INVESTIGATING THE ROLE OF EXTERIOR CAVITY WALLS IN IMPROVING  BUILDING ENVELOPE THERMAL PERFORMANCE THROUGH REAL-TIME DATA  MONITORING AND SIMULATION

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ABSTRACT

Integrated cavity-wall systems are typically designed to shade the exterior of buildings. They can also eradicate day-time heat absorption by thermal convection. The combined heat loss through the natural night-time blackbody radiation, the cavity wall shading effect, and the thermal convective loop results in a significantly improved building envelope performance.

This paper outlines the design, construction, and monitoring of a south-facing cavity wall system integrated into a single family residence in Southern Arizona. Implemented as a ‘heat transfer regulator’, the cavity wall functioned as a thermal break between the external and internal thermal forces through the south wall of the building envelope. The outside “Sol-air” surface temperatures of the cavity walls were found to be consistently lower than the standard non-cavity walls during extreme summer conditions. This was due to the combined effect of shading as well as stack-ventilation heat loss triggered by solar radiation received by the south cavity walls. Results from the monitoring and simulated yielded a minimized operation of mechanical system, reduction in energy consumption, and optimized human thermal comfort.

1. INTRODUCTION

In Hot-arid climates, extreme diurnal temperature swing occurs due to a natural regional phenomenon referred to as ‘blackbody radiation’. In such heat-dominated regions, intense solar energy absorbed by building envelopes through roof and walls during the day is radiated back into the clear night sky through blackbody radiation, thus helping cool the building. Furthermore, integrated ‘cavity-wall systems’ provide an added opportunity to shade the exterior of a thermal envelope and eradicate day-time heat absorption by thermal convection. Cavity walls consist of two ‘skins’ separated by a hollow space (cavity). Therefore, the combined effect of 1) heat loss through night-time blackbody radiation, 2) the wall shading effect, and 3) convective heat loss through the cavity, can improve building envelope thermal performance beyond conventional insulation.

Cavity walls are not new, they have been observed in ancient Greek and Roman structures. Some stone wall of cavity type construction at the Greco Roman town of Pergamum still exists. Cavity walls were first built in the United States late in the 19th century. However, it was not until 1937 that this type of construction gained official acceptance by any building or construction agency in the United States. Since then, interest in and use of cavity walls in this country has increased rapidly. This has resulted in extensive testing to determine cavity wall properties and performance.

2. PROJECT DESCRIPTION

In 2005, the University of Arizona’s College of Architecture and Landscape Architecture through the Drachman Institute, responded to a City of Tucson’s proposal to develop an energy efficient affordable housing demonstration project base on a high-end market-rate housing development at the edge of the City known as the Community of Civano²

Fig. 1: Barrio San Antonio site of the project in Tucson.
The project team proposed to develop the site to include five single-story residences, all vary between 1000 ft\(^2\) to 1400 ft\(^2\), and built with different construction materials for the purpose of comparing their performance through monitoring and simulation of data.

Fig. 2: Site plan of the proposed five residences.

Three of the five homes will utilize light-gauge steel framing, concrete masonry units and mud adobe constructions respectively, while the subject home is constructed using conventional wood framing. The compound of the five residences will become a community showcase of affordable, energy-efficient housing, demonstrating regional principles of sustainable design in hot-arid regions.

The house under investigation is called the DDDBC2 and is a single story three-bedroom 1072ft\(^2\) built with wood frame. The house long axis is facing south to take advantage of solar orientation.

Fig. 3: Floor plan of DDDBC2 wood frame house
Design: Richard Eribes    Drawing: Stefanie Gerstle

Intended as heat regulator, the vented roof is designed to have a single slope towards the east to facilitate the movement and dissipation of warm air collected on the roof and from the south wall. The south wall is designed to function as a thermal break and thus have a 3.5” air cavity vented towards the top of the wall with inlet vents from the bottom.

Fig. 4: Longitudinal west-east section

Fig. 5: Cavity wall located at the south-west corner

The objectives of the efforts for this project include the following:

- Analysis and synthesis of goals and outcomes of Civano energy and water conservation strategies to date, resulting in Guidelines for transfer of Civano-based technologies to the lowest cost strata of housing construction.
- Application of energy efficiency and water conservation technologies outlined in the Guidelines to the design of four model home plans and construction of two of these homes for affordable homeownership in Barrio San Antonio in Tucson.
- Monitoring of energy efficiency and water conservation data for one year for the first two homes built in Barrio San Antonio and modifications to model plan documents based on results.
- Dissemination of post construction evaluations of efficacy of strategies through public workshops and one-on-one consultation sessions with local builders/developers of affordable housing.

3. PERFORMANCE MONITORING

After the DDDBC2 house was constructed and occupied, the authors began the performance monitoring process. Data acquisition included monitoring and collecting both the site climate and the building surface and air moisture and temperatures. To first monitor the site climate conditions a
Central weather station was installed on a structure near the house and on the highest and most uninterrupted location. The weather station is capable of collecting eight major climate parameters including dry-bulb and wet-bulb temperatures, relative humidity, wind and gust speeds and directions, and global solar radiation.

- Bedroom and living room air and surface temperatures
- Living room mean radiant temperature
- Roof surface temperature
- Cavity wall surface temperature
- Cavity inlet and outlet air temperature
- Cavity air movement

![DDBC2 Weather Station](image)

**Fig. 6:** Students at CALA installing the station (above), and schematic diagram (below).

Indoor data collection was achieved through the installation of a HOBO U30 GSM Cellular Data Logger. It is a remote data logging and monitoring device with built-in cellular communications that can be reconfigured and adapted to measure a wide variety of parameters. Up to 15 channels of data can be recorded and monitored remotely via Onset’s web-enabled software platform.

Limited by the 15 parameters the U30 is collecting, the author strategically distributed different sensors around the residence to monitor the followings:

- Bedroom and living room air and surface temperatures
- Living room mean radiant temperature
- Roof surface temperature
- Cavity wall surface temperature
- Cavity inlet and outlet air temperature
- Cavity air movement

![Weather station, data logger, and sensors floor plan](image)

**Fig. 7:** Weather station, data logger, and sensors floor plan

Drawings by Stefanie Gerstle

![Cavity wall showing sensor locations](image)

**Figure 8:** Cavity wall showing sensor locations at the exterior surface of the assembly, inside of the air cavity, and the interior surface of the south façade, and at the inlet and outlet of the cavity.

During the monitoring phase, real-time data was
 instantaneous available for remote viewing by faculty and students with internet access from any location in the world. Twenty two sets of data were retrieved at 3 minute intervals and time-stamped every 15 minutes. Air movement sensors, as well as surface The author

4. DATA ANALYSIS

Data retrieved from the weather station was first analyzed to verify the accuracy of the installed systems. Solar radiation, temperatures and moisture data were found to be displaying responsive thermodynamic properties of moist air. On a diurnal cycle, morning solar radiation causes air temperatures to rise and relative humidity values to drop (see figure 9 below).

Figure 9: Thermodynamics properties of moist air as displayed by the data acquisition system.

Results from the collected cavity wall data demonstrated anticipated results. During the day in the extreme summer months the cavity wall accomplished two primary functions: 1) acting as a shading device, air temperature inside the cavity air space was reduced by up to 40% while 2) the direct solar radiation raised the Sol-air temperature of the exterior triggering a convective thermal loop resulting in increased heat loss.

For example, daytime air velocity in the cavity during August 21 was recorded at a high of 301.9 fpm (1.534 m/s) and a low of 139.5 fpm (0.709 m/s). Additionally, as heat was carried from the wall surface by convection, the daytime temperature of the inlet air at the base of the cavity was cooler than that of the outlet air from the top of the cavity by an average of 12°F. This observation, when combined with the shading effect and the nighttime blackbody heat loss, yielded a significant improvement in thermal performance of the building envelope.

Fig. 10: Performance of the cavity wall

To understand the effect of the rising temperature as the main force on the cavity convective air movement, a plot of the data in August 21st is illustrated in the figure below. As the sun rise about starts to hit the south façade, the temperature inside the cavity is on the rise thus triggering the convective loop. When the sun is setting, the temperature drops and now the air inside the cavity is still.

Fig. 11: Cavity convective loop is triggered by solar radiation.

5. ENERGY PERFORMANCE

To estimate the impact of the cavity wall on the thermal performance of the residence, a computer simulation was first conducted. Intention of the performance is to predict the energy consumption before and after the implementation of the cavity wall. This way, the contribution of the cavity wall can be assessed.

To simulate the house performance, The Energy-10 computer software was used. Energy-10 is a software component of a project to develop design guidelines for low-energy buildings—generally buildings 10,000 sq ft (1000 sq m) or less—that can be characterized by one or two thermal zones. It features the integration of daylighting, passive solar heating, and low-energy cooling strategies with energy-efficient shell design and mechanical equipment. The program facilitates decision-making early in the design process.
The purpose of ENERGY-10 is to keep the evaluation of energy performance simple so that it becomes feasible to incorporate into the design process of a small building. This is greatly facilitated by special ENERGY-10 features; AutoBuild, APPLY, RANK, and AutoSize.

The whole house energy performance was predicted and the cooling and heating consumption without incorporating the cavity wall design were found to be 6995 KWh and 3123 KWh respectively.

After the cavity wall was simulated the cooling and heating consumption values changed to 6600 KWh and 3273 KWh respectively. Although the heating consumption slightly increased, the cooling saving yielded an overall 5.8% saving (figure 12 below).

Figure 12: Energy savings as predicted by the E-10 simulation software.

If the cavity wall air inlet or outlet vents were operable, one could close them in the winter and allow the heating of the cavity to contribute to heating the space. This way the cavity wall will contribute positive savings for both the heating and the cooling consumption values.

6. CONCLUSION

Cavity wall design has been observed for a long time way back in the Greek and Roman structures. They gained official acceptance and application rapidly and thus underwent extensive testing performance prediction. The research team at the University of Arizona’s CALA implemented the cavity wall design as one appropriate energy conservation strategy in the desert southwest. A design/built single family residence demonstrated how a cavity wall system performed as a ‘heat transfer regulator’, and functioned as a thermal break between the external and internal thermal forces through the south wall of the building envelope. This was due to the combined effect of shading as well as stack-ventilation heat loss triggered by solar radiation received by the south cavity walls.

Results from the monitored data and computer simulations yielded an overall energy saving of 5.8%. The savings could have been optimized and increased if the cavity inlet or outlet vents were operable.

Although not documented in this paper for space limitation, the cavity wall also contributed to damping the temperature swing of the residence and contributed to increased thermal comfort.

7. ACKNOWLEDGMENTS

The author would like to recognize Professor Mary Hardin, director of the DDBC design/build outreach program at CALA for her collaboration and support of the project. Professor Richard Eribes, for the design of the DDBC house, Adjunct research professor Stefanie gurgle worked very hard with the author on the installation and configuration of the data acquisition systems, and the Homeowners. Last but not least the two senior students Heidi Grimwood and Amanda Spear who without their generous efforts and energies this work could have never been completed.

8. REFERENCES