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Upgrading the building envelope to reduce cooling loads

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ABSTRACT

Cooling buildings in summer is one of the main environmental problems for architects and builders in many Middle East countries. The weather during that period reaches peaks of more than 50 °C in some. Compressor air conditioners can solve the problem but they put a heavy strain on the electricity load. Evaporative coolers consume far less but sometimes do not lower the temperature enough for comfortable living. A procedure was tested for this research to combine the best of both by employing evaporative systems to cool only the structural envelope. A test building was modified in Baghdad, Iraq to test the system. The roof was cooled using a pool in a tunnel like compartment. The latter was ventilated by a small fan. The walls enclosed a 10 cm cavity. Cooled air from a small evaporative cooler was pumped into it. The test results showed a drop in interior temperature of more than 10 °C to an average of 31.76 °C. This system allows a compressor air conditioner to be used to further cool the interior. Calculations revealed that after using it to reduce temperatures to comfortable levels, the cooling load was less by up to 88% compared to untreated rooms.

1. Introduction

The weather in Iraq is hot dry in summer and cold in winter. Heating in winter is not a big problem because of the availability of cheap fossil fuel. In the summer the situation changes considerably. The temperature inside the cities during the months of July and August rises to peaks of around 48–50 °C. The minimum hovers between 28 °C and 33 °C. This puts a heavy strain on the cooling loads of air-conditioned buildings.

There is an alternative cooling system which is much cheaper. That would be to use evaporative coolers. These are readily available, cheaper and need much less power. However they also consume water, which in some places is quite rare. Recycled grey water is suitable and may even be better than tap water. The soap content prohibits the buildup of salt precipitate. Furthermore, unlike compressor air conditioners, the temperature drop that they bring about increases with the rise in exterior temperature. Regrettably once the outside heat climbs above the 40°'s, this drop is not enough to provide a comfortable interior. The situation is further aggravated by the fact that evaporative coolers introduce higher levels of humidity to the room causing even less comfort.

Indirect evaporative coolers are more sophisticated variants and provide cooled output air with little or no additional humidity. However they are big, noisy, more expensive, and not available commercially in the Middle East. Although they are quite worthy, the reason they are so rare is that very few people are aware of their existence and benefits.

Combining evaporative cooling and compressor air cooling to cool a room has in the past not been possible. Evaporative coolers push in a large volume of fresh air from the outside which must be released from the room by an opening. This conflicts with compressor air conditioners because these depend on re-circulating the cooled interior air in an enclosed space.

This paper will attempt to combine the best of both systems. Evaporative cooling will be used to cool the building envelope without introducing any humid air inside. There will be no need to release any exhaust air from it. The interior space will remain completely insulated. It may then be cooled by compressor air conditioners. The difference is that the cooling load should be reduced by the cooler envelope.

Considerable work has been done on reducing the cooling load in buildings in hot climates. The work has spread along a host of possible solutions such as shading, earth shelters, plant protection of buildings, roof cooling using ponds and water sprays, ventilation, and double skin walls among others. Nahar et al. tested eight different passive cooling methods on roofs in particular and concluded "*The evaporative cooling has been found best for conventional roof*" [1]. The research most relevant to this study is that done on roof ponds, evaporative cooling, and to some extent, double skin walls.

Roof pond cooling is not a new subject. Several permutations have been developed. Hay and Yellot did work on a one room system in Arizona in the late sixties [2]. It was covered by insulation

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Table 1
Recorded data on performance of evaporative coolers in Baghdad.

Outside air temp (°C)	Outside air RH	Outside air WB (°C)	Output air temp (°C)	Output air RH	Cooling efficiency
24.9	58.2	19.2	22.3	84.1	62%
27	41	18	23	74.6	57%
32	32	20	23.8	78.3	68%
34.4	27.5	20.7	25.3	72.5	67%
37.5	23.6	21.8	27	74.8	67%
39.8	19.5	22.1	28.5	73.4	67%
43.5	16.2	24	30.3	73.2	68%
44.3	16.4	23.8	31.3	70.7	65%
Median					67%

panels during the day to keep the heat out. These were removed by hand during the night to let the water cool. This system was further improved by more recent work from the Arizona Solar Center [3] and the Passive Solar Research group in the University of Nebraska [4]. The pools used for their work were 6–12 in. deep. The Arizona Solar Center's "Passive Solar Heating and Cooling Manual" [4] describes how the pool will absorb the heat during daytime and release in the night. It explains that an average home will gain around 60–120 kwh on a hot July day. A 15 cm roof pond will rise only 4–8 °C from this heat and will be completely released during nighttime.

The "Nebraska Pond" attempted to avoid the winter problems associated with using a pool on the roof. They employed a rigid layer of insulation floating above the pool and a submersible pump. During the night water was pumped over the insulation to cool. The cold water would then seep downwards through the cracks in the insulation into the pond [5]. The insulation would help keep the water cool for the remainder of the day.

Runsheng et al. tested a system using floating wetted cloth [6]. Their findings concluded that this system performs slightly better than the pond with moving insulation.

Work has also been done on the mathematical and digital simulation of indoor temperatures in spaces cooled by a roof pond [7,8]. A general technical report meant to be a single stop reference on the subject has also been written [9].

Evaporative coolers have been in use for some time now. A great deal of literature regarding their use is available. Most research concentrates on cooling efficiency. Improvement is mainly achieved through changes in the wetting media. Claims of 80% and above have been made [10]. Saleem et al. tried several variations of Iraqi and imported media to increase the cooling efficiency of the system. They managed levels of up to 87% using special types of cellulose corrugated sheets [11].

Double skin walls are a more recent development and have been used in a few high rise buildings. The idea is to isolate the building shell from the hot exterior. They use naturally ventilating double walls to do so [12]. Actually the "walls" are usually window facades. Problems have risen due to difficulty of ventilating interior spaces and accumulation of dirt on windows that are difficult to clean. A paper by Naticchia et al. [13] tested the effect of using a water spraying system to cool the space in a cavity wall. They recorded that the experimental analyses showed the effectiveness of this technology. Miyazaki et al. studied the use of an evaporative cooled ceiling assisted by a solar chimney [14].

A study by Shaaban is worthy of mention because it uses actual walls [15], as does the system proposed in this work. He calculated the energy savings on the cooling load made possible by protecting the inner shell using an outer permeant wall. The wall was made of sun breaker looking elements covering all five exterior surfaces. The composition led to an inner shell completely protected from the sun but totally recipient to outside air movement. The test results were corroborated by a theoretical study. However his estimate that the system could offer savings of up to 65% is probably optimistic. Calculations using the Ecotect computer program show that shading a one room building 7.5 m × 4.5 m completely, in dry hot weather, reduces the cooling load by only 32%.

2. Evaporative cooling in a dry climate

The evaporative cooler is often described as being "green" or "environmentally friendly". This is because it delivers fresh filtered cool air to the interior using a fraction of the power that a compressor air conditioning unit does [10]. However, its cooling capability is not steady. A single unit's performance depends on a number of factors. These include the weather it is performing in and its own efficiency.

An evaporative cooler will drop the temperature more when the outside heat is higher and the humidity lower. This seems ideal for the Baghdad climate except for two drawbacks. Both of them have a negative effect on human comfort. The first is that output air from the cooling unit carries along with it considerable moisture. The second is that when the outside temperature passes 40 °C, the drop that the cooler provides is not enough.

Some thermal tests were conducted in Baghdad on a commercial evaporative cooler in July of the summer of 2006. The machine had a rated flow of 7600 m^3/h and maximum cooling of 16 kW. Temperatures were measured using laboratory mercury thermometers with a resolution of 0.2 °C. The cooler was placed outside in shaded conditions. It was typically left to operate for an hour until operating conditions stabilized before measurements were taken. The results are shown in Table 1.

As expected, when comfort values were calculated for these results, they were unacceptable at the higher temperatures. The conditions that were assumed for comfort calculations were as follows:

- Sedentary activity.
- Light clothing of trousers and T-shirt.
- The air movement caused by the cooler was rated at 0.5 m/s.
- Radiant temperature equal to the indoor temperature.

The results of the calculations are in Table 2. PMV and PPD are short for "Predicted Mean Vote" and "Predicted People Dissatisfied".

The table shows that while the outside temperature is around 37.5 °C the PMV rating is good and the PPD acceptable at 8%. How-

Table 2
A few thermal comfort figures related to evaporative cooler output.

Outside temp (°C)	Indoor temp (°C)	Indoor RH	PMV	PPD
37.5	27	74.8	0.28	8%
39.8	28.5	73.4	0.95	24%
44.3	31.3	70.7	1.80	67%