Annex 28 Low Energy Cooling January 2001

Low Energy Cooling

Technology Selection and Early Design Guidance

Edited by
Nick Barnard
Denice Jaunzens

IEA Energy Conservation in Buildings and Community Systems Programme

IEA Energy Conservation in Buildings and Community Systems Programme

IEA Annex 28 Subtask 2: Design tools for low energy cooling

Technology selection and early design guidance

Edited by

Nick Barnard and Denice Jaunzens

This document contains two reports in a series produced by Annex 28 to assist with the design of low energy cooling systems:

Selection guidance for low energy cooling technologies
Early design guidance for low energy cooling technologies

The other reports are:

Review of low energy cooling technologies
Detailed design tools for low energy cooling technologies
Case studies of low energy cooling technologies

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Contents

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Preface

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through: energy conservation, the development of alternative energy sources, and energy research, development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this programme.

The Energy Conservation in Buildings and Community Systems Programme

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, and comparison of calculation methods, as well as studies of air quality and occupancy. Seventeen countries have elected to participate and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation had been restricted to governments. The importance of associating industry with government-sponsored energy research and development is recognised in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme is maintained by the Executive Committee (ExCo) and the Implementation Agreement on Energy Conservation in Buildings and Community Systems (B&CS), which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed Annexes are identified by an asterisk *):

1 Load energy determination of buildings*
2 Ekistics and advanced community energy systems*
3 Energy conservation in residential buildings*
4 Glasgow commercial building monitoring*
5 Air infiltration and ventilation centre
6 Energy systems and design of communities*

7 Local government energy planning*
8 Inhabitant behaviour with regard to ventilation*
9 Minimum ventilation rates*
10 Building HVAC systems simulation*
11 Energy auditing*
12 Windows and fenestration*
13 Energy management in hospitals*
14 Condensation*
15 Energy efficiency in schools*
16 BEMS – 1: User guidance*
17 BEMS – 2: Evaluation and emulation techniques*
18 Demand controlled ventilating systems*
19 Low slope roof systems*
20 Air flow patterns within buildings*
21 Thermal modelling*
22 Energy efficient communities*
23 Multizone air flow modelling (COMIS)*
24 Heat air and moisture transfer in envelopes*
25 Real time HVAC simulation*
26 Energy efficient ventilation of large enclosures*
27 Evaluation and demonstration of domestic ventilation systems
28 Low energy cooling systems
29 Daylighting in buildings
30 Bringing simulation to application
31 Energy related environmental impact of buildings
32 Integral building envelope performance assessment
33 Advanced local energy planning
34 Computer aided fault detection and diagnosis
35 HYBVENT

Introduction

Cooling is a significant user of energy in buildings, and its impact as a contributor to greenhouse gas emissions is enhanced by the fact that these systems are usually electrically driven. Increasing use of information technology has led to an increasing demand for cooling in the commercial buildings sector, with consequent problems for utilities companies.

In response to these issues, the IEA's Future Building Forum Workshop on Innovative Cooling (held in the United Kingdom in 1992) identified a number of technologies with the potential to reduce energy consumption in the field of alternative cooling strategies and systems, leading to the establishment of Annex 28. The emphasis for the project was on passive and hybrid cooling technologies and strategies. These require close integration of the dynamics of the building structure with the HVAC systems, and this is precisely the area in which the B&CS ExCo has established expertise.

Objective

Passive and hybrid cooling systems will only be taken up in practice if such systems can be shown to meet certain criteria. The objective of the Annex was to work towards fulfilling the following requirements.

- the life cycle costs (including energy, maintenance, etc) of such systems are less than 'conventional' systems;
- the level of thermal comfort provided is acceptable to the occupants in the context of their task;

- the systems are sufficiently robust to changes in building occupancy and use;
- the design concepts for such systems are well defined, and appropriate levels of guidance are available at all stages of the design process, from sketch plan to detailed plans;
- the necessary design tools are available in a form which designers can use in practice; and
- the cooling system is shown to integrate with the other systems (eg heating and ventilation), as well as with the building and control strategy.

Means

The project was subdivided into three subtasks relating to the tbree phases of researching and documenting the various cooling strategies.

Subtask 1: Description of cooling strategies

The aim of this subtask was to establish the current state of the technologies in the participating countries. The findings are detailed in the report: *Review of low energy cooling technologies.* The report also contains national data for climate, building standards, heat gains, comfort criteria, energy and water costs for each of the participating countries.

Snbtask 2: Development of design tools

Different levels of tool are required throughout the design process. Initially little detailed data will be available and the emphasis will be on tools using 'rules of thumb'. When suitable options have been established, approximate performance data and practical guidance will be needed for early design and assessment. Finally, when tbe broad principles of the design have been established, techniques such as simulation modelling can be used for detailed design and optimisation. To reflect these requirements, three different levels of tool have been developed by the Annex:

- *Selection guidance for low energy cooling technologies* (included in this publication)
  This tool provides guidance on the initial selection of suitable low energy technologies. Paper and software (Visual Basic) versions of the tool have been produced.

- *Early design guidance for low energy cooling technologies* (included in this publication)
  A collection of simplified tools based on design charts and tables, and practical guidance, to assist with early design development of a technology.

- *Detailed design tools for low energy cooling technologies*
  A report on a collection of tools for use as part of, or in conjunction with, simulation software.

Subtask 3: Case studies

The third element of the work was to illustrate the various cooling technologies through demonstrated case studies. Approximately twenty case studies have been documented in the Annex report *Case studies of low energy cooling technologies.* The case studies give feedback on performance and operation in practice and include design details and monitored performance data.

Scope

A number of different technologies have been considered by the Annex. The table gives an overview of which of the Annex reports have information on which of the technologies.

Low energy cooling technologies included in Annex reports

Technology	Review	Selection guidance	Early design guidance	Detailed design tools	Case studies
Night cooling (natural ventilation)	✔	✔	✔	✔	✔
Night cooling (mechanical ventilation)	✔	✔	✔	✔	✔
Slab cooling (air)	✔	✔		✔	
Slab cooling (water)	✔	✔	✔	✔	✔
Evaporative cooling (direct and indirect)	✔	✔	✔	✔	✔
Desiccant + evaporative cooling	✔	✔		✔	✔
Chilled ceilings/beams	✔	✔			✔
Displacement ventilation	✔	✔		✔	✔
Ground cooling (air)	✔	✔	✔	✔	✔
Aquifer	✔	✔		✔	✔
Sea/river/lake water cooling		✔			✔

Participation

The participating countries in this task are Canada, Germany, Finland, France, The Netherlands, Portugal, Sweden, Switzerland, the United Kingdom and the United States of America. The funding groups for each country are given below.

Canada	Buildings Group CANMET- Energy Technology Branch, NRCan 580 Booth St Ottawa, Ontario K1A 0E4
	Heat Management Technologies Energy Diversification Research Laboratory 1615, Montée Ste-Julie CP 4800 Varennes, Québec J3X 1S6
Germany	Bundesministerium für Bildung Technologie und Forschung (BMBE) Postfach 200240 Bonn, Germany
Finland	Technology Development Centre PO Box 69 Fin - 00101 Helsinki

France	Agence de l'environnement et de la maitrise de l'énergie Fédération nationale du bâtiment Ministère de l'équipement - Plan Construction Architecture Centre scientifique et technique du bâtiment Ecole des mines de Paris Gaz de France Costic
The Netherlands	Novem BV Swentiboldstraat 21 PO Box 17 6130 AA Sittard
Portugal	Center for Energy Conservation Praceta à Estrada de Alfragide Alfragide 2700 Amadora Department of Mechanical Engineering University of Porto R Bragas 4099 PORTO Codex
Sweden	Swedish Council for Building Research PO Box 12866 SE - 11298 Stockholm
Switzerland	Swiss Federal Office of Energy CH - 3003 Berne
United Kingdom	British Gas EA Technology Gardiner & Theobald Haden Young/Balfour Beatty Building MEPC Investments Oscar Faber Ove Arup Department of the Environment, Transport and the Regions Building Research Establishment Ltd
United States of America	Office of Building Technologies US Department of Energy 1001 Independence Avenue Washington DC 20585

IEA Annex 28 Subtask 2 Report 1

Selection guidance for low energy cooling technologies

Contents

A software version of this tool has also been produced.

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Summary

The aim of Annex 28 is to investigate the feasibility of, and provide design tools and guidance on, the application of alternative cooling strategies to buildings. Outputs from the Annex include a review of the technologies, early design guidance, detailed design tools and case study descriptions. The aim of this report is to assist with the initial selection of suitable low energy cooling technologies or combinations of technologies.

The report is based on a Selection Chart to help to identify which of the technologies are likely to be suitable for a particular application on the basis of key building parameters. This is supported by Summary Sheets for each of the technologies giving a brief description and key information. These can be used to refine the selection of technologies for further consideration.

The scope is limited to the technologies included in the Annex. The report should not be used in isolation as the sole means of selecting a technology, but as a means of focusing on a few technologies which are likely to be suitable and should be considered in more detail. The selection criteria are based on broad parameters and the way in which they will influence decisions in the majority of cases. Other parameters may be important in specific cases and there may be exceptions in the way the parameters included influence decisions. This will need to be assessed by the designer for each particular design.

The information provided reflects the state of the technologies in a country or countries participating in the Annex and should not be taken as representative of the situation on a world-wide basis.

Introduction

The aim of this report is to assist with the initial selection of suitable low energy cooling technologies. The guidance is given in the form of a Selection Chart (page 6) to help to identify which of the technologies are likely to be suitable for a particular application. The chart is based on feasibility (F) and suitability (S) ratings which reflect the impact of key building parameters on each of the technologies. Feasibility ratings are used to indicate if the use of a technology can generally be ruled out by a certain parameter. Suitability ratings indicate whether a parameter is likely to have a positive or negative effect on the performance or appropriateness of a technology. The chart is supported by Summary Sheets for each of the technologies, giving a brief description and key information. These can be used to refine the selection of technologies for further consideration.

To use the chart:

1. Highlight the parameters and associated ratings (see example on page 10). Notes are provided for each of the input parameters to help you to decide whether they are applicable or not.
2. Eliminate technologies that are not feasible, ie those with a –F rating.
3. Add the suitability (+S, –S) ratings for the remaining technologies to give an overall rating. A positive rating is favourable and a negative rating unfavourable. No rating implies no significant impact. The net S rating will give an indication of the suitability of a techuology for the application: positive = high suitability, none or zero = medium suitability, negative = low suitability.

Daytime natural and mechanical ventilation are included in the chart as a lower bound to indicate where no specific cooling provision (low energy or otherwise) is required. Mechanical cooling (refrigerant compression) is included as an upper bound. No summary sheets are provided for these technologies.

It should be noted that the parameters and ratings in the cbart consider selection primarily from a technical viewpoint. Other parameters such as cost will also need to be taken into account to refine the selection. Typical cost indicators and other key information are included on the subsequent summary sheets to assist selection of options from those which are technically suitable. The costs are given relative to a conventional heating, ventilation and air conditioning (HVAC) system and include all HVAC costs:

 ~50%

 ~75%

 ~100%

 ~125%

It is emphasised that these are only indicative for use in an initial assessment. Costs can vary considerably from application to application and specific costs should be assessed as soon as possible.

The summary sheets provide a brief description of each technology as an introduction. Common applications are noted together with rule-of-thumb performance data and spatial requirements. A check zone lists favourable and unfavourable factors for a given application, and aims and requirements for the design. One common aim for low energy cooling which precedes consideration of a cooling technology is the minimisation of heat gains*.

An important consideration is use of the technologies in combination to meet greater cooling loads or to reduce energy consumption, cost, etc. Common combination options are noted on the summary sheets. Technologies will generally work well together where they provide cooling in different ways. An example of this is ground cooling by air, which precools supply air, in combination with night cooling, which provides cooling via cool exposed surfaces in the space. Combinations are also possible where the technologies perform a different function in the cooling process. For example, ground cooling by water can provide cool water for use by chilled ceilings/ beams.

More details on the technologies are available in IEA Annex 28 Report *Review of low energy cooling technologies.*

*It should be emphasised that a prerequisite of low energy cooling is minimisation of heat gains to the space. Measures which should be considered to achieve this aim include suitable building orientation and form, solar shading, optimisation of glazing areas with regard to natural light versus solar heat gain, control of artificial lighting, and localised extract from heat sources. Documents providing guidance on these issues are listed under *Further reading.*

Selection chart: template and example

Selection chart template

Steps:

1 Delete non-applicable parameters.
2 Determine rating of each technology:
   negative F = low feasibility
   no F, negative S = low suitability
   no F, zero/no S = medium suitability
   no F, positive S = high suitability

Input parameters (see notes and maps)		Daytime natural ventilation	Daytime mechanical ventilation	Night cooling (natural ventilation)	Night cooling (mechanical ventilation)	Slab cooling (air)	Slab cooling (water)	Evaporative cooling (direct & indirect)	Desiccant + evaporative cooling[1]	Chilled ceilings/beams	Displacement ventilation	Ground cooling (air)	Aquifer[2]	Sea/river/lake water cooling[3]	Mechanical cooling
F/S rating															
Temperature	Hot	-F	-F	-F	-F	-F						-S	-S		+S
	Warm	-S	-S	-S	-S										
	Cool					+S	+S	+S				+S			
Humidity	Humid							-F							+S
	Semi - humid														
	Dry							+S	-S						
Noisy/Polluted air		-F		-F											
Ground pollution												-F			
Residential		+S[4]		+S[4]						-S			-S	-S	
Retrofit						-F[5]	-S[7]					-S[6]			
Limited floor/ceiling height		-S		-S							-S				
Deep plan/cellular space		-F		-F											
Heavyweight				+S	+S	+S	+S[8]								
Limited solar protection/High solar gains		-S	-S	-S	-S	-S	-S	-S		+S		-S	+S	+S	+S
High internal gains		-S	-S	-S	-S	-S	-S	-S		+S		-S	+S	+S	+S
Close temperature control		-F	-F	-F	-F	-F	-F	-F	-S	-S	-S	-S			+S
Close humidity control		-F	-F	-F	-F	-F	-F	-F	-F	-S	-S	-S			+S

Note 1: Applications limited by availability of low cost heat source.
Note 2: Geographic restrictions re presence of aquifer.
Note 3: Geographic restrictions re location near sea/river/lake.
Note 4: Natural ventilation is particularly suited to residential applications due to low cost.
Note 5: Applies to hollow core systems. Other approaches suitable for retrofitting are under development.
Note 6: Applies to ground cooling systems installed under buildings. In some applications it may be possible to install the system beneath adjacent ground.
Note 7: Not applicable if system already installed for heating.
Note 8: Use of slab cooling — water requires exposure of the slab and so the space will be heavyweight.

Notes for input parameters

Input parameters (also see temperature and humidity maps)

Temperature	Hot	$SDT^9 > 28°C$ and $SNT^{10} > 20°C$.
	Warm	$SDT^9 > 28°C$ and $SNT^{10} < 20°C$.
	Cool	$SDT^9 < 28°C$ and $SNT^{10} < 20°C$ (eg UK).
Humidity	Humid	$MC^{11} > 0.014$ kg/kg.
	Semi - humid	$MC^{11} < 0.014$ kg/kg and $WBD^{12} < 8$ K (eg UK).
	Dry	$MC^{11} < 0.014$ kg/kg and $WBD^{12} > 8$ K.
Noisy/Polluted air		Relative to desired internal environment.
Ground pollution		Eg Radon.
Residential		Less stringent comfort criteria likely to apply, smaller scale of development.
Retrofit		Space restrictions probable.
Limited floor/ceiling height		Reduces effectiveness of natural ventilation and displacement ventilation (~2.7 m minimum).
Deep plan/cellular space		Depth reduces effectiveness of natural ventilation (maximum ~7.5 m for single sided vent, ~15 m for cross vent). Cellular arrangement impedes air movement.
Heavyweight		Eg exposed soffit or floor.
Limited solar protection/High solar gains		Window solar factor*window area/floor area > 0.15 (typical solar factors; clear glazing ~0.8; solar control glass ~0.5 ; external shading ~0.2).
High internal gains		Internal design gains from occupants + equipment + lighting > 30W/m².
Close temperature control		Eg design criteria 22+/-2°C.
Close humidity control		Eg design criteria 40-70 %RH.

Note 9: SDT is the summer peak design temperature (°C).
Note 10: SNT is the summer night minimum design temperature corresponding to summer peak design temperature (°C).
Note 11: MC is the summer design moisture content (kg/kg dry air).
Note 12: WBD is the wet bulb depression, the difference between the summer design ambient dry and wet bulb temperatures

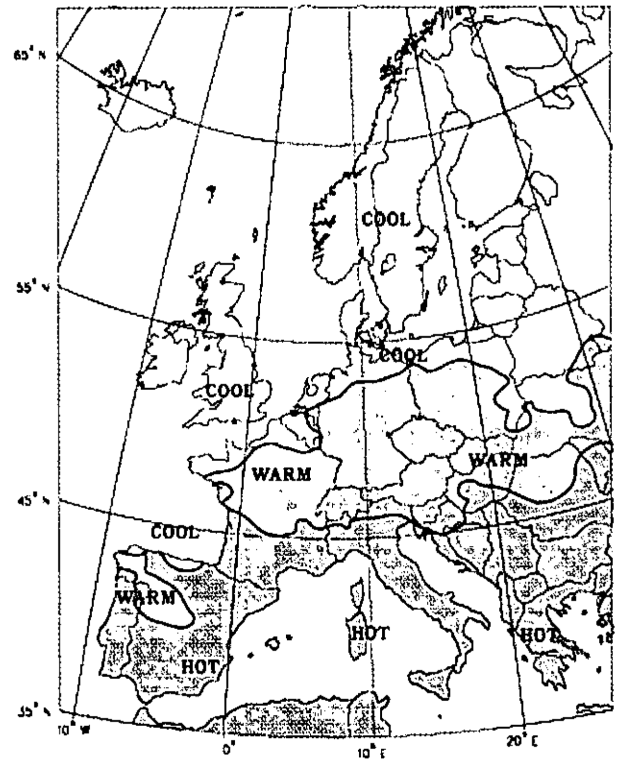
Temperature maps

European temperature map

Summer temperature zones

This map is based on ASHRAE 0.4% annual temperature data. It has been produced to provide initial guidance only and contains some simplifications — a specific assessment will need to be made by the designer for the particular location. Refer to Selection Chart for zone classifications.

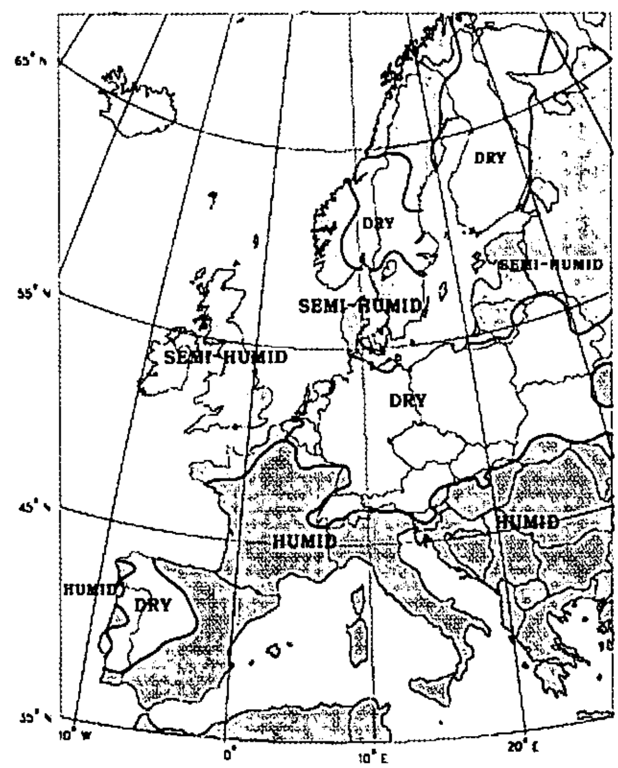
Note: Night minimum design temperature taken as day peak design temperature — mean daily range.



European humidity map

Summer humidity zones

This map is based on ASHRAE 0.4% annual humidity data. It has been produced to provide initial guidance only and contains some simplifications — a specific assessment will need to be made by the designer for the particular location. Refer to Selection Chart for zone classifications.



North American temperature map

Summer temperature zones

This map is based on ASHRAE 0.4% annual temperature data. It has been produced to provide initial guidance only and contains some simplifications — a specific assessment will need to be made by the designer for the particular location. Refer to Selection Chart for zone classifications.

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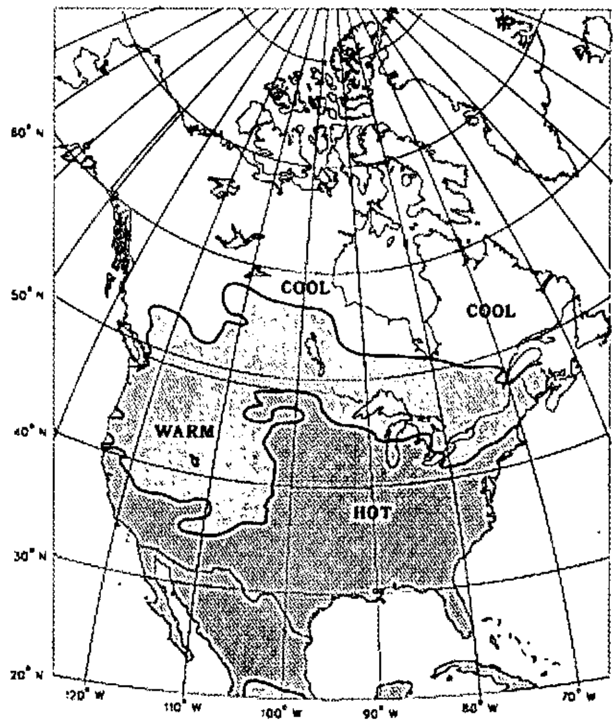

North American humidity map

Summer humidity zones

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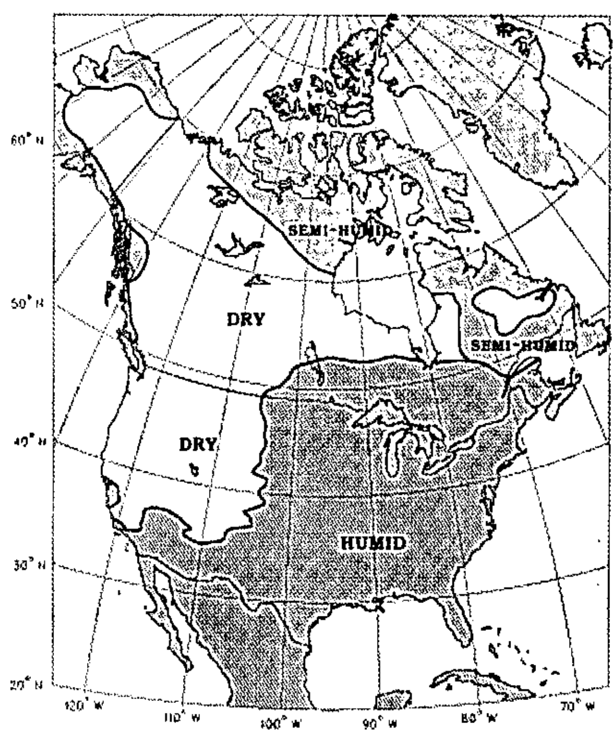


Selection chart example

A new commercial development in the UK in a noisy urban environment. Construction will be heavyweight plan. Reasonable solar protection will be provided but internal heat gains will be ~35 W/m^2. Close temperature/ humidity control is not required.

Steps:

1. Highlight applicable parameters: cool climate, semi-humid climate, noisy/polluted air, heavyweight, high internal gains.
2. Identify technologies with highlighted feasibility (–F) ratings; daytime — natural ventilation, night cooling (natural).
3. Add highlighted suitability (+S, –S) ratings for remaining technologies.

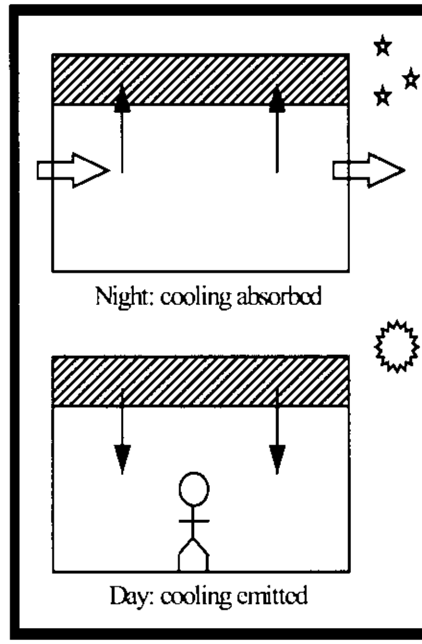
Input parameters (see notes and maps)

Technologies		Daytime natural ventilation	Daytime mechanical ventilation	Night cooling (natural ventilation)	Night cooling (mechanical ventilation)	Slab cooling (air)	Slab cooling (water)	Evaporative cooling (direct & indirect)	Desiccant + evaporative cooling[1]	Chilled ceilings/beams	Displacement ventilation	Ground cooling (air)	Aquifer[2]	Sea/river/lake water cooling[3]	Mechanical cooling
F/S rating		-F	-S	-F		+S	+S			+S			+S	+S	+S
Temperature	Hot	-F	-F	-F	-F	-F						-S	-S		-S
	Warm	-S	-S	-S	-S										
	Cool					+S	+S	+S				+S			
Humidity	Humid							-F							-S
	Semi - humid														
	Dry							+S	-S						
Noisy/Polluted air		-F		-F											
Ground pollution												-F			
Residential		+S[4]		+S[4]						-S			-S	-S	
Retrofit						-F[5]	-S[7]					-S[6]			
Limited floor/ceiling height		-S		-S							-S				
Deep plan/cellular space		-F		-F											
Heavyweight				+S	+S	+S	+S[8]								
Limited solar protection/High solar gains		-S	-S	-S	-S	-S	-S	-S		+S		-S	+S	+S	+S
High internal gains		-S	-S	-S	-S	-S	-S	-S		+S		-S	+S	+S	+S
Close temperature control		-F	-F	-F	-F	-F	-F	-F	-S	-S	-S	-S			-S
Close humidity control		-F	-F	-F	-F	-F	-F	-F	-F	-S	-S	-S			-S

Note 1: Applications limited by availability of low cost heat source.
Note 2: Geographic restrictions re presence of aquifer.
Note 3: Geographic restrictions re location near sea/river/lake.
Note 4: Natural ventilation is particularly suited to residential applications due to low cost.
Note 5: Applies to hollow core systems. Other approaches suitable for retrofitting are under development.
Note 6: Applies to ground cooling systems installed under buildings. In some applications it may be possible to install the system beneath adjacent ground.
Note 7: Not applicable if system already installed for heating.
Note 8: Use of slab cooling — water requires exposure of the slab and so the space will be heavyweight.

Summary sheets

Night cooling (natural ventilation)



Description

Air flow is introduced into the building at night by opening windows/vents. Operation of windows/vents can be manual or automatic. As the air circulates, it comes into thermal contact with and cools the exposed building fabric in the occupied zone. The cool exposed surfaces will offset heat gains the following day.

Applications

Most new and retrofit buildings with low sensible cooling loads, in particular those with periodic loads such as offices. May be unsuitable in cities due to air and noise pollution. Security and privacy concerns could also hinder application.

Benefits

- Very low capital and operating cost.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- Very low, but cost may be incurred in other areas, eg provision of special shutters/windows/vents, automating operation, wind towers etc

Operation - Energy
- Very low

Operation - Maintenance
- Very low, although some will be required for automatic opening devices and additional cleaning may be needed in urban areas

Favourable factors	**Unfavourable factors**
- Cool climate - Periodic loads	- Hot climate - External noise and air pollution - Limited floor/ceiling height - Deep plan/cellular space - High heat gains - Close temperature/humidity control
CHECK ZONE	
Design aims	**Design requirements**
- Cross ventilation air flow - Avoid overcooling	- Effective air/fabric thermal linking - Openable windows or equivalent - Security and privacy

Performance (cool climate)

Night cooling of heavyweight constructions will offset in the region of 20 to 30 W/m^2 of heat gains. Corresponding internal peak space temperature reductions are of the order of 2 to 3 K. Performance will be reduced for lightweight constructions with little exposed mass.

Spatial considerations

- Exposed mass.
- Ventilation openings in facade.
- Unobstructed air flow paths.

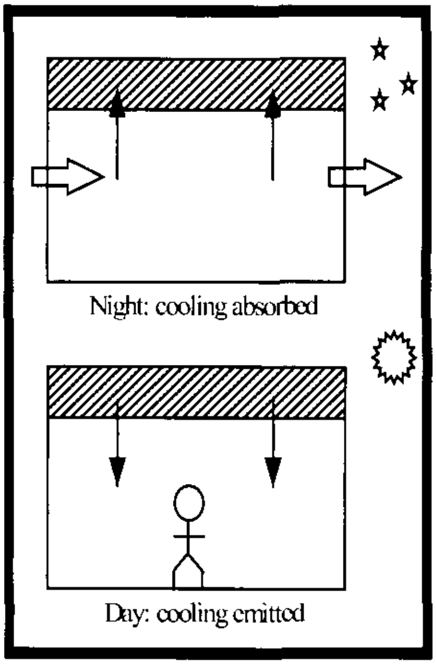
Combinations with other technologies

- Night cooling (mechanical ventilation) to boost cooling during peak periods.

Night cooling (mechanical ventilation)

Description

Fans are used to circulate cool ambient air through the building space overnight. As the air circulates, it comes into thermal contact with and cools the exposed building fabric in the occupied space. The cool exposed surfaces will offset heat gains the following day. (See also slab cooling - air where heat transfer takes place between the air and the slab in dedicated air paths to pre-cool the supply air.)


Night: cooling absorbed

Day: cooling emitted

Applications

Most new and retrofit buildings with low sensible cooling loads, in particular those with periodic daily loads such as offices.

Benefits

- Low capital and operating costs.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- Low

Operating - Energy
- Low for system (supply + extract) pressure drops < 1000 Pa, high for pressure drops > 1500 Pa

Operating - Maintenance
- Low

Favourable factors	**Unfavourable factors**
- Cool climate - Periodic loads	- Hot climate - High heat gains - Close temperature/humidity control
CHECK ZONE	
Design aims	**Design requirements**
- Minimise fan pressure drops - Avoid overcooling	- Effective air/fabric thermal linking - Space for ventilation system

Performance (cool climate)

Night cooling of heavyweight constructions will offset in the region of 20 to 30 W/m^2 of heat gains. Corresponding internal peak space temperature reductions are of the order of 2 to 3 K. Performance will be reduced for lightweight constructions with little exposed mass.

Cooling to fan energy ratio is approximately inversely proportional to system (supply + extract) pressure drop, and is typically ~3 @ 1000 Pa.

Spatial considerations

- Exposed mass.
- Ventilation system including fans, distribution ductwork, diffusers, etc.

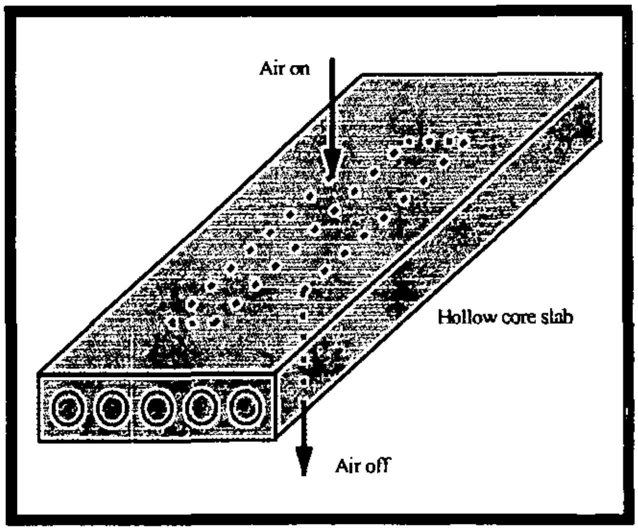
Combinations with other technologies

- Displacement ventilation to reduce temperatures in the occupied zone.
- One of the following to pre-cool the daytime supply air; ground cooling (air); evaporative cooling (direct and/or indirect); desiccant + evaporative cooling; slab cooling (air).

Slab cooling (air)

Description

The supply air is passed through dedicated air paths to bring it into thermal contact with the slab before entering the occupied space. High rates of air/slab heat transfer (and therefore charging/discharging of cooling) can be achieved in a number of ways. One is to use the cores in the slabs as ducts for the air supply. During the summer, the cool night air is passed through the slabs to lower their temperature. This stored cooling is then released the following day by using the slabs to pre-cool the supply air. The lower surface of the slab is also often exposed to provide direct heat exchange with the occupied space (see night cooling - mechanical ventilation).



Applications

New buildings with moderate sensible cooling loads, in particular those with periodic loads such as offices. The hollow core approach is restricted to new applications. (Other approaches suitable for retrofitting are under development.)

Benefits

- Low capital and operating cost.

Typical cost indicators (relative to a conventional HVAC system)

◕ Capital
- Low

◕ Operating - Energy
- Low for system pressure drops < 1000 Pa, high for pressure drops > 1500 Pa

◕ Operating - Maintenance
- Low

Favourable factors	**Unfavourable factors**
- Cool climate - Periodic loads	- Hot climate - High internal gains - Close temperature/humidity control
CHECK ZONE	
Design aims	**Design requirements**
- Minimise system pressure drop - Avoid overcooling at night - Use slab for heat storage in winter	- Effective air/slab thermal linking - Access for cleaning and maintenance of airways - Space for ventilation system

Performance (cool climate)

Systems can generally keep peak internal space temperature below ambient for heat gains up to ~40 W/m^2 without exposed lower slab surface, ~60 W/m^2 with an exposed lower slab surface.
Cooling to fan energy ratio is approximately inversely proportional to system (supply + extract) pressure drop, and is typically ~3 @ 1000 Pa.

Spatial considerations

- Possible increase in slab depth or floor void to incorporate air paths.
- Ventilation system including fans, distribution ductwork, diffusers, etc.

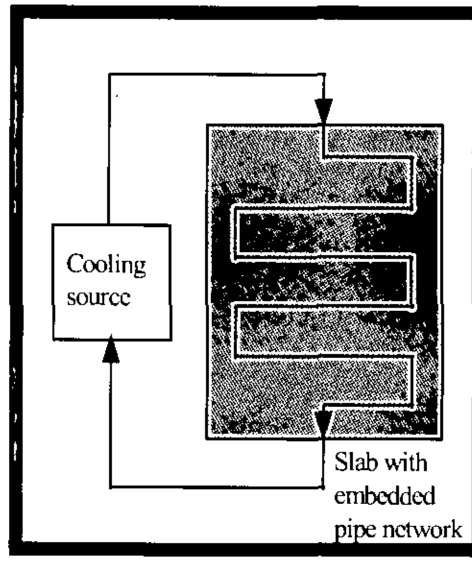
Combinations with other technologies

- Displacement ventilation to reduce temperatures in the occupied zone.
- Night cooling (mechanical ventilation) to provide space cooling.
- Mechanical cooling to meet peak loads.

Slab cooling (water)

Description

A pipe network is typically embedded in the slab itself or in a floating slab ~70 mm thick and located on the bearing slab. Water is circulated through the pipework from a cooling source such as a cooling tower or a heat pump, etc. The cooling is stored in the slabs. Cooling of the space is via heat transfer from the top or bottom surface of the slab. The system can also be used for heating in winter.



Applications

Best suited to new buildings with moderate sensible heat gains. It provides sensible cooling only and so is not suitable for climates with high humidity.

Benefits

- Low capital and operating costs.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- Similar (low when utilising system for heating as well)

Operating - Energy
- Low

Operating - Maintenance
- Low

Favourable factors	**Unfavourable factors**
- Low energy/quality source of cooling - Ability to use system for heating in winter	- Hot climate - High heat gains - Close temperature/humidity control
CHECK ZONE	
Design aims	**Design requirements**
- Avoidance of condensation problems - Surface/air temp. differential < 4 K	- Pipework connections accessible - Effective slab/air thermal linking - Space for central cooling and distribution system

Performance

Cooled floors	30 to 40 W/m² with cooling water @ 22°C occupied space @ 26°C
Cooled ceilings	40 to 50 W/m² with cooling water @ 20°C occupied space @ 26°C

(NB A larger radiant temperature asymmetry is tolerable with cooled ceilings than floors giving a higher cooling capacity.)

The ratio of cooling produced to energy for generation and distribution will primarily depend on the source of cooling utilised.

Spatial considerations

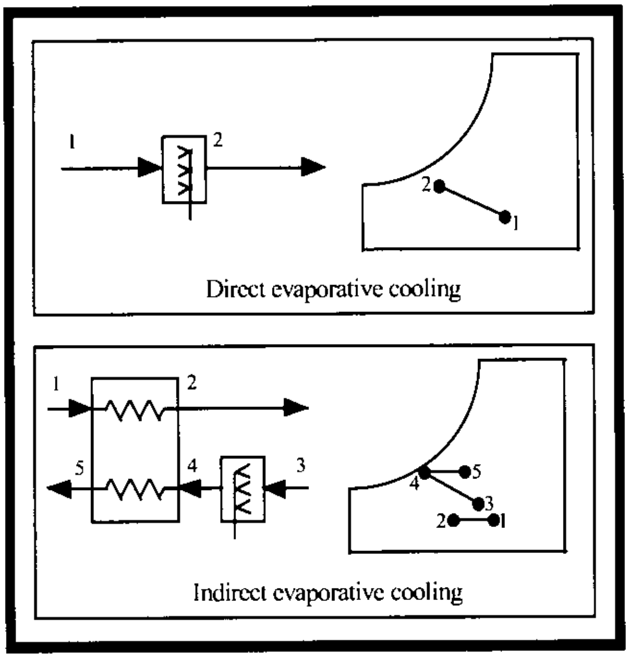
- Exposed slab surface.
- Central cooling plant and distribution system including pumps, pipework and cooling source (eg cooling towers, ground cooling - water, sea water cooling, mechanical cooling.)

Combinations with other technologies

- Low energy/quality sources of cooling including cooling towers, aquifer and sea/river/lake water cooling.
- Mechanical cooling, possibly utilising a low energy source for condenser cooling, eg aquifer or sea/river/lake water cooling.
- Displacement ventilation with cooled ceilings to reduce temperatures in the occupied zone.
- One of the following technologies to pre-cool the supply air; slab cooling (air); ground cooling (air).

Evaporative cooling (direct and indirect)

Description
Water is evaporated in non-saturated air to produce a drop in dry bulb temperature and an associated rise in the moisture content. Direct evaporative cooling is where this takes place in the supply airstream. The indirect approach cools the exhaust airstream. This air then sensibly cools the supply air via an air-to-air heat exchanger (which can also be used for heat recovery in winter). The two approaches can be used in isolation or in an indirect/direct combination.



Direct evaporative cooling

Indirect evaporative cooling

Applications
New or retrofit buildings with low internal gains. (Also used to pre-cool condenser air.)

Benefits
- Low cooling energy cost.
- Low capital cost.
- High fresh air flow rates give good ventilation.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- Low

Operating - Energy
- Low, small amount of extra fan and pump power plus water consumption

Operating - Maintenance
- Similar

Favourable factors	**Unfavourable factors**
- Dry climate	- Humid climate - High heat gains - Close temperature/humidity control - Legionella concern although risk limited by low water temperatures
CHECK ZONE	
Design aims	**Design requirements**
- Heat recovery using heat exchanger to pre-heat outdoor air in winter	- Space for ventilation system

Performance (dry climate)

Direct coolers	Subcooling of supply air ~80% of wet bulb depression[1] Ratio of cooling delivered to energy for generation and distribution ~7 Water consumption ~1.3 l/MJ of cooling
Indirect/direct coolers	Subcooling of supply air ~120% of wet bulb depression[1] Ratio of cooling delivered to energy for generation and distribution ~4 Water consumption ~1.5 MJ/l of cooling

Spatial considerations
- Ventilation system including fans, evaporators, distribution ductwork, diffusers, etc.

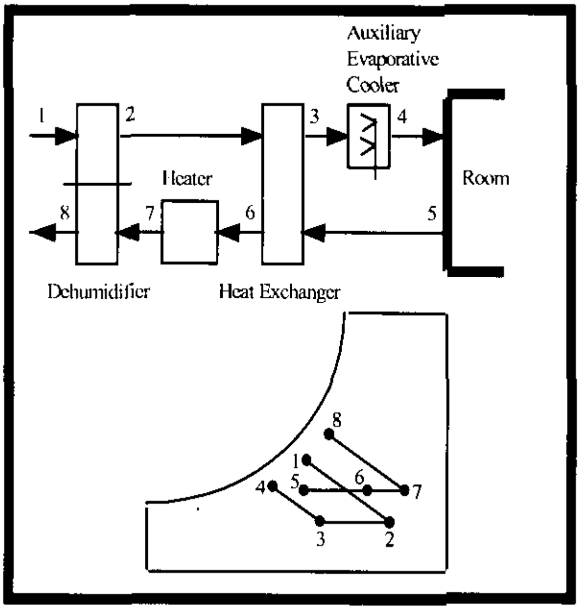
Combinations with other technologies
- Night cooling (mechanical ventilation) to provide space cooling.
- Displacement ventilation to reduce temperatures in the occupied zone.
- Mechanical cooling to meet peak loads.

[1]The wet bulb depression is the difference between the ambient dry and wet bulb temperatures.

Desiccant and evaporative cooling

Description

Moisture in the supply air is removed by a desiccant material in the dehumidifier. During dehumidification heat is released increasing the dry bulb temperature. The dry bulb temperature is then reduced by heat exchange with the exhaust air followed by auxiliary direct evaporative cooling.
The desiccant can either be solid or liquid.



Applications

Best suited to new and retrofit buildings where low cost heat energy is available.

Benefits

- Use of alternative energy sources and waste heat for regeneration.
- Load management by shifting electrical consumption to a thermal source.
- Improvement in IAQ (Indoor Air Quality) for desiccants which act as bactericides.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- High

Operating - Energy
- Low if waste heat or cheap thermal source available

Operating - Maintenance
- Similar

Favourable factors	Unfavourable factors
- Waste heat or cheap thermal source available	- Close temperature/humidity control - Dry climate

CHECK ZONE

Design aims	Design requirements
- Air filters to increase life span of dehumidifier	- Space for ventilation system - Supply and extract airstreams normally adjacent

Performance

Overall ratios of cooling output to regeneration and ancillary energy input of about 1 are achievable at present. Development of advanced desiccant materials and improved cycles may give ratios above 1.7. (NB These values should be seen in the context of use of alternative energy sources/waste heat and the low dew point temperatures which can be achieved.) Performance of auxilliary evaporative cooler will typically be as detailed under evaporative cooling. Example delivered cooling performance figures for a gas driven unit in a warm semi-humid climate are gas CoP =2.6, electrical CoP=11.6.

Spatial considerations

- Ventilation system including fans, desiccant device, evaporators, distribution ductwork, diffusers, etc.

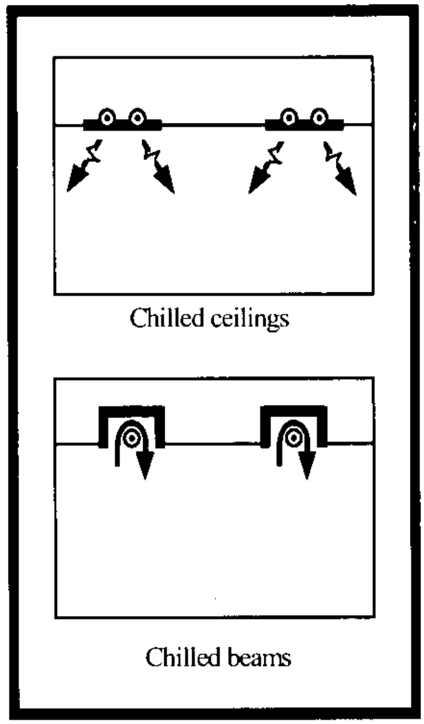
Combinations with other technologies

- Night cooling (mechanical ventilation) to provide space cooling
- Displacement ventilation to reduce temperatures in the occupied zone.
- Evaporative cooling of the reactivation airstream, reducing the requirement for auxiliary cooling but increasing the amount of heat needed for reactivation.

Specialist Applications

Desiccant cooling with mechanical rather than evaporative auxiliary cooling is applicable as a low energy cooling option in specialist applications where low humidity or separate control of temperature and humidity is required eg ice rinks, supermarkets, etc.

Chilled ceilings/beams



Description

The cooling units are often integrated with false ceilings. Cooling is provided by circulating cool water (~16°C) through the units. Chilled ceilings have flat panel units which transfer cooling to the space primarily by radiation. Chilled beams have a more open structure and rely on convective air movement as the principle mechanism for heat transfer.

Applications

New and retrofit buildings with medium internal gains.

Benefits

- Can be used in conjunction with a low quality source of cooling due to the relatively high cooling water temperature.
- Cooling supplied within the space limiting the requirements of the ventilation system to providing fresh air, so reducing plant and ductwork space requirements and fan energy consumption.

Typical cost indicators (relative to a conventional HVAC system)

Capital - High

Operating - Energy - Low

Operating - Maintenance - Similar

Favourable factors	Unfavourable factors
- Low energy/quality source of cooling	- Close temperature/humidity control
CHECK ZONE	
Design aims	**Design requirements**
- Avoidance of condensation problems	- Space for cooling elements - Space for central cooling and distribution system

Performance

Chilled ceilings ~40 W/m² typically assuming 50% active area with cooling water @16°C occupied space @26°C

Chilled beams ~60 W/m² typically with cooling water @16°C occupied space @26°C

The performance of both is approximately proportional to cooling water/occupied space temperature differential.

Output from chilled beams can vary considerably with design.

Overall cooling Coefficient of Performance (CoP) will be dependent on cooling source selected.

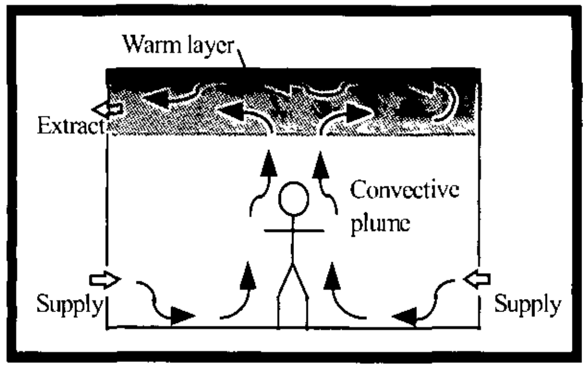
Spatial considerations

- Chilled ceilings/beams.
- Central cooling plant and distribution including pumps, pipework and cooling source (eg cooling towers, ground cooling - water, sea/river/lake water cooling, mechanical cooling).

Combinations with other technologies

- Displacement ventilation to reduce temperatures in the occupied zone and to provide fresh air and humidity control with chilled ceilings. (NB Interaction of chilled beams with displacement ventilation not established.)
- One of the following technologies to pre-cool the supply air; slab cooling (air); ground cooling (air).
- Low energy/quality sources of cooling including cooling towers, aquifer and sea/river/lake water cooling.
- Mechanical cooling, possibly utilising a low energy source for condenser cooling, eg aquifer or sea/river/lake water cooling.

Displacement ventilation



Description

Displacement ventilation is buoyancy driven air movement rather than forced as is the case for conventional mixed ventilation systems. Cool air is gently introduced into the conditioned space at low level. This spreads slowly across the space, providing a source of cool air for convective plumes which form around local heat sources. The plumes spread out below the ceiling to form a warm stratified layer from which the air is extracted.

Applications

Most new and retrofit buildings with moderate cooling loads.
Higher cooling loads are often met by using in combination with chilled ceilings.

Benefits

- Higher air supply/extract temperatures than for conventional mixed systems can reduce cooling energy consumption.
- More effective removal of contaminants than for conventional mixed systems because removal is direct rather than via dilution.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- Low

Operating - Energy
- Low

Operating - Maintenance
- Similar

Favourable factors	Unfavourable factors
- Surface temperature of heat sources >35°C	- Close temperature/humidity control - Strong disturbances to air flows from eg movements or downdrafts

CHECK ZONE

Design aims	Design requirements
- Supply air temperature >18°C - Space vertical temp. gradient <1.5 K/m	-Large floor to ceiling height required ie >2.7 m - Space for low velocity air terminal devices at low level

Performance

Capacity limited to 30 to 40 W/m^2 by maximum tolerable vertical temperature gradient in the occupied zone. (NB Higher gains could be met if a significant proportion are at high level out of the occupied zone eg lights.)
Often used in conjunction with chilled ceilings to meet higher cooling loads. In these applications the primary function of the displacement ventilation is normally to provide fresh air and humidity control.
Displacement air flow systems will typically reduce effective occupied space temperature by ~1 K (equivalent to offsetting ~5 W/m^2 of heat gains) in comparison with conventional mixed systems.

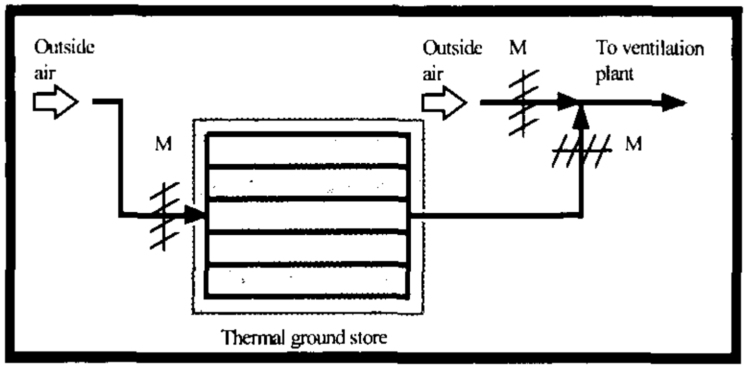
Spatial considerations

- Large floor to ceiling height, > 2.7 m
- Low velocity air terminal devices.

Combinations with other technologies

- One of the following to provide space cooling; night cooling (mechanical ventilation); chilled ceilings - interaction with chilled beams not established; slab cooling (water).
- One of the following to pre-cool the supply air; ground cooling (air); evaporative cooling (direct and/or indirect); desiccant + evaporative cooling; slab cooling (air); aquifer cooling; sea/river/lake water cooling; mechanical cooling.

Ground cooling (air)



Description
Outside air is drawn through an underground piping system by the ventilation plant. Heat transfer from the ground provides pre-cooling in the summer and pre-heating in the winter.

Applications
New mechanically ventilated buildings with suitable ground conditions.
Best suited to office buildings with a moderate cooling demand.

Benefits
Reduces peak demand for cooling and heating. This produces lower energy and installation costs for the rest of the HVAC system.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- High (to low for residential buildings)

Operating - Energy
- Low

Operating - Maintenance
- Low

Favourable factors	**Unfavourable factors**
- Ground temperature 12°C or lower - Located in sand/gravel + below water level - Moving ground water	- Hot climate - Rocky ground - Ground pollution eg radon - High heat gains - Close temperature/humidity control
CHECK ZONE	
Design aims - Insulate the system from building heat gains - Minimise piping system pressure drops	**Design requirements** - Space requirement for piping system - Access requirements for maintenance - Sealing in wet ground

Performance (cool climate)

Peak	
- Cooling with ambient air @ 32°C	45 W/m² of ground coupling area
- Heating with ambient air @ -5°C	45 W/m² of ground coupling area
Seasonal	
- Cooling	8-10 kWh/m² of ground coupling area
- Heating	10-15 kWh/m² of ground coupling area

Spatial considerations
- *Ground cooling system*, typically at 5 m depth, area a function of output as noted under performance.
- Access to ground cooling system.

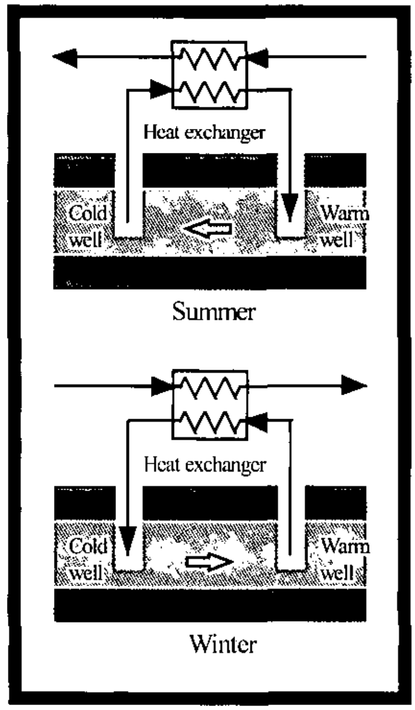
Combinations with other technologies
- Displacement ventilation to reduce temperatures in the occupied zone.
- One of the following to provide space cooling; night cooling (mechanical ventilation); chilled ceilings/beams; slab cooling (water) - cooled ceiling.

Aquifer

Description

The basic system consists of two well sets drilled in the sand bed. Water is pumped from one well set to the other in summer with cooling extracted via a heat exchanger. This cooling can either be used directly to cool the space/supply air, or indirectly as condenser water.

The cycle is reversed in winter with the extracted heat normally used to warm the ventilation supply air.



Applications

New and retrofit buildings with gross areas in excess of 6,000 m^2 with a suitable aquifer between 30 m and 200 m in depth limited by tight layers of clay or a similar type of soil material.

Benefits

- Low cooling energy cost.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- High (to similar for small systems)

Operating - Energy
- Low

Operating - Maintenance
- Similar

Favourable factors	Unfavourable factors
- Aquifer of sand or limestone bounded by tight layers of clay or similar soil material - Climates with a heating **and** cooling season for interseasonal storage	- Hot climate - Taxes or restrictions on ground water use - Moving ground water compromising interseasonal storage
CHECK ZONE	
Design aims - Balance heating and cooling extracted	**Design requirements** - Cold and warm well sets should be 100 to 150 m apart - Space for heat exchanger etc

Performance (cool climate)

Cool wells remain between 6 to 10°C, producing cooling water @~12°C in Summer
Warm wells remain between 12 to 22°C, producing heating water @~10°C in Winter
Water extraction typically ~25 l/s per well pair giving a peak capacity of ~900 kW cooling
Seasonal cooling storage per well pair ~1000 kWh/annum
Ratio of cooling produced to energy for generation (not distribution) ~10.

Spatial considerations

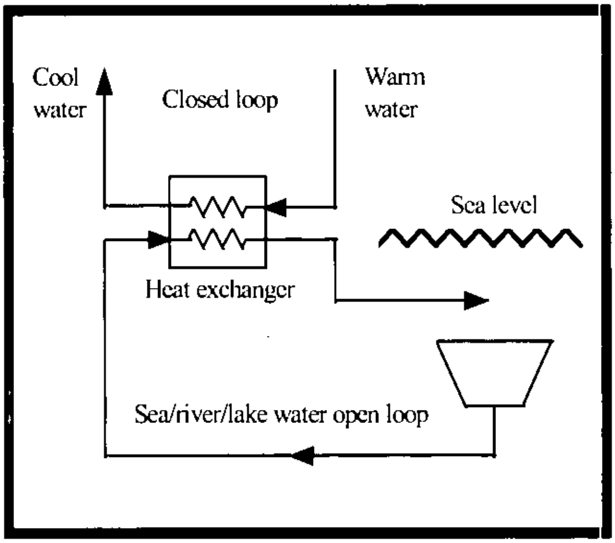
- Ground cooling system with cold and warm well sets 100 to 150 m apart, depth typically 30 to 200 m, size typically 1.5 x 1.5 m, number of wells is a function of output as noted under performance.
- Heat exchanger, circulating pumps, distribution pipework etc.

Combinations with other technologies

- One of the following technologies to use the low quality cooling to directly cool the space; chilled ceilings/beams; slab cooling (water).
- Displacement ventilation to reduce temperatures in the occupied zone.
- Mechanical cooling using the low quality cooling water as condenser water.

Sea/river/lake water cooling

Description
Water is pumped from the depths by an open loop system and cooling extracted via a heat exchanger. This cooling can either be used directly to cool the space/supply air, or indirectly as condenser water.
In winter, warm water returning to the heat exchanger can be used to pre-heat incoming fresh air.



Applications
New and retrofit buildings with moderate cooling loads which are located near sea/river/lake with low temperatures.

Benefits
- "Free" cooling can be provided by the cold water source for most of the year.
- Low operating cost.

Typical cost indicators (relative to a conventional HVAC system)

Capital
- High (but can be lower depending on system size and availability)

Operating - Energy
- Low

Operating - Maintenance
- Similar

Favourable factors
- Proximity to cold water source

Unfavourable factors
- Hot climate
- Great depth required to reach cold water
- Salinity in sea water encouraging corrosion in equipment

CHECK ZONE

Design aims
- Minimise cold water source pumping costs
- Eliminate corrosion and fouling possibilities
- Compatibility with mechanical cooling

Design requirements
- Space for heat exchanger etc

Performance
Effective direct cooling occurs only when intake temperatures are below 10°C. Lower intake temperatures may not be sufficient however when building cooling loads are high and heat transfer rates are constrained by pumping capacities. Indirect cooling of condensers in conjunction with mechanical cooling is effective provided intake temperatures remain below 13°C.
Cathodic protection is often used as a means to impede marine growth and corrosion in equipment.

Spatial considerations
- Heat exchanger, circulating pumps, distribution pipework etc.

Combinations with other technologies
- One of the following technologies to use the water to directly cool the space; chilled ceilings/beams; slab cooling (water).
- Mechanical cooling using the cool water as condenser water.
- Displacement ventilation to reduce temperatures in the occupied zone.

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IEA Annex 28 Subtask 2 Report 2

Early design guidance for low energy cooling technologies

Contents

Summary

The aim of Annex 28 is to investigate the feasibility of, and provide design tools and guidance on, the application of alternative cooling strategies to buildings. Outputs from the Annex include a review of the technologies, design tools and case study descriptions. This report is a compilation of guidance developed for use during early design. The guidance has been contributed by the individual member countries participating in the Annex.

The guidance is based on design charts and tables and practical information. The type of guidance varies between the technologies as appropriate, depending on their type and state of development. For example, the guidance for night cooling is predominantly design charts and tables as the equipment and construction techniques used are well established. This is not the case for a technology like ground cooling (air) for which a considerable amount of practical guidance has been provided.

The content of the chapters is as follows.

Chapter A *The applicability of evaporative cooling in commercial office buildings*
Tabulated maximum temperatures, percentage hours undercooled and electricity consumption (fans and cooling) for 14 system configurations and 24 climates.
Generated by DOE software.

Chapter B *Evaporative cooling in office buildings*
Tabulated peak temperatures/cooling coil loads under summer design conditions plus annual energy (heating, cooling and fan) and water consumptions per annum for French climates Trappes, Carpentras and Nice.
Generated by COMET thermal software.

Chapter C *Slab cooling system with water*
Charts for estimating the cooling provided in combination with a cooling tower based on indoor plus outdoor dry and wet bulb temperatures.

Chapter D *Night cooling ventilation in UK commercial buildings*
Design curves to predict peak temperatures, free cooling provided and fan energy consumption for south-east UK climate.
Generated by IES FACET software.

Chapter E *Night cooling in residential buildings*
Tabulated data to establish minimum solar protection required to limit peak temperatures for four French climates.
Generated by COMET thermal software.

Chapter F *Ground coupled air systems*
Design curves for capacity and sizing of simple systems based on Detailed Design Tool documented in IEA Annex 28 Subtask 2 Report 3.
Practical installation guidance.

Introduction

This report is a compilation of guidance for low energy cooling technologies intended for use during early design. It constitutes part of the output of the IEA's project Annex 28 in fulfilling its aim to provide design tools and guidance on the application of alternative cooling strategies to buildings. Guidance has also been developed by the Annex to assist with technology selection prior to early design (Report 1, which is included in this publication). Detailed design tools have been developed for the detailed design and simulation. A review of the technologies and case study descriptions have also been produced (see Preface).

The guidance is hased on design charts and tables and practical information. The type of guidance varies between the technologies as appropriate depending on their type and state of development. For example, the guidance for night cooling is predominantly design charts and tables as the equipment and construction techniques used are well established. This is not the case for a technology like ground cooling (air) for which a considerable amount of practical guidance has been provided.

Where design charts and tables have been provided, the data for these have generally been generated by simulation using the Detailed Design Tools documented in Annex 28 Subtask 2 Report 3. In some cases, the data have been generated only for the climate of the guidance originator. In these cases it may be that other Annex Participants have produced data for their own climates.

The tools all contain the following parts:

1 Introduction – a brief description of the technology and the tool
2 Parameters – definition of assumptions made for generating the design guidance
3 Design charts or tables – the design guidance

Other parts have been added to tools as necessary to cover practical guidance, references, etc.

Chapter A The applicability of evaporative cooling in commercial office buildings

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1 Introduction

To determine the applicability of evaporative cooling in commercial office buildings, computer simulations were done using the DOE-2.1E program[1] for various evaporative cooling systems as either stand-alone systems or precoolers for air-conditioning systems in a range of building conditions and climate variations. The performance of the evaporative cooling system was evaluated in terms of both comfort conditions and electricity use as compared with a standard air-conditioning system.

The results are presented as a set of tables showing the maximum indoor temperatures, percentage of annual hours undercooled, and the electricity consumption for cooling and fans for 14 system configurations (nine stand-alone, four precooling, and one conventional packaged variable-air-volume system) and 12 building variations (two levels of internal gains, two thermal mass conditions, three solar apertures). Twenty-four climate conditions have been studied, 14 in North America (11 in the US and three in Canada) and ten in Europe (two in Portugal, three in France, and one each in the UK, The Netherlands, Switzerland, Germany and Finland).

2 Parameters

The intent of the study is to provide guidelines on the general applicability of evaporative cooling by climate for a range of typical building conditions and operating conditions, rather than to analyse any particular building or control strategy in depth. The typical prototype building is a 1858 m^2 office building of either two or three floors, modelled as ten zones (five perimeter zones and one core zone on each floor).

● **Solar aperture**

Three levels of solar gain are studied:
low (30% window-to-wall ratio, 0.70 shading coefficient),
medium (30% window-to-wall ratio, 1.0 shading coefficient), and
high (60% window-to-wall ratio, 1.0 shading coefficient).
The windows are modelled as either single or double pane depending on location.

● **Internal gains**

Two levels of internal gains are studied:
high (39 W/m^2 for lights, 11 W/m^2 for equipment), and
low (16 W/m^2 for lights and 5 W/m^2 for equipment).
The hourly schedules for lights, electrical equipment, and occupants are shown in Figure 1.

● **Thermal inertia**

Two conditions of thermal mass are considered:

high, representing a heavy concrete construction with 30 cm concrete masonry walls, 20 cm heavy concrete floors, and a floor weight of 636 kg/m^2, and

light representing a light steel-frame construction with 15 cm lightweight walls, 10 cm lightweight concrete floors and a floor weight of 150 kg/m^2.

● **Occupancy and shell thermal integrity**

The occupant density and level of thermal integrity of the building have been varied by location based on government survey data for the US[2] or Appendix B of the IEA Annex 28 Subtask 1 report for other countries[3]. These are summarised in Table 1.

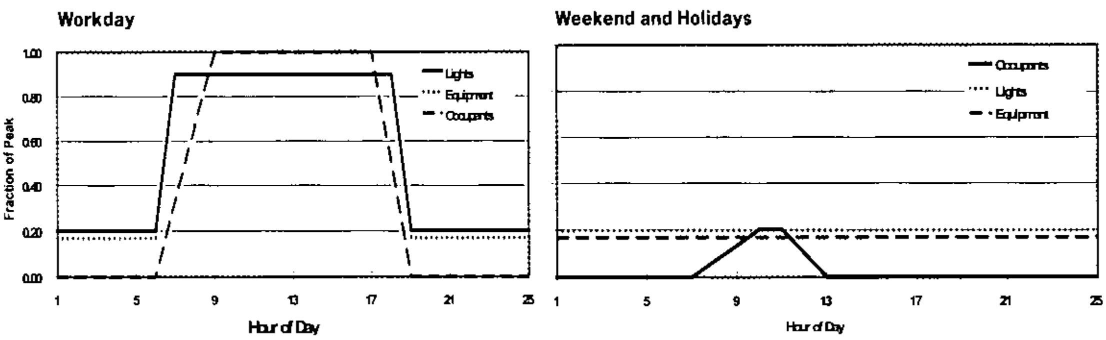

Figure 1 Building internal schedules

Table 1 Occupancy and shell thermal integrity for Annex 28 participating countries

	Occupancy (m^2/person)		U-value (W/m^2°C)		Window
Countries	**Perimeter**	**Core**	**Wall**	**Roof**	**panes**
US Northeast	20	20	0.52	0.33	2
US North Central	35	35	0.40	0.24	2
US South	25	25	0.52–2.30	0.33–0.42	1
US West	33	33	0.47–1.15	0.29–0.57	1
Canada	25	25	0.37	0.26	2
Portugal	10	10	0.60	0.60	2
The Netherlands	10	14	0.30	0.30	2
France	10	10	0.40	0.40	2
Germany	20	10	0.50	0.30	2
UK	10	10	0.60	0.45	2
Switzerland	13	17	0.25	0.20	2
Finland	8	8	0.28	0.22	3
Sweden	10	34	0.30	0.20	3

2.1 Climate variations

Fourteen locations in North America and ten in Europe have been considered in this study. The 11 US climates include the six categorised previously for Annex 28 (IEA Subtask 1 report[3]), plus two additional locations in the Midwest, two in the West, and one on the West Coast. The two West climates (Denver and Albuquerque) have short dry summers for which evaporative cooling is particularly suited. The three Canadian climates (Halifax, Toronto and Edmonton) are cool, but with very different levels of bumidity. The European climates are all cool compared with US climates, but most are semi-humid or humid, reducing the effectiveness for evaporative cooling. The general climate statistics for the 24 climates are shown in Table 2. The locations of the 24 cities are shown in Figure 2.

Table 2 Climate statistics for selected North American and European locations

City	Climate description	Cooling degree hours$_{25}$* (°C)	Enthalpy hours$_{25/40}$* (kJ/(kg°C))	Cooling degree hours$_{18}$* (°C)	Enthalpy hours$_{18/40}$* (kJ/(kg°C))
North American locations					
Minneapolis	US 1 (warm/semi-humid)	2 540	21 341	13 106	56 359
New York	US 2 (warm/semi-humid)	2 570	25 698	15 942	68 783
Washington	US 3 (hot/humid)	4 238	42 946	22 142	93 286
Miami	US 4 (very hot/very humid)	11 896	144 969	59 420	254 614
Phoenix	US 5 (very hot/dry)	27 256	39 738	59 910	96 329
Los Angeles	US 6 (mild/semi-humid)	574	8 667	7 552	64 019
Chicago	Warm and semi-humid	3 390	22 140	16 366	60 552
Fort Worth	Hot and semi-humid	12 176	75 416	39 240	141 860
Denver	Warm and dry	3 680	2 086	14 392	24 426
Albuquerque	Warm and very dry	6 136	8 603	22 892	38 049
San Francisco	Cool and semi-humid	194	3 065	3 782	26 890
Halifax	Canada 5 (cool/humid)	122	3 806	2 266	26 432
Toronto	Canada 1 (cool/semi-humid)	1 042	15 164	8 652	45 602
Edmonton	Canada 3 (cool/dry)	112	1 607	2 360	13 372
European locations					
Porto	Portugal 1	1 388	13 080	10 570	74 004
Lisbon	Portugal 1	1 936	12 287	12 122	64 204
Trappes	France 2	264	361	2 922	20 367
Carpentras	France 3	2 136	9 949	11 652	43 769
Nice	France 4	70	18 175	9 046	64 789
Eelde	The Netherlands	148	1 829	2 464	22 811
Kew	United Kingdom	34	1 746	2 382	24 218
Zurich	Switzerland	346	3 786	4 244	26 968
Frankfurt	Germany	654	3 151	5 684	27 573
Helsinki	Finland	28	372	1 496	13 547

* For explanation of climate parameters, see p 64 of Subtask 1 report[3]

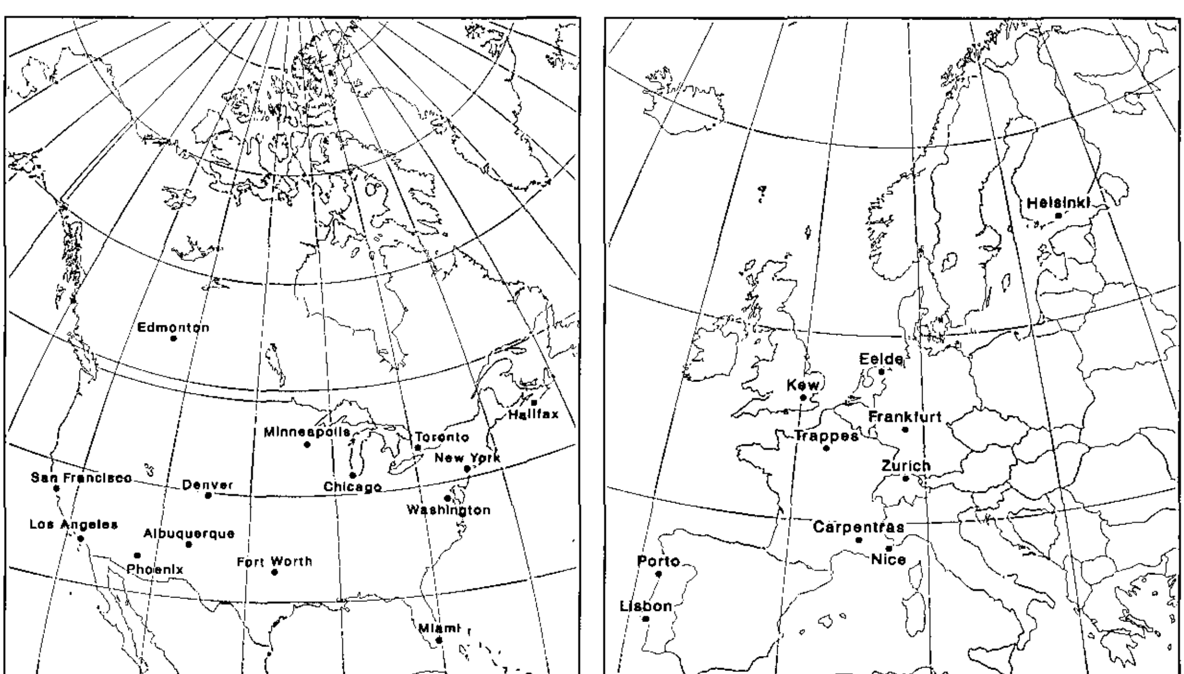

Figure 2 Representative North American and European climates studied

2.2 System characteristics

2.2.1 Stand-alone evaporative cooling systems

This analysis considered three types of stand-alone systems (direct, indirect, and indirect/direct) of four sizes providing 4, 8, 12 or 16 air changes per hour (ach) of evaporatively-cooled outdoor air. A schematic drawing of the evaporative cooling system configured in DOE-2 is shown in Figure 3. The effectiveness of a direct module is modelled as 0.85 at full-load conditions, while that of an indirect module is modelled as 0.60 at a wet-bulb temperature of 26.7 °C. Since the stand-alone units are assumed to have constant-volume fans, there is no change in effectiveness at part-load conditions, but the indirect effectiveness varies with the wet-bulh temperature based on the calculations using the Detailed Design Tool[4] (also see Figure 4).

To calculate the energy consumed by the evaporative cooling systems, the following modelling assumptions are used for fan static pressure and efficiency:

- direct systems — 100 mm of water, 0.00025 kW/m^3/hour
- indirect systems — 100 mm of water, 0.00068 kW/m^3/hour
- indirect/direct system — 125 mm of water, 0.0010 kW/m^3/hour

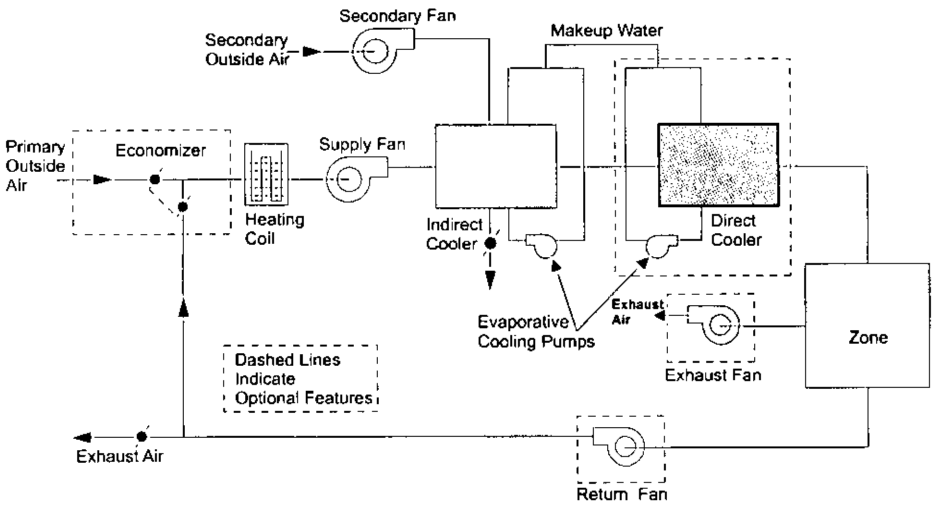

Figure 3 Stand-alone evaporative cooling systems

2.2.2 Evaporative precooling systems

There are many situations where evaporative cooling cannot provide sufficient cooling to warrant use as a stand-alone system, but it can be used effectively to precool the supply air and reduce the need for mechanical cooling. Four evaporative precooling configurations are considered in this study: indirect with outdoor air as the secondary air, indirect with room exhaust air as the secondary air, and indirect/direct systems with the same two secondary air choices.

As with the stand-alone units, the effectiveness of the direct and indirect modules is assumed as 0.85 and 0.60 respectively. However, since the systems have variable-speed fans, their full-load effectiveness increases under part-load conditions as shown in Figure 4. Both the direct and indirect systems are assumed to increase the fan static pressure by 12 mm of water, while the indirect/direct system is assumed to increase it by 25 mm of water.

The mechanical cooling system is assumed to be a packaged variable-air-volume system identical to the conventional air-conditioning system described in the following section. No attempt has been made to downsize the mechanical system since under peak wet-bulb conditions, evaporative precooling potential is probably very small to nil. Figure 5 is a schematic drawing of a standard mechanical cooling system with evaporative precooling. The drawing shows outside air being used as the secondary air, but room exhaust air is also considered in the simulations.

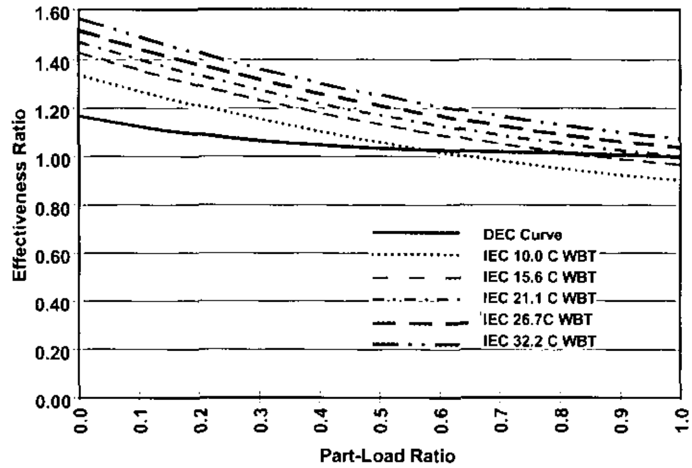

Figure 4 Evaporative cooling effectiveness curves

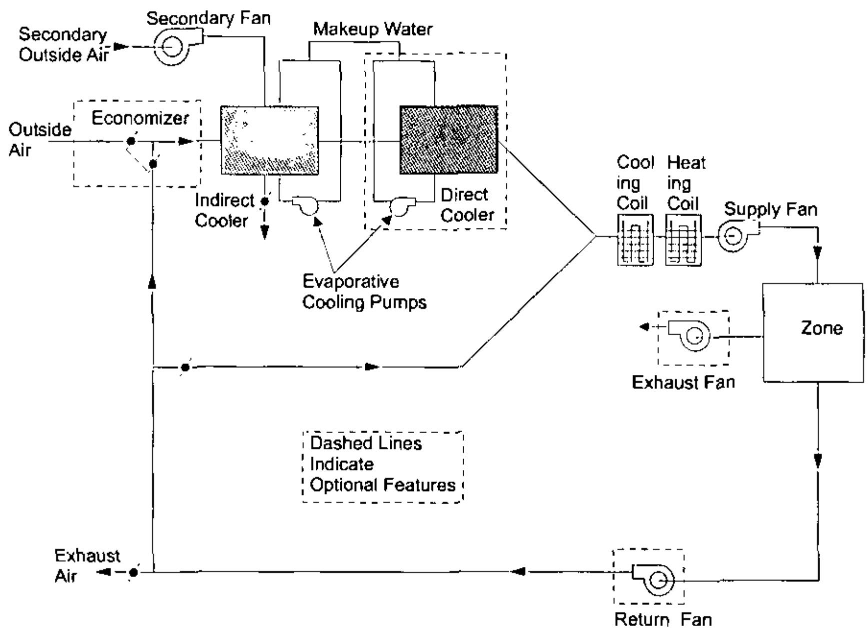

Figure 5 Evaporative precooling systems

2.2.3 Conventional air-conditioning system

The conventional air-conditioning system is modelled as a packaged variable-air-volume system (PVAVS) similar to those typically installed in small- to medium-sized office buildings. The PVAVS is modelled using DOE-2 default values, ie a COP of 2.78, and a supply fan efficiency of 0.0012 kW/m^3/hour. The DOE-2 program is also used to size the system automatically based on the building's cooling load. A schematic representation of the PVAVS is shown in Figure 6.

2.3 System operation

The HVAC system is assumed to be operated with a typical office schedule that runs from 07.00 h to 18.00 h on work days, 08.00 to 14.00 h on Saturdays, and off on Sundays and holidays. When the system is on, heating is set to 21.1 °C and cooling to 25.8 °C. The stand-alone evaporative cooling system is also operated with the same schedule.

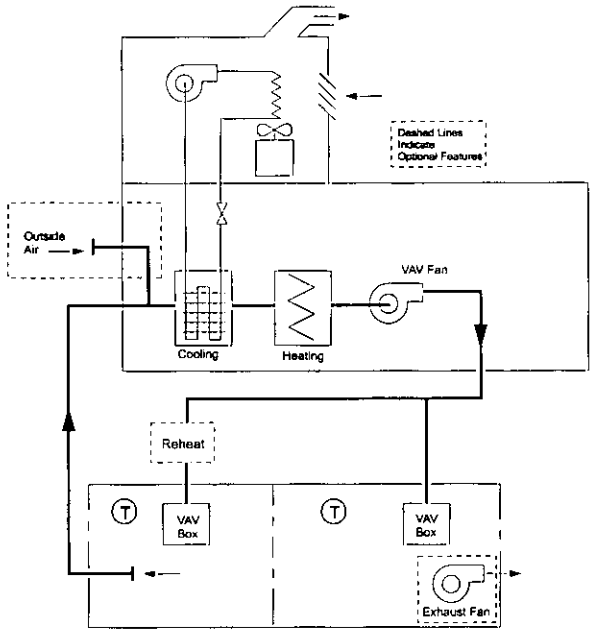

Figure 6 Conventional packaged variable-air-volume system

3 Design tables

The results from the DOE-2 simulations are shown in Tables 3 to 26 using a format similar to that developed by J R Millet in his parallel Annex 28 study on evaporative cooling in France[5]. Each table gives the results for one location. The 12 building conditions are shown across the top in order of increasing cooling loads from a building with low internal gains, low solar aperture, and high thermal inertia, to one with high internal gains, high solar aperture, and low thermal inertia. The sub-tables show (from top to hottom):

1 the peak indoor temperatures in the perimeter (**per**) and core (**cor**) zones in °C;
2 the percentage of annual hours where zone temperatures exceeded the thermostat setting (1% = 87.6 hours); and
3 the total electricity consumed by the fans and cooling system in kWh/m^2 of floor area.

The first sub-table indicates the performance of the evaporative cooling systems under design or peak conditions. The boxes are shaded dark, with white numbers, if the maximum zone temperatures exceed 34 °C, medium if they are between 30 °C and 34 °C, and light if they are between 26 °C and 30 °C. If the maximum zone temperature never reached 26 °C, the box is left white.

The second sub-table indicates the seasonal performance of the evaporative cooling systems by showing the number of hours when they are unable to maintain the thermostat settings. The boxes are shaded dark, with white numbers, if the total number of undercooled hours exceeds 10% or 876 hours, medium if it is between 5 and 10% (438–875 hours), and light if it is between 1% and 5% (88–438 hours). If the total number of undercooled hours is below 1% or 88 hours, the box is left white.

The third sub-table indicates the energy savings of the evaporative cooling systems relative to the reference PVAV system. The row showing total electricity consumed by the reference system is highlighted with light shading. The boxes showing the electricity consumed by the various evaporative cooling or evaporative precooling systems have medium shading if they exceed that of the reference cooling system, indicating energy penalties.

Table 3

	Location	Minneapolis MN																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	27	30	27	32	27	30	28	31	28	33	28	32	30	32	30	34	31	33	31	33	31	35	31
	indirect	30	28	31	28	32	28	31	29	31	29	34	29	32	31	33	31	34	31	33	32	34	32	[illegible]	32
	dir/indir	28	26	29	26	31	26	29	27	30	27	32	27	31	29	31	29	33	29	31	30	32	30	34	30
12 ACH	direct	28	27	29	27	30	27	29	27	29	27	31	27	30	29	31	29	32	29	31	30	31	30	33	30
	indirect	29	28	30	28	31	28	30	28	30	28	32	29	31	30	32	30	33	30	32	31	32	31	34	31
	dir-indirect	27	26	28	26	29	26	28	26	28	26	30	26	29	28	30	28	31	28	30	28	30	28	32	28
16 ACH	direct	28	27	29	27	30	27	29	28	29	28	31	28	30	29	30	29	31	29	30	29	31	29	32	29
	indirect	29	28	30	28	31	28	30	29	30	29	32	29	31	30	31	30	32	30	32	31	32	31	33	31
	dir-indirect	27	26	28	26	29	26	28	26	28	26	30	26	29	28	29	28	30	28	29	28	30	28	31	28
A/C only	PVAVS	25	26	25	26	25	25	24	25	24	25	24	25	26	26	26	26	25	26	25	26	25	25	24	25
Evap. Pre-Cooling	PVAVS + ind/OA	25	26	26	26	25	25	24	25	24	25	24	25	26	27	26	27	25	26	25	27	25	26	24	25
	PVAVS + ind/RA	25	25	25	25	25	25	24	25	24	25	24	24	25	26	26	26	25	26	24	26	24	25	24	25
	PVAVS + ind/dir/OA	25	26	25	26	25	25	24	25	24	25	24	25	26	27	26	27	25	26	25	26	24	26	24	25
	PVAVS + ind/dir/RA	25	25	25	25	25	25	24	25	24	25	24	24	26	26	26	26	25	26	24	26	24	25	24	25

Percent hours undercooled																									
8 ACH	direct	4	2	5	2	7	2	4	2	5	2	7	2	8	7	9	7	[illegible]	7	8	7	9	7	10	7
	indirect	5	3	6	3	8	3	5	3	6	3	8	3	9	8	10	8	[illegible]	8	9	8	10	8	[illegible]	8
	dir/indir	2	0	3	0	6	1	3	1	3	1	6	1	7	5	8	5	10	5	7	5	8	5	9	5
12 ACH	direct	2	1	3	1	5	1	3	1	3	1	5	1	5	4	6	4	8	4	5	4	6	4	7	4
	indirect	4	2	4	2	6	2	4	2	4	2	6	2	7	5	7	5	9	6	6	5	7	5	8	6
	dir-indirect	1	0	2	0	3	0	1	0	2	0	3	0	3	2	4	2	6	2	3	2	4	2	6	2
16 ACH	direct	2	1	2	1	4	1	2	1	2	1	4	1	4	3	4	3	6	3	4	3	4	3	5	3
	indirect	3	2	3	2	5	2	3	2	3	2	5	2	5	4	6	4	7	4	5	4	6	4	6	4
	dir-indirect	0	0	1	0	2	0	1	0	1	0	2	0	2	1	2	1	4	1	2	1	3	1	4	1
A/C	PVAVS	0	3	0	3	0	3	0	0	0	0	0	0	1	7	1	7	0	6	0	3	0	2	0	0
Evap. Pre-Cooling	PVAVS + ind/OA	0	2	0	3	0	2	0	0	0	0	0	0	1	6	1	6	0	5	0	2	0	2	0	0
	PVAVS + ind/RA	0	2	0	2	0	2	0	0	0	0	0	0	1	6	1	6	0	5	0	2	0	1	0	0
	PVAVS + ind/dir/OA	0	2	0	2	0	1	0	0	0	0	0	0	1	5	1	5	0	4	0	2	0	1	0	0
	PVAVS + ind/dir/RA	0	2	0	2	0	1	0	0	0	0	0	0	1	5	1	5	0	4	0	1	0	1	0	0

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	11	12	13	11	12	13	16	17	18	17	17	19
	indirect	15	16	18	15	16	18	22	22	24	22	23	24
	dir/indir	17	18	21	17	18	21	27	28	30	27	28	30
12 ACH	direct	13	14	16	13	14	16	20	21	22	20	21	23
	indirect	18	20	22	19	20	22	27	28	30	28	29	31
	dir-indirect	19	21	25	20	21	25	32	34	36	33	34	37
16 ACH	direct	14	16	18	15	16	18	23	24	25	23	24	26
	indirect	21	23	26	22	23	26	32	33	35	32	33	35
	dir-indirect	21	23	28	21	24	28	36	38	41	36	38	41
A/C	PVAVS	23	26	38	26	30	45	41	44	56	44	48	63
Evap. Pre-Cooling	PVAVS + ind/OA	23	26	38	25	29	45	41	45	56	44	48	63
	PVAVS + ind/RA	23	26	38	25	29	45	41	45	55	44	48	63
	PVAVS + ind/dir/OA	23	26	38	25	29	44	42	45	56	44	49	63
	PVAVS + ind/dir/RA	23	26	38	26	30	45	42	46	57	45	49	64

Table 4

	Location	New York NY																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	28	30	28	32	28	30	29	31	29	33	29	32	31	32	31	34	31	33	32	34	32	35	32
	indirect	30	29	31	29	33	29	31	30	32	30	34	30	33	32	33	32	35	32	34	33	35	33	36	33
	dir/indir	29	27	29	27	31	27	30	28	30	28	32	28	31	30	32	30	33	30	32	31	33	31	35	31
12 ACH	direct	29	28	29	28	30	28	29	28	30	28	32	28	30	30	31	30	32	30	31	30	32	30	33	30
	indirect	30	28	30	28	31	29	30	29	31	29	33	29	31	31	32	31	33	31	32	31	33	31	34	31
	dir-indirect	28	27	28	27	30	27	29	27	29	27	31	27	30	29	30	29	31	29	31	30	31	30	32	30
16 ACH	direct	29	28	29	28	30	28	29	28	30	28	31	29	30	30	31	30	32	30	31	30	31	30	33	30
	indirect	30	29	30	29	31	29	31	30	31	30	32	30	31	31	32	31	33	31	32	31	32	31	34	31
	dir-indirect	28	27	28	27	30	27	29	28	29	28	30	28	30	29	30	29	31	29	30	29	31	29	32	29
A/C	PVAVS	25	25	25	25	25	25	24	25	24	25	24	25	26	26	26	26	25	26	25	25	25	25	24	25
Evap.	PVAVS + ind/OA	25	26	25	26	25	26	25	25	24	25	24	25	27	28	27	28	25	27	26	27	25	27	24	25
Pre-	PVAVS + ind/RA	25	25	25	25	25	25	24	25	24	25	24	25	26	27	26	27	25	26	24	25	24	25	24	25
Cooling	PVAVS + ind/dir/OA	25	26	25	25	25	25	24	25	24	25	24	25	26	27	26	27	25	26	25	26	24	26	24	25
	PVAVS + ind/dir/RA	25	25	25	25	25	25	24	25	24	25	24	24	25	26	25	26	25	26	24	25	24	25	24	25

Percent hours undercooled																									
8 ACH	direct	5	3	6	3	8	3	5	3	6	3	8	4	10	8	11	8	13	8	9	8	10	8	12	8
	indirect	7	5	8	5	10	5	7	5	8	5	10	5	12	11	13	11	14	11	11	10	12	10	14	10
	dir/indir	4	2	5	2	7	2	4	2	5	2	7	2	8	7	9	7	11	7	8	7	9	7	11	7
12 ACH	direct	4	2	4	2	6	2	4	2	5	2	6	2	6	5	7	5	9	5	7	5	7	6	9	6
	indirect	5	4	6	4	7	4	5	4	6	4	8	4	8	7	9	7	10	7	8	7	9	7	10	7
	dir-indirect	2	1	3	1	5	1	2	1	3	1	5	1	5	4	6	4	7	4	5	4	6	4	7	4
16 ACH	direct	3	2	3	2	5	2	3	2	4	2	5	2	5	4	5	4	7	4	5	4	5	4	6	4
	indirect	4	3	5	3	6	3	4	3	5	3	6	3	6	6	7	6	8	6	6	6	7	6	8	6
	dir-indirect	1	1	2	1	3	1	2	1	2	1	3	1	3	3	4	3	5	3	4	3	4	3	5	3
A/C	PVAVS	0	3	0	3	0	3	0	1	0	1	0	1	1	7	1	7	0	6	0	3	0	3	0	2
Evap.	PVAVS + ind/OA	0	3	0	3	0	3	0	1	0	1	0	0	2	6	1	6	0	5	0	3	0	2	0	1
Pre-	PVAVS + ind/RA	0	2	0	2	0	2	0	0	0	0	0	0	0	6	0	6	0	5	0	2	0	1	0	0
Cooling	PVAVS + ind/dir/OA	0	2	0	2	0	2	0	0	0	0	0	0	1	5	1	5	0	4	0	2	0	1	0	1
	PVAVS + ind/dir/RA	0	2	0	2	0	1	0	0	0	0	0	0	0	5	0	5	0	4	0	1	0	1	0	0

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	12	13	14	12	13	14	18	19	20	19	20	20
	indirect	17	18	20	17	18	20	25	26	27	26	27	28
	dir/indir	19	21	23	20	21	23	31	32	33	31	32	34
12 ACH	direct	15	16	18	15	16	18	23	24	25	23	24	25
	indirect	22	23	25	22	23	26	32	33	35	33	34	35
	dir-indirect	23	25	28	23	25	29	37	38	41	38	39	41
16 ACH	direct	17	18	21	17	18	21	26	27	29	26	27	29
	indirect	26	27	30	26	27	30	38	39	41	38	39	41
	dir-indirect	26	28	32	26	28	32	42	44	46	42	44	47
A/C	PVAVS	28	31	43	31	36	50	51	54	65	55	59	72
Evap.	PVAVS + ind/OA	27	31	42	31	35	48	50	54	65	54	58	71
Pre-	PVAVS + ind/RA	27	31	42	31	34	48	50	53	64	53	57	70
Cooling	PVAVS + ind/dir/OA	27	30	41	30	33	47	49	52	63	52	56	69
	PVAVS + ind/dir/RA	27	30	41	30	34	48	49	53	63	53	56	69

Table 5

	Location	Washington DC																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	31	30	32	30	33	30	32	30	32	30	34	30	33	32	33	32	34	32	34	33	34	33	36	33
	indirect	32	31	33	31	34	31	33	31	33	31	35	31	34	33	34	33	35	33	35	34	35	34	36	34
	dir/indir	30	29	31	29	32	29	31	29	31	29	33	29	32	31	33	31	34	31	33	32	33	32	35	32
12 ACH	direct	31	30	31	30	32	30	31	30	32	30	33	30	32	32	33	32	33	32	33	32	33	32	34	32
	indirect	32	31	32	31	33	31	32	31	33	31	34	31	33	33	33	33	34	33	34	33	34	33	35	33
	dir-indirect	30	29	30	29	31	29	30	29	31	29	32	29	31	31	32	31	33	31	32	31	32	31	33	31
16 ACH	direct	31	30	31	30	32	30	32	30	32	30	33	30	32	32	33	32	33	32	33	32	33	32	34	32
	indirect	32	31	32	31	33	31	33	31	33	31	34	31	33	33	34	33	34	33	34	33	34	33	35	33
	dir-indirect	30	29	31	29	31	29	31	29	31	29	32	29	31	31	32	31	32	31	32	31	32	31	33	31
A/C	PVAVS	25	26	25	26	25	26	24	25	24	25	24	25	25	26	25	26	25	26	25	25	24	25	24	25
Evap.	PVAVS + ind/OA	26	27	26	27	25	26	25	26	25	26	24	25	27	28	27	28	27	28	27	28	27	28	24	26
Pre-	PVAVS + Ind/RA	25	26	25	26	25	25	24	25	24	25	24	25	26	27	26	27	25	26	24	26	24	26	24	25
Cooling	PVAVS + ind/dir/OA	25	26	25	26	25	26	25	26	24	25	24	25	27	28	27	28	26	27	26	27	25	27	24	25
	PVAVS + ind/dir/RA	25	25	25	26	25	25	24	25	24	25	24	25	26	27	26	27	25	26	25	26	24	26	24	25

	Percent hours undercooled																								
8 ACH	direct	8	6	9	6	11	6	8	6	9	6	11	6	12	11	12	11	14	11	11	10	12	10	13	10
	indirect	10	8	11	8	12	8	10	8	10	8	12	8	13	12	14	12	15	13	13	12	14	12	15	12
	dir/indir	7	5	7	5	10	5	6	5	7	5	9	5	10	9	11	9	12	9	10	9	11	9	12	9
12 ACH	direct	6	5	7	5	9	5	6	5	7	5	8	5	9	8	10	8	11	8	9	8	9	8	10	8
	indirect	8	7	9	7	10	7	8	7	9	7	10	7	11	10	11	10	12	10	10	10	11	10	12	10
	dir-indirect	5	3	5	3	7	3	5	3	5	3	7	3	7	6	8	6	9	6	7	6	8	6	9	6
16 ACH	direct	5	4	6	4	7	4	5	4	6	4	7	4	7	6	8	6	9	6	7	6	8	6	9	6
	indirect	7	6	8	6	9	6	7	6	8	6	9	6	9	8	10	8	11	8	9	8	9	8	10	8
	dir-indirect	4	3	4	3	6	3	4	3	4	3	6	3	6	5	6	5	7	5	6	5	6	5	7	5
A/C	PVAVS	0	5	0	5	0	4	0	1	0	1	0	1	1	10	1	10	0	9	0	4	0	3	0	2
Evap.	PVAVS + ind/OA	1	5	1	5	0	5	0	2	0	2	0	1	2	9	2	9	1	8	0	4	0	4	0	2
Pre-	PVAVS + Ind/RA	0	3	0	4	0	3	0	1	0	0	0	0	0	8	0	8	0	6	0	2	0	2	0	0
Cooling	PVAVS + ind/dir/OA	0	4	0	4	0	4	0	1	0	1	0	0	1	8	1	8	0	6	0	3	0	3	0	1
	PVAVS + ind/dir/RA	0	3	0	3	0	3	0	0	0	0	0	0	0	7	0	7	0	5	0	2	0	1	0	0

	Cooling and Fan Energy Use (kWh/m2)												
8 ACH	direct	20	21	22	20	21	23	28	29	30	29	29	30
	indirect	28	29	32	29	30	32	39	41	42	40	41	42
	dir/indir	32	34	37	32	34	37	47	48	50	47	49	50
12 ACH	direct	25	26	29	26	27	29	36	37	38	36	37	38
	indirect	37	38	41	38	39	42	51	52	54	51	53	54
	dir-indirect	41	42	46	40	42	46	58	60	62	59	60	63
16 ACH	direct	30	31	34	30	32	34	42	43	45	42	43	45
	indirect	45	46	50	46	47	51	61	63	65	62	63	65
	dir-indirect	48	50	54	47	50	54	68	70	73	68	70	73
A/C	PVAVS	35	39	52	38	43	60	63	67	79	66	71	87
Evap.	PVAVS + ind/OA	36	40	53	39	43	59	64	69	81	67	72	87
Pre-	PVAVS + ind/RA	35	38	51	37	42	58	62	66	78	64	69	84
Cooling	PVAVS + ind/dir/OA	35	39	52	37	42	58	63	67	79	66	70	86
	PVAVS + ind/dir/RA	34	37	50	36	41	57	61	65	76	63	68	83

Table 6

	Location	Miami FL																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	28	30	28	32	28	30	29	31	29	33	29	32	31	33	32	34	32	33	32	34	32	35	32
	indirect	30	29	31	29	33	29	31	30	32	30	34	30	33	32	33	32	35	33	34	33	35	33	36	33
	dir/indir	29	27	29	27	31	27	30	28	30	28	32	28	31	30	33	32	34	31	32	31	33	31	35	31
12 ACH	direct	29	28	29	28	30	28	29	28	30	28	32	28	30	30	32	31	33	32	31	30	32	30	33	30
	indirect	30	28	30	28	31	29	30	29	31	29	33	29	31	31	32	32	34	33	32	31	33	31	34	31
	dir-indirect	28	27	28	27	30	27	29	27	29	27	31	27	30	29	32	31	33	31	31	30	31	30	32	30
16 ACH	direct	31	30	31	30	32	30	32	30	32	30	32	30	32	31	32	31	33	31	33	31	33	31	33	31
	indirect	31	31	32	31	32	31	32	31	32	31	33	31	32	32	33	32	33	32	33	32	33	32	34	32
	dir-indirect	31	30	31	30	32	30	31	30	32	30	32	30	32	31	32	31	33	31	32	31	33	31	33	31
A/C only	PVAVS	25	25	25	25	25	25	24	25	24	25	24	25	26	26	26	27	25	26	25	25	25	25	24	25
Evap.	PVAVS + ind/OA	25	26	25	26	25	26	25	25	24	25	24	25	27	28	29	31	27	28	26	27	25	27	24	25
Pre-	PVAVS + ind/RA	25	25	25	25	25	25	24	25	24	25	24	25	26	27	27	28	25	26	24	25	24	25	24	25
Cooling	PVAVS + ind/dir/OA	25	26	25	25	25	25	24	25	24	25	24	25	26	27	27	29	26	27	25	26	24	26	24	25
	PVAVS + ind/dir/RA	25	25	25	25	25	25	24	25	24	25	24	24	25	26	27	28	25	26	24	25	24	25	24	25

Percent hours undercooled																									
8 ACH	direct	29	25	31	25	34	25	29	25	31	25	34	25	36	36	38	36	40	36	36	36	37	36	39	36
	indirect	32	29	33	29	36	29	32	29	33	29	35	29	38	39	39	39	41	39	37	38	38	38	40	38
	dir/indir	27	21	29	21	33	22	27	21	29	21	33	21	36	35	37	35	39	35	35	34	36	34	38	34
12 ACH	direct	25	22	26	22	30	22	26	21	27	21	29	21	31	29	32	29	34	29	31	29	32	29	34	29
	indirect	28	26	30	26	32	26	29	26	30	26	32	26	34	33	35	33	36	33	33	32	34	32	36	32
	dir-indirect	22	18	24	18	26	18	23	18	24	18	27	18	29	27	31	27	33	27	29	26	30	26	33	26
16 ACH	direct	23	20	24	20	26	20	23	20	24	20	26	20	27	25	28	25	31	25	27	25	28	25	30	25
	indirect	26	24	27	24	30	24	27	24	28	24	29	24	30	29	31	29	33	29	30	29	31	29	33	29
	dir-indirect	20	16	21	16	24	16	20	16	21	16	24	16	25	22	26	22	29	22	25	22	26	22	28	22
A/C	PVAVS	4	21	3	21	0	19	0	12	0	12	0	11	7	27	5	26	1	24	0	11	0	11	0	10
Evap.	PVAVS + ind/OA	10	23	9	23	2	21	0	12	0	12	0	11	14	29	12	28	4	25	1	14	0	13	0	10
Pre-	PVAVS + ind/RA	4	20	2	20	0	17	0	10	0	10	0	10	6	25	4	25	0	21	0	10	0	9	0	8
Cooling	PVAVS + ind/dir/OA	6	22	4	21	0	19	0	11	0	11	0	10	10	25	7	25	1	21	0	10	0	10	0	8
	PVAVS + ind/dir/RA	3	19	2	19	0	16	0	10	0	10	0	9	5	23	4	22	0	18	0	9	0	8	0	7

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	53	54	56	52	53	55	62	62	64	61	62	63
	indirect	72	74	76	72	73	75	82	83	85	81	83	84
	dir/indir	90	92	95	89	91	94	105	107	109	104	106	108
12 ACH	direct	73	74	77	72	74	76	85	87	88	85	86	87
	indirect	101	103	106	101	102	105	116	117	119	115	116	118
	dir-indirect	123	126	130	123	125	129	146	148	151	145	147	149
16 ACH	direct	91	93	96	91	92	95	107	108	110	106	107	109
	indirect	128	131	134	128	130	134	147	148	151	146	147	150
	dir-indirect	153	156	162	152	155	161	182	184	188	181	183	187
A/C	PVAVS	70	76	94	77	84	104	118	125	144	126	133	153
Evap.	PVAVS + ind/OA	78	85	106	85	92	114	134	142	165	143	150	171
Pre-	PVAVS + ind/RA	67	72	88	71	78	97	116	122	136	117	124	142
Cooling	PVAVS + ind/dir/OA	78	85	105	84	92	114	135	142	162	141	148	170
	PVAVS + ind/dir/RA	69	75	91	74	81	101	120	125	141	122	129	148

Table 7

	Location	Phoenix AZ																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	32	30	32	30	34	30	32	30	33	30	35	30	33	32	34	32	35	32	34	32	35	32	36	32
	indirect	33	32	34	32	36	32	34	32	35	32	37	32	35	34	35	34	37	34	36	34	37	34	39	34
	dir/indir	30	28	30	28	32	28	30	28	31	28	33	28	31	30	32	30	33	30	32	30	32	30	34	30
12 ACH	direct	31	29	31	29	32	29	31	29	32	29	33	29	32	31	32	31	34	31	33	31	33	31	34	31
	indirect	33	32	33	32	34	32	33	32	34	32	35	32	34	33	34	33	35	33	35	33	35	33	37	33
	dir-indirect	29	27	29	27	30	27	29	27	29	27	31	27	30	29	30	29	31	29	30	29	31	29	32	29
16 ACH	direct	31	30	31	30	32	30	31	30	32	30	33	30	32	31	32	31	33	31	32	31	33	31	34	31
	indirect	33	32	33	32	34	32	34	32	34	32	35	32	34	33	34	33	35	33	35	33	35	33	36	33
	dir-indirect	29	27	29	27	30	28	29	28	29	28	30	28	30	29	30	29	31	29	30	29	30	29	31	29
AC only	PVAVS	26	27	26	27	25	26	25	26	24	26	24	25	26	28	26	28	25	27	25	26	25	26	24	26
Evap.	PVAVS + ind/OA	26	27	26	27	25	26	24	26	24	26	24	25	26	29	26	28	25	27	25	27	24	27	24	26
Pre-	PVAVS + ind/RA	26	26	25	26	25	25	24	26	24	25	24	25	26	28	26	28	25	26	24	26	24	26	24	25
Cooling	PVAVS + ind/dir/OA	26	27	25	26	25	26	24	26	24	26	24	25	26	28	26	28	25	27	25	27	24	26	24	26
	PVAVS + ind/dir/RA	26	26	25	26	25	25	24	26	24	25	24	25	26	28	25	28	25	26	24	26	24	26	24	25

Percent hours undercooled																									
8 ACH	direct	14	9	16	10	20	10	14	9	16	9	20	9	19	16	21	16	25	16	19	16	21	16	24	16
	indirect	17	13	19	13	23	13	17	13	19	13	23	13	21	19	24	19	28	19	22	19	24	19	28	19
	dir/indir	11	4	14	4	18	4	11	3	13	3	18	3	17	14	19	14	23	14	17	13	19	13	23	13
12 ACH	direct	11	8	12	8	15	8	11	8	12	8	15	8	14	11	15	11	18	11	14	10	15	10	18	10
	indirect	14	12	15	12	18	12	14	12	15	12	18	12	17	15	18	15	21	15	17	14	18	14	21	14
	dir-indirect	7	2	8	2	13	2	7	2	8	2	12	2	11	5	13	5	16	5	11	5	12	5	16	5
16 ACH	direct	10	7	10	7	12	7	9	7	10	7	12	7	11	9	12	9	15	9	11	9	12	9	14	9
	indirect	13	11	14	11	16	11	13	11	13	11	16	11	15	13	15	13	18	13	15	13	15	13	18	13
	dir-indirect	4	1	5	1	9	1	4	1	5	1	8	1	7	3	8	3	12	3	7	3	8	3	11	3
A/C	PVAVS	5	11	3	10	0	6	0	6	0	6	0	5	6	19	4	18	0	15	0	12	0	10	0	7
Evap.	PVAVS + ind/OA	3	9	3	8	0	6	0	5	0	5	0	4	4	16	3	15	0	12	0	9	0	7	0	5
Pre-	PVAVS + ind/RA	3	9	2	8	0	5	0	5	0	5	0	4	3	16	2	15	0	12	0	8	0	6	0	4
Cooling	PVAVS + ind/dir/OA	3	9	2	8	0	5	0	5	0	4	0	4	4	15	2	14	0	10	0	7	0	5	0	4
	PVAVS + ind/dir/RA	2	9	2	7	0	5	0	5	0	4	0	4	3	15	2	14	0	11	0	6	0	5	0	4

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	30	31	34	30	32	35	41	43	45	41	43	45
	indirect	43	45	50	44	46	50	57	59	62	58	60	62
	dir/indir	45	48	52	45	48	52	64	66	69	64	66	69
12 ACH	direct	38	40	44	38	40	44	52	54	57	52	54	57
	indirect	57	60	65	58	61	66	74	76	80	74	76	80
	dir-indirect	55	58	65	55	58	65	79	82	87	79	82	86
16 ACH	direct	45	48	52	46	48	52	61	63	66	61	63	66
	indirect	69	72	78	71	74	79	89	91	96	89	91	96
	dir-indirect	62	66	75	62	66	74	90	94	100	90	93	99
A/C	PVAVS	62	69	99	68	78	109	97	106	136	105	116	146
Evap.	PVAVS + ind/OA	55	62	90	62	70	101	85	94	122	94	104	132
Pre-	PVAVS + ind/RA	53	60	87	60	68	99	82	90	118	90	100	128
Cooling	PVAVS + ind/dir/OA	55	61	88	60	69	97	84	93	120	92	101	128
	PVAVS + ind/dir/RA	55	62	89	61	69	99	85	94	122	93	103	130

Table 8

	Location	Los Angeles CA																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	28	26	29	26	32	26	31	27	32	27	34	27	31	29	32	29	34	29	34	30	36	30	37	30
	indirect	30	27	31	27	33	27	33	29	34	29	36	29	33	31	33	31	35	31	36	33	37	33	39	33
	dir/indir	27	25	28	25	30	25	28	25	30	25	33	25	29	28	30	28	33	28	31	29	32	29	35	29
8 ACH	direct	27	25	27	25	29	25	28	26	29	26	31	26	29	27	29	27	31	27	30	28	31	28	33	28
	indirect	29	27	30	27	32	27	31	28	32	29	34	29	31	30	32	30	33	30	33	31	34	31	35	31
	dir/indir	25	24	25	24	27	24	26	24	27	24	29	24	26	25	27	25	29	25	28	26	28	26	30	26
12 ACH	direct	26	25	27	25	28	25	27	25	28	25	29	25	27	26	28	26	29	26	29	27	29	27	31	27
	indirect	29	27	29	27	31	27	30	28	31	28	32	28	30	29	31	29	32	29	32	30	32	30	34	30
	dir-indirect	24	24	25	24	26	24	25	24	25	24	27	24	25	25	26	25	27	25	26	25	26	25	28	25
A/C only	PVAVS	24	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	26	25	25	24	25	24	25
Evap.	PVAVS + ind/OA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	25
Pre-	PVAVS + ind/RA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	24
Cooling	PVAVS + ind/dir/OA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	24
	PVAVS + ind/dir/RA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	3	2	6	2	10	2	4	2	6	2	10	2	11	12	14	12	17	12	12	12	14	12	17	12
	indirect	5	3	7	3	11	3	5	3	8	3	12	3	13	15	16	15	18	15	13	15	16	15	19	15
	dir/indir	2	1	4	1	9	1	3	1	5	1	9	1	9	10	12	10	15	10	10	10	13	10	16	10
8 ACH	direct	0	0	1	0	3	0	1	0	2	0	4	0	4	3	5	3	7	3	4	3	5	3	8	3
	indirect	1	0	2	0	5	0	2	0	3	0	6	0	5	5	6	5	9	5	5	4	7	4	10	4
	dir/indir	0	0	0	0	2	0	0	0	1	0	3	0	2	2	3	2	6	2	3	2	4	2	6	2
12 ACH	direct	0	0	0	0	1	0	0	0	0	0	2	0	1	0	2	0	3	0	1	0	2	0	4	0
	indirect	0	0	1	0	2	0	1	0	1	0	3	0	2	2	3	2	5	2	3	2	3	2	5	2
	dir-indirect	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	2	0	0	0	1	0	3	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	6	0	4	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3	0	1	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	1	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	8	10	11	9	10	11	18	19	19	18	19	19
	indirect	12	14	16	13	15	16	25	26	27	25	26	27
	dir/indir	14	16	19	14	16	19	30	32	33	30	32	33
8 ACH	direct	10	12	14	11	12	15	23	25	26	23	25	26
	indirect	16	18	22	17	19	22	34	36	38	34	36	38
	dir/indir	16	19	23	17	20	24	37	40	43	38	40	43
12 ACH	direct	11	13	16	12	14	17	25	27	29	26	27	30
	indirect	18	20	25	19	21	26	38	41	44	39	41	44
	dir-indirect	17	20	25	18	21	26	40	44	47	41	44	48
A/C	PVAVS	29	33	47	36	41	58	54	59	71	61	66	83
Evap.	PVAS + ind/OA	29	33	46	36	41	58	54	59	71	61	66	83
Pre-	PVAS + ind/RA	30	34	49	38	43	61	57	62	75	64	69	87
Cooling	PVAS + ind-dir/OA	27	31	44	34	39	55	51	56	67	57	62	78
	PVAS + ind-dir/RA	29	33	47	36	42	59	55	60	72	62	67	84

Table 9

	Location	Chicago IL																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	27	29	27	31	27	30	28	30	28	33	28	31	30	32	30	33	30	32	31	33	31	35	31
	indirect	30	28	30	28	32	28	31	29	32	29	34	29	32	31	33	31	34	31	33	32	34	32	36	32
	dir/indir	28	26	28	26	30	26	29	27	29	27	31	27	30	29	31	29	32	29	31	30	32	30	34	30
12 ACH	direct	28	27	29	27	30	27	29	27	29	27	31	27	30	29	30	29	32	29	31	30	31	30	33	30
	indirect	29	28	30	28	31	28	30	28	31	29	32	29	31	30	31	30	33	30	32	31	32	31	34	31
	dir-indirect	27	26	28	26	29	26	28	26	28	26	30	26	29	28	29	28	31	28	30	29	30	29	31	29
16 ACH	direct	28	27	29	27	30	27	29	28	29	28	31	28	30	29	30	29	31	29	30	29	31	29	32	29
	indirect	29	28	30	28	31	28	30	29	30	29	32	29	31	30	31	30	32	30	31	31	32	31	33	31
	dir-indirect	27	26	28	26	29	27	28	27	28	27	30	27	29	28	29	28	30	28	29	28	30	28	31	28
A/C	PVAVS	25	26	25	26	25	26	25	25	24	25	24	25	26	27	26	26	25	26	25	26	25	26	24	25
Evap.	PVAVS + ind/OA	25	26	25	26	25	26	24	25	24	25	24	25	26	27	26	27	25	27	25	27	25	26	24	25
Pre-	PVAVS + ind/RA	25	26	25	26	25	25	24	25	24	25	24	25	25	26	25	26	25	26	24	26	24	25	24	25
Cooling	PVAVS + ind/dir/OA	25	26	25	26	25	26	24	25	24	25	24	25	26	27	26	27	25	26	25	26	24	26	24	25
	PVAVS + ind/dir/RA	25	26	25	26	25	25	24	25	24	25	24	25	25	27	25	26	25	26	24	26	24	25	24	25

Percent hours undercooled																									
8 ACH	direct	5	3	7	3	9	3	5	3	7	3	9	3	10	9	11	9	13	9	10	9	11	9	13	9
	indirect	7	5	8	5	11	5	7	5	8	5	10	5	12	11	13	11	14	11	12	10	12	10	14	11
	dir/indir	3	1	4	1	7	1	3	1	5	1	7	1	8	6	9	6	11	6	8	6	9	6	11	6
12 ACH	direct	3	2	4	2	6	2	3	2	4	2	6	2	7	5	7	5	9	5	7	5	7	5	9	5
	indirect	5	3	6	3	8	4	5	3	6	4	8	4	9	7	9	7	11	7	8	7	9	7	10	7
	dir-indirect	2	0	2	0	4	0	2	0	2	0	4	0	4	3	5	3	7	3	4	3	5	3	7	3
16 ACH	direct	2	1	3	1	5	1	2	1	3	1	5	1	5	4	6	4	7	4	5	4	5	4	7	4
	indirect	4	3	5	3	6	3	4	3	5	3	6	3	7	6	7	6	9	6	7	6	7	6	8	6
	dir-indirect	1	0	1	0	3	0	1	0	1	0	3	0	3	2	3	2	5	2	3	2	3	2	5	2
A/C	PVAVS	0	6	0	6	0	6	0	2	0	2	0	2	2	9	2	9	0	8	0	5	0	4	0	2
Evap.	PVAVS + ind/OA	0	5	0	5	0	5	0	2	0	2	0	1	2	8	2	8	0	7	0	4	0	3	0	2
Pre-	PVAVS + ind/RA	0	5	0	5	0	4	0	2	0	2	0	1	1	8	1	8	0	7	0	3	0	2	0	1
Cooling	PVAVS + ind/dir/OA	0	5	0	5	0	4	0	2	0	1	0	1	1	7	1	7	0	6	0	3	0	2	0	1
	PVAVS + ind/dir/RA	0	4	0	5	0	4	0	1	0	1	0	1	1	7	1	7	0	6	0	3	0	2	0	1

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	12	13	15	12	13	15	18	19	20	19	19	20
	indirect	17	18	20	18	19	21	25	26	27	25	26	27
	dir/indir	19	21	24	19	21	24	30	31	33	31	32	34
12 ACH	direct	15	16	18	15	16	18	23	24	25	23	24	25
	indirect	22	23	26	22	24	26	32	33	34	32	33	35
	dir-indirect	22	24	28	23	25	29	37	38	41	37	39	41
16 ACH	direct	17	18	21	17	18	21	26	27	29	26	28	29
	indirect	26	27	30	26	28	31	38	39	41	38	39	41
	dir-indirect	25	27	32	25	27	32	41	43	46	41	43	46
A/C	PVAVS	26	30	43	29	34	49	47	51	64	51	56	71
Evap.	PVAVS + ind/OA	25	29	41	28	32	47	46	50	62	49	54	68
Pre-	PVAVS + ind/RA	25	29	41	28	32	47	46	50	61	49	54	67
Cooling	PVAVS + ind/dir/OA	25	29	41	28	32	47	46	50	62	50	54	68
	PVAVS + ind/dir/RA	25	29	42	29	33	48	47	51	63	50	55	69

Table 10

	Location	Fort Worth TX																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	31	30	32	30	33	30	32	30	32	30	34	30	33	32	33	32	35	32	34	32	34	32	36	32
	indirect	33	31	33	31	35	31	33	31	34	31	36	31	34	33	35	33	36	33	35	34	36	34	36	34
	dir/indir	30	29	31	29	32	29	31	30	31	30	33	30	32	32	33	32	33	32	33	32	33	32	35	32
12 ACH	direct	31	29	31	29	32	29	31	30	32	30	33	30	32	31	32	31	33	31	33	31	33	31	34	31
	indirect	32	31	33	31	34	31	33	31	33	31	35	31	34	33	34	33	35	33	34	33	35	33	36	33
	dir-indirect	30	29	30	29	31	29	30	29	30	29	32	29	31	31	32	31	32	31	32	31	32	31	33	31
16 ACH	direct	31	30	31	30	32	30	31	30	32	30	33	30	32	31	32	31	33	31	32	31	33	31	34	31
	indirect	33	31	33	31	34	31	33	32	33	32	35	32	34	33	34	33	35	33	34	33	35	33	36	33
	dir-indirect	30	29	31	29	31	29	30	30	31	30	32	30	32	31	32	31	32	31	32	32	32	32	33	32
A/C	PVAVS	26	27	26	27	25	27	25	26	24	26	24	26	27	28	26	28	25	26	25	26	25	26	24	25
Evap. Pre-Cooling	PVAVS + ind/OA	27	28	27	28	25	27	26	27	25	27	24	26	29	30	28	30	28	30	28	30	28	30	24	26
	PVAVS + ind/RA	26	27	26	27	25	26	25	26	24	26	24	26	26	27	26	27	25	26	24	26	24	26	24	25
	PVAVS + ind/dir/OA	26	28	26	28	25	27	25	27	24	26	24	26	29	30	29	30	26	28	28	30	26	28	24	26
	PVAVS + ind/dir/RA	26	27	26	27	25	26	25	26	24	26	24	26	27	29	26	28	25	26	25	27	24	26	24	25

Percent hours undercooled																									
8 ACH	direct	16	14	16	14	18	14	16	14	16	14	18	14	19	16	19	18	21	18	19	18	19	18	21	18
	indirect	17	15	18	15	20	15	17	15	18	15	20	15	20	19	21	19	23	19	20	19	21	19	23	19
	dir/indir	14	11	15	11	17	11	14	11	16	11	17	11	17	16	18	16	19	16	17	16	18	16	20	16
12 ACH	direct	14	12	14	12	16	12	14	12	14	12	16	12	16	15	17	15	18	15	16	15	17	15	18	15
	indirect	15	14	16	14	17	14	15	14	16	14	17	14	17	17	18	17	19	17	17	17	18	17	19	17
	dir-indirect	12	9	13	9	14	9	12	9	12	9	14	9	15	13	15	13	16	13	15	13	15	13	16	13
16 ACH	direct	13	11	13	11	14	11	13	11	13	11	14	11	15	14	15	14	16	14	15	14	15	14	16	14
	indirect	14	13	15	13	16	13	14	13	15	13	16	13	16	15	16	15	17	15	16	15	16	15	17	15
	dir-indirect	10	7	11	7	13	7	10	7	11	7	12	7	13	11	14	11	15	11	13	11	13	11	14	11
A/C	PVAVS	3	12	2	12	0	10	0	6	0	6	0	6	4	14	3	14	0	11	0	7	0	5	0	4
Evap. Pre-Cooling	PVAVS + ind/OA	4	13	3	13	0	10	0	7	0	6	0	5	6	15	5	14	0	11	0	9	0	7	0	4
	PVAVS + ind/RA	2	11	1	11	0	8	0	6	0	6	0	5	3	13	2	12	0	9	0	5	0	5	0	3
	PVAVS + ind/dir/OA	3	12	2	12	0	9	0	6	0	6	0	5	5	14	3	13	0	10	0	7	0	6	0	4
	PVAVS + ind/dir/RA	2	11	1	11	0	8	0	6	0	6	0	5	3	12	2	12	0	8	0	5	0	5	0	3

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	29	30	33	30	31	33	39	40	41	39	40	41
	indirect	41	43	45	42	44	47	54	55	57	54	56	57
	dir/indir	50	52	55	51	53	56	65	67	69	66	68	70
12 ACH	direct	40	42	44	41	42	45	51	52	54	51	52	54
	indirect	56	58	61	58	59	63	71	73	75	72	74	76
	dir-indirect	68	70	74	68	70	75	86	88	91	87	88	91
16 ACH	direct	50	52	54	51	52	55	62	64	65	63	64	66
	indirect	70	73	76	72	74	78	88	90	92	88	90	93
	dir-indirect	84	86	91	84	86	91	105	107	110	105	107	111
A/C	PVAVS	49	54	75	53	59	85	84	89	111	88	95	120
Evap. Pre-Cooling	PVAVS + ind/OA	52	58	79	56	62	88	90	96	118	95	101	126
	PVAVS + ind/RA	48	53	72	51	57	82	83	88	107	86	92	116
	PVAVS + ind/dir/OA	53	58	80	56	62	87	91	97	119	95	102	126
	PVAVS + ind/dir/RA	49	54	74	52	58	83	86	91	110	89	95	119

Table 11

	Location	Denver CO																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	27	24	28	24	30	24	27	25	28	25	32	25	29	28	30	28	32	28	30	28	31	28	34	28
	indirect	29	26	30	26	32	26	29	27	30	27	33	27	31	30	32	30	34	30	32	30	33	30	36	30
	dir/indir	25	24	26	24	29	24	26	24	27	24	30	24	28	27	29	27	31	27	28	27	30	27	32	27
8 ACH	direct	25	24	25	24	27	24	25	24	26	24	28	24	26	25	27	25	29	25	27	25	27	25	29	25
	indirect	27	25	28	25	29	25	27	25	28	25	30	25	29	28	29	28	31	28	29	28	30	28	32	28
	dir/indir	24	23	24	23	26	23	24	23	24	23	26	23	25	24	25	24	27	24	25	24	26	24	28	24
12 ACH	direct	24	23	25	23	26	23	24	23	25	23	26	23	25	24	25	24	27	24	25	24	26	24	27	24
	indirect	26	25	27	25	28	25	26	25	27	25	29	25	28	26	28	26	29	27	28	27	28	27	30	27
	dir-indirect	23	23	24	23	24	23	24	23	24	23	25	23	24	24	24	24	25	24	24	24	24	24	26	24
AC only	PVAVS	25	25	25	25	25	25	24	25	24	24	24	24	26	27	26	26	25	26	24	25	24	25	24	25
Evap.	PVAVS + ind/OA	25	25	25	25	24	25	24	24	24	24	24	24	25	26	25	26	24	25	24	25	24	25	24	24
Pre-	PVAVS + ind/RA	25	25	25	25	24	25	24	24	24	24	24	24	25	26	25	26	24	25	24	25	24	25	24	24
Cooling	PVAVS + ind/dir/OA	24	25	25	25	24	24	24	24	24	24	24	24	25	25	25	25	24	25	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	25	25	25	24	25	24	24	24	24	24	24	25	25	25	25	24	25	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	3	0	4	0	8	0	3	0	4	0	8	0	7	6	9	6	12	6	8	6	10	6	12	6
	indirect	5	2	7	2	10	2	5	2	7	2	10	2	10	10	12	10	14	10	10	10	12	10	14	10
	dir/indir	1	0	2	0	6	0	1	0	3	0	6	0	5	4	7	4	10	4	6	4	8	4	10	4
8 ACH	direct	0	0	1	0	2	0	0	0	1	0	3	0	2	1	3	1	5	1	2	1	3	1	5	1
	indirect	2	0	3	0	5	0	2	0	3	0	5	0	5	3	6	3	8	3	5	3	6	3	8	3
	dir/indir	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	2	0	0	0	1	0	3	0
12 ACH	direct	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	2	0	0	0	1	0	2	0
	indirect	1	0	1	0	3	0	1	0	2	0	3	0	3	1	3	1	5	1	3	1	3	1	5	1
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	2	0	2	0	1	0	0	0	0	0	0	1	6	1	6	0	5	0	2	0	1	0	0
Evap.	PVAVS + ind/OA	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	1	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	6	7	9	7	8	9	12	13	14	13	14	15
	indirect	11	12	13	11	12	14	18	19	20	19	20	21
	dir/indir	9	11	13	10	11	14	19	21	22	20	22	23
8 ACH	direct	7	9	11	8	9	12	15	17	18	16	17	19
	indirect	14	16	19	15	17	19	26	27	29	26	28	30
	dir/indir	10	12	16	11	13	17	22	25	27	23	25	28
12 ACH	direct	8	9	12	8	10	13	16	18	20	17	18	21
	indirect	16	18	22	17	19	23	30	32	34	31	32	35
	dir-indirect	11	12	17	11	13	18	23	25	29	24	26	30
A/C	PVAVS	23	27	41	27	32	51	42	47	60	47	52	71
Evap.	PVAVS + ind/OA	19	22	34	22	26	43	34	37	48	37	42	58
Pre-	PVAVS + ind/RA	20	24	37	24	29	47	37	40	53	41	46	64
Cooling	PVAVS + ind/dir/OA	17	20	31	20	24	39	31	34	44	35	38	52
	PVAVS + ind/dir/RA	19	21	33	22	26	41	34	37	48	37	41	57

Table 12

	Location	Albuquerque NM																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	29	26	30	26	32	26	30	26	31	26	34	26	32	30	32	30	34	30	33	30	33	30	36	30
	indirect	31	29	32	29	34	29	32	29	33	29	36	29	34	32	34	32	36	32	35	33	38	33	38	33
	dir/indir	27	25	28	25	31	25	28	25	29	25	32	25	30	28	31	28	33	28	31	29	32	29	34	29
8 ACH	direct	27	25	27	25	29	25	27	25	28	25	30	25	29	27	29	27	31	27	29	27	30	27	32	27
	indirect	30	27	30	27	32	27	30	28	31	28	33	28	31	30	32	30	33	30	32	30	32	30	34	30
	dir/indir	25	24	26	24	27	24	25	24	26	24	28	24	27	25	27	25	29	25	27	25	28	25	29	25
12 ACH	direct	26	24	26	24	28	24	26	24	26	24	28	24	27	26	27	26	29	26	27	26	28	26	29	26
	indirect	29	27	29	27	31	27	29	27	30	27	31	27	30	29	31	29	32	29	30	29	31	29	32	29
	dir-indirect	24	24	25	24	26	24	24	24	25	24	26	24	25	25	26	25	27	25	25	25	26	25	27	25
A/C	PVAVS	26	26	26	26	25	26	24	25	24	25	24	25	26	27	26	26	25	26	25	26	24	25	24	25
Evap.	PVAVS + ind/OA	25	26	25	26	25	25	24	25	24	25	24	25	25	26	25	26	25	25	24	25	24	25	24	25
Pre-	PVAVS + ind/RA	25	26	25	26	25	25	24	25	24	25	24	25	25	26	25	26	25	25	24	25	24	25	24	24
Cooling	PVAVS + ind/dir/OA	25	26	25	26	24	25	24	25	24	25	24	24	25	26	25	26	24	25	24	25	24	25	24	24
	PVAVS + ind/dir/RA	25	26	25	26	24	25	24	25	24	25	24	24	25	26	25	26	24	25	24	25	24	25	24	24

Percent hours undercooled																									
4 ACH	direct	5	2	7	2	11	2	6	2	7	2	12	2	11	9	13	9	16	9	11	8	13	8	16	8
	indirect	8	5	10	5	14	5	8	5	10	5	14	5	13	13	15	13	18	13	14	12	16	12	19	12
	dir/indir	3	0	5	0	9	0	3	0	5	0	10	0	8	6	11	6	14	5	9	5	11	5	14	5
8 ACH	direct	1	0	2	0	5	0	1	0	2	0	5	0	4	2	5	2	7	2	4	2	5	2	7	2
	indirect	5	2	6	2	8	2	5	2	6	2	8	2	8	6	9	6	11	6	7	6	8	6	11	6
	dir/indir	0	0	0	0	2	0	0	0	0	0	3	0	2	0	2	0	5	0	2	0	2	0	5	0
12 ACH	direct	0	0	1	0	2	0	0	0	1	0	2	0	2	0	2	0	4	0	2	0	2	0	4	0
	indirect	3	1	4	1	5	1	3	1	4	1	5	1	5	4	6	4	7	4	5	3	6	3	7	3
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
A/C	PVAVS	1	6	1	6	0	4	0	1	0	1	0	0	1	9	1	9	0	7	0	3	0	3	0	1
Evap.	PVAVS + ind/OA	0	4	0	4	0	2	0	0	0	0	0	0	1	6	1	6	0	4	0	1	0	1	0	0
Pre-	PVAVS + ind/RA	0	4	0	4	0	2	0	0	0	0	0	0	1	7	0	6	0	4	0	1	0	1	0	0
Cooling	PVAVS + ind/dir/OA	0	3	0	3	0	2	0	0	0	0	0	0	0	5	0	4	0	2	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	3	0	3	0	2	0	0	0	0	0	0	0	5	0	5	0	2	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	9	10	11	9	10	12	15	16	17	15	16	17
	indirect	14	16	18	15	16	18	22	24	25	23	24	25
	dir/indir	13	15	18	14	15	18	24	26	27	25	26	28
8 ACH	direct	11	12	15	11	12	15	20	21	23	20	21	23
	indirect	21	22	25	21	23	26	32	34	36	33	34	36
	dir/indir	15	17	22	16	18	23	29	32	35	30	32	35
12 ACH	direct	12	13	17	12	14	17	22	23	26	22	23	26
	indirect	25	27	31	25	27	31	39	41	44	39	41	44
	dir-indirect	16	18	24	16	19	24	31	34	38	31	34	38
A/C	PVAVS	30	35	51	34	39	61	54	59	76	58	64	86
Evap.	PVAVS + ind/OA	24	28	42	27	32	51	43	47	61	46	51	70
Pre-	PVAVS + ind/RA	26	30	45	30	35	56	46	50	65	50	55	75
Cooling	PVAVS + ind/dir/OA	22	25	38	25	29	46	39	43	55	42	46	62
	PVAVS + ind/dir/RA	23	27	40	26	31	49	42	46	59	45	50	66

Table 13

	Location	San Francisco CA																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	26	25	27	25	30	25	28	25	29	25	32	25	29	28	30	28	32	28	31	29	32	29	34	29
	indirect	27	26	28	26	31	26	29	27	31	27	33	27	30	29	31	29	33	29	32	31	34	31	36	31
	dir/indir	25	24	26	24	28	24	26	24	27	24	30	24	27	26	28	26	31	26	29	27	30	27	33	27
8 ACH	direct	25	24	26	24	28	24	26	24	27	24	29	24	27	26	27	26	29	26	28	26	29	26	31	26
	indirect	27	25	27	25	29	25	28	26	29	26	31	26	28	28	29	28	31	28	30	29	31	29	32	29
	dir/indir	24	23	24	23	26	23	24	23	25	23	27	23	25	24	25	24	27	24	26	24	26	24	29	24
12 ACH	direct	25	24	25	24	27	24	25	24	26	24	27	24	26	25	26	25	28	25	27	26	27	26	29	26
	indirect	26	25	27	25	28	25	28	26	28	26	30	26	28	28	28	28	30	28	29	28	29	28	31	28
	dir-indirect	23	23	24	23	25	23	24	23	24	23	25	23	24	24	25	24	25	24	25	24	25	24	26	24
A/C	PVAVS	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	24	25	24	25	24	24
Evap.	PVAVS + ind/OA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
Pre-	PVAVS + ind/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	25	24	24	24	24	24	24
Cooling	PVAVS + ind/dir/OA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	24	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	24	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	0	0	1	0	3	0	0	0	2	0	4	0	3	5	5	5	8	5	4	5	6	5	9	5
	indirect	0	0	1	0	4	0	1	0	2	0	5	0	4	7	7	7	9	7	5	7	8	7	10	7
	dir/indir	0	0	0	0	2	0	0	0	1	0	3	0	2	4	4	4	7	4	3	4	5	4	8	4
8 ACH	direct	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	2	0
	indirect	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	3	0	1	0	2	0	3	0
	dir/indir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	4	5	6	4	5	6	12	13	13	12	13	14
	indirect	5	7	8	6	8	9	17	18	19	17	19	19
	dir/indir	6	7	9	7	8	10	20	21	22	20	22	22
8 ACH	direct	4	5	7	5	6	8	14	15	16	14	16	17
	indirect	6	8	10	7	9	11	20	22	23	21	23	24
	dir/indir	6	8	11	7	9	12	22	24	26	23	25	26
12 ACH	direct	4	5	7	5	6	8	14	16	17	15	16	18
	indirect	6	8	11	8	10	12	21	23	25	22	24	26
	dir-indirect	6	8	11	7	9	13	22	25	27	23	26	28
A/C	PVAVS	20	23	34	25	30	44	38	41	52	44	48	63
Evap.	PVAVS + ind/OA	19	22	32	24	28	43	36	39	49	42	46	61
Pre-	PVAVS + ind/RA	21	24	36	27	31	47	40	44	54	46	51	67
Cooling	PVAVS + ind/dir/OA	17	20	30	22	26	40	34	37	46	39	43	56
	PVAVS + ind/dir/RA	20	23	35	26	30	46	39	42	53	45	50	65

Table 14

	Location	Halifax NS																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	27	26	28	26	31	26	29	26	30	26	34	26	31	30	32	30	34	30	33	31	35	31	37	31
	indirect	28	26	29	26	32	26	30	27	31	27	34	27	32	30	33	30	35	30	34	32	35	32	38	32
	dir/indir	27	25	28	25	31	25	29	26	30	26	33	26	30	29	32	29	34	29	33	31	34	31	37	31
8 ACH	direct	26	25	27	25	29	25	27	26	28	26	31	26	28	27	29	27	31	27	30	28	31	28	33	28
	indirect	27	26	28	26	29	26	28	26	29	26	31	26	29	28	30	28	32	28	31	29	31	29	33	29
	dir/indir	26	25	27	25	28	25	27	25	28	25	30	25	28	27	29	27	30	27	29	28	30	28	32	28
12 ACH	direct	26	25	27	25	28	25	27	25	27	25	29	25	28	27	28	27	29	27	28	27	29	27	31	27
	indirect	27	26	27	26	28	26	27	26	28	26	30	26	28	27	29	27	30	27	29	28	30	28	31	28
	dir-indirect	26	25	26	25	27	25	26	25	27	25	29	25	27	26	28	26	29	26	28	27	28	27	30	27
A/C	PVAVS	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	24	24	24
Evap.	PVAVS + ind/OA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	24	25	24	24	24	24	24	24
Pre-	PVAVS + ind/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
Cooling	PVAVS + ind/dir/OA	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	24	25	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	25	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	0	0	2	0	5	0	1	0	2	0	5	0	8	8	10	8	11	8	8	8	10	8	12	8
	indirect	1	0	2	0	5	0	1	0	3	0	6	0	8	9	10	9	12	10	9	9	10	9	12	9
	dir/indir	0	0	1	0	4	0	0	0	2	0	5	0	7	7	9	8	11	8	7	8	9	8	11	8
8 ACH	direct	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	3	0	1	0	2	0	3	0
	indirect	0	0	0	0	1	0	0	0	0	0	1	0	1	1	2	1	4	1	2	1	3	1	4	1
	dir/indir	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	3	0	0	0	1	0	3	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	4	5	6	5	5	6	9	10	10	9	10	10
	indirect	6	6	7	6	7	8	11	12	12	12	12	13
	dir/indir	7	8	9	7	8	9	14	15	15	15	16	16
8 ACH	direct	5	6	7	5	6	7	11	12	13	12	13	14
	indirect	7	8	9	7	8	10	15	16	17	15	16	17
	dir/indir	8	9	11	8	9	11	18	19	20	19	20	21
12 ACH	direct	5	6	8	6	6	8	12	13	14	13	14	15
	indirect	7	8	10	8	9	11	16	17	19	17	18	19
	dir-indirect	8	9	12	8	10	12	19	20	22	20	21	23
A/C	PVAVS	16	18	28	19	22	35	29	32	40	32	36	48
Evap.	PVAVS + ind/OA	16	18	28	19	23	36	30	32	40	33	36	48
Pre-	PVAVS + ind/RA	17	19	29	20	23	37	31	34	42	34	38	50
Cooling	PVAVS + ind/dir/OA	16	18	28	19	22	35	29	32	40	32	36	47
	PVAVS + ind/dir/RA	17	19	29	20	23	37	31	34	42	34	38	50

Table 15

	Location	Toronto ON																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	27	30	27	31	27	30	28	31	28	33	28	31	30	32	30	34	30	33	31	33	31	35	31
	indirect	29	28	30	28	32	28	31	29	31	29	33	29	32	31	33	31	34	31	33	32	34	32	36	32
	dir/indir	28	26	29	26	31	27	29	27	30	27	32	27	31	30	31	30	33	30	32	30	33	30	34	30
12 ACH	direct	28	27	29	27	31	27	30	28	30	28	32	28	31	30	31	30	32	30	32	31	32	31	33	31
	indirect	29	28	30	28	31	28	30	28	31	28	32	28	31	30	32	30	33	30	32	31	33	31	34	31
	dir-indirect	28	26	29	26	30	26	29	27	29	27	31	27	30	29	30	29	32	29	31	30	31	30	32	30
16 ACH	direct	29	27	30	27	31	27	30	28	31	28	32	28	31	30	31	30	32	30	32	31	32	31	33	31
	indirect	29	28	30	28	32	28	31	29	31	29	32	29	32	31	32	31	33	31	32	32	33	32	34	32
	dir-indirect	28	27	29	27	30	27	29	28	30	28	31	28	30	29	30	29	31	29	31	30	31	30	32	30
A/C	PVAVS	25	25	25	25	25	25	24	25	24	25	24	24	25	26	25	26	25	26	24	25	24	25	24	25
Evap.	PVAVS + ind/OA	25	25	25	25	25	25	24	25	24	25	24	24	26	27	26	27	26	27	25	26	25	26	24	25
Pre-	PVAVS + ind/RA	25	25	25	25	24	25	24	25	24	25	24	24	25	26	25	26	25	26	24	25	24	25	24	25
Cooling	PVAVS + ind/dir/OA	25	25	25	25	25	25	24	25	24	25	24	24	26	26	26	26	25	26	24	25	24	25	24	25
	PVAVS + ind/dir/RA	25	25	25	25	24	25	24	25	24	25	24	24	26	26	25	26	25	26	24	25	24	25	24	25

Percent hours undercooled																									
8 ACH	direct	2	1	4	1	6	1	3	1	4	1	6	1	7	6	8	6	9	6	7	5	8	5	9	6
	indirect	3	1	5	2	7	2	4	2	5	2	7	2	8	7	9	7	10	7	8	7	9	7	10	7
	dir/indir	1	1	2	1	5	1	2	1	3	1	5	1	6	4	7	4	9	4	6	4	7	4	8	4
12 ACH	direct	1	1	2	1	4	1	1	1	2	1	4	1	4	2	5	2	6	3	4	3	5	3	6	3
	indirect	2	1	3	1	5	1	2	1	3	1	5	1	5	4	6	4	7	4	5	4	6	4	7	4
	dir-indirect	1	0	1	0	2	0	1	0	1	0	3	0	2	1	3	1	5	2	2	2	3	2	5	2
16 ACH	direct	1	0	1	0	2	0	1	0	1	0	2	1	2	1	3	2	4	2	2	2	3	2	4	2
	indirect	1	1	2	1	3	1	2	1	2	1	3	1	3	2	4	2	5	2	4	2	4	2	5	2
	dir-indirect	0	0	1	0	1	0	1	0	1	0	1	0	1	1	2	1	3	1	1	1	2	1	3	1
A/C	PVAVS	0	1	0	1	0	1	0	0	0	0	0	0	1	6	1	6	0	5	0	1	0	1	0	0
Evap.	PVAVS + ind/OA	0	1	0	1	0	0	0	0	0	0	0	0	1	5	1	5	0	4	0	1	0	0	0	0
Pre-	PVAVS + ind/RA	0	1	0	1	0	0	0	0	0	0	0	0	0	6	0	6	0	4	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	1	0	1	0	0	0	0	0	0	0	0	0	4	0	4	0	3	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	5	0	3	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	10	10	12	10	10	12	16	16	17	16	17	18
	indirect	13	14	16	13	14	16	21	22	23	21	22	23
	dir/indir	15	17	19	15	17	19	26	27	29	27	28	29
12 ACH	direct	11	12	14	11	12	14	19	20	21	19	20	21
	indirect	16	17	20	16	17	20	26	27	28	26	27	29
	dir-indirect	17	19	23	17	19	23	30	32	34	31	32	35
16 ACH	direct	12	13	16	12	14	16	21	22	24	21	22	24
	indirect	18	19	23	18	20	23	30	31	33	30	31	33
	dir-indirect	19	21	25	19	21	25	33	35	38	34	36	38
A/C	PVAVS	22	26	37	25	29	44	40	43	53	43	47	61
Evap.	PVAVS + ind/OA	22	26	36	25	29	43	40	44	54	43	47	61
Pre-	PVAVS + ind/RA	23	26	37	25	29	44	41	44	54	44	48	62
Cooling	PVAVS + ind/dir/OA	22	25	36	24	28	43	40	44	54	43	47	60
	PVAVS + ind/dir/RA	23	26	37	25	29	44	41	45	55	44	48	62

Table 16

	Location	Edmonton AB																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	26	25	27	25	30	25	28	25	29	25	32	25	30	28	31	29	33	29	32	30	33	30	35	30
	indirect	27	25	28	25	31	25	28	26	30	26	33	26	31	29	32	29	34	29	32	31	34	31	36	31
	dir/indir	26	24	27	24	29	24	27	24	28	24	31	24	29	28	30	28	32	28	31	29	32	29	35	29
8 ACH	direct	25	24	26	24	27	24	26	24	26	24	29	24	27	26	28	26	29	26	28	26	29	26	31	26
	indirect	26	25	26	25	28	25	27	25	27	25	30	25	28	27	29	27	30	27	29	27	30	27	32	27
	dir/indir	24	24	25	24	27	24	25	24	26	24	28	24	26	25	27	25	29	25	27	25	28	25	30	25
12 ACH	direct	24	24	25	24	26	24	25	24	25	24	27	24	26	25	26	25	28	25	26	25	27	25	29	25
	indirect	25	24	26	24	27	24	26	25	26	25	28	25	27	26	27	26	29	26	28	26	28	26	30	26
	dir-indirect	24	23	24	23	26	23	24	23	25	23	26	23	25	24	25	24	27	24	25	24	26	24	28	24
A/C	PVAVS	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24
Evap.	PVAVS + ind/OA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
Pre-	PVAVS + ind/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
Cooling	PVAVS + ind/dir/OA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	24	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	24	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	0	0	1	0	4	0	1	0	2	0	4	0	5	4	7	4	11	5	5	4	8	4	11	5
	indirect	1	0	2	0	5	0	1	0	3	0	5	0	6	6	8	6	12	6	7	6	9	6	12	6
	dir/indir	0	0	1	0	3	0	0	0	1	0	4	0	4	3	6	3	11	4	5	3	7	3	11	4
8 ACH	direct	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	3	0	1	0	1	0	3	0
	indirect	0	0	0	0	1	0	0	0	0	0	2	0	1	0	2	0	3	0	1	0	2	0	4	0
	dir/indir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	2	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	indirect	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	4	5	6	4	5	6	8	9	10	9	9	10
	indirect	5	6	8	6	7	8	11	11	12	11	12	13
	dir/indir	6	7	9	7	8	9	13	14	15	14	15	16
8 ACH	direct	5	5	7	5	6	8	10	11	12	11	11	13
	indirect	6	7	10	7	8	10	13	14	16	14	15	17
	dir/indir	7	8	11	7	9	11	15	17	19	16	17	20
12 ACH	direct	5	6	8	5	6	8	10	11	13	11	12	14
	indirect	7	8	11	7	9	11	14	16	18	15	16	18
	dir-indirect	7	9	12	8	9	12	16	17	20	17	18	21
A/C	PVAVS	16	19	29	20	24	38	26	29	39	30	34	48
Evap.	PVAVS + ind/OA	15	18	28	19	22	36	25	27	37	29	32	46
Pre-	PVAVS + ind/RA	16	19	30	21	24	39	27	30	40	31	35	50
Cooling	PVAVS + ind/dir/OA	14	17	26	18	21	34	23	26	34	27	30	43
	PVAVS + ind/dir/RA	15	18	28	19	22	36	25	28	37	29	32	46

Table 17

	Location	Porto POR																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	28	27	29	27	30	27	29	28	30	28	31	28	32	32	33	32	33	32	34	33	34	33	35	33
	indirect	29	29	30	29	31	29	31	30	31	30	32	30	33	34	34	34	34	34	35	35	36	35	36	35
	dir/indir	27	26	27	26	28	26	28	27	28	27	30	27	31	31	31	31	32	31	32	32	33	32	33	32
8 ACH	direct	27	26	27	26	28	26	27	26	28	26	29	26	29	29	29	29	30	29	30	30	30	30	31	30
	indirect	28	28	28	28	29	28	29	29	30	29	31	29	31	31	31	31	32	31	32	32	32	32	33	32
	dir/indir	25	25	25	25	26	25	26	25	26	25	27	25	28	27	28	27	28	27	28	28	29	28	29	28
12 ACH	direct	26	26	26	26	27	26	27	26	27	26	28	26	28	27	28	27	29	27	29	28	29	28	29	28
	indirect	28	27	28	27	29	27	29	28	29	28	30	28	30	29	30	29	30	29	31	30	31	30	32	30
	dir-indirect	25	25	25	25	25	25	25	25	25	25	26	25	26	26	27	26	27	26	27	27	27	27	28	27
A/C	PVAVS	25	25	25	25	24	25	24	25	24	25	24	25	25	26	25	26	25	26	25	25	24	25	24	25
Evap.	PVAVS + ind/OA	24	25	24	25	24	25	24	24	24	24	24	24	25	25	25	26	25	25	24	25	24	25	24	25
Pre-	PVAVS + ind/RA	24	25	24	25	24	25	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	25
Cooling	PVAVS + ind/dir/OA	24	25	24	25	24	25	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	25
	PVAVS + ind/dir/RA	24	25	24	25	24	25	24	24	24	24	24	24	25	25	25	25	24	25	24	25	24	25	24	25
Percent hours undercooled																									
4 ACH	direct	3	3	4	3	5	3	4	4	5	4	6	4	17	24	18	24	18	24	17	25	18	25	18	26
	indirect	4	5	5	5	7	5	5	5	6	6	8	6	19	25	20	25	19	25	18	26	20	26	19	27
	dir/indir	2	1	3	1	4	1	2	2	3	2	5	2	16	23	17	23	17	23	16	25	18	25	18	26
8 ACH	direct	1	0	1	0	2	0	1	1	2	1	2	1	5	6	6	6	6	6	6	6	6	6	7	6
	indirect	2	2	2	2	3	2	2	2	3	2	3	2	7	9	8	9	9	9	8	9	8	9	9	9
	dir/indir	0	0	0	0	1	0	0	0	0	0	1	0	3	4	4	4	5	4	4	4	4	4	5	4
12 ACH	direct	0	0	0	0	1	0	1	0	1	0	1	0	2	2	2	2	3	2	2	2	3	2	3	2
	indirect	1	1	1	1	2	1	1	1	2	1	2	1	4	4	4	4	5	4	4	4	4	4	5	4
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	1	1	1	1	1	2	1
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	2	0	1	0	1	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	7	8	8	8	8	8	15	15	15	15	15	15
	indirect	10	11	11	11	11	12	19	20	19	20	20	19
	dir/indir	12	13	13	13	13	14	25	25	24	25	25	24
8 ACH	direct	9	10	11	10	11	11	22	22	22	22	23	22
	indirect	14	15	16	15	16	16	30	30	30	30	30	30
	dir/indir	14	15	16	15	16	18	35	36	35	36	37	36
12 ACH	direct	10	11	12	11	12	13	25	26	25	25	26	26
	indirect	16	17	18	17	18	19	35	36	35	36	36	36
	dir-indirect	15	17	18	17	18	19	39	40	40	40	41	41
A/C	PVAVS	28	30	36	33	35	42	57	59	63	61	63	69
Evap.	PVAVS + ind/OA	28	30	36	32	34	41	56	57	62	60	62	67
Pre-	PVAVS + ind/RA	29	31	37	33	35	43	58	60	64	62	64	69
Cooling	PVAVS + ind/dir/OA	27	29	35	31	33	41	55	57	61	59	61	66
	PVAVS + ind/dir/RA	30	31	38	34	36	44	59	60	65	63	65	70

Table 18

	Location	Lisbon POR																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
8 ACH	direct	29	27	29	27	32	27	30	28	31	28	33	28	31	30	32	30	33	30	32	30	33	30	35	30
	indirect	30	28	31	28	33	28	31	29	32	29	35	29	32	31	33	31	35	31	34	32	35	32	37	32
	dir/indir	27	26	28	26	30	26	29	26	29	26	32	26	30	28	31	28	32	28	31	29	32	29	34	29
12 ACH	direct	28	27	29	27	30	27	29	27	30	27	32	27	30	29	30	29	32	29	31	29	31	29	33	29
	indirect	29	28	30	28	32	28	31	29	31	29	33	29	31	30	32	30	33	30	32	31	33	31	35	31
	dir-indirect	27	25	27	25	29	25	27	26	28	26	30	26	28	27	29	27	30	27	29	27	30	28	31	28
16 ACH	direct	28	27	29	27	30	27	29	28	30	28	31	28	29	29	30	29	31	29	30	29	31	29	32	29
	indirect	30	28	30	28	32	28	31	29	32	29	33	29	31	30	31	30	33	30	32	31	33	31	34	31
	dir-indirect	27	26	27	26	29	26	27	26	28	26	29	26	28	27	28	27	30	27	29	27	29	27	31	27
A/C	PVAVS	25	25	25	25	25	25	24	25	24	25	24	25	26	26	26	26	25	25	25	25	25	25	24	25
Evap.	PVAVS + ind/OA	25	25	25	25	25	25	24	25	24	25	24	25	25	26	25	26	25	25	24	25	24	25	24	25
Pre-	PVAVS + ind/RA	25	25	25	25	25	25	24	25	24	25	24	24	25	26	25	26	25	25	24	25	24	25	24	24
Cooling	PVAVS + ind/dir/OA	25	25	25	25	25	25	24	25	24	25	24	24	25	26	25	25	25	25	24	25	24	25	24	24
	PVAVS + ind/dir/RA	25	25	25	25	25	25	24	25	24	25	24	24	25	25	25	25	25	25	24	25	24	24	24	24
Percent hours undercooled																									
8 ACH	direct	3	1	5	1	8	1	3	1	5	1	8	1	9	7	11	7	15	7	9	7	11	7	14	7
	indirect	5	3	6	3	10	3	5	2	6	2	10	2	12	10	13	10	17	10	11	9	13	9	16	9
	dir/indir	2	0	3	0	7	0	2	0	3	0	6	0	7	5	9	5	14	5	7	5	9	5	13	5
12 ACH	direct	2	0	2	0	4	0	2	1	2	1	4	1	4	3	5	3	8	3	4	3	5	3	7	3
	indirect	3	1	4	2	6	2	3	2	4	2	6	2	6	5	7	5	10	5	6	4	7	4	9	4
	dir-indirect	0	0	1	0	3	0	1	0	1	0	3	0	3	1	4	1	6	1	3	1	3	1	6	1
16 ACH	direct	1	0	1	0	3	0	1	0	1	0	3	0	2	1	3	1	5	2	3	1	3	1	4	1
	indirect	2	1	2	1	4	1	2	1	3	1	4	1	4	3	5	3	6	3	4	3	5	3	6	3
	dir-indirect	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	3	0	1	0	2	0	3	0
A/C	PVAVS	0	3	0	3	0	2	0	1	0	1	0	0	1	6	1	6	0	4	0	2	0	1	0	0
Evap.	PVAVS + ind/OA	0	2	0	2	0	2	0	0	0	0	0	0	0	5	0	5	0	3	0	1	0	0	0	0
Pre-	PVAVS + ind/RA	0	2	0	2	0	2	0	0	0	0	0	0	0	5	0	5	0	3	0	1	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	2	0	2	0	1	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	2	0	2	0	1	0	0	0	0	0	0	0	4	0	4	0	2	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
8 ACH	direct	14	16	18	14	16	18	25	26	27	25	26	27
	indirect	20	22	24	20	22	24	33	34	35	32	34	35
	dir/indir	22	25	29	22	25	28	40	42	44	40	42	44
12 ACH	direct	16	18	21	16	18	20	29	30	32	28	30	32
	indirect	23	25	29	23	26	29	39	41	43	39	41	43
	dir-indirect	24	27	33	25	28	32	46	48	52	45	48	51
16 ACH	direct	17	19	23	17	19	22	31	33	35	31	33	35
	indirect	26	28	33	26	28	33	43	46	49	43	45	48
	dir-indirect	26	29	35	26	29	35	49	52	56	48	51	55
A/C	PVAVS	38	43	59	44	51	72	65	70	86	71	78	99
Evap.	PVAVS + ind/OA	37	42	58	44	50	72	64	69	85	70	77	99
Pre-	PVAVS + ind/RA	39	44	60	45	51	74	67	72	88	72	79	101
Cooling	PVAVS + ind/dir/OA	36	42	57	43	49	71	63	68	84	69	76	97
	PVAVS + ind/dir/RA	39	45	62	46	53	76	68	73	90	74	81	104

Table 19

	Location	Trappes FR																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	24	24	25	24	28	24	25	24	26	24	30	24	27	26	28	26	30	26	29	26	30	26	33	26
	indirect	28	27	29	27	32	27	30	27	31	28	34	28	32	32	33	32	35	32	34	33	35	33	37	33
	dir/indir	24	23	25	23	27	23	25	24	26	24	29	24	26	25	28	25	30	25	28	25	29	25	32	25
8 ACH	direct	24	23	24	23	25	23	24	23	24	23	25	23	24	24	24	24	26	24	24	24	25	24	27	24
	indirect	26	25	27	25	29	25	28	26	29	26	31	26	29	28	29	28	31	28	30	29	31	29	33	29
	dir/indir	23	23	24	23	24	23	24	23	24	23	25	23	24	24	24	24	25	24	24	24	24	24	26	24
12 ACH	direct	23	23	23	23	24	23	23	23	24	23	24	23	24	23	24	23	24	23	24	23	24	23	25	23
	indirect	26	25	26	25	28	25	27	26	28	26	29	26	28	27	28	27	29	27	29	28	29	28	31	28
	dir-indirect	23	23	23	23	24	23	23	23	23	23	24	23	23	23	24	23	24	23	24	23	24	23	24	23
A/C	PVAVS	24	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	25
Evap.	PVAVS + ind/OA	24	25	24	25	25	25	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	24
Pre-	PVAVS + ind/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
Cooling	PVAVS + ind/dir/OA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	25	25	24	25	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	24	24	24	24	24	24	24	24	24	24	24	24	25	24	25	24	25	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	0	0	0	0	1	0	0	0	0	0	2	0	3	1	6	1	9	1	4	1	7	1	9	1
	indirect	3	1	5	1	7	1	3	1	5	2	7	2	12	15	14	15	15	15	11	14	13	14	14	14
	dir/indir	0	0	0	0	1	0	0	0	0	0	2	0	4	1	7	1	10	1	4	1	7	1	9	1
8 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	indirect	0	0	1	0	3	0	1	0	1	0	3	0	3	2	4	2	6	3	3	2	4	2	6	2
	dir/indir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	indirect	0	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	3	1	1	1	2	1	3	1
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	3	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	4	4	5	4	4	6	11	12	11	11	12	11
	indirect	8	9	10	8	9	10	16	16	16	16	16	16
	dir/indir	6	7	8	6	7	9	16	17	16	16	17	17
8 ACH	direct	4	4	5	4	5	6	12	13	13	12	13	13
	indirect	10	11	13	10	11	13	21	22	22	21	22	22
	dir/indir	6	7	9	7	7	10	17	19	19	18	19	19
12 ACH	direct	4	5	6	4	5	6	12	13	13	12	13	13
	indirect	11	12	14	11	13	14	23	24	25	23	25	25
	dir-indirect	6	7	9	7	8	10	18	19	19	18	19	20
A/C	PVAVS	18	21	29	22	26	37	34	37	45	38	42	52
Evap.	PVAVS + ind/OA	18	21	29	22	25	36	33	36	43	37	41	51
Pre-	PVAVS + ind/RA	17	19	26	20	23	31	28	30	36	31	34	43
Cooling	PVAVS + ind/dir/OA	11	12	17	13	15	22	21	22	26	23	25	31
	PVAVS + ind/dir/RA	11	12	17	13	15	21	20	22	26	22	24	30

Table 20

	Location	Carpentras FR																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	26	25	26	25	28	25	27	25	27	25	30	25	28	27	28	27	30	27	29	28	30	28	33	28
	indirect	26	25	27	25	28	25	27	26	28	26	31	26	28	27	28	27	31	27	30	28	31	28	34	28
	dir/indir	25	24	26	24	27	24	26	25	27	25	30	25	27	27	28	27	30	27	29	27	30	27	33	27
8 ACH	direct	25	24	25	24	26	24	25	24	26	24	28	24	26	25	26	25	28	25	27	26	28	26	31	26
	indirect	25	24	26	24	27	24	26	25	26	25	29	25	27	26	27	26	29	26	28	27	29	27	32	27
	dir/indir	24	23	25	23	26	23	25	24	25	24	27	24	25	25	26	25	28	25	27	25	27	25	29	25
12 ACH	direct	24	24	25	24	26	24	25	24	25	24	27	24	25	25	26	25	27	25	27	25	27	25	29	25
	indirect	25	24	25	24	26	24	26	25	26	25	28	25	26	25	26	25	28	25	27	26	28	26	30	26
	dir-indirect	24	23	24	23	25	23	24	23	24	23	26	23	25	24	25	24	27	24	26	24	26	24	28	24
A/C	PVAVS	18	9	19	9	22	10	21	12	21	12	23	13	22	19	22	19	23	20	22	22	23	22	23	22
Evap.	PVAVS + ind/OA	18	9	19	9	22	10	21	12	22	13	23	13	22	20	22	20	23	20	22	22	23	22	23	22
Pre-	PVAVS + ind/RA	18	9	19	9	22	10	21	12	22	13	23	13	22	19	22	20	23	20	22	22	23	22	23	22
Cooling	PVAVS + ind/dir/OA	18	9	20	9	22	10	21	12	22	13	23	13	22	20	22	20	23	20	22	22	23	22	23	22
	PVAVS + ind/dir/RA	18	9	20	9	22	10	21	12	22	13	23	13	22	20	22	20	23	20	22	22	23	22	23	22
Percent hours undercooled																									
4 ACH	direct	5	3	6	3	8	3	5	3	6	3	7	3	9	9	10	9	11	9	9	9	10	9	12	9
	indirect	6	5	7	5	8	5	6	4	7	4	8	4	9	10	10	10	11	10	9	9	10	9	13	10
	dir/indir	4	2	6	2	7	2	4	2	5	2	7	2	8	8	9	8	10	8	8	8	9	8	11	8
8 ACH	direct	2	1	3	1	4	1	2	1	2	1	4	1	4	3	5	3	6	3	4	3	5	3	6	3
	indirect	3	2	3	2	5	2	3	2	3	2	5	2	5	5	6	5	7	5	5	4	5	4	7	4
	dir/indir	1	0	1	0	3	0	1	0	1	0	3	0	3	2	4	2	5	2	3	2	4	2	5	2
12 ACH	direct	1	0	1	0	2	0	1	0	1	0	2	0	2	2	3	2	4	2	2	1	3	1	4	1
	indirect	2	1	2	1	3	1	2	1	2	1	3	1	3	3	4	3	5	3	3	3	4	3	5	3
	dir-indirect	0	0	0	0	1	0	0	0	0	0	1	0	1	0	2	0	3	0	1	0	2	0	3	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	10	10	10	9	9	9	10	10	10	10	10	10
	indirect	11	11	11	10	11	11	12	12	12	11	11	12
	dir/indir	13	14	13	13	13	13	15	15	15	14	14	15
8 ACH	direct	12	12	12	12	12	12	13	13	13	13	13	14
	indirect	14	15	15	14	14	14	16	16	16	15	16	17
	dir/indir	17	17	17	16	16	17	19	20	20	19	19	20
12 ACH	direct	14	14	14	13	13	14	15	15	15	14	15	16
	indirect	17	17	17	16	16	17	19	19	19	18	18	20
	dir-indirect	19	19	20	18	18	19	22	22	22	21	21	23
A/C	PVAVS	47	53	73	59	65	89	75	80	100	84	88	111
Evap.	PVAVS + ind/OA	45	51	71	56	62	86	72	77	96	80	84	106
Pre-	PVAVS + ind/RA	43	51	74	57	64	92	76	83	104	86	91	115
Cooling	PVAVS + ind/dir/OA	43	49	68	54	60	83	68	74	92	76	81	102
	PVAVS + ind/dir/RA	42	49	71	55	62	87	72	78	98	81	86	109

Table 21

	Location	Nice FR																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	26	25	26	25	28	25	26	25	27	25	31	25	27	27	28	27	31	27	29	27	31	27	34	27
	indirect	26	25	26	25	28	25	26	25	27	25	31	25	28	27	28	27	31	27	30	28	31	28	34	28
	dir/indir	25	24	26	24	28	24	26	25	27	25	30	25	27	27	28	27	31	27	29	27	30	27	33	27
8 ACH	direct	24	23	25	23	27	23	25	24	26	24	28	24	26	25	26	25	28	25	27	25	28	25	30	25
	indirect	24	24	25	24	27	24	25	24	26	24	28	24	26	25	27	25	29	25	27	26	28	26	31	26
	dir/indir	24	23	25	23	26	23	25	24	26	24	28	24	26	25	26	25	28	25	27	25	28	25	30	25
12 ACH	direct	24	23	24	23	26	23	24	23	25	23	27	23	25	24	26	24	27	24	26	25	27	25	29	25
	indirect	24	23	24	23	26	23	24	24	25	24	27	24	25	25	26	25	28	25	27	25	27	25	29	25
	dir-indirect	24	23	24	23	26	23	24	23	25	23	27	23	25	24	26	24	27	24	26	24	27	24	29	24
A/C	PVAVS	19	12	20	12	22	12	21	14	22	14	23	14	22	20	22	20	23	20	23	22	23	22	23	22
Evap.	PVAVS + ind/OA	19	12	20	12	22	12	21	14	22	14	23	14	22	20	22	20	23	20	23	22	23	22	23	22
Pre-	PVAVS + ind/RA	19	12	20	12	22	12	21	14	22	14	23	14	22	20	22	20	23	20	23	22	23	22	23	22
Cooling	PVAVS + ind/dir/OA	19	12	20	12	22	12	21	14	22	14	23	14	22	20	22	20	23	20	23	22	23	22	23	22
	PVAVS + ind/dir/RA	19	12	20	12	22	12	21	14	22	14	23	14	22	20	22	20	23	20	23	22	23	22	23	22

Percent hours undercooled																									
4 ACH	direct	6	4	7	4	9	4	6	4	7	4	10	4	10	10	11	10	13	10	11	10	12	10	15	10
	indirect	7	5	8	5	10	5	6	5	8	5	10	5	11	11	12	11	14	11	11	11	12	11	15	11
	dir/indir	5	4	7	4	9	4	5	3	7	3	9	3	10	10	11	10	13	10	10	10	12	10	14	10
8 ACH	direct	2	1	3	1	5	1	2	1	3	1	5	1	6	5	6	5	8	5	5	5	6	5	8	5
	indirect	3	2	4	2	5	2	3	2	4	2	5	2	6	6	7	6	8	6	6	5	7	5	9	5
	dir/indir	2	0	3	0	4	0	2	0	3	0	4	0	5	4	6	4	7	4	5	4	5	4	8	4
12 ACH	direct	1	0	2	0	3	0	1	0	2	0	3	0	3	2	4	2	5	2	3	2	3	2	5	2
	indirect	2	1	2	1	4	1	2	1	2	1	4	1	4	3	4	3	6	3	4	3	4	3	6	3
	dir-indirect	1	0	1	0	2	0	1	0	1	0	2	0	2	2	3	2	4	2	2	1	3	1	4	1
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	9	9	9	9	9	9	10	10	10	9	9	10
	indirect	10	11	10	10	10	11	12	12	12	11	11	12
	dir/indir	13	13	13	12	13	13	15	15	15	14	14	16
8 ACH	direct	12	12	12	11	11	12	13	13	13	13	13	14
	indirect	14	14	14	13	14	15	16	16	17	15	16	18
	dir/indir	17	17	18	16	17	18	20	20	21	19	20	22
12 ACH	direct	13	14	14	13	13	14	15	15	16	14	15	17
	indirect	16	17	17	16	16	17	19	19	20	18	19	22
	dir-indirect	19	20	20	18	19	21	23	23	25	22	23	26
A/C	PVAVS	49	56	80	64	73	96	77	84	105	84	92	111
Evap.	PVAVS + ind/OA	48	55	78	62	71	95	75	82	103	81	89	108
Pre-	PVAVS + ind/RA	47	56	83	64	75	101	80	88	110	87	96	116
Cooling	PVAVS + ind/dir/OA	46	53	76	59	69	92	73	79	99	78	85	105
	PVAVS + ind/dir/RA	46	54	79	61	71	97	77	84	105	83	91	111

Table 22

	Location	Eelde NETH																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	24	23	25	23	27	23	25	24	26	24	29	24	26	25	27	25	29	25	28	27	29	27	32	27
	indirect	25	23	25	23	27	23	26	24	27	24	29	24	27	26	28	26	30	26	29	27	30	27	32	27
	dir/indir	24	23	24	23	26	23	25	23	26	23	28	23	26	25	27	25	28	25	28	26	29	26	31	26
8 ACH	direct	23	22	24	22	25	22	24	23	24	23	27	23	25	24	25	24	27	24	26	24	27	24	29	24
	indirect	24	23	24	23	26	23	25	24	25	24	27	24	25	25	26	25	28	25	27	25	28	25	30	25
	dir/indir	23	22	23	22	24	22	23	22	24	22	26	22	24	23	25	23	26	23	25	24	26	24	27	24
12 ACH	direct	23	22	23	22	24	22	23	22	24	22	25	22	24	23	24	23	26	23	25	24	26	24	27	24
	indirect	24	23	24	23	25	23	24	23	25	23	27	23	25	24	25	24	27	24	26	25	27	25	28	25
	dir-indirect	22	22	23	22	24	22	23	22	23	22	25	22	23	23	24	23	25	23	24	23	25	23	26	23
A/C	PVAVS	18	10	19	10	22	11	21	12	22	12	23	13	22	20	22	20	23	20	22	21	23	21	23	21
Evap. Pre-Cooling	PVAVS + ind/OA	18	10	20	10	22	10	21	12	22	12	23	13	22	19	22	20	23	20	22	21	23	21	23	21
	PVAVS + ind/RA	18	10	20	10	22	11	21	12	22	12	23	13	22	19	22	20	23	20	22	21	23	21	23	21
	PVAVS + ind/dir/OA	18	10	20	10	22	10	21	12	22	12	23	13	22	20	22	20	23	20	22	21	23	21	23	21
	PVAVS + ind/dir/RA	18	10	20	10	22	10	21	12	22	12	23	13	22	20	22	20	23	20	22	21	23	21	23	21
Percent hours undercooled																									
4 ACH	direct	0	0	1	0	3	0	1	0	1	0	3	0	5	6	6	6	6	6	5	6	6	6	6	6
	indirect	1	0	2	0	3	0	1	0	2	0	3	0	6	6	6	6	7	6	5	6	6	6	7	6
	dir/indir	0	0	1	0	2	0	0	0	1	0	2	0	5	5	6	5	6	5	5	5	5	5	6	5
8 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	1	0	2	0
	indirect	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	2	0	1	0	1	0	2	0
	dir/indir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evap. Pre-Cooling	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	internal gains	low internal gains						high internal gains					
	solar gains	low		medium		high		low		medium		high	
	Inertia	high	low	high	low	high	low	high	low	high	low	high	low
Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	9	9	9	8	8	8	9	9	9	9	9	9
	indirect	9	10	10	9	9	9	10	10	10	10	10	10
	dir/indir	12	12	12	11	11	11	13	13	13	13	13	13
8 ACH	direct	10	11	11	10	10	10	11	12	11	11	11	11
	indirect	11	12	12	11	11	11	13	13	13	13	13	13
	dir/indir	14	14	14	13	13	14	16	16	17	15	16	16
12 ACH	direct	11	11	12	11	11	11	12	12	13	12	12	12
	indirect	12	13	13	12	12	12	14	15	15	14	14	14
	dir-indirect	15	15	16	14	14	15	17	18	18	17	17	17
A/C	PVAVS	35	39	55	42	48	69	58	62	77	63	69	87
Evap. Pre-Cooling	PVAVS + ind/OA	35	39	56	42	48	70	58	63	78	64	70	88
	PVAVS + ind/RA	32	38	58	41	49	73	61	66	82	67	73	92
	PVAVS + ind/dir/OA	34	39	55	41	47	69	57	61	76	62	68	86
	PVAVS + ind/dir/RA	32	38	57	41	48	72	60	65	81	66	72	92

Table 23

	Location	Kew GB																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	24	23	24	23	26	23	25	23	25	23	28	23	26	26	27	26	28	26	28	26	28	26	31	26
	indirect	24	23	25	23	26	23	25	24	26	24	28	24	26	26	27	26	29	26	28	27	29	27	31	27
	dir/indir	23	23	24	23	25	23	24	23	25	23	27	23	26	25	26	25	28	25	27	26	28	26	30	26
8 ACH	direct	23	22	23	22	24	22	24	23	24	23	26	23	24	24	25	24	26	24	26	24	26	24	28	24
	indirect	23	23	24	23	25	23	24	23	24	23	26	23	25	24	25	24	27	24	26	25	27	25	29	25
	dir/indir	22	22	23	22	24	22	23	22	23	22	25	22	24	23	24	23	25	23	25	24	25	24	27	24
12 ACH	direct	23	22	23	22	24	22	23	22	23	22	25	22	24	23	24	23	25	23	25	23	25	23	26	23
	indirect	23	23	23	23	24	23	24	23	24	23	26	23	24	24	24	24	26	24	25	24	26	24	28	24
	dir-indirect	22	22	22	22	23	22	23	22	23	22	24	22	23	23	23	23	24	23	24	23	24	23	26	23
A/C	PVAVS	17	11	19	11	21	11	20	13	21	13	22	14	22	20	22	20	23	20	22	22	23	22	23	22
Evap.	PVAVS + ind/OA	17	11	19	11	21	11	20	13	21	13	22	14	22	20	22	20	23	20	22	22	23	22	23	22
Pre-	PVAVS + ind/RA	17	11	19	11	21	11	20	13	21	13	22	14	22	20	22	20	22	20	22	22	23	22	23	22
Cooling	PVAVS + ind/dir/OA	17	11	19	11	21	11	20	13	21	13	22	14	22	20	22	20	22	20	22	22	23	22	23	22
	PVAVS + ind/dir/RA	17	11	19	11	21	11	20	13	21	13	22	14	22	20	22	20	22	20	22	22	23	22	23	22

Percent hours undercooled																									
4 ACH	direct	0	0	1	0	2	0	0	0	1	0	2	0	4	5	5	5	5	5	4	5	5	5	5	5
	indirect	0	0	1	0	2	0	1	0	1	0	2	0	4	6	5	6	6	6	4	6	5	6	6	6
	dir/indir	0	0	0	0	2	0	0	0	0	0	2	0	3	4	4	4	5	4	3	4	4	4	5	4
8 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0
	indirect	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	2	0	1	0	1	0	2	0
	dir/indir	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	8	8	8	7	8	8	9	9	8	8	8	8
	indirect	9	9	9	8	8	8	10	10	10	9	9	9
	dir/indir	11	11	11	10	10	10	12	13	12	12	12	12
8 ACH	direct	10	10	10	9	9	9	10	11	10	10	10	10
	indirect	10	10	11	10	10	10	12	12	12	12	12	12
	dir/indir	12	13	13	12	12	12	15	15	15	14	15	15
12 ACH	direct	10	10	10	10	10	10	11	11	11	11	11	11
	indirect	11	11	12	11	11	11	13	13	13	13	13	13
	dir-indirect	13	14	14	13	13	13	16	16	16	15	15	16
A/C	PVAVS	36	40	55	44	50	70	59	63	76	61	66	82
Evap.	PVAVS + ind/OA	35	39	54	43	49	69	58	62	75	60	65	81
Pre-	PVAVS + ind/RA	33	39	57	44	51	73	62	66	81	65	70	87
Cooling	PVAVS + ind/dir/OA	33	37	51	40	46	65	55	58	71	57	61	76
	PVAVS + ind/dir/RA	33	38	55	42	49	71	60	64	78	63	68	85

Table 24

	Location	Zurich HEL																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	28	26	29	26	31	26	29	26	30	26	33	26	32	31	33	31	35	31	33	32	34	32	36	32
	indirect	29	26	30	27	32	27	30	27	31	27	34	27	33	32	34	32	35	32	34	33	35	33	37	33
	dir/indir	27	25	28	25	31	25	28	25	29	25	32	25	31	30	32	30	34	30	32	31	33	31	35	31
8 ACH	direct	26	25	27	25	29	25	27	25	27	25	29	25	28	27	29	27	31	27	29	28	30	28	32	28
	indirect	27	26	28	26	30	26	28	26	29	26	31	26	30	28	31	28	32	28	31	29	32	29	33	29
	dir/indir	25	24	26	24	27	24	25	24	26	24	28	24	27	26	28	26	30	26	28	26	29	26	30	26
12 ACH	direct	25	24	26	24	27	24	26	24	26	24	28	24	27	26	27	26	29	26	27	26	28	26	30	26
	indirect	27	26	28	26	29	26	28	26	28	26	30	26	29	28	29	28	31	28	30	28	30	28	32	28
	dir-indirect	24	24	25	24	26	24	24	24	25	24	26	24	26	25	26	25	27	25	26	25	26	25	28	25
A/C	PVAVS	25	25	25	25	25	25	24	25	24	25	24	24	25	26	26	26	25	26	25	25	24	25	24	25
Evap.	PVAVS + ind/OA	25	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	24
Pre-	PVAVS + ind/RA	25	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	24
Cooling	PVAVS + ind/dir/OA	24	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	24
	PVAVS + ind/dir/RA	24	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	24

Percent hours undercooled																									
4 ACH	direct	2	0	4	0	7	0	3	1	4	1	7	1	10	10	12	11	14	11	10	10	12	10	14	10
	indirect	3	1	5	1	7	1	4	2	5	2	8	2	11	12	13	12	15	12	11	12	13	12	14	12
	dir/indir	2	0	3	0	6	0	2	0	3	0	6	0	9	9	12	9	13	9	9	9	12	9	13	9
8 ACH	direct	0	0	1	0	2	0	0	0	1	0	2	0	2	1	3	1	5	1	3	1	3	1	5	1
	indirect	1	0	1	0	3	0	1	0	2	0	3	0	4	3	4	3	6	3	4	3	4	3	6	3
	dir/indir	0	0	0	0	1	0	0	0	0	0	1	0	1	0	2	0	4	0	2	1	2	1	4	1
12 ACH	direct	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	2	0	1	0	1	0	2	0
	indirect	0	0	0	0	1	0	0	0	1	0	2	0	2	1	2	1	3	1	2	1	2	1	3	1
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	4	0	4	0	1	0	1	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	2	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	0	3	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	1	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	2	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	6	6	7	6	6	7	12	13	12	12	13	13
	indirect	8	9	9	8	9	10	15	16	16	16	16	16
	dir/indir	9	10	11	9	10	12	19	20	20	20	20	20
8 ACH	direct	7	8	9	7	8	9	15	16	16	16	16	16
	indirect	10	11	12	10	11	13	20	21	21	20	21	22
	dir/indir	10	12	14	11	12	14	24	25	26	24	26	26
12 ACH	direct	7	8	10	7	8	10	17	18	18	17	18	18
	indirect	11	12	14	11	12	14	23	24	24	23	24	25
	dir-indirect	11	12	15	11	13	16	26	27	28	26	28	29
A/C	PVAVS	19	21	30	22	25	37	35	38	46	38	42	54
Evap.	PVAVS + ind/OA	18	20	28	20	24	36	34	37	44	37	41	51
Pre-	PVAVS + ind/RA	19	22	30	22	26	38	37	40	48	40	44	55
Cooling	PVAVS + ind/dir/OA	17	19	27	19	23	34	33	35	42	35	39	49
	PVAVS + ind/dir/RA	19	22	30	22	25	38	36	39	46	39	43	54

Table 25

	Location	Frankfurt GER																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	28	26	29	26	32	26	29	26	30	26	34	26	32	31	33	31	35	31	33	32	34	32	37	32
	indirect	29	27	30	27	33	27	30	28	31	28	35	28	33	32	34	32	36	32	34	33	35	33	38	33
	dir/indir	27	25	28	25	31	25	28	25	29	25	33	25	31	30	32	30	34	30	32	30	33	30	36	31
8 ACH	direct	26	25	27	25	29	25	27	25	28	25	30	25	28	27	29	27	31	27	29	28	30	28	32	28
	indirect	27	26	28	26	30	26	28	26	29	26	31	26	29	28	30	28	32	28	31	29	31	29	33	29
	dir/indir	25	24	25	24	28	24	25	24	26	24	29	24	27	26	28	26	29	26	28	26	29	26	31	26
12 ACH	direct	25	24	26	24	27	24	26	25	27	25	28	25	27	26	27	26	29	26	28	26	28	26	30	26
	indirect	26	26	27	26	29	26	27	26	28	26	30	26	28	27	29	27	30	27	29	28	30	28	31	28
	dir-indirect	24	24	24	24	26	24	24	24	25	24	27	24	25	25	26	25	27	25	26	25	26	25	28	25
A/C	PVAVS	25	25	25	25	25	25	24	24	24	24	24	24	25	26	25	26	25	25	24	25	24	25	24	24
Evap.	PVAVS + ind/OA	24	25	25	25	25	24	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	24	24	24
Pre-	PVAVS + ind/RA	24	25	25	25	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24
Cooling	PVAVS + ind/dir/OA	24	24	25	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24
	PVAVS + ind/dir/RA	24	24	25	24	24	24	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24

Percent hours undercooled																									
4 ACH	direct	3	1	4	1	8	1	3	1	5	1	8	1	10	12	12	12	14	12	10	11	12	11	14	11
	indirect	3	2	5	2	8	2	4	2	6	2	8	2	11	13	13	13	15	13	11	13	13	13	14	13
	dir/indir	2	0	3	0	7	0	2	0	4	0	7	0	9	10	11	10	13	10	9	10	11	10	13	10
8 ACH	direct	0	0	1	0	2	0	0	0	1	0	2	0	3	2	4	2	5	2	3	2	4	2	5	2
	indirect	1	0	1	0	3	0	1	0	2	0	3	0	4	3	5	3	7	3	4	3	5	3	7	3
	dir/indir	0	0	0	0	1	0	0	0	0	0	1	0	1	1	2	1	4	1	2	1	2	1	4	1
12 ACH	direct	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	2	0	1	0	1	0	2	0
	indirect	0	0	1	0	2	0	0	0	1	0	2	0	2	1	2	1	3	1	2	1	2	1	3	1
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	0	1	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0

Cooling and Fan Energy Use (kWh/m2)													
4 ACH	direct	6	6	7	6	7	7	11	11	12	11	12	12
	indirect	8	9	10	8	9	10	14	14	15	14	15	15
	dir/indir	9	10	12	9	10	12	18	18	19	18	19	19
8 ACH	direct	7	8	9	7	8	10	14	15	16	15	15	16
	indirect	10	11	13	10	11	13	19	20	21	20	20	21
	dir/indir	10	12	15	11	12	15	23	24	25	23	24	25
12 ACH	direct	7	8	10	8	9	11	16	17	18	16	17	18
	indirect	11	12	15	11	13	15	22	23	24	22	23	25
	dir-indirect	11	13	16	11	13	16	24	26	28	25	26	28
A/C	PVAVS	20	22	32	23	27	41	36	39	48	40	44	57
Evap.	PVAVS + ind/OA	19	21	31	22	26	39	35	38	46	38	42	54
Pre-	PVAVS + ind/RA	20	23	33	24	28	41	37	40	49	40	44	58
Cooling	PVAVS + ind/dir/OA	18	21	30	21	25	37	34	37	45	37	41	52
	PVAVS + ind/dir/RA	20	23	33	24	28	41	37	40	49	40	44	57

Table 26

	Location	Helsinki FIN																							
	internal gains	low internal gains												high internal gains											
	solar gains	low				medium				high				low				medium				high			
	Inertia	high		low		high		low		high		low		high		low		high		low		high		low	
	bldg location	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor	per	cor
Maximum Indoor Temperatures (C)																									
4 ACH	direct	27	25	29	25	32	25	28	25	30	25	33	25	31	29	33	29	35	29	33	30	34	30	37	30
	indirect	28	25	29	25	33	26	29	26	31	26	34	26	32	30	33	30	36	30	33	31	35	31	38	31
	dir/indir	26	25	28	25	31	25	27	25	29	25	32	25	30	29	31	29	34	29	31	29	33	30	36	30
8 ACH	direct	25	24	26	24	28	24	25	24	26	24	29	24	27	26	28	26	30	26	28	26	29	26	31	26
	indirect	26	24	26	24	29	24	26	24	27	24	30	24	28	26	29	26	31	26	29	27	29	27	32	27
	dir/indir	24	24	25	24	27	24	24	24	25	24	27	24	26	25	27	25	29	25	26	25	27	25	29	25
12 ACH	direct	24	24	25	24	26	24	24	24	25	24	26	24	25	25	26	25	28	25	26	24	26	24	28	24
	indirect	25	24	25	24	27	24	25	24	25	24	27	24	26	25	27	25	28	25	26	25	27	25	29	25
	dir-indirect	24	24	24	24	25	24	24	24	24	24	25	24	25	24	25	24	26	24	25	24	25	24	26	24
A/C	PVAVS	25	25	26	25	26	25	25	25	25	25	25	25	26	26	26	26	26	25	25	25	25	25	25	25
Evap.	PVAVS + ind/OA	25	25	25	25	25	25	24	24	25	24	24	24	25	25	26	25	25	25	25	25	25	25	24	25
Pre-	PVAVS + ind/RA	25	25	25	25	25	25	25	24	25	24	24	24	25	25	26	25	25	25	25	25	25	25	24	25
Cooling	PVAVS + ind/dir/OA	25	24	25	25	25	25	24	24	24	24	24	24	25	25	25	25	25	25	24	24	24	24	24	24
	PVAVS + ind/dir/RA	25	25	25	25	25	25	24	24	24	24	24	24	25	25	25	25	25	25	24	25	24	25	24	24
Percent hours undercooled																									
4 ACH	direct	1	0	3	0	7	0	2	0	3	0	7	0	9	8	11	8	14	8	9	8	12	8	14	8
	indirect	2	0	4	0	8	0	2	0	4	0	8	0	10	9	12	9	16	9	10	9	12	9	14	9
	dir/indir	1	0	2	0	6	0	1	0	3	0	6	0	8	6	10	6	14	7	9	7	11	7	14	7
8 ACH	direct	0	0	0	0	1	0	0	0	0	0	2	0	1	0	2	0	4	0	1	0	2	0	4	0
	indirect	0	0	0	0	2	0	0	0	1	0	2	0	2	1	3	1	5	1	2	1	3	1	5	1
	dir/indir	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	3	0	1	0	1	0	3	0
12 ACH	direct	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	indirect	0	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	2	0	0	0	1	0	2	0
	dir-indirect	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
A/C	PVAVS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
Evap.	PVAVS + ind/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-	PVAVS + ind/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
Cooling	PVAVS + ind/dir/OA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	PVAVS + ind/dir/RA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cooling and Fan Energy Use (kWh/m2)																									
4 ACH	direct	5		5		6		5		5		7		9		9		10		10		11		11	
	indirect	6		7		8		6		7		9		12		12		13		12		13		13	
	dir/indir	7		9		10		8		9		11		15		15		16		16		16		17	
8 ACH	direct	5		6		8		5		6		8		11		12		14		12		13		14	
	indirect	7		8		10		7		8		11		15		16		17		16		17		18	
	dir/indir	8		9		12		8		10		13		18		19		21		19		20		22	
12 ACH	direct	5		6		8		6		6		8		11		13		15		13		14		15	
	indirect	7		8		11		8		9		11		15		17		19		17		18		20	
	dir-indirect	8		10		13		9		10		13		18		20		23		20		21		23	
A/C	PVAVS	18		19		28		20		22		33		30		31		39		32		34		45	
Evap.	PVAVS + ind/OA	17		19		27		20		22		32		29		30		38		31		34		44	
Pre-	PVAVS + ind/RA	19		20		29		21		23		34		32		33		41		34		36		47	
Cooling	PVAVS + ind/dir/OA	17		18		26		19		21		31		28		30		37		31		33		42	
	PVAVS + ind/dir/RA	18		20		28		21		23		33		31		32		40		33		35		46	

4 Conclusions

The tables show that the performance of evaporative cooling varies tremendously with the humidity, or more specifically, wet-bulb temperatures, for a given climate. Furthermore, because the capacity of evaporative cooling is constrained by atmospheric conditions and economically justifiable air flow rates, its applicahility also depends on the amount of cooling loads that must be removed.

Tables 3, 4, 5, 9 and 15 show that in the humid summer conditions throughout the eastern part of the US and Canada (Minneapolis, New York, Washington, Chicago and Toronto), stand-alone evaporative cooling systems have minimal applicability, except possibly indirect/direct units at 12 ach in well designed buildings. Even so, the indoor temperatures will be noticeably higher than in air-conditioned buildings, and the energy savings will be small to negative. As precoolers, however, evaporative cooling can still provide energy savings, particularly when the room exhaust air is used as the secondary air. This can be considered as a way to recover the coolness from the refrigerated exhaust air.

Tables 6 and 10 show that in the extremely humid climates of Miami and Fort Worth, evaporative cooling does not work for all building conditions. There are small energy savings for precooling with room exhaust air, but they are probably not economically justifiable.

Tables 11 and 16 show that evaporative cooling performs very well in Denver and Edmonton, which have moderately hot but dry summers. Stand-alone evaporative cooling systems, even direct systems, will maintain satisfactory indoor temperatures at 8 ach in all hut the most unfavourable building conditions, eg perimeter zones with high solar gains. At 12 ach, the indoor temperatures are similar to those with conventional air conditioning, but the energy savings are reduced from 30–50% to 15–30%.

Table 12 shows that in Albuquerque, which has hotter but equally dry summers as Denver, an indirect/direct evaporative cooling system at 8 ach is sufficient for buildings with low to moderate loads, but 12 ach may be needed in buildings with higher cooling loads. In both climates there are also substantial energy savings from the use of evaporative precooling.

Table 8 shows that in Los Angeles, which has a Mediterranean climate with mild but semi-humid conditions, stand-alone indirect/direct evaporative cooling at between 4 and 8 ach will maintain adequate indoor temperatures provided that the building has low to moderate amounts of solar gains. In buildings with larger cooling loads, stand-alone indirect/direct units at 12 ach are necessary. In terms of energy savings, the stand-alone units are always beneficial, but only if they are indirect/direct evaporative precooling systems.

Table 7 shows that for Phoenix, which has a very hot and dry desert climate, the cooling loads are so large that very high air fbw rates are needed to provide adequate evaporative cooling, and even then only for buildings with low cooling loads. Although Phoenix is the centre of the residential evaporative cooling market, the simulations show that for a medium-sized office building, indoor temperatures will be unacceptably high, except possibly for indirect/direct systems at 16 ach in a well built building. Even so, there are no energy savings compared with conventional air conditioning. As a precooling system, both indirect and indirect/direct systems provide moderate savings with no difference between using return or outside air as the secondary air.

For the European climates studied, evaporative cooling showed good potential in most locations because of their low cooling loads and moderate humidity during the summer, especially Trappes, Carpentras, Nice, The Netherlands, Kew and Helsinki (Tables 19 to 23 and 26). In Porto, Lisbon, Zurich and Frankfurt, evaporative cooling potentials seem limited to systems with 8 ach or more in well built buildings with low cooling loads. There is very little energy savings benefits from evaporative precooling in any of the European climates studied.

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Chapter B Evaporative cooling in office buildings

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1 Introduction

For evaporative cooling, evaporation of water is used to decrease the dry-bulb temperature of air. Wetted-pad media or water sprays may be used for evaporation of the water. There are two main categories of evaporative cooling: direct and indirect.

For direct evaporative cooling, water is evaporated directly in the supply air stream, reducing the air stream's dry-bulb temperature, but increasing its absolute humidity.

For indirect evaporative cooling, two air streams are used. A secondary (or scavenger) air stream of outdoor air or exhaust air (see Figure 1) is cooled by evaporation and then exhausted. This cooler moist secondary air stream is then used to cool the primary supply air stream indirectly tbrough an air-to-air heat exchanger (which can also be used to pre-heat outdoor air in winter).

Six different systems are considered:

1 No evaporative cooling – night cooling only
2 Direct evaporative cooling
3 Indirect evaporative cooling
4 Direct + indirect evaporative cooling
5 No night cooling + cooling coil
6 Indirect evaporative cooling + cooling coil

The plant configuration is illustrated in Figure 1.

This tool for evaporative cooling in office buildings gives the maximum internal temperatures under summer design conditions for the first four systems listed above and the cooling coil load for the other two systems, which have mechanical cooling. Annual energy (heating, cooling and fan) and

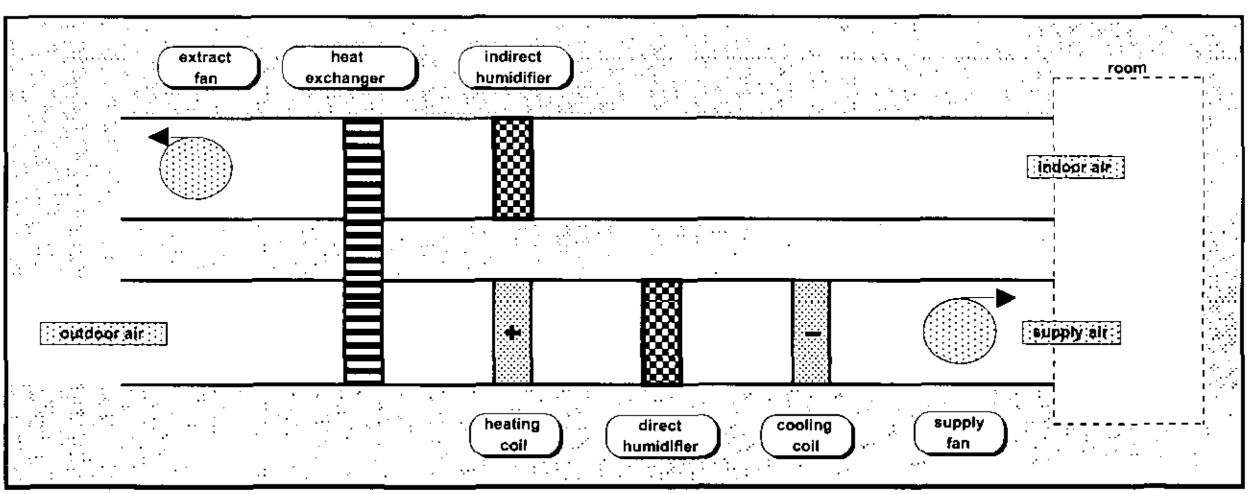


Figure 1 Plant configuration

water consumptions per annum are also provided. The values have been generated using the simplified thermal model COMET where the room behaviour is represented by an RC (resistance-capacitance) network.

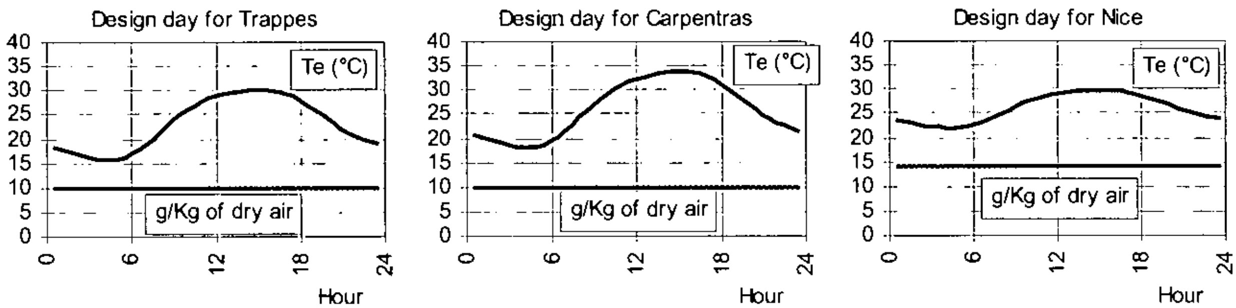
The parameters of climate, building design (thermal inertia, window solar protection and internal gains) and plant are defined in the next section. The results from the simulations are presented in the form of design tables in Section 3.

2 Parameters

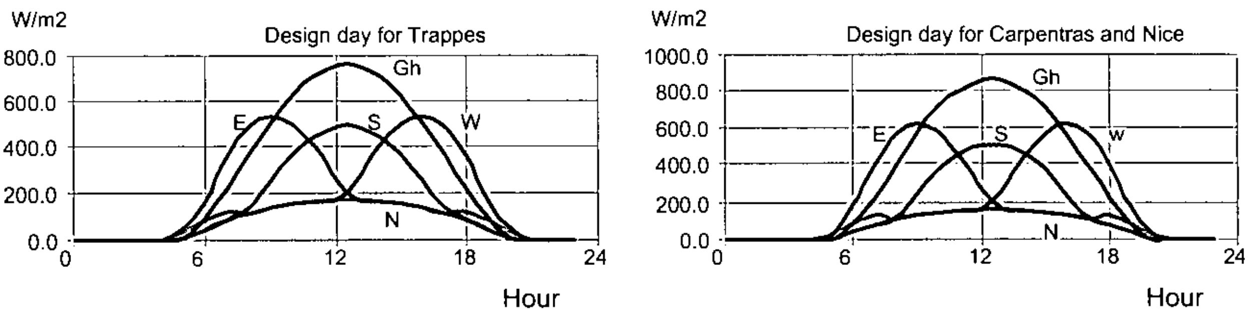
2.1 Climate

Three climatic areas are considered: centre of France (Trappes), south inland (Carpentras), and south near the Mediterranean coast (Nice).

2.1.1 Temperature and humidity



2.1.2 Solar



2.2 Building design

The basic information is the expected maximum operative temperature in summer, depending on the building design. Two cases are defined on the next page for inertia, solar gains and internal gains. Building design is classified as good or bad on the basis of these factors as defined in the following table.

	Building design	
	Good	**Bad**
Inertia	High	Low
Solar gains index: window solar factor × window area/floor area	0.05	0.15
Internal gains (W/m^2 during occupancy)	10	30

Interpretation of each of these parameters is discussed below. Results are only provided for east and west orientations.

2.2.1 Thermal inertia

Low means one ceiling or floor of high inertia.
High means ceiling, floor and side walls all of high inertia.

2.2.2 Window solar protection

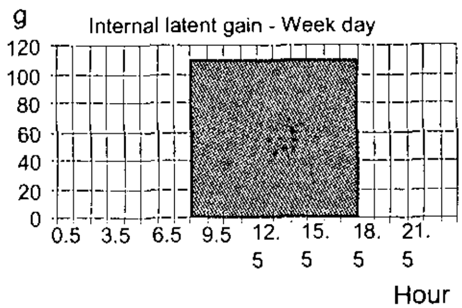
The ratio S × Ab/Al is defined where:

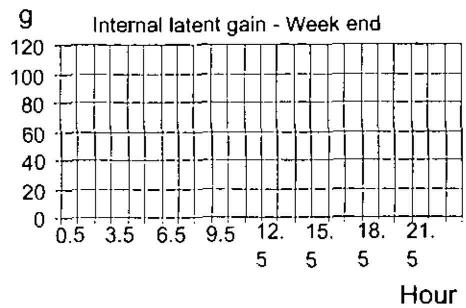
S = window solar factor
Ab = window area
Al = room area

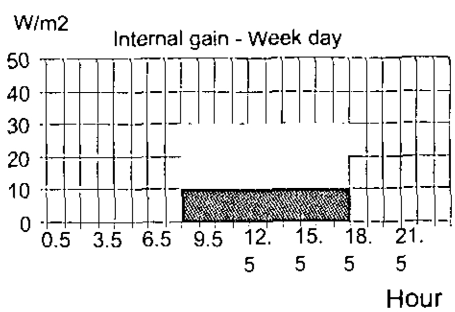
The two reference ratio values used are 0.05 and 0.15.

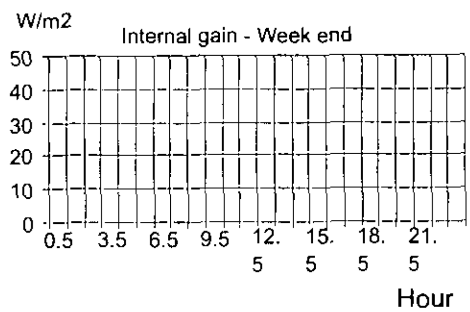
2.2.3 Internal loads

Occupants, equipment and lighting: 10 and 30 W/m² (radiant fraction: 0.5).









2.3 Plant

2.3.1 Air flow

Four maximum air flow rates have been considered corresponding to 2, 4, 6 and 8 air changes per hour.

2.3.2 Systems

Without cooling plant

- No evaporative cooling – night cooling only
- Direct evaporative system
- Indirect evaporative system
- Direct + indirect evaporative system

With cooling plant

- No night cooling + cooling coil
- Indirect evaporative system + cooling coil

For all systems, 'night cooling' is used if of benefit.

2.3.3 Control

For each system, except where specifically excluded, 24-hour control matrices have been defined for summer and for winter conditions. Descriptions of the control matrices are provided in the IEA Annex 28 Subtask 2 Report 3 *Detailed design tools for low energy cooling technologies.*

For annual simulations it is necessary to define transitions between winter control matrix and summer control matrix. When the calculation is done with winter control matrix, the indoor air temperature between 07.00 h and 08.00 h is checked. If this temperature is higher than 23 °C, the transition with summer control matrix is made. When the calculation is done with summer control matrix, the indoor air temperature between 08.00 h and 09.00 h is checked. If this temperature is lower than 19 °C, the transition with winter control matrix is made.

3 Design tables

Two sets of simulations have been undertaken for the three different sites (Trappes, Carpentras, Nice).

The first set is related to sizing and is based on a reference warm day. In this case the outputs are the indoor temperature and required cooling power if a cooling coil is used.

The second set of runs is for a typical year, for which the outputs are the heating, cooling and fan electrical energy consumptions and water consumption.

Key to tables

Maximum operative temperature during occupancy for the reference warm day:

≤26 °C	boxes with light shading
> 26 °C and <30 °C	boxes left white
≥30 °C and <33 °C	boxes with medium shading
≥33 °C	boxes with dark shading, and no numbers

3.1 Results for a reference warm day

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30	[illegible]	[illegible]
	direct	26	26	28	29	30	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]
	indirect	28	28	30	30	32	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]
	direct+indirect	25	26	27	28	29	29	32	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25	32	[illegible]
4 vol/h	none	28	28	31	31	31	31	[illegible]	[illegible]	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28	[illegible]	[illegible]
	direct	24	24	25	26	26	26	29	30	28	28	30	[illegible]	30	31	[illegible]	[illegible]	24	29	[illegible]
	indirect	25	26	27	28	28	28	31	32	30	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25	31	[illegible]
	direct+indirect	24	25	25	26	26	26	28	29	27	28	29	32	29	30	32	[illegible]	24	28	[illegible]
6 vol/h	none	27	28	30	31	30	30	[illegible]	[illegible]	31	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	32	[illegible]
	direct	23	24	24	25	25	25	27	28	26	26	28	30	28	28	31	[illegible]	23	27	[illegible]
	indirect	24	25	26	27	26	27	29	30	28	28	30	[illegible]	30	31	[illegible]	[illegible]	24	29	[illegible]
	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	[illegible]	30	31	[illegible]	[illegible]	32	32	[illegible]	[illegible]	27	32	[illegible]
	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	[illegible]	24	28	[illegible]
	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	[illegible]	32	32	[illegible]	[illegible]		30	
	max	30	30	32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24	30	[illegible]
	cool.plant only	25	25	26	27	27	28	31	32	30	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25	31	[illegible]
4 vol/h	ind.+Cool. plant	24	24	24	25	24	25	26	27	25	26	27	30	27	28	30	[illegible]	24	27	[illegible]
	cool.plant only	24	24	24	25	25	25	27	28	26	27	29	31	28	28	31	[illegible]	24	27	[illegible]
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	[illegible]		27	
	max	25	25	26	27	27	28	31	32	30	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	16	[illegible]
	cool.plant only	18	18	19	21	21	21	23	23	23	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	22	[illegible]
4 vol/h	ind.+Cool. plant	12	15	18	26	26	26	27	27	26	26	28	29	28	28	30	[illegible]	12	25	[illegible]
	cool.plant only	27	31	33	36	37	39	40	43	39	39	44	46	43	43	47	[illegible]	27	39	[illegible]
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	[illegible]		35	
	max	34	38	39	52	53	57	61	71	59	70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Carpentras (Dept : 84)

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	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
	direct	28	28	29	31	32	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	28	[redacted]	[redacted]
	indirect	30	30	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	30	[redacted]	[redacted]
	direct+indirect	27	27	28	30	31	31	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	27	[redacted]	[redacted]
4 vol/h	none	31	31	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	31	[redacted]	[redacted]
	direct	25	25	26	28	27	28	30	31	30	30	32	[redacted]	32	[redacted]	[redacted]	[redacted]	25	30	[redacted]
	indirect	27	28	29	30	30	31	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	27	[redacted]	[redacted]
	direct+indirect	25	25	26	27	27	27	29	30	29	29	31	[redacted]	31	32	[redacted]	[redacted]	25	29	[redacted]
6 vol/h	none	31	31	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	31	[redacted]	[redacted]
	direct	24	24	25	26	26	26	28	29	27	28	29	32	29	30	32	[redacted]	24	28	[redacted]
	indirect	26	26	28	29	28	29	31	32	30	31	32	[redacted]	32	[redacted]	[redacted]	[redacted]	26	31	[redacted]
	direct+indirect	25	25	25	26	25	26	27	28	26	27	28	31	28	29	30	[redacted]	25	28	[redacted]
8 vol/h	none	30	30	[redacted]	[redacted]	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	30	[redacted]	[redacted]
	direct	24	24	24	26	25	25	27	28	26	27	28	31	28	28	30	[redacted]	24	27	[redacted]
	indirect	26	26	27	28	27	28	30	31	29	30	31	[redacted]	31	31	[redacted]	[redacted]	26	30	[redacted]
	direct+indirect	24	25	25	26	25	25	26	27	25	26	27	30	26	28	29	32	24	27	32
	min	24	24	24	26	25	25	26	27	25	26	27	30	26	28	29	32	24		
	Ave	27	27	29	30	30	30	32	[redacted]	32	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]		32	
	max	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			[redacted]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	25	25	27	28	28	29	31	32	32	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	25	32	[redacted]
	cool.plant only	26	26	27	29	29	29	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	26	[redacted]	[redacted]
4 vol/h	ind.+Cool. plant	24	24	24	26	25	25	27	28	26	27	29	31	28	29	31	[redacted]	24	28	[redacted]
	cool.plant only	24	25	25	26	26	26	28	29	27	27	30	32	29	30	[redacted]	[redacted]	24	28	[redacted]
6 vol/h	ind.+Cool. plant	24	24	24	25	24	25	25	26	25	26	27	29	26	27	29	31	24	26	31
	cool.plant only	24	24	25	25	25	25	26	27	26	26	28	30	27	28	30	32	24	27	32
8 vol/h	ind.+Cool. plant	24	24	24	25	24	25	25	25	25	25	26	28	25	26	27	29	24	25	29
	cool.plant only	24	24	24	25	25	25	25	26	25	26	27	29	26	27	28	30	24	26	30
	min	24	24	24	25	24	25	25	25	25	25	26	28	25	26	27	29	24		
	Ave	24	25	25	26	26	26	27	28	27	28	30	32	29	30	32	[redacted]		28	
	max	26	26	27	29	29	29	32	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			[redacted]

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	15	15	16	16	16	16	17	17	18	17	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	15	17	[redacted]
	cool.plant only	20	20	22	22	23	23	26	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	20	[redacted]	[redacted]
4 vol/h	ind.+Cool. plant	20	24	25	29	29	29	30	31	30	30	32	33	31	31	34	[redacted]	20	29	[redacted]
	cool.plant only	35	38	39	40	40	40	44	47	42	42	47	52	47	47	[redacted]	[redacted]	35	44	[redacted]
6 vol/h	ind.+Cool. plant	19	24	24	38	35	40	43	43	42	43	44	46	44	44	47	48	19	39	48
	cool.plant only	40	45	45	57	58	58	60	62	59	59	64	70	63	63	70	77	40	59	77
8 vol/h	ind.+Cool. plant	18	23	25	38	34	40	43	56	41	53	54	58	57	57	58	61	18	45	61
	cool.plant only	44	50	50	66	64	70	72	78	72	77	80	85	80	80	86	94	44	72	94
	min	15	15	16	16	16	16	17	17	18	17	18	19	19	19	20	21	15		
	Ave	26	30	31	38	38	40	42	45	42	44	46	49	46	46	50	[redacted]		41	
	max	44	50	50	66	64	70	72	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]			[redacted]

Nice (Dept : 06)

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																			
	direct	31	31															31		
	indirect	32	32															32		
	direct+indirect	30	30	31	32													30		
4 vol/h	none	31	31	32														31		
	direct	29	29	31	32	31	32											29		
	indirect	29	29	30	31	32	32											29		
	direct+indirect	27	27	28	29	30	30	32		32								27		
6 vol/h	none	30	31	32		32	32											30		
	direct	28	28	30	30	30	30	32		32	32							28	32	
	indirect	28	28	29	30	30	30	32		32								28		
	direct+indirect	26	26	27	28	28	28	30	31	30	30	32		32	32			26	30	
8 vol/h	none	30	30	32		32	32											30		
	direct	27	28	29	30	29	30	31		31	31	32		32				27	31	
	indirect	27	28	28	29	29	29	31	32	31	31			32				27	31	
	direct+indirect	25	26	26	27	27	27	28	30	28	29	30	32	30	31	32		25	29	
	min	25	26	26	27	27	27	28	30	28	29	30	32	30	31	32		25		
	Ave	29	29	30	31	31	32													
	max																			

Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	25	25	27	28	28	29	31	32	32								25	32	
	cool.plant only	25	26	27	28	29	29	32		32								25		
4 vol/h	ind.+Cool. plant	24	24	25	26	25	25	27	28	26	27	30	31	28	29	31		24	28	
	cool.plant only	24	25	25	26	26	26	27	29	27	27	30	32	29	30	32		24	28	
6 vol/h	ind.+Cool. plant	24	24	24	25	24	25	25	26	25	26	28	29	26	27	29	31	24	26	31
	cool.plant only	24	24	25	25	25	25	25	27	26	26	29	30	27	27	30	32	24	27	32
8 vol/h	ind.+Cool. plant	24	24	24	25	24	25	25	25	25	25	27	28	25	26	28	29	24	26	29
	cool.plant only	24	24	25	25	24	25	25	25	25	26	27	28	26	26	29	30	24	26	30
	min	24	24	24	25	24	25	25	25	25	25	27	28	25	26	28	29	24		
	Ave	24	25	25	26	26	26	27	28	27	28	30	31	29	30	32			28	
	max	25	26	27	28	29	29	32		32										

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	14	14	15	15	15	15	16	16	17								14	17	
	cool.plant only	19	19	21	22	23	23	23		23								19		
4 vol/h	ind.+Cool. plant	20	23	26	27	27	27	29	29	28	28	30	31	30	30	32		20	28	
	cool.plant only	30	35	36	37	37	37	41	44	39	41	46	46	46	46	46		30	41	
6 vol/h	ind.+Cool. plant	21	25	27	35	34	39	40	41	40	41	42	44	42	42	44	46	21	38	46
	cool.plant only	34	39	42	53	52	53	55	57	55	55	65	66	58	62	69	69	34	55	69
8 vol/h	ind.+Cool. plant	22	26	28	36	35	40	41	53	42	51	53	56	53	54	56	58	22	44	58
	cool.plant only	37	42	45	56	56	61	63	72	66	71	77	83	73	74	87	91	37	66	91
	min	14	14	15	15	15	15	16	16	17	17	18	18	18	18	19	21	14		
	Ave	25	28	30	35	35	37	39	42	39	41	44	46	43	44	47			39	
	max	37	42	45	56	56	61	63		66										

3.2 Results for a reference year

Reference year : Trappes

Heating needs (kWh/m2)

Air flow	Evap.system																	min	Ave	max
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	34	35	34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]
	direct	34	35	34	35	12	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]
	indirect	34	35	34	35	12	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	[illegible]
	direct+indirect	34	35	34	35	12	12	16	[illegible]	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	19	[illegible]
4 vol/h	none	40	40	41	41	14	15	[illegible]	[illegible]	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]
	direct	40	40	41	41	14	14	20	20	23	24	26	[illegible]	7	8	[illegible]	[illegible]	7	23	[illegible]
	indirect	40	40	41	41	14	14	20	20	23	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	23	[illegible]
	direct+indirect	40	40	41	41	14	14	20	20	23	24	26	26	7	8	14	[illegible]	7	23	[illegible]
6 vol/h	none	40	41	41	41	14	15	[illegible]	[illegible]	23	24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	24	[illegible]
	direct	40	40	41	41	14	14	20	21	23	24	27	27	7	8	14	[illegible]	7	23	[illegible]
	indirect	40	40	41	41	14	14	20	21	23	24	26	[illegible]	7	8	[illegible]	[illegible]	7	23	[illegible]
	direct+indirect	40	40	41	41	14	14	20	21	23	24	26	27	7	8	14	14	7	23	41
8 vol/h	none	40	41	41	41	14	15	21	[illegible]	23	24	[illegible]	[illegible]	8	9	[illegible]	[illegible]	8	24	[illegible]
	direct	40	40	41	41	14	15	21	21	23	24	27	27	7	8	14	14	7	24	41
	indirect	40	40	41	41	14	14	21	21	23	24	27	27	7	8	14	[illegible]	7	23	[illegible]
	direct+indirect	40	40	41	41	14	14	21	21	23	24	27	27	7	8	14	14	7	23	41
	min	**34**	**35**	**34**	**35**	**12**	**12**	**16**	**16**	**20**	**20**	**22**	**22**	**6**	**6**	**11**	**10**	**6**		
	Ave	**39**	**39**	**39**	**40**	**13**	**14**	**19**	**20**	**23**	**23**	**25**	[illegible]	**7**	**7**	[illegible]	[illegible]		**22**	
	max	**40**	**41**	**41**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	34	35	34	35	12	12	16	17	20	20	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	19	[illegible]
	cool.plant only	34	34	34	34	11	11	16	16	19	20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	19	[illegible]
4 vol/h	ind.+Cool. plant	40	40	41	41	14	14	20	20	23	24	26	26	7	8	14	[illegible]	7	23	[illegible]
	cool.plant only	39	39	41	41	13	13	20	20	23	23	26	26	7	7	13	[illegible]	7	23	[illegible]
6 vol/h	ind.+Cool. plant	40	40	41	41	14	14	20	21	23	24	26	27	7	8	14	14	7	23	41
	cool.plant only	39	39	41	41	13	13	20	21	23	23	26	26	7	7	14	13	7	23	41
8 vol/h	ind.+Cool. plant	40	40	41	41	14	14	21	21	23	24	27	27	7	8	14	14	7	23	41
	cool.plant only	39	39	41	41	13	13	20	21	23	23	26	26	7	7	14	14	7	23	41
	min	**34**	**34**	**34**	**34**	**11**	**11**	**16**	**16**	**19**	**20**	**21**	**22**	**5**	**6**	**10**	**10**	**5**		
	Ave	**38**	**38**	**39**	**40**	**13**	**13**	**19**	**20**	**22**	**23**	**25**	**25**	**7**	**7**	**13**	[illegible]		**22**	
	max	**40**	**40**	**41**	**41**	**14**	**14**	**21**	**21**	**23**	**24**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Cooling needs (kWh/m2)

Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	2	2	4	4	8	8	12	11	16	15	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	12	[illegible]
	cool.plant only	6	5	9	8	14	13	15	15	20	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	16	[illegible]
4 vol/h	ind.+Cool. plant	1	1	3	4	5	5	12	12	11	10	20	18	20	19	28	[illegible]	1	12	[illegible]
	cool.plant only	6	6	10	9	16	15	20	19	26	24	29	27	35	33	35	[illegible]	6	21	[illegible]
6 vol/h	ind.+Cool. plant	1	1	3	3	4	4	10	11	8	7	18	17	16	15	28	26	1	11	28
	cool.plant only	7	6	10	10	16	16	21	20	27	25	33	31	38	36	42	40	6	24	42
8 vol/h	ind.+Cool. plant	1	1	3	3	3	3	9	10	6	6	16	16	13	13	26	25	1	10	26
	cool.plant only	7	7	10	10	16	16	21	21	27	25	33	33	39	37	45	44	7	25	45
	min	**1**	**1**	**3**	**3**	**3**	**3**	**9**	**10**	**6**	**6**	**16**	**16**	**13**	**13**	**22**	**20**	**1**		
	Ave	**4**	**4**	**7**	**7**	**10**	**10**	**15**	**15**	**18**	**16**	**23**	**22**	**26**	**24**	**31**	[illegible]		**16**	
	max	**7**	**7**	**10**	**10**	**16**	**16**	**21**	**21**	**27**	**25**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Reference year : Trappes

fan electrical energy (kWh/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	Without cooling plant																min	Ave	max
2 vol/h	none	13	13	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12	[illegible]	[illegible]
	direct	11	11	11	10	15	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]
	indirect	12	12	12	11	17	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
	direct+indirect	11	11	11	11	16	15	15	[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	16	[illegible]
4 vol/h	none	19	19	19	17	24	24	[illegible]	[illegible]	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17	[illegible]	[illegible]
	direct	13	13	13	13	17	17	19	19	24	23	24	[illegible]	30	29	[illegible]	[illegible]	13	21	[illegible]
	indirect	16	15	16	16	21	21	22	21	28	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	24	[illegible]
	direct+indirect	14	14	15	14	19	19	20	19	25	24	25	23	31	30	30	[illegible]	14	22	[illegible]
6 vol/h	none	23	22	23	21	30	29	[illegible]	[illegible]	36	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	32	[illegible]
	direct	15	15	15	15	20	20	23	22	28	27	28	27	35	34	37	[illegible]	15	25	[illegible]
	indirect	19	19	20	19	26	25	28	26	34	33	34	[illegible]	41	40	[illegible]	[illegible]	19	30	[illegible]
	direct+indirect	17	16	18	17	23	23	25	24	30	29	31	29	38	37	38	36	16	27	38
8 vol/h	none	26	26	28	24	34	34	36	[illegible]	42	41	[illegible]	[illegible]	51	49	[illegible]	[illegible]	24	38	[illegible]
	direct	18	18	18	18	24	24	26	26	33	32	33	32	41	40	43	41	18	29	43
	indirect	23	23	24	23	31	31	33	32	40	39	40	38	49	48	49	[illegible]	23	36	[illegible]
	direct+indirect	20	20	21	21	28	27	30	29	36	35	37	34	45	44	45	43	20	32	45
	min	11	11	11	10	15	15	15	15	18	18	18	17	22	22	21	20	10		
	Ave	17	17	17	16	23	22	24	23	29	28	29	[illegible]	35	34	[illegible]	[illegible]		26	
	max	26	26	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	12	12	11	11	16	16	15	15	18	18	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	16	[illegible]
	cool.plant only	7	7	8	8	11	11	12	12	15	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	13	[illegible]
4 vol/h	ind.+Cool. plant	15	15	15	14	19	19	20	19	26	25	24	23	31	30	30	[illegible]	14	22	[illegible]
	cool.plant only	9	9	10	10	12	11	15	14	17	17	18	18	22	21	24	[illegible]	9	16	[illegible]
6 vol/h	ind.+Cool. plant	18	18	18	17	24	23	24	23	31	31	30	28	38	37	37	35	17	27	38
	cool.plant only	11	11	12	12	14	14	18	17	20	20	22	21	26	25	29	28	11	19	29
8 vol/h	ind.+Cool. plant	22	22	21	21	28	28	29	28	37	36	35	34	45	44	44	42	21	32	45
	cool.plant only	13	13	14	14	18	18	21	21	25	24	26	25	31	30	34	33	13	23	34
	min	7	7	8	8	11	11	12	12	15	15	14	14	19	19	18	18	7		
	Ave	13	13	14	13	18	18	19	19	24	23	23	22	29	29	30	[illegible]		21	
	max	22	22	21	21	28	28	29	28	37	36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

water needs (l/m2)

Air flow	Evap.system	Without cooling plant																min	Ave	max
2 vol/h	none	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
	direct	9	8	11	9	14	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	[illegible]	[illegible]
	indirect	5	5	7	5	6	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]
	direct+indirect	9	8	11	10	14	14	16	[illegible]	17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8	15	[illegible]
4 vol/h	none	0	0	0	0	0	0	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
	direct	11	11	15	13	19	19	21	19	27	25	28	[illegible]	31	30	[illegible]	[illegible]	11	22	[illegible]
	indirect	8	7	12	10	13	12	14	12	16	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	12	[illegible]
	direct+indirect	11	11	16	14	20	18	24	22	29	27	31	29	33	32	33	[illegible]	11	24	[illegible]
6 vol/h	none	0	0	0	0	0	0	[illegible]	[illegible]	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]
	direct	13	13	18	16	22	21	26	24	33	30	37	33	40	38	41	[illegible]	13	28	[illegible]
	indirect	10	9	16	13	16	14	21	18	23	19	24	[illegible]	25	23	[illegible]	[illegible]	9	18	[illegible]
	direct+indirect	13	12	19	17	22	21	29	26	35	32	41	38	43	40	45	43	12	30	45
8 vol/h	none	0	0	0	0	0	0	0	[illegible]	0	0	[illegible]	[illegible]	0	0	[illegible]	[illegible]	0	0	[illegible]
	direct	15	14	20	18	25	24	30	27	37	34	44	38	47	43	50	45	14	32	50
	indirect	11	10	19	16	18	17	27	23	28	24	34	28	33	29	31	[illegible]	10	23	[illegible]
	direct+indirect	14	14	22	20	25	23	33	30	39	36	48	44	49	45	54	51	14	34	54
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Ave	8	8	12	10	13	13	16	15	19	17	21	[illegible]	22	21	[illegible]	[illegible]		16	
	max	15	14	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	5	5	7	6	8	7	8	7	8	8	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	7	[illegible]
	cool.plant only	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	[illegible]
4 vol/h	ind.+Cool. plant	8	7	11	9	12	11	16	13	16	15	18	16	18	17	16	[illegible]	7	14	[illegible]
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0	[illegible]
6 vol/h	ind.+Cool. plant	9	8	14	11	15	13	20	17	21	19	26	22	26	23	28	25	8	19	28
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 vol/h	ind.+Cool. plant	11	10	17	14	17	15	23	19	26	22	31	28	31	28	36	31	10	22	36
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Ave	4	4	6	5	6	6	8	7	9	8	10	9	10	9	11	[illegible]		8	
	max	11	10	17	14	17	15	23	19	26	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Reference year : Carpentras

Heating needs (kWh/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	Without cooling plant																min	Ave	max
2 vol/h	none	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	direct	19	20	20	20	5	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	indirect	19	20	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	direct+indirect	19	20	19	20	5	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
4 vol/h	none	22	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]
	direct	22	22	23	24	6	6	11	11	8	9	11	[illegible]	1	[illegible]	[illegible]	[illegible]	1	11	[illegible]
	indirect	22	22	23	24	6	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	direct+indirect	22	22	23	24	6	6	11	11	8	8	11	[illegible]	1	1	[illegible]	[illegible]	1	11	[illegible]
6 vol/h	none	22	23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]
	direct	22	22	23	24	6	6	11	11	8	9	11	11	1	1	6	[illegible]	1	11	[illegible]
	indirect	22	22	23	24	6	6	11	12	8	9	11	[illegible]	1	[illegible]	[illegible]	[illegible]	1	11	[illegible]
	direct+indirect	22	22	23	24	6	6	11	11	8	9	11	11	1	1	6	[illegible]	1	11	[illegible]
8 vol/h	none	22	23	[illegible]	[illegible]	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	[illegible]	[illegible]
	direct	22	22	23	24	6	6	12	12	8	8	11	11	1	2	6	[illegible]	1	11	[illegible]
	indirect	22	22	23	24	6	6	12	12	8	8	11	[illegible]	1	1	[illegible]	[illegible]	1	11	[illegible]
	direct+indirect	22	22	23	24	6	6	12	12	8	8	11	11	1	1	6	6	1	11	24
	min	19	20	19	20	5	4	9	9	7	7	9	9	1	1	4	4	1		
	Ave	21	22	22	23	6	6	11	[illegible]	8	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		11	
	max	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	19	20	19	20	5	4	9	9	7	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	9	[illegible]
	cool.plant only	19	19	19	20	4	4	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
4 vol/h	ind.+Cool. plant	22	22	23	24	6	6	11	11	8	8	11	11	1	1	6	[illegible]	1	11	[illegible]
	cool.plant only	22	22	23	23	4	4	11	11	8	8	10	11	1	0	[illegible]	[illegible]	0	11	[illegible]
6 vol/h	ind.+Cool. plant	22	22	23	24	6	6	11	11	8	9	11	11	1	1	6	6	1	11	24
	cool.plant only	22	22	23	23	4	4	11	11	8	8	11	11	1	0	6	6	0	11	23
8 vol/h	ind.+Cool. plant	22	22	23	24	6	6	12	12	8	8	11	11	1	1	6	6	1	11	24
	cool.plant only	22	22	23	23	4	4	11	11	8	8	11	11	1	0	6	6	0	11	23
	min	19	19	19	20	4	4	9	9	7	7	9	9	0	0	4	4	0		
	Ave	21	21	22	23	5	5	11	11	8	8	10	10	1	1	6	[illegible]		10	
	max	22	22	23	24	6	6	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Cooling needs (kWh/m2)

Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	7	8	10	11	18	18	20	20	27	27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	22	[illegible]
	cool.plant only	19	19	23	21	31	30	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19	[illegible]	[illegible]
4 vol/h	ind.+Cool. plant	4	4	8	10	12	12	20	21	24	24	32	30	36	36	42	[illegible]	4	22	[illegible]
	cool.plant only	22	21	28	26	39	38	44	41	57	53	60	54	69	66	[illegible]	[illegible]	21	47	[illegible]
6 vol/h	ind.+Cool. plant	2	2	7	8	8	9	18	20	18	18	30	30	29	29	43	41	2	20	43
	cool.plant only	24	23	29	28	42	40	49	46	63	59	71	65	80	75	84	78	23	54	84
8 vol/h	ind.+Cool. plant	1	2	6	8	7	7	16	18	14	14	28	28	25	24	42	40	1	17	42
	cool.plant only	26	24	31	30	44	42	52	49	66	62	76	71	85	80	94	88	24	58	94
	min	1	2	6	8	7	7	16	18	14	14	28	27	25	24	36	33	1		
	Ave	13	13	18	18	25	24	31	31	38	37	45	43	50	48	56	[illegible]		34	
	max	26	24	31	30	44	42	52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Reference year : Carpentras

fan electrical energy (kWh/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	Without cooling plant																min	Ave	max
2 vol/h	none	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	direct	13	13	13	13	18	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13	[illegible]	[illegible]
	indirect	16	16	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15	[illegible]	[illegible]
	direct+indirect	14	14	14	14	19	19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14	[illegible]	[illegible]
4 vol/h	none	28	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	[illegible]	[illegible]
	direct	15	16	16	16	21	21	24	23	29	28	29	[illegible]	35	[illegible]	[illegible]	[illegible]	15	25	[illegible]
	indirect	23	22	23	22	29	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22	[illegible]	[illegible]
	direct+indirect	18	18	19	18	24	24	25	24	31	30	30	[illegible]	37	37	[illegible]	[illegible]	18	27	[illegible]
6 vol/h	none	37	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	[illegible]
	direct	18	18	18	20	25	25	28	28	34	34	35	33	43	42	44	[illegible]	18	30	[illegible]
	indirect	28	28	29	28	37	37	38	37	46	45	45	[illegible]	54	[illegible]	[illegible]	[illegible]	28	41	[illegible]
	direct+indirect	21	21	23	23	30	30	32	31	39	38	38	36	47	46	46	[illegible]	21	34	[illegible]
8 vol/h	none	46	45	[illegible]	[illegible]	57	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	[illegible]	[illegible]
	direct	21	22	21	23	28	29	33	34	40	39	40	39	50	49	51	[illegible]	21	36	[illegible]
	indirect	34	34	35	33	45	44	46	44	56	54	54	[illegible]	66	64	[illegible]	[illegible]	33	49	[illegible]
	direct+indirect	26	26	29	28	37	36	39	38	47	45	46	43	57	55	55	53	26	41	57
	min	13	13	13	13	18	18	18	18	21	21	21	20	26	25	25	24	13		
	Ave	24	23	24	23	31	30	32	[illegible]	38	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		34	
	max	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	15	15	15	14	20	19	20	19	22	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14	20	[illegible]
	cool.plant only	11	11	11	11	15	15	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11	[illegible]	[illegible]
4 vol/h	ind.+Cool. plant	20	21	19	19	26	26	27	26	33	32	32	30	39	38	39	[illegible]	19	29	[illegible]
	cool.plant only	13	13	14	14	17	17	20	20	25	24	24	24	31	31	[illegible]	[illegible]	13	22	[illegible]
6 vol/h	ind.+Cool. plant	26	26	24	24	33	33	32	32	42	41	39	37	50	49	48	46	24	36	50
	cool.plant only	16	16	17	17	22	22	25	25	30	30	30	30	37	37	38	38	16	27	38
8 vol/h	ind.+Cool. plant	31	31	28	29	39	39	38	39	50	49	46	45	59	58	57	55	28	43	59
	cool.plant only	21	21	22	22	27	27	31	31	36	36	36	36	44	44	46	45	21	33	46
	min	11	11	11	11	15	15	16	16	19	19	19	19	23	23	23	23	11		
	Ave	19	19	19	19	25	25	26	26	32	32	31	30	38	38	38	[illegible]		28	
	max	31	31	28	29	39	39	38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

water needs (l/m2)

Air flow	Evap.system	Without cooling plant																min	Ave	max
2 vol/h	none	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	direct	28	27	31	27	40	39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27	[illegible]	[illegible]
	indirect	23	22	29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	[illegible]	[illegible]
	direct+indirect	32	31	39	33	48	46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]
4 vol/h	none	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
	direct	35	34	42	36	55	53	59	52	74	68	77	[illegible]	86	[illegible]	[illegible]	[illegible]	34	61	[illegible]
	indirect	36	34	47	39	52	49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34	[illegible]	[illegible]
	direct+indirect	40	39	52	45	64	61	76	66	91	82	103	[illegible]	107	99	[illegible]	[illegible]	39	76	[illegible]
6 vol/h	none	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
	direct	39	38	46	42	62	60	69	60	88	81	97	83	106	99	109	[illegible]	38	74	[illegible]
	indirect	45	43	59	50	65	62	81	71	87	77	108	[illegible]	102	[illegible]	[illegible]	[illegible]	43	76	[illegible]
	direct+indirect	46	45	60	53	73	70	89	79	106	97	126	108	130	120	145	[illegible]	45	92	[illegible]
8 vol/h	none	0	0	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
	direct	42	42	49	45	66	64	75	66	97	90	109	95	120	112	127	[illegible]	42	82	[illegible]
	indirect	53	51	68	59	76	73	95	82	104	92	131	[illegible]	123	110	[illegible]	[illegible]	51	93	[illegible]
	direct+indirect	51	50	66	59	80	77	97	86	117	108	140	125	144	134	165	147	50	103	165
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Ave	29	29	37	32	44	43	52	[illegible]	60	55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		52	
	max	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	23	22	28	21	31	29	33	26	33	31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	29	[illegible]
	cool.plant only	0	0	0	0	0	0	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]
4 vol/h	ind.+Cool. plant	34	32	41	33	49	46	57	44	61	54	72	56	69	63	75	[illegible]	32	53	[illegible]
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]	[illegible]	0	0	[illegible]
6 vol/h	ind.+Cool. plant	42	40	51	42	60	57	69	55	80	70	94	77	93	83	106	87	40	69	106
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 vol/h	ind.+Cool. plant	49	48	58	49	70	67	79	63	95	84	110	92	111	100	126	107	48	82	126
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Ave	19	18	22	18	26	25	30	24	34	30	39	32	38	34	42	[illegible]		29	
	max	49	48	58	49	70	67	79	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]

Reference year : Nice

Heating needs (kWh/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	Without cooling plant																min	Ave	max
2 vol/h	none	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	direct	10	9	■	■	■	■	■	■	■	■	■	■	■	■	■	■	1	■	■
	indirect	10	9	■	■	■	■	■	■	■	■	■	■	■	■	■	■	1	■	■
	direct+indirect	10	9	10	10	■	■	■	■	■	■	■	■	■	■	■	■	1	■	■
4 vol/h	none	11	11	12	■	■	■	■	■	■	■	■	■	■	■	■	■	1	■	■
	direct	11	11	12	12	2	2	■	■	■	■	■	■	■	■	■	■	1	■	■
	indirect	11	11	12	12	2	1	■	■	■	■	■	■	■	■	■	■	1	■	■
	direct+indirect	11	11	12	12	2	1	5	■	3	■	■	■	■	■	■	■	1	■	■
6 vol/h	none	11	11	12	■	2	3	■	■	■	■	■	■	■	■	■	■	1	■	■
	direct	11	11	12	12	2	2	5	■	3	3	■	■	■	■	■	■	1	5	■
	indirect	11	11	12	12	2	1	5	■	3	■	■	■	■	■	■	■	1	■	■
	direct+indirect	11	11	12	12	2	1	5	5	3	3	5	■	1	1	■	■	1	5	■
8 vol/h	none	11	11	12	■	3	3	■	■	■	■	■	■	■	■	■	■	2	■	■
	direct	11	11	12	12	2	2	5	■	3	3	5	■	1	■	■	■	1	5	■
	indirect	11	11	12	12	2	1	5	5	3	3	■	■	1	■	■	■	1	5	■
	direct+indirect	11	11	12	12	2	1	5	5	3	3	5	5	1	1	3	■	1	5	■
	min	9	9	10	10	2	1	4	4	3	2	4	4	1	1	2	■	1		
	Ave	10	10	11	12	2	2	■	■	■	■	■	■	■	■	■	■		■	
	max	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			■
Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	10	9	10	10	2	1	4	4	3	■	■	■	■	■	■	■	1	4	■
	cool.plant only	9	9	10	10	1	1	4	■	2	■	■	■	■	■	■	■	0	■	■
4 vol/h	ind.+Cool. plant	11	11	12	12	2	1	5	5	3	3	5	5	1	1	3	■	1	5	■
	cool.plant only	11	10	12	12	1	1	5	5	2	2	5	5	0	0	2	■	0	5	■
6 vol/h	ind.+Cool. plant	11	11	12	12	2	1	5	5	3	3	5	5	1	1	3	2	1	5	12
	cool.plant only	11	10	12	12	1	1	5	5	2	2	5	5	0	0	2	2	0	5	12
8 vol/h	ind.+Cool. plant	11	11	12	12	2	1	5	5	3	3	5	5	1	1	3	2	1	5	12
	cool.plant only	10	10	12	12	1	1	5	5	3	2	5	5	0	0	2	2	0	5	12
	min	9	9	10	10	1	1	4	4	2	2	4	4	0	0	1	1	0		
	Ave	10	10	11	12	1	1	5	5	3	2	5	5	0	1	2	■		5	
	max	11	11	12	12	2	1	5	■	3	■	■	■	■	■	■	■			■

Cooling needs (kWh/m2)

Air flow	Evap.system	With cooling plant																min	Ave	max
2 vol/h	ind.+Cool. plant	13	13	15	15	25	25	27	26	36	■	■	■	■	■	■	■	13	29	■
	cool.plant only	22	22	24	23	36	35	34	■	43	■	■	■	■	■	■	■	22	■	■
4 vol/h	ind.+Cool. plant	10	10	14	14	22	22	27	26	36	36	42	39	51	50	54	■	10	32	■
	cool.plant only	24	23	27	26	42	41	44	41	61	58	60	57	75	73	71	■	23	49	■
6 vol/h	ind.+Cool. plant	9	9	13	13	19	19	26	26	32	32	42	40	46	46	56	53	9	30	56
	cool.plant only	25	24	29	28	43	42	49	45	64	61	70	64	84	80	84	80	24	55	84
8 vol/h	ind.+Cool. plant	8	9	13	13	18	18	26	25	29	29	40	39	43	42	57	53	8	29	57
	cool.plant only	27	26	30	29	45	44	50	48	65	62	74	69	87	83	93	87	26	57	93
	min	8	9	13	13	18	18	26	25	29	29	37	35	42	41	43	41	8		
	Ave	17	17	20	20	31	31	36	34	46	44	51	48	59	58	63	■		40	
	max	27	26	30	29	45	44	50	■	65	■	■	■	■	■	■	■			■

Reference year : Nice

fan electrical energy (kWh/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**	**Without cooling plant**																**min**	**Ave**	**max**
2 vol/h	none																			
	direct	17	16															16		
	indirect	18	17															17		
	direct+indirect	17	17	17	16													16		
4 vol/h	none	30	30	31														29		
	direct	24	24	24	24	31	31											24		
	indirect	28	28	28	27	35	35											27		
	direct+indirect	25	25	26	25	33	32	34		38								25		
6 vol/h	none	42	42	43		51	51											41		
	direct	32	32	32	31	41	41	42		48	47							31	44	
	indirect	39	38	39	37	48	47	49		55								37		
	direct+indirect	34	33	35	33	44	43	45	43	51	49	50		60	58			33	46	
8 vol/h	none	53	54	54		63	63											52		
	direct	40	40	40	39	50	50	52		59	58	59		70				39	54	
	indirect	49	48	49	47	61	60	61	59	69	67			79				47	63	
	direct+indirect	43	42	44	42	55	54	56	54	64	61	62	59	74	72	72		42	58	
	min	17	16	16	16	22	21	22	21	24	23	24	23	29	29	28		16		
	Ave	32	31	32	31	40	40													
	max																			
Air flow	**Evap.system**	**With cooling plant**																**min**	**Ave**	**max**
2 vol/h	ind.+Cool. plant	17	16	17	16	22	22	22	21	25								16	23	
	cool.plant only	12	12	12	12	17	17	17		21								12		
4 vol/h	ind.+Cool. plant	25	25	25	24	33	32	34	32	38	36	38	35	45	44	45		24	35	
	cool.plant only	13	13	14	14	19	19	22	22	27	26	27	26	34	34	34		13	23	
6 vol/h	ind.+Cool. plant	34	34	33	32	43	43	43	42	50	48	50	46	59	58	58	55	32	46	59
	cool.plant only	17	17	18	18	24	24	27	28	32	32	33	32	41	41	42	41	17	29	42
8 vol/h	ind.+Cool. plant	44	43	42	41	54	53	53	52	62	60	61	57	73	71	71	67	41	57	73
	cool.plant only	23	22	23	23	30	30	33	34	40	39	40	39	49	49	50	49	22	36	50
	min	12	12	12	12	17	17	17	17	21	20	21	20	26	25	25	25	12		
	Ave	23	23	23	22	30	30	31	31	37	36	36	35	45	44	44			33	
	max	44	43	42	41	54	53	53		62										

water needs (l/m2)

Air flow	Evap.system	Without cooling plant																min	Ave	max
2 vol/h	none																			
	direct	18	17															16		
	indirect	9	9															2		
	direct+indirect	20	19	20	18													18		
4 vol/h	none	0	0	0														0		
	direct	27	26	27	24	37	36											24		
	indirect	21	20	22	19	21	21											13		
	direct+indirect	31	29	32	28	41	39	39		48								28		
6 vol/h	none	0	0	0		0	0											0		
	direct	33	32	34	30	46	45	43		56	53							30	47	
	indirect	28	27	31	26	33	32	33		34								26		
	direct+indirect	38	37	40	36	51	49	50	46	64	59	65		71	67			36	54	
8 vol/h	none	0	0	0		0	0											0		
	direct	38	37	40	36	54	52	51		67	62	66		77				36	55	
	indirect	35	33	38	33	43	41	44	38	46	42			47				33	41	
	direct+indirect	44	43	46	42	59	57	59	54	75	70	77	65	85	81	83		42	63	
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0		
	Ave	21	21	22	20	28	27													
	max																			
Air flow	**Evap.system**	**With cooling plant**																**min**	**Ave**	**max**
2 vol/h	ind.+Cool. plant	16	15	17	15	21	20	20	18	20								13	17	
	cool.plant only	0	0	0	0	0	0	0		0								0		
4 vol/h	ind.+Cool. plant	22	21	24	22	31	29	33	30	39	36	42	35	44	42	43		21	33	
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	
6 vol/h	ind.+Cool. plant	27	26	30	27	37	35	40	37	47	43	53	45	55	52	60	51	26	42	60
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8 vol/h	ind.+Cool. plant	33	31	36	32	43	41	47	43	54	49	61	53	63	59	71	61	31	49	71
	cool.plant only	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	min	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
	Ave	12	12	13	12	16	16	17	16	20	18	22	19	22	21	24			18	
	max	33	31	36	32	43	41	47		54										

Chapter C Slab cooling system with water

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1 Introduction

The main purpose of the tool for slab cooling systems with water is to provide the designer with a simple means of evaluating the suitability of the technology in terms of cooling capacity in the early stages of design.

2 Parameters

This tool gives an estimate of the cooling that the system is able to remove from the conditioned space as a function of the known indoor air temperature, the outside wet-bulb and the outdoor dry-bulb air temperatures. It provides the designer with mean expected cooling capacity of the system. (Note that a cooling tower is assumed to provide cooling to the slab.)

The charts in Section 3 give the specific cooling capacity of the system for the usual ranges of the three input values for the model. The lines shown are the best fit correlation and carry an average uncertainty of 7.86%.

The absorbed heat flux by the upper surface the slab and by the cooling system (Figure 1) can be evaluated by the following expression:

$$q_{\text{absorbed heat}} = q_{\text{tdb}} + q_{\text{twb}}$$

where q_{tdb} and q_{twb} are given in Figure 2.

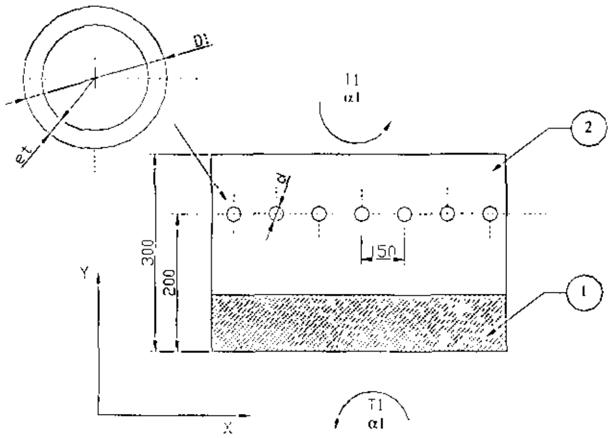
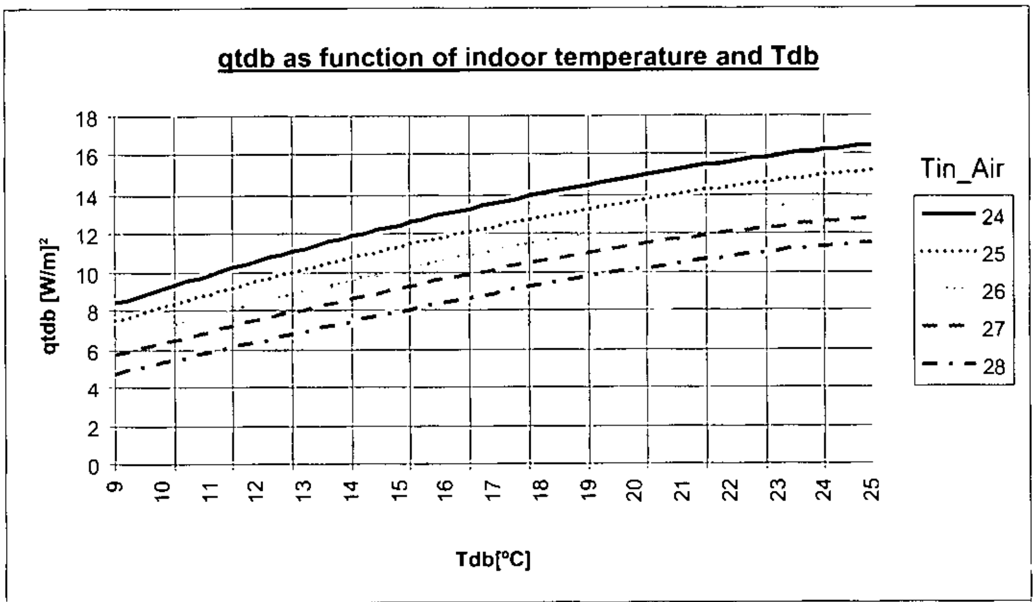


Figure 1 Slab construction

3 Design charts

$q = q_{tdb} + q_{twb}$



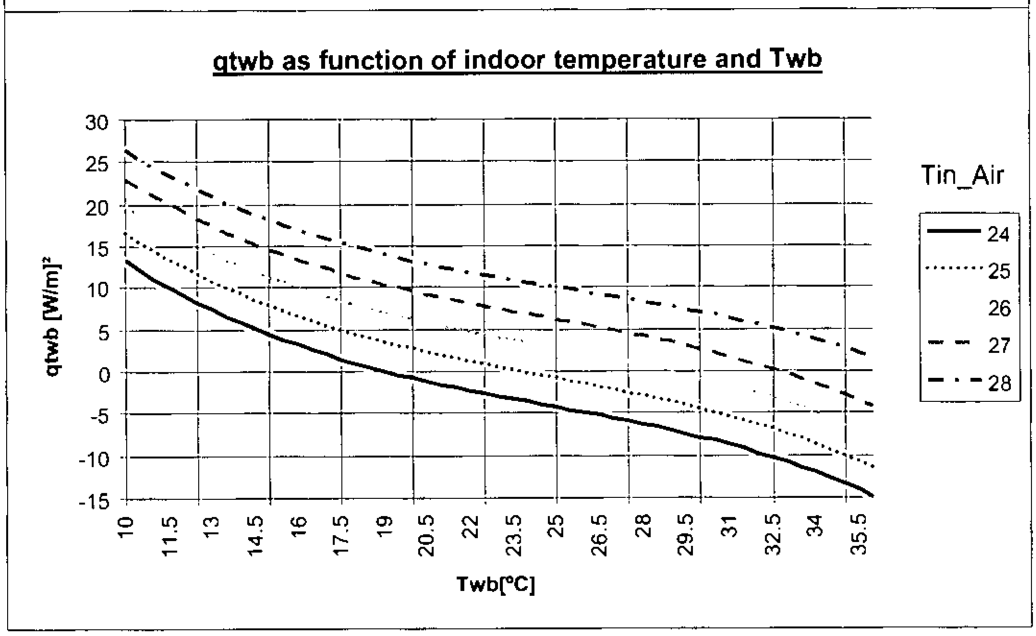


Figure 2 Cooling removed by slab cooling systems with water

4 Accuracy

Figure 3 shows the absorbed heat flux for an indoor temperature of 24 °C obtained by this simplified tool and by the detailed design tool described in IEA Annex 28 Report *Detailed design tools for low energy cooling technologies.* Cooling increases when the ratio Twb/Tdb is lowest, ie when the outdoor air is drier, because a cooling tower is assumed to be the cooling source.

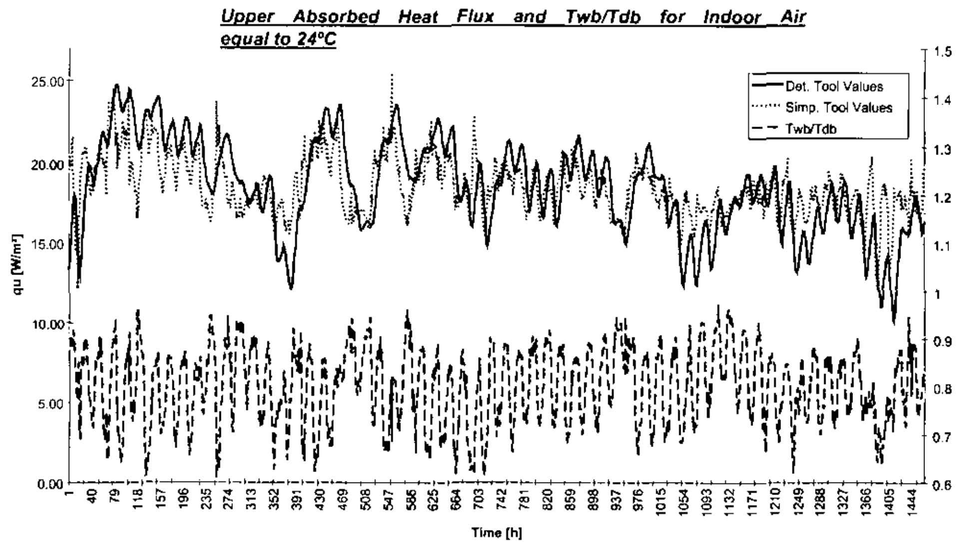


Figure 3 Detailed tool and simplified tool values

Chapter D Night cooling ventilation in UK commercial buildings

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1 Introduction

It has been established over recent years through research work and built examples that night ventilation is an effective low energy cooling technique for appropriately designed modern buildings, especially in climates similar to that of the UK with relatively low peak summer temperatures during the day and medium to large diurnal temperature differences. Such climates permit the thermal mass of the building to use the cool night air to discard the heat absorbed during the day. Therefore cooling using night ventilation is particularly suited to office buildings, which are usually unoccupied during the night so that relatively high air flows can be used to provide maximum cooling effect. Buildings using night ventilation for cooling have been evaluated in the UK and encouraging results are reported[1,2,3].

In order to belp designers to explore the application of night ventilation cooling in the early design stage, pre-design computer tools have been developed[4,5]. These are based on various simplified theoretical and empirical models and typical design days or user defined weather (typically for one week). Such tools provide the opportunity to explore quickly various scenarios in terms of internal heat gaius, ventilation rates, occupancy patterns and external temperatures. They predict peak temperatures or daily temperature profiles and they can give an indication of expected energy benefits by extrapolation of data to the whole cooling period. One such user-friendly tool is Nitecool, which is now available from the BRE website (http://projects.bre.co.uk/refurb/nitecool). This is for use at the early stages of design development when the basic form and organisation of the building is being evolved. User input is limited to a few key variables such as glazing ratio, orientation, internal gains, ventilation rates and thermal mass. This technique allows the designer to explore rapidly the effects of a range of design variables. Nitecool can be used not only to assess the potential for night cooling, but also to consider appropriate ventilation strategies for refurbishment.

The design charts and tables included in this tool have been derived from simulating the performance of a 'typical' office module throughout the summer period using full weather data and a finite difference thermal simulation model. In this way, more detailed analysis is provided but only for the SE England climate considered. In addition, the potential energy savings have been derived by comparing the hourly temperatures achieved in the night-cooled office with an identical office controlled to the same conditions by an active cooling system.

This tool gives the maximum temperature and the fan hours operation for night cooling on the basis of the following parameters:

- Climate
- Building thermal inertia
- Window solar protection

- Internal gains
- Plant

These are defined in Section 2. The results from the simulations are presented in the form of design charts (Section 3). Example calculations are included to illustrate the intended method of use.

Thermal model and weather data

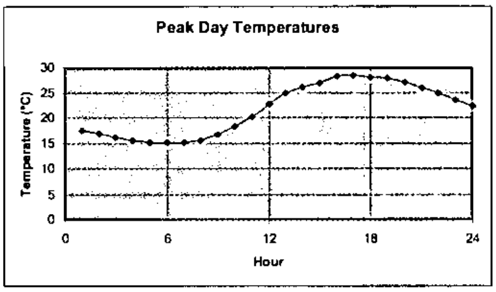
The two constructions and the control strategy were programmed into the thermal model APACHE and simulations performed for the four summer months from June to September. For each simulation temperature, frequency distributions and related energy data have been generated for those months.

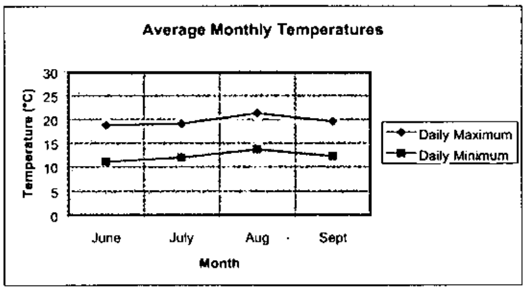
2 Parameters

2.1 Climate

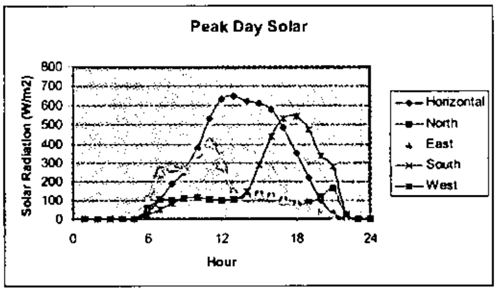
Heathrow weather data were used for the simulations. They are characterised by a peak temperature of 29 °C and solar radiation values typical for SE England.

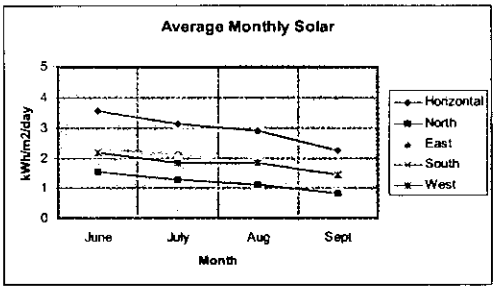
2.1.1 Temperature





2.1.2 Solar





2.2 Building thermal inertia

The building model is based on a typical cellular office with dimensions 10 m width, 6 m depth and 3 m floor-to-ceiling height. It is positioned in the middle of a row of offices on the middle floor of a three-storey office block and has 0.2 m^2 glazing per m^2 of floor area. This module has been derived as a suitable office for night cooling through previous research work[6]. A thermally heavyweight and a thermally lightweight construction are simulated as the two extremes for creating the curves. In both constructions the thermal conductivity of the external wall is kept similar with 100 mm mineral fibre insulation, while the internal partitions, floor and ceilings are assumed to be adjacent to spaces with similar temperatures to the simulated space. For the heavyweight construction the required exposed thermal mass is provided by

75 mm exposed concrete on the ceiling and 100 mm plastered concrete block on the external wall. In contrast, the reference (internally lightweight) module has a false ceiling and 400 mm air gap underneath a 150 mm concrete slab. The external wall is insulated framed construction with lightweight plaster on the internal face. In both cases the floor is carpeted and the internal partitions are lightweight plasterboard.

2.3 Window solar protection

Estimated solar gains need to be added to the internal gains to use the design charts. Values have been generated for two extreme glazing types: low gain (eg reflective double glazing) and high gain (eg single clear glass). These are given in Table 1.

2.4 Internal gains

Occupancy is assumed between 08.00 and 18.00 h during weekdays only.

2.5 Plant

Day ventilation is operated to correspond with occupancy between 08.00 and 18.00 h during weekdays only.

Night ventilation is operated between 24.00 and 07.00 h. The controls are as follows based on work by BSRIA[7] which operate night cooling when all the following conditions are satisfied:

- The time is between midnight and 07.00 h
- Inside air temperature >18 °C
- Outside temperature >12 °C
- Outside air temperature < inside air temperature

3 Design charts and tables

The charts and tables can be used to estimate three parameters in turn: peak temperatures, free cooling provided and fan energy required.

3.1 Peak temperatures

Figure 1 shows the peak day internal dry resultant temperature **exceeded for 30 h** over the 4-month period. The temperatures are shown as a function of the following parameters:

- Combined solar and internal heat gains
- Exposed thermal mass
- Day ventilation rate
- Night ventilation rate

From Figure 1 it can be seen that the lowest temperatures are achieved in the case of high day ventilation rates and exposed thermal mass office. In general, there is a 2 °C temperature difference between the reference and the exposed thermal mass office.

It should be noted that the observed positive aspects of daytime ventilation

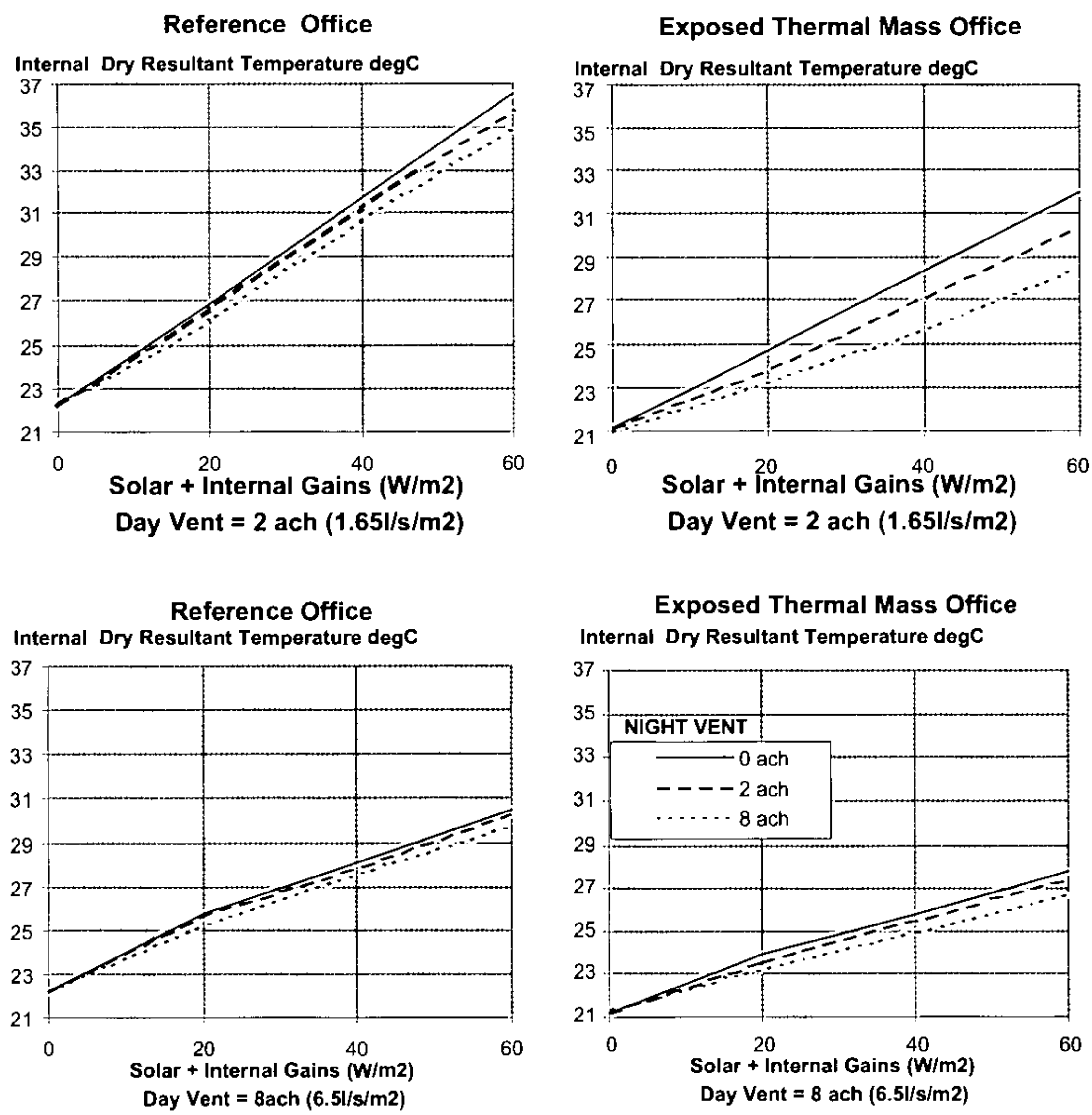


Figure 1 Internal dry resultant temperatures exceeded for 30 h in reference and exposed thermal mass offices, using Heathrow weather data

are related to and are dependent on external temperatures such as those usually found in the UK and other moderate summer climates (ie peak external temperatures up to 29 °C). However, in hot climates and indeed during hot days in the UK, minimum daytime ventilation rates would be more beneficial.

Calculation of solar and internal gains

In order to use the graphs of Figure 1, an estimate of the likely solar and internal gains is required. Internal gains will depend on the design of the office and occupancy patterns. Typical good practice values are 5–25 W/m^2 for occupants, 5–10 W/m^2 for lighting and 10–15 W/m^2 for IT equipment.

Solar gains are more difficult to estimate and will depend on orientation, area and type of glazing, and type and extent of solar shading. However, as a rule of thumb the values in Table 1 are provided for the case with no shading in the UK. It should be noted that solar gains would be different for different latitudes, especially lower ones where south heat gains are usually less than those from east and west. Again, as a rule of thumb, it can be assumed that solar gains are proportional to the glazing area and to the shading coefficient. The values presented in Table 1 have been derived from simulations using the reference office with the same weather and occupancy conditions as those described above.

Table 1 Predicted solar gains using Heathrow weather data

	Orientation			
	North (W/m^2)	East (W/m^2)	South (W/m^2)	West (W/m^2)
Low-gain glazing (eg reflective double glass)	7	12	20	20
High-gain glazing (eg single clear glass)	10	24	35	35

Figure 1 presents the internal dry resultant temperatures that were exceeded for 30 h in a reference office and an exposed thermal mass office using Heathrow weather data. Maximum space temperatures were predicted to be higher by about 1.5 to 2.0 °C for the reference office and 1.0 to 1.5 °C for the exposed thermal mass office. It should be noted that in mechanical systems, and in particular when high ventilation rates are utilised, fan pick-up can increase temperatures by about 0.5 to 1.0 °C.

3.2 Free cooling provided

It should be noted that Figure 1 presents peak temperature reductions only. In many cases, larger reductions are achieved during other times of the occupied period especially during the morning hours, as presented schematically in Figure 2. This effect is taken into account for the calculation of total free cooling provided during occupancy hours as presented in Figure 3.

The free cooling has been quantified in terms of energy saved per unit floor area during the summer months of June to September. It is clear that the free energy provided by night ventilation is a worthwhile strategy in the exposed thermal mass office, providing between 6 and 20 kWh/m^2/annum of free energy. However, there is some benefit in night ventilating a reference-type building as the free energy provided ranges between 2 and 5 kWh/m^2/annum. In the reference building, the benefits might be offset by the energy required to run a fan in mechanical systems, although night ventilation would certainly be a worthwhile strategy if it is provided by natural means.

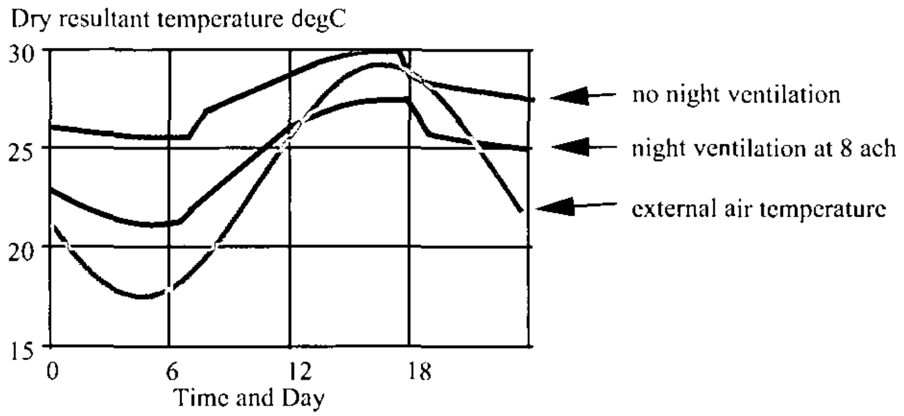


Figure 2 Schematic of hourly temperature in an exposed thermal mass office with and without night ventilation. Internal gains are set to 25 W/m², infiltration to 0.4 air changes per hour (ach) and day ventilation to 2 ach

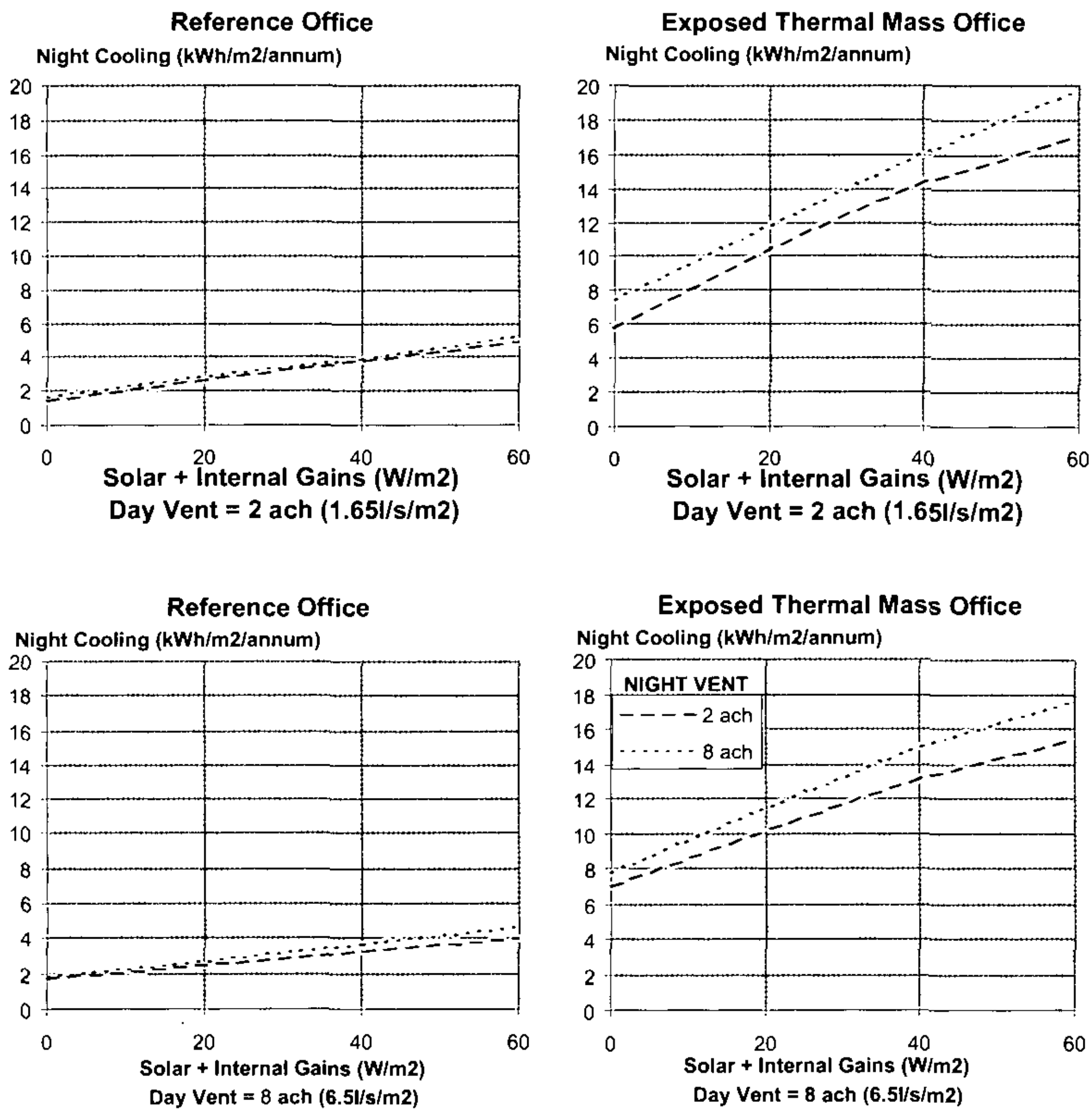


Figure 3 Free cooling provided with night ventilation in reference and exposed thermal mass offices, using Heathrow weather data

3.3 Fan energy required

If the night ventilation is provided through a mechanical system, some energy is required for the fans during the night. An indication of the required energy is presented in Figure 4 in terms of fan hours run. These estimated fan hours can be multiplied by the fan power to obtain fan energy consumption as follows:

$$E_{fan} = SFP \times Q_a \times h$$

where: E_{fan} = fan energy consumption ($Wh/m^2/annum$)
SFP = specific fan power (W/l/s)
Q_a = air flow rate ($l/s/m^2$)
h = fan run hours during summer

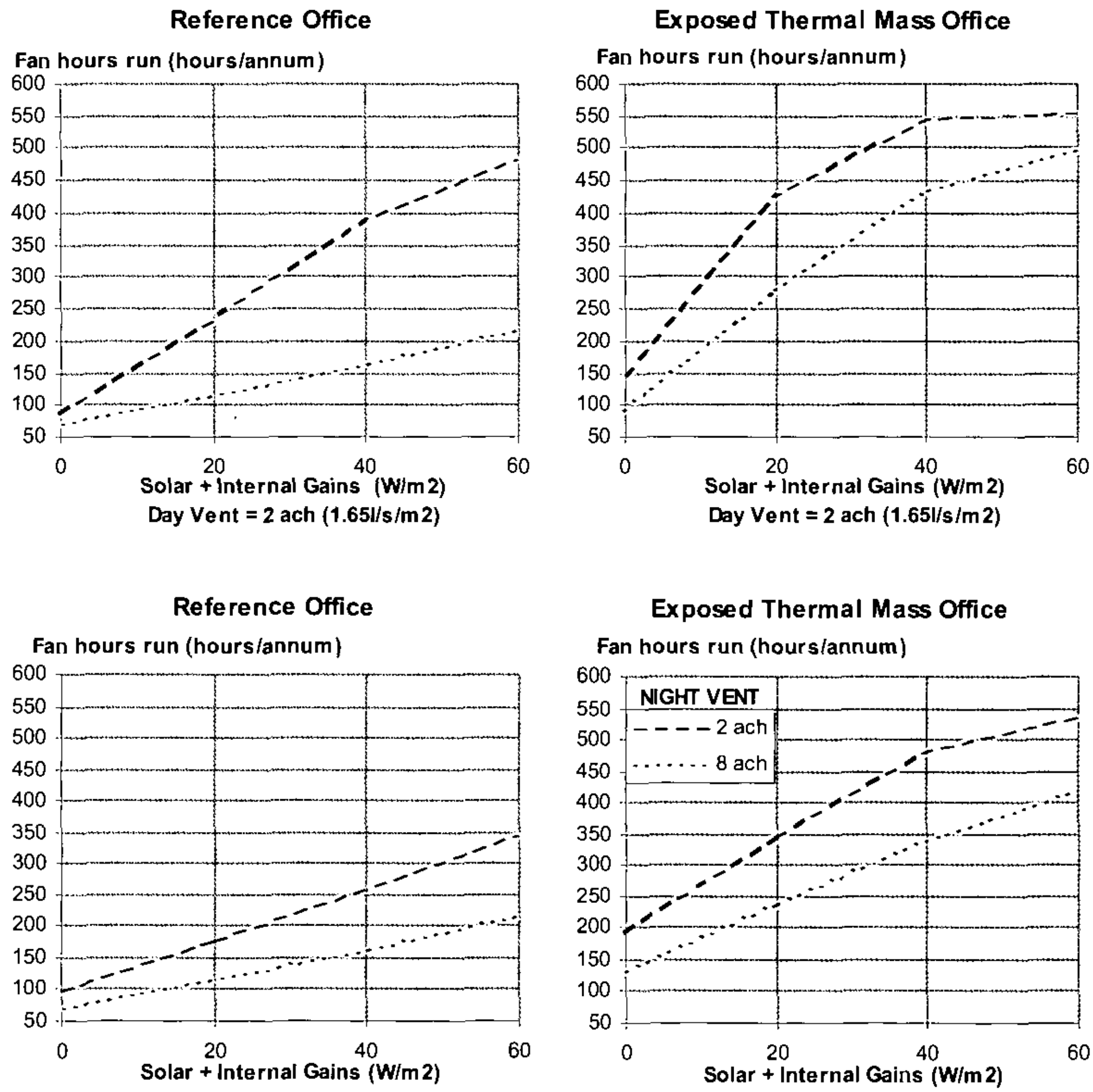


Figure 4 Number of fan hours to provide the free cooling predicted in Figure 3

3.4 Example calculations

Table 2 provides some example calculations for a case with internal + solar gains of 25 W/m². It can be seen that the energy required by advanced and best practice (SFP = 0.75 to 1+) fans is only a small percentage of the free cooling provided by night ventilation. It could be a worthwhile strategy for exposed mass building when using less efficient fans, but the benefits may be offset by the fan energy consumption for the reference case and at higher ventilation rates.

Table 2 Example calculations for fan energy consumption (internal + solar gains 25 W/m²)

Day ventilation (ach)	Night ventilation (ach)	Temp (°C) (Fig 1)	Cooling (kWh/m²/annum) (Fig 3)	Fan run (h) (Fig 4)	Fan energy (kWh/m²/annum) SFP=0.75	SFP=1	SFP=2
Reference office							
2	2	28	3	275	0.35	0.45	0.9
2	8	26.5	3.25	125	0.6	0.8	1.6
Exposed thermal mass office							
2	2	25	11	450	0.55	0.75	1.5
2	8	24	13	315	1.5	2	4

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Chapter E Night cooling in residential buildings

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1 Introduction

Night cooling is introduced into the building at night by opening windows or vents. As the air circulates it comes into thermal contact with, and cools, the exposed building fabric. The stored coolness helps to limit temperature rises the following day.

With natural ventilation systems in residential buildings, the air flow is mainly due to windows being opened. Typical air change rates of between 5 and 20 air changes per hour may be achieved in residential buildings, but issues such as privacy, security and outdoor noise must be addressed. It is important with natural ventilation cooling that the designs allow for cross ventilation, with windows on each side of the building. To enable good control of the air flow rate during the night, windows should have some means of being kept open in various positions (eg half opened or completely opened). Additionally, in some cases, shutters should be designed in order to allow air flow but to provide security against robbery or protection from unwanted natural light (eg for bedrooms).

Whether the system is controlled automatically or manually, the goal is to precool the building as much as possible during night-time in order to prevent overheating the following day. During warm weather, night ventilation can always be used, but when days are cooler there can be a conflict between comfort during the night and comfort during the day. This is often the case when internal temperature swings are high, which occurs for lightweight buildings or ones with large solar gains. Air speed must also be limited so as not to cause thermal discomfort, especially at night when outdoor temperatures may be less than about 15 °C.

This tool gives the gives minimum solar protection required to limit the maximum internal temperature to specified values. The data presented have been generated using the simplified thermal model COMET where the room behaviour is represented by an RC (resistance-capacitance) network.

The parameters of climate, building thermal inertia, window solar protection, ventilation strategy and noise exposure of facades are defined in Section 2. The results from the simulations are presented in the form of design tables in Section 3.

2 Parameters

2.1 Climate

Four different climates have been considered (**F1, F2, F3, F4**) with temperatures and solar radiation characteristics as detailed in Figure 1.

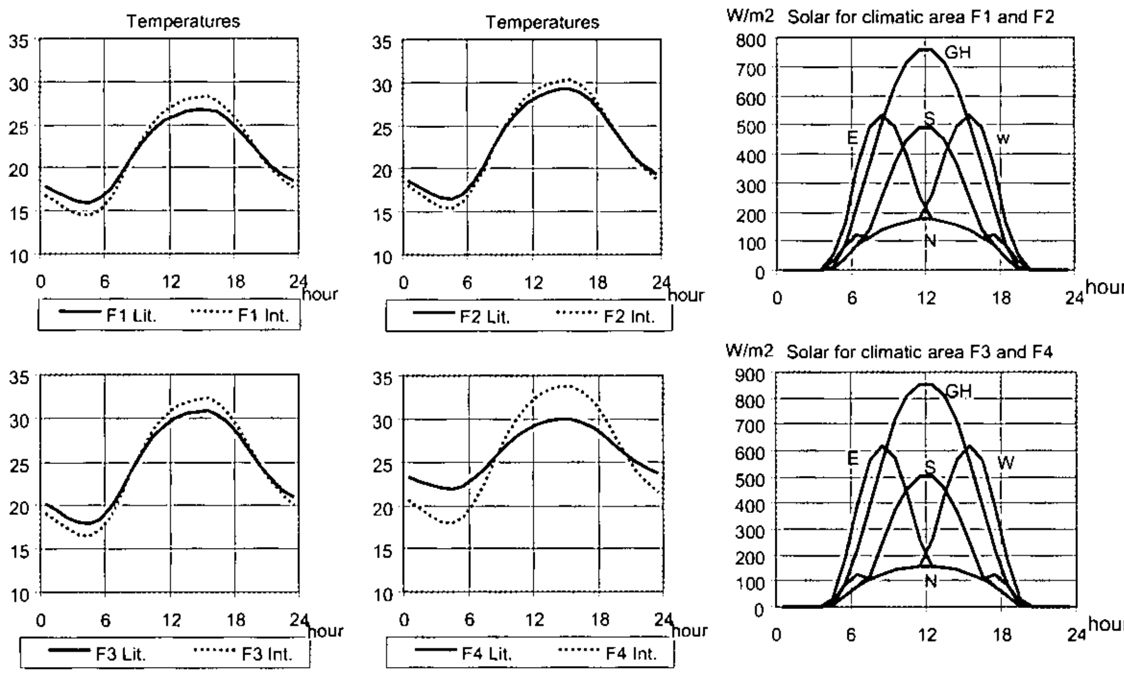

Figure 1 Characteristics of the four climates

2.2 Building thermal inertia

Five classes of thermal inertia have been included:

TL Very heavy
L Heavy
ML Medium
Le Light
TLe Very light

They are as defined by the following table.

Inertia class	Ceiling or roof	Floor	External wall	Internal wall between dwellings	Internal wall in the dwelling
TL Very heavy	Heavy	Ground inertia	Heavy	—	—
TL Very heavy	Heavy	Ground inertia	—	Heavy	Heavy
L Heavy	Heavy	Heavy	Heavy	—	—
L Heavy	Heavy	Heavy	—	Heavy	Heavy
ML Medium	Heavy	Heavy	—	—	—
Le Light	—	Heavy	—	—	—
Le Light	Heavy	—	—	—	—
TLe Very light	—	—	—	—	—

2.3 Window solar protection

The definition of solar protection classes is as follows :

PP Permeable window protection: this kind of protection enables natural ventilation even when they are operated at night. If there are security hazards, the protection must be suitable

PNP Non-permeable window protection: other types of protection with transparency less than 10%

SPD Without any window protection but with architectural solar protection as overhangs

SP Other cases

The overhangs for **SPD** must be equal at least to ¾ of the window height with a length equal at least to twice the window width (see Figure 2).

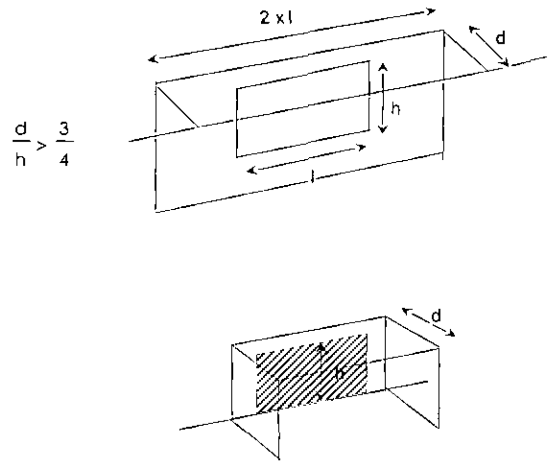

Figure 2 Size of overhangs for windows

2.4 Ventilation strategy and noise exposure of facades

Two cases of noise exposure are defined:

EB1 Bedroom not exposed to noise, other rooms exposed to a noise requiring an acoustic insulation less or equal to 30 dB(A)

EB2 Other cases

Four base cases have been considered on the basis of these exposures:

A Dwelling with cross ventilation, all rooms EB1

B Dwelling without cross ventilation, all rooms EB1

C Dwelling with cross ventilation, 35 % of windows (area-based) in EB1 situation

D Other cases

3 Design tables

These tables define the minimum solar protection required to obtain specified maximum values of indoor operative temperature (28, 29 and 30 °C) as a function of the parameters described in Section 2. The blank cells indicate that a passive solution is not sufficient, and that for these cases additional cooling equipment would be needed.

For basic cases, the following table can be used.

Tref		28 °C				29 °C				30 °C			
Zone	CASE	A	B	C	D	A	B	C	D	A	B	C	D
F1	TL			SPD	PNP			SPD	PNP				PNP
	L		SPD	SPD	PNP			SPD	PNP			SPD	PNP
	ML		SPD	SPD	PNP			SPD	PNP			SPD	PNP
	Le	SPD	SPD	PNP			SPD	SPD	PNP		SPD	SPD	PNP
	TLe	PNP	PNP	PP		SPD	PNP	PNP		SPD	SPD	PNP	PNP
F2	TL							SPD	PNP			SPD	PNP
	L						SPD	SPD	PNP			SPD	PNP
	ML						SPD	PNP	PNP			SPD	PNP
	Le					SPD	SPD	PNP			SPD	PNP	PNP
	TLe					PNP	PNP			SPD	PNP	PNP	
F3	TL					SPD	SPD	PNP			SPD	SPD	PNP
	L					SPD	SPD	PNP			SPD	PNP	
	ML					SPD	PNP	PNP		SPD	SPD	PNP	
	Le					PNP	PNP			SPD	PNP	PNP	
	TLe									PNP			
F4	TL					PNP	PP			SPD	PNP	PP	
	L					PNP				SPD	PNP	PP	
	ML					PNP				PNP	PNP	PP	
	Le									PNP	PP		
	TLe												

More detailed results are given below.

Inertia	Zone F1				Zone F2				Zone F3				Zone F4			

Maximum operative temperature: 27 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL		SPD	SPD	PNP	SPD	SPD	PNP		PNP	PNP						
L		SPD	PNP	PNP	SPD	SPD	PNP		PNP							
ML		SPD	PNP		SPD	PNP	PP		PNP							
Le	SPD	PNP	PNP		PNP	PP										
TLe	PNP	PP														

Maximum operative temperature: 28 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL			SPD	PNP		SPD	PNP	PNP	SPD	PNP	PP		PP			
L		SPD	SPD	PNP		SPD	PNP		SPD	PNP	PP					
ML		SPD	SPD	PNP	SPD	SPD	PNP		SPD	PNP						
Le	SPD	SPD	PNP		SPD	PNP	PP		PNP							
TLe	PNP	PNP	PP		PNP											

Maximum operative temperature: 29 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL			SPD	PNP			SPD	PNP	SPD	SPD	PNP		PNP	PP		
L			SPD	PNP		SPD	SPD	PNP	SPD	SPD	PNP		PNP			
ML			SPD	PNP		SPD	PNP	PNP	SPD	PNP	PNP		PNP			
Le		SPD	SPD	PNP	SPD	SPD	PNP		PNP	PNP						
TLe	SPD	PNP	PNP		PNP	PNP										

Maximum operative temperature: 30 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL				PNP			SPD	PNP		SPD	SPD	PNP	SPD	PNP	PP	
L			SPD	PNP			SPD	PNP		SPD	PNP		SPD	PNP	PP	
ML			SPD	PNP			SPD	PNP	SPD	SPD	PNP		PNP	PNP		
Le		SPD	SPD	PNP		SPD	PNP	PNP	SPD	PNP	PNP		PNP			
TLe	SPD	SPD	PNP	PNP	SPD	PNP	PNP		PNP							

Maximum operative temperature: 31 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL				SPD			SPD	PNP		SPD	SPD	PNP	SPD	SPD	PNP	
L				SPD			SPD	PNP		SPD	SPD	PNP	SPD	SPD	PNP	
ML				PNP			SPD	PNP		SPD	SPD	PNP	SPD	PNP	PNP	
Le			SPD	PNP		SPD	SPD	PNP	SPD	SPD	PNP		SPD	PNP	PP	
TLe	SPD	SPD	SPD	PNP	SPD	PNP	PNP		PNP	PNP	PP		PNP			

Maximum operative temperature: 32 °C

CASE	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
TL				SPD				SPD			SPD	PNP		SPD	PNP	PNP
L				SPD				PNP			SPD	PNP		SPD	PNP	
ML				SPD			SPD	PNP		SPD	SPD	PNP	SPD	SPD	PNP	
Le				PNP			SPD	PNP		SPD	PNP	PNP	SPD	PNP	PNP	
TLe		SPD	SPD	PNP	SPD	SPD	PNP	PNP	SPD	PNP	PNP		PNP	PNP		

Chapter F Ground coupled air systems

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1 Introduction

Ground coupled air systems have become quite popular in Central Europe. They are primarily used for preconditioning outdoor air in summer. The outdoor air is supplied to the ventilation system via an underground ducting system where the ground functions as thermal mass, helping to compensate seasonal and daily temperature variations. As well as the cooling effect in summer, there is also an air preheating effect in winter. (See Figures 1 and 2.) However the benefit is greatest in summer since air preheating in winter only acts to reduce the heat recuperation in the exhaust air heat exchanger. One advantage, however, is to help to prevent icing of the heat exchanger, leading to a simpler mode of operation.

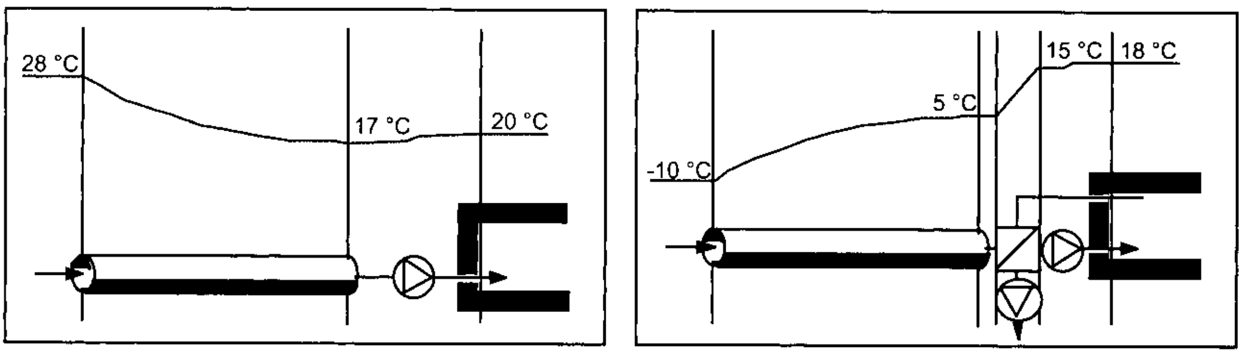


Figure 1 Typical operating schemes of an air ground coupling system in summer (left) and in winter (right)

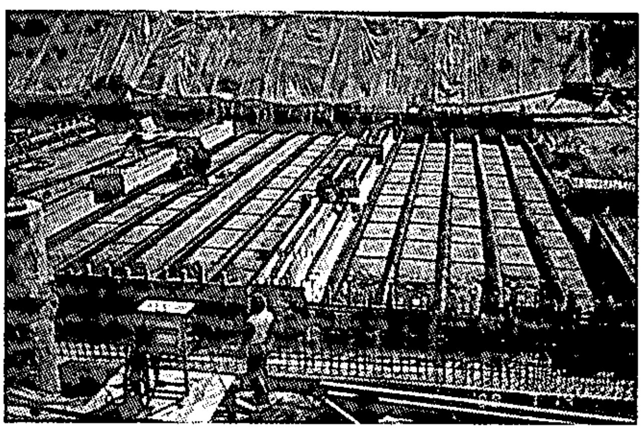


Figure 2 Large ground coupling system[1] during construction. The pipes are brought into position before the basement slab is cast

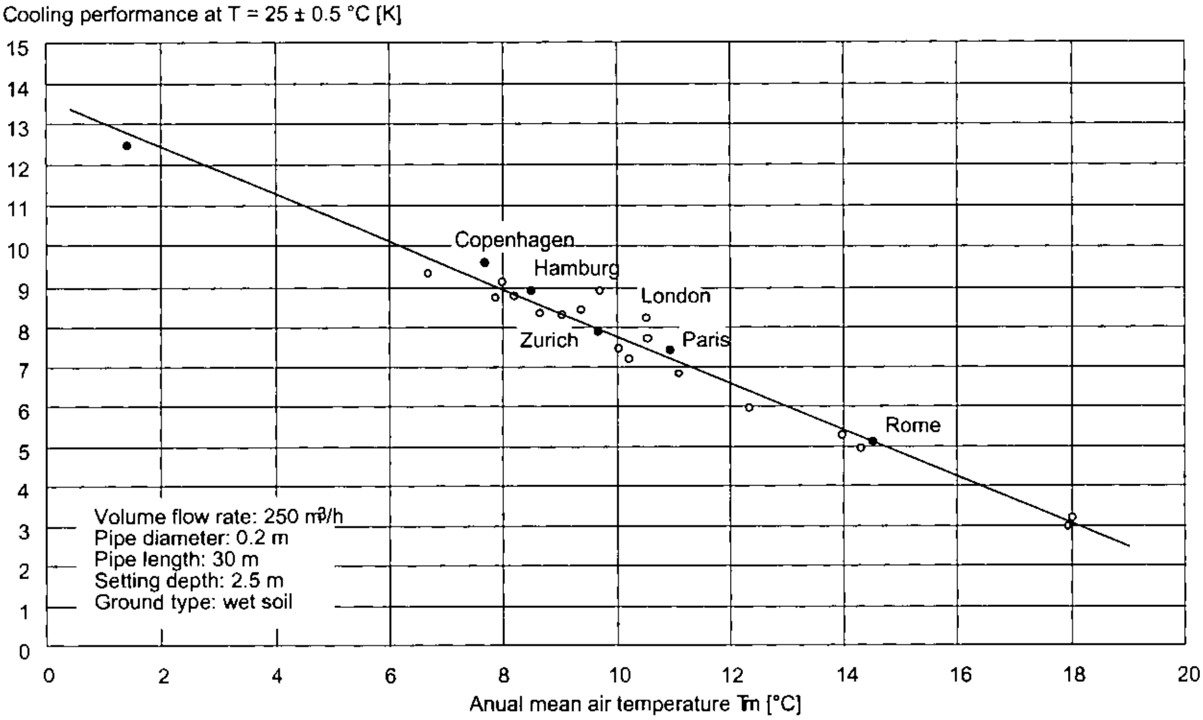


Figure 3 Ground coupling system performance for different climates

The use of ground coupling is suited to climates having a large temperature differential between summer and winter, and also between day and night. Figure 3 shows the performance in different climates. The most appropriate applications are in the moderate climate of Central Europe. The cooling power is reduced in very hot climates whereas in cooler climates, as well as the cooling power being greater, there is normally only a small cooling demand which has to be met.

In principle, ground coupled air systems can be used both for independent cooling of room air and to supplement other cooling systems. As ground coupling merely precools the air, further cooling of the supply air can (if necessary) be done by additional cooling, or alternatively heat can be extracted from a room using static cooling surfaces (eg cooling ceilings, slab cooling). The following combinations may be considered:

- Ground coupled air systems with natural night-time air cooling
- Ground coupled air systems with mechanical night-time air cooling
- Ground coupled air systems with slab cooling/cooled ceiling

Combinations with adiabatic systems (evaporation cooling) are less appropriate. Combinations with geothermal wells or using ground-water are possible, but it is usually more economic to use the latter as stand-alone systems, ie without ground coupled air systems.

In designing the ground coupled air systems, a distinction should be made between the following systems (see Figure 4).

Comfort cooling

Ground coupling is used solely to improve comfort without predefined cooling capacity. Typical applications are displacement ventilation systems for office buildings with low internal loads and for conditioning outdoor air in domestic buildings, atria, etc, with mechanical ventilation. In both these cases the air flow rates are relatively small (air chauge rate 0.5–1.0 h^{-1}), and it is important that the supply temperature lies below room temperature. Ground coupled air systems fulfil this important criterion for displacement ventilation systems as the exit temperature from ground coupled air systems is always below that of the room air, provided the room is not otherwise cooled.

However, it must be permissible for the room air temperature to rise on hotter days. With increasing outdoor air temperature, the output of ground coupling systems increases strongly as a function of temperature difference between ground and outdoor air. Ground coupling is thus particularly well suited to the efficient removal of external heat loads.

Room cooling

The function of ground coupled air systems is to remove internal heat loads via the ventilation system. In cases where internal heat loads have to be removed, larger air flow rates are required. The cooling capacity depends primarily on outdoor temperature and on the condition of the ground. Under constant load, the cooling capacity of the ground may become exhausted. As a stand-alone measure, it is not generally possible for the ground to meet a constant level of high loads. From experience, the maximum values lie around 30–50 Wh/m^{2}d (with respect to the total floor area) at an air change rate of 2.0 h^{-1}. As soon as the outdoor temperature falls below 19 °C (eg at night-time), provision should be made for outdoor air to be extracted directly via a by-pass, and the air change rate increased to around 4.0 h^{-1}. This mode of operation permits regeneration of the ground coupling system.

Auxiliary cooling

Ground coupled air systems are used to supplement an existing cooling system. Greater heat loads can be removed by combining ground coupled air systems with other cooling systems. For example, existing refrigeration plant can be used to cover peak loads. However, it should be remembered that as a rule both low supply air temperatures (for reasons of comfort) and large air flow rates (leading to high fan consumption) should be avoided. For still higher loads, it is an advantage to separate ventilation and cooling systems. Here, the ground coupled air system supplies cooled outdoor air to the room, while the static cooling surfaces remove the remaining heat. At a heat load of around 100 Wh/m^{2}d, this can be achieved very efficiently by means of concrete slab cooling. For extreme heat loads, mechanically cooled ceilings are appropriate.

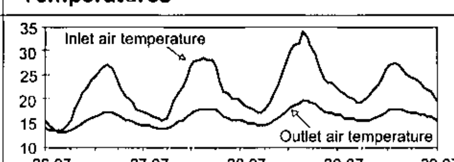
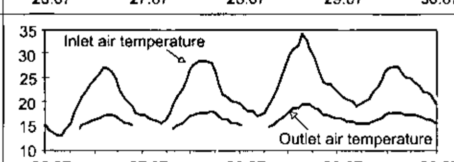
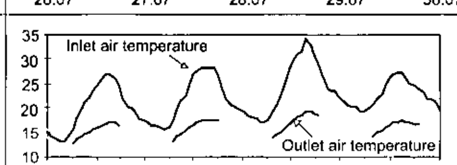
Operation mode	Temperatures	Performances	
Comfort cooling no control		Cooling at 25 °C Cooling perform. Service hours	8.3 K 1138 kWh/a 8760 h
Room Cooling temperature controlled, on at Text > 19 °C		Cooling at 25 °C Cooling perform. Service hours	8.6 K 558 kWh/a 926 h
Auxiliary Cooling controlled by main cooling system, here: 06.00-18.00 hours		Cooling at 25 °C Cooling perform. Service hours	9.3 K 873 kWh/a 4380 h

Figure 4 Overview of typical operation modes for ground coupled air systems. Long operation hours give a high yearly performance whereas short operation hours result in better peak performance (Zürich, 1 pipe, 250 m^3/h, diameter 0.2 m, length 30 m, depth 2.5 m)

2 Parameters

2.1 Positioning

The ground coupling system should be positioned as deep as possible in the ground. Figure 5 shows the ground temperatures as a function of depth and time of year. However, the excavation costs for laying the ground coupling system represent a significant fraction of total installation costs, and costs for deeper excavation are usually prohibitive.

The distance between the pipes should be about 1.0 m. At smaller spacings, mutual interference between the pipes is too great. For the daily charging and discharging cycle to function correctly, much greater spacings are not advisable. When positioned beneath a building, it is essential that the basement rooms are unheated. Even on the assumption that the basement is well insulated (U = 0.5 W/m^{2}K), about 40 kWh/m^{2}a of heat is lost, causing the ground to heat up.

Although wet and heavy soils are an advantage in terms of thermal performance, the presence of ground-water involves extensive sealing precautions carrying a cost penalty (see Table 1).

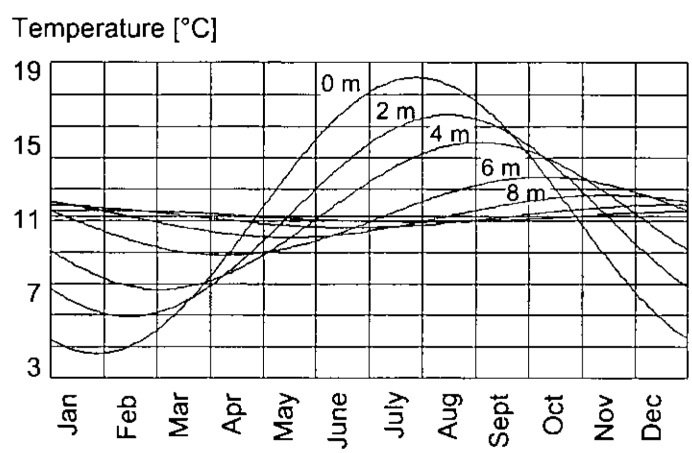


Figure 5 Ground temperatures at different depths for Zurich. A depth of 2 to 4 m is recommended for ground coupled air systems. Owing to the time shift, temperatures are still relatively low at this depth during the month of July

Table 1 Properties of different soil qualities[2]. The influence on the cooling performance is less than ±10 % and therefore relatively small

	Properties			
Ground type	**W/mK**	**kg/m^3**	**J/kgK**	**Cooling (%)**
Wet soil	1.5	1400	1400	100
Dry sand	0.7	1500	920	90
Wet sand	1.88	1500	1200	98
Damp clay	1.45	1800	1340	104
Wet clay	2.9	1800	1590	105

2.2 Size

The size of ground coupling systems depends on the design air flow rate and on the area available. Smaller systems, for example for improving comfort in domestic buildings, can be built at relatively low cost. In particular, the inlet and outlet ducts can be simply designed. Larger plants, as well as those immersed in ground-water, are considerably more costly since large inlet and outlet ducts are required as terminal point, for the pipes.

To limit the pressure drops in the piping system, the air velocity in the pipe should be about 2.0 m/s. In the case of plastic pipes in common use with a diameter of 20 cm, this is equivalent to a flow rate of 250 m^3/h per pipe. The exact values can be taken from Figure 6.

The optimum pipe length is a function of pipe diameter and air velocity. Pipes over 40 m in length perform efficiently only when of larger diameter (see Figure 7). With long pipes, thermal expansion must be very carefully considered.

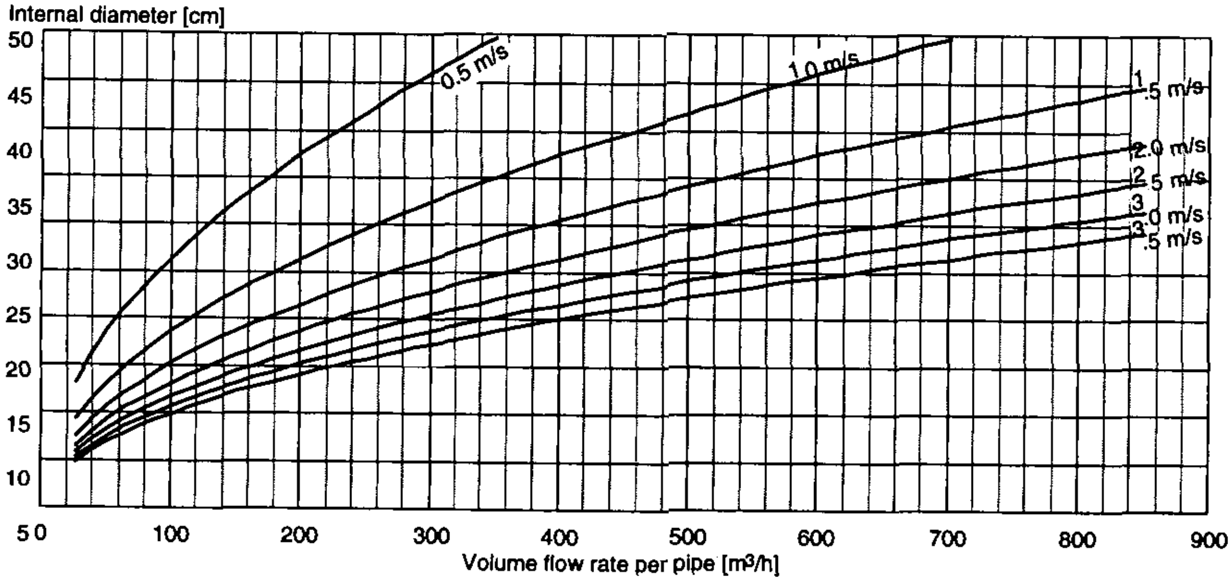


Figure 6 Volume flow rate per ground coupling pipe. When selecting the type of pipe it is advisable to choose small diameters between 15 and 25 cm with air velocities around 2 m/s

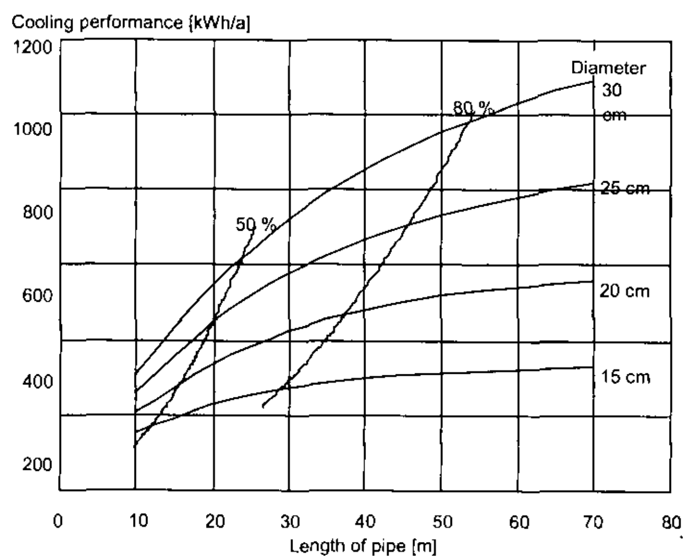


Figure 7 Influence of pipe length on cooling performance. 80% of the maximum performance should be considered as optimum. If long distribution ducts are situated before the piping system, their influence on the performance can also be taken into account

2.3 Operation

The mode of operation depends primarily on the particular application. Wherever possible, complex control procedures should be avoided. The following modes of operation are recommended for the three typical systems mentioned earlier.

Comfort cooling

To achieve best results, the air should always be passed through the ground coupling system. Air flow rate and duration of operation depend on the ventilation system. Ground regeneration should take place when outdoor temperatures are low.

Room cooling

In cases where internal loads must be removed and where the ground coupling system must ensure that a maximum room temperature is not exceeded, the system should be in operation only when absolutely necessary. For outdoor temperatures below 19 °C, the simplest procedure is to supply outdoor air directly by means of a by-pass. If a building control system is installed, the temperature difference between the room and outdoor air (eg $\Delta T > 5$ K) can be used as a criterion for direct supply. Since the supply of outdoor air is practically unlimited, the air flow rate can be increased in this mode of operation to correspond to an air change rate of 4 h^{-1}. For this system most of the heat should be removed by outdoor air cooling, so that the ground coupling system is only required for peak loads during daytime.

Auxiliary cooling

With auxiliary cooling, continuous operation of the ground coupled air systems is also to be recommended. Regulation of total cooling capacity is best delegated to the conventional system. The ground coupled air system has a compensating effect, reducing temperature extremes, and is self-regenerating during cold periods.

3 Design charts and tables

When the location, position and mode of operation have been determined, an estimate of the ground coupling system output can be made. The peak performance as well as the yearly output performance have to be considered. Figure 7 and Table 2 give an overview of the relationship between these two performances. Usually, the calculation of the peak performance will be more important. Figures 8 and 9 and Table 3 can be used to size simple systems.

In more complex cases, or to obtain more precise values, simulations should be carried out using a suitable computer program (see box).

Table 2 Cooling performance (K) of ground coupled air systems for different weather conditions and different locations (pipe length 30 m, pipe diameter 0.2 m, depth in ground 2.5 m, volume flow rate 250 m^3/h). The table shows how much the air can be cooled at different temperature levels (±0.5 is degrees K) and the service hours at these temperatures (SD = standard deviation)

	Annual	Inlet temp (°C):											
	mean	15±0.5		20±0.5		25±0.5		30±0.5		Service hours			
Location	**temp (°C)**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**15**	**20**	**25**	**30**
Almeria (Spain)	18.0	0.8	0.2	1.8	0.9	3.2	1.2	6.2	0.9	27	266	361	132
Messina (Italy)	17.9	0.7	0.1	2.0	1.0	3.0	1.2	6.0	0.6	36	180	307	149
Sacramento (USA)	15.0	1.7	0.7	2.2	1.3	5.4	1.4	8.4	0.8	69	111	64	54
Rome (Italy)	14.5	2.2	0.9	2.4	1.6	5.1	1.2	8.2	0.9	142	308	153	75
Marseilles (France)	14.3	1.9	0.9	2.4	1.5	5.0	1.0	7.8	0.7	170	392	201	59
Madrid (Spain)	13.9	2.2	0.8	2.3	1.7	5.3	1.4	8.3	0.8	173	393	164	60
Milano (Italy)	12.3	2.8	1.2	3.0	1.8	6.0	1.4	9.2	1.1	201	324	164	62
Locarno (Switzerland)	11.1	2.7	1.6	3.9	1.5	6.8	0.9	9.9	0.6	223	299	143	11
Paris (France)	10.9	2.2	1.3	4.2	1.0	7.4	0.8	10.3	—	359	244	65	1
Macon (France)	10.6	2.2	1.4	4.4	1.4	7.7	1.1	10.8	0.7	280	205	95	18
London (Britain)	10.5	2.0	1.2	5.0	1.0	8.3	0.7	—	—	493	198	47	0
Vienna (Austria)	10.2	2.7	1.6	4.3	1.4	7.2	1.0	10.8	0.7	256	311	103	10
Geneva (Switzerland)	10.0	2.5	1.7	4.7	1.4	7.5	0.9	10.7	0.8	266	226	99	25
Dublin (Ireland)	9.7	2.6	1.1	5.6	0.7	8.9	0.8	12.2	0.0	376	123	17	2
Bonn (Germany)	9.7	1.9	1.2	5.2	1.2	7.9	0.8	11.3	—	376	240	58	1
De Bilt (Netherlands)	9.4	2.4	1.3	5.2	1.1	8.5	0.9	10.5	0.5	369	137	45	2
Zurich (Switzerland)	9.0	2.4	1.5	5.3	1.4	8.3	0.9	11.2	0.5	383	194	62	7
Berne (Switzerland)	8.7	2.6	1.6	5.7	1.5	8.4	0.8	11.5	0.6	359	186	66	10
Hamburg (Germany)	8.5	2.5	1.1	5.8	1.1	8.9	0.7	12.6	—	398	161	47	1
Innsbruck (Austria)	8.2	2.8	1.7	5.9	1.4	8.8	1.1	11.7	0.4	386	187	42	8
Prague (Czech)	8.0	2.7	1.5	5.9	1.3	9.1	1.1	11.8	0.5	352	162	67	3
Warsaw (Poland)	7.9	2.7	1.5	5.6	1.6	8.7	1.0	11.2	0.6	348	174	68	20
Copenhagen (Denmark)	7.7	3.0	1.1	6.1	0.7	9.6	0.6	—	—	449	142	24	0
Stockholm (Sweden)	6.7	3.2	1.4	6.4	1.0	9.4	0.6	—	—	327	153	37	0
Samedan (Switzerland)	1.4	7.0	1.4	9.7	0.7	12.5	—	—	—	163	61	1	0

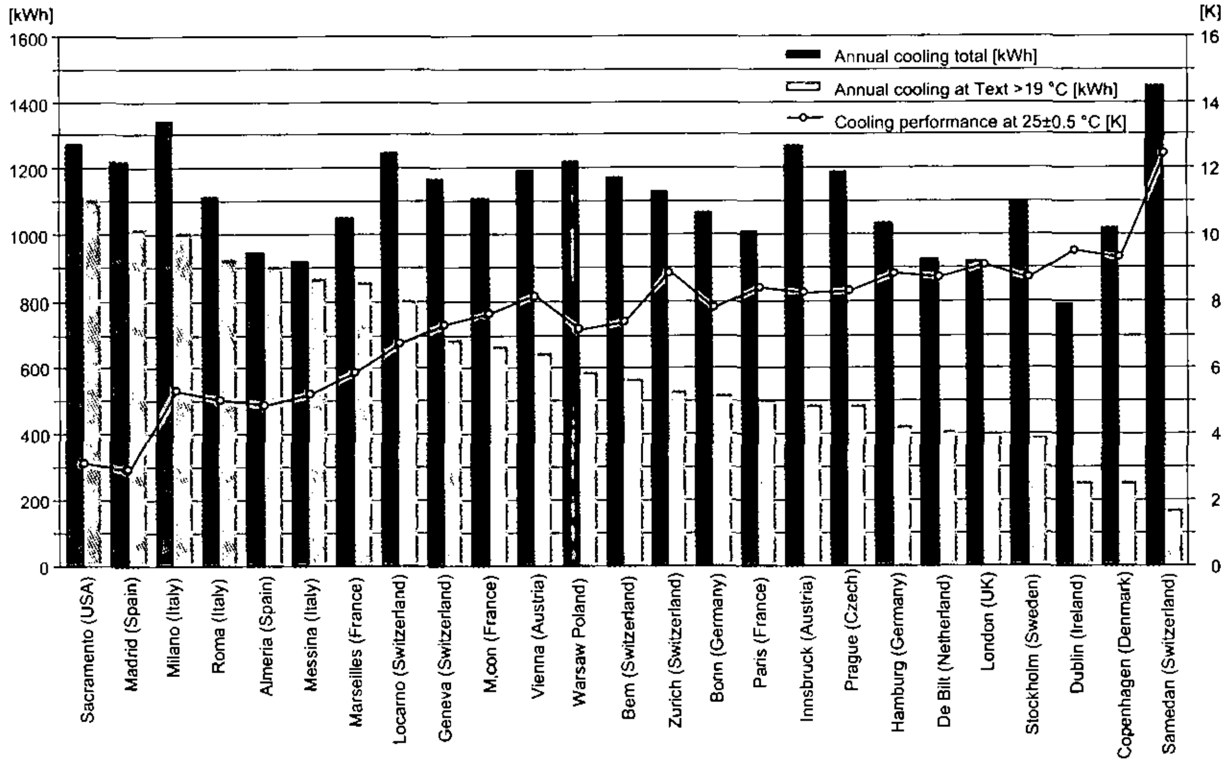


Figure 8 Cooling performance and peak performance of ground coupled air systems for different locations (for system definition see Table 2)

The Resistance-Capacity Model (detailed in IEA Annex 28 Subtask 2 Report 3)

The calculation of ground coupled air systems is complex because the real geometrical situation and the dynamic behaviour of the system are difficult to simulate. Good results can be obtained with the Resistance-Capacity Model WKM[3], originally developed by Arthur Huber.

The WKM considers only a single pipe, surrounded by 50 cm of soil. For daily charging and discharging, only this 50 cm layer is calculated with three possible boundary conditions:

- Undisturbed ground, whose temperature is calculated according to the depth in the ground and the outdoor climate
- Ground underneath a building: the boundary temperature is calculated using the basement temperature of the building and the thermal resistance between building and pipe
- Ground between ground coupling pipes: this part is considered to be adiabatic. There is no heat flux through the boundary layer, but the capacity of the soil is considered

The WKM program is analogous to an electrical circuit with resistance and capacity. The portions of the ground with different boundary conditions (undisturbed, building influenced, adiabatic) have to be estimated according to the real conditions. The program calculates four temperature nodes for each boundary condition. The length of pipe is divided into six pipe segments, where the outlet temperature of one segment is the inlet temperature of the next segment.

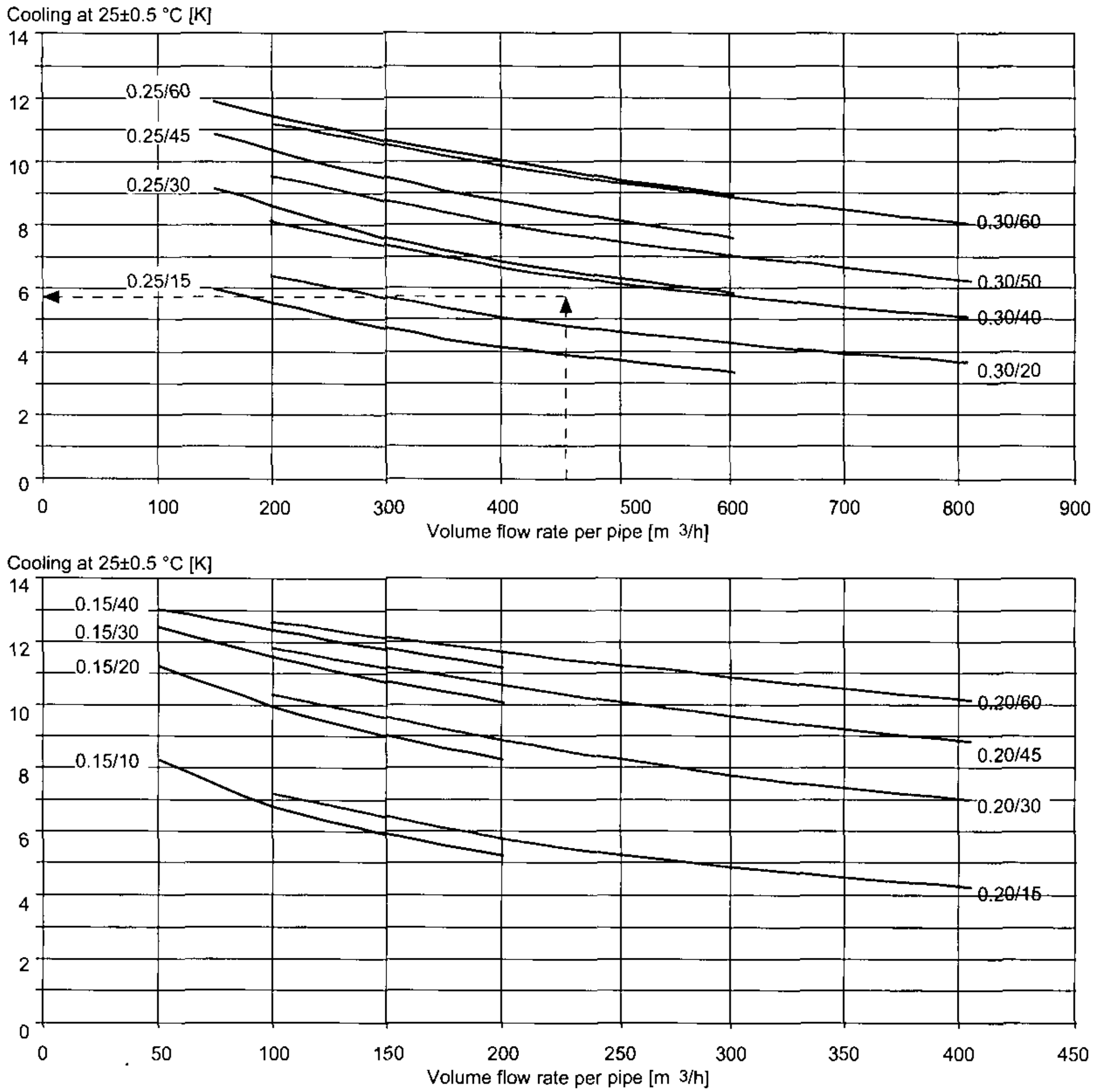


Figure 9 Cooling power as a function of pipe diameter, pipe length and volume flow rate for Zürich, continuous operation and depth in ground of 2.5 m (inner diameter of pipe/length of pipe). For locations other than Zürich the corrections in Table 3 should be used

Table 3 Correction factors for cooling power at 25 °C for different climates (annual mean temperatures), depths of piping systems under ground, and types of ground

Annual mean temp (°C)	Correction factor	Depth under ground (m)	Correction factor	Ground type	Correction factor
5	1.29	7.0	1.175	Wet clay	105
6	1.22	6.0	1.17	Damp clay	104
7	1.15	5.0	1.16	Wet soil	100
8	1.08	4.0	1.12	Wet sand	98
9	1.01	3.5	1.09	Dry sand	90
10	0.94	3.0	1.05		
11	0.87	2.5	1.00		
12	0.80	2.0	0.94		
13	0.73	1.5	0.87		
14	0.66	1.0	0.79		

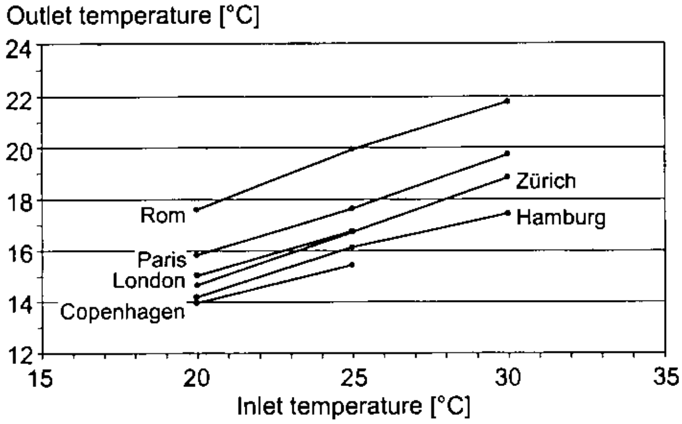


Figure 10 Cooling power as a function of inlet temperature and location (pipe length 30 m, diameter 0.2 m, depth 2.5 m, volume flow rate 250 m^3/h)

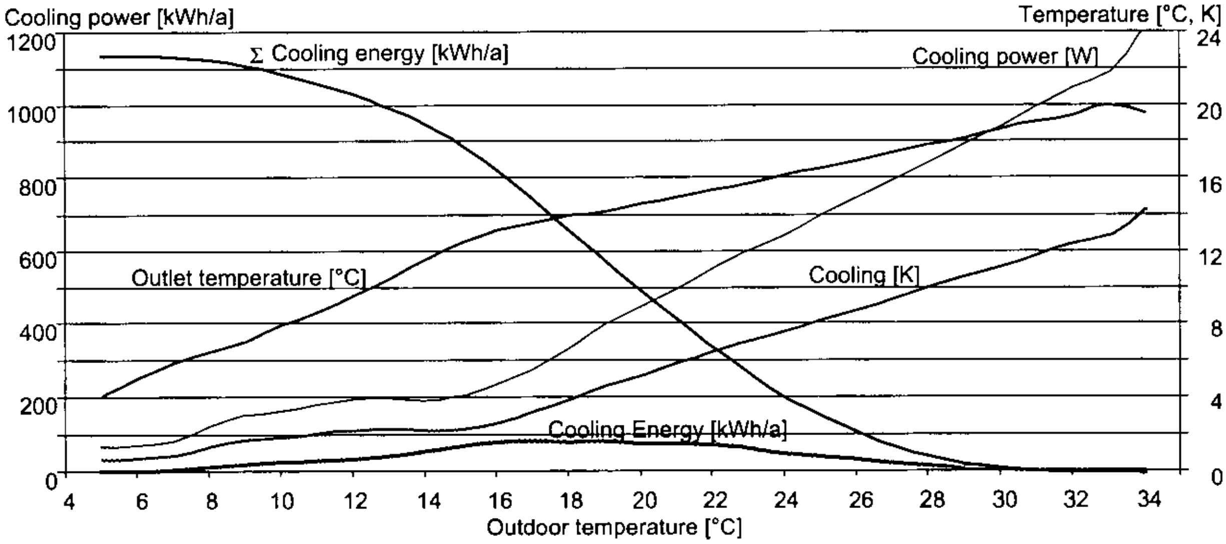


Figure 11 Relationship between cooling power, cooling energy and outdoor temperature (Zürich, 250 m^3/h, pipe diameter 0.2 m, pipe length 30 m, depth 2.5 m, wet soil). The summation curve indicates the amount of cooling energy that can be expected above a selected set point

Example

- Four-storey office building, 25 × 16 m, total floor area 1600 m^2.
- Air flow rate corresponding to an air change rate of 2.0/h (room cooling): volume 10 240 m^3.
- Number of pipes: 20, diameter 30 cm, 16 m long (note: 15 pipes with diameter of 35 cm are less effective).
- Distribution ducts: with regard to their cooling effect the concrete distribution ducts together (1.8 m × 0.8 m) correspond in total to 100 m of pipes (with respect to area of ground contact). This effect is taken into account by a fictitious increase in pipe length of 10 m, giving a total length of 26 m.
- Cooling of inlet air (at outdoor temperatures 25 °C) by 5.8 K to 19.2 °C (Figure 8).

If the building is situated in London with a yearly mean temperature of 10.5 °C the cooling power can be corrected according to Table 3. This results in a corrected cooling of 0.9 × 5.8 K = 5.22 K. If the depth of the pipes is 4 m below ground, a second adjustment can be made with a factor of 1.12 (see also Table 2). The ground correction has only to be applied for extremely dry or wet ground. The final cooling will be 5.85 K, resulting in a cooling power of 512 m^3/h × 5.85 K × 0.32 Wh/m^3K ≈ 960 W, total ≈ 19 kW.

Conclusion

The ground coupling system can remove about 12 W/m^2. If the internal load is 40 kW (25 W/m^2) the excess heat may be stored in the building mass and removed by night ventilation.

A combination of the ground coupled air system and night-time ventilation could provide the required standard of comfort. Neither the ground coupled air system nor night-time ventilation alone would be sufficient to fulfil the room temperature criterion of 26 °C.

4 Practical guidance

4.1 Air intake

The procedure for air intake has a decisive influence on the quality of the supply air. In addition to fouling of the intake by birds and other small animals, by children, and contamination by suspended particles, etc, the quality of the air at the point of intake is of great importance.

Raising the intake above the ground prevents ingestion of radon gas, which may seep through the ground at any point, reduces the concentration of exhaust fumes from road vehicles, and, as a rule, reduces the air intake temperature. To further ensure low intake temperatures, air intake above parts of the building exposed to strong sunshine or over macadamised surfaces should be avoided. Placement of (odourless) vegetation around the intake can also considerably reduce intake temperatures.

Fouling can be avoided both by restricting access and by mounting a tight-fitting grille. Filters can only be recommended if regular inspection and maintenance are assured. Coarse and fine particle filters effectively remove non-volatile air pollutants such as pollen, fungal spores and bacteria. This option should be considered in situations where professional maintenance facilities are available. (See Figures 12 and 13.)

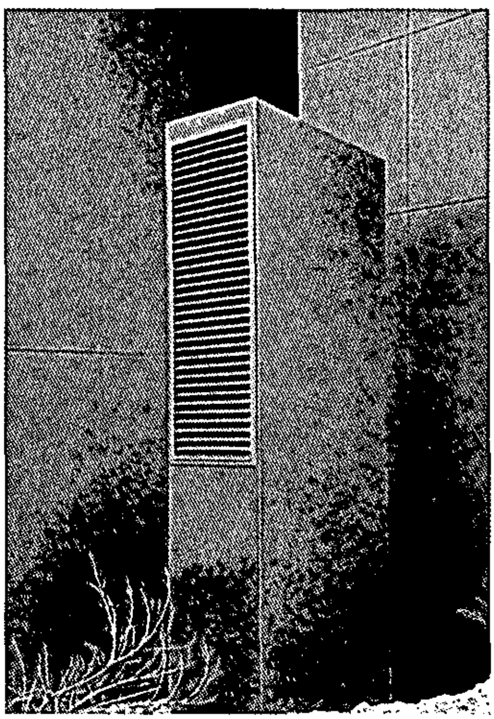


Figure 12 Air inlet for a medium-sized ground coupling system. Filters for the removal of small particles are placed between the ground coupling system and ventilation plant

Figure 13 Air inlet for a small ground coupling system with only two pipes. If the inlet is via a vertical well as illustrated, it has to be ensured that no radon gas will enter the system

4.2 Distribution and collection ducts

In larger plant, air delivery to the ground coupling system pipes is via a distribution duct. This should be generously sized to ensure that the pressure losses for all air paths are of similar magnitude. The same applies to the collection duct. This ensures that all pipes have the same flow rate.

Distribution and collector ducts should be man-sized, or at a minimum

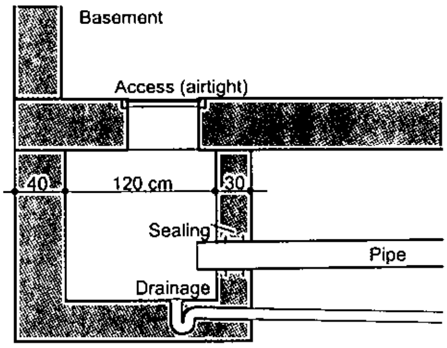


Figure 14 Section through concrete distribution duct of a large ground coupling system. The pipes have to allow for thermal expansion

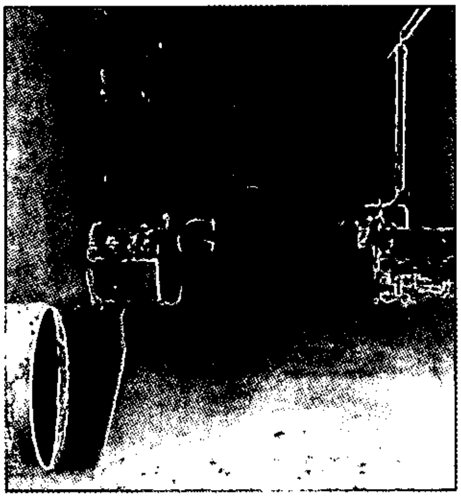


Figure 15 Concrete collection duct of a large ground coupling system. All pipes are accessible for maintenance

provide crawling access, to enable the ground coupling system to be inspected, and, if necessary, to be cleaned. Both ducts should, as far as possible, be airtight and fitted with drainage and siphon. (See Figures 14 and 15.)

As the distribution duct is at a lower level than the collector duct, drainage here is particularly important to enable condensate, any ground-water or water remaining from cleaning to escape.

If possible, heavy concrete distribution ducts should be chosen. These have the advantage of cooling down outdoor air in summer and preheating it in winter. Ground coupling systems positioned beneath the building are protected against icing. The distribution duct should, if possible, be situated away from the building and be in contact with the ground on all sides.

4.3 Ground coupling piping system

Ground coupling pipes are constructed exclusively of round plastic, cement or cement fibre pipes. The choice of material is primarily a question of cost. Figure 16 shows the material costs as a function of diameter. For smaller pipes with diameters of up to about 30 cm, plastic piping based on PVC or HDPE is preferable. For larger diameters, cement pipes are cheaper. However, when

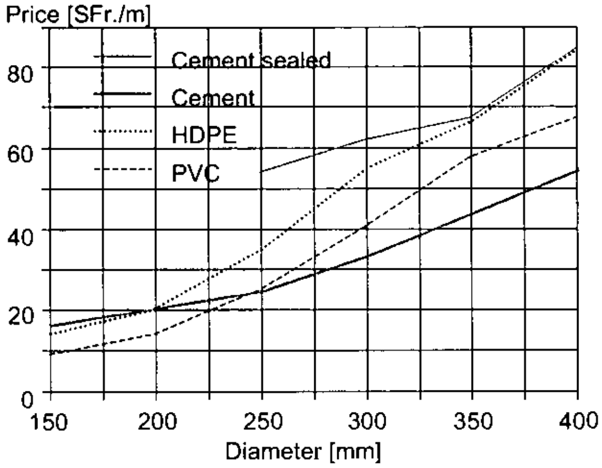


Figure 16 Prices for different pipe materials (1 US$ = 1.5 SFr). Small diameters are generally more economic and also thermally more efficient

special seals are called for, this is a very expensive option. In general, larger numbers of small pipes have a better cost-benefit ratio than fewer large pipes.

The position of ground coupling pipes makes them very difficult to repair, so that emphasis should be placed on a long life-cycle (>50 years). For this reason, thin-walled ribbed pipes or hoses are not suitable. The latter are also quite critical as regards fouling, and are also very difficult to clean.

To ensure that condensate, any ground-water or remaining cleaning water can drain off, ground coupling pipes should be inclined at approximately 1% towards the intake (ie against the direction of air flow). In general, it is sufficient to bed the pipes on sand in clean trenches, while shorter cement pipes can be bedded on a small amount of lean concrete.

Straight pipes are the best choice as they are easy to inspect, but curved pipes can also be used. It should be remembered that, owing to temperature changes, pipes are subject to considerable thermal expansion (0.2 mm/mK for HDPE pipes, 0.08 mm/mK for PVC pipes). The distribution and collection ducts must be designed to accommodate thermal expansion. For this, rubber seals are normally provided, which not only permit axial movement but also protect against ground-water. To prevent long-term lateral movement, the pipes are cemented-in at the centre.

5 Maintenance

Ground coupled air systems are generally maintenance-free. Inspections carried out on a range of older plant showed no marked degree of fouling[4]. The concentration of airborne spores and bacteria was also measured. In the majority of cases air quality with respect to these contaminants was better after passing through the ground coupling system than in the original air (see Figures 17 and 18).

As a precautionary measure it is nevertheless recommended that regular inspections of the ground coupling system and of the remaining system components be made. Attention should be paid in particular to the intake, ducts and other equipment. Particularly in plants with ground-water seepage, regular optical inspections are essential. As with hollow electrical piping, curved ground coupling pipes should be fitted with a non-corrosive wire with which to draw cleaning material tbrougb when necessary. The inclination ensures that cleaning water can drain off.

Particularly with larger plant, it is essential to ensure that intake ducts are not used for storage (especially wood fuel), as this can lead to air contamination.

Filters of the type used in ventilation systems are quite adequate. Pressure loss and fouling should be monitored and the filters cleaned or changed as necessary. In applications where for hygienic reasons higher standards of air quality must be met, further reduction of bacterial and spore concentrations can be achieved by means of fine particle filters.

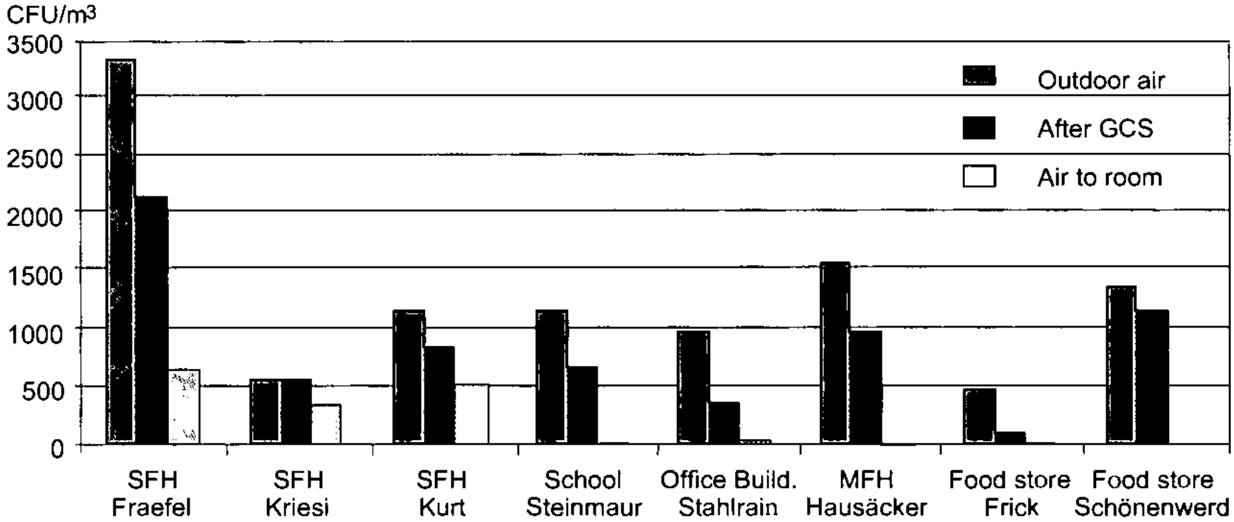


Figure 17 Concentrations during summer of fungal spores in the outdoor air, the air leaving the ground coupling system, and the air entering the rooms[4]. The numbers of spores are much higher than during winter, but the relationship between the concentrations is similar. No values were available for the fungal concentration entering the food store in Schönenwerd

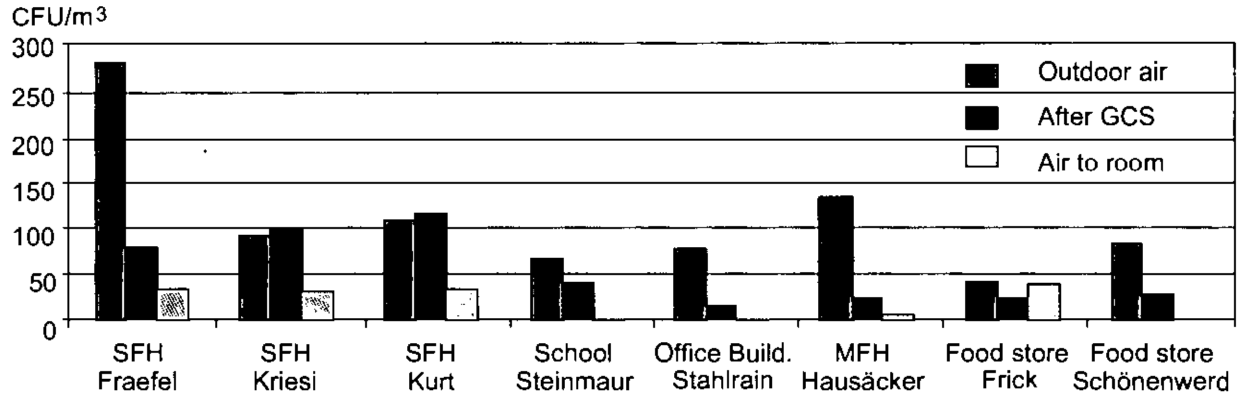


Figure 18 Concentrations of bacteria during summer[4]

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