Evaluation of evaporative cooling of walls in hot climates

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When a cooling based climate is considered, evaporative cooling of outer walls during summer can be a very valuable tool for reducing cooling energy from outer skin of the buildings. Simulation results show that applying an evaporative layer on the inner surfaces of the outer walls is more successful than the thermal insulation in Mediterranean climate.

Keywords: Energy efficient buildings, Evaporative cooling of walls, Mediterranean Climate

When a cooling based climate is considered, evaporative cooling of outer walls during summer can be a very valuable tool for reducing cooling energy from outer skin of the buildings. There are some solutions in the literature based on this principle. However, applying such an evaporative layer on the inner surfaces of the outer walls is a novel approach. At this stage only the idea has been evaluated.

A case study, in which the target is reducing cooling energy (heat gains) from outer walls for energy conservation has been conducted. Cooling inner surfaces of the outer walls reduces heat gain from the outer walls and more importantly increases the thermal comfort indoors in summer conditions by decreasing the wall temperatures.

Simulation results show that this system is more successful comparing to the thermal insulation in Mediterranean climate. Depending on the design parameters the peak heat gain through the outer walls can be compensated by the system without any additional insulation layer. Even in some favourable conditions an additional cooling effect can be achieved besides avoiding heat gains from outer walls.

Introduction

The definition of energy efficiency measures and packages are strictly related to the climate, considering both temperature and humidity. Therefore, for hot and dry regions, specific solutions are certainly required. In particular, Mediterranean climate is characterized by a dominant cooling demand and varying outdoor conditions along the day.

Behaviour of outer walls plays an important role on heat gains and heat losses of the building. Thermal insulation of walls is known as an important measure to reduce static heat loss of buildings for cold and mild climates. However, increasing thermal insulation thickness plays a reverse effect on heat gains due to dynamically changing outdoor conditions for hot climates [1]. Instead of increasing thermal insulation thickness, evaporative cooling of outer walls can be used reducing cooling energy from outer skin of a building in such climates.

An evaporative layer to be applied on the inner surfaces of outer walls has been designed to reduce the cooling energy of buildings in Mediterranean region in this study. This can be considered as a new approach.

This work presents a case study. A building in Mediterranean region has been considered as an air conditioning system that keeps indoor temperatures at the required level. The target is reducing cooling energy (heat gains) from outer walls for energy conservation. The proposed heat absorbing layer basically consists of two plates with a gap between them and it is applied on the inner side of the outer walls. Indoor air passes through this gap from bottom to top, across all the length of the wall. Back plate is actually a moist pad and evaporation of water from this pad creates a cooled wall surface. Cooling inner surfaces of the outer walls reduces heat gain from the outer walls and, more importantly, increases the thermal comfort indoors in summer conditions.

A dynamic computer model has been developed to simulate the system. This model can consider the effects of thermal mass of the wall too.

It is shown that this system is successful in Mediterranean climate. Depending on the design parameters, the heat gain through the outer walls can be compensated by the system without any additional insulation layer. Even in some favourable conditions an additional cooling can be achieved. This layer is also effective during the winter conditions. In winter season, the layer is used in dry state and it reduces the heat loses.

Methodology

A standard building in Izmir-Turkey is considered as the reference case in this study. Izmir is selected as the representative of the Mediterranean climate. The building is a two storey residential house with 512 m^2 total floor area. Total outer wall area is 314 m^2 and only 211 m^2 of this wall can be covered by the proposed layer. Density of 5 cm thick concrete external walls is 1,600 kg/m^3. Thermal mass is an important parameter effecting on thermal performance of the building skin and this value has been parametrically studied in this paper. 5 cm thick thermal insulation is necessary, in this case, to remain within the limits of the standard. All other external and internal heat gains/losses have not been taken into consideration in this study.

It is assumed that there is an ideal HVAC system which controls indoor temperatures ideally. Cooling set point temperature is 24°C for summer period. Heating set point temperature is 21°C during the winter period. Total ventilation air rate is 1,013 m^3/h which corresponds to 0.66 air change per hour.

Evaporative cooling layer modules

This approach is based on a modular evaporative layer to be applied on the inner surface of the outer walls. This layer is to be attached to the wall surfaces tightly by screws and it should be leak-proof. The drawing of a module is seen in (**Figure 1**). These modules can be connected to each other and all the outer wall inner surfaces can be covered with these elements. Frame of the module is steel and the panels of the module can be either plastic or sheet steel. There is a porous pad attached to the back-side panel of the module, there is a gap for air flow between this pad and the front side panel of the module. The pad is made of synthetic fibers and it is wetted by the water dripping nozzles at the top. Gap dimensions and air flow rate have been defined by the help of the developed computer program. Room air is introduced to the gap from bottom of the module and this air picks up the evaporated water from wetted pad. Collected moist air at the top of the gap is exhausted to the outdoor by the help of a fan. This air circulation system can also be part of the mechanical ventilation system of the building. In this system, no moist air is introduced in indoors.

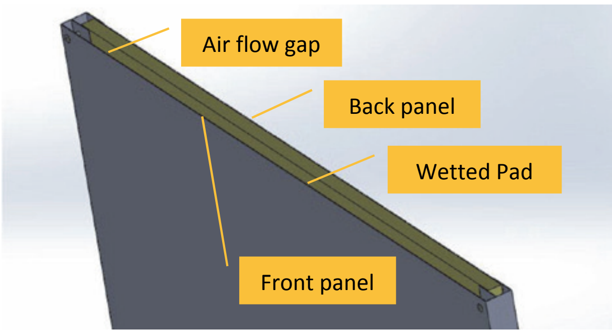

Figure 1. Drawing of the designed evaporative module.

Performance of the modules for the sample building

Two different cases have been studied as wetted pad in summer and dry pad in winter to evaluate the year-round performance of the proposed layer. Hourly temperature and humidity variations and the resultant heat gain/loss values have been solved for these cases. Using the model results, optimized dimensions, air flow rates and water feeding rates have been determined. Effects of wall thermal inertia have been investigated, performance of the proposed system have been evaluated.

The optimized air flow gap/clearance is 0.01 m and optimized air flow velocity is 0.8 m/s. Indoor air temperature (and the air temperature at the entrance of the layer) is 24°C and the humidity ratio of air is 0.0093 kg/kg for summer season. This humidity ratio corresponds to 50% relative humidity. Indoor air temperature (and the air temperature at the entrance of the layer) is 21°C and the humidity ratio of air is 0.0078 kg/kg for winter season. Hourly changing outdoor temperature and solar radiations on the outer surfaces of the wall in each direction have been considered as boundary conditions. Hourly weather data of the typical year has been taken from International Weather for Energy Calculations Database [2].

Evaporative layer performance: case a) wet layer in summer

In Case A, the pad is kept wet by supplying water from top. With the help of evaporation, inside wall surface temperatures can be kept below the room temperature. In these conditions, besides preventing heat gain from outer walls, an additional cooling effect is seen. A heat loss occurs from indoor air. Low inner surface temperatures also help improving comfort conditions due to radiative heat transfer between cooled wall and the human body. Mean leaving air temperature at the middle of the wall for the first week of July in a typical year is 25.3°C which is very close to the room air. Meanwhile, specific humidity increases from 9.3 g/kg to 17.6 g/kg in exhaust air. Leaving air specific humidity corresponds to approximately 70% relative humidity value. This humid and cool air can be used in a conventional heat recovery unit to reduce the temperature of incoming hot ventilation air.

Heat gains through cooling months are given in **Table 1**. Negative values indicate heat loss (additional cooling) and positive values indicate heat gain. Besides preventing heat gains from outer walls, additional cooling created by the evaporative layer along five cooling months, is 16,294 kWh. However, without applying this evaporative layer, total heat gain from same bare walls was 43,925 kWh. Thermal insulation can reduce the heat gain to a certain extent in summer months, but additional cooling effect cannot be created by only a thermal insulation. It seems adding such a layer inside the walls, causes much better performance than the thermal insulation for hot and dry regions and in dynamically changing outdoor conditions.

Table 1. Monthly heat gains of the building only from the outer walls [kWh].

	EvapWall	Bare Wall	With Isolation
May	−4587	4516	983
Jun	−2838	9885	2189
Jul	−2512	11637	2593
Agu	−2827	10452	2325
Sep	−3530	7435	1663

Evaporative layer performance: case b) dry layer in winter (no evaporation)

Heat loss should be reduced from the outer walls in winter. November, December, January and February are four winter months. The common solution for this is applying thick thermal insulation to the outer walls. Without any thermal insulation, mean inner surface temperature of bare wall is 16°C in a typical January week.

In (Case B) the pad is kept dry but the air flow continues. It is assumed that indoor temperature is kept constant at 21°C by the heating system in winter. Inside wall surface temperatures can be increased by the flowing warm room air in the layer gap. These elevated inner surface temperatures reduce the heat loss and also help improving comfort conditions. The mean temperature of air is 19.1°C in the gap and the mean temperature difference between the room and the layer is about 2°C. In winter conditions, this proposed dry layer can be considered as a heat recovery unit. Air flow rate is also the same as in the summer case and correspond to the ventilation air rate (total 1,013 m³/h). There could be a conventional heat recovery unit in the system, in this case, this layer and heat recovery unit work in parallel.

Heat loss through winter months are given in **Table 2**. Total heating energy for 4 winter months is 15,779 kWh. Without applying this dry evaporative layer, total heat loss from same bare walls is 25,413 kWh. This reduction is big enough to consider.

Thermal insulation is the most effective solution in winter. However, without any thermal insulation EvapWall decreases heat losses almost half compared to the bare wall.

Table 2. Monthly heat losses of the building only from the outer walls [kWh].

	DRY	BareWall	Isolation
Jan	−4572	−7352	−1652
Feb	−4011	−6465	−1443
Nov	−2494	−4020	−854
Dec	−4701	−7576	−1672

Annual performance of the proposed layer

Considering both summer and winter performances of the proposed layer, annual energy need for the building and the outer wall have been calculated. This performance value has been compared with the bare wall and the 5 cm thick insulation covered wall. Evaporative layer will work wet during the five summer months and will work dry during the 4 winter months. Building energy simulation has been carried out by using Energy-Plus software for bare wall and the insulated wall. Temperature set points are again 21 for four winter months and 24°C for the rest of the year with air conditioning system that operates 24 hours. Results are given in **Table 3**. Negative sign for EvapWall indicates additional cooling effect. All other figures are considered as load and there is no sign of differentiation for heat gain or loss in the table. March, April and October can be considered as intermediate season. Both cooling and heating are required during these months. However, outer walls in each case more or less perform as a cooling element and reduce total mechanical cooling load in these months.

According to these results, applying evaporative layer is the best solution for İzmir. The 5 cm thick thermal insulation reduces annual building energy requirement from **134,391 kWh** to **72,810 kWh**. Saving of energy is about **61,581 kWh** annually. However, in case of proposed evaporative layer, annual energy saving is higher comparing the thermal insulation. The proposed layer reduces annual building energy requirement from **134,391 kWh** to **61,380 kWh** and saving of energy is about **73,012 kWh** annually. It seems that this proposed system is advantageous for hot and dry climates.

Effects of wall thermal mass

Thermal mass of the wall highly influences the performance of the outer wall. When outdoor whether conditions change daily and heat loss and gain occurs in the same day, thermal mass of the wall becomes important. Increasing thermal mass improves the thermal performance in dynamic climate conditions. This is especially effective during intermediate seasons. Wall thickness has been doubled in this case study and all the calculations were repeated for the EvapWall case. Calculated heat loss values are given in **Table 4**. Because these values are always heat loss, the sign is negative. This monthly negative value should be as low as possible in winter and as much as possible in summer. In case of thick wall, heat loss decreases in winter and cooling effect increases in summer. This means increasing thermal mass acts positively in a year-round performance of the wall.

Conclusions

Evaporative layer to be applied inside surfaces of outer walls in Mediterranean climate is a novel approach.

Table 3. Total monthly heat (energy) lost/gain only from outer walls [kWh].

	Insulated wall		Bare wall		EvapWall	
Month	Heat loss/gain by the wall (kWh)	Total energy requirement of the system (heating or cooling) (kWh)	Heat loss/gain by the wall (kWh)	Total energy requirement of the system (heating or cooling) (kWh)	Heat loss/gain by the wall (kWh)	Total energy requirement of the system (heating or cooling) (kWh)
January	1652	6800	7352	12500	4572	9720
February	1443	6735	6465	11757	4011	9303
March	1430	4196	6178	8944	3804	6570
April	660	2700	3038	5078	1849	3889
May	983	4919	4516	8452	–4587	0
June	2189	8011	9885	15707	–2838	2984
July	2593	8025	11637	17069	–2512	2920
August	2325	10452	10452	18579	–2827	5300
September	1663	5493	7435	11265	–3530	300
October	127	3226	618	3717	373	3472
November	854	5803	4020	8969	2494	7443
December	1672	6450	7576	12354	4701	9479
Annual		72810		134391		61380

This novel element has been designed and its performance has been investigated in this study.

Simulation results indicate that this layer prevents heat gain from outer walls and provides additional cooling during summer period in İzmir conditions.

This layer can also be used in winter conditions as dry.

The other benefit of this layer is improving thermal comfort conditions of the indoor environment.

It has been shown that evaporative layer is the best solution for İzmir. In case of proposed evaporative layer, annual energy saving is higher comparing to the thermal insulation. The proposed layer reduces annual building energy requirement from **134,391 kWh** to **61,380 kWh** and the saving of energy is about **73,012 kWh** annually. ■

Table 4. Comparison of thermal mass on wall thermal performance. Monthly heat loss of outer walls [kWh.]

	EvapWall Heavyweight heat loss	EvapWall Lightweight heat loss
Jan	–4572	–5779
Feb	–4011	–5050
Mar	–8040	–8253
Apr	–6795	–6614
May	–4587	–3496
Jun	–2838	–1258
Jul	–2512	–734
Agu	–2827	–1145
Sep	–3530	–2194
Oct	–6194	–5699
Nov	–2494	–3153,
Dec	–4701	–5941,

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