LOW-ENERGY COOLING TECHNOLOGIES—
IEA ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

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ABSTRACT

The aim of IEA ECBCS Annex 28 was to investigate the feasibility and provide design tools/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 scope was limited to the technologies included in the Annex. The information provided reflects the state of the technologies in a country or countries that participated in the Annex and should not be taken as representative of the situation on a world wide basis.
Ten countries participated in the Annex. The technologies varied from night cooling through natural ventilation and slab cooling to desiccant cooling and aquifers. This paper presents some of the buildings that illustrated the various cooling technologies through demonstrated case studies. The case study buildings are located in countries with different climatic conditions. The temperatures and relative humidity of the outside air gives different prerequisites for the studied technologies. The suitability of a technical alternative is thus often dependent on the location of the building.

Key Words: ***heat pumps, building energy systems, passive cooling, slab cooling, evaporative cooling, desiccant cooling, aquifers, sea water cooling***

1 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. In response to these issues, the IEA Implementing Agreement Energy Conservation in Buildings and Community Systems started Annex 28, Low Energy Cooling Technologies.

The aim of Annex 28 was to investigate the feasibility and provide design tools/guidance on the application of alternative cooling strategies to buildings. Output from the Annex included a review of the technologies, early design guidance, detailed design tools and case study descriptions. The emphasis for the project was on passive and hybrid cooling technologies and strategies. These require close integration of the dynamics of the building.

Passive and hybrid cooling technologies will only be taken up in practice if such systems can e.g. be shown to have lower life cycle costs than ‘conventional’ systems, can provide an acceptable level of thermal comfort to the occupants, are sufficiently robust to changes in building occupancy and use, and will integrate with the other systems in the building as well as with the building and its control strategy.

Eighteen case studies in the project illustrated the various cooling technologies through demonstrated case studies giving a feedback on performance and operation in practice. Ten countries participated in the project. The case studies are thus located in countries with different climate conditions ranging from hot and humid to dry and cool giving different prerequisites for the studied technologies. These included among others night cooling through natural and mechanical ventilation, slab cooling, evaporative cooling, desiccant cooling, ground cooling, aquifers, and sea water cooling.

2 THE CASE STUDIES

Evaluating case studies presents a unique possibility to exchange and gain experience from similar technologies tested under scientific conditions in different countries. Different conditions influence the choice of alternatives and the feasibility differs. The case studies offer guidance based on experience, but do not give any guarantee for the suitability of a technology.

The case study buildings are located in countries with different climatic conditions. The map shows the location of the eighteen different case study buildings. The temperatures and relative humidity of the outside air gives different prerequisites for the studied technologies. The suitability of a technical alternative is thus often dependent on the location of the building.

Fig. 1. Location of the case study buildings

1. The ACT2 Stanford Ranch House,
   Rocklin, CA, USA
2. The One Utah Centre Building
   Salt Lake City, USA
3. The Advanced House
   Laval, Quebec, Canada
4. The Purdy's Wharf
   Halifax, Canada
5. Villa Nova de Gaia
   Porto, Portugal
6. The IONICA Office Building
   Cambridge, UK
7. The Open University Design Studio
   Milton Keynes, UK
8. The Groene Hart Hospital
   Gouda, Netherlands
9. Gaz de France Research Centre
   Paris, France
10. The Nestlé – France Head Office
    Noisel, France
11. Hamburg Regional Bank
    Hamburg, Germany
12. The Schwerzenbacherhof
    Zurich, Switzerland
13. Sarinaport Office Building
    Fribourg, Switzerland
14. The Dow Building
    Horgen, Switzerland
15. InfraCity Commercial Centre
    Stockholm, Sweden
16. SAS Frösundavik
    Stockholm, Sweden
17. The Wärtsilä Diesel Building
    Vaasa, Finland
18. The Granlund Office Building
    Helsinki, Finland

3 ENERGY

Most of the case studies showed that energy can be conserved by using these technologies instead of “conventional installations,” usually meaning mechanical refrigeration. The studied technologies can either be used solely or as a first step in combination with other technical solutions, e.g. with mechanical cooling.

Most of the case studies use the building, or the ground under the building, as an energy store thus reducing both energy use and the size of the installed power.

4 COSTS

One of the objectives of the project was that the life cycle costs of a passive or hybrid cooling system as studied in this Annex should be lower than the equivalent costs of a “conventional system” (normally meaning a mechanical system). Environmental considerations might in some cases justify a cost in the same order.

When comparing costs, local and national conditions, such as material costs, wages, exchange rates, make it difficult to transfer the result from one country to another or from one time to another. Bearing these uncertainties in mind, the cost comparisons presented in the case study reports are to be regarded as relative and could as such give certain guidance.

5 COOLING STRATEGIES EXAMINED IN THE CASE STUDIES

(Numbers below refer to location of the study case buildings shown in Fig 1.)

- **Night Cooling / Natural Ventilation**

Two buildings, a single-family house in Porto, Portugal, and an office building in UK covered this area.

Vila Nova de Gaia, single-family residence in Porto, Portugal (5)

This building is typical example of how to obtain comfortable indoor environment in summer without the help of mechanical cooling. A few hours of a day of natural ventilation at night can pre-cool the building structure enough so that daytime solar gains, provided that they are well controlled, do not overheat the building.

The Open University Design Studio, office building in Milton Keynes, UK (7)

When this building was refurbished, no mechanical cooling was installed. Instead the aim was to reduce internal gains and enhance natural night cooling to prevent summertime overheating. The original single glaze windows were exchanged to new better ones providing improved solar protection, better ventilation, and greater user control. The heat storage capacity of the building was increased by removing ceiling tiles to expose the concrete soffit. Occupant surveys confirmed that staff found the conditions had improved especially in hot weather.

- **Night Cooling / Mechanical Ventilation**

The IONICA building, office building in Cambridge, UK (6)

The building is provided with a selection of cooling options – wind towers extracting air from the atrium, hollow core slabs to enhance thermal storage capacity, natural and mechanical night cooling, indirect evaporative cooling, and heat pump cooling. To utilize these options in an efficient way a fine tuned control system was required.

- **Slab Cooling (Water)**

Slab cooling utilizes the building structure as energy store to smoothen out sudden temperature changes in the room and often to improve the efficiency of night cooling.

Two office buildings in Switzerland demonstrated this technology. Energy legislation in Switzerland only permits active cooling in exceptional cases. This has encouraged efforts to develop passive HVAC systems capable of achieving an acceptable level of indoor comfort.

The DOW office building in Horgen, Switzerland (14)

Concrete slab stores the heat gain from day to night when it is removed via air coolers connected to the water loops in the slab. Mechanical ventilation provides displacement ventilation through supply air inlets integrated in the suspended lamp support frames in the rooms. The cool air descends to the floor with low turbulence. Utilizing free cooling during two thirds of the time, the building is very energy effective compared to a fully mechanically cooled building.

The building envelope, of aluminum and glass, is airtight and well insulated. The entire building is equipped with automatically controlled external shading devices that can be operated separately for each façade and/or directly by the occupants. Room cooling is achieved, on a similar basis to floor heating systems using cooling pipes embedded in the concrete slabs. The cooling water circulation through air coolers on the roof is started around midnight and continued until the temperature difference on the water side in the cooler is less than 1 K. Two thirds of the total cooling load of the building is covered by free cooling.

The Sarinaport office building in Fribourg, Switzerland (13)

The heavy concrete floor slabs of the building are used both for heating and cooling. Both supply air ducts and pipes for cooling and heating are embedded in the concrete slabs. The heavy slabs have the ability to quickly store excess heat, and, when necessary, to provide heating energy to the room. Due to the low temperature differences, this process is entirely self-regulating. As soon as the room becomes too hot, heat is rejected to the slab, whereas if it is too cool, heat is withdrawn. The air to the rooms is supplied through plastic ducts embedded in the concrete slab and connected to displacement ventilation air inlets under the windows. The capital costs are lower and the annual operating costs are less than half of those for a conventional system providing the same comfort.

- **Evaporative Cooling**

Evaporative cooling can be used either “direct” in the supply air or “indirect.” In the two US case studies cooling towers are used to cool water supplied to cooling coils in the supply air. In the French case study this is achieved by humidifying the return air that is then cooling the supply air via a heat exchanger. Often both applications, direct and indirect, are combined. In dry and semi-dry climates evaporative cooling is efficient and cost effective and can be used as sole source for cooling or as a first pre-cooling step.

The ACT2 Stanford ranch house, single-family residence in Rocklin, California, USA (1)

This building has an innovative combination of evaporative cooling, energy storage and slab cooling. The water passing the loop in the ground below the floor slab is effectively cooled at night in a cooling tower and provides thus the building with radiant cooling. At peak periods the cool loop water is run through a supply air fan coil unit.

The One Utah Centre building, office building in Salt Lake City, USA (2)

The building has an interesting combination of evaporative and mechanical cooling. The supply air is chilled in up to three steps in the air handling unit, (1) indirectly by a cooling coil connected to the a cooling tower, (2) by a chilled water coil connected to a water chiller, and (3) directly. Steps 1 and 3 are always used at outside temperatures above 12 ^{o}C, step 2 only if needed to bring down the temperature before step 3 to 12 ^{o}C. Step 3 was also found to be an excellent air washer that removes pollen and dust from the supply air.

Gaz de France Research Centre, office building in Paris, France (9)

This office building near Paris uses an indirect evaporative cooling system that was chosen after extensive testing. In summer the plant is run at night to provide night cooling. During a very warm summer with very hot outdoor air the internal temperature raised above the comfort zone. The occupants should therefore be informed about the risk for overheating with this type of low-grade air-conditioning system. Experience gained from reported deficiencies will be used when planning new plants.

- **Desiccant Cooling**

InfraCity Commercial Centre, office building in Stockholm, Sweden (15)

Desiccant cooling proved to be an interesting alternative when renovating a thirty year old office building only equipped with ventilation and no air-conditioning. The duct systems could still be used unchanged; only the roof mounted air handling unit had to be replaced. Both installation and annual costs were found to be lower than for a conventional system. The users were very satisfied and the same type of system has also been chosen for other buildings within the same area. It is important to use a low cost source of energy for regenerating the drier; in InfraCity district heating water is used and bought at low summer prices.

- **Ventilated Chilled Beams**

With this system the temperature in each room is controlled individually by chilled water supplied to convector coils at ceiling level. Two Finnish office buildings demonstrated this technology.

The Granlund Office Building, office building in Helsinki, Finland (18)

The office rooms of this building have high heat loads necessitating cooling. This was achieved with ceiling mounted cooling beams used in as room units. By using free cooling the energy use was reduced by 38 % compared to mechanical cooling.

The Wärtsilä Diesel Building, office building in Vaasa, Finland (17)

This renovated office building with high internal loads was provided with chilled beam room units combining cooling and air distribution. Mechanical and free cooling are used in parallel. Existing radiators are used for heating.

- **Chilled Ceiling and Displacement Ventilation**

In both these cases, in France and Germany, the systems were installed as part of a renovation of the buildings. The users are reported to be satisfied not only with the thermal climate but also expressed satisfaction with the silent system. As the main part of the cooling load is carried by water, the air flow can be reduced to cover only the hygienic air flow necessary for the air quality in the room. The system requires a ceiling height that permits the installation of the false ceiling and in the French study also a raised floor for the supply air distribution).

The Nestlé France office building in Noisiel, France (10)

This is a historic building that was renovated and equipped with a chilled ceiling that, by changing the water loops, is used for heating in winter. The supply air to the rooms is distributed via ducts in a false floor to supply air grilles under the windows thus keeping the floor area free from terminal devices.

The Hamburg Regional Bank, office building in Hamburg, Germany (11)

An old high-pressure air system no longer met the requirements and had to be replaced. Several alternatives were evaluated. The chosen system was found to result both in large energy savings and to reduce installation costs compared to a conventional air-conditioning system.

- **Ground Coupled Reversible Heat Pump**

The Advanced House in Laval, single-family residence in Laval, Quebec, Canada (3)

As should be the case with an advanced house, this building comprises several innovative solutions. The cooling system utilizes two rain water storage tanks, two ground water wells under the slab and a reversible heat pump, operating in this order at raising indoor temperature to cool the supply air to the house.

- **Ground Cooling (Air)**

The Schwerzenbacherhof, office and industrial building in Schwerzenbach, Switzerland (12)

The supply air is cooled in summer and preheated in winter as it passes through an extensive duct system in the ground under the bottom slab below the ground water level. The system has proved to function well both in summer and in winter operation. It has provided the occupants with a thermal climate within the comfort zone. For this type of system it is important for good performance that the bottom slab is well insulated to keep it isolated from the ground coupled system.

- **Aquifer**

Both these plants, in Sweden and in Netherlands, have worked very well and have proved that aquifers constitute a both reliable and cost-saving alternative provided that the local geotechnical conditions are suitable. The advantage with this solution is that it provides an annual energy store where the cold well water picks up the excess heat from the building in summer and stores it for use in the winter and vice versa. In both cases it was found that the plants were equipped with control plants ensuring that the aquifer storing capacity is used in an efficient manner both in winter and summer.

SAS Frösundavik, office building in Stockholm, Sweden (16)

The plant has had 100 % availability; it has reduced the annual operating costs considerably and has saved 65 % of the energy needed with a conventional plant. The room cooling is achieved by using cooling panels connected via a heat exchanger to the cold well loop. The ventilation air is cooled in summer and preheated in winter by aquifer water pumped through a second heat exchanger also connected to the heat pump evaporators. The heat pumps are connected to the final heaters of the air handling units and to the tap water heater.

Groene Hart Hospital, hospital building in Gouda, Netherlands (8)

The plant has shown considerable savings on both natural gas and electricity. During extremely warm periods or at the end of the summer season when the cold well temperature is relatively high, a cold buffer can be formed in the aquifer at night to be used the next day.

- **Sea Water Cooling**

The Purdy's Wharf, commercial centre in Halifax, Canada (4)

The two large buildings located at the waterfront of Halifax are using free cooling from the cold sea water during ten months of the year. The salt sea water is run in an open loop through a titanium heat exchanger cooling the closed fresh water loop used for cooling the building. During fall when the sea water temperature raises above 10 ^{o}C the sea water is used to cool the condensers of two water chillers. The annual cost savings due to reduced electricity load are high giving a simple payback or about two years for the plant.

PARTICIPATING NATIONAL EXPERTS IN THE ANNEX

Twenty-two national experts have substantially contributed to the Low Energy Cooling project:

Canada

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Fraser & Associates
Calgary

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Finland

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