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A novel concept of façade for daylighting and natural cooling

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Abstract

The role of metallic surfaces is not only to save energy in winter and in summer by separating the inside and the outside. New and inexpensive ways of collecting solar energy for internal heating, new ways of ventilating, heating and cooling through the fabric elements are described. Two very significant prospects are: radiative cooling by metallic surfaces and enhancement of indirect daylighting by optimised ceilings. The subject of the European CURES program is to promote these new technologies by simulating and testing them.

INTRODUCTION

The companies who created the CURES consortium consider that there is a potential for improved daylight and natural cooling in office buildings with a number of new steel made components. The undertook research on a novel concept of facade is part of a project entitled 'Components for Use in Renewable Energy Systems' (CURES) under a European Commission contract (JOR3-CT96-0102) managed by Dr Georges Deschamps. The project belongs to the JOULE research and development programme on non nuclear energy technologies [1].

The objective of the work is to produce a manufacture demonstration of a serviced ceiling component and of a facade component appropriate for industrial production. They will have good aesthetic and durability qualities, and will be capable of production at minimum cost while giving significant improvement in energy consumption and user comfort. They will be for application on either new build, or for retrofitting on the existing building stock.

The members of the consortium and their specific objectives are :

- Sollac, steel manufacturer, to produce innovative steel components ;
- Sir Norman Foster, architect, to promote new aesthetic concept of facade ;
- Setec, thermal consultant, to simulate and carry out experiment ;
- EDF, electric utility company, for its knowledge of innovative buildings for its own use and its customers;
- Energy Centre of Ecole des Mines for its knowledge of thermal computation.

BACKGROUND INFORMATION

Architectural characteristic of metallic construction

Metallic surfaces in buildings can take many aesthetics and can realise many thermal functions at the same time. When correctly coated, such surfaces can insulate, heat, cool, light.

The metallic building presents some uncontested advantages (lightness, assembly quickness, design freedom, savings) which are largely developed in industrial, commercial or farming buildings, and gains ground in public amenities (high schools, gymnasiums, station buildings, airports...). However from here it is a long step to having gained control over the domain of non residential buildings and private house sectors, except a few particular sectors like cyclones areas. Specific benefits in terms of daylight or thermal performance have to be found and have been found recently.

Daylighting characteristic

The evolution of modern architecture leads to give more place to natural lighting. The "international" glassed architecture is the reference everywhere, adapted or not to climate.

As in car industry, where the designers impose glazing surfaces larger and larger as well, the engineers attempt in building construction to control the overheating effects by a control of solar penetration. In particular, all the new facade glazing allow to some spectral filtering, inferior to those developed for the car market.

On hot days with a high solar angle, users are turning on their lights to counteract the glare from the sunlit landscape outside the window, and the relative darkness of the office space. The solution we are investigating involves throwing daylight on to a reflective ceiling so that the space appears to be brighter. The Commerzbank Headquarters in Frankfurt is an example of natural daylighting.

The architect has to avoid too violent contrasts, which is the reason for the frequent resort to natural indirect lighting [2, 3] reflected by the ceiling. We have to help him with optimised components. Porch roofs and sunscreens made of steel exist ; their properties of reflection, diffuse or direct, remain to optimise.

Thermal characteristic

From a comfort or energy savings point of view, the metallic construction is not well thought of ; it still refers to volumes difficult to heat in winter and overheated in summer [4]. Regarding heating, the metallic surfaces ("radiators") have quickly taken over at the end of 19th century from the hot air systems, except in the US. The metallic heating surfaces are placed in general along the vertical walls, to benefit from radiation and convection both.

With the traditional air-conditioning, the air is still the dominant vector [5]. However, in Germany, the cooling ceiling has been developing for a decade ; it is an irrigated metallic surface, used as false ceiling and designed to ensure both convective and radiative transfer. In that case, the fluid is water which has better thermal exchange characteristics than air. This technology, noiseless and with low air speeds, is also developing currently in France. As an example, we can mention the rehabilitation of the head office of Nestlé company by Clestra.

Its cooling power is limited except if one finds optimised radiative coatings or some other way to enhance heat extraction. If the ceiling is both chilled and daylit, it will remove the heat from the sunlit patch before it can warm up the room (besides reducing the heat produced by electric lighting). As a sunlit patch will be much warmer than the ambient room temperature, the water in the chilled ceiling will be able to carry away greater quantities of heat than from the areas that are not sunlit. In other words, the room can be more brightly lit than a traditional sunshaded space without discomfort to the user and while still using a water-based system for cooling.

OVERALL SYSTEM

The current research project is based on lessons learnt from a previous low energy building for EDF in Bordeaux, by the architects, Sir Norman Foster and Partners.

That building achieved a 39% reduction in energy consumption compared to similar EDF buildings, by providing sunshading, combined with a reflective light shelf, and using a chilled/heated floor together with night cooling.

Further possibilities were apparent that were to be the basis for our work in this project.

There are three basic options for the components (See Figure 1). One is to reflect heat gain outside while still providing good levels of daylight inside ; the second one is to use solar irradiation to heat the space during winter ; the third one is to carry away excess heat in summer from occupied space through a ceiling component to provide comfort conditions without altering ambient temperatures.

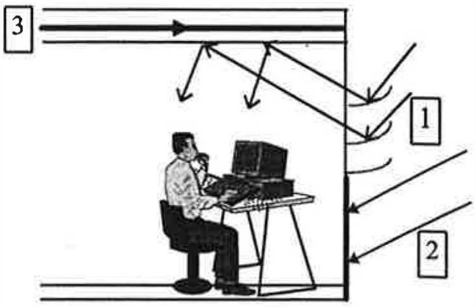

Figure 1. The three principles used

Facade component

The facade component will reflect solar gain before it reaches the room (a classical-sized office), so that it will not actively heat the space. Thus, it will reduce peak loads for cooling so that a chilled ceiling will be adequate. The facade is divided into two zones ; an opaque highly insulated zone used as solar collector (2), a transparent zone with reflector panels to maximise daylight penetration at high level onto the ceiling (1).

We looked at currently available technologies to see if any could serve as a starting point.

Transparent insulation material sends too much diffuse light and heat into the room. This can be controlled by an external blind but the consequent reduced diffuse light can make the room look gloomy.

Interstitial venetian blinds [6, 7] are prone to mechanical failure. They do not send light very far back into the room and are not recommended for use in windows with opening lights that open far enough for effective natural ventilation.

Existing fixed interstitial reflectors tend to obstruct the view and are recommended for rooflights only.

We developed a geometry of reflector that had minimum impact on the view through the window.

We first of all looked at a ventilated Klima facade with highly reflective special profile reflectors.

We developed geometries that would send sunlight, regardless of time of day or date during the cooling season, onto a controlled area of the ceiling. They may be ventilated with external air for a better prevention of solar gains transfer to the inside (See Figure 2).

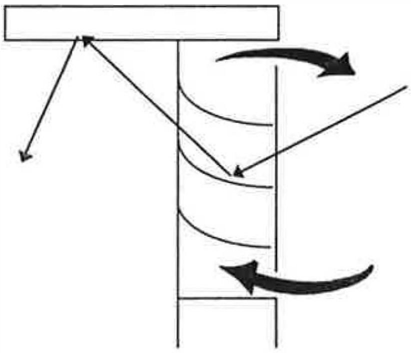

Figure 2. Ventilated zone of facade (with reflectors)

Ceiling component

The ceiling component (3) has two objectives. Firstly it allows cooling and heating to be water based rather than air based, cutting down on the energy needed to move heat around the building. Moreover, it is very important that the visible spectrum of daylighting is maximised, and that it is homogeneously distributed on the working surface. To achieve this, the ceiling will also act as a reflector delivering daylight as deep into the room as possible.

The output from the ceiling could be further increased by using the ceiling voids as an air supply plenum. Instead of a displacement ventilation system we suggest to throw fresh air under the ceiling. The maximum power of the ceiling is thus expected to be improved by increasing convection. The same principle lead us to design a "double face" ceiling with an active face towards the office and another one towards the ceiling. The latter would exchange heat or cool by convection with the fresh air blown into the false ceiling.

While the technology for the chilled ceiling is relatively straight forward, we rely on an hypothetical sunscreen that can throw sunlight in a controlled way on to the ceiling.

STUDY OF CURES CONCEPT

Heating and cooling plants

In winter, hot water is produced by vertical solar collectors located on the south facade. Those collectors supply the corresponding ceiling for each office cell with water through a local storage.

In summer, cold water is centrally produced by an absorption chiller which is supplied with hot water by horizontal solar collectors located on the roof. A central storage between solar collectors and absorption chiller is realised with a water tank with an electric extra back up.

Simulations

Two kinds of simulations were made for two sites, Lille (France) and Madrid (Spain) and with hourly meteorological data for a real year (1996 in Lille and 1995 in Madrid).

HEATING AND COOLING NEEDS

The first simulation is a dynamic simulation of the thermal behaviour of the cell. Convection, conduction and radiation phenomena as well as inertia are modelled so as to assess heating and cooling needs of the office cell (See Fig. 3, 4).

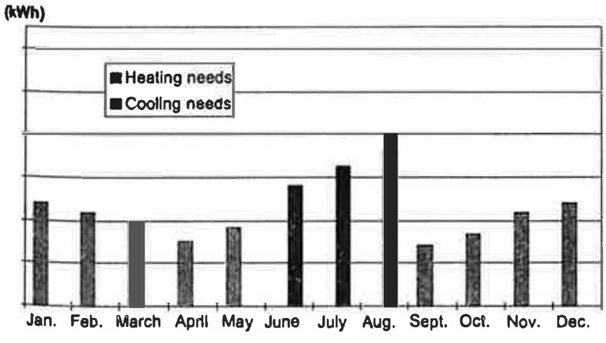

Figure 3. Lille, heating and cooling needs

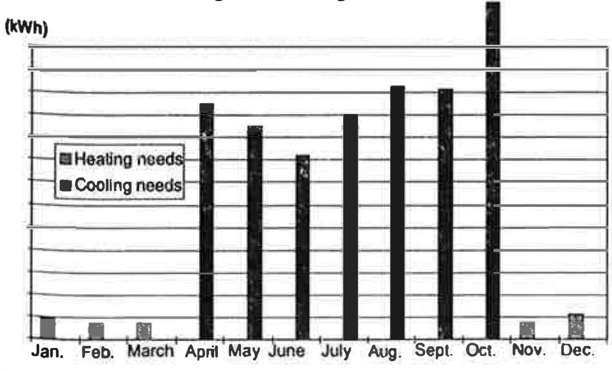

Figure 4. Madrid, heating and cooling needs

COLLECTED SOLAR ENERGY

The second simulation allows to assess the energy extracted from solar collectors located vertically on a south facade, in function of meteorological conditions, solar position and other characteristics (optical factor and loss coefficient).

Different types of solar collectors were considered and their performances were compared (See Figures 5, 6). The reference is a standard solar collector with a glass in front of it and an air layer. We improved this solar collector by adding a Transparent Insulation Material (TIM) instead of the air layer. This collector has better performance in winter but is more expensive. A very cheap solar collector is a steel made one, with no glass protection. Its winter performances are very low. However, it could be financially interesting because of its very low investment cost.

Actually if we compare the heating needs of an office cell and the energy recoverable in a steel solar collector (See Figures 7, 8), we notice that we provide a fraction of the heating energy required : from 16% in Lille to 50% in Madrid.

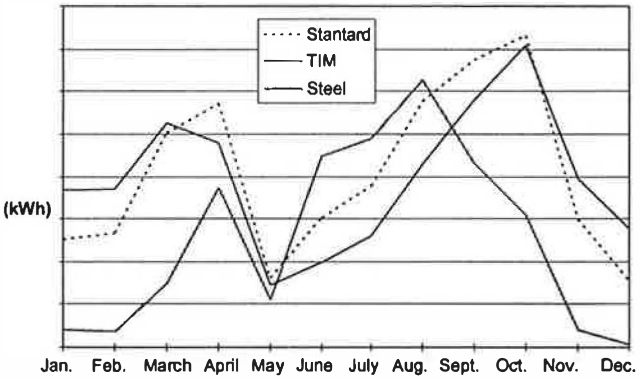

Figure 5. Lille, Energy collected from solar collectors ; orientation : south, water temperature: 30°C

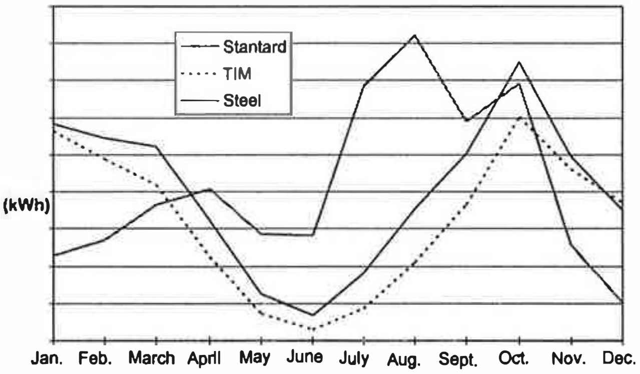

Figure 6. Madrid, Energy collected from solar collector ; orientation: south, water temperature: 30°C

Experiments

Experiments are being performed on PASSYS test rig in Cadarache (in the south of France). Firstly, the cell is set with a standard radiant ceiling, a standard collector with TIM and with reflectors.

The first measurement campaign will allow to check the simulations and to design a steel made ceiling and solar collector. The latter will then be tested during a second campaign.

The first results showed that the Klima facade was prone to drawing dust and airborne particles into the ventilated cavity, depositing them onto the reflectors, drastically reducing their efficiency.

Currently, work is underway incorporating them into a double glazed unit. We are looking at a 50 mm thick system respirant to allow for any pressure build-up due to the heating of the reflectors. First studies indicate that these reflectors may remove the need for solar control glass. This saving could go some way to paying for the reflectors.

These thicker glazed units can be incorporated in a facade system with insulated steel faced panels, or even solar collector panels.

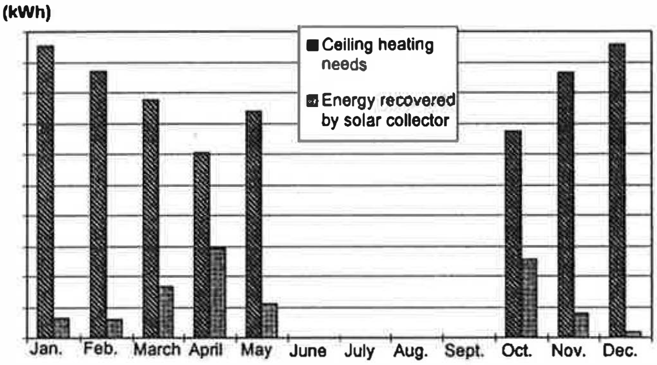

Figure 7. Lille, Ceiling heating needs and energy extracted from solar collectors

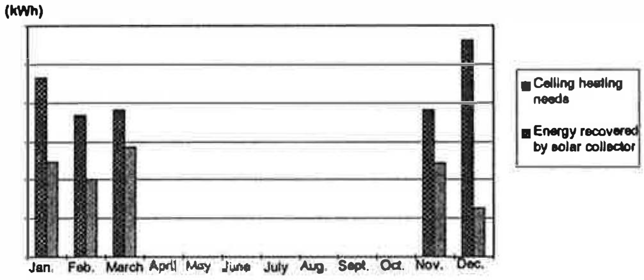

Figure 8. Madrid, Ceiling heating needs and energy extracted from solar collector

CONCLUSION

The final results of testing and consequently the final products will be known in a few months. The study puts forward the new advantages for steel used in construction : to improve daylighting, less expensive and more comfortable heating and cooling, together with traditional advantages of low inertia.

The partners are going to enter the European THERMIE program for industrialisation.

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