

Justification for the Outlooks of Design and Application of Local Recirculation Diffusers for Energy-efficient Ventilation Systems

Dmitry Vladimirovich Kapko

LTD "NPO THERMEC" Dmitrovskoe highway, 46-2, Moscow, 127238, Russia.

Vyacheslav Erikovich Shkarpet

LTD "Arktos" 6 Predportoviy proezd, 4, Saint-Petersburg, 196240, Russia.

Lyudmila Yakovlevna Balandina

LTD "Arktos" 6 Predportoviy proezd, 4, Saint-Petersburg, 196240, Russia.

Kristina Vladimirovna Kochariants

LTD "Arktos" 6 Predportoviy proezd, 4, Saint-Petersburg, 196240, Russia.

Georgi Vasilievich Esaulov

*Moscow Architectural Institute (State Academy),
11/4-1 building 4, Rozhdestvenka street, Moscow, 107031, Russia.*

Abstract

A new scheme of ventilation system with local recirculation diffusers (LRD) was proposed. A local recirculation diffuser was designed. Requirement specifications for LRD capacity were developed. Proposals on the parameters of LRD were developed. The topic of improving the quality of internal air while keeping power consumption of the ventilation and air conditioning systems as low as possible has been getting increased attention in the past years [7], [5], [4], [3], [6], [2]. To date, the standard heat insulation level of the building envelope has grown significantly [9]. At the same time, significant amounts of heat are generated in certain types of public buildings, such as office premises, retail buildings, sports, and catering facilities, in course of their operation. Using traditional heating and ventilation solutions in the cold and transition seasons results in overconsumption of energy resources because the outdoor air is heated in the input unit up to a specified temperature (which usually equals the temperature of the air in the room) while the air conditioning system consumes cold to assimilate the heat generated internally. The aim of this research is to design a ventilation system with local recirculation diffusers that is capable of assimilating excessive internal heat by underheating the intake air. The article presents the ventilation system with local recirculation diffusers ("LRD"), the LRD design, requirements to LRD capacity, and proposals on the sets of LRD parameters.

Keywords: Ventilation, recirculation, air diffuser, energy efficiency, energy consumption reduction, circuit, air processing capacity, parametric series, LRD.

Introduction

A designer of an internal ventilation system has to solve two problems: maintaining a high quality of air in the room, and

reducing energy consumption [11], [12]. In view of this, more and more attention is paid to researches into existing schemes of ventilation systems and designing new ones [7], [5], [4], [3], [6], [2]. The authors have developed ventilation system with local recirculation diffusers. The technical solutions used in the ventilation system under review and its special features are described in Article [1]. The proposed system's main functionality is assimilation of excessive internal heat in the cold and transition seasons by means of under heating the outdoor air in the input system. Optimal parameters of the supply air jet flowing into the work area of the room are attained by mixing under heated intake air with the room air (recirculation air) in the local recirculation diffusers. The area of application of the proposed ventilation systems includes public buildings with significant heat emission levels, which are observed not only in the warm period, but also in the transition and even cold periods, such as office buildings, public catering facilities (restaurants, cafes, canteens), shopping centres, and sports facilities [13], [14]. Ventilation systems with local recirculation diffusers have the following advantages:

- reduced consumption of heating energy used to heat the outdoor air (as opposed to through-flow ventilation systems);
- reduced consumption of electric power used by the air conditioning system to assimilate internal heat emissions;
- reduced consumption of electric power used to move the ventilation air (as opposed to central recirculation ventilation systems);
- prevention of contaminant spreading from one room to other rooms serviced by one ventilation system (as opposed to central recirculation systems).

This article presents the results of further research into ventilation systems with local recirculation diffusers.

Main Text

At first, two versions of a local recirculation diffuser were considered.

- A ventilation circuit mixing outdoor air (in this article, the outdoor air is the air supplied from outdoors, cleaned and heated to a subambient temperature ($\geq 6^{\circ}\text{C}$) in the central air conditioning unit) with the recirculation air directly in the local recirculation diffuser (Figure 1)-Diagram # 1;
- A ventilation circuit mixing outdoor and recirculation air in the room (Figure 2)-Diagram #2

Since consumption of outdoor air must remain stable throughout the ventilation system operation, the main parameter required from a local recirculation diffuser in our research was stability of the air pressure fall in the outdoor air circuit in case of changes in recirculation air use. This is why the authors chose Diagram#2, and local recirculation diffusers were designed for the mixing system where input air is supplied from above in streams spreading parallel to the ceiling, and the outdoor air is mixed in the room with the recirculation air (Figure 3).

The local recirculation diffuser works as follows. The outdoor air is supplied at a subambient temperature ($\geq 6^{\circ}\text{C}$) from the input system in Pipe 4; Diffuser 5 generates a fan-shaped stream flowing under the ceiling; outdoor air consumption stays stable throughout the system's operation. Fan 7 feeds recirculation air (the air from the serviced room) through Pipe 6 into Static Pressure Chamber 1; the air is cleaned as it passes through Filter 8. Eddying Cells 3 on Surface 2 generate a fan-shaped stream of recirculation air that spreads parallel to the ceiling. This process ensures sufficient mixing of the outdoor air with the recirculation air (which was confirmed by computer modelling; its results will be published in our next article).

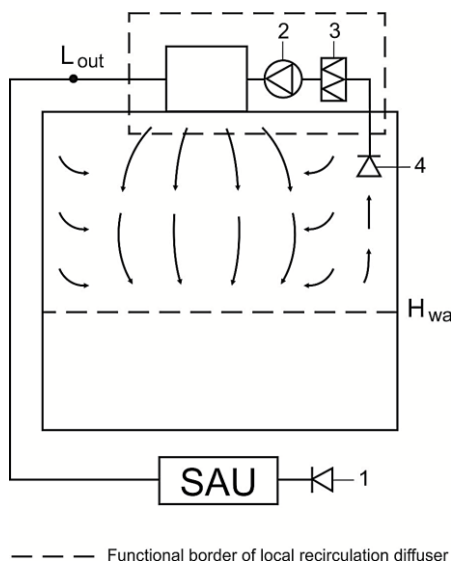


Figure 1: Diagram #1. Ventilation system mixing recirculation air with outdoor air in the local recirculation diffuser 1-intake of outdoor air; 2-fan of local recirculation diffuser; 3-filter; 4-intake of recirculation air, SAU – supply air unit

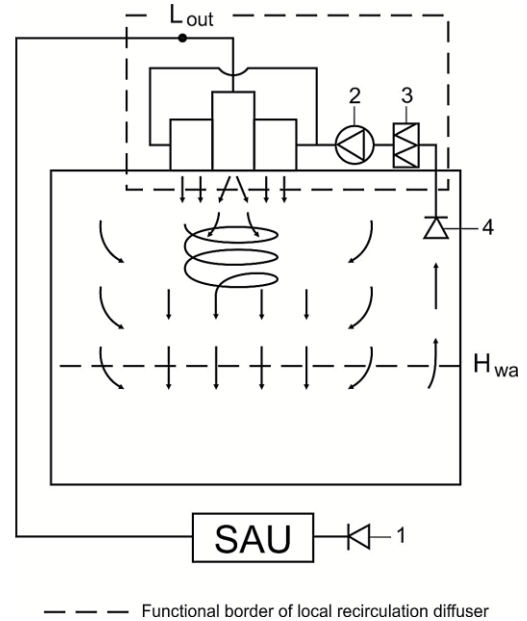


Figure 2: Diagram #2. Ventilation system mixing recirculation air with outdoor air in the room 1-intake of outdoor air; 2-fan of local recirculation diffuser, 3-filter; 4-intake of recirculation air, SAU – supply air unit

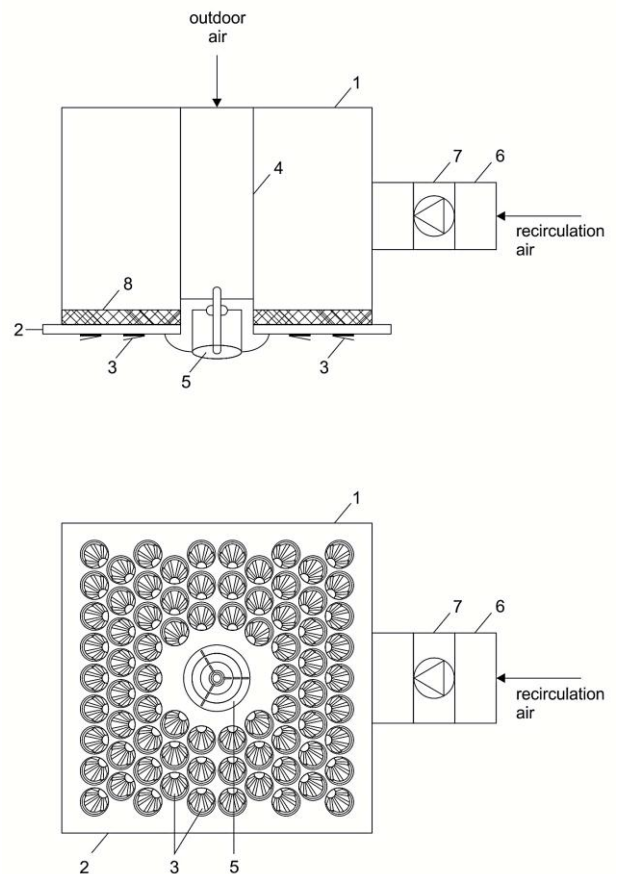


Figure 3: Local recirculation diffuser design

At the next stage of their work, the authors determined the requirements to the air processing capacity of the local

recirculation diffuser and to the way the outdoor air-recirculation air ratio is controlled.

The capacity of local recirculation diffusers depends on:

- The purpose of the room, which determines the number of people per 1 m² of the room, target amount of outdoor air supplied per 1 person in the room, heat insulation qualities of the building envelope, highest internal heat generation values, and room geometry.
- The air distribution layout in the room, which determines the area serviced by one local recirculation diffuser in order to ensure the best thermal acceptability parameters in the work area of the room in question.

Local recirculation diffusers should be used primarily to supply outdoor air; the air amount is calculated based on the number of people in the room and the regulations on outdoor air consumption per one person in the given room type. Table 1 shows outdoor air consumption values per one person in accordance with the regulations existing in the Russian Federation[15].

Considering that one person can occupy the whole room alone only in an office building, the minimum outdoor air processing capacity of the recirculation air diffuser was taken as 40 m³/hr.

Table 1: Outdoor air consumption rates per one person in the room, $L_{1\ person}$, m³/hrperson

Purpose of the room	$L_{1\ person}$, m ³ /hrperson
Restaurant	40
Cafe	30
Canteen	20
Office premises with natural ventilation	40
Office premises without natural ventilation	60
Shopping centre	20
Sports hall without spectator seating	80

For ventilation systems with recirculation air diffusers, consumption rates of recirculation air L_r , m³/hr, added to outdoor air are calculated using the following formula:

$$L_r = \frac{L_{out}(t_s - t_{out})}{t_{in} - t_s} \quad (1)$$

Where

L_{out} , t_{out} is the use m³/hr, and the temperature, °C, of the outdoor air.

t_{in} is the internal air temperature in the room, °C;

t_s is the temperature of supply air, °C.

The temperature of outdoor air, t_{out} , °C, must have a limit in order to prevent water vapour condensation on the air duct surface. Table 2 presents the ranges of air temperature and relative humidity that are optimal during the cold season in the rooms featuring significant heat emissions according to Rulebook of the Russian Federation GOST 30494-2011[8].

Table 2: Optimal room air temperature and relative humidity in the serviced area of public and administrative buildings during the cold season.

Room description	Air temperature, °C.	Relative humidity, %
Classrooms and premises for intellectual labour	19 ÷ 21	45 ÷ 30
High occupancy premises where people mostly sit without outerwear	20 ÷ 21	45 ÷ 30
High occupancy premises where people mostly sit with outerwear on.	14 ÷ 16	45 ÷ 30
High occupancy premises where people mostly stand without outerwear	18 ÷ 20	45 ÷ 30
Rooms for active sports	17 ÷ 19	45 ÷ 30

Upon analysing the standard parameters of internal air in the rooms under review with an i-d diagram, the authors found that condensate will form on the air duct surface at the following temperatures:

+8. 6°C for classrooms and premises for intellectual labour, high occupancy premises where people mostly sit without outerwear;

+7. 5°C for high occupancy premises where people mostly stand without outerwear;

+6. 8°C for rooms for active sports;

+4. 3°C for high occupancy premises where people mostly sit with outerwear on.

The following formula is used to establish the temperature on the air duct surface τ_{in} , °C, (Figure 4).

$$\tau_{in} = t_{in} - \frac{R_{in}(t_{in} - t_{out})}{R_o} \quad (2)$$

Where

t_{in} is the room air temperature, °C;

t_{out} is the temperature of air inside the air duct, °C;

R_{in} the heat transfer resistance of the air layer around the air duct on the room side, m²•°C/W, is established according to formula

$$R_{in} = \frac{1}{\alpha_{in}} \quad (3)$$

Where

α_{in} is the heat loss ratio of the air duct's outer surface, W/(m²•°C);

R_o is the overall heat transfer resistance of the air duct, m²•°C/W, is established using the following formula:

$$R_o = R_{in} + R_1 + R_{out} = \frac{1}{\alpha_{in}} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_{out}} \quad (4)$$

Where

α_{out} is the heat loss ratio of the air duct's internal surface, W/(m²•°C);

δ_1 is the air duct wall thickness, mm;

λ_1 is the air duct wall heat transfer ratio, W/(m•°C).

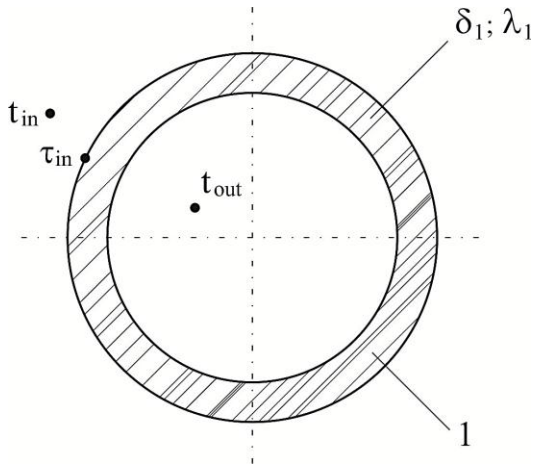


Figure 4: Design circuit of the air duct heat transfer 1-air duct with the δ_1 thick wall that has the heat transfer ratio λ_1 t_{out} - intake air temperature; t_{in} - room air temperature; τ_{in} - temperature on air duct surface

Using formula (2), we express the air temperature inside the air duct, t_{out} , °C:

$$t_{out} = t_{in} - \frac{R_o(t_{in} - \tau_{in})}{R_{in}} \quad (5)$$

Using formula (5), we calculate the values of air temperature in the duct that will lead to condensation of water vapours on the duct surface for various room groups; the resulting values are shown in Table 3.

Table 3: Values of air temperature inside the duct, at which water vapours start condensing on the duct surface in various room types in public and administrative buildings

Room description	Water vapour condensation temperature, °C	Temperature of air inside the air duct, °C
Classrooms and premises for intellectual labour	8. 6	4. 66
High occupancy premises where people mostly sit without outerwear	8. 6	4. 29
High occupancy premises where people mostly sit with outerwear on.	4. 3	0. 63
High occupancy premises where people mostly stand without outerwear	7. 5	3. 52
Rooms for active sports	6. 8	2. 94

Using the values shown in Table 3 we can infer that water vapour condensation on the air duct surface can occur at the outdoor temperature around +5°C. In view of this, in course of

subsequent design of ventilation systems with local recirculation diffusers, the lowest temperature of air supplied from the input system to the LRD is assumed to be +6°C. Thus,

$$t_{out} \geq 6^\circ\text{C} \quad (6)$$

Using equation 1, we can express the value t_{out} , °C:

$$t_{out} = t_s - \frac{L_r}{L_{out}}(t_{in} - t_s) \quad (7)$$

If we do equations 6 and 7 together, we arrive at the following result:

$$\frac{L_r}{L_{out}} \frac{t_s - 6}{t_{in} - t_s} \quad (8)$$

Thus, the highest ratio of the recirculation air to the outdoor air is described by the following expression:

$$\left(\frac{L_r}{L_{out}}\right)_{max} = \frac{t_s - 6}{t_{in} - t_s} \quad (9)$$

Table 4 shows the values of the highest relation between the recirculation air and outdoor air calculated using Formula 9 for various room air temperatures, t_{in} , °C, and the difference between the room air temperature and the intake air temperature at the supply air opening, $t_{in} - t_s$, °C.

Table 4: The required highest ratio of recirculation air to outdoor air at various room air temperatures and the difference between the room air temperature and the intake air temperature at the supply air opening

The internal air temperature in the room, t_{in} , °C	Differences between the room air temperature and the intake air temperature, $t_{in} - t_s$, °C							
	1	2	3	4	5	6	7	8
14	7.00	3.00	1.67	1.00	0.60	0.33	0.14	0.00
15	8.00	3.50	2.00	1.25	0.80	0.50	0.29	0.13
16	9.00	4.00	2.30	1.50	1.00	0.67	0.43	0.25
17	10.00	4.50	2.70	1.75	1.20	0.83	0.57	0.38
18	11.00	5.00	3.00	2.00	1.40	2.00	0.71	0.50
19	12.00	5.50	3.30	2.25	1.60	1.17	0.86	0.63
20	13.00	6.00	3.70	2.50	1.80	1.33	1.00	0.75
21	14.00	6.50	4.00	2.75	2.00	1.50	1.14	0.88

Table 5 shows permissible temperature deviations in the intake air flows from the standard air temperature in the work area for the case where excessive heat in the public building is assimilated according to Construction Regulation SP 60. 13330. 2012 [10].

Table 5: Permissible temperature deviations in the intake air flow from the standard air temperature in the work area for the case where excessive heat in the public buildings is assimilated.

How people are placed in the room	Permissible deviations in the air temperature, °C
In the area directly reached by the supply air jet	1. 5
Outside the area directly reached by the supply air jet.	2. 0

If we compare Tables 4 and 5, we can conclude that a local recirculation diffuser can be used in all of the rooms in question in mixing ventilation systems supplying air streams from above that spread parallel to the ceiling, subject to the following recirculation air-outdoor air ratio:

$$\frac{L_r}{L_{out}} \geq 4 \quad (10)$$

After this, the authors analysed the following parameters of the rooms that affected air distribution and the resulting microclimate:

- room area per one person $F_{1\text{ person}}$, m²/ person;
- standard outdoor air consumption rates per one person in the room, $L_{1\text{ person}}$, m³/(hr person);
- room height, h_o , m;
- work area height in the room, h_{wa} , m;
- air distribution in the room.

Proposals on a set of parameters of local recirculation diffusers were developed based on the analysis results (Table 6).

Table 6: Set of parameters of local recirculation diffusers

#	Outdoor air consumption, L_{out} , m ³ /hr	Recirculation air consumption, L_r , m ³ /hr	Total outdoor air consumption, L_o , m ³ /hr	Dimensions of the recirculation air diffuser panel, A x B, mm
1	40 ÷ 120	0 ÷ 440	40 ÷ 560	450 x 450
2	100 ÷ 180	0 ÷ 720	100 ÷ 900	600 x 600
3	170 ÷ 250	0 ÷ 1000	170 ÷ 1250	750 x 750

The set includes three LRD sizes with the following parameters:

- Outdoor air supply: 40÷120 m³/hr for standard size 1, 100÷180 m³/hr for standard size 2, 170÷250 m³/hr for standard size 3;
- recirculation air supply within the following range of values: 0÷440 m³/hr for standard size 1, 0÷720 m³/hr for standard size 2, 0÷1000 m³/hr for standard size 3;
- dimensions of the local recirculation diffuser pane: 450x450 mm for standard size 1, 600x600 mm for standard size 2, 750x750 mm for standard size 3.

Conclusion

Ventilation systems with local recirculation diffusers have good outlooks because their use in rooms with significant heat emissions ensures reductions both in heating and electric power consumption [7].

The authors have designed a system of local recirculation diffusers, developed air processing capacity technical requirements, and proposed parameter sets.

Local recirculation diffusers require further research and, in particular, experimental measurements of thermal acceptability in the rooms where they are used.

Acknowledgements

This research was supported by the Ministry of Education and Science of the Russian Federation under the federal target program “Research and Development on Priority Directions of the Research and Technological Complex of Russia in the Years 2014-2020” (Grant Agreement # 14. 576. 21. 0037 dated 27 June 2014, Unique Identifier RFMEFI57614X0037).

References

- [1] Naumov, A. L. , Kapko, D. V. (2013). Results of experimental studies of a local air conditioning system in administration buildings. *Industrial and Civil Engineering*, 4, 17-19. <http://www.pgs1923.ru/russian/rindex.htm>.
- [2] Dutton, S. M. , Fisk, W. J. (2014). Energy and indoor air quality implications of alternative minimum ventilation rates in California offices. *Building and Environment*, 82, 121-127. <http://www.sciencedirect.com/science/article/pii/S0360132314002613>.
- [3] Han, Kw. , Zhang, J. S. , Guo, B. (2014). A novel approach of integrating ventilation and air cleaning for sustainable and healthy office environments. *Energy and Buildings*, 76, 32-42. <http://www.sciencedirect.com/science/article/pii/S0378778814001698>.
- [4] Naumov A. L. , Kapko, D. V. , Brodach, M. M. (2014). Ventilation systems with local recirculation diffusers. *Energy and Buildings*, 85, 560-563. <http://www.sciencedirect.com/science/article/pii/S0378778814007889>.
- [5] Rakes, A. , Waring, M. S. (2014). Using multiobjective optimizations to discover dynamic building ventilation strategies that can improve indoor air quality and reduce energy use. *Energy and Buildings*, 75, 272-280. <http://www.sciencedirect.com/science/article/pii/S0378778814001364>.
- [6] Kim M. J. , Braatz, Richard D. , Kim J. T. , Yoo Ch. K. . (2015). Indoor air quality control for improving passenger health in subway platforms using an outdoor air quality dependent ventilation system. *Building and Environment*, 92, 407-417. <http://www.sciencedirect.com/science/article/pii/S036013231500222X>.
- [7] Persily, A. K. , Ng, L. C. , Emmerich, S. J. (2015). IAQ and energy impacts of ventilation strategies and building envelope air tightness in a big box retail building. *Building and Environment*, 92, 627-634. <http://www.sciencedirect.com/science/article/pii/S0360132315300093>.
- [8] Rulebook of the Russian Federation GOST 30494-2011 Residential and public buildings. Microclimate parameters for indoor enclosures.
- [9] Rulebook of the Russian Federation SP 50. 13330. 2012 Thermal protection of buildings.
- [10] Rulebook of the Russian Federation SP 60. 13330. 2012 Heating, ventilation and conditioning.
- [11] Joo, J. , Zheng, Q. , Lee, G. , Tai Kim J. , Kim S. (2012). Optimum energy use to satisfy indoor air

- quality needs. *Energy and Buildings*, 46, 62-67. <http://www.sciencedirect.com/science/article/pii/S0378778811005081>.
- [12] Van den Bulck N. , Coomans, M. , Wittemans, L. , Hanssens, J. , Steppe, K. (2013). Monitoring and energetic performance analysis of an innovative ventilation concept in a Belgian greenhouse. *Energy and Buildings*, 57, 51-57. <http://www.sciencedirect.com/science/article/pii/S037877881200624X>.
- [13] Tarabanov M. G. (2008). Design features of high-rise buildings air conditioning systems // *ABOK*, 7, 56-60. http://www.abok.ru/for_spec/articles.php?nid=4121
- [14] Kokorin O. Ya. (2009) Energy efficient air conditioning systems of high-rise buildings K // *ABOK*, 1, 19-23. http://www.abok.ru/for_spec/articles.php?nid=4214
- [15] Rulebook of the Russian Federation SP 118. 13330. 2012 Public buildings and works.