Sustainable Construction Methods Using Ancient *BAD GIR* (Wind Catcher) Technology

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ABSTRACT

The 21st Century requires the incorporation of sustainable means and methods in all phases of construction to ensure that future generations will have the same benefits we currently enjoy. Leadership in Environment and Energy Design (LEED) is now moving the green building industry forward. The use of passive air cooling/ventilation systems is a technology that aligns itself with LEED requirements by promoting advanced energy performance through elimination of excess fuel/energy consumption to cool buildings.

Few modern passive air cooling/ventilation systems exist in the USA but one successful installation has been constructed at the Zion National Park visitor's center (ZNPVC) in southern Utah. Our research has investigated the use of an ancient Iranian passive air cooling/ventilation system called "*BAD GIR*" (meaning "wind catcher" in Persian) as an answer to the need for passively cooling structures in Southwestern U.S. Both Iran and Utah contain high desert plateaus with both having similar climates and topography. The constructability, methodology, and viability of *BAD GIR* technology for residential and small commercial applications in Utah and surrounding arid regions will be studied and proposed as an architectural structure for a visitor's center on the Timbisha Indian Tribal lands in Death Valley California.

INTRODUCTION

A basic requirement of life in mid-latitude arid or desert environments is that of obtaining a comfortable temperature inside one's living quarters. Because many ancient civilizations have sprung from mid-latitude desert environments the search for summertime comfort in those deserts has existed for as long as humankind has occupied them. The earliest examples of using passive residential cooling come from the oldest civilizations in North Africa and the Middle East. Models/drawings of dwellings kept cool by moving and storing chilled air have been discovered by archeologists and date from 3300 yrs BP in Egypt. These cooling systems were known in Arabic as *malquaf* architecture (Attia and de Herde, 2009) and consisted principally of buildings with thick adobe walls, few windows facing the sun, and air intakes facing toward the prevailing wind on one side of the structure with exit vents on the opposite wall. A later interior cooling system used ponds of water (Izadpanah and Zareie, 2011) on the windward side of the building, which cooled the air by evaporation as it moved across the pond before it entered the building. Centuries later this system was refined in the Persian Civilization to include structural variations, which allowed for better cooling in the high deserts of Iran. This region of Iran had earlier developed and utilized a sophisticated irrigation system which brought fresh water from the mountains through miles of hand excavated tunnels to irrigate fields in the lower valleys, which were known as *qanats*. These subterranean, cool irrigation waters flowing through the *qanats* allowed for a more efficient system called *BAD GIR* (meaning “wind catcher” in Persian) a marked improvement to the Arabic *malquaf* (see Figure 1).

Figure 1. *BAD GIR* tower in Tehran, Iran.

The *BAD GIR* system was a quantum leap forward in the effectiveness of cooling buildings. In one variation, air cooled by the *qanat's* cold water flowing below the surface was funneled into a building by digging an air intake into the *qanat* at an upstream location and another where the water flowed beneath the building. (Izadpanah and Zareie, 2011) This edifice would have a tower that rose above the level of the structure allowing the wind to flow through it, which would draw cool air (by the Coanda effect) from below through the building and out through the wind catcher tower (see Figure 2).

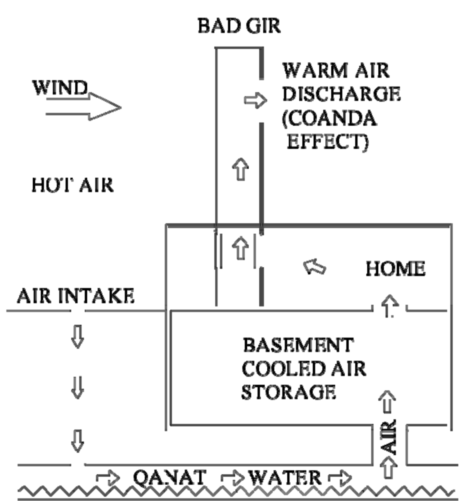

Figure 2. *BAD GIR* system coupled with *qanat* cooling.

A second variation was to use the water from the *qanat* stored in elevated tanks that would be used to moisten material in the top of the *BAD GIR*. Evaporation would then cool the air as it passed through the wind catcher, thus allowing this more dense air to settle down through the shaft cooling the interior of the building (see Figure 3). Both of these systems were eventually refined to the point that they could, at times, reach refrigeration temperatures (Javaheri, 2012).

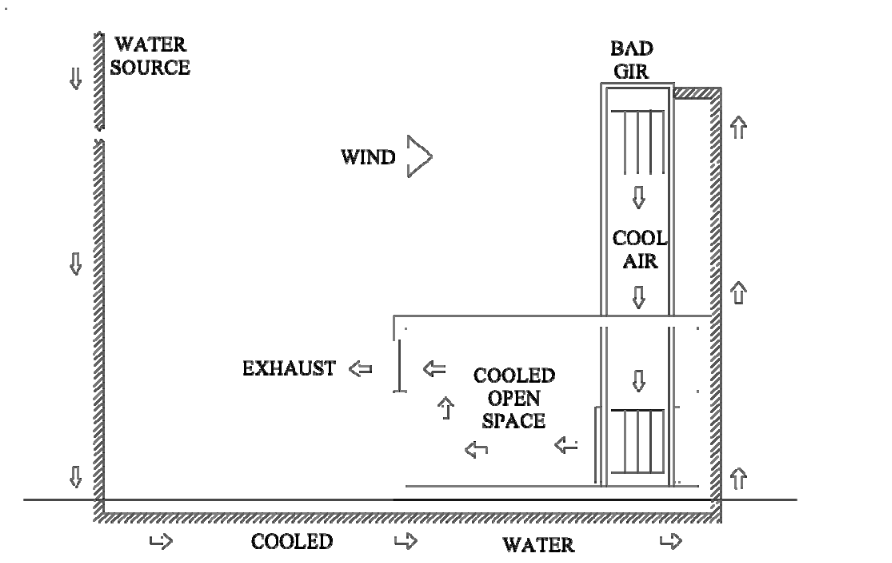

Figure 3. *BAD GIR* with evaporative cooling tower and elevated water source.

A modern example of utilizing wind catchers and other "green technology" for public buildings can be found at Zion National Park Visitors Center (ZNPVC) in Utah. The center utilizes wind catcher technology for summer cooling, a trombe wall for winter heating, plus solar panels for electrical generation. When visited by the authors in July 2013 the ambient outside temperature at Zion Park was 102° F (39° C) with a relative humidity <20% and a south wind at 3-5 knots. At the same time the temperature inside the visitor's center was 73° F (23° C) and the relative humidity >20% despite the constant foot traffic through double doors on the north side of the building. This structure offers complete comfort in both summer and winter seasons without the need for outside energy sources and, except for extreme situations, supplies its excess energy to the existing electric grid (Torcellini, et al., 2005). The building is proof of the design and effective use of green technology using the wind catcher concept for environmentally friendly cooling (see Figure 4).

Forward thinking designers and city entities are looking to alternative designs and green technology to help alleviate environmental degradation and reduce costs for the consumer. Even though central air-conditioning or evaporative cooling units may be affordable for mid- and upper-income individuals, these approaches to cooling can be financially difficult to obtain for lower income populations especially those in extreme rural conditions, which are epitomized by the American Indians found on reservations throughout much of the southwestern United States. We propose a plan that will implement *BAD GIR* wind catcher technology for a cultural center to be built for the Timbisha Shoshone on their tribal lands in Death Valley, CA to reduce their costs for cooling and minimize their carbon footprint by using the alternative *BAD GIR* technology.

Figure 4. Wind catcher tower at Zion National Park Visitors Center.

BACKGROUND

Students and faculty of Weber State University (WSU) have taken the initiative to develop a plan for the construction of a Timbisha Cultural Center and Museum (TCCM) on the Timbisha Indian reservation in Death Valley National Park, CA. This initiative has grown out of a long-standing relationship between the Department of Geography at WSU and the Timbisha Tribe due to annual Death Valley National Park field excursions by faculty and students to study desert environments.

Ongoing communication between WSU faculty and the Timbisha tribal leaders has developed into an overarching goal to work with the tribal members to construct the TCCM that will unify the tribe, promote their rich heritage, and educate the general public about this Native American culture. The Timbisha would like the TCCM to be built with green technology and have recently advertised for an "environmental specialist" to work within their tribal hierarchy (Hess, 2013). This specialist could help in the planning and construction of a "green" cultural center.

Timbisha Shoshone and Death Valley tribal land history

The Timbisha Shoshone are a small, Native American tribe with 285 enrolled members that suffer from 40% unemployment while 80% of the tribe's households fall below the 1993 poverty threshold of $13,950 for a family of four (Updike, 2001). This struggling tribal unit has made its home in the Death Valley region for hundreds of years where they survived by practicing “transhumance”, which is living, hunting, and gathering in the valley bottom during winter and then moving upslope to the surrounding mountains in the summer. Their transhumanic life-style gave them little or no claim to ownership of any part of Death Valley in the eyes of the U.S. government. In 1933, when President Franklin D. Roosevelt signed a bill creating Death Valley National Monument, the Timbisha were given no homeland and were confined by a subsequent 1936 bill to a tiny remnant (several acres) of their traditional lands, which were so unclearly defined that they were forced to move to different locations four times (Updike, 2001). They often found their homes destroyed when the U.S. government decided they were encroaching on federal domain. After struggling over 50 years with the U.S. Government the Timbisha were finally recognized in 1983 as a legitimate tribe but were given no land. On 31 October 1994, Death Valley National Monument was expanded by 1.3 million acres (5,300 km^2) and re-designated as a national park. Six years later with the passage of the Timbisha Shoshone Homeland Act on 1 November 2000, approximately 313 acres (1.27 km^2) near Furnace Creek in Death Valley National Park was deeded to the Timbisha with an allotment of water rights (Tamez, 2010). Overall, the Timbisha tribe has faced many challenges due to its small population size, location of their tribal lands inside a national park, and the actions of the U.S. Government. Today, the Tribal administrator Barbara Dunham conceded that the tribe now has its homeland secured but is worried that “our tribe is losing its culture…deprived of keeping traditions, songs, stories, cultural practices, and kinship” (Updike, 2001). For this reason she feels that a cultural center and museum would be the answer to the survival of the Timbisha’s tribal heritage (Durham, 2013).

Death Valley climate

Death Valley is known for environmental extremes thus, it is important to have an understanding of the weather and climate of the area where the TCCM would be built. Death Valley, CA is one of the hottest and driest locations in North America and recorded the hottest temperature in the world at 134° F (57° C) on the 10 July 1913. This record was retained for 10 years until it was eclipsed by a measurement of 136.4° F (58° C) taken in the eastern hemisphere at El Azziz, Libya (Roof and Callagan, 2003). Libya still holds this world temperature record but Death Valley claims to be the hottest in the western hemisphere. Summer temperatures in Death Valley are rather extreme with the hottest recorded summer having 161 days >100° F (38° C) and 119 days >110° F (43° C). This fact is important because the higher the temperature and the lower the humidity, the more efficient wind catcher technology can be. A second climatic factor to consider is wind direction and velocity in Death Valley. Because the valley is a “graben” or downthrown block of earth material between two north-south trending linear mountain ranges, this creates an elongated valley that orients the wind in the same direction. The wind generally blows toward the north in the summer and to the south in the winter (Roof and Callagan, 2003). The number of days with rainfall during the year is normally less than 12 but during the period 1931-1934 (coeval with the American Dust Bowl) only 0.68 inches (17 mm) of rain fell during a 5-year period. There have been several years since that time when no recorded precipitation has fallen (Roof and Callagan, 2003) making Death Valley one of the driest areas in North America.

PROJECT DESCRIPTION AND METHODOLOGY

It is proposed that a student-faculty construction project be undertaken for the completion of a Timbisha Cultural Center and Museum (TCCM) for this Native American tribe located approximately 0.5 miles (0.8 km) south of the Death Valley National Park headquarters. This project-based learning approach for students will build strong teamwork and communication skills plus broaden their perspectives on topics relating to environmental, economic, and social issues. The Timbisha center would be constructed with a similar design to that used for the ZNPVC (see Figure 5). The U.S. National Park Service and the National Renewable Energy Laboratory (NREL) utilized green technology and *BAD GIR* wind catchers for the ZNPVC project. The TCCM structure will be about 50% as large as ZNPVC with ~900 ft^2 (~308 m^2) open museum space and ~332 ft^2 (~93 m^2) of storage, utility, and staff support space. It is projected that the TCCM will utilize one *BAD GIR* cooling tower. The TCCM would be used principally as a tribal museum for the preservation of Timbisha history/culture and will attract visitors who wish to learn about the tribal customs.

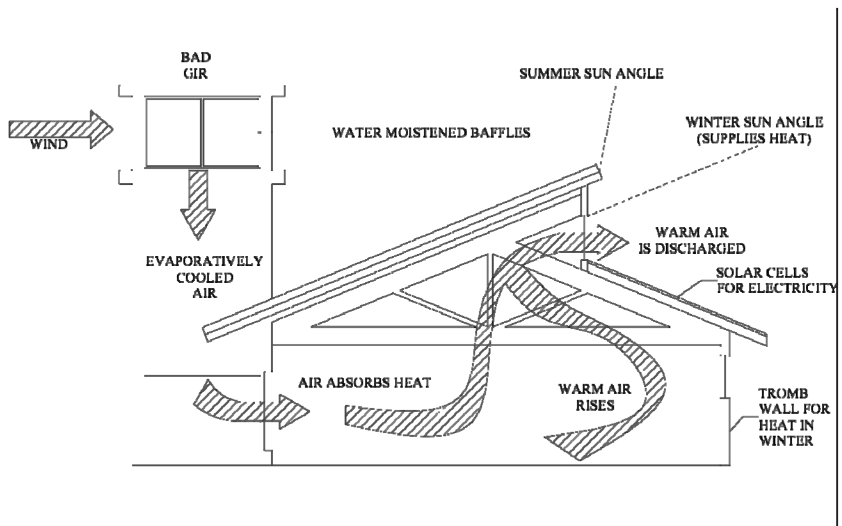

Figure 5. Proposed Timbisha Cultural Center and Museum (TCCM).

In order to assist with the building design and efficiency WSU Geography students will design an on-site weather station to record temperature, wind speed, wind direction, and solar radiation, plus develop sun-path diagrams. This station will record information through four seasons to gain an understanding of environmental conditions through the year. Weather data for the region will also be collected from Mesowest (http://mesowest.utah.edu/), a cooperative that collects and archives weather conditions across the United States. This information will be shared with WSU construction management technology (CMT) students who will engineer a workable design and create architectural, mechanical, electrical, and Building Information Modeling (BIM) for structural construction.

With faculty advisors and outside engineering consultants, both geography and CMT students will present the design to the Timbisha tribal leaders for approval. Once the design is approved, students would determine the construction schedule, cost estimate, and management plan for the TCCM project in Death Valley.

The authors spent time with James Butterfus (Park Architect), and Kirk Rose (HVAC Maintenance Technician) at Zion National Park. These Park Service employees felt that the National Park Service would be willing to share design and other information, to assist in the building of the TCCM structure. Butterfus and Rose shared the following "lessons learned" which will be incorporated into the TCCM project:

- Windcatcher (or *BAD GIR*) worked well in cooling the open spaces of the ZNPVC but weren't as effective in closed-off areas such as offices and storage space. We would, therefore, want to provide more open spaces in the design for the TCCM and limit office and storage space or possibly not include any.
- Collected daylight in the ZNPVC design was used to minimize electricity consumption. However, what was subsequently used for finishing the interior was pine tongue and groove paneling, which was esthetically pleasing but turned out to be darker than originally planned with less reflectance. In the TCCM design we would want to construct the ceiling and walls to be as white-toned as possible to improve reflectivity.
- Solar-electric or photovoltaics in the ZNPVC project turned out to be of poorer quality than those available on the market at the time. The TCCM project would need to carefully verify the efficiency and quality of all such materials considered for the project.
- The ZNPVC study originally had back-up electrical heat radiation panels in its design. The TCCM project would need to conduct research to determine if back-up heating would be necessary during the winter.

Other aspects for the TCCM project to be considered by WSU faculty and students include:

- TCCM site location. In order to determine the best location for the TCCM, WSU geography students have constructed a drone that is equipped with a GoPro© camera that will be flown over the desert floor at different altitudes giving tribal leaders and University personnel imagery from which to choose the best construction site. A provisional date for the aerial reconnaissance of the site has been set and agreed upon by the tribal elders for 13 February 2014.
- *BAD GIR* characteristics. The height and size of the *BAD GIR* is critical as is the depth of the filter pads located at the top of the structure. At the ZNPVC, water is pumped up to a basin in the *BAD GIR* and then distributed over the evaporative filter pads, much like a modern evaporative cooler. As the filter media pads are saturated natural air flows through them becoming heavier with temperature loss through evaporation and descends to the floor level ventilating the open space. The water used needs to be clean and relatively free of alkaline minerals, which would block the distribution orifices of the *BAD GIR*. If the Death Valley source water from Furnace Creek contains too many minerals, a reverse osmosis or water conditioning system will be used to reduce mineral content.
- Trombe wall construction. The trombe wall basically acts as a "heat sink" (Torcellini and Pless, 2004). There is sufficient clayey earth material in the nearby vicinity, which could be used to make a tamped earth "trombe wall" to provide

heating for the TCCM during winter months. Meteorological data collected on-site will help determine the trombe wall’s basic characteristics (e.g., construction material, size, location, aspect).

- Clerestory application. The ZNPVC uses a clerestory to entrain solar energy and provide natural lighting to the structure. A similar application would also be necessary for the Death Valley project. The TCCM clerestory would have operable windows allowing rising hot air to evacuate the building while the cooler air from the *BAD GIR* enters from below. This cooler heavier air descends to the floor level through the *BAD GIR* naturally ventilating and cooling the open space occupied by warmer air that rises up and out through windows at the top of the building completing the convection cycle. The position of the exterior operable windows and the amount of natural lighting will be taken into consideration.
- R-value design. The TCCM plan would need to determine the R-values required for walls, floors, and roofs, to obtain similar efficiency in Death Valley as that obtained at ZNPVC. Consideration will be given to a computer-controlled system, which would open and close the windows independent of manual effort in order to facilitate the convective flow through the building. The cost of said system, however, might preclude its use as a replacement for a more simple manual design.
- Use of local materials and labor. Local material to construct the building will be one of the optimal goals of the project. Footings and foundation will be emplaced in existing aridisols (desert soils), which include an indurated caliche layer that allows for a strong foundation. Construction materials currently used in Death Valley are concrete and CMU block. These blocks could be constructed from local resources available in the area. This type of construction material could easily be utilized by volunteer labor to make quality walls and partitions at a very low cost. Wood building material is unavailable in Death Valley and would have to be obtained or donated. The students will research the cost of CMU block versus other types of materials for the structure (e.g., straw bale construction has been suggested). The trombe wall will need to be evaluated for the possible use of local materials. A group of WSU students and faculty will visit Death Valley February 2014 and investigate local materials for the Trombe wall. Trombe walls are typically made of concrete, stone, or tamped earth (Torcellini and Pless, 2004). The students will take samples of local building material (stone and clayey soil) to evaluate its use in the TCCM Trombe wall construction. During this same visit, the students and faculty will also review other buildings erected by the National Park Service in Death Valley for evaluation of construction techniques, materials, and methods utilized. One of the goals of this project would be to involve the Timbisha people, particularly the youth, in the building of the structure. WSU students could assist, oversee, and instruct the Timbisha in construction methods and materials.
- Project schedule. WSU CMT students will develop a detailed project schedule that will involve the Timbisha Tribe volunteers, WSU students and other volunteers to reach a workable time line for the Timbisha Tribe. As in other student-based projects, it is feasible for students to volunteer at various times throughout the year but not for more than two to three weeks at a time. Summer is the most desirable time frame for students. Once the design is complete, the timeline for student volunteers to assist in the actual construction will be used.

- Project cost estimate. WSU CMT students will develop a detailed estimate from the design to assist in procuring the materials necessary to build the structure. WSU student involvement is a main objective of this project. The estimating process can be a senior student project for a group of students where they would itemize the necessary materials and their procurement. A further objective for their project would be to utilize as many local materials as possible.
- Project funding. WSU students and faculty will recruit contractors and businesses that can be instrumental in providing funding for this project, either by actual monetary donation, donation of materials, or providing volunteer workers to bring this project to fruition. Governmental funds may be available for the completion of the TCCM but the student group will also organize various fund raising events and apply for grants to support the project.
- Tentative timeline. Students will be able to put into place the construction management plan and travel to Death Valley to assist in the construction of the visitor's center during late spring 2015. It is expected that one of the goals of this project would be to involve the Timbisha people in the building of the structure. The WSU students could assist, oversee, and instruct the Timbisha in construction methods and materials.
- Previous prototype projects. Other WSU student construction projects have been used as an example for the TCCM project (e.g., Rwanda, Africa-Educational Center and Orphanage completed Summer 2006; Mozambique, Africa-Women's Center to be completed June 2014). For these construction projects it was necessary to hire local professionals to do the excavation, footings and foundation, main slab concrete placement, and structural members. It is expected that the TCCM project will follow the same format. The student groups could be organized to install interior walls, finishes, and furnishings.

CONCLUSIONS

An environmentally friendly, sustainable, passive air-cooling system known historically in Persian as *BAD GIR* will have a modern application in the design and construction of a cultural center for the Timbisha Native American tribe in Death Valley, CA. WSU students in CMT and Geography together with other WSU students, faculty, professionals, and volunteers from the community at large will engage in a "project-based learning" activity designed to preserve and elevate the image the Timbisha tribe, the benefits of which will accrue to all of those who participate. The educational advantages for students will be learning about passive air technology and its application in a modern setting. They will also become trained in the fundamentals of construction materials and methods, as well as all aspects of construction management skills as they help design and build the TCCM. Perhaps the greatest impactful the project will have upon the students will be the association and friendship gained by helping those who may not be able to bring this project to fruition by themselves. Faculty and other professional volunteers will benefit from this project by providing an atmosphere of engaged community learning plus the satisfaction of directing and guiding the project through to its completion. The Timbisha tribe will benefit by allowing others to assist them in acquiring a cultural center. The TCCM will be a source of pride providing a location where their history can be preserved; where tribal activities, skills, knowledge and social benefits can be perpetuated. The Timbisha will also gain, through the construction phase of the TCCM, skills and knowledge provided by WSU faculty, professionals, and students in aspects of modern construction. These skills and knowledge will make the Timbisha more marketable and hopefully benefit them financially in the long term.

REFERENCES

Attia, S., and de Herde, A. (2009), Designing the *Malqaf* for summer cooling in low-rise housing, and experiemental study, PLEA2009 26th Conference on Passive and Low Energy Architecture, Quebec City, Canada.

Durham, B. (2013), Tribal Historic Preservation Officer, pers. commun. with J. Rich (May 2013).

Hess, M. (2013), Tribal Administrator, pers. commun. with J. Rich (May 2013).

Izadpanah, P. and Zareie, H. (2011), "Wind Catchers" the cooling systems in traditional Iranian architecture, Iranian Architecture. Circle of Ancient Iranian Studies (CAIS), <http://www.cais-soas.com/CAIS/Architecture/wind.htm> (June 28, 2013).

Javaheri, E. (2012), How Ancient Persian Architecture Captured Wind Energy Underground to Green Buildings, This Big City, <http://thisbigcity.net/how-ancient-persian-architecture-captured-wind-energy-underground-to-green-buildings/> (May 18, 2013).

Roof, S. and Callagan, C. (2003), The climate of Death Valley, California. American Meteorological Society 84, 1725-1739.

Tamez, S. (2010), The Return of the Timbisha Shoshone Homelands. News from Native California 24(1), 17.

Torcellini, P., Long, N., Pless, S., Judkoff, R. (2005) Evaluation of the Low-Energy Design and Energy Performance of the Zion National Park Visitor Center. National Renewable Energy Laboratory (NREL), Report No. TP-550-34607, 138 pp.

Torcellini, P. and Pless S. (2004) Trombe Walls in Low-Energy Buildings: Practical Experiences. National Renewable Energy Laboratory (NREL), Report No. CP-550-36277, World Renewable Energy Congress VIII and Expo, Denver, Colorado, 8 pp.

Updike, W.A. (2001), Tribe recieves trust lands in Death Valley, NPCA Park News. National Parks Conservation Association, pp. 22-23.