Chapter 3

Air Conditioning Systems with Dual Ducts: Innovative Approaches for the Design of the Transport Network of the Air

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Additional information is available at the end of the chapter

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Abstract

We present two methods for sizing the network for the transport of the air, from the air handling unit to the terminal units, for a dual duct system, where air flows in the "cold" duct at a temperature less than the ambient temperature, while air flows in the "hot" duct at a temperature higher than the ambient temperature. The methods, compared to the traditional design criteria, lead to a reduction of channel size and, therefore, of overall network size and cost as well. The first method requires the "cold" channel to transport air at a temperature value slightly lower (1 ÷ 2°C) than the minimum inlet temperature (variable with time) required by the zones. The second requires the "hot" channel to transport air at a temperature value slightly higher (1 ÷ 2°C) than the maximum inlet temperature (variable with time) required by the zones. The methods have been applied to some reference networks. The saving of side surface of the networks varies between 14 and 27% with respect to the traditional approach; the constraint on the maximum speed of the air through the ducts is always respected, while this does not always occur with traditional criteria.

Keywords: dual duct, ductwork design, healthcare facilities, network size, cost saving

1. Introduction

The control of the thermo-hygrometric conditions and indoor air quality (IAQ) in rooms generally requires extensive networks for the transport of heat transfer fluids, most commonly water and air. A network of air distribution, due to the low density of the air, is considerably bulky. In general in healthcare facilities, and in any case in many critical environments contained therein, the indoor air quality (IAQ) plays a significant role. For the health of patients, particularly immunosuppressed patients, it is necessary to maintain at the lowest possible levels the concentration of particulate matter, which may also be a support for the formation of colonies of microorganisms, and the concentration of chemical pollutants. This is achieved with a significant dilution of the contaminants, by means of the introduction into the environment of considerable airflows. Italian law [1–3] establishes that the air is drawn exclusively from outside (therefore recirculation is forbidden) and subjected to various filtration stages.

In these cases (particularly in operating rooms, intensive care units, or departments for immunosuppressed patients), the air conditioning systems generally used are all-air systems with (outdoor) constant flow (CAV), since the high number of air changes per hour (ACH) must be guaranteed (sometimes values up to 50 are achieved). The leading value of the flow rate is that related to ventilation, rather than to summer or winter loads, and all-air systems with variable airflow (VAV) have to be excluded.

The constraint on the airflow rate is very strict in all those cases in which the protection of persons from the propagation of pathogens and/or the action of chemical pollutants must be guaranteed, even outside strictly health-related environments. In fact, new problems always emerge relative to air quality: the resurgence of diseases originally eradicated, not least tuberculosis (TB); the onset of respiratory syndromes of acute type, some resistant to drugs and therefore potentially pandemics, as SARS [4–8]; and the threats of chemical and biological terrorism.

If it is necessary to remain in the context of the constant flow rate systems, one of the options is that of the dual duct system. It ensures a local control of temperature conditions, up to the individual environments (rooms), even if some require "hot" while others require "cold", and an excellent level of air quality.

On the other hand, this type of system implies expensive and bulky air distribution networks, requiring spaces for the installation of the duct systems not easily available in the building sector, and high energy consumption [9–14], conceivably due to the remarkable availability of cheap energy at the time when this type of system has been developed (1940s–1960s of the last century).

As it is known, two parallel branched networks transport the air from the air handling unit (AHU) to the terminal units. Air flows through the so-called hot duct at higher temperature, compared to the required temperature in the room [15–17], whereas it flows at lower temperature (than the room temperature) through the so-called cold duct. A mixing box, thermostatically controlled, draws air from the hot and cold ducts and supplies each zone with the required flow rate, at the appropriate supply air conditions.

By virtue of these supply air conditions, more specifically the supply air temperature, widely variable during daytime and along the course of the year, the conditions of comfort into the room can be ensured, for which the mean radiant temperature is not taken into account.

The mixing box limits the noise levels as well. Indeed, in order to avoid huge overall dimensions of ducts that may become excessive with respect to the spaces normally available for

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their installation, high values, depending on the flow rate, are set for velocities through the ducts. At values between 12.5 and 30 m/s, the arising aerodynamic noise may be greatly disturbing, and this noise problem is only partially solved by properly designing the channel configuration [18]. Nevertheless, the overall dimensions of the dual-channel networks still remain high.

The choice of constant temperature values for the cold duct and for the hot duct, respectively, lower and higher than the room temperature, implies that the hot and the cold flow rates, arising from the calculations, have high values, significantly close to the total flow rate that must be carried by the trunks. In fact, while the supply air temperature varies over time, tending to t_c in summer and to t_h in winter, the air temperatures of cold and hot ducts are generally kept almost constant. When the zones require cold (presumably in summer), almost entire flow rates of the zones come from the cold duct; if the zones require heat, presumably in winter, the most part of the total airflow rates comes from the hot duct. Then, both the cold and the hot duct should each be able to carry more than 80—90% of the flow rate of the zone.

In this chapter, an innovative approach is presented for the dimensioning of the channels, based on the choice of not constant values for the temperatures of hot and cold duct. The cold channel carries air at a temperature equal or slightly lower than the minimum supply air temperature, among those required by the different zones, variable with time. The hot duct delivers air at a constant temperature, higher than the absolute maximum value of the zone supply temperature [19]. As alternative, the hot channel transports air at a temperature value slightly higher (1 ÷ 2°C) than the maximum inlet temperature (variable with time) required by the zones, while the cold duct delivers air at a constant temperature, lower than the absolute minimum value of the zone supply temperature.

The method has been applied to some reference buildings, a day center for dialysis located in the Italian city of Lecce and a private hospital located in the Italian city of Rome. A comparison is produced with the results obtained from the design criteria traditionally used.

2. Dimensioning criteria for the channel network

The network of channels has a tree structure with the root representing the AHU and the leaves the terminal units of each zone.

The different supply air conditions determine the different thermal zones. The calculation proceeds by considering the sensible thermal load $\Phi_i(\tau)$ (of the ith environment), variable over time, and evaluating the constant flow rate G_i able to compensate these loads in each room. The calculation is also based on the usual constraint related to the temperature difference between air supply and room and takes into account the flow rate required for ventilation. The mixing box serving the zone, where the ith room is included, will supply the computed airflow rate required by the zone; into the mixing box will enter hot and cold airflow rates coming from the terminal trunks of the dual duct system.

For the first trunk departing from AHU, one can write the conservation of mass and energy as

$$G = \sum_i G_i = G_c(\tau) + G_h(\tau) \quad (1)$$

$$\sum_i \Phi_i(\tau) + c_p G_h(\tau)[t_h(\tau) - t_r(\tau)] + c_p G_c(\tau)[t_c(\tau) - t_r(\tau)] = 0 \quad (2)$$

where G is the total mass flow rate carried by the trunk; $G_c(\tau)$ and $G_h(\tau)$ are the flow rates carried by the cold and hot trunks at the temperatures $t_c(\tau)$ and $t_h(\tau)$, respectively; $t_r(\tau)$ is the room temperature; c_p is the specific heat at constant pressure of moist air; and $\Phi_i(\tau)$ is the thermal load, varying over time, in each environment. The subscripts "c" and "h" refer to the cold and hot channels, respectively. These relationships, in conditions of maximum sensible load in summer $\Phi_{s,sum}$ and in winter $\Phi_{s,win}$ (subscripts "sum" and "win" refer to these conditions, respectively) become

$$G = G_{c,sum} + G_{h,sum} \quad (3)$$

$$\Phi_{s,sum} + c_p G_{h,sum}(t_{h,sum} - t_{r,sum}) = c_p G_{c,sum}(t_{r,sum} - t_{c,sum}) \quad (4)$$

$$G = G_{c,win} + G_{h,win} \quad (5)$$

$$\Phi_{s,win} + c_p G_{c,win}(t_{r,win} - t_{c,win}) = c_p G_{h,win}(t_{h,win} - t_{r,win}) \quad (6)$$

We can write similar equations for any trunk.

For the channels of the first trunk, departing from AHU, the airflow rates $G_{c,sum}$, $G_{c,win}$, $G_{h,sum}$, and $G_{h,win}$ can be calculated from the equations above, once the temperature values $t_{c,sum}$, $t_{c,win}$, $t_{h,sum}$, and $t_{h,win}$ are properly set; similar equations allow one to calculate the airflow rates for the other trunks, for cold and hot air, and winter and summer conditions, at all levels of the network.

With regard to the control of the relative humidity in the environment, it should be recalled that by normal practice, it is performed centrally, while the temperature control is assigned to the mixing boxes. Usually the air treated by the AHU exits with a moisture content corresponding to the thermodynamic state characterized by the temperature of the environment ($t_{r,sum}$ or $t_{r,win}$) and 45% of relative humidity.

Once the layout of the network is given, the sizing of the channels can be derived if the air speeds in the various trunks k are properly set; a usual criterion to choose the air speeds, starting from the range of values of the airflow rates Q_{hk}, Q_{ck} carried by the trunks, is reported as example in **Table 1** [20, 21].

In practical cases, as it is well known, a conventional sizing criterion is used. The criterion is based on the assumption that for each trunk, and therefore for each level of the network, it is possible to establish a priori the distribution between heat demand and cold demand, satisfied by hot duct and cold duct, respectively, once this distribution is known for the main trunk departing from the AHU (and therefore for the system as a whole). The method proceeds as follows:

a. The total airflow rates at each level of the network, that related to system (departing from the AHU) and those related to the various trunks, are determined from the supply airflow

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Airflow rate through the trunks Q_{hk}, Q_{ck}, m^3/h	$v_{max}, m/s$
10^5–7×10^4	30
7×10^4–4.5×10^4	25
4.5×10^4–2.5×10^4	22.5
2.5×10^4–1.7×10^4	20
1.7×10^4–10^4	17.5
10^4–5×10^3	15
5×10^3–2×10^3	12.5

Table 1. Maximum air speed in the ducts.

A	**B**	**C**
$G_{c,sum}/G$	$G_{c,k}/G_k$	$G_{h,k}/G_{c,k}$
1.0–0.90	1	0.7
0.89–0.85	0.95	0.7
0.84–0.80	0.9	0.75
0.79–0.75	0.85	0.75
≤0.74	0.8	0.8

Table 2. Conventional ratios for the sizing of hot and cold ducts, in the absence of perimeter heating.

rates required by individual environments and served by the trunk, as it has been previously described.

b. Similarly, the airflow rates of hot and cold channels in the first trunk departing from the AHU are evaluated, once that the temperatures $t_{c,sum}$, $t_{c,win}$, $t_{h,sum}$, and $t_{h,win}$ have been set.

c. By considering the summer case, the ratio is calculated between the total flow rate in the cold channel, $G_{c,sum}$, and the total airflow rate of the plant G.

d. Once this ratio, representing the request of cold, is known, the corresponding values for the kth trunk of the same ratio $G_{c,k}/G_k$ are chosen, for example, according to the values of column B of **Table 2** [21]. In **Table 2**, one can set the range of values in column A, related to the first trunk departing from the AHU, and then obtain, from column B and C, the values of the ratio to assign to the trunks, for cold and hot duct, respectively, at each level of the network. This procedure avoids to solve the equations for each trunk, which require the thermal loads be known for each level of the network.

e. From the total flow rate G_k of the trunk, one can obtain the airflow rate of the cold channel $G_{c,k}$ of the trunk from the ratio of column B.

f. For each trunk, one can calculate the airflow of the hot duct $G_{h,k}$ as a percentage of the flow rate of the relative cold duct, with reference to the column C of **Table 2**.

In order to evaluate the order of magnitude of the airflow rate, let us consider the mass balance:

$$G_n = \left[\sum G_i\right]_n = G_{c,n}(\tau) + G_{h,n}(\tau) \tag{7}$$

with reference to the generic zone n of the plant, and the energy balance

$$\left[\sum_i \Phi_i(\tau)\right]_{n,sum} + c_p G_{h,sum,n}(\tau)[t_{h,sum}(\tau) - t_{r,sum}] = c_p G_{c,sum,n}(\tau)[t_{r,sum} - t_{c,sum}(\tau)] \tag{8}$$

in summer and

$$\left[\sum_i \Phi_i(\tau)\right]_{n,win} + c_p G_{c,win,n}(\tau)[t_{r,win} - t_{c,win}(\tau)] = c_p G_{h,win,n}(\tau)[t_{h,win}(\tau) - t_{r,win}] \tag{9}$$

in winter. On the other hand, we also have in summer:

$$\left[\sum_i \Phi_i(\tau)\right]_{n,sum} = c_p G_n[t_{r,sum} - t_{in,sum}(\tau)] = [G_{c,n}(\tau) + G_{h,n}(\tau)][t_{r,sum} - t_{in,sum}(\tau)] \tag{10}$$

and in winter:

$$\left[\sum_i \Phi_i(\tau)\right]_{n,win} = c_p G_n[t_{in,win}(\tau) - t_{r,win}] = [G_{c,n}(\tau) + G_{h,n}(\tau)][t_{in,win}(\tau) - t_{r,win}] \tag{11}$$

where the subscript "in" refers to the variable for inlet conditions (supply air conditions). By substitution, one obtains for both summer and winter:

$$G_{h,n}(\tau)[t_h(\tau) - t_{in}(\tau)] = G_{c,n}(\tau)[t_{in}(\tau) - t_c(\tau)] \tag{12}$$

$$\frac{G_{c,n}}{G_{h,n}} = \frac{[t_h(\tau) - t_{in}(\tau)]}{[t_{in}(\tau) - t_c(\tau)]} = \frac{\Delta t_{h,in}}{\Delta t_{c,in}} \tag{13}$$

Generally, temperatures of the cold and hot channel are kept almost constant, while the zone supply temperature varies over time, tending to t_c in summer and to t_h in winter. It implies that the computed airflow rates, for the hot and the cold duct, are significant fractions of the total airflow rate in the trunks. The air supplied to each zone, in summer, comes largely from the cold duct and in winter flows largely in the hot one. Then, both the cold and the hot ducts should each be able to carry more than 80–90% of the flow rate of the zone.

The trunk, which consists of the pair of hot and cold ducts, is coherently dimensioned to carry 1.7–1.8 times the supply airflow rate of the zone, once that one sets the values of the airspeed, and this occurs at all the levels of the network, with consequently considerable overall dimensions and high costs.

3. The new method for network dimensioning

As alternative method for network dimensioning, an innovative approach is presented here, based on the choice of not constant values for the temperatures of hot and cold duct, where either one of the hot and cold networks always carries the most part of the flow rate of the trunks k.

In the first case (method 1), the cold channel carries air at a temperature equal to or slightly lower (1 or 2°C) than the minimum supply air temperature, among those required by the different zones (which varies in time). The hot duct delivers air at a constant temperature t_h, higher than the absolute maximum value of the zone supply temperature [19]. The value of the minimum supply air temperature $t_{in,\,\mathrm{min}j}$ can be over time either lower or higher than the room temperature t_r (this occurs generally in summer time and in winter time, respectively); as a consequence, the value t_c of the cold network temperature can be either lower or higher than t_r. As alternative (method 2), the hot channel transports air at a temperature value slightly higher (1 ÷ 2°C) than the maximum inlet temperature (variable with time) required by the zones, while the cold duct delivers air at a constant temperature, lower than the absolute minimum value of the zone supply temperature.

The new approach implies reduced overall dimensions (reduced space requirements) and lower installation costs of the networks and therefore represents an improvement with regard to the two critical aspects of the dual duct systems currently designed.

For the generic zone n, once that the values of

$$t_c(\tau) = t_{in,\,min}(\tau) - \delta, \qquad\qquad \delta = 1 - 2^{\circ}C \tag{14}$$

are fixed and the mass balance is written as

$$G_n = \left[\sum G_i\right]_n = G_{c,\,n}(\tau) + G_{h,\,n}(\tau) \tag{15}$$

the energy balance becomes

$$\Phi_{s,\,sum} + c_p G_{h,\,sum}(t_{h,\,sum} - t_{r,\,sum}) = c_p G_{c,\,sum}\left(t_{r,\,sum} - t^*_{c,\,sum}\right) \tag{16}$$

$$\Phi_{s,\,sum} = c_p G_{n,\,sum}[t_{r,\,sum} - t_{in}(\tau)] \tag{17}$$

for summer conditions and

$$\Phi_{s,\,win} + c_p G_{c,\,win}\left(t_{r,\,win} - t^*_{c,\,win}\right) = c_p G_{h,\,win}(t_{h,\,win} - t_{r,\,win}) \tag{18}$$

$$\Phi_{s,\,win} = c_p G_{n,\,win}[t_{in}(\tau) - t_{r,\,win}] \tag{19}$$

for the winter ones.

By substitution we obtain for both summer and winter:

$$G_{c,\,n}(\tau)\left[t_{in}(\tau) - t^*_c(\tau)\right] = G_{h,\,n}(\tau)[t_h - t_{in}(\tau)] \tag{20}$$

$$\frac{G_{c,\,n}}{G_{h,\,n}} = \frac{[t_h(\tau) - t_{in}(\tau)]}{\left[t_{in}(\tau) - t^*_c(\tau)\right]} \tag{21}$$

Eq. (21) says that, both in winter and summer, the cold airflow rates $G_{c,n}$ flowing through the cold trunks and supplying the mixing boxes represent higher fractions of the total flow rates of the zones if the differences, between the constant hot duct temperature and the supply temperatures, are high and if the differences between those and the minimum supply air temperature are small.

For each zone, sensible thermal loads can be calculated as a function of time, and the same can be done for the supply air temperature values in the environments of the zone:

$$t_{in}(\tau) = t_r - \frac{\Phi_{s,n}(\tau)}{c_p G_n} \tag{22}$$

The minimum value of the supply air temperature $t_{in,min}(\tau)$ reduced by δ, hour by hour, represents the temperature of the cold channel $t_c^*(\tau)$. For each trunk k of the network, for each time interval j, one can write the energy and mass balances, in winter and in summer, as

$$G_k = G_{c,kj} + G_{h,kj} \tag{23}$$

$$\Phi_{s,sum,kj} + c_p G_{h,sum,kj}[t_{h,sum} - t_{r,sum}] = c_p G_{c,sum,kj}\left[t_{r,sum} - t_{cj}^*\right] \tag{24}$$

$$\Phi_{s,win,kj} + c_p G_{c,win,kj}\left[t_{r,win} - t_{cj}^*\right] = c_p G_{h,win,kj}[t_{h,win} - t_{r,win}] \tag{25}$$

Once that the air velocity values in all different trunks are fixed, referring to **Table 1**, for example, and from the maximum values of the cold and hot airflow rates in the trunks, the diameters of the hot and cold ducts of each trunk can be evaluated. Once the lengths of the various trunks of the network are known, one can calculate the surfaces of the ducts and so the weight of the network.

With a similar approach, we can write

$$t_h(\tau) = t_{in,max}(\tau) + \delta, \qquad \delta = 1 - 2^{\circ}C \tag{14$'$}$$

and fix the temperature $t_c(\tau)$, for example, equal to the dew point value. With the same consideration of the previous case, we obtain Eq. (20′) and Eq. (21′) as

$$G_{c,n}(\tau)[t_{in}(\tau) - t_c] = G_{h,n}(\tau)\left[t_h^*(\tau) - t_{in}(\tau)\right] \tag{20$'$}$$

$$\frac{G_{c,n}}{G_{h,n}} = \frac{\left[t_h^*(\tau) - t_{in}(\tau)\right]}{[t_{in}(\tau) - t_c]} \tag{21$'$}$$

4. Application example of the proposed method

The proposed method is applied here to calculate the dual duct networks of two reference buildings. The first (building A) is a day center for dialysis located in the city of Lecce (Southern Italy); the second is a private hospital located in the city of Rome (Central Italy).

The room temperature in summer is equal to 26°C for both the buildings; the room temperature in winter is equal to 22 and 20°C, respectively, for building A and building B.

For a day type for each month of the year and a daily period of 12 h (from 6:00 AM to 6:00 PM), the thermal loads of the different zones have been obtained as a function of time. Therefore, it has been possible to define the thermal zones and to evaluate the airflow rates required for each environment, to cope with the maximum sensible load in summer, the maximum sensible load in winter, and the ventilation needs. The AHU processes a total flow rate of air that obviously is the sum of the greatest of the three previous values, extended to all the zones.

In order to limit a priori the network extension, two AHUs have been used for building A, one serving 12 zones and 20 trunks as one serving 11 zones and 18 trunks. For building B, three AHUs have been used, each one serving 6 zones and 11 trunks.

Data for each network, namely, the lengths, airflow rates and maximum speeds in the trunks, are given in **Tables 3** and **4** for building A and building B, respectively.

Network AA				**Network AB**		
k	$l_k[m]$	$v_{max}[m/s]$	$Q_k[m^3/h]$	$l_k[m]$	$v_{max}[m/s]$	$Q_k[m^3/h]$
1	2.00	22.50	35980.30	2.00	22.50	32022.85
2	3.00	15.00	7582.58	3.00	15.00	7877.03
3	1.00	12.50	2641.67	1.00	12.50	2708.71
4	2.00	12.50	1993.48	2.00	12.50	2708.71
5	3.00	12.50	2947.43	3.00	12.50	2459.61
6	7.00	22.50	28397.72	7.00	20.50	24145.83
7	4.50	20.00	19172.40	4.50	17.50	15317.31
8	1.00	15.00	8705.97	1.00	20.00	9131.37
9	1.00	12.50	2697.94	1.00	12.50	2247.55
10	3.00	12.50	2033.26	3.00	12.50	2708.71
11	2.00	12.50	3974.76	2.00	12.50	4175.11
12	4.00	15.00	10466.43	4.00	15.00	6185.94
13	10.00	12.50	3919.05	10.00	12.50	3203.69
14	1.00	15.00	28397.72	1.00	15.00	24145.83
15	1.00	12.50	2861.81	1.00	12.50	2950.86
16	3.00	12.50	3517.49	3.00	12.50	2944.17
17	1.00	12.50	2846.02	1.00	12.50	2933.49
18	2.00	15.00	10466.43	2.00	12.50	6185.94
19	2.00	12.50	3562.29			
20	2.00	12.50	2985.09			

Table 3. Data of the networks AA and AB of building A.

Network BA				Network BB			Network BC		
k	$l_k[m]$	$v_{max}[m/s]$	$Q_k[m^3/h]$	$l_k[m]$	$v_{max}[m/s]$	$Q_k[m^3/h]$	$l_k[m]$	$v_{max}[m/s]$	$Q_k[m^3/h]$
1	3.00	17.50	12551.76	3.00	17.50	14691.15	3.00	17.50	13593.78
2	2.50	12.50	1774.82	2.50	12.50	2143.52	2.50	12.50	2089.40
3	5.00	17.50	10776.94	5.00	17.50	12547.63	5.00	17.50	11504.38
4	3.00	17.50	8573.20	3.00	17.50	10790.94	3.00	17.50	9563.88
5	2.50	12.50	2562.82	2.50	12.50	2586.83	2.50	12.50	2043.60
6	8.00	15.00	6010.38	8.00	15.00	8204.11	8.00	15.00	7520.28
7	3.00	15.00	4166.51	3.00	15.00	5965.41	3.00	15.00	5385.96
8	2.50	12.50	1982.66	2.50	12.50	3402.44	2.50	12.50	3463.73
9	6.00	12.50	2183.85	6.00	12.50	2562.98	6.00	12.50	1922.23
10	2.50	12.50	1843.87	2.50	12.50	2238.69	2.50	12.50	2134.32
11	2.50	12.50	2203.74	2.50	12.50	1756.69	2.50	12.50	1940.50

Table 4. Data of the networks BA, BB, and BC of building B.

The diameters of the hot and cold channels are representative of the size of the whole network; the peripheral surface of the ducts stands as indicative parameter for the weight of the network and therefore of its cost. As an index of the overall dimension of the single trunk $\boldsymbol{k}$, the covering factor $\boldsymbol{F_k}$ was also introduced, according to [16, 19]:

$$\boldsymbol{F_k} = \frac{\boldsymbol{G_{k,\,max}}}{\boldsymbol{G_k}} \tag{26}$$

It is defined as the ratio between the airflow rate $\boldsymbol{G_k}$ that flows through the $\boldsymbol{k}$th trunk and $\boldsymbol{G_{k,\,max}}$

$$\boldsymbol{G_{k,\,max}} = \frac{\boldsymbol{\pi}}{\boldsymbol{4}} \boldsymbol{v_k} \left[\boldsymbol{D_{hk}^2} + \boldsymbol{D_{ck}^2}\right] \tag{27}$$

which represents the flow rate that the trunk, already dimensioned, could carry if the air flowed at the maximum set speed.

The $\boldsymbol{F_k}$ factor takes values between 1 and 2; it approaches 1 when only one of the two ducts actually carries the entire flow rate of the trunk, while the other duct carries only a small correction. The factor tends instead to 2 when the both hot and cold ducts can both carry the entire flow rate of the trunk. With regard to the whole network, the $\boldsymbol{F_{net}}$ factor can be defined as the weighted average of $\boldsymbol{F_k}$, where the weights are the products between the lengths and the flow rates of the trunks:

$$\boldsymbol{F_{net}} = \frac{\sum_k \boldsymbol{F_k G_k l_k}}{\sum_k \boldsymbol{G_k l_k}} \tag{28}$$

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5. Analysis of results

The results of the dimensioning of the networks with the first approach (method 1) refer to the networks AA, AB and BA, BB, and BC in the case of air temperature t_c in the cold duct taken equal to the minimum required (minus 1°C) and of the air temperature t_h in the hot duct taken as equal to 40°C. Results obtained with the second approach (method 2) refer to the same networks, in the case of air temperature t_h in the hot duct taken equal to the maximum required (plus 1°C) and of air temperature t_c in the cold duct taken as equal to the dew point value (for building A, 13°C in summer and 10°C in winter, for building B, 13°C in summer and 7°C in winter).

In order to make a comparison between the results obtained with the traditional sizing method, the savings are briefly presented in **Tables 5** and **6**, respectively, for building A and building B, as they are obtained for the five networks, in terms of the peripheral surface of the channels and of the evaluated values of the network factor F_{net}.

In **Table 7** we report the savings of side surface and the network factor by considering the whole building A and the whole building B.

For the building A, the maximum value obtained for F_{net} is 1.33, and it occurs for the network AA when the hot duct temperature t_h varies (method 2); it decreases to 1.15, for the networks AB when we use the method 1. For the building B, the maximum is obtained for the network BC when method 2 is used; the minimum occurs for the network BA with method 2 again. The achieved values of F_{net} with the proposed methods are always smaller than those obtained by using the traditional design criteria.

	Method 1	**Method 2**	**Traditional method**
	Saved surface (%)-F_{net}		F_{net}
Network AA	31–1.26	14–1.33	1.76
Network AB	22–1.15	13–1.21	1.60

For method 1: $t_h = 40^\circ C$. For method 2: $t_{c,sum} = 13^\circ C$, $t_{c,win} = 10^\circ C$.

Table 5. Savings' percentage of the total side surface and network factors for building A.

	Method 1	**Method 2**	**Traditional method**
	Saved surface (%)-F_{net}		F_{net}
Network BA	18–1.41	14–1.283	1.65
Network BB	25–1.34	18–1.36	1.70
Network BC	19–1.43	15–1.47	1.80

For method 1: $t_h = 40^\circ C$. For method 2: $t_{c,sum} = 13^\circ C$, $t_{c,win} = 7^\circ C$.

Table 6. Savings' percentage of the total side surface and network factors for building B.

	Method 1	Method 2	Traditional method
	Saved surface (%)-F_{net}		F_{net}
Building A	27–1.21	14–1.28	1.7
Building B	21–1.35	17–1.37	1.72

Table 7. Savings' percentage of the total side surface and network factors for buildings A and B.

The results prove that the new methods allow a substantial reduction in the overall dimensions. This reduction is largely shared by the whole network. For all trunks, and with regard to method 1, a substantial equivalence, or a weak increase of the diameters of the cold duct (compared to those obtained with the traditional methods), is counteracted by a significant reduction of the diameters of the hot duct. Vice versa, with regard to method 2, a weak increase of diameters of the hot duct is counteracted by a substantial reduction of diameter of the cold duct. The effect on the overall dimensions can be represented in terms of sum of the diameters of cold and hot ducts. The comparison between the methods is reported in **Figure 1** for each trunk of a network. **Figure 1** refers to the case of the building A (network AA). Similar behaviors occur for the other networks; in terms of reduction of overall dimensions, method 1 seems to be more efficient.

The surface fraction, saved by using both the new methods compared to the traditional one, presents not negligible values. With reference to the traditional method, the savings range

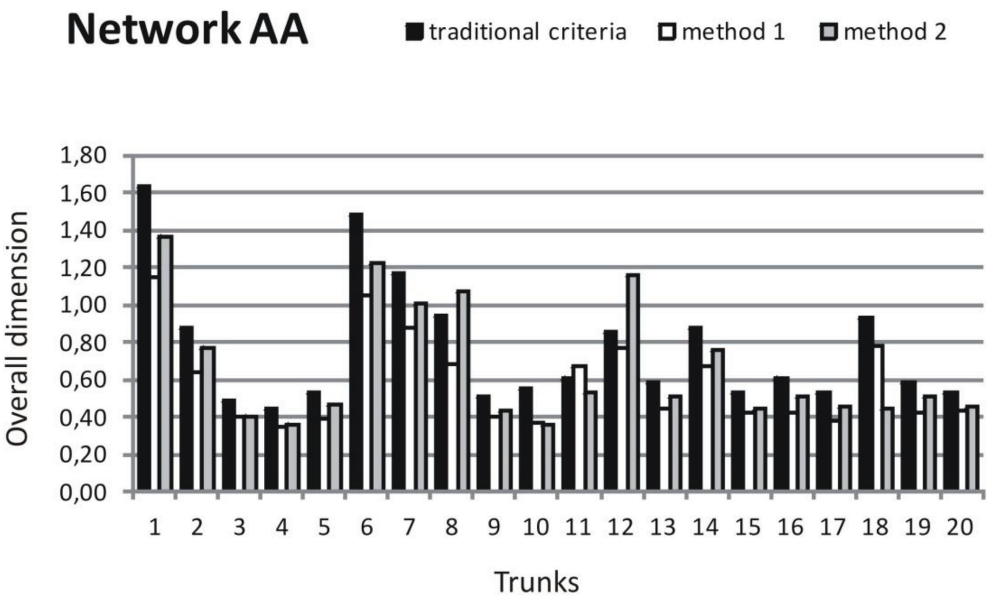

Figure 1. Overall dimensions for each trunk of the network: sum of diameters of cold and hot ducts.

between 14 and 27% for the building A (located in Lecce), when methods 2 and 1 are used, respectively, and between 17 and 21% for the building B.

Therefore, both methods imply a reduction of side surface (and cost). For the building B (located in Rome), for which the room temperature in winter is lower, the savings obtained in terms of surface, by using the two methods, differ only for 4%. For the building A (in Lecce), for which the room temperature in winter is higher, the savings obtained with method 2 is almost half of that obtained with method 1. Method 2 works better for the building B, where room temperature is higher.

Both methods imply lower network factors, with respect to the traditional method, but it is preferable to use one method rather than another according to the summer and winter design temperatures. In our study, a lower winter design temperature implies an increase in savings by using method 2.

If we consider the absolute maximum and minimum values of the supply temperature (for all hours, all year round, and regardless of the zone), we can see that the network factors tend to increase with the difference between these maximum and minimum values, for both methods 1 and 2. In general, method 1 allows to obtain lower network factors.

6. Conclusions

In general in healthcare facilities, and in any case in many critical environments contained therein, the indoor air quality (IAQ) plays a significant role. For the health of patients, particularly immunosuppressed patients, it is necessary to maintain at the lowest possible levels the concentration of particulate matter, which may also be a support for the formation of colonies of microorganisms, and the concentration of chemical pollutants.

In these cases (particularly in operating rooms, intensive care units, or departments for immunosuppressed patients), the air conditioning systems generally used are all-air systems with (outdoor) constant flow (CAV), since the high number of air changes per hour (ACH) must be guaranteed (sometimes values up to 50 are achieved). The leading value of the flow rate is that related to ventilation, rather than to summer or winter loads, and all-air systems with variable airflow (VAV) are to be excluded.

The dual duct system ensures excellent IAQ and good control of the thermo-hygrometric conditions and allows temperature adjustment in each zone, up to individual environments (rooms).

In this chapter, an innovative approach is presented for the channel dimensioning, based on the choice of not constant values for the temperatures of hot and cold duct. More specifically, two approaches are described.

For the first approach, the cold duct carries air at a not constant temperature, equal to or slightly lower than the minimum supply air temperature, among those required hour by hour by the different zones; the hot duct carries air at a constant temperature, higher than the absolute maximum value of the zone supply temperature. For the second one, the hot duct transports air at a temperature value slightly higher than the maximum inlet temperature (variable with time) required by the zones, while the cold duct delivers air at a constant temperature, lower than the absolute minimum value of the zone supply temperature.

The new approach implies reduced overall dimensions and cost of the channel network.

The method has been applied to some networks of channels, and results were compared with those obtained, on the same networks, using the traditional sizing criteria.

The comparison was carried out in terms of diameters, network factors, and total side surfaces of the network. It shows that the overall dimensions of the networks decrease compared to the traditional sizing methods; the factor F_{net} varies between 1.21 and 1.37, while in traditional sizing, it assumes values around 1.7. As it has been seen in previous works [19], the decrease of network factor (and of side surfaces) is more significant for higher temperature of the hot duct (method 1) and lower temperature of cold duct (method 2). The constraint on the maximum speed of the air in the various trunks of the network is always respected, while it does not always occur with traditional criteria. The saving in terms of side surface varies between 27 and 21% with reference to the traditional approach for method 1 and between 14 and 17% for method 2. Both methods imply lower network factors, with respect to the traditional method, but it is preferable to use one method rather than another according to the summer and winter design temperatures. In our study, a lower winter design temperature implies an increase in savings by using method 2.

These new methods of sizing a dual duct network allow for a lighter network, with obvious economic advantages, and are easier to place. The network is able to guarantee the thermo-hygrometric comfort conditions for all conditions of thermal load, even in the medium periods; in addition, it allows a control of the air speed, always remaining below the maximum allowed values (this does not always happen with the traditional method).

It must be remembered that, unlike the traditional method that plans fixed temperature values for the hot and cold ducts, the proposed methods require a more complex control system that, starting from the value of the minimum or maximum supply temperatures of the different zones (which vary over time), can vary the temperature of the cold or hot duct.

For method 1, which guarantees better results compared to method 2, a further postheating battery dedicated to the cold duct must be provided.

Conflict of interest

The author declares that she has no conflict of interest.

Nomenclature

Acronyms

ACH air changes per hour

AHU air handling unit

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IAQ	indoor air quality
SARS	severe acute respiratory syndrome
TB	tuberculosis

Symbols

c_p	specific heat at constant pressure of moist air (J/kg °C)
D	diameter of the duct (m)
$\Delta t_{h,\mathbf{in}} = t_h(\tau) - t_{\mathbf{in}}(\tau)$	temperature difference between hot duct and inlet air conditions (°C)
$\Delta t_{c,\mathbf{in}} = t_{\mathbf{in}}(\tau) - t_c(\tau)$	temperature difference between inlet conditions and cold duct (°C)
F_k	covering factor of the kth trunk
F_{net}	covering factor of the whole network
G	air mass flow rate (kg/h)
$G_{k,\max}$	mass flow rate that the k-trunk could carry if the air flowed at the maximum set speed (kg/h)
$\mathrm{l_k}$	length of the kth trunk (m)
Q	volume airflow rate (m^3/h)
t	temperature (°C)
$t_{in,\min j}$	minimum inlet temperature at the time j (°C)
v_{max}	maximum air speed in the ducts (m/s)
$\Phi(\tau)$	sensible thermal loads (J/h)

Subscripts

r	refers the variables to the room conditions
h	refers the variables to the hot duct
i	refers the variables to the ith environment
in	refers the variables to the supply (inlet) conditions
j	refers the variables to the jth time interval
k	refers the variables to the kth trunk
n	refers the variables to the nth zone
sum	refers the variables to the summer conditions
win	refers the variables to the winter conditions

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