Integration of natural ventilation systems and factory building's architectural elements, related with thermal comfort and indoor environment air quality

TERESA C. F. QUEIROZ* AND LEOPOLDO E. G. BASTOS

Universidade Federal do Rio de Janeiro/ Faculdade de Arquitetura e Urbanismo/DARF
COPPE/Prog./Dep. de Engenharia Mecânica
Av. Brig. Trompowski, s/n, Prédio da Reitoria, Cidade Universitária, Ilha do Fundão
Rio de Janeiro/ RJ, Brasil, CEP 21945-970
arqind@proarq.ufrj.br and bastos@serv.com.ufrj.br

Abstract

The aim of this work is to present an analysis related with the indoor environment conditions in a naval metallurgy-"Arsenal de Marinha", located in Rio de Janeiro, Brazil. This factory building has significant historical and architectural values. The objectives of this paper are: to evaluate the integration of passive ventilation besides the building architectural characteristics, as well as, to make some indoor environment improvements, related with the reduction of thermal stress conditions for the workmen, assuring health and safety. In this way, from the analysis performed, it is obtained for the factory improvements on: ventilation systems, thermal comfort, environment air quality and electric energy conservation. Also it is emphasized the treatment of the architectural elements, faced to the natural and artificial low energy systems for air ventilation.

INTRODUCTION

The aim of this paper is to analyse an existing industrial building, faced to its integration with some introduced passive ventilation systems, and promoting the indoor human health and thermal comfort.

The field related with the architectural factory projects emphasizing technique, function and form is known as large and complex.

A good performance of ventilation systems can reduce heat stress conditions for workmen, assuring health and thermal comfort.

It is selected as a case study a metallurgy building, located at a naval yard and industrial isle, in Rio de Janeiro, Brazil.

The activities inside this building cause also safety risks for workers due to the polluted indoor environment air. In this way, this work presents some passive ventilation and exhaust systems, faced to air quality and low energy consumption.

The present analysis considers the following phases: description of constructive characteristics and architectural project, indoor performed work, identification of risk areas related with thermal exposure and air pollution, indoor environment air temperature measurements, environmental thermal evaluation, natural air renovation measurements, passive exhaust systems with low energy consumption and propositions for architectural elements.

CASE STUDY

The factory building's architecture

The factory building architecture has been preserved since 1930. The construction is arranged on three large pavilions, with concrete portico and visible beams. There are lanterns upper covering. The cover is constructed with framework and cement tile (see figure 1).

The building façade is built with: brick, mortar, glass, metallic frame windows and windowettes. The plant is divided in four floors: ground floor (industrial production); first floor (+3,20m, the vestry); second floor (+6,30, the offices and workshop); third floor (+9,80m, the deposits).

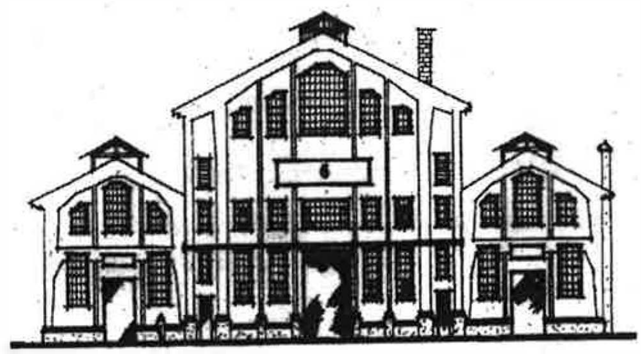

Figure 1. Schematic Frontal Façade [1; p. 110].

Hazards areas characteristics

The indoor activities developed in the ground floor, are: metal foundry and forging. In order to identify hazard areas, related with thermal stress and pollution, it was applied a methodology, presented by the Brazilian Regulation Norms of Occupational Safety and Health, called 'NR 15' [2]. These norms emphasize the evaluation of insalubrious conditions and heat exposure limits.

In order to study the problem, a preliminary evaluation was considered for the building, taking in account: location, orientation, façades characteristics, overtures and climatic local outdoor characteristics. Beside of this, the indoor environment conditions (work room layout, illumination, moisture, solar gain) and the existing air ventilation systems are analysed being selected the hot and polluted internal spaces in accordance to the 'NR-15'[2], which is adopted by the Prevention Brazilian Association for Occupational Accidents [3].

Measurements- thermal exchanges with the environment

The measurements include mean temperature and moisture values for the indoor environment. These measurements were made with dry-bulb and wet-bulb thermometers (scale of 0.1°C). These instruments are protected against radiation effects and placed on hazard areas of local thermal discomfort.

In order to evaluate thermal stress for human occupancy, the measurements are expressed as working time per hour, under long term exposure to heat conditions and during the heating season (March-April-May).

From the temperature data it is evaluated the heat-stress index 'WBGT', that combines wet-bulb temperature and black globe temperature [4]. The results of this evaluation present workers metabolic heat (Kcal/h). The heat-stress index 'WBTG' data (°C) is compared with metabolic heat (Kcal/h) graphically, and the results are expressed as working time per hour, recommended to heat stress exposure limits, for acclimatized workers in the industrial environment [5].

Natural air renovation

In order to evaluate natural air renovation, it is considered local environmental conditions (incident sun radiation orientation, wind directions, vegetation, relief), outdoor environment of building and original constructive characteristics of architecture. From the analysis performed, these conditions can cause interference in following effects: air entrances, faced to wind directions and according to façades orientation to sun radiation; indoor natural air flow; heat air exhaust.

Architectural elements and its performance for natural air ventilation

LANTERNS

The lanterns are architectural elements for natural ventilation and illumination, placed on upper covering of buildings. Lantern design characterizes architecture of many factories buildings in form of pavilion since the past century in world [6].

In contemporary industrial buildings, there are many designs of lanterns. In some of these, placed in tropical climate and with indoor environment heat sources, typical design lanterns make improvements on: heat air exhaust, natural air ventilation and protection from rain and dust particles.

In according to make improvements for thermal performance lanterns, it is considered the following characteristics: typology (form, geometric dimensions, material, colour, maintenance), local wind directions, vents and rainy interference. Figure 2 shows three typical design lanterns, using in industrial buildings [7, p. 259]. In this figure, the lantern (a) with venetian blinds, can protect covering for direct sun radiation. In design (b), without blinds and with vents, it is possible to enter particles dust and rain. In design (c), the 'exhaust lantern', has the best performance, faced to heat exhaust. This 'exhaust lantern' design was developed to make improvements in gas concentrations, particles and vapours [7, p. 259].

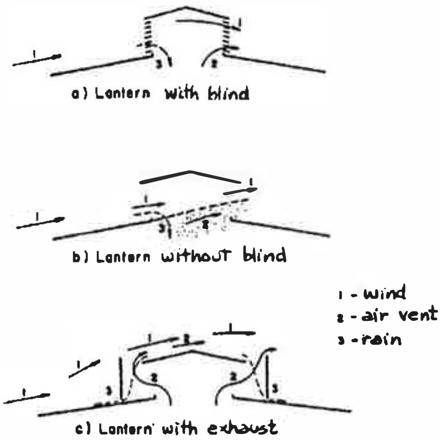

Figure 2. Schematic design of lanterns [7, p. 259].

In figure 3, see a schematic design of a lantern in form of curve. The advantage of using this form is related to its power of exhaust and no admittance of rain or particles.

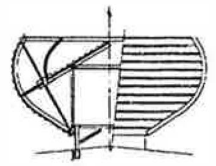

Figure 3. Lantern in form of curve for exhaust [7, p. 261].

However, the 'exhaust lantern' design can cause interference in the aesthetic form of an architectural building (see figure 4). In figure 4, it is studied the location of the 'exhaust lantern on upper cover of the industrial building (case study). Being used this lantern, the original architecture form will not be preserved.

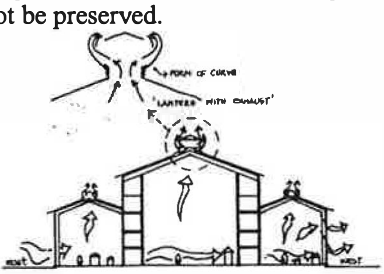

Figure 4. Study of integration between lantern for exhaust and architecture [1, p. 199].

TURBINES CAPS

In industrial buildings with great heat sources, indoor environment, for instance-metallurgy of iron and steel, situated in local heating climate, it is used a 'turbine cap' for exhaust, that also is placed on upper the covering of buildings (see figure 5).

The turbine cap is a type of artificial system, designed for outlet exhaust stack application. Turbine cap design has the advantage of to let pass gas concentrations, odorous and particles through outdoor cap [8].

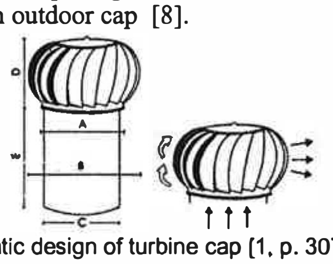

Figure 5. Schematic design of turbine cap [1, p. 307].

Generally, the turbines have aerodynamic form and are made of aluminium and steel. Its performance depends on wind velocity and pressure differences, caused for stack effect. The advantages of using turbine caps in industrial buildings are: electric energy conservation, low cost of installation and maintenance. In some cases of indoor environment industrial buildings, according to make an efficient exhaust, it is useful a great number of turbines caps (see topic 'estimation of results', as well as table 2).

The estimation of turbines caps depends on: type (geometric dimensions, material, volumetric flow rate of outdoor air through cap), volume space of building, seasonal winds conditions (velocity and direction), openings measurements and location, air exchange rates for work activities.

However, there are some disadvantages of using turbine caps, as following: turbine cap designs doesn't have a system of treatment for controlling fallow contaminant particles that may pass through the cap openings. These particles and gas concentrations may be generated due to the nature of indoor space in industrial building, by occupants and their activities. In many cases, air contaminant can affect environmental outside. Turbine cap design can also cause interference in the aesthetic of original architecture plane.

Natural air exchanges rates

In order to estimate natural air exchange rates for useful volumetric space, in this case it is used a methodology [9, p. 39], that considers the following conditions:

1. winds pressure (seasonal wind velocity, wind direction) and overtures surface and location;
2. stack effect for heating (temperature differences between indoor and outdoor environment building and between ground floor and covering), wind velocity and windows height;
3. combination between items 1 and 2.

In this case it was considered the effectiveness of the windows overtures, according to air flow direction, for the air exchange rates [10].

Estimation of results

In this case study, the air exchanges rates calculated are compared with the ASHRAE recommendations [11] to environment industrial buildings. As a result, 'table 1' shows natural air exchanges for the building. In case (a), air exchange rates are estimated due to [1, p. 157-161]: useful volumetric space (m^3), volumetric flow rate of indoor air (m^3/min), 50% of seasonal winds velocity (m/min) and openings to air flow areas (m^2). In case (b), it is also included stack effects, in which temperatures differences (°C), between indoor and outdoor buildings, cause air density differences. At last, the case (c) presents recommendations from the ASHRAE recommendations [11] for foundry.

Table 2 presents an estimation about the required number of turbine caps according ASHRAE [11]. In this analysis, it is considered a turbine cap with characteristics given by local manufacturers, as these following:

1. exhaust turbine material: aluminium
2. base material: steel
3. rotation: 70 rotations for minute
4. turbine cap type: called 'RV60-renovar'
5. measures: base height (330 mm), base diameter (550 mm), rotor height (510 mm), rotor diameter (840 mm), weight (10 Kg)
6. volumetric flow rate of outdoor air turbine estimate (in according to local manufacturers), faced to 50% of seasonal winds velocity): 3500 m^3/h.

The number of turbines, faced to recommendable air exchanges rates to the volumetric space is very high [1, p. 194]. Thus it will be an interference in the architectural aesthetic.

Openings for natural air flow and exhaust

The performance of natural air flow and exhaust is assured by the typology of openings and its location.

For the building studied, there are few openings to air flow and there is a large window glass surface and some windowettes. The area of lanterns, on the cover, is insignificant to attend an efficient natural air exchange and to exhaust. The lanterns without venetian blinds permit the entrance of particles and rain.

It is possible to replace large window glass surfaces in the lateral façades with translucent venetian blinds. These windows can assure sunlight and natural air exchanges, protecting them from the direct sun radiation and rain.

Indoor air quality

Faced to the ASHRAE Fundamentals [12], 'an industrial hygienist evaluating must be effective in recognizing occupational hazards'. The field of environmental health faced to indoor of industrial buildings is a complex application to be developed by professional industrial hygienist.

Table 1. Evaluation-natural air exchange rates [1; p. 191-194].

Local	volume (m^3)	Air exchange rate/hour, due to:		
		a) wind pressure	b) stack effect	c) ASHRAE
Production area (three pavilions)	73.313,97	3,21	7,90	5-20
Foundry-east pavilion	13020,48	4,61	11,51	5-20
Foundry-west pavilion	14.024,16	4,03	15,37	5-20

Table 2. Estimate of turbines caps [1; p. 194]

Local	volume (m^3)	Air exchange rate/hour, due to:		Number of turbines
		a) stack effect	b) ASHRAE	
Production area (three pavilions)	73.313,97	7,90	5-20	272
Foundry-east pavilion	13020,48	11,51	5-20	56
Foundry-west pavilion	14.024,16	15,37	5-20	80

The recognition of occupational hazards presents these points: air contaminant, dusts, fumes, gases, mist, fibres, physical, chemical, ergonomic and microbiological hazards. In this case study it is applied a primarily evaluate in order to identify some hazard areas, indoor environment. In which are produced contaminants, from furnaces and other foundry machinery. These contaminants can affect workmen health. In this case, the environment outside may be affected too.

In order to identify the hazard work areas, it is considered some characteristics, as following:

1. type of gases (organic and inorganic), mist, fibres, fumes and dusts;
2. foundry machinery location;
3. air quality treatment for controlling system conditions;
4. constructive characteristics (openings, volumetric spaces, measurements of windows).

The objectives of this evaluation is to characterize the most hazard area of foundry work and to propose a local exhaust system, faced to assure workmen health and safety. In this case, it is recognized that workmen are generally exposed to air contaminants from oil furnaces, as following: fumes, organic gases (carbon monoxide, carbon dioxide), inorganic gases (oxides of sulphur, oxides of nitrogen). It is important to put a local exhaust and ventilation system, with control of air contaminant.

PROPOSITIONS

Architectural parameters

Due to the architecture of this case study has a significant value in Brazilian Engineering History [13] and faced to integration original architectural characteristics between natural ventilation systems and from the results of this application, the propositions of this work can assure a comfortable and healthy indoor environment for occupants with electric energy conservation:

1. To replace large glass surfaces in façades, with thermal and translucent venetian blinds. This type of windows guarantees sunlight, natural air flow and protects the façades from direct sun radiation.
2. To use venetian blinds in lanterns, on upper covering. Being used venetian blinds, the original architecture, with lantern on upper cover, will be preserved. These elements protect indoor environment from rain and particles, assuring sunlight.
3. It is possible to replace the existing lanterns to others of the same form, but of higher dimensions, which will contribute to increase the volumetric air exchange.

Indoor air quality

From the analysis performed, a particular hazard area affects workmen health, which is placed indoor west pavilion. In this area, there are heat sources with oil furnaces, that produce air contaminants, as well as, gas and vapour.

In order to reduce exposure to air contaminant, a primary proposition is to replace a local exhaust and ventilation system, using filters, to assure indoor environmental health and safety [14].

CONCLUSIONS

From this case study presented, it can be observed the complexity of the problem of evaluation and control of indoor environment occupation conditions, requiring industrial hygiene engineering people and others professionals too.

In event, in some cases, it is very difficult to control all the actions related with indoor environmental performance of industrial buildings. In this way, the present paper shows that professionals of architectural and structural fields have an essential role in helping mechanical engineering designers.

Finally, these architectural actions involved can provide better comfortable conditions (physical and mental) for the indoor workmen and optimize the thermal building behaving contributions to energy conservation.

REFERENCES

1. T. Queiroz, 'Edifício Industrial-Avaliação Ambiental das Condições de Ventilação. Es udo de Caso: Arsenal de Marinha do Rio de Janeiro-oficinas de metalurgia naval' ('Industrial Building-Environment Evaluation of Ventilation Condition.Case Study:Rio de Janeiro Naval Yard-naval metallurgy'). (Rio de Janeiro: UFRJ, FAU, Mestrado em Arquitetura, 1996).
2. 'Manuais de Legislação: Segurança e Medicina do Trabalho. Normas Regulamentadoras' ('Regulation Norms of Safe y and Employment Medicine') ed. Atlas, N. 27. (São Paulo, 1994).
3. B. Goelzer, 'Avaliação da Sobrecarga Térmica no Ambiente de Trabalho' ('Work Environment's Thermal Surcharge Evaluation') ed. Bernardino Ramazzini, vol. 2. (São Paulo: ABPA, s/d).
4. 'American Society of Heating, Refrigerating and Air-conditioning Engineers', ASHRAE Fundamentals Handbook, SI edition, 'Thermal Comfort', chapter 8. (Atlante,USA, 1997), p. 8.20.
5. T. C. F. Queiroz and L. E. G. Bastos, 'Riscos de Exposição ao Calor e Circulação de Poluentes em Ambiente de Trabalho Industrial: método de análise em oficina de fundição naval' ('Risks of Heat and Pollution in Indoor Industrial Workroom: methodolog of analysis in naval foundry') in 'Encontro Nacional de Engenharia de Produção'. CD-ROM, ENEGEP'97. (Gramado, RGS: UFRGS, 1997).
6. S. Giedion, 'Espacio, Tiempo y Arquitectura' (Space, Time and Architecture'). Trad. Isidro Puig, ed. Dossat, ed. N. 5. (Madrid, 1978), p. 250.
7. I. Bellei, 'Edifícios Industriais em Aço' ('Industrial Buildings in Iron'), ed. Pini. (São Paulo, 1994), p. 261.
8. G. J. Ducar and G. Engholm, 'ASHRAE Transactions', n. 1916.
9. A. J. Macintyre, 'Ventilação Industrial e Controle da Poluição' ('Industrial Ventilation and Pollution Control'), ed. Guanabara. (Rio de Janeiro, 1990).
10. T. Ferreira and L. Gonçalves, 'Ventilação Natural em Oficina de Fundição Naval' ('Natural Ventilation in Naval Foundry Workroom') in 'III Congresso Iberoamericano de Ingeniería Mecánica'. CD-ROM, CIDIM'97. (Havana, Cuba: Instituto Superior Politécnico José Antonio Echeverría, 1997).
11. 'American Society of Heating, Refrigerating and Air-conditioning Engineers', ASHRAE Systems Handbook, in A. L. Mesquita, 'Engenharia de Ventilação Industrial' ('Industrial Ventilation Engineering') ed. Edgard Blücher. (S. Paulo, 1977), p. 154.
12. 'American Society of Heating, Refrigerating and Air-conditioning Engineers', ASHRAE Fundamentals Handbook, SI ed., 'Indoor Environmental Health', chapter 9. (Atlante, USA, 1997).
13. P. Telles, 'História da Engenharia no Brasil' ('Brazilian Engineering History') vol. 2. (Rio de Janeiro, 1984-1993).
14. 'Conception et Calcul des Installations de Ventilation des Bâtimen s et des Ouvrages' ('Conception and Calculation of Ventilation Systems' Buildings and Constructions') ed. PYC. (Pa s: AICVF, 1992).