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Water-flow Gazing Curtain-wall and Ground Source Heat Pump as an Energy Saving Strategy in Buildings

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Abstract

Background: The thermal challenge raised by the use of traditional air-chamber glazing in contemporary architecture is not coherent with the current goals for buildings in terms of energy efficiency **Methods:** This paper explores the possibilities of the active water-flow glazing technology in the form of a curtain-wall, and its integration with a geothermal heat exchanger. A simulation is carried out in order to evaluate such installation, and the results of this simulation are then compared to real data collected from a built and functioning example in Spain. **Findings:** In order to evaluate the energy savings resulted from this installation, the two studies (simulation and real data) are followed by two parallel estimations of energy savings when compared to a theoretical electric energy expense in HVAC of a building with a more conventional building technology. The active water-flow glazing tackles the problem by flowing water through the chamber between glass panes; the windows become solar energy collectors, and a closed water circuit provides the building with the thermal inertia needed to prevent high temperature oscillations. Combining this emerging technology of active water-flow glazing with low-cost heating and cooling strategies such as geothermal exchangers, free cooling and seasonal heat storage would enable maximum use of daylight by a transparent glass façade and, at the same time, achieve Zero Energy Building performance. **Applications:** When compared to a traditional double-pane curtain-wall connected to an air-water heat pump, a combination of water-flow glazing and ground source heat pump proves to entail substantial energy savings (close to 40%) in a building's overall cooling costs.

Keywords: Energy Efficiency, Ground Source Heat Pump, Thermal Inertia, Water-flow Glazing

1. Introduction

A main feature in 21st Century Architecture is the lightness and transparency of its envelopes; large glazed surfaces increase the building's luminosity and allow for visual relations never accomplished before. However, glass is a poor thermal insulator[1]. Great part of the solar radiation passes through it, hence playing a major role in the building's climate-control system expenditure. The use of a glazed façade has the effect of introducing an excess of energy in the building due to solar radiation, becoming a disadvantage during summer months. The absence of "conventional walls" able to absorb this thermal load causes the interior space to overheat, with the consequent need to cool it by means of high energy-consuming air-conditioning installations.

New glass technologies address the energy problems arising from the use of large glazed surfaces in buildings: double and triple-pane glazing, layer coatings placed on the surface (such as solar control or low-emissivity coatings), thermochromic and electrochromic technologies, among others[2]. Acting on the space between panes has also been explored; both by vacuuming the chamber or by introducing an inert gas, the transmittance of the

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glazing is reduced and its thermal insulation substantially increases[3]. Among the solutions that tackle the energy problem by acting in the chamber between glass panes is the active water-flow glazing.

1.1 Active Water-flow Glazing

A water-flow window includes a circuit that allows a stream of clean water to flow within the entire space between two glass panes. Transmission and absorption of solar radiation in double-pane glazing depends on the specific spectral properties of glass; each pane has a different transmissivity coefficient depending on the radiation's wavelength. Clear glass is very transparent to visible and NIR wavelengths. Water, however, is transparent to visible wavelengths but opaque to NIR wavelengths[4]. Therefore, water changes temperature while circulating through the window, capturing most of the infrared solar radiation and allowing the visible component to pass through in Figure 1. This provides the surface with the same luminosity as conventional glazing, only lessening the heat transfer towards the interior space. Furthermore, the circulation of water through the chamber allows using, storing, or dissipating the energy captured by the water in motion as deemed appropriate[5].

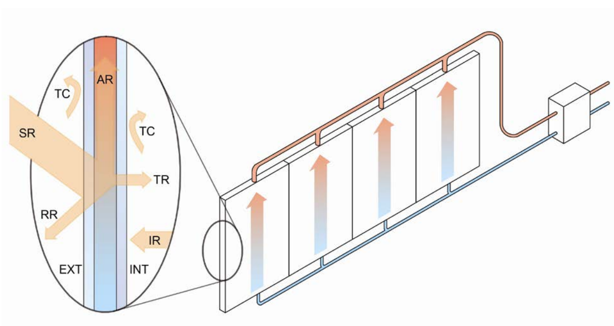

Figure 1. Diagram of the water-flow glazing's thermal behavior in summer conditions.

1.2 Contributing to Energy Efficiency in Buildings

Perhaps the most interesting application of this system is its use in exteriors: façades, curtain-walls, skylights and rooftops. Here is where the special characteristics of active water-flow glazing can be harnessed in order to reduce a building's energy consumption.

The basic thermal behavior of this technology is shown in Figure 1. The solar radiation (SR) striking the exterior glass pane breaks down into the heat absorbed by the water flowing upwards (AR), the reflected radiation (RR), and the heat transmitted towards the interior (TR). Added to these effects is the thermal convection (TC), due to the air in contact with the glass panes at a different temperature, and the interior heat load transmission towards the glazing (IR), since the interior glass pane is at a lower temperature than the overall interior air temperature.

This glazing technology reduces the solar radiation that penetrates the interior space without needing to reflect it outwards (as in the case of solar control glazing); the flowing water captures most of the solar radiation load, therefore substantially reducing both the reflected radiation and the thermal load transmitted to the interior space. The fact that the flowing water carries most of the thermal load allows for the development of a new set of strategies, such as seasonal or daily energy storage in buffer tanks, façade homogenization, as well as night cooling or evaporative cooling techniques. All of the strategies mentioned aim towards a close-to-zero energy consumption in the climate-control of a building, in line with the increasing regulations promoting energy efficiency[6].

1.3 The Role of Thermal Inertia in Active Water-flow Glazing Installations

Thermal inertia is one of the main factors in the building's energy performance, since it cushions the daily variations in the exterior temperature. By lessening these oscillations, the HVAC systems need much less power to cope with the thermal loads, therefore reducing consumption.

Active water-flow glazing increases the thermal inertia when compared to conventional glazing, due to the water it holds in its system. Since the water inside is in constant movement, it manages to reach a thermal inertia value comparable to that of other traditional construction elements (such as a concrete wall), by simply increasing the mass of the buffer tank. The glazing's thermal inertia can be regulated by means of changing the flow that circulates through them. The lower the flow, the lesser the damping effect.

Combining active water-flow glazing with a ground source heat pump benefits both systems[7–9]. On one hand, the active curtain-wall can circulate the water at a comfort temperature at a very low energy cost, taking advantage of the ground's thermal inertia. On the other hand, the ground temperature regenerates during the summer thanks to the heat captured by the water flowing through the façade, which is dissipated in the geothermal wells. Therefore, the water-flow glazing combines the efficiency associated to thermal inertia with the aesthetic values of 21st Century architecture.

2. Objectives and Methodology

The goal of this paper is to study the integration of active water-flow glazing with a geothermal heat exchanger, and to evaluate the energy savings in summer conditions when compared to a traditional curtain-wall and climate-control system.

To achieve this, firstly a simulation is carried out with a proprietary building physics software developed by the Polytechnic University of Madrid. This software is able to simulate the thermal and spectral behavior of active water-flow glazing.

A second study is then carried out, using real data collected from a built and functioning example of an active water-flow curtain-wall connected to a ground source heat pump and geothermal wells in Cuenca, in the region of Castilla la Mancha, Spain. Since this study is focused on the behavior of this installation during summer conditions, the data of three consecutive days in mid-July 2013 are chosen as representative and suitable for the analysis.

In order to evaluate the energy savings of this installation, the two studies mentioned above (simulation and real data) are followed by two parallel estimations of energy savings when compared to a theoretical electric energy expense in HVAC of a building with a conventional double-glazing curtain-wall connected to an air-water heat pump.

2.1 Simulation

The data introduced in the simulation is coherent with that of the built example (see 2.2), in order to later verify the reliability of the simulation and obtain comparable energy savings estimations.

Main data introduced in the program:

- Surface of the active water-flow façade: $10m^2$
- Orientation: West
- Latitude: 40ºN

The functional layout designed in order to simulate the thermal behavior of this facility is shown in Figure 2 a closed circuit distributes the water at a certain temperature (21ºC in the winter, 25ºC in the summer) throughout the 10 m^2 of water-flow glazing (WG). These active windows perform as solar collectors, aided by the circulation pumps. The closed circuit mentioned can include a plate heat exchanger (HE) to transfer the excess of energy captured by the windows to a buffer tank (BT). The volume of this buffer tank is 1000 m^3. The control system decides whether to dissipate the heat by means of geothermal wells (GW) or by the ground source geothermal heat pump (GHP). To determine the design flow per square meter, the maximum increase in temperature allowed between the windows' supply and return water is 7 degrees.

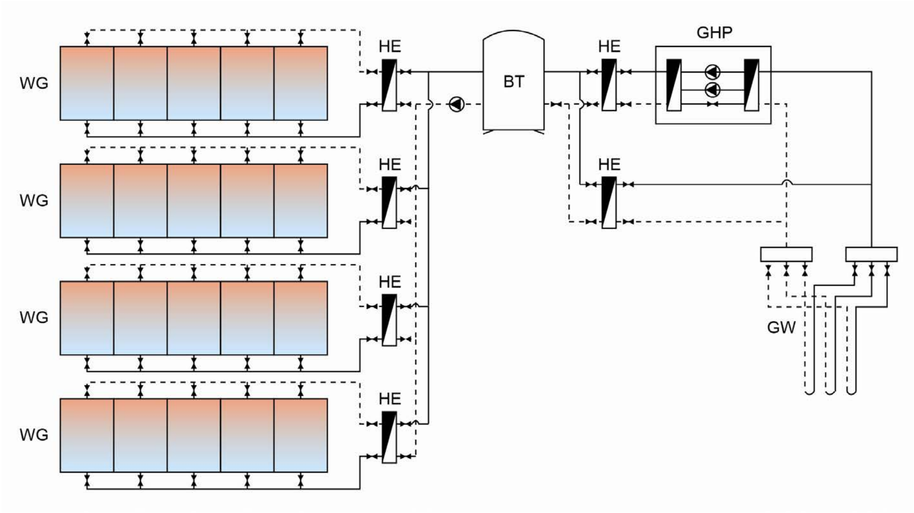

Figure 2. Functional layout of the facility.

According to the data shown in Figure 3, the peak solar load is considered to be 590W/m^2 for the West façade. Thereby, the design flow is 1 l/(min m^2) for the windows, and the total flow is 10 l per minute.

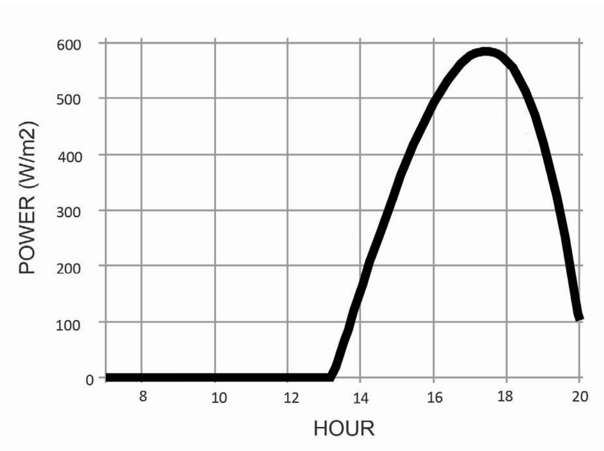

Figure 3. Simulated solar radiation striking 1m^2 of glass.

2.2 Real Data

The facility layout studied in this paper has been implemented in 2011 in a building in Cuenca, Spain: The Faculty of Journalism of Castilla La Mancha University Figure 4. This building has a west-facing 160m^2 active water-flow curtain-wall, connected to a geothermal heat pump and geothermal wells. The constant monitoring of this installation allows for the collection of real, on-site data from the sensors throughout the year. With an active water-flow curtain-wall facing west, the building is exposed to heavy heat loads during the afternoons see Figure 5.

Three consecutive summer days are chosen as representative and suitable for the analysis proposed in this paper: 15th, 16th and 17th July 2013.

3. Results

3.1 Results from the Simulation

Figure 6 shown the peak solar radiation that strikes the curtain-wall is about 600W/m^2 during the summer. If we consider a 10m^2 façade, there will be certain moments of the day in which 6kW of heat will have to be dissipated. However, when including the water-flow glazing, the water circulating through them heats up because of the

Figure 4. Exterior and interior views of the monitored active water-flow curtain wall in Cuenca, Spain.

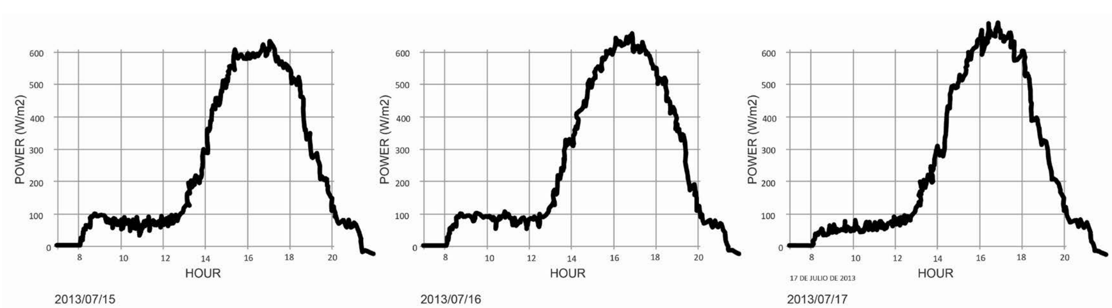

Figure 5. Solar radiation striking 1m^2 of glass for the 15th, 16th and 17th July 2013.

solar radiation and cools down because of the geothermal heat exchanger. This double effect reduces the need to cool the studied space.

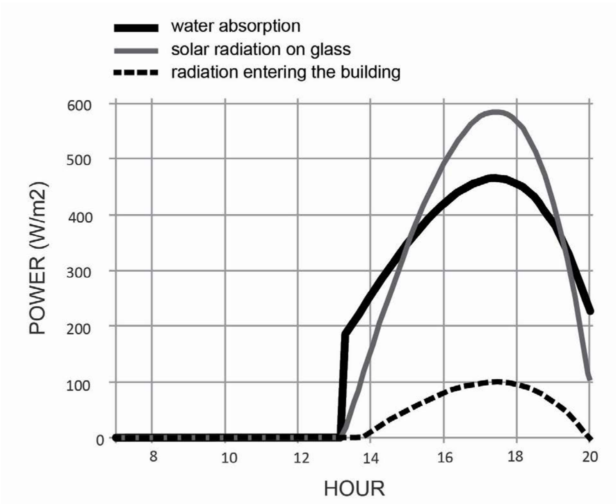

Figure 6. Simulation of the solar radiation breakdown when striking the active glazing.

The energy per unit of time absorbed by the fluid (or, in other words, evacuated by the glazing) equals the sum of acting energy fluxes: a portion of the solar radiation absorbed by the glazing plus the energy exchange with the outside air due to natural/forced convection and radiation, plus the energy exchange with the inside of the building due to natural convection and radiation.

$$\overset{\circ}{m} c(T_w - T_{ext}) = i_o S_e \alpha_w - h_{ext} S(T_w - T_{ext}) - h_{\text{int}} S(T_w - T_{\text{int}})$$

where:
$\overset{\circ}{m}$ is the water flow in Kg/s;
c is the specific heat of water in J/(kg K);
T_w is the temperature of the water between two glass panes;
T_{ext} is the exterior temperature;
i_0 is the solar radiation in W/m^2;
S_e is the surface of the window projected perpendicularly to the sun direction;
α_w is the absorption coefficient of the water chamber;
h_{ext} is the exterior heat transfer coefficient or film coefficient and
h_{int} is the interior heat transfer coefficient or film coefficient.

A large percentage of the absorbed energy can be easily evacuated into the water flow due to its high heat capacity (4.186 kJ/kg K) and can be stored in a buffer tank, providing sufficient thermal inertia to the system. A typical water-storage volume is 100 liters per m^2 of glazing. Figure 7 shows the temperatures obtained in the supply and return circuits that provide windows with water.

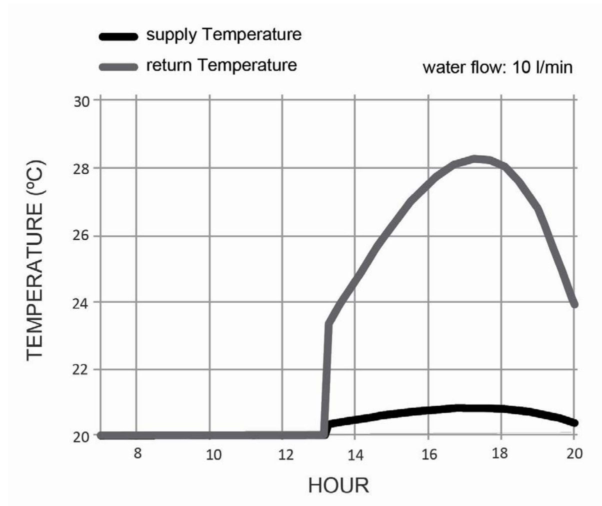

Figure 7. Simulation of the supply and return temperature of the water.

The energy absorbed by the water in the active façade is:

$$Q = \overset{\circ}{m} c(T_r - T_s)$$

Where:
Q is the power absorbed by the water in W/m^2;
$\overset{\circ}{m}$ is the water flow in Kg/s m^2;
c is the specific heat of water in J/kg K;
T_r is the temperature of the return water in K and
T_s is the temperature of the supply water in K.

The resulting energy absorbed within the active glazing is 24,4 kWh for a 10m^2 façade.

3.2 Results from the Real Data

The system works from 8am to 8pm; for the remaining hours, the water does not circulate. The highest air temperature recorded over the three studied days is 38ºC. As shown in Figures 8, 9 and 10, the maximum increase in temperature between the windows' supply and return water is 8 degrees and occurs when the maximum amount of solar radiation strikes the west façade.

Due to the increase of the curtain wall thermal inertia, interior temperature never exceeds 25ºC.

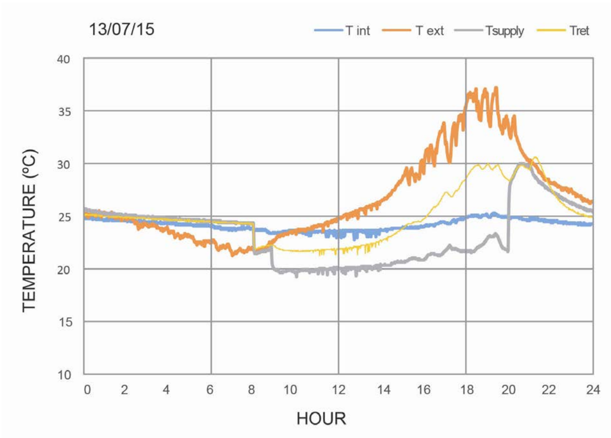

Figure 8. Relevant water and air temperatures from real data (15th July 2013).

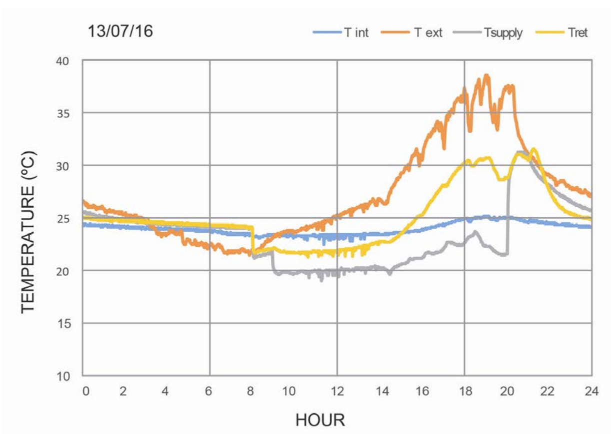

Figure 9. Relevant water and air temperatures from real data (16th July 2013).

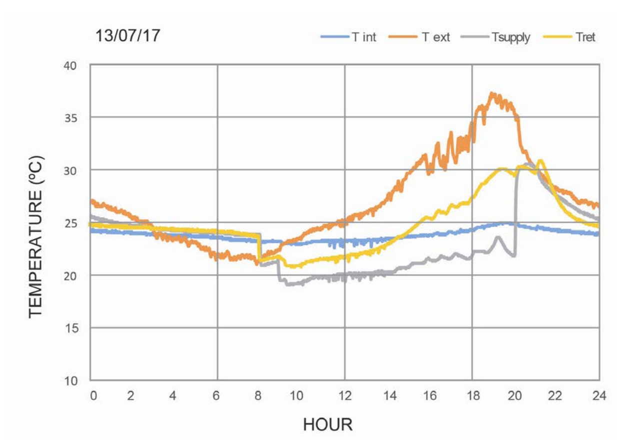

Figure 10. Relevant water and air temperatures from real data (17th July 2013).

4. Discussion

4.1 Energy Savings from the Simulation

As seen above, the resulting energy absorbed by the water for this simulation is 24.4kWh for a 10m^2 façade. If we consider the Coefficient Of Performance (COP) of the geothermal heat pump to be 4 (based on the specifications in the machine used in real conditions), we obtain an electric energy expense of 24.4/4 = 6.10 kWh/day.

The expense in a more traditional system, composed of a double-pane curtain-wall and an air-water heat pump, is estimated as follows: if the HVAC system is used in order to dissipate this energy (which otherwise would be absorbed by the water in the case of the active water-flow glazing) with air-water machines with a COP of 2.5 the expense in electric energy obtained is 24.4/2.5 = 9.76 kWh/day.

The energy saving when comparing the two systems described, therefore, is 9.76 – 6.10 = 3.66 kW/h, making the cooling expense for the proposed installation a 37.5% less than the more traditional installation.

4.2 Energy Savings from the Real Data

Table 1 shows the energy absorbed by the water when flowing through the active glazing is around 450-550 kWh/day.

Table 1. Energy absorption by water from real data

Date	Energy absorbed by water per 10m^2 active curtain-wall (KWh/day)	Energy absorbed by water, 160m^2 active Curtain-wall Kwh/day)	Electric energy expense (160m^2 active curtain-wall, cop=4) (KWh/day)
2013/07/15	35.79	572.68	143.17
2013/07/16	30.41	486.55	121.64
2013/07/17	27.97	447.56	111.89
Average	31,39	502.26	125,57

Estimated energy expense for the traditional system described in 4.1: 502.26/2.5 = 200.1 kWh/day. The energy saving therefore, when comparing the two systems, would amount to 200.1 – 125.57 = 74.53 kWh/day, which constitutes a 37,25% difference in cooling expense among systems.

5. Conclusion

Water-flow gazing, when applied as a curtain-wall, reduces the thermal gains in summer conditions and provides the system with the thermal inertia needed to reduce high temperature oscillations. This has a direct impact on interior comfort conditions without sacrificing the transparency of the glass. Alongside, ground source heat pumps have proven over the last years their suitability in terms of energy efficiency.

These water-flow window panels work as thermal solar energy collectors; they prevent radiation from entering the interior space, while the heat absorbed by the water is transported elsewhere. This allows for energy storing in a buffer tank, working as a pre-heating device for Domestic Hot Water.

The integration of active water-flow glazing technology with a geothermal heat exchanger is studied in this paper, proving to entail substantial energy savings in summer conditions (37,5% for the simulated data, 37,25% for the real data) in a building's overall cooling costs when compared to a traditional double-pane curtain-wall connected to an air-water heat pump.

All in all, combining the emerging technology of active water-flow glazing with low-cost heating and cooling strategies such as geothermia, free cooling and seasonal heat storage would enable maximum use of daylight by a transparent glass façade and, at the same time, achieve Zero Energy Building performance.

6. Acknowledgement

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