

Natural ventilation feasibility in typical patients wards in a Belgian hospital during summer

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Abstract

Natural ventilation is an interesting topic of research. It could contribute in supplying adequate airflow rates, achieving thermal comfort in patients' wards in hospitals and reduce energy consumption. Although, it's still challenging due to the high fluctuations in ambient airflow and changeable weather conditions which should be studied carefully to be able to achieve stable and comfortable thermal conditions in patients' wards.

This study investigates the feasibility of integrating natural ventilation with existing HVAC system, when it's possible to have natural ventilation as an efficient alternative and to which extent could we use natural ventilation in summer. This will be explored using Ecotect weather tool thermal simulation model and computational fluid dynamics using DesignBuilder. Picardy Wallonia Medical Center was chosen as a case study since it was precisely designed to benefit from natural ventilation and all windows in patients' wards could be opened to benefit from ambient air. Moreover, it contains two typical prototypes of patients' wards: single-bed ward which presents the present orientation in patient ward design, and a creative multiple-bed prototype which was designed to achieve better functional design solutions and more comfortable thermal conditions.

The expected results of metrological analysis will evaluate ambient weather suitability for natural ventilation and how some uncomfortable conditions could be solved using passive techniques. Based on metrological analysis single patient ward will be subjected to CFD simulation to investigate their actual ventilation performance when windows are open when natural ventilation is a potential.

This study will be useful for designers and HVAC engineers to give them a perspective regarding natural ventilation as a potential in ward design. Also it will be useful for standards organizations to have a deeper look regarding natural ventilation margins in patients' wards in hospitals.

Keywords: Natural Ventilation, Patients Wards, Hospitals Thermal Comfort.

Nomenclature

CFD	Computational Fluid Dynamics
PWMC	Picardy Wallonia Medical Center
IRM	L'Institut royal météorologique
PMV	Predicted Mean Vote
PPD	Percentage of People Dissatisfied

1. Introduction

Ventilation moves outdoor air into a building or a room, and distributes the air within the building or room. The general purpose of ventilation in buildings is to provide healthy air for breathing by both diluting the pollutants originating in the building and removing the pollutants from it [1].

Ancient civilizations realize the importance of ambient air and delighting for natural ventilation to provide healthy indoor environment, and innovate various techniques and architectural elements for ventilation

purposes such as domes and vaults, wind-catchers, and courtyards. Classical U, L, H, and T shaped limited depth plan and maximum windows sizes used to utilize ambient air and daylight to the maximum extent. Recently, in the beginning of 21st century and in conjunction with international style in architecture, high rise buildings and mega structures, natural ventilation was replaced with mechanical ventilation which was effective solution for this new style and was efficient to control indoor environmental conditions in these complex buildings [2].

The excessive use and dependency on mechanical ventilation which is mainly dependent on unclean energy sources leads to environmental hazards and global warming. Natural ventilation is a clean and efficient alternative and can reduce energy consumption in buildings up to 40% [3]. Moreover natural ventilation is one of the important bases in sustainable buildings and became a new trend in architectural design in many building types even highly indoor climate control buildings such as hospitals. However, natural ventilation is mainly dependent on natural forces that generate it and its utilization differs according to local climate and

surrounding environment characteristics such as noise and pollution situation.

Mechanical ventilation is not without its limitations and determinants, and should be accurately designed and regularly subjected to maintenance to give the required results for indoor environment according to standards and guidelines that take into account all aspects of IAQ and energy efficiency [4].

According to infection control view, both mechanical and natural ventilation contribute in reducing infection and providing healthier environment. Natural ventilation provides much more air change per hour than mechanical ventilation but only works when natural forces are available. On the other hand, mechanical ventilation requires accurate design and installation, in addition to regular maintenance because any fault or failure in any part may increase the risk of disease transmission in spaces and ultimately cause discomfort in these spaces. For this reason we should activate natural ventilation as much as possible, even if we use mechanical ventilation systems natural ventilation alternative should be ready for any emergency case.

Healthcare buildings and especially hospitals should be flexible to acclimate with changeable weather conditions to provide indoor spaces with suitable and comfortable environment regardless to excessive outdoor conditions. These buildings-type collect several types of users, working staff in hospital usually stay for long period of time and their performance means life or death issue for patients. Also patients are very sensitive to spaces quality such as elderly and infants, which in sometimes could be one of the reasons for recovery and healing patients. Moreover, hospitals are the core of national strategy to provide for citizens the right of healthy life and welfare [5].

British department of health stated that wards could be naturally ventilated and is the best solution for ventilating a space, which provide adequate quality and quantity of required air, and could be easily controlled by design to suit space requirements, which should be flexible to adapt climate changes and fluctuations [6].

The advantages, benefits and techniques of ventilating operation theaters and isolation rooms are thoroughly studied and well investigated, but still unclear in patients' wards, that is because of there is little amount of research in this field. From this point of view our research takes its strength and originality [7].

Referring to guidelines for ventilation in healthcare facilities, we will find most of them concerned about operation theaters, isolation rooms, bronchoscopy suite and other facilities where infection transmission through airborne is potentially possible and well recognized, but patients' wards ventilation guidelines are still unclear and sometimes unrealistic [8]. However, all guidelines agreed of necessity and importance of thermal comfort in patients' wards because of the nature of long residence period of most of patients in these wards. AIA guidelines recommended (2 ACH of fresh air, 4-6 total ACH) for patients' wards [8], but Ferhard et al. argued that this amount is too low in extreme winter conditions [9].

2. Research Methods and Strategies

The methods of this study are simple and objective based. Picardy Wallonia Medical Center was chosen as a case study for research investigation. Single bed ward prototype in PWMC was taken as a typical model.

Weather data was achieved from (IRM) in Belgium to define external boundary conditions. Ambient weather conditions were analyzed using Ecotect weather tool to test weather suitability for utilizing passive techniques such as natural ventilation. Summer season was chosen to test natural ventilation feasibility based on meteorological data analysis. Various indoor air quality parameters were assumed in typical summer day to define internal wards boundary conditions to be simulated using CFD DesignBuilder program. Then data was analyzed and results were discussed to evaluate natural ventilation feasibility at single wards and to crystallize recommendations to be considered in future development.

3. Research Analysis and Simulation

3.1. Case Study Selection:

Picardy Wallonia Medical Center was chosen as a case study because it is part of CHwapi which is composed of four hospital sites and a polyclinics and is one of the most important hospital institutions in Wallonia, with over 2500 employees including 300 physicians, 24,500 admissions per year. It has many strengths to meet the challenges to the well-being of the patient and optimal management. The research chose PWMC at Tournai, west-southwest of Brussels which has a new 7-story building complex extension designed by BAEV bureau with net area of (73,000 m²) and (601) beds. The complex has a remarkable example to study natural ventilation in general wards. The wards were designed with openable windows and have two prototypes of patients' wards: the first is the standard single wards, and the second is a multiple bed ward with creative concept concerning ventilation and infection control, the beds were designed to have the maximum distance between patients and visitors [10].

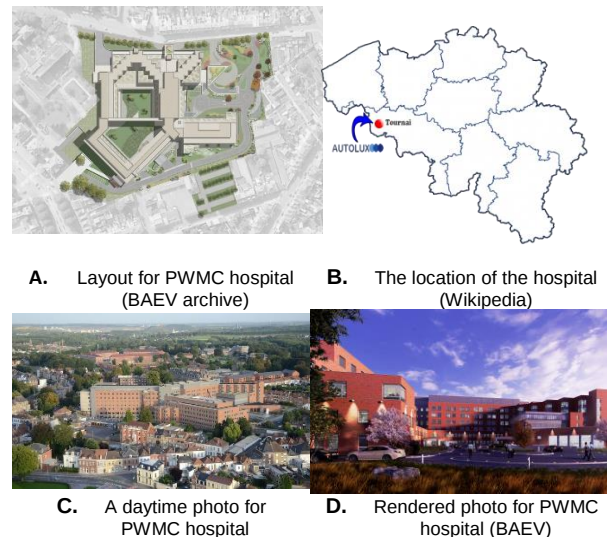


Fig. 1. Illustrations for PWMC

3.1.1. Single Bed Ward

There are two types of patients' wards in PWMC. Multiple beds wards which are mainly situated on building wings. The other type is single bed wards. This study focuses on single bed wards as shown on figure below:

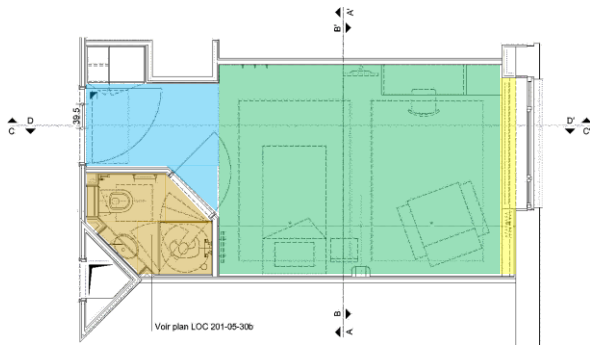


Fig. 2. Single bed ward plan in PWMC

3.1.1.1 Description of physical problem

Single bed ward chosen for this study is divided into three zones as shown on figure above:

- Entrance lobby (3.4 m²) area with floor to ceiling height (2.4 m) and have two doors, main door with area (2.5 m²) and toilet door with area (1.9 m²)
- Toilet room (3.25 m²) area with floor to ceiling height (2.4 m) and has exhaust outlet with capacity (75 m³/hr)
- Patients' space (16.4 m²) area with floor to ceiling height (2.7 m) with two inlets with total capacity (100 m³/hr) in case of HVAC active.

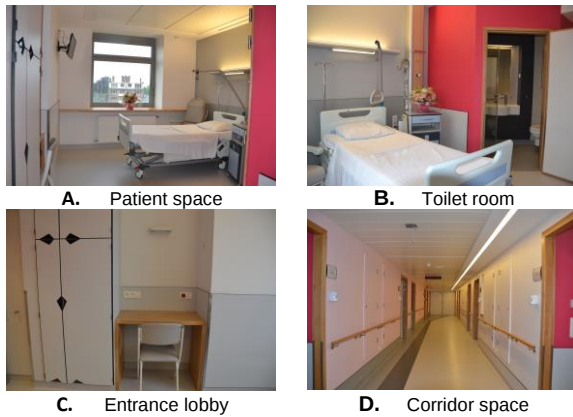


Fig. 3. Illustrations for single bed ward

- Window space (0.7 m²) area with floor to ceiling height (3.0 m), radiator with capacity 1100W and with operable window as shown on figure below:

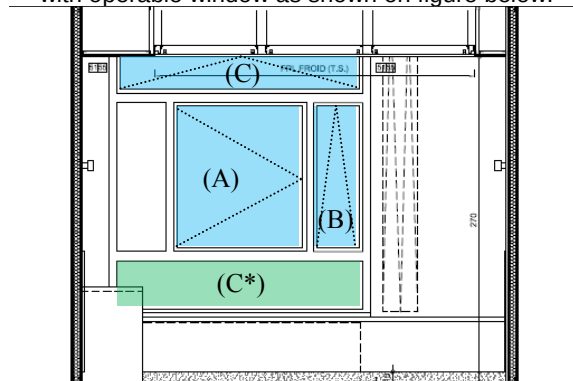


Fig. 4. Single bed ward plan in PWMC

The walls, floor and ceiling were assumed to be adiabatic to neglect their influence on air temperature in the selected ward. Also furniture assumed to be adiabatic as well and lighting influence was neglected.

3.2. Meteorological Findings

Psychrometric chart analysis showed that more than 50% of ambient weather conditions at summer could be modified using passive techniques, also it shows that natural ventilation has a remarkable influence in improving thermal comfort in buildings in general based on meteorological findings as shown on figure below:

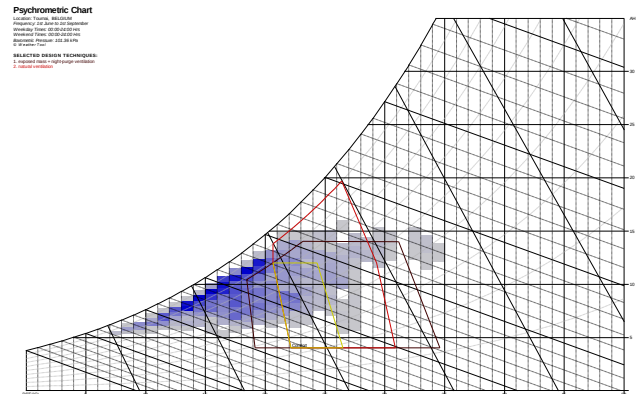


Fig. 5. Tournai summer psychrometric chart

Summer wind rose analysis also illustrates that prevailing wind blow frequently from southwest with airspeed (15-20 km/hr) or (4-5 m/s) and temperature (20-25 °C) at daytime and (15-20 °C) at nighttime as shown on figure below:

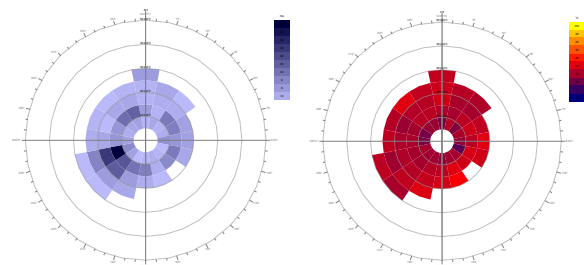


Fig. 6. Tournai summer wind rose

This graphical result which is based on simple psychometrics analysis of meteorological data for comfort zone in base case before using natural ventilation and after using design techniques of natural ventilation:

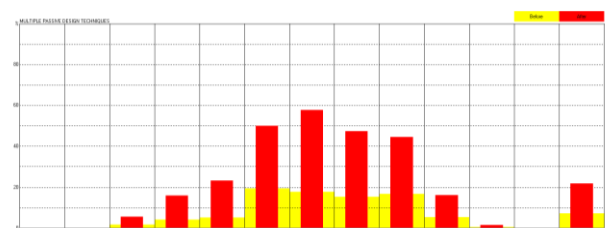


Fig. 7. Comfort percentage before and after using NV

3.3. External CFD analysis

An external CFD model was built using OpenFOAM to study airflow speed at building scale. Airflow speed was set at urban scale (25 m height) to be (5 m/s) based on average meteorological data at summer season and wind rose illustrations as shown above. The results showed that wind speed reduces at building scale to less than (1 m/s) as shown on figure below:

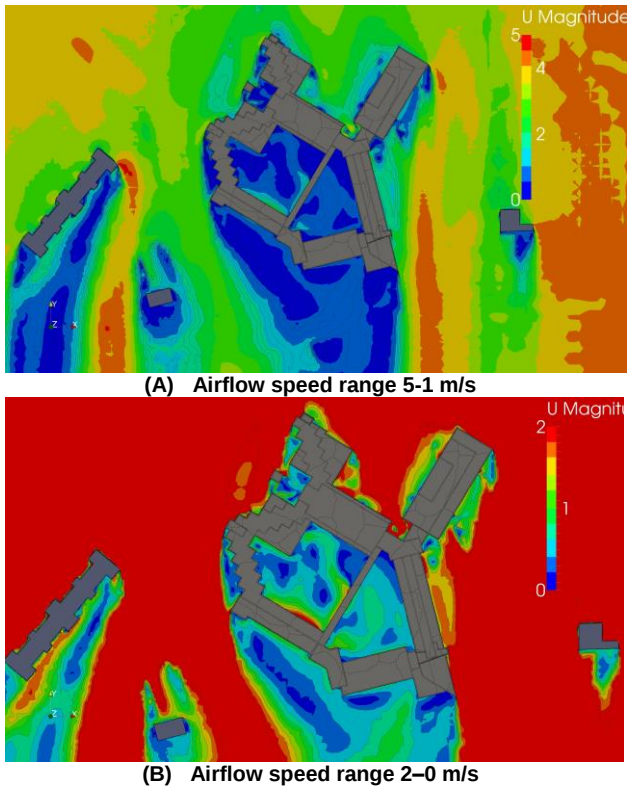


Fig. 8. External CFD analysis

When wind strikes a building, it induces a positive pressure on the windward face and negative pressure on the leeward face. This drives the air to flow through windward openings into the building to the low-pressure openings at the leeward face as shown on figure. For single-sided ventilation rooms, there is no contribution from wind pressures, only from fluctuating components;

Stack pressure (buoyancy) is generated from density difference between indoor and outdoor air as a result of temperature and or humidity difference which results instability in pressure gradients of the interior and exterior air columns, causing a vertical pressure difference. The ventilation rate through a stack is a function of the pressure differential between the two openings of that stack.

Based on our previous CFD external simulation the average pressure difference in façade generates airflow speed on the windows less than (1.0 m/s) and also the natural ventilation system followed in design is single sided ventilation system which bend mainly on stack pressure effect (see figure below). For this reason air flow was assumed to be (0.2 m/s) which generates (4 ACH) in the single wards. This assumption was taken to our internal CFD simulation (see ward model Fig. 10).

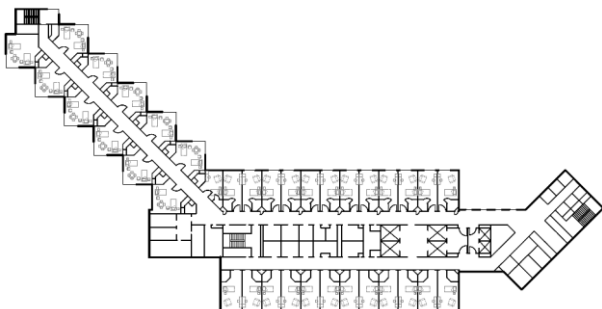


Fig. 9. Typical ward plan - PWMC

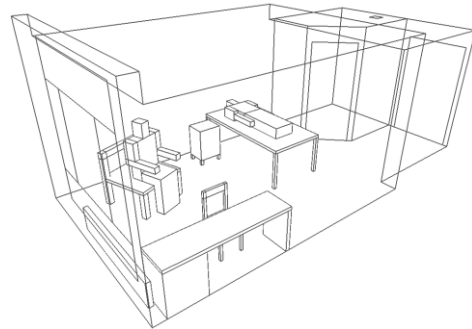


Fig. 10. Internal CFD ward-model

3.4. Internal CFD analysis

Various ventilation indices have been assumed to study airflow behavior using DesignBuilder. Simulation results given by DesignBuilder CFD tool were analyzed and presented. Also air flow in and out ward domain was assumed based on window type as follows:

	(A)		(B)		(C)	
Operable Window	in (l/s)	out (l/s)	in (l/s)	out (l/s)	in (l/s)	out (l/s)
	70	40	70	20	70,10	40
Main door	-	10	-	10	-	10
Toilet door	-	20	-	20	-	20
Window C, C*	-	-	-	20	60*	-

Table. 1. CFD Internal airflow in-out distribution

3.4.1. Window (A)

Based on CFD results window (A) gives acceptable airflow (0.1 m/s) over patient. The result of age of air shows that fresh air takes (8 minutes) to reach the patient which is relatively high in comparison with window patient distance as shown on figure below:

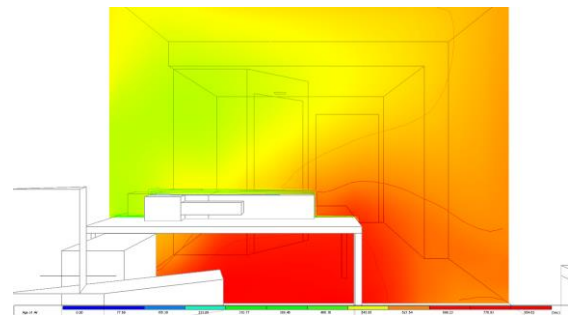


Fig. 11. Age of air (0-860 sec) window (A)

3.4.2. Window (B)

Window (B) gives acceptable airflow speed (0.18 m/s) over patient. Also age of air shows that fresh air takes (6 minutes) to reach patient which is less than case (A) as shown on figure below:

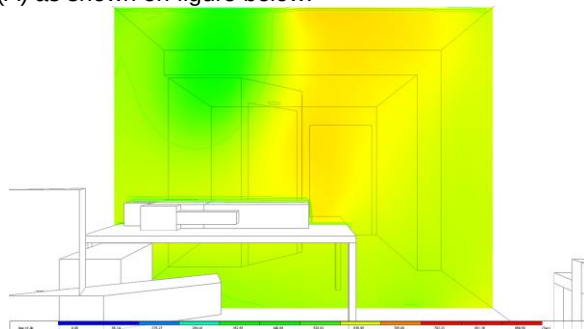


Fig. 12. Age of air (0-960 sec) window (B)

3.4.3. Window (C)

Window (C) gives slow airflow speed (0.04 m/s) over patient. Also age of air shows that fresh air takes more than (20 minutes) to reach patient which is much more than the previous two cases:

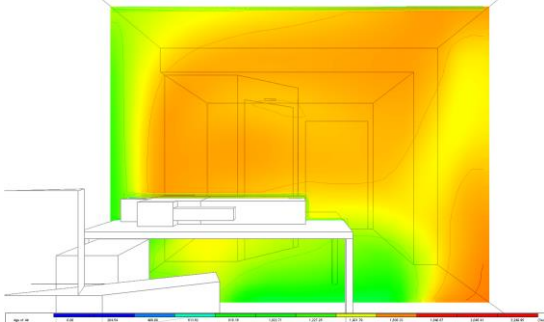


Fig. 12. Age of air (0-2250 sec) window (C)

If window (C*) opened in companion with (C) the results will improve. Airflow speed over the patient will become (0.07) and fresh air will take (9 minutes) to reach the patient. Still the previous two cases give better results than the last case.

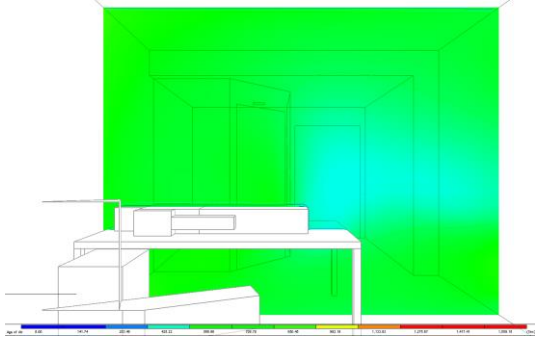


Fig. 12. Age of air (0-1560 sec) window (C,C*)

4. Conclusion

Results showed that window (B) gives best results for patient. This result did not consider building thermal calculations and solar radiation through window. Further research is needed to study the effect these parameters on natural ventilation feasibility.

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