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DETERMINATION OF RELATIVE DURATION OF DISCOMFORT (RDD) IN AN OFFICES BUILDING WITH VAV FREE - COOLING SYSTEM

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SUMMARY

P. Desaubies and R. Langendries : Relative duration of discomfort with VAV free-cooling system : In offices buildings without mechanical refrigeration but with allowance for window opening, problems can arise such as overheating or cold air draughts. The authors present these problem in a specific case and show how a variable air volume, free-cooling system can solve them. The RDD is calculated with the LPB1 Program for different values of diurnal and nocturnal ventilation rates. The effect of window opening on balancing the air distribution is shortly approached.

Introduction

With the increasing prices of energy, some users of office buildings are willing to accept some lack of comfort to reduce the overall energy cost for heating and ventilating.
But engineers fell themselves responsible for the indoor climate obtained with the installations they conceive and have to face new constraints.

In this paper we show how we tried to reduce to a minimum the degree of discomfort during the cooling days in an office building without mechanical cooling and with the freedom of window opening in each season, while minimizing energy consumption.

After a short presentation of the problems we faced, we describe briefly the general principle of the HV system, then we present the calculation method we used to optimize air flows and some results of the calculation. We end with a very short description of the control system.

The problem

The building is erected just along a five-lines avenue with very high density of traffic. Its principal characteristics are listed in Annex 1.
The principal façade of the building, facing this avenue, is S-S-E oriented (referred here as the south façade).
The rear of the building is thus NNW oriented.
This North façade is viewing a much quieter environment.
Neither the architect nor the building's user accepted the proposition of external solar protections on the South façade.
The offices themselves are situated from the third to the ninth level. (see fig. 1).

The building's user wished to avoid air-conditionning and, in spite of the very noisy situation, wished that anyone in any particular office could open his window in winter as well as in summer or mid-season.

But it is known that, for well insulated buildings with internal gains usual for offices and important external gains due to a nearly South orientation, the temperature of no-heating is below 10 °C.

Thus, we feared difficult situations if only static heating with natural ventilation through window opening is realised :
- cold air draughts in winter
- overheating in mid season and summer.

We chose thus a mechanical ventilation system, with VAV-optimized night and day free-cooling.

Description of the system and how it works

In each office static heating is performed by radiators with thermostatic valves and mechanical ventilation is provided with air centrally prepared.

Nevertheless, if the occupant opens his window, valves on air ducts (both in and out) are automatically turned off.

A schematic view of air distribution in a typical office room is given in fig. 2.

With D = supplied air flow
TP = supplied air temperature
TE = outdoor temperature
TI = indoor temperature,

for an increasing outdoor temperature the ventilation scheme is :

- loss conditions
  D MIN, TP = 20 °C
- gain conditions, with TE < TI
  TP varies between 20 and 15 °C, then
  D varies between D MIN and D MAX, with TP = TE
- gain conditions, with TE > or = TI
  D MIN, TP = TE

During the night, when off-peak electricity rates apply and the outside temperature has lowered, the building is cooled down by a high rate ventilation giving an inner temperature of minimum 21 °C the next morning.

The air valves on individual air ducts in each office are the ON-OFF type.

The general principles described here above apply separately for the two faces of the building.

Optimizing the system

As previously mentionned, the user of the building wished to avoid air conditioning. This excluded the possibility of a refrigerating production.

It is to be understood that in the absence of a refrigerating production capable of perfectly counterbalancing the heat gains received, it was essential to have at one's disposal a precise tool evaluating the evolution of the temperature and at the same time enabling a parametric analysis with the following main components :

- definition of the day and night ventilation flows leading to the best conditions of comfort ;
- comparison of the variable flow and constant flow ventilations ;
- evaluation of the efficiency of the sun protections.

The criteria of comfort chosen was the number of hours upon a given period during which the indoor temperature exceeds the critical levels of 25 °C or 28 °C.

This was no longer the calculation of a consumption, but that of an indication of comfort reached, namely the indoor temperature ; the reliability of the simulation is thus of the greatest importance in this case.

Obviously, the optimization of this VAV free-cooling system needs a dynamic simulation of the thermal behaviour of the building taking into account its inertia.
We did this with the LPB1 Program of the University of Liège (prof. J. LEBRUN) which can calculate hour by hour the evolution of indoor temperature for varying external and internal gains and losses, for constant air temperature and flow rate.
We implemented a sub-program simulating the scheme of ventilation described above and calculating for every hour the positive and negative energy contributions introduced by the thus defined ventilation.

It has been possible to directly take out the data relating to the indoor temperatures exceeding the fixed level, as also the graphic representation of the monotones of the indoor and outdoor temperatures, for the various cases under consideration.

It will be underlined, when reading these results and our comments, that some of those apply only to the building under study, with the climatic conditions specific to Belgium and the specific data relating to internal gains introduced in the simulation program.

The mean climatic year used in the LPB1 Program is a year composed with real months where each is the closest to mean climatic conditions (temperature and solar radiation).
To study the effect of a warm period, we introduced also the period between the 10 and the 25 august 1959, during which the mean temperature was particularly high.

We proceeded to the simulation in two steps.
At first, we introduced nominal air changes varying from 2 to 8/h during the occupational period and from 4 to 10/h during the night ; as other parameters, we introduced an external solar protection in one case and constant flow instead of VAV in another one.
In table 1 are given the results for a South-oriented premise during July. The percentages indicated are those of the number of hours during which the indoor temperature exceeds 25 °C respectively 28 °C between 8 a.m. and 6 p.m.

Table 1. First simulation - Relative duration of discomfort - S. oriented premise - July.

Case studied nom.diurn. (*)	nom.noct. (*)	ind. temp. > 25°C (%)	ind. temp. > 28°C (%)
2	4	71.1	22.2
5	10	20.8	6.7
8	10	22.7	1.9
4 (**)	8	21.3	5.8
5 (***)	10	7.3	0

(*) number of nominal diurnal (resp. nocturnal) air changes per hour

(**) constant flow (instead of VAV for other cases)

(***) external solar protection (instead of internal for other cases)

From this first simulation, we can observe that :

- a high nominal ventilation rate can have detrimental effects : increasing from 5 to 8 a.c./h the diurnal ventilation doesn't decrease the relative duration of discomfort above 25 °C (RDD/25). This can be explained by the fact that self adjusting air diffusers in VAV cannot give good results regarding air mixing and span while the air flow remains under 25 % of nominal flow. The minimum allowable air flow grows with the nominal air flow and this rises the heat brought by the ventilation during the period when outside temperature is higher than inside temperature.

- external solar protections are very effective for comfort compared to internal protections : with external solar protection, the RDD/25 decreases from 20.8 % to 7.3 % and the RDD/23 from 6.7 % to 0 %.

- in our case, nominal diurnal ventilation rates around or slightly above 5 a.c./h seemed to give good results.

Looking further for an optimum, we performed a second simulation, the results of which are presented in Table 2. They relate to the 10 h/day occupancy period (from 8 a.m. to 6 p.m.) ; for June only or for the period extending from April to September.

Table 2 - Relative Duration of Discomfort (RDD) Second Simulation.

Orientation	Vent.rates (diurn/noct) (a.c./h)	RDD 25 (ind.temp >25°C) (%) June	RDD 25 (ind.temp >25°C) (%) Apr/Sept	RDD 28 (ind.temp >28°C) (%) June	RDD 28 (ind.temp >28°C) (%) Apr/Sept
South	3/6	27.3	15.63	1.7	0.55
South	4/6	26.0	13.83	0	0.22
South	4/8	20.7	10.33	0	0
South	5/8	16.3	7.98	0	0
South	5/10	16.7	6.89	0	0
North	3/6	31.7	14.70	0	0
North	4/8	21.3	8.96	0	0
North	5/10	16.3	5.74	0	0
Outside temperature(*) :		19.3	6.72	4.3	0.98

(*) : Relative duration during wich the outside temperature exceeds the level (25 or 28 °C) during the period considered.

This second simulation shows that :
- it is possible to obtain, with adequate diurnal and nocturnal air flows but without mechanical cooling, indoor conditions identical or more comfortable than outside

- in the simulation, we supposed that, during sunny hours, internal protections were closed on the South façade ; the comparison between North and South oriented offices for the same ventilation rates shows thus the effect of diffuse radiation gains.

Regulation of the H.V. system

The supplied air temperature and variable flowrate, as well as the nocturnal high flow ventilation are controlled by both the return air temperature, measured in the return air duct of representative premises and the outside condition.
The question was : how to cope with the problem of window opening ?
As said before, a magnetic switch on each window controls the valves on supply and exhaust air ducts for the corresponding premises.
A detection loop reports to the control system of the ventilation plant the number of closed valves.
This information allows a microprocessor to adapt the relationship between outside temperature, indoor temperature and air flow to the new situation.

Conclusions and prospects

The growing importance of the factors of energy consumption, linked to the specific requirements of the owners of the work or the building's users on the one hand, the answers which have to be given individually to encompass the physical and architectural characteristics of the building on the other hand, will inevitably lead to the increasing use of dynamic analysis.

The LPB1 program has shown, in our specific case of research of temperatures reached, its adaptation abilities to answer specific problems. These qualities combined with its scientific accuracy make it a priviledged instrument of a dynamic simulation.

We are convinced of the necessity of an active dialogue, right from the beginning of a project, between the architect and the services engineer so that the latter may intervene right from the definition of the shell of the building.

ANNEX 1

Data relative to the building

General :

Heavy concrete structure

- Floor area : 17 000 m^2
- Levels :
  - -2)
  - -1) : Parking areas and plant rooms
  - G : Entrance hall, conference rooms, printing workshop...
  - +1 : Hall
  - +2 +8 : Offices and meeting rooms
  - 9 : Offices and plant rooms

Characteristics of office premises studied

$l \times L \times h = 3.6 \times 5.4 \times 2.75\ m^3 = 53.5\ m^3$

transmission coefficient of external wall : 0.48 $W/m^2\ °C$

transmission coefficient of window (acoustic glass) : 2.9 $W/m^2\ °C$

frame of window : in wood

percentage of window : (transparent part) : 17 %

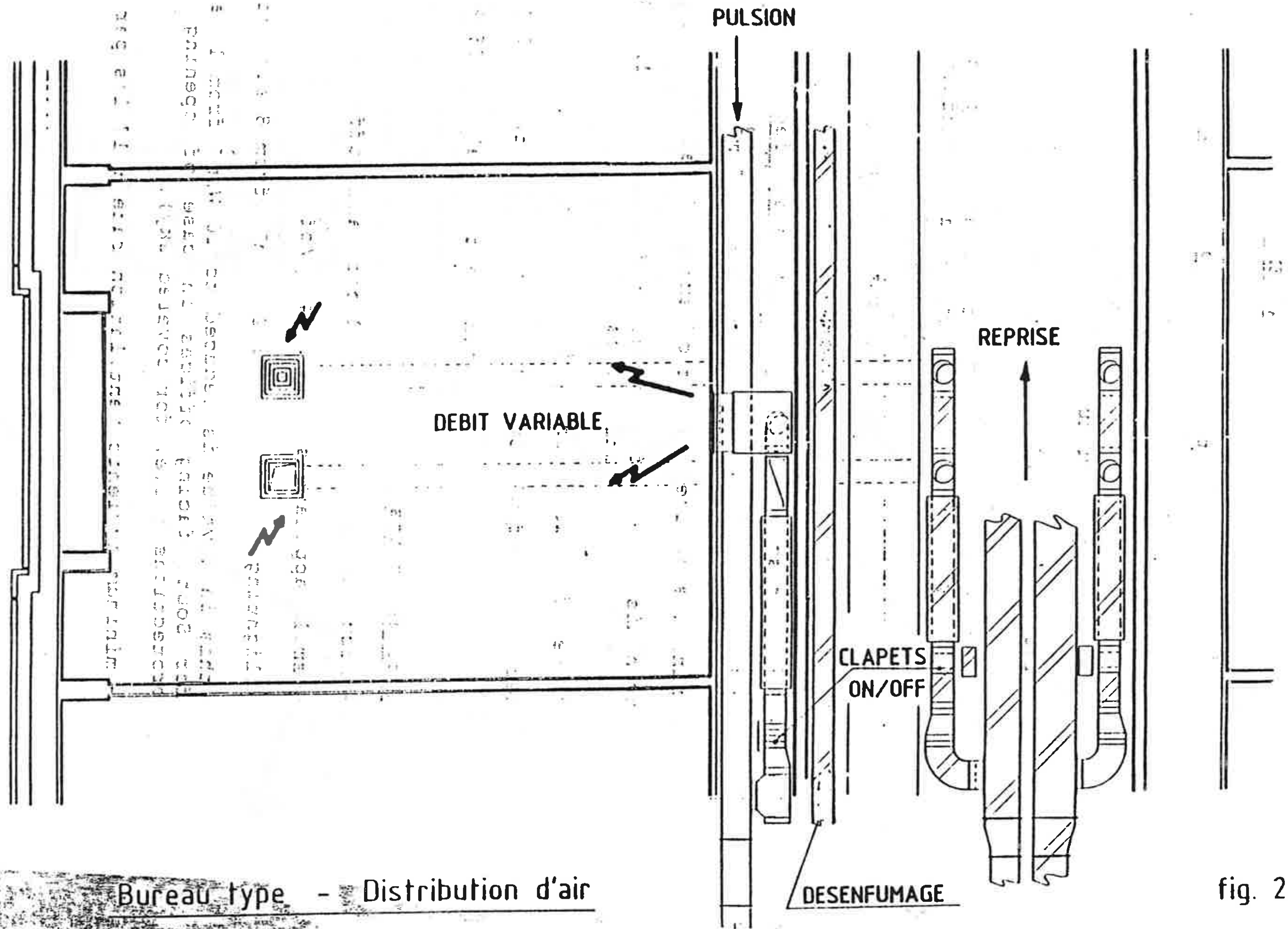
(glass and frame) : 26 %

Internal gains

- occupancy : 2 occupants/office
- small appliances : 240 W/office
- lighting : 20 W/m^2 (from 8 a.m. to 6 p.m.)

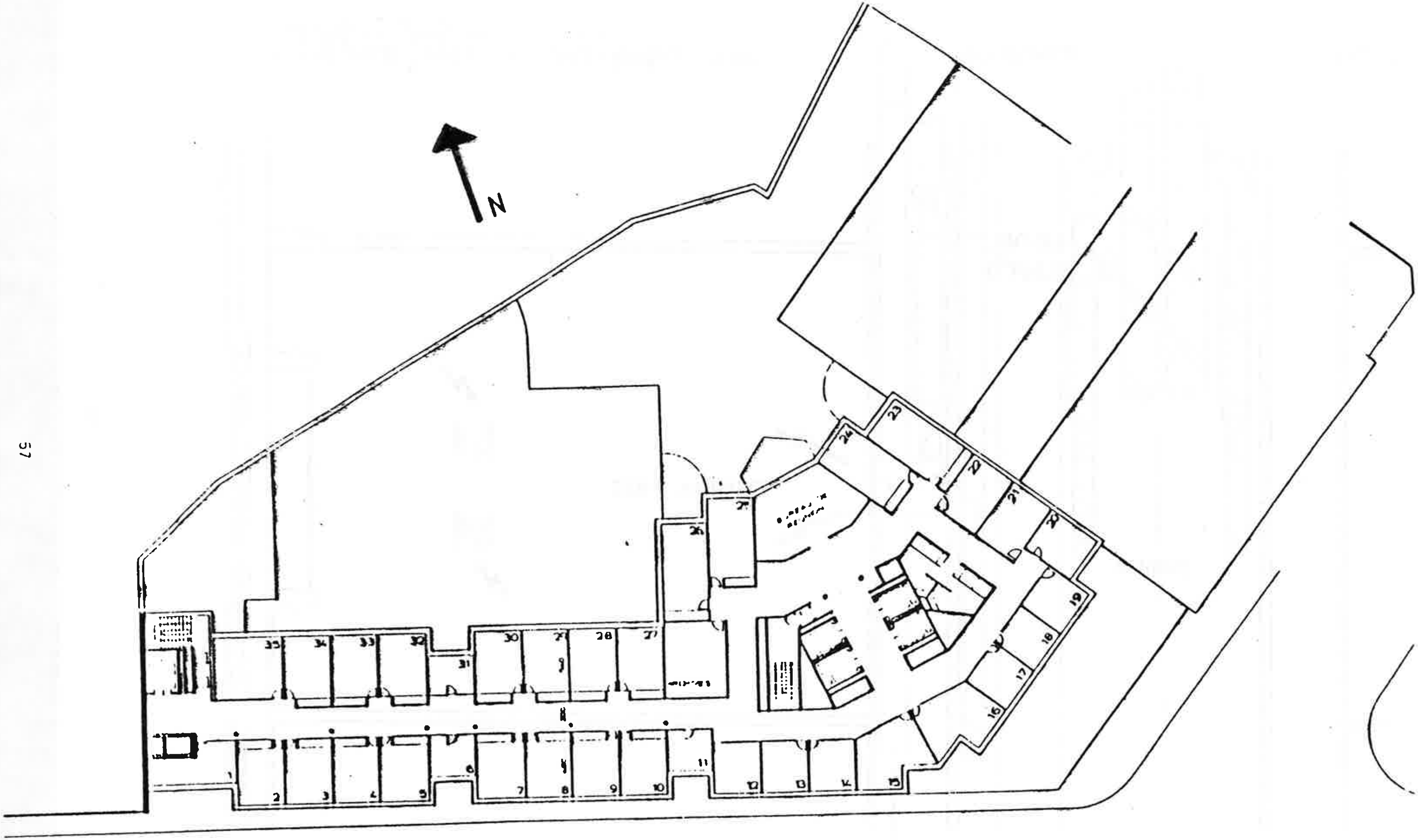
(this last value is reduced to 10 W/m^2 from 10 a.m. to 3 p.m. for South facing offices in case of opening of solar protections : i.e. for covered sky).

- minimum hygienic ventilation rate : 17 l/s per office.



Bureau type - Distribution d'air

fig. 2



Etage type

fig. 1