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Basic drawings as primary material for teaching natural balanced ventilation systems

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ABSTRACT: With the increasing recognition of the role played by properly functioning natural ventilation systems in optimising the indoor environment, it is necessary to address more comprehensively within architectural teaching the consequent issues, through various educational methods and tools. The main objective of the authors' study described here was to familiarise architecture students with the problems of properly functioning natural ventilation in residential buildings, to discuss the issues related to innovative technical solutions in this area, and to provide them with natural balanced ventilation concepts. This was accomplished with an introductory lecture on the concept, to supplement general information on ventilation building systems, and the provision of basic drawings. Referred to in the article are the results produced from the inclusion of these basic drawings, concerning the operating of the new natural balanced ventilation model, as a supplementary teaching tool within the practical section of the Building Construction course.

INTRODUCTION

Existing residential buildings in Poland are, in most cases, structures built with a natural ventilation system. Meanwhile, the construction works that are to provide thermal modernisation of buildings and limitation of the inflow of a proper air stream to rooms frequently cause problems related to the proper functioning of natural ventilation. The result of thermal modernisation of buildings is the installation of new, tight windows and doors that make buildings over-sealed, and the proper functioning of the natural ventilation system is thus disturbed. This can lead to reverse draughts in ventilation ducts and potentially harmful consequences for the building occupants.

According to current Polish building regulations, new residential buildings, up to nine floors high, can be equipped exclusively with a natural ventilation system [1]. This system, due to relatively low costs of installation and maintenance of ventilation devices, requires a reduced amount of energy necessary for its operation, giving the occupants the possibility of individual control over the inner air. To assure high performance of the system, broad knowledge of the technical aspects of building systems and the ability to implement them in practice, are required on the part of architects.

With the increasing recognition of the role of properly functioning natural ventilation systems in optimising the indoor environment, and the impact on health and well-being of the occupants of interior spaces, there is a necessity to address these issues more comprehensively in teaching architecture. The modified concepts to improve fresh air distribution in interior spaces can be treated as a factor diminishing heating, ventilation and air conditioning (HVAC) loads and subsequently a decrease in energy consumption [2]. Therefore, it is becoming a determinant for sustainable architectural design.

Well-taught and skilled architecture students should have acquired the knowledge and abilities that ensure they avoid clients' and end-users' complaints lodged against designers, because of the faulty performance of buildings [3]. This should also result in the implementation of environmentally sustainable designs and technical devices (e.g. ground storage tanks, solar chimneys), to enhance performance, while reducing energy consumption.

Environmentally oriented architectural designs include open spaces to promote cross-ventilation, the strategic placement of windows and opening upper- and lower-storey windows to take advantage of the chimney effect [4]. Also included are elements of the passive stack ventilation system [5] (i.e. a combination of cross-ventilation generated through air pressure difference and a stack effect, as well as the Venturi effect, ventilation ducts linking selected rooms with a terminal on the rooftop or ridge tiles). These are supplemented with passive interior design methods and instruments [6], e.g. functional zoning of interior spaces, volume, materials specification, as well as multifunctionality of constitutive interior components.

The significance of the effective-ventilation-system problem implies the introduction of unconventional teaching methods and instruments to resolve problems related to the proper operation of a ventilation system. Basic drawings to examine the performance of a given ventilation system, as analysed by the authors, can be considered as exemplary teaching tools to follow lectures based on multimedia presentations, and to supplement learning activities in the current teaching framework (e.g. interdisciplinary workshops conducted by the practitioners, seminars, discussions and field studies).

Addressed in this article is the role of these basic drawings complemented by surveys, and introduced into the practical class of the Building Construction course delivered to architecture students. Also analysed is the new natural balanced ventilation concept and its impact on the improvement of indoor environmental quality, as well as its effect on the performance of a building ventilation system.

AIR INTAKE AND THE NATURAL VENTILATION SYSTEM

One of the design problems architects must consider from the conceptual phase of the design process is the inclusion of an air intake and a natural ventilation air duct. A properly developed design requires a good knowledge of the components of a natural ventilation system. Special attention should be paid to the quality of the designed natural exhaust system, achieved by connecting the internal space of the room with surroundings by means of a ventilation duct installed above roof level. With the location of the pressure equalisation plane above the room, the pressure lower than the atmospheric one is set for the whole interior. This type of ventilation, called natural exhaust ventilation, has a high performance conditioned by the constant inflow of external air into the ventilated rooms.

Thus, the prerequisite, when designing negative or positive pressure in the ventilation system is to ensure sufficient air supply to the building. To meet this requirement, an air intake, preferably located in the basement or ground floor of the building, and on the northern, eastern or north-eastern side of the building, should be placed in the immediate vicinity of the vertical ducts. The room intended for the installation equipment should be heated (recommended air temperature ranges from 16 °C to 18 °C, relative humidity from 40% to 60%), periodically cleaned and have all walls and floors made of washable materials. The area should be not less than 2.0 m^2, and the height at least 2.2 m (these values are based on normal utility needs).

The air intake grille must be installed at a minimum height of 100 centimetres from the ground surface and fitted with a filter to prevent dust particles and other contaminants from entering the grille. The cross-sectional area of the air intake duct must be at least twice as large as the sum of the cross-sectional areas of the ducts supplying the air from the intake to individual utility rooms. This is because of the resistance occurring during the flow of air masses through the filter and its movement, which should not exceed 0.5 m/s in closed rooms, and its optimum value is 0.15 m/s (Polish standards define the air flow rate in closed rooms at the level of 0.7 m/s) [1][7].

One of the environmentally sustainable and technologically advanced solutions enable connection of the air intake to an underground air storage tank below the ground freezing level. In this case, the air used for ventilation is preheated in the storage tank, which results in energy savings through minimal heat loss as a result of the exchange of air in rooms [8][9]. The concept of the natural balanced ventilation system, developed by T. Gaczoł as part of his research on the technical solutions to assure system effectiveness [10][11], and based on the consideration of the properly situated air intakes, is to endorse air circulation within the building, complementing the heat exchanging devices mentioned above.

METHODOLOGY

The general objective of a survey conducted among architecture students participating in this class was to verify their awareness of the need to develop design methods directly related to the quality of a ventilation system, and to stimulate a critical approach to the design given the scale of a building, as well as their understanding of the problem from a wider environmental perspective. Theoretical introductory lectures along with the practical section were designed to provide students with the knowledge and abilities to recognise architectural design contribution towards three main requirements:

1. Enhancement of the natural ventilation system efficiency in new buildings and in existing facilities subject to building thermal upgrading associated with insulation of external walls, and in accordance with thermal insulation requirements.
2. Endorsement of the ventilation system performance, as to balance the installation of airtight windows and doors in refurbished and retrofitted buildings.
3. Enabling the maintenance of ventilation equipment to eliminate potentially toxic or harmful chemical substances present in inner air.

The detailed objective of the study was to verify the inclusion of basic drawings, as explanatory material concerning the natural balanced ventilation building system, in the practical class of the Building Construction course which, along with Building Structures, Building Physics and Building Materials and Technical Services, is a basic subject of the technical module in the architectural teaching framework [3]. To verify the area for use of these graphic instruments, the second-year undergraduate architecture students attending the Building Construction course in the Faculty of Architecture at Cracow University of Technology had been engaged in the seminar. The aim of this seminar was to:

1. Provide students with information on the problems concerning the high performance of natural ventilation systems in residential buildings.

2. Discuss issues related to innovative technical solutions to improve the effectiveness of the building system with the use of diagrams containing basic drawings.
3. Verify students' critical approach to the questions of proper distribution and circulation of the air within the scale of the referenced building, as well as their identification of the problem from a wider environmental perspective.

The main part of the study comprised graphic illustrations of the system concept which were analysed and summarised by the students. These were introduced as a supplementary learning tool to enable students' understanding of relations between the building spatial configuration and air intake position to ensure high performance and appropriate indoor environment quality to result in efficient inner air exchange.

The aim of introducing the basic drawings into the architecture students' teaching was to facilitate analysis of the consequences of spatial organisation on building ventilation system performance. They were a way to clarify the possible interaction and interconnectedness of the built and natural environments and to inform their design, as well as to indicate the necessary conditions for the outlet-positive pressure and proper draught in the ventilation duct.

This graphic material played a similar role in verification of the theoretical knowledge on the ventilation system, as did the visuals or environmental drawings [12], proposed for the modified teaching scheme of the Building Construction course, in a search of design methods to enhance building system performance. The illustrative material within class and accompanied by the remarks and opinions made by the architecture students were verified for their potential as an explanatory part of a preconstruction drawing set.

The study was inaugurated with a preliminary multiple-choice questionnaire after the introductory lecture specifically dedicated to air distribution with the use of the natural ventilation system. Then, the two-part survey conducted among participating students complemented the graphic part of the study. This was combined with the close-ended questionnaires, as well as the descriptive part. Students were to respond to the set of questions related to the natural balanced ventilation system and the impact of it on the architectural design. The students were provided with a main concept brief within the introductory lecture before the practical part of the class.

The objective of the first part of the developed survey was students' self-assessment of their understanding of the effective execution of the ventilation system, conditioning the performance of the building. The descriptive part of the survey was based on students' opinions of the methods of presentation of the problem, as employed by the educators. Students were encouraged to present their reflections on the teaching methodology within the practical module of the Building Construction course.

CASE STUDY

The group of 37 second-year undergraduate architecture students attending the compulsory course on Building Construction were engaged in the study. Students worked within a two-hour session with prepared sketches and diagrams, to analyse possible differences in ventilation effectiveness as a function of air intake and exhaust positioning in a residential building. They were to examine two theoretical cases, with regard to the air pressure quality in rooms, as a substantial factor for the high functioning of the system.

The study began with the questionnaire to verify if the presented problem of a natural ventilation system was adequately explained in the lecture within the introductory phase of the enquiry. This preliminary multiple-choice questionnaire, to be fulfilled in advance as an analysis of the problem with use of graphics, encompassed the following:

1. Impact of the natural ventilation system on the interior microclimate parameters, with the emphasis on inner air quality.
2. Impact of the natural ventilation system on users' health and well-being, as well as psycho-physical comfort.
3. Effects of the natural ventilation system solutions on the cost-effectiveness of architectural design, as related to energy consumption.
4. Influence of the natural balanced ventilation concept on the enhancement of air exchange in interior spaces.

The diagrams developed by the instructors to be completed by the students were to help identify differences between the proposed air intake locations within the building structure and the combined basic drawings, to assess alternative solutions with regard to the ventilation system effectiveness of these spatial configurations. Students were required to indicate the direction of the air movement, as the precondition of the properly functioning ventilation system, and then to identify air pressure in the analysed rooms due to positioning of the air inlet, as negative or positive.

In the first example identified as case 1 and 1a, students were to assess the two proposals for the ventilation system where a clean room with air intake located on the low floors of the building; namely, the basement or ground floor, was combined with a high gravitational exhaust ventilation duct. Students were to identify the presence of negative air pressure created in the room, and the increase in the rate of it due to the reduction of the inflowing air, as occurs when the air-filling cubic volume of the room constantly is sucked-in and discharged to the outside.

While analysing the problem, students were to make an assumption that the external air masses are fed to the ventilated room from the air intake through the same walled duct (if it descends to the level of the air intake) or through the newly designed one, making the pressure difference equalised. The main tasks to accomplish by the students were to:

1. Recognise that inflow and outflow will occur within the same stream of air, regardless of the fact that the windows in the room are tightly closed and the building is thermally insulated.
2. Indicate that the separation of the inlet and outlet ducts (i.e. ducts walled in) for the system operating on the basis of a natural ventilation duct, is a necessary condition for efficient air exchange.
3. Notice that when the only existing natural ventilation duct begins at the level of the ventilated storey, a new supply duct must be connected to it.

In the second example considered by the students, the room located on the high floor of the building with an air inlet, was equipped with a short, vertical natural ventilation duct. Students were to solve the problem making the assumption that the external air masses are fed from the air intake to the ventilated room through the same walled duct (if it descends to the air intake level) or through a newly designed one. The main tasks to accomplish by the students were to:

1. Note that the negative pressure occurring initially in the room increases with the reduction in the air flow, due to the phenomenon of sucking the air filling the cubic volume of the room, preventing discharge of it to the outside.
2. Recognise that there will be an increased gravitational inflow of air into the room, and that inflow and outflow will occur within the same air stream.
3. Specify that rooms located on different levels are equally ventilated regardless of the difference in height of the exhaust duct (assuming the same cross-section).

The second part of the survey, with a closed-ended questionnaire, was concerned with the students' assessment of the problem through the proposed learning tool, and the value of the introduction of the basic drawings as a teaching tool. Students were asked to:

1. Indicate the explanatory value of the introductory lecture on the presented concept of natural balanced ventilation.
2. Explain if the basic drawings as materials to be completed were prepared in a comprehensive manner.
3. Point out if these graphics helped to recognise the building physics problems, as substantial for the environmental performance of buildings.
4. Specify if the analysed concept required adjustments in design method in terms of cohesiveness of functional and spatial requirements.

The closing part of the survey consisted of students' remarks on the specific assets of the natural balanced system of ventilation presented as an air exchange system. Students were encouraged to indicate their assessment of the concept in comparison to the commonly introduced natural ventilation system in residential buildings.

DISCUSSION

The students' responses to the preliminary multiple-choice questionnaire, given after the introductory theoretical lecture, revealed their good understanding of the meaning of natural ventilation for the indoor environmental quality, with 87% of affirmative responses (see Figure 1). Positive assessment of the impact of a building system on the well-being of users was 76% of participants, while 44% of them noticed the influence of the inclusion of natural ventilation on cost-effectiveness, as related to the reduction in energy consumption. Students recognised the value of the adjusted ventilation method, as demonstrated during the class, with 73% affirmative responses.

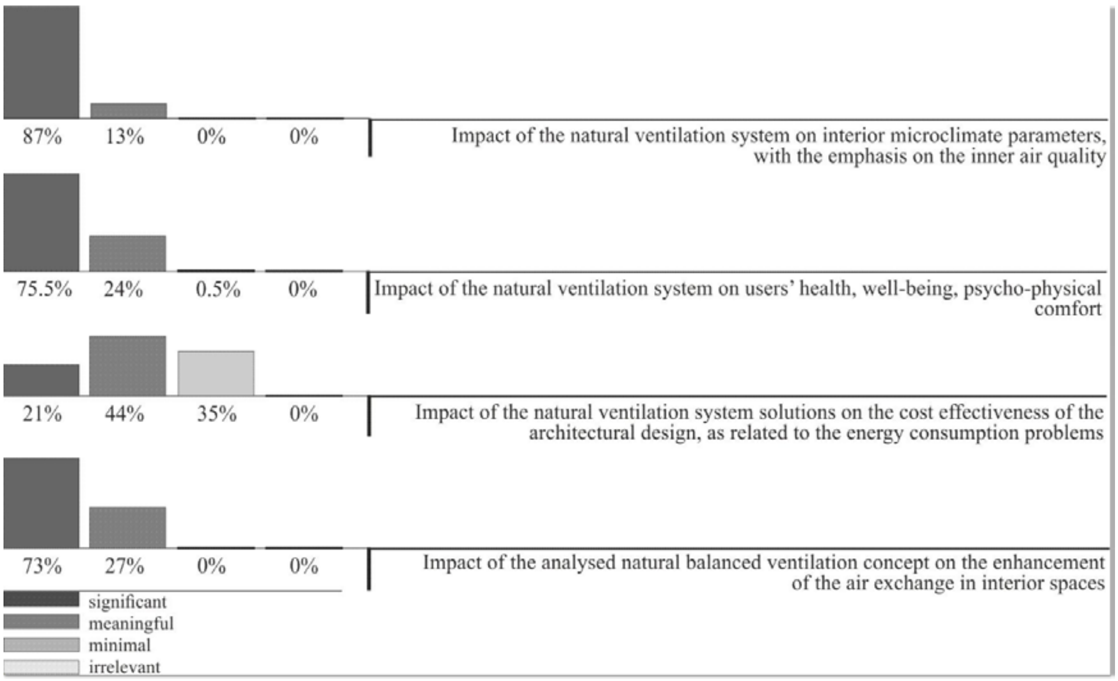

Figure 1: Preliminary multiple-choice questionnaire on the possible impact of natural ventilation (Source: Authors' drawing).

The second part of the study consisted in the completion of a set of basic drawings, to correctly mark the air movement direction, value of air pressure in indicated rooms (i.e. positive or negative), value of draught in ventilation ducts depending on the air intake location, and necessity for the introduction of separated ventilation ducts to induce pressure difference to assure system effectiveness (see Figure 2). Out of 37 students participating in the study, only seven were correct on this task.

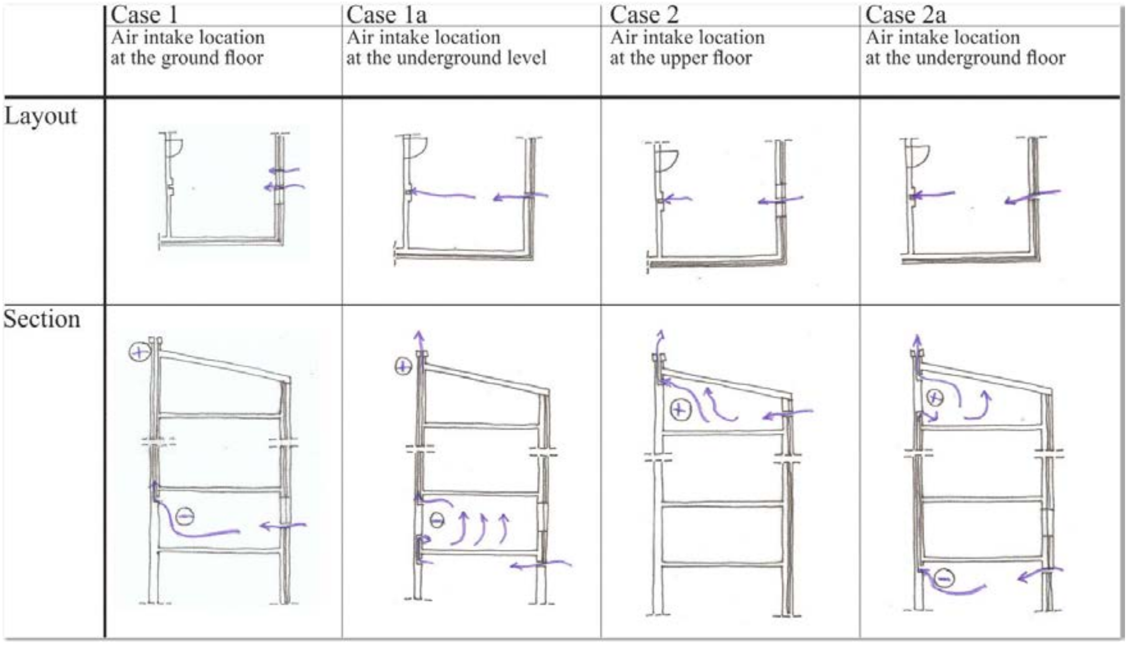

Figure 2: Study on the natural balanced ventilation system. Assessment of the air pressure, draught in the ventilation system with regard to the changing air intake location. Author: Student G. Konieczny. Supervisor: T. Gaczoł (Source: Archive of the Chair of Building Design, Faculty of Architecture at Cracow University of Technology).

The first part of the closing survey embedded with closed-ended questionnaires concerning the students' assessment of the proposed teaching tool to verify their theoretical knowledge, indicated the students' positive opinion on the legibility of the graphic tool as an explanatory means of the presented concept (see Figure 3). Still, 24% of them recognised there are differences in the analysed cases 1 and 2, because of the location of clean rooms that require modifications in the ventilation ducts to provide upper rooms with air pressure. Almost every student noticed the effect of the introduced system to promote effective air exchange, on the adjustments in the spatial organisation to fulfil functional requirements.

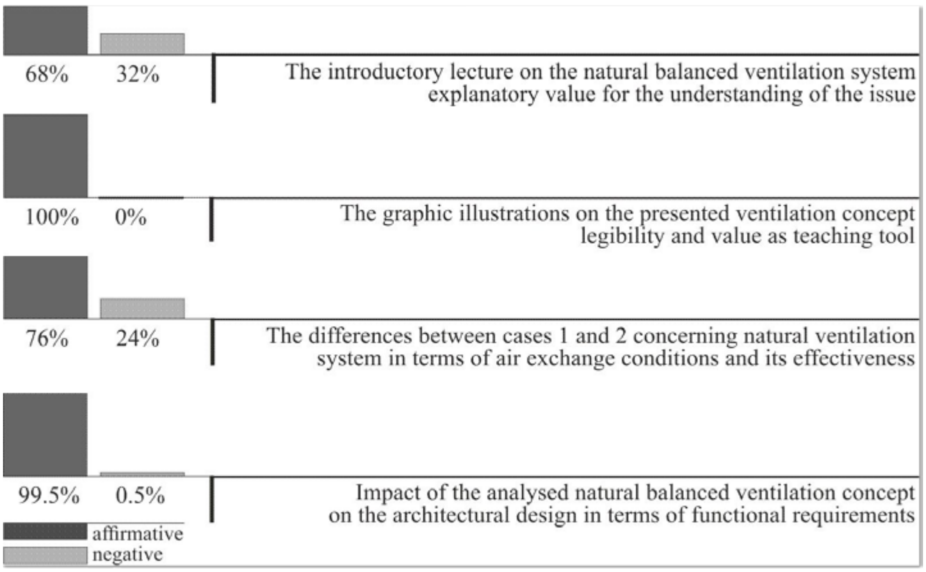

Figure 3: Closed-ended questionnaire on the assessment of basic drawings as an explanatory teaching tool (Source: Authors' drawing).

The students' comments on the inclusion of the natural balanced ventilation system in the residential building design, as enclosed in the descriptive part of the survey, referred to such specific issues as: improvement in the quality of inner air due to the effectiveness of air circulation; advancement in the microclimate of the indoor environment; progress in the air exchange rate; decrease in the possibility of air return; interconnectedness of proper design and system effectiveness.

CONCLUSIONS

The preliminary questionnaire, to assess the theoretical knowledge delivered within the introductory lecture, confirmed the students' perception of the impact of a natural ventilation system on indoor environmental quality and performance of a building, as well as the necessity to develop adjustments in the architectural design to endorse this building system concept. Although students, as disclosed in the closed-ended questionnaire, claimed their comprehension of the issue due to the introductory lecture, and their declaration of the understanding of basic drawings as tools to visualise problems related to the presented ventilation model, evaluation of their work revealed students' weakness in understanding the problem. This especially was in recognition of the phenomenon of the air flow and air pressure, as appearing in different examples of buildings.

In the opinions presented in the survey closing the study, students claimed their conviction that properly functioning ventilation systems require implementation of informed design based on the understanding of building construction, as well as building physics. Assessment of the study results indicates that basic drawings introduced as a supplementary teaching tool into the practice class of the Construction Building course require further development to provide students with abilities to recognise the design methods that would improve effectiveness of the inner air circulation, as a substantial criterion of informed design. The inclusion of basic drawings as a learning tool into the architectural educational framework into the Building Physics programme should be considered as a method to clarify the issue.

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