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Guidance and tools for night and evaporative cooling in office buildings

1 zone model →
× controle op ≠ cooling install..
× veel resultaten
— o a ook verbonk wate.

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1. INTRODUCTION

In France, mechanical cooling is increasingly used in office buildings. This situation is related to a demand for a better comfort, the increase of the thermal insulation and internal gains, and the changes in the building design.

Nevertheless, in many cases, it is possible to achieve a thermally comfortable environment by passive means - as thermal inertia, and solar protection of the external envelope - and use of low energy techniques as night or evaporative cooling. When mechanical cooling is yet required, the same approach can be used to reduce the peak demand and the energy needs.

These parameters have to be taken into account at the early stages of building design. Therefore, there is a need for simple tools enabling to give first guidance to the designer. On another hand, these tools must be produced by a more precise one in order to improve the design in further stages, or to take into account specific situations.

In addition, the development of efficient strategies in this field requires to take into account the fact that the maximum cooling power is generally available at night, and the cooling peak demand occurs in the middle of the day. This leads to two consequences :

1. The tools must take into account in a quite accurate way the non steady state thermal behaviour of the rooms,

2. The control strategies must compensate the lack of maximum cooling power by precooling the building at night, while keeping the indoor climate comfortable during occupancy.

The works conducted at CSTB aims to fulfil the above requirements. Developed within the framework of IEA annex 28 "low energy cooling", they are based on two kinds of tools : detailed tools, and guidance ones.

2. DETAILED DESIGN TOOLS :

The air handling plant shown in fig 1 has the following components :

- a rotating exchanger,
- a humidifier for the return air,
- a heating coil,
- a humidifier for the supply air,
- a cooling coil,
- two fans providing different airflow rates (equal for both fans).

The system control is based on a set of set point temperatures related to the running possibilities of the different components of the system. The running of one component is modified within a temperature band where the control is assumed to be linear or equivalent to it for the timestep.

Additional control can be taken into account in order to avoid misfunctionings. The system heating or cooling power is then related only to the indoor air temperature Ti by Fsyst (Ti). On another hand, the room behaviour for a given timestep can be described as Froom (Ti) function, which describes the indoor temperature resulting from a given heating (or cooling) power. It is here considered that this relationship is linear.

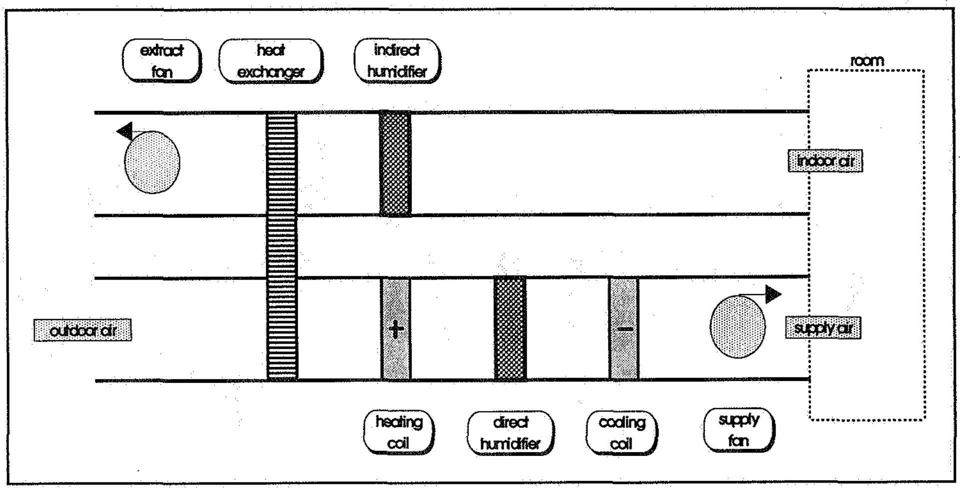


figure1 air handling plant components

The calculation model for the room behaviour COMET developed at CSTB is based on the simplification of the heat transfers between the internal and external environment reported in figure 2.

RC model voor 1 zone

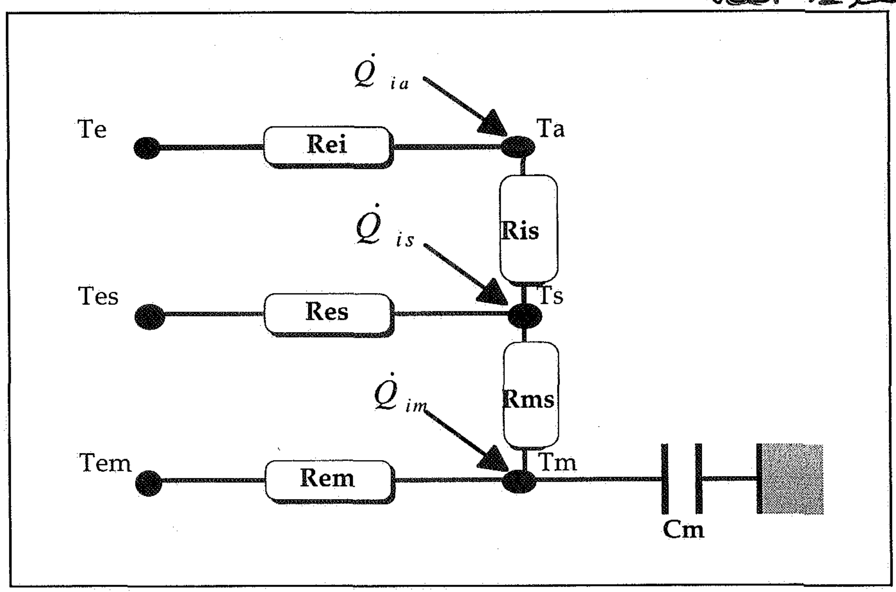


Figure 2 - Equivalent electric representation of the building model

Compared to other programs, this calculation model requires less detailed input datas as more detailed codes (as TRNSYS for example) : for example, external components are only described by their U value, solar factor and depth.

On the other hand, it enables to distinguish between the indoor operative and air temperature, which can be up to 2 or 3 K for air conditioned buildings when most of the simplified method only uses one value for both.

It has been validated using TRNSYS as a reference. (figure 3) . Starting of a base room, main parameters (orientation, window solar factor,inertia, internal gains, ventilation, system control) where modified and yearly heating and cooling needs calculated.

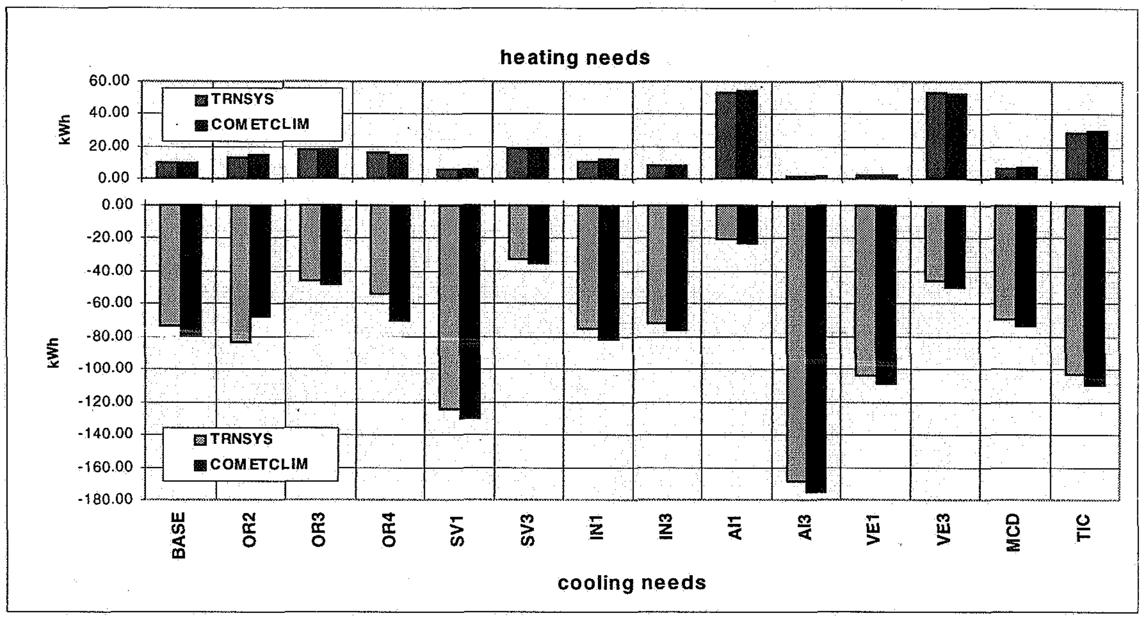


figure 3 - Comparison between TRNSYS and COMET

The functioning set point is obtained by solving the two equations at each timestep. A simple algorithm is then used to calculate the actual indoor temperature as shown in the figure 4.

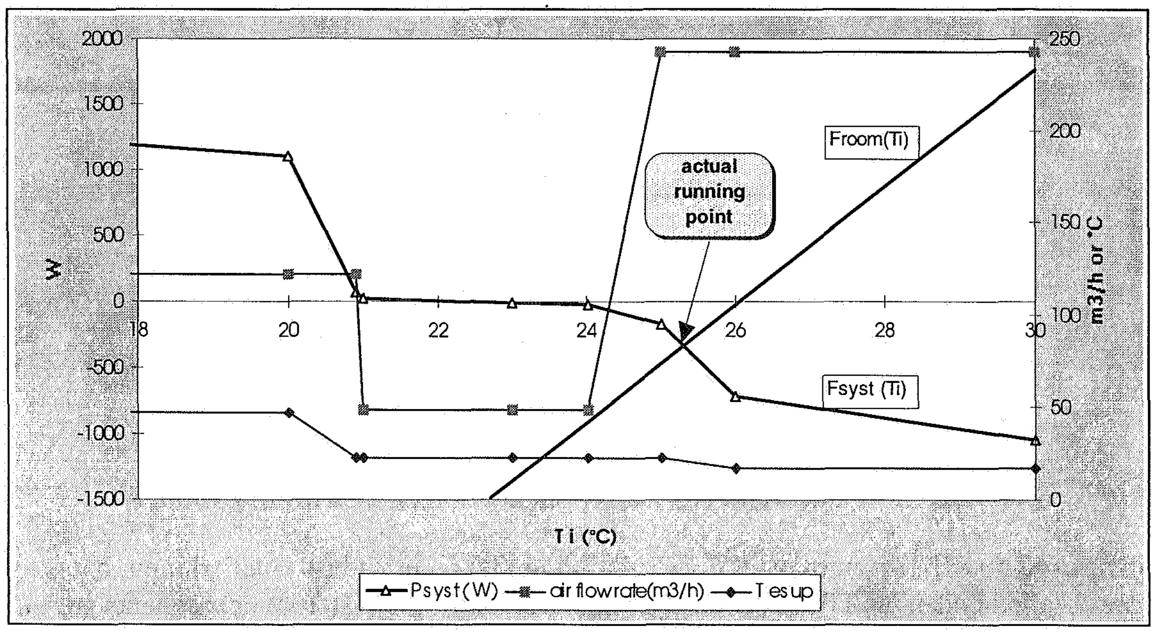


figure 4 - example of running point calculation

2.1 SYSTEM CONTROL

Each component is controlled by an on-off or by fixing values through a temperature band. It is important to notice that the control description must be based on its equivalent behaviour for the calculation timestep. As a general rule, it is considered here that the behaviour is linear within the band control.

For example, if the heating band control is 20 °C - 21 °C, it is assumed that the heating power will be at its maximum value for Ti < 20°C, equal to 0 for Ti > 21 °C and vary linearly between 20 °C and 21 °C. This does not mean that the control system must be a proportional one : a simple on-off control can lead to the same equivalent behaviour. A second rule here applied is that a control band must corresponds to a linear variation of supply air temperature and air flow. The set point temperatures can be constant or vary with time (the set point for heating can for example be reduced at night in winter).

2.1.1 control matrixes

For each system, we have defined control matrixes for summer and for winter conditions, during occupancy and inoccupancy (24 control matrixes). Examples of such matrixes are shown in fig 5.

2.1.2 transition

When we do a calculation for a complete typical year, we have to define transitions between winter control matrix and summer control matrix. When calculation is done with winter control matrix, we check the indoor air temperature between 7h and 8h. If this temperature becomes higher than 23°C, the transition with summer control matrix is done. When calculation is done with summer control matrix, we check the indoor air temperature between 8h and 9h. If this temperature becomes lower than 19°C, the transition with winter control matrix is done.

2.1.3 additional controls

- indirect humidification is used if permitted by the set point control and if the humidified air Thum as a temperature lower than the outdoor air Te . The control is as follows :

Te > Thum + dThic ⇒ control by set point

Te ≤ Thum + dThic ⇒ no humidification

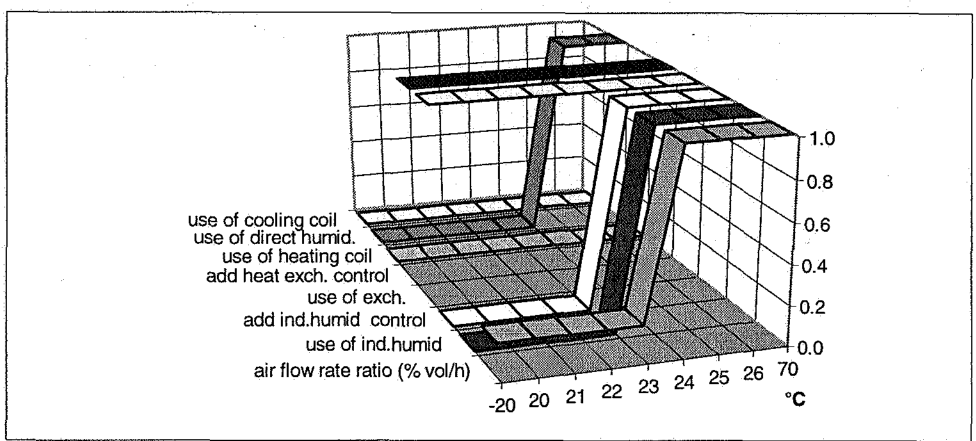
The dThic value is used to avoid humidification if it is of low efficiency regarding outdoor temperature. It can be for example fixed to 2 K.

- heat exchange

When the room requires cooling, the heat exchanger is stopped if outdoor air has a temperature lower than extract air before heat exchanger. In any case, the heat exchanger is controlled in order to avoid temperature lower than a limit value Teexlim (16°C during occupancy and 11°C during non occupancy). If this limitation occurs, direct humidification can't be used.

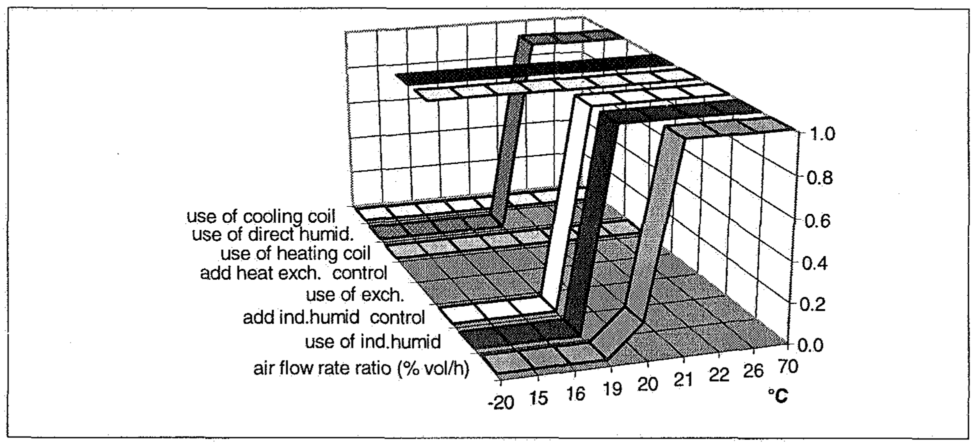
- direct humidification. The direct humidification is controlled in order to avoid air absolute humidity higher than a limit value wehumlim.

ti-occ	-20	20	21	22	23	24	25	26	70
air flow rate ratio (% vol/h)	0.17	0.17	0.17	0.17	0.17	**1.0**	1.0	1.0	1.0
use of	0	0	0	0	0	1	1	1	1
add ind.humid	0	0	0	0	0	1	1	1	1
use of	1	1	1	1	1	1	1	1	1
add heat exch.	1	1	1	1	1	1	1	1	1
use of heating	0	0	0	0	0	0	0	0	0
use of direct	0	0	0	0	0	0	1	1	1
use of cooling	0	0	0	0	0	0	0	0	0



during occupancy time

ti-inoc	-20	15	16	19	20	21	22	26	70
air flow rate ratio (% vol/h)	0.01	0.01	0.01	0.01	0.17	**1.0**	1.0	1.0	1.0
use of	0	0	0	0	1	1	1	1	1
add ind.humid	0	0	0	0	1	1	1	1	1
use of	1	1	1	1	1	1	1	1	1
add heat exch.	1	1	1	1	1	1	1	1	1
use of heating	0	0	0	0	0	0	0	0	0
use of direct	0	0	0	0	0	1	1	1	1
use of cooling	0	0	0	0	0	0	0	0	0



during non occupancy time

fig 5 - example of control scheme for an evaporative indirect/direct system in summer

We give hereafter detailed results for a typical warm day in summer (system dimensioning) at Trappes (Paris area). The system is a direct + indirect evaporative one. The building is of high inertia and East oriented.

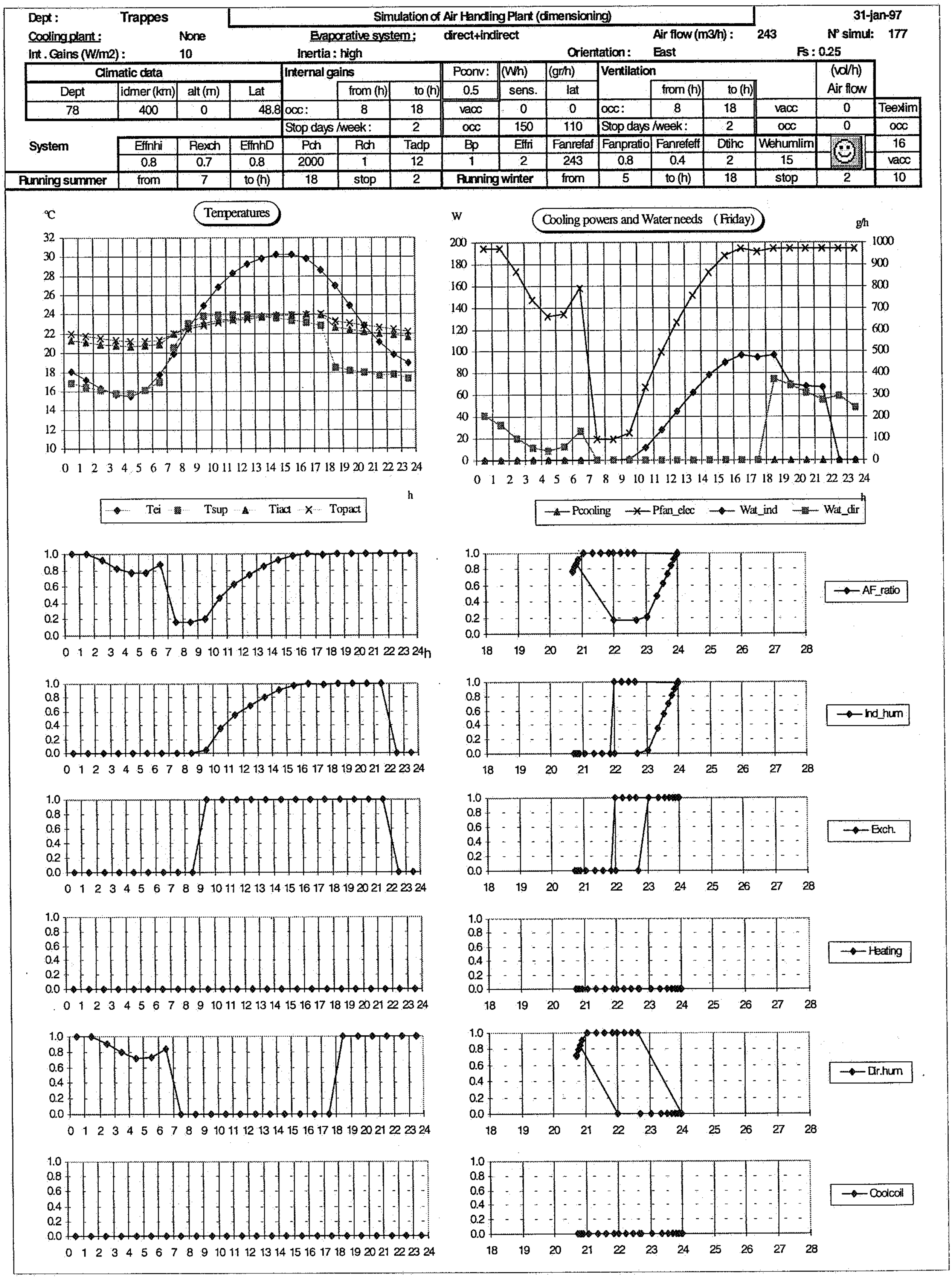


figure 6 example of result for a reference warm day

3. SIMPLIFIED DESIGN TOOLS

We choose to present basic results directly as indoor temperatures ,required coil cooling power and yearly energy and water needs for typical cases. The "worst" cases here taken into account are the worst possibles ones, considering that the use of evaporative and night cooling requires a minimum attention on the building design.

3.1.1 climatic area

3 climatic areas : center of France (Trappes) ; south interland (Carpentras) and south near the Mediterranean coast (Nice).

3.1.2 building characteristics

- **internal gains :** Occupants , equipment and lighting : 10 and 30 W/m^2 .

- **solar gains :** we define the ratio S Ab /Al with two reference values :0.05 ; 0.15 with S : window solar factor; Ab : window area, Al : room area

- **inertia :** low and high . Low means one ceiling or floor of high inertia; high means both ceiling and floor and side walls of high inertia.

- **orientation :** East and West.

3.1.3 system characteristics

- **air flow :** We choose 4 air flows corresponding to 2, 4, 6, 8 a.c./h.and 6 systems :

<u>without cooling plant :</u>

- no evaporative system ("night cooling" only),
- direct evaporative system,
- indirect evaporative system,
- direct + indirect evaporative system.

<u>with cooling plant :</u>

- without "night cooling" + cooling coil,
- indirect evaporative + cooling coil.

For all systems, "night cooling" is used if of interest.

For each system, we have defined control matrixes for summer and for winter conditions, during occupancy and inoccupancy (24 control matrixes).

3.1.4 simplified tool

Two sets of simulations were made for the three different sites (Trappes, Carpentras, Nice), using the equivalent RC dynamic model Comet developed at CSTB . The first set is related to sizing and dimensioning and is based on a reference warm day (figure 7). In this case we focus on indoor temperature and required cooling power if a cooling coil is used. The second set of runs were done for a complete typical year. Then, we focus on heating, cooling, fan electrical energy and water needs. About 2500 runs were performed , either on the typical day or on a complete reference year.

⬜	Correspond to maximum operative temperature in occupancy during the reference warm day <=26°C
░	Correspond to maximum operative temperature in occupancy during the reference warm day >26°C and <30°C
▒	Correspond to maximum operative temperature in occupancy during the reference warm day >=30°C and < 33°C
⬛	Correspond to maximum operative temperature in occupancy during the reference warm day >=33°C

Trappes (Dept : 78)

Reference warm day

Maximum operative temperature in occupancy

Solar gains S*Aglaz/Aroom		0.05								0.15										
Int. gain w/m² (8h to 18h)		10				30				10				30						
Inertia		High		Low		High		Low		High		Low		High		Low				
Orientation		E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W			
Air flow	**Evap.system**	**Without cooling plant**																**min**	**Ave**	**max**
2 vol/h	none	30	30	32														30		
	direct	26	26	28	29	30	30											26		
	indirect	28	28	30	30	32	32											28		
	direct+indirect	25	26	27	28	29	29	32		32								25	32	
4 vol/h	none	28	28	31	31	31	31			32								28		
	direct	24	24	25	26	26	26	29	30	28	28	30		30	31			24	29	
	indirect	25	26	27	28	28	28	31	32	30	31							25	31	
	direct+indirect	24	25	25	26	26	26	28	29	27	28	29	32	29	30	32		24	28	
6 vol/h	none	27	28	30	31	30	30			31	32							27	32	
	direct	23	24	24	25	25	25	27	28	26	26	28	30	28	28	31		23	27	
	indirect	24	25	26	27	26	27	29	30	28	28	30		30	31			24	29	
	direct+indirect	24	24	25	25	25	25	26	27	25	26	27	30	27	28	29	32	24	27	32
8 vol/h	none	27	27	30	30	29	30	32		30	31			32	32			27	32	
	direct	23	23	24	25	24	24	26	27	25	26	27	29	26	27	29	31	23	26	31
	indirect	24	24	26	27	26	26	28	29	27	27	29	31	28	29	31		24	28	
	direct+indirect	24	24	25	25	25	25	25	26	25	26	26	28	26	27	28	30	24	26	30
	min	23	23	24	25	24	24	25	26	25	26	26	28	26	27	28	30	23		
	Ave	26	26	27	28	28	28	30	31	29	30	32		32	32				30	
	max	30	30	32																
Air flow	**Evap.system**	**With cooling plant**																**min**	**Ave**	**max**
2 vol/h	ind.+Cool. plant	24	25	25	27	27	27	30	31	30	30	32						24	30	
	cool.plant only	25	25	26	27	27	28	31	32	30	31							25	31	
4 vol/h	ind.+Cool. plant	24	24	24	25	24	25	26	27	25	26	27	30	27	28	30		24	27	
	cool.plant only	24	24	24	25	25	25	27	28	26	27	29	31	28	28	31		24	27	
6 vol/h	ind.+Cool. plant	24	24	24	25	24	24	25	25	25	25	26	28	25	26	27	30	24	25	30
	cool.plant only	24	24	24	25	24	25	25	26	25	26	27	29	26	27	29	31	24	26	31
8 vol/h	ind.+Cool. plant	24	24	24	24	24	24	24	25	24	25	25	27	25	25	26	28	24	25	28
	cool.plant only	24	24	24	25	24	25	25	25	25	25	26	27	25	26	27	29	24	25	29
	min	24	24	24	24	24	24	24	25	24	25	25	27	25	25	26	28	24		
	Ave	24	24	25	25	25	25	26	27	26	27	28	30	28	29	31			27	
	max	25	25	26	27	27	28	31	32	30	31									

Maximum cooling power (W/m2)

Solar gains S*Aglaz/Aroom		0.05								0.15										
Int. gain w/m² (8h to 18h)		10				30				10				30						
Inertia		High		Low		High		Low		High		Low		High		Low				
Orientation		E	W	E	W	E	W	E	W	E	W	E	W	E	W	E	W			
Air flow	**Evap.system**																	**min**	**Ave**	**max**
2 vol/h	ind.+Cool. plant	13	13	14	14	14	14	15	15	15	15	16						13	16	
	cool.plant only	18	18	19	21	21	21	23	23	23	23							18	22	
4 vol/h	ind.+Cool. plant	12	15	18	26	26	26	27	27	26	26	28	29	28	28	30		12	25	
	cool.plant only	27	31	33	36	37	39	40	43	39	39	44	46	43	43	47		27	39	
6 vol/h	ind.+Cool. plant	10	12	17	27	24	28	34	39	29	38	39	40	39	39	41	43	10	31	43
	cool.plant only	30	35	36	48	49	53	54	56	54	54	58	64	58	58	67	69	30	53	69
8 vol/h	ind.+Cool. plant	9	11	17	26	23	27	33	44	28	37	41	52	42	50	52	54	9	34	54
	cool.plant only	34	38	39	52	53	57	61	71	59	70	71	77	72	73	78	86	34	62	86
	min	9	11	14	14	14	14	15	15	15	15	16	17	17	17	18	19	9		
	Ave	19	22	24	31	31	33	36	40	34	38	40	43	40	41	44			35	
	max	34	38	39	52	53	57	61	71	59	70									

figure 7 - example of simplified tool sheet for evaporative cooling system :
The maximum operative temperature, and the required cooling power (if use of a cooling coal) can be checked according to the building and system characteristics

4. CONCLUSION

The results of the works are as follows :

1. a simplified reference calculation method enabling to calculate the indoor temperature profile for a reference warm day according to a zoning of metropolitan French territory. Apart from the buildings characteristics, a focusing point is the description and the control of the air handling plant. This tool is based on an equivalent RC model and gives also the energy and water needs for a reference warm day and all over the year. A particular point of interest is the electrical needs for fans, as they can compensate in some case the reduction of energy required for cooling.

2. a predesign guidance document, which makes it possible for the most common cases to define the required buildings and air unit characteristics to achieve a given level of comfort by use of charts and tables and to evaluate the additional required cooling power if needed as well as the yearly water and energy needs.

Used primarily for new buildings, these tools will be also a help for retrofitting .

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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