Revista Română de Inginerie Civilă, Volumul 10 (2019), Numărul 3

The influence of external air supply to air-conditioning systems with fan coil units on the design set-points and the energy consumption

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Abstract. Air-conditioning systems with fan coil units are used in multi-room buildings to adjust air parameters in many rooms with different thermal loads and various uses. These systems are commonly used to set the internal conditions in hotel rooms, offices, small retail stores in shopping centres and others. In fan coil units, the circulating air is treated to ensure that the design set-points are adjusted to the instantaneous heat loads in individual rooms. This treatment is individually controlled by temperature signals from individual rooms. As a result, at a given instance, the circulating air may be heated in some rooms, whilst cooled in the remaining. In this case, the central air treatment affects the overall energy demand for HVAC system. Additionally, the method of external air supply to air-conditioned rooms (direct or through fan coil units) affects both the treated external air set-point and the design parameters of fan coil units. In the paper, we discuss the methods of supplying the external air to air-conditioned rooms. We emphasise how each method influences the design set-points of the centrally-treated air, the size and duty points of fan coil units and the overall energy demand for the HVAC system under investigation.

1 Introduction

Reducing energy consumption in multi-space commercial buildings is ever more pressing these days, due to strict energy policies imposed in recent years. Simulations of HVAC operation have become thus crucial even during early design stages [1]. Also, diagnostic methods for HVAC subsystems, i.e. fan coil units, have been developed to enable fault detection and to improve accuracy of these simulations [2]. While these steps appear to contribute to some energy savings, there are still technological inefficiencies in the current designs of HVAC systems in multi-space buildings. In this paper, we focus on addressing the inefficiencies on the supply air side of the air conditioning systems with two-stage air treatment

Air conditioning systems with two-stage air treatment are commonly used to adjust thermal conditions in rooms with different purposes and usage [8]. Each system consists of a central supply-extract air handling unit (AHU) for the external air treatment/ transport and many individual devices (fan coil units, FCUs) for the circulating air treatment/transport [3]. Central and individual units are designed to operate both independently (e.g. in the periods of non-use) and closely together. While the air treatment tasks in these units are distinct, the overall outcome corresponds to reaching the design set-points in all the air-conditioned rooms. In the central AHU, the external air is treated to the assumed parameters, common for all the air-conditioned rooms, regardless of the individual instantaneous heat loads.

The advantages of systems with FCUs make them particularly suitable for applications to multi-room buildings, where individual rooms have relatively small areas and different thermal loads [9]. In these applications, it is possible to maintain individual temperature set-points in different rooms. The second stage treatment gives individual users flexibility to control and adjust temperature set-points locally, so that user-defined thermal comfort conditions are achieved.

The system restrictions are caused by limited capacity to control air humidity locally in individual rooms. In basic design solutions, air humidity in an individual room results from the AHU setting, properties of the air flow supplied, the FCU settings and individual moisture gains within a room.

Different aspects of improving performance of air-conditioning systems with two-stage air treatment with FCUs have been investigated. For instance, [5-6] discuss the necessity to account for the preparation of heating medium and refrigerant when assessing the system's energy consumption. Subsequently, [7] show that systems with variable water flow appear to improve energy performance of spaces, particularly under variable heat loads. [9] show that improving the system's

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control can lead to maximising energy savings. As a follow-up, [3] form a set of guidelines to design an intelligent control system for ventilation systems with fan coils.

We are, however, not aware of any studies on the impact of the method of supplying external air to the rooms on the energy demand for air treatment and transport. This issue seems to be interesting considering the widespread use of these systems and the large number of FCUs used in buildings.

2 Materials and method

In the context of the discussed systems, two airflows enter air-conditioned rooms, namely the external airflow and the circulating airflow sucked in by FCU. Although both airflows cooperate to adjust the conditions within the room (e. g. thermodynamic parameters of the air, air quality, flow speed in the occupied zone), these can be supplied independently. Both airflows can be supplied to the room through either common or separate diffusers. Fig. 1. shows schematically possible connections of external and circulating airflows supplied into the room. Fig. 1.a shows separate supplies of external and circulating air. Fig. 1.b-c show common supplies of external and circulating air, when connecting external air to FCU on the fan discharge (b) and suction (c) sides, respectively.

When supplying through common diffusers, it is a mixture of external and circulating airflows. In this case, external air, usually thermally-treated, can be fed into either the suction or discharge of the FCU. The room air-conditioning flow is the sum of the external and circulating airflows, therefore

$$V = V_e + V_i \tag{1}$$

With separate supplies of external and circulating air, Fig.1.a, set-points of both the thermally-treated external and circulating airflows should ensure thermal comfort within the occupied zone. Also, their direct impact on people should not cause discomfort, especially in areas with permanent work stations. A careful design of external air supply path is needed to ensure good air quality throughout the room. The desired outcome corresponds to the external air supply evenly dissolving throughout the room and ensuring the required hygienic conditions at all work stations. The external air is treated in a central AHU and distributed to individual rooms via ducts. The circulating air is sucked in by the FCU from the room and after purification and thermodynamic treatment, supplied back into the room. The circulating airflow is equal to the airflow forced through the FCU, hence

$$V_v = V_i \tag{2}$$

Temperature and humidity of the external and circulating air supplies usually vary. Typically, temperature of the thermally-treated external air depends on the outside air temperature. For a given outdoor air temperature, the external air temperature set-point after passing through AHU is thus, regardless of external and internal disturbances, constant. The temperature of the circulating air, on the other hand, varies from the minimum, when a cooling coil operates in the FCU, to the maximum, when a heating coil is in operation. As a result, at any given time, thermally-treated external air of equivalent parameters is supplied to all rooms, whereas the temperature set-point of the circulating air, treated in the FCU, can vary significantly in individual rooms to meet the occupant's local requirements.

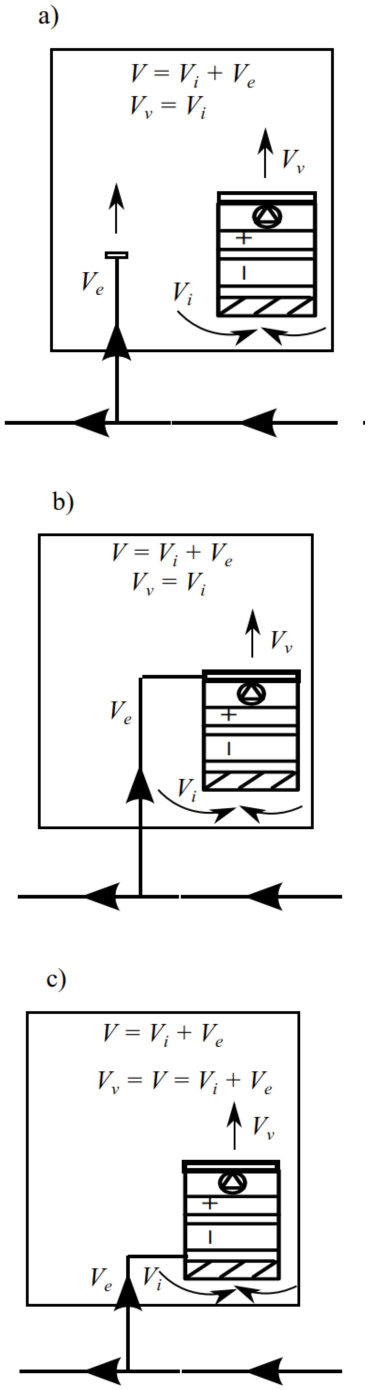

Fig. 1. Schematics of possible entries of external air into air-conditioned space through system with FCUs.

The common supply of external and circulating air occurs when both airflows are mixed prior to reaching supply diffusers (Fig. 1.b-c). The concept of design solution in Fig. 1.b is based on the supply of a mixture of separately-treated external and circulating airflows. The ventilating airflow can be determined from eq. (1). The circulating airflow is equal to the flow drawn by the FCU.

Fig. 1.c presents the concept of design solution in which the entire supply airflow goes through the FCU. The external air mixes with the circulating air. The mixture flows through the FCU, where the entire airflow is purified and thermally-treated (heated or cooled). The supply airflow is, thus, equal to the flow through the FCU, i.e.

$$V_v = V \tag{3}$$

When the mixture of external and circulating airflows is supplied, the supply temperature set-point depends on the thermodynamic changes in the exchangers of individual FCUs and may vary for individual FCUs. At a given time, the external air of corresponding parameters is supplied to all rooms and the circulating air, thermally-treated in FCU, sets the room air temperature.

We perform static modelling to compare the three supply methods under winter and summer design conditions. Our results are based on the following assumptions:
- the maximum supply air temperature increase is set at $\Delta t_s = t_i - t_s = 7$K, where t_i and t_s are room and supply air temperatures,
- the external airflow constitutes 25% of the air-conditioning airflow,
- room air temperature is 20ºC (winter design conditions) and 25ºC (summer),
- room air humidity ranges from 40 to 55%,
- increase of moisture content in the external air supplied corresponds to 1.5 g/kgda in winter and 2.3 g/kgda in summer (grams per kilogram of dry air),
- FCU max air heating by 10ºC.

We show the results on the Mollier Diagram (i-x). The results can be readily used to compare each method through the design set-points of AHUs, the size and duty points of FCUs and the overall energy demand for the HVAC system.

3 Results

Fig. 2. - Fig. 5. show the air treatment processes under winter and summer design conditions for the above-mentioned supply methods.

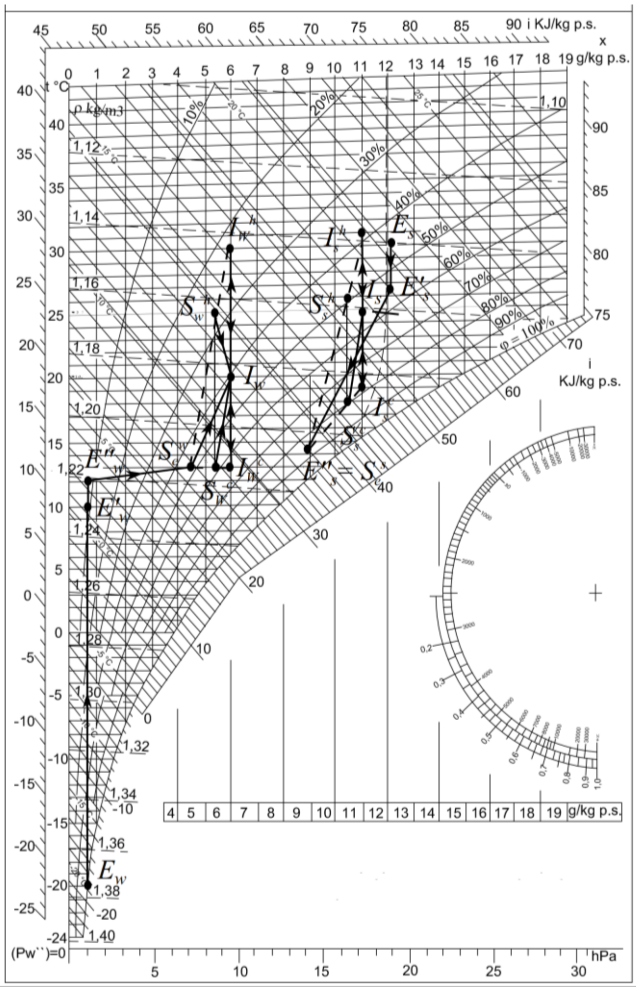

Fig. 2. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with external air supplied to FCU discharge side (see p.5 for full list of symbols).

When adjusting air parameters in the FCUs, the aim is to reduce or even eliminate air dehumidification. It is achievable when, in the summer period, the moisture released in a room is assimilated by the thermally-treated external air and the thermodynamic changes of the circulating air are carried out without changing the moisture content.

Keeping the relative air humidity set-point in rooms is possible with proper dehumidification of the external air. This is achieved by cooling the external air down to approximately 14°C. The airflow at such a low temperature, in the summer period, should, however, not be supplied into rooms. With the joint supply of external and circulating airflows (Fig. 2 and Fig. 3), a mixture of a higher temperature, as discussed in the paragraph on assumptions, is supplied into rooms.

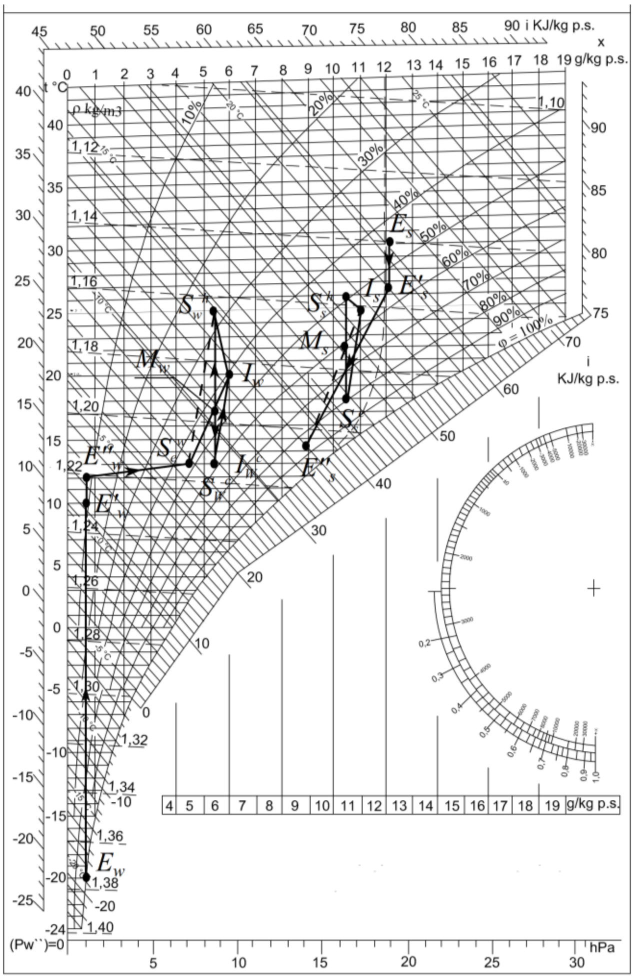

Fig. 3. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with external air supplied to FCU suction side (see p.5 for full list of symbols).

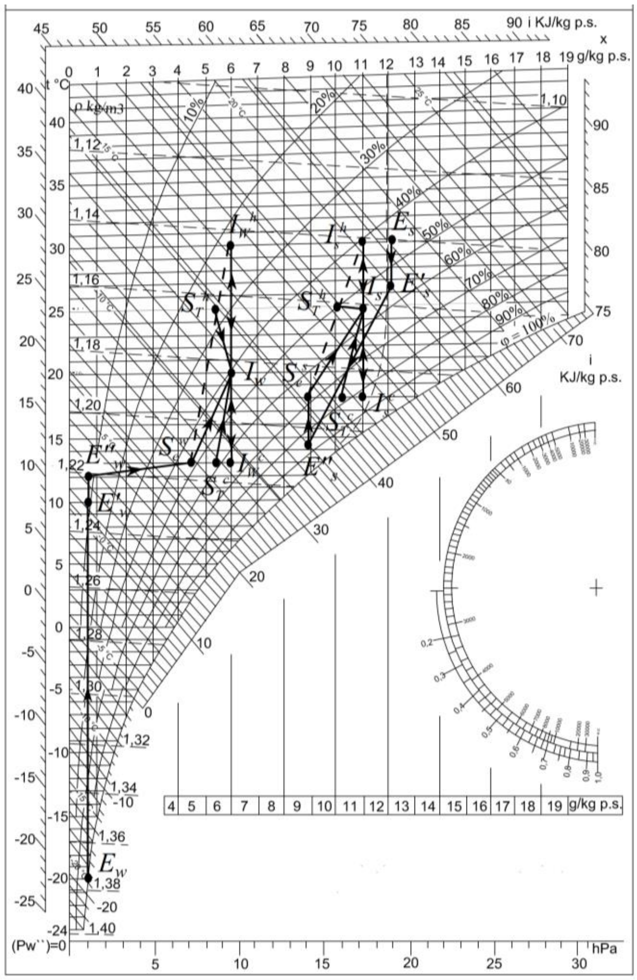

Fig. 4. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with direct external air supply to room and cooling without dehumidification (see p.5 for full list of symbols).

However, in the case of direct air supply, the external air should be heated to a higher temperature after cooling and dehumidification (Fig. 4). The alternative solution corresponds to restricting the external air cooling, thus limiting air dehumidification and relying on FCU to dehumidify the circulating air (Fig. 5).

The method of supplying the thermally-treated external air into the room determines the efficiency of the FCUs. With the direct supply of external air (Fig. 1.a, Fig. 4 and Fig. 5) or the joint supply with external air connected to FCU on discharge side (Fig. 1.b and Fig. 2), the airflows of treated air transported through the FCUs correspond to the circulating air flows. On the other hand, when the external airflows are connected to FCUs on the suction side (Fig. 3), the airflows transported by FCUs are equal to the sum of the circulating and external airflows. Also, the external airflow which is thermally-treated in the central AHU is subjected to thermodynamic re-treatment in the FCU.

The external air supply method to air-conditioned rooms affects the energy demand for treatment and transport of air-conditioning, external and recirculating air. To compare this demand, for the presented design solutions, we assume the air-conditioning airflow of 10 m^3/s, of which 2.5 m^3/s corresponds to the external airflow and 7.5 m^3/s to the circulating airflow.

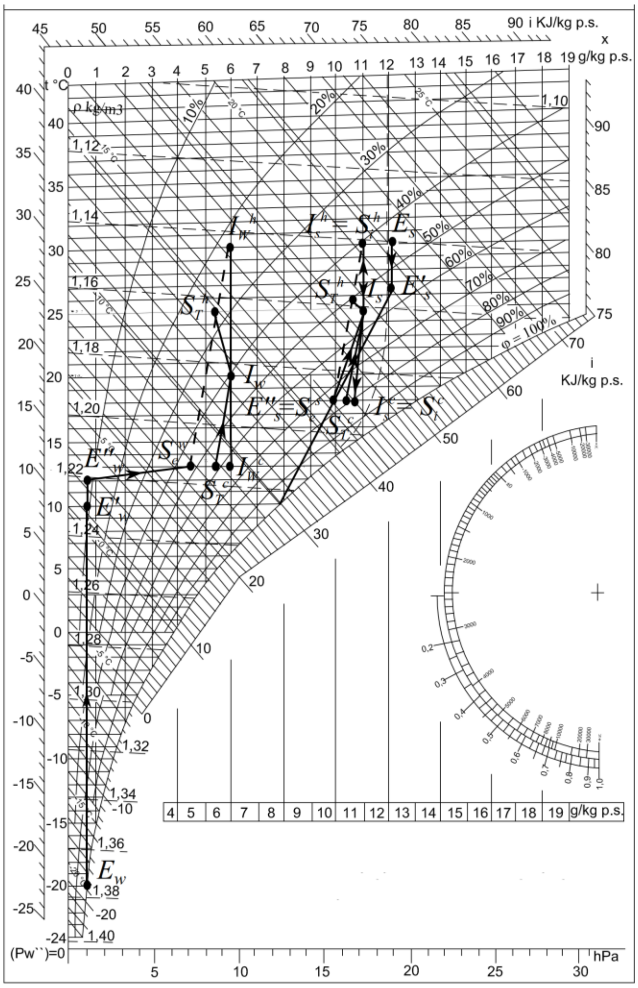

Fig. 5. Processes of air-conditioning airflow treatment and air transitions within a room under summer and winter design conditions for system with direct external air supply to room and cooling with dehumidification (see below for full list of symbols).

4 Conclusions

Air-conditioning systems with FCUs, for individual air treatment of circulating air, are commonly used to set air parameters in multi-space buildings. While systems under investigation are relatively well-known, these are hardly ever discussed in the context of reducing energy demand in the annual cycle of operation. This paper addresses this gap and investigates the impact of external air connection into the treated room on the energy consumption. This paper outlines four design solutions for thermal treatment of airflow in the system consisting of central AHU (for fresh air preparation) and FCUs (for individual treatment of circulating airflow). Two design solutions are based on the separate treatment and separate supplies of fresh air and circulating air (cases 1, 2). The latter two solutions are based on the common supply (cases 3, 4). Our simulations are based on the ventilating airflow of 10 m^3/s. Fig. 6 provides an overview of each case through comparisons of design parameters.

In the case of separate supplies, the energy demand for cooling under summer design conditions corresponds to:

- 126 kW, when circulating air is not dehumidified and external airflow (dehumidified) is heated in the heating coil of 12 kW duty or
- 115.5 kW, when both airflows are dehumidified.

In both cases, 45 FCUs are used to provide individual treatment of circulating air. These correspond to power drive exceeding 4 kW.

The common supply is achieved either by mixing both airflows in the suction or discharge side of FCU. In both cases, the cooling load required to treat 10 m^3/s of air-conditioned air corresponds to 113-114kW. For treatment of the circulating air, for mixing in the discharge side, 45 FCUs are to be charged by over 4 kW drive power. When mixing occurs in the suction side of FCU, air transport requirement is fulfilled by either 60 FCUs of 600 m^3/h duty or 45 FCUs of 800 m^3/h duty. Drive power for these solutions corresponds to 5.5kW.

In order to compare design solutions under consideration, we use identical parameters and design set-points (i.e. airflows, temperature set-points, temperature increments, etc). The most energy-efficient design solutions are based on separate supply of the fresh and circulating air with partial air dehumidification in FCU or mixing the airflows on the discharge side. The connection of the external air (common vs separate) is shown to be another governing parameter, which influences the energy consumption in the annual cycle of operation.

Symbols

V – air- conditioning airflow,
V_e – thermally-treated external airflow,
V_i - circulating airflow,
V_v – airflow on FCU discharge,
E_s – summer design parameters of external airflow,
E_s' - summer design parameters of external airflow after passing through the heat recovery exchanger,
E_s''- summer design parameters of external airflow after passing through the heat recovery exchanger and cooling coil,
E_w – winter design parameters of external air,
E_w' - winter design parameters of external air after passing through the heat recovery exchanger,
E_w'' - winter design parameters of external air after passing through the heat recovery exchanger and heating coil,
I_s – summer design parameters of room airflow,
I_s^c - summer design parameters of recirculating air after cooling,
I_s^h – summer design parameters of recirculating air after heating,
I_w – winter design parameters of room air,
I_w^c – winter design parameters of recirculating air after cooling,
I_w^h – winter design parameters of recirculating air after heating,
S_e^s - set-point of thermally-treated external air supplied into the room under summer design conditions,
S_e^w – set-point of thermally-treated external air supplied into the room under winter design conditions,

$S_T^{\,c}$ - theoretical supply air set-point when the circulating air is cooled,
$S_T^{\,h}$ - theoretical supply air set-point when the circulating air is heated,
$S_s^{\,c}$ - supply air set-point when the circulating air is cooled under summer design conditions,
$S_s^{\,h}$ - supply air set-point when heating the circulating air under summer design conditions,
$S_w^{\,c}$ - supply air set-point when the circulating air is cooled under winter design conditions,
$S_w^{\,h}$ - supply air set-point when the circulating air is heated under winter design conditions,
M_s – set-point of the mixture of thermally-treated external air and circulating air under summer design conditions,
M_w – set-point of the mixture of thermally-treated external air and circulating air under winter design conditions,

References

1. I. Korolija, Y. Zhang, L. Marjanovic-Halburd, V. I. Hanby, Energy and Buildings **59**, 214-227 (2013).
2. S. Pourarian, J. Wen, D. Veronica, A. Pertzborn, X. Zhou, R. Liu, Energy and Buildings **136**, 151-160 (2017).
3. E. Przydróżny, A. Przydróżna, Proceedings of *RoomVent & Ventilation*, 517-522 (2018)
4. E. Przydróżny, *Wysokosprawne systemy wentylacji i klimatyzcji- technologie i projektowanie.* **85**(50) (2007).
5. E. Przydróżny, F. Ruszel, Chłodnictwo i Klimatyzacja **11**, 33-36 (2003).
6. E. Przydróżny, F. Ruszel, Chłodnictwo i Klimatyzacja **12**, 31-35 (2003).
7. E. Przydróżny, F. Ruszel, Instal **2**, 2-7 (2003).
8. E. Przydróżny, F. Ruszel, Chłodnictwo i Klimatyzacja **6**, 18-26 (2006).
9. E. Przydróżny, A. Trybulec, Instal **10**, 49-52 (2014).

Acknowledgements

The paper was financially supported by Department of Air Conditioning, Heating, Gas Engineering and Air Protection; Wroclaw University of Science and Technology

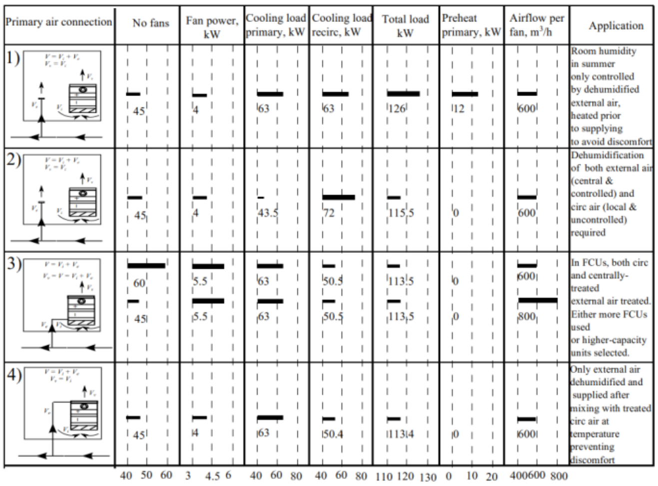

Fig.6. Governing parameters: number of fans, fan power, primary cooling load, circ cooling load, total load, preheat primary, airflow per fan for four cases under investigation.