5-1-2016

Water Harvesting Methods and the Built Environment: The Role of Architecture in Providing Water Security

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WATER HARVESTING METHODS AND THE BUILT ENVIRONMENT: THE ROLE OF ARCHITECTURE IN PROVIDING WATER SECURITY

by

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2008

A thesis submitted in partial fulfillment
of the requirements for the

Master of Architecture

School of Architecture
College of Fine Arts
The Graduate College

University of Nevada, Las Vegas
May 2016

UNLV | GRADUATE COLLEGE

Thesis Approval

The Graduate College
The University of Nevada, Las Vegas

April 15, 2016

This thesis prepared by

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entitled

Water Harvesting Methods and the Built Environment: The Role of Architecture in Providing Water Security

is approved in partial fulfillment of the requirements for the degree of

Master of Architecture
School of Architecture

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ABSTRACT

Two prototype thermoelectric atmospheric water generator (AWG) devices were constructed and evaluated for their performance in collecting water. The devices consisted of two Peltier thermoelectric cooling (TEC) modules connected to a heat sink and a condensing surface. The TEC/heat sink assembly was anchored to an air-well constructed of extruded polystyrene and 3D-printed frames, and a fan was installed to draw in surrounding air. The condensing surfaces were either copper or aluminum and featured a surface area larger than the cold side of the TEC. The performance of aluminum and copper surfaces were compared by measuring condensate collected after a test period of 5 hours (300 minutes). Relative humidity, ambient temperature and dew-point temperature were recorded at 15 minute intervals. Tests were conducted in Las Vegas, Nevada and Oceanside, CA. Oceanside featured a much higher average relative humidity than Las Vegas (65.3%) and overall, the average condensation collected was higher than condensation collected in Las Vegas, 11.8 mL versus 0.4 mL. Aluminum performed the best, with average condensate of 5.9 mL, suggesting thermal conductivity is not an essential measure of performance. The highest observed condensate collected was 26.9 mL in Oceanside, CA with a 68.4 in^2 aluminum surface. T-tests were utilized to compare mean values between datasets to determine significance. Comparisons suggest that in arid environments air inside the air well is significantly colder than ambient temperature (~2°F), however there is no significant difference in humidity. Regression analysis was performed on the data to characterize the relationship between environmental variables. The highest R^2 values were associated with relative humidity and the ratio of sensible heat to latent heat. Calculations suggest that large numbers of these devices could generate a large amount of water on-site. The applications to architectural systems are discussed along with the significance in reducing water consumption in buildings.

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o1 | INTRODUCTION

"*Water is the driving force of all nature.*"
-Leonardo Da Vinci

Climate change is the impetus behind the greatest problems that our civilization faces today. As the effects of climate change become increasingly tangible, one of its largest symptoms, drought, is intensifying in specific regions of the world. D'Odorico et al. specifically identify *desertification* as the major problem lending momentum to climate change, expressing it as a "change in soil properties, vegetation or climate, which results in a persistent loss of ecosystem services that are fundamental to sustaining life." (D'Odorico et al. 2013, 326-344) If the current destabilization of our vast and varied ecosystems continues, the ecosystem services upon which civilization depends may become threatened.

Overall, the consequences are severe, including limited agricultural yield, increased wildfire risks and extreme weather conditions and most importantly, exacerbated scarcity of freshwater sources. (MacDonald and Turner 2010, 21256-21262) As groundwater mining increases and reservoirs, such as Lake Mead in Nevada, drop to dangerously low levels, the water crisis is rapidly approaching an event horizon from which there may be no viable path to recovery within the near future. Careful revision of existing water policy and infrastructure is essential, but issues of baseline consumption also need to be addressed. For the purposes of this research project, the American Southwest serves as the locus of interest, in that it is one of the regions hardest hit by worsening desertification in the face of climate change.

Climate change is threatening the stability of our communities and standard of living. The findings of the IPCC have corroborated the artificial culpability in exacerbating the global greenhouse effect, and the effects are just now beginning to manifest. In many ways, climate change has become the Gordian Knot of our era, representing a series of worsening environmental problems that are dramatically outpacing our ability to ameliorate them through either legislation or action. The inertia involving sociopolitical, economic and behavioral patterns in regard to these concerns is immense and there has yet to be a consensus on the approach to resolving these environmental problems. All the while the consequences are becoming more severe. Rising carbon dioxide levels have been observed since 1958, when the construction of the Keeling Curve began, (SIO 2016) inferred from data readings in Mauna Loa.

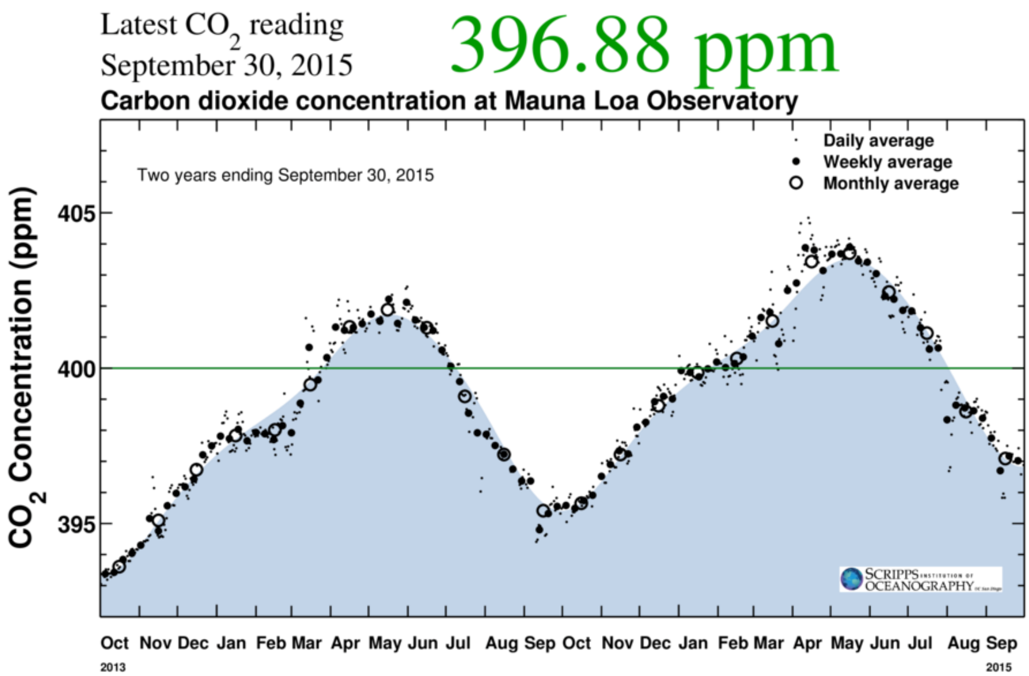


Fig. 1.1: Keeling Curve; provided by the Scripps Institute of Oceanography (SIO, 2016)

Unfortunately, even in the face of compelling evidence and continued warnings from the scientific community, little progress has been made to prevent these levels from climbing. As it stands, global carbon-dioxide levels are hovering at an observed high of 400 parts per million, pushing us handily toward an increase of two degrees Celsius predicted by the models developed by the IPCC (Field et al. 2014). Ultimately, this means that innovative and unconventional solutions to very mundane and serious problems must be found to help prevent the worst-case scenario from taking place. Ideally, this will involve systems that are capable of providing multiple benefits simultaneously.

In green building efforts, energy use and carbon emissions are often the poster-child of sustainable initiatives and methods, but energy and fossil fuels are not the only critical resources upon which we depend. Often, fresh, potable water is overlooked, but the criticality of this resource to everyday life cannot be overstated. Sagan's 'pale blue dot' earns its namesakes from the vast quantity of water that covers the planet – nearly 71% in total. (UNESCO 2014, 12) However, the majority of this water is actually undrinkable saltwater, leaving only about 2.5% of freshwater available for consumption worldwide. Furthermore, nearly 68% of the total estimated freshwater on the planet constitutes the polar ice-caps and ice sheets (which, until those melt entirely, remains unusable). (UNESCO 2014, 12) The paltry remainder leftover is the finite quantity of freshwater that must be shared by all of the occupants of the planet.

Failing to curb these levels is resulting in dramatic shifts in the weather patterns observed, particularly in the movements of the atmospheric jet stream as well as persistently elevated sea surface temperatures. Increasing desertification, resource scarcity. Human management of these particular problems can help to alleviate them, but for climate change to be mitigated will require bold, innovative solutions in numerous sectors. Specifically, climate change has the potential to dramatically affect the global hydrological cycle, which relies on a delicate balance of the processes of evaporation, transpiration, precipitation and percolation. (Bronstert and SpringerLink (Online service) 2005) Disruption to one or more of these processes tends to create a feedback loop that further worsens the effect. For instance, deforestation simultaneously affects the rates of transpiration and percolation into the ground. (Bronstert and SpringerLink (Online service) 2005) Exacerbated desertification is one of the most devastating, predicted results of unchecked climate change. Persistent drought conditions in the Southwest are the most visible evidence of this transformation, caused by an unbroken pattern of rainfall deficits as the region becomes more arid. (Seager et al. 2007, 1181-1184)

The most striking consequence is a significant drawback of regional annual precipitation and seasonal snowpack that reduces the total water supply available to the Southwestern States and the Basin States. (Rhoades et al. 2016, 173-196) The major source of water for the states of California, Nevada, Arizona, Colorado, Wyoming, New Mexico and Utah are the Colorado River and groundwater extraction. Groundwater, unlike seasonal runoff from snowmelt or apportioned water from the Colorado River, recharges gradually, making it extremely vulnerable to overconsumption. (Kibert 2013) Without careful stewardship of this resource, and adequate seasonal input to percolate back into ground aquifers, groundwater will be consumed too quickly to remain a sustainable alternative for water needs in the region. Once groundwater is no longer a viable source of water, demand in these regions may not be able to be met. Groundwater is also a critical structural component of the upper layers of the earth. Removing this water can reduce the structural stability of the rock itself, leading to the formation of catastrophic sinkholes and collapses. (Kibert 2013) The water levels in Lake Mead are dropping to levels that prevent the Hoover Dam from being able to operate efficiently and also provide water to consumers, in spite of recent retrofits added to the dam to allow distribution to be maintained to supply municipal and agricultural needs. (Brean 2016)

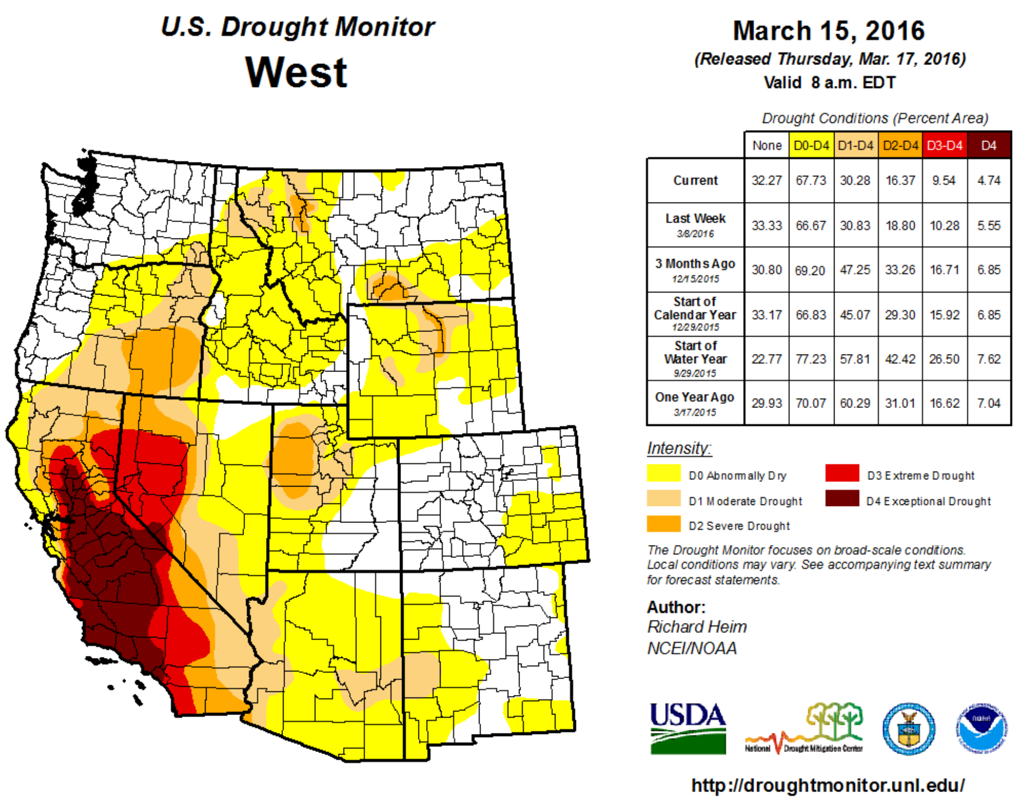


Fig. 1.2: Drought data for the Southwestern United States, from the U.S. Drought Monitor at the University of Nebraska, Lincoln (UNL, 2016)

The Colorado River is a major source of freshwater for the Southwestern United States, particularly the states that comprise the Colorado River Basin proper: Wyoming, California, Arizona, Nevada, Utah, Colorado and New Mexico. However, recent findings have suggested that the total hydrological flow of the river has dropped by as much as 45%. (Hoerling and Eischeid 2007, 18-19) Ultimately, the modeling employed to assess these changes is a matter of debate, and another paper suggests that the total river flow is reduced by only 6%. (Christensen and Lettenmaier 2007, 1417-1434) Regardless of what the actual, quantified levels of reduction are, this is most likely attributed to groundwater extraction as well as reduced levels of precipitation in the region (U.S Bureau of Reclamation 2007, Ch. 4, p.15) Reservoirs in the region, such as Lake Mead and Lake Powell, are highly sensitive to the amount of hydrological inflow from the river, and as such, models run through the year 2100 depict levels of these man-made reservoirs as consistently falling well-below 1,025 ft msl, which will prompt the revisiting the Law of the River (the Colorado River Compact) to discuss alternative and additional conservation measures that can be employed or enacted among the Basin States. (U.S Bureau of Reclamation 2007, Ch. 4, p.15)

When considering the implications of climate change, concerns over energy production and carbon footprint often overshadow the concerns over the availability of and access to potable water. While the issues surrounding energy production and carbon emissions are exceedingly important to our environmental welfare, legislation and policy initiatives focus on these issues at the expense of sustainable practices and policies regarding water use and management. For instance, the LEED system, largely regarded as the preeminent measure by which the built-environment can be evaluated for sustainability, only devotes a maximum of 11 credits out of the possible 110 measured by the system. For comparison, the “Energy and Atmosphere” section of the LEED scorecard offers a maximum of 33 credits (USGBC 2016b), emphasizing the reduction of carbon emissions and energy consumption over water management.

Domestic Water Use in the Western United States (gal/person/day) *Source: U.S. Geological Survey (Mauban, 2014)*	
State	
Alaska	92
Washington	103
New Mexico	107
Montana	112
Colorado	121
Oregon	121
California	124
Arizona	140
Wyoming	152
Hawaii	165
Utah	186
Idaho	187
Nevada	190
Western States Avg.	128.9
National Avg.	98
Non-Western States Avg.	88.5

Table 1.1*: Water consumption in the American West (in gallons/person/day); adapted from data found in the USGS Circular (Maupin, 2014)*

That said, the production of energy to satisfy consumer demand has many potential avenues to explore and implement, particularly in regard to renewable energy. Water production, however, is limited exclusively to methods of recycling. Approximately 97% of the water on the planet is salty ocean water that cannot be utilized for consumption. (Zhou and Richard S. J. Tol 2005, W03003-n/a) Potable, fresh water comprises only approximately one percent of the water on the entire planet available for human use. (Kibert 2013) Mismanagement of this precious resource is threatening water security in the most arid regions of the world, particularly in the Southwestern United States, where per capita water consumption ranks among the highest of all the states in the country. (Maupin et al. 2014, 56) Specifically, Nevada has the largest per capita water consumption, at a staggering 190 gallons/person/year, whereas the national average stands at approximately 98 gallons/person/year. (Ackerman and Stanton 2011) For reference, the WHO recommends a minimum of 1.98 gallons (7.5 L) per capita per day as a basic requirement for sanitation and health (even then, this is at the bottom of the acceptable limit) and an ideal amount of 26.4 gallons (100 L) per capita per day. This means that average water consumption in the United States is 370% of the amount suggested by WHO recommendations, and consumption in Nevada amounts to 719% of the WHO guidelines. (Howard and

Bartram 2003, 3) As climate change continues, the costs associated with water consumption are projected to rise in step, soaring anywhere from an additional $7 billion to $60 billion in the U.S. alone. (Ackerman and Stanton 2011) To minimize these costs as well as curtail water overdrafts a combination of technological innovation, policy changes and lifestyle changes must be enacted throughout the developed and the developing world alike.

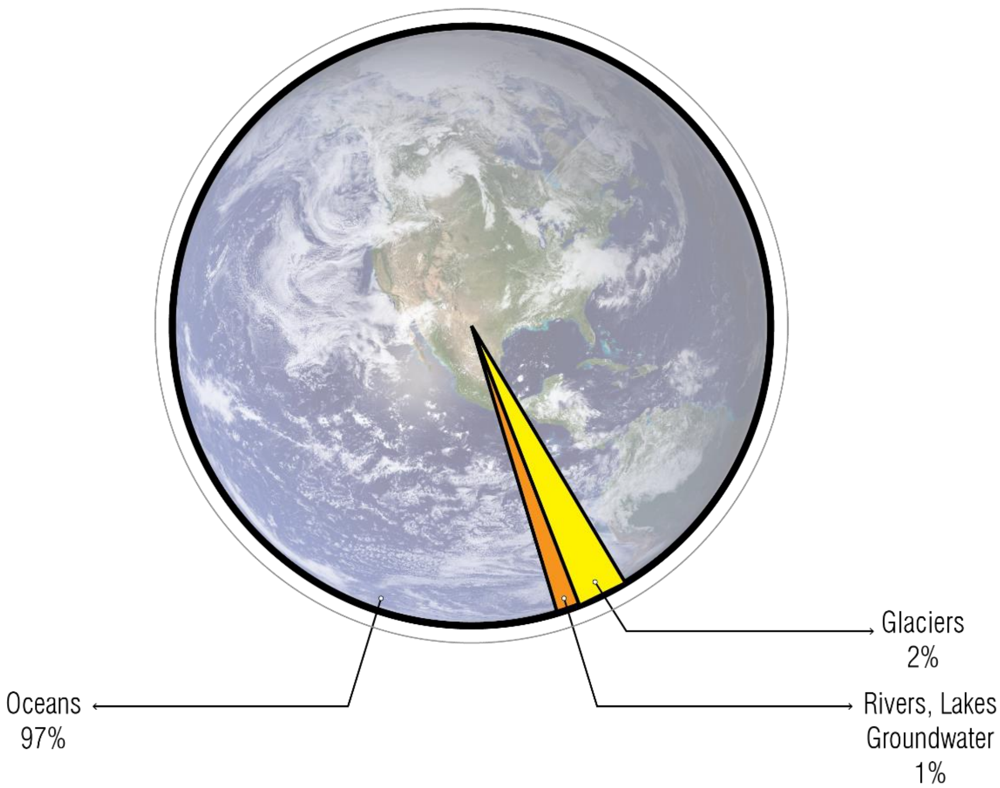
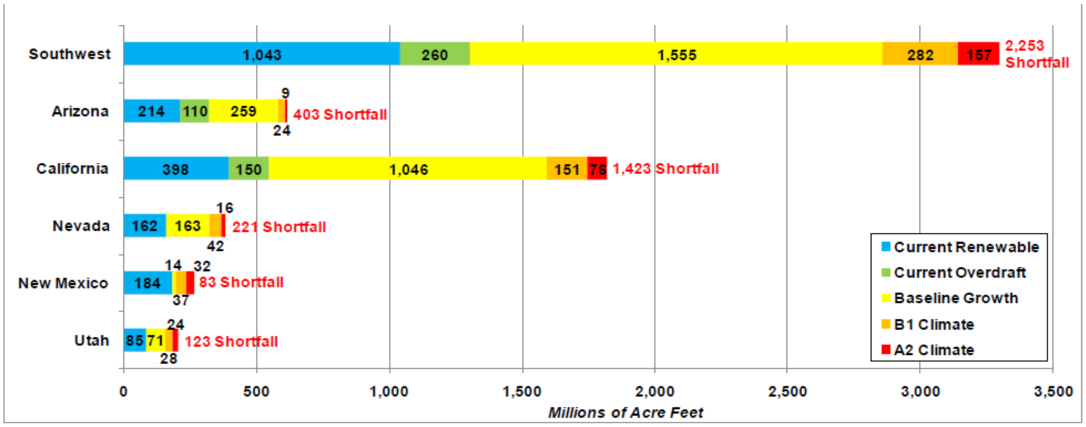


Fig. 1.3: *Usable Water in the World, by source.*



Note: Shortfall = sum of all groundwater use, beyond the renewable (blue) level, under A2 climate assumptions.

Fig. 1.4: Groundwater use in the Southwestern United States (Ackerman 2011)

However, while per capita water consumption in the United States is quite high, the majority of water use in the southwest is directed to agricultural purposes – largely for irrigation. Crops grown in these regions utilize vast quantities of water, suggesting that alternative crops should be grown instead, or that alternative sources of water should be found, in place of relying on mined groundwater or drawing from public supply. Consider the five principles of sustainable agriculture offered by UNESCO in their WWDR 2015 (UNESCO 2015, pp.48)

1. Improving efficiency in the use of resources
2. Sustainability requires direct action to conserve, protect and enhance natural resources
3. Agriculture that fails to protect and improve rural livelihoods and social well-being is unsustainable
4. Enhanced resilience of people, communities and ecosystems is key to sustainable agriculture
5. Sustainable food and agriculture requires responsible and effective governance

The forecast El Niño event projected to affect the Southwest in the winter of 2016, that is California in particular, will likely do little to ease the regional drought, though it might help reduce water shortfalls in the short-term. (Hoell et al. 2016, 819) Specifically, estimates from the models characterized by Hoell suggest about an 85% probability that rainfall in the region will be greater than normal. While the data collected in this study is statistically compelling, the authors also admit that this phenomenon would only partially counteract the rainfall shortfalls that have plagued California for the past several years. However, while the Southwestern

United States is certainly the epitome of the effects of long-term regional drought conditions, it is certainly not limited to that region of the world. As the global temperature rises toward the predicted +2 °C model, global desertification will intensify, spreading outward from already desertified areas. (Field et al. 2014)

State	Total Withdrawals by Use (%) Public Supply	Domestic	Irrigation	Livestock	Aquaculture	Industrial	Mining	Thermoelectric
Alaska	7.15	1.33	0	0	67.92	1.16	18.6	3.17
Washington	17.55	1.52	62.41	0.54	0.67	8.64	0.47	8.09
New Mexico	8.59	0.96	84.38	1.52	0.61	0.4	1.76	1.68
Montana	1.41	0.23	95.74	0.39	0.42	0.66	0.4	0.89
Colorado	6.35	0.25	90.44	0.24	0.65	1.04	0.16	0.9
Oregon	7.34	1.08	79.09	0.25	9.49	2.38	0.22	0.12
California	15.3	1.06	53.39	0.43	1.41	0.21	0.67	27.68
Arizona	18.75	0.44	77.08	0.18	0.18	0.36	1.66	1.44
Wyoming	2.1	0.14	86.93	0.35	0.51	0.13	4.98	4.86
Hawaii	13.81	0.65	5.17	0.11	0.26	1.64	0.1	78.72
Utah	11.68	0.27	78.13	0.35	1.71	3.17	3.26	1.21
Idaho	1.26	0.44	85.13	0.23	12.77	0.32	0.12	0.01
Nevada	28.4	1.57	63.03	0.36	0.64	0.25	4.16	1.55
National Average	10.78	0.93	31.22	0.52	2.14	4.44	0.98	49.05

***Table 1.2**: Water withdrawals by end-use in the American Southwest.*

The crisis surrounding water security is not just an American problem. Worldwide, the outlook for water conservation and management is bleak. The World Economic Forum indicated that water-related crises would be both the most likely and most seriously catastrophic risk in the forthcoming decade. (WEF 2015) Whether the attention shifts to the persistent drought in the Southwest of the United States or the rest of the world, desertification is growing worse, and availability of freshwater sources is declining.

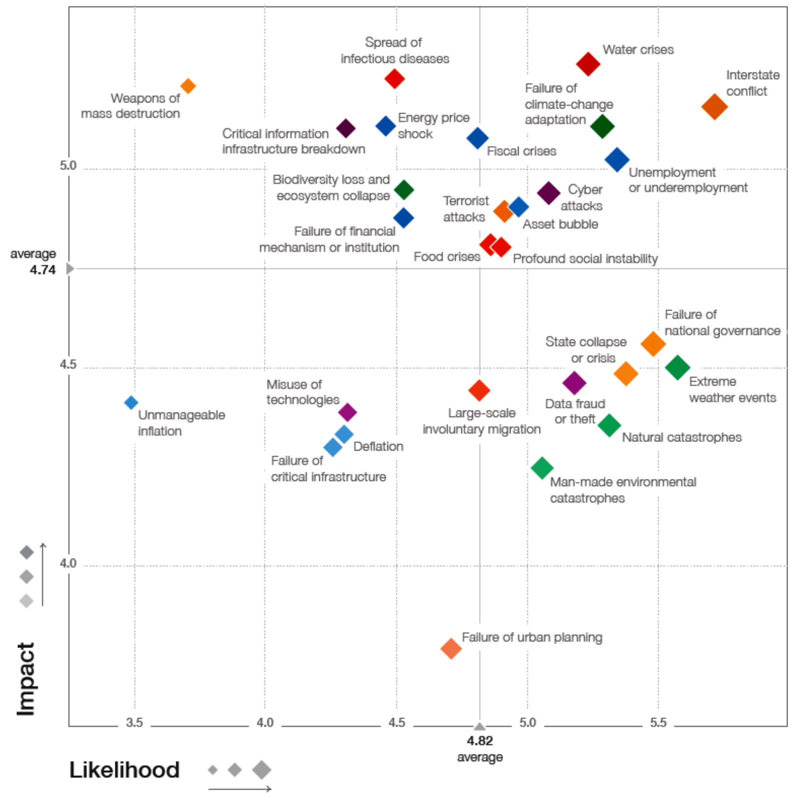


Fig. 1.5: World Economic Forum prediction matrix outlining the greatest threats to global civilization within the next decade. Listed in the upper-right is "Water Crises", indicating that this eventuality is both one of the most likely and most serious occurrences the global population could face.

Global water demand can be broken down into three sectors: agricultural, industrial and domestic. The largest volume of consumption, by far, rests in the agricultural sector, accounting for nearly 71% of the total water withdrawals worldwide (approximately 3100 billion cubic meters of water). Industrial and domestic uses account for only 16% and 14% of water withdrawals, respectively. (Fisher and Ackerman 2011) Adjustments to the efficiency in which water is managed agriculturally would certainly have the largest effect on total water consumption, simply from a mathematical perspective. However, it stands to reason that the demand for water for agricultural purposes is largely intertwined to food and trade requirements, and as the world population is only expected to continue to increase, more food will be required to sustain the burgeoning population. Therefore, it is important to understand that for water security to be achieved, any and all methods of reducing water consumption must be obtained, with the ultimate objective being net-zero water consumption in buildings.

The Dublin Statement on Water and Sustainable Development frames the global water crisis in the following terms from the 1992 Conference on Water and the Environment:

> "Scarcity and misuse of fresh water pose a serious and growing threat to sustainable development and protection of the environment. Human health and welfare, food security, industrial development and the ecosystems on which they depend are at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past."(Bronstert and SpringerLink (Online service) 2005)

The Global Water Partnership defines a 'water secure' world as "a world where every person has enough safe, affordable water to lead a clean, healthy and productive life." (Global Water Partnership 2012)

In many of these regions, water is already a resource in incredibly short supply. Further stressing access to that resource has the potential to worsen sociopolitical and economic conditions in the developing and developed world alike. The Middle East and Africa are certainly among the most vulnerable places, and physical water scarcity is not limited to developing countries. For example: "Australia is in the midst of a 30-year dry spell, and population growth in urban centers of sub-Saharan Africa is straining resources. Asia has 60 percent of the world's population, but only about 30 percent of its freshwater." (Skoloff 2007) This is indicative of the unequal distribution of water in the world at large and highlights the need to carefully steward a globally precious resource.

Resource conservation is largely dependent on the ability to recycle that resource. Solar and wind energy are renewable forms of energy because they derive power from essentially limitless sources, as is implied by the term 'renewable'. (Gross, Mautz, and Ebooks Corporation 2014) Energy, however, exists in many forms, and many of the current sources are finite and exhaustible, such as fossil fuels. Unfortunately, due to the action of entropy, energy from an open system will always be lost – no matter the. The same principal problem applies to the freshwater supplies of the earth. The freshwater that exists is finite – it is not renewable. However, water, unlike energy, is recyclable. All of the water currently on the planet is all that ever will exist. (Kibert 2013) Water can be recycled and reused, but it is not renewable. It is this quality that makes freshwater in all of its sources such a precious resource that requires absolutely careful stewardship to properly manage. and currently, innovations in renewable energy sources are manifold and varied. If we look at the Sun as an infinite power source, it could be argued that, if enough progress in efficiency is made, the world could essentially have access to all the power it needs.

A large problem in water management is that the very small fraction of potable water available for human consumption is scattered across the entire planet, to be (ideally) shared equally by everyone. Differences between the management policies and infrastructure of regions and countries make equitably managing this resource quite difficult, and there are numerous people worldwide living under considerable threat to their health due to lack of sufficient water resources. (UNESCO 2014) As an example, water management in the United States is largely different from management in Asia in that each region faces its own suite of problems and issues in water stewardship, owing to its own economic incentives and industrial endeavors. (McKinsey & Co. 2009) This can be particularly true in regions that are critically undersupplied with adequate freshwater, such as parts of Africa or the Middle East. (UNESCO 2014) As it stands, without improvements to efficiency in water management across industrial, agricultural and domestic sectors, there will simply not be enough water worldwide to meet demand by 2030, resulting in the shortfalls being leveraged from non-renewable sources, such as groundwater aquifers. This ancient water is extremely slow to recharge, and is a highly unsustainable source of water. Eventually, demand will not be met at all. When freshwater becomes that scarce, it has the potential to create immense conflict in order to ensure access to it. (McKinsey & Co. 2009)

A significant amount of energy is used to transport potable water from the source to the consumer, upwards of 3-4% of the total electricity consumption in the U.S. alone. Devices that can allow a building to provide even a small portion of the water for its occupants and systems would tremendously impact the municipal water supply. (Craig 2009, 225) This is perhaps the most important aspect of how the built environment can substantially impact water consumption in the regions of the world most heavily struck by continued drought conditions. An argument often made by proponents of green building is that the built environment accounts for a substantial portion of global energy consumption and carbon emissions – the largest portions of each parameter, actually. Significant modifications in the design, construction and operation of buildings results in a tremendous cut in the amount of energy required and carbon emissions associated with that energy.

The same logic can apply to water. While net-zero water buildings are more difficult to achieve (Joustra and Yeh 2015, 121-132), the principle is the same. A reduction in water consumption per building has the potential to alleviate a substantial amount of pressure on freshwater resources in the American Southwest. Thus, there should be significant incentive for developing novel systems that are capable of generating freshwater on-site as a way of reducing the energy needs of a building or at least reducing the amount of water that must be piped in from afar. A more detailed analysis of the costs associated with various methods of water production as compared to the theoretical production of the experimental system developed in this study is discussed in the Results section of this document.

A significant cost in supplying water to the public is involved simply in pumping that water from a source to its end-users, particularly in California where large quantities of water are imported from afar. (Hodges, Hansen, and McLeod 2014, 703-720) For example, in 2010, the San Diego County Water Authority imported 89% of the water delivered to end-users from non-local sources. (Hodges, Hansen, and McLeod 2014, 703-720). Developing on-site water catchment and collection systems solves two problems simultaneously. First, it allows water to be generated locally, reducing the amount of water that needs to be transported to the site, thereby reducing the costs associated with that transportation as well as the energy consumption (and carbon-dioxide emissions associated with the transportation). Second, it reduces the overall demand of freshwater from the public supply, regardless of the intended use of collected water (and regardless of the mechanism by which the water is collected).

Transport costs and infrastructure costs are just part of the manifold problem of adequately providing supply to meet end-use demand. However, it is also logical to conclude that a reduction in water consumption can also be satisfied through reductions in the demand-side of the equation. This has been seen particularly in the wide-spread implementation of high-efficiency water fixtures, which have been mandated by Federal law in the United States since the passage of the Energy Policy Act of 1992. (Sharp 1992, 123) Such regulations have the ability to dramatically reduce the amount of water consumed, but there is room for improvements in many household, commercial and industrial applications – not simply just irrigation. Paradoxically, in spite of the increase in population in the country, overall consumption of water has actually been driven down by 25%, largely due to legislation such as the Energy Policy Act and green building initiatives such as the LEED program. (Grondzik et al. 2010) These endeavors raise public awareness of the importance regarding water conservation, and also encourage innovation in developing ways to raise efficiency standards.

Regardless, the community at large could benefit from innovations civil water infrastructure leading to immense resource savings in the long-term. Meeting demand for water in the coming years is a complex issue, and a single solution will not be enough to remedy the problems faced by the world's desertified and desertifying areas. The solution must combine the approaches of blending policy changes, infrastructure changes and conscientious design choices made about the built environment.

Codified programs such as LEED and the Living Building Challenge have put in place a series of benchmarks and achievements required to move the built-environment toward achieving net-zero consumption of energy and resources. (Joustra and Yeh 2015, 121-132) The potential here is that the built environment in its totality is capable of effecting significant changes on our environment, serving an almost regenerative purpose. Specifically, the application of layers of technologically innovative systems onto structures allows not only for buildings to ameliorate their deleterious effects on the environment, but also to go so far as to begin reversing those effects. Renewable energy infrastructure, such as wind turbines and solar panels, is just one aspect of this. However, to reach toward net-zero efficiencies in all resources, buildings must find ways to recycle, reuse or generate water for storage or consumption on-site. (Adeyeye 2014)

Atmospheric water generation (AWG) is a promising candidate for such a technology to be applied to a net-zero structure, particularly in areas with high relative humidity. Furthermore, the same technology could be applied to more remote, unforgiving environments where water is extremely difficult to locate. Whatever the end use, AWG has the potential to reduce the amount of water withdrawals that are related to buildings and their occupants.

Objective of the Study

To evaluate and characterize the capacity of AWG as applied to building systems. An experimental instrument was constructed that employs the thermoelectric effect to use an electric current to refrigerate air to below the dew-point associated with the local relative humidity and ambient temperature. According to the United Nations, “using economic arguments for preserving ecosystems can make them relevant to decision-makers and planners.” (UNESCO 2015, p.31) Following this principle, scientific arguments could be made to justify the same decisions, only as applied to the built environment and its performance as an artificial ecosystem service. Identifying and quantifying the impact of AWG systems would pave the way for further investigation and refining of an experimental apparatus resulting in a feasible technology that could help make net-zero water consumption in buildings a reality. Quantifying the relationship between the environment and the performance of the apparatus is essential in predicting the amount of water that could be reliably harvested if the system were employed in a specific environment.

Hypothesis

Atmospheric Water Generation can provide an efficient, supplemental source of water. It should be possible to characterize a relationship between environmental parameters and the amount of moisture capable of being collected. Metals with greater thermal conductivity should collect more moisture. Furthermore, larger surface areas should correspond to larger volumes of condensate to be collected from an AWG system. While atmospheric water generation may not reach the cost efficiency of other large-scale technologies, such as desalination, it does not generate a toxic, concentrated effluent and can be integrated synergistically with contemporary building systems, such as the structural system. Additionally, it is likely that the air temperature and the relative humidity inside the constructed apparatus are lower than their associated ambient values. This would favor the notion that AWG systems can serve as a means of providing supplemental space cooling and potentially in reclaiming water lost through traditional refrigeration methods, such as a swamp cooler.

Scope and Limitations

The thermoelectric condenser system will be tested in two experimental environments: Oceanside, California and Las Vegas, Nevada. Studying the performance of the device in these two disparate regions should provide valuable insight into the optimal parameters necessary to generate the most condensation. Perhaps the greatest limiting factor is the length of time to conduct the study, which constrains the amount of test points that can be collected. The performance analysis would benefit from a larger pool of data, but further investigative opportunities will provide the chance to refine the apparatus itself as well as develop a more intricate system for recording environmental data, as well as continuously measuring the surface temperature of the condenser material.

Another major limitation is the choice of materials selected as an ideal condenser surface. A more detailed explanation of each surface employed will be discussed in the Methodology section, but for the sake of discussion here, experimental surfaces were limited to aluminum and copper. Silver and diamond are much better thermal conductors (Powell, Ho, and Liley 1966), but the cost of such materials is prohibitive for a proof of concept study such as this.

Keywords and Terms

Ambient Temperature (T_a)
Atmospheric Water Generator (AWG)
Dew-Point Temperature (T_d)
Relative Humidity (RH)
Dry-Bulb Temperature
Wet-Bulb Temperature
Latent Heat
Sensible Heat
Thermoelectric Cooling (TEC)
Coefficient of Thermal Conductivity

02 | LITERATURE REVIEW

Water rights in the Southwestern states are the most significant hurdle in adopting a coherent set of modernized water management policies. Early in the 20th century, the establishment of the Colorado River Compact was a way to explicitly spell out the rights and ownership of water from the Colorado River among the states through which the river passes. (Olson 1926) Considering that, apart from groundwater sources, the Colorado River is the largest source of freshwater for the Southwest region, the apportioned values of water assigned to each state are extremely relevant. Granted, this agreement was the first conscious, diplomatic effort to quantify the amount of water that each state was entitled to; however, it has not been updated with accurate hydrogeological information (i.e. the amount of water that flows through the Colorado River), since its inception.

Additionally, values have not been revised according to changing populations in the signatory states. For instance, the population of Las Vegas alone has increased from 89,000 to 2.84 million in the interval of 1928 to 2014, (U.S. Census Bureau 2016) yet the water apportioned to Nevada through the compact has remained at the value assigned to it in 1928, 0.30 million acre-feet. (Lochhead 2001, 290) In the event of extreme drought conditions – such as if the levels of Lake Mead drop to a level below an acceptable value of 1,025 ft., the apportioned value is to be increased to 0.35 million acre-feet. (U.S Bureau of Reclamation 2007, Ch. 4, p.15)

Therefore, a significant first step in resolving the water security problem in the region lies in amending the Compact further in an effort to eliminate competing interests and to more accurately assess the available volume of the Colorado River to meet the needs of the cities upon which it depends. After all, the Western states were assigned these numbers based on outdated population data, mainly as an anticipatory prediction of need, and an updated, modernized definition clearly outlining "need" should be agreed upon. (Ruckriegle 2013, 172) The most recent adjustment to the management of water reservoirs in Nevada was in 2005, in an amendment that updated the criteria set to manage water releases from both Lake Powell and Lake Mead, though no significant legislation has been made since. (U.S Bureau of Reclamation 1970) Specifically, this piece of legislation gives the Secretary of the Interior of the United States full authority in assessing and re-evaluating the amount of water allocated for specific uses outlined in the Compact, particularly concerning times when depletions in the reservoir bring the reserves to below critical supply levels.

Another issue compounding water security is the inability of some states in the region to tap into all available sources of water in the area. Specifically, rainwater harvesting, it seems, is the only currently viable alternative to groundwater extraction in the Southwest, where it is too hot and dry to rely on radiative condensation collection and fog events are too rare to make fog collection a viable option.

According to McKinsey & Co., there are essentially three routes that countries can undertake to better manage their water supply and demand. These are (1) increase the overall supply available, (2) increase the efficiency in which water is actually used and (3) lower demand-side consumption by encouraging different ways of using water (or eliminating water usage for certain activities). (McKinsey & Co. 2009) For urban and rural regions across the globe, a system of supplementing readily available water sources to meet end-use demand would be a very valuable addition to civic infrastructure.

Methods of Water Collection

Numerous methods of collecting water have been utilized historically, to varying degrees of success. Each method tends to be developed specifically for use in the climate in which it is employed. In many ways, this parallels the evolution of desert organisms, which have formed strategic physiological traits that allow them to persevere throughout such a harsh environment.

Rainwater Collection

Rainwater collection is perhaps one of the most useful methods of collecting water. It can readily take advantage of the weather in certain parts of the world where there is a pronounced dry season and a storm-laden monsoon season. In the monsoon season, water can be collected for use in more demanding parts of the year when water is not as readily available. In this regard, rainwater collection is a way to quickly collect large amounts of precipitation during heavy rainfall events; however, the water is usually not potable, due to the amount of pollutants that exist on the collection surface. Perhaps the most recognizable examples of this technique are the stepwells found throughout India and Pakistan – immense, subterranean structures that functioned as a vast cistern to collect seasonal monsoon rainwater. Hygienic issues aside, some stepwells were believed to be able to hold upwards of X gallons of water which would provide the people with potable water even in the driest parts of the year. While the idea is commendable, the size and quantity of resources necessary to construct such a project make them infeasible for countries today.

Fig. 2.1: *Stepwell in Rajasthan, India.* (Doron 2003)

Some modern devices feature mechanisms that flush the first several gallons of any collected volume in an effort to minimize contamination, but there is still a risk for pollutants to infiltrate the collected water volume. Many states allow for rainwater collection, utilizing the slope and surface area of the roof of a building to collect water and store it in a cistern on-site, typically for irrigation or other purposes that require graywater. (Helmreich and Horn 2009, 118-124)

Some, but not all states allow for rainwater collection to supplement their water needs, but Nevada is not one of them. Arizona does allow for water collection through this method, as well as Texas. Nevada does allow for rainwater collection if a proper water right can be demonstrated, although a variance can sometimes be applied for through the State Engineer’s Office (Campbell and National Business Institute 2005), though it is an arduous task to do so. Unfortunately, rainwater collection infrastructure is largely barred due to the obligations of the state to abide by the Colorado River Compact, as the collection of rainwater could impact the recharge of Lake Mead and Lake Powell and ultimately the amount of water that flows back to the Colorado River.

The Mojave Desert in general receives very little rainfall, but when rain events do occur, they tend to result in large volumes of water that, if catchment systems were employed, could result in significant amounts of water being collected and stored for later use. Given the absence of such infrastructure, this means that the majority of water from rainfall events is lost to either (1) adsorption into the soil to be utilized by plants, microbes and insects, (2) lost to the air again by evapotranspiration or (3) diverted back to other bodies of water such as rivers, creeks or lakes where it is eventually carried back to the ocean. (Agam and Berliner 2006, 572-590)

Buildings in Nevada that implement stormwater collection systems can accomplish a series of ecosystem and community services: (1) they prevent polluted runoff from being returned via stormwater systems, to Lake Mead, reducing the amount of contaminants in the valley's primary source of drinking water; (2) they allow water to be stored for use at a later time when it is more urgently needed, such as in the drier parts of the year when little rainfall is observed. (Field, O'Shea, and Chin 1993) Based on an average yearly precipitation in Las Vegas of 4.40 in., (refer to Table 3.1 for regional climate data pertaining to Las Vegas) a

$100ft^2$ collection surface, with a conservative estimated efficiency of 75%, (Grondzik et al. 2010) we could anticipate an approximate amount of water collected to be:

$$= (\ 4.4 \text{ in. / year } (1{,}000ft^2)\ ) * 0.75 * (0.62 \text{ gal. / } ft^2 \text{ / in.})$$
$$= 2{,}046.0 \text{ gal. / year}$$

Of course, the size of the roof collector would vary from structure to structure, but this gives an idea of the amount of water collection that could be obtained. Water obtained in this manner is not potable, but would be more than suitable for agricultural purposes (the sector that utilizes the most water) thereby allowing more water to be maintained in Lake Mead or used for public consumption. Given that per capita consumption of water in Nevada is 190 gallons/person/day (Maupin et al. 2014, 56), that amounts to a staggering 69,350 gallons/year. With a population of 613,599, this would amount to approximately 42.6×10^9 gallons required by the urban population. For comparison, the apportioned amount of water entitled to the State of Nevada is 300,000 acre-feet (SNWA 2015) per year, which equates to $977{,}554.3 \times 10^6$ gallons.

Following the catchment calculation above, at 2,046.0 gal./year, if there was one $1000ft^2$ collector surface area per capita, then a total of 1.3×10^9 gallons could be collected. This generalized calculation makes several assumptions, and a more detailed quantification would be required if any actual adjustments to the city's infrastructure were to be made.

Collaboration between the States of the Colorado River Basin is essential in maintaining regional water security. For instance, the Brock Reservoir was a collaborative endeavor between Nevada, Arizona and California. (US DOI 2014) The Southern Nevada Water Authority was responsible for funds in the amount of $115 million, and the Metropolitan Water District of Southern California and the Central Arizona Project provided $28.6 million apiece. Due to the shared investment in the capital costs of construction and delivery, Nevada will receive 400,000 acre-feet from Lake Mead at a maximum of 40,000 acre-feet per year until 2036. California and Arizona will each be entitled to 100,000 acre-feet with a yearly maximum of 65,000 acre-feet for the time between 2016 and 2036. Projects such as these benefit multiple states and help to alleviate water supply burden on water-stressed areas.

Nevertheless, there are several obstacles to implementing collection strategies. An issue with rainwater collection in Nevada is that it prevents water from being diverted back into the municipal sewer system for treatment and to return to the Colorado River. Therefore, doing so would be a violation of the Colorado River Compact. However, as mentioned above, a workaround for this would be to treat the water collected as public property, calling for a system that is capable of handling the extra water (apparently approximately 1.3 billion gallons of water per year) by diverting it into the stormwater collection system to drain to Lake Mead, where it would be circulated into the city's treatment system or into the municipal sewer system where it would also be treated and delivered back into circulation for use. This would simultaneously accomplish the need to add water to the municipal reservoir, easing pressures on Lake Mead and the water delivered there via the Colorado River (directly allowing more water to be either sold or given to other states in the Compact).

Additionally, this same system could be adopted into any city that has existing legislation amenable to rainwater harvesting. As an analogy, this suggestion is similar to individuals that install solar system arrays and any excess power generated by the photovoltaic system is fed back into the city power grid. A system of credits or incentives could be developed if private users fronted the cost for such a system; or it could be spearheaded by the city government itself, or the water utility of that area, with a modest increase in water delivery charges.

However, rainwater harvesting, particularly in areas that see little annual rainfall, should look to other methods to find water security. Nevertheless, a tandem approach that combines an alternative method with rainwater harvesting would be more effective in the desert. One of the least looked at options is aerial condensation. This study will attempt to develop and quantify the performance of an envelope system meant to adopt a series of properties that can allow it to efficiently condense water, acting as an additional, passive response that a structure can offer to alleviate the burden placed on municipal water reserves. Unlike water collected by rainwater harvesting, water collected through condensation is essentially distilled water, and therefore potable. While rainwater collection is not the only method of water capture (more methods will be discussed in detail further below), it is the most viable for the Southwest region, and the only method that is directly barred by policy particulars in the state.

Fog Collection

Fog collection is another viable option for arid climates, but ones that receive significantly moister air than rain shadow deserts. A good example of where this practice still finds use is the Atacama Desert (Kidron 1999, 1-8), which, while an arid land, still receives largely moist air from the Atlantic air that moves across it. Fog events are common, but extracting the moisture from the air is key. Devices such as fog nets are essentially a mesh meant to attract water molecules out of the air and collect them to a common reservoir. (Park et al. 2013, 13269-13277) Amounts collected vary seasonally, but are usually very productive. One particular fog-collecting apparatus, the Fog Hive, employed in South America by Dr. Cristian Sau, was reported to have collected 1.4 L/m^2/day. (Suau 2011, pp. 31-40). These devices are intensely dependent on the size and material of the filaments that constitute the net meant for fog collection, and so they should not be discounted as an excellent method of mitigating water supply shortfalls.

There are some examples of project teams developing fog collectors in desert regions more similar to the Mojave than the Atacama Desert, such as parts of Israel and Saudi Arabia, but these efforts are either at higher elevations (Gandhidasan and Abualhamayel 2012, 1019-1036) or in areas that are influenced by oceanic air currents (Kidron 1999, 1-8). Thus, while they are effective at collecting impressive volumes of water, they are not quite applicable to Las Vegas. They would have some significant merit if employed in Oceanside or any other coastal area that has frequent fog, but unfortunately, Las Vegas does not usually receive fog in any quantity, and extracting moisture from the atmosphere in this manner would prove immensely difficult due to the low relative humidity and high dew point. In fact, the air is so dry that condensation will only form on a surface if it reaches significantly below the dew-point (T_d). Additionally, the purpose of this study was to experiment with an apparatus that could be evaluated in two different regions where there would be reasonable applicability.

Groundwater

Groundwater mining and extraction is the method employed most frequently to compensate for water shortfalls, particularly in the Southwest. However, groundwater recharges at a rate much slower than other bodies of water, and the exact amount of groundwater available is also difficult to quantify without sophisticated prospecting and analysis. Therefore, it is difficult to estimate when an aquifer will be depleted. (McKinsey & Co. 2009) Groundwater extraction is typically accomplished through the construction of wells and pumps, which are quite costly to develop and do not always successful. Relying on groundwater creates a cyclical problem: more water mined now means less water is available later, unless it is recharged somehow.

Additionally, the Southwest and Pacific Northwest are suffering from reduced snowpack each year, reducing the amount of snowmelt and associated freshwater that can be sourced from the mountains in these environments. (Ackerman and Stanton 2011) This places a greater stress on the groundwater extracted to meet demand, and additionally pushes the regions into further water deficit.

Desalination

Desalination has gained a significant amount of attention in recent years, particularly in California where the stranglehold of the persistent drought has been felt very heavily. While the process of desalinating water requires a tremendous amount of energy input, the amount of water that it can generate is essentially limitless, given that most desalination plants currently under construction are being built in California along the coast.

Some other parts of the country, such as Texas, have experimented with constructing desalination plants meant to extract potable water from brackish water sources, which requires a substantially less upfront energy input. While the merits of this technology should be lauded, the costs of such technology do not necessarily make it a viable option to all regions and countries suffering from drought conditions. (Kelkar et al. 2003, 243-261)

Additionally, not all desertified areas have ready access to abundant seawater or the capital necessary to construct the infrastructure to adequately undertake desalination. Furthermore, the processes associated with desalination produce a significant amount of toxins and waste buildup that produces yet another problem. Even for consumers in societies that could afford the capital costs, the cost of water produced is dramatically higher than typical rates, even for imported water. For example, San Diego imports about 90% of its water. The newly constructed Claude Lewis Desalination Plant in Carlsbad, California located on the Encina Power Station campus and part of the San Diego County Water District, generates approximately 50 million gallons of potable water per day (Poseidon Water 2016). Desalination technology is a critical asset in producing large quantities of freshwater in the face of ongoing droughts and continued deficits in public supply of water, and as such this project should not be taken to criticize desalination technology. Instead the work discussed in this paper is meant to offer an alternative in regions where desalination may not be the most effective technology. The systems are likely to only improve over time as it is adopted in more regions and the technology becomes more refined. Nevertheless, a method of water production that is at least mostly passive in nature and capable of being deployed in a wide range of regions should be the most sought-after solution to avoid resorting to unsustainable groundwater withdrawals to compensate for water supply shortfalls.

Atmospheric Water Generation

Lastly, the remaining source of water condensation is that of aerial condensation. Historically, there were numerous attempts to resurrect what was thought to be a lost form of technology, in the form of an air well (Nikolayev et al. 1996, 19-35). It was thought that large, mysterious structures located in the region of ancient Byzantium, specifically Theodosia, were meant to condense dew within them, providing ample freshwater supply to the inhabitants of the cities there. (Zibold 1905) However, these attempts were incorrectly based on the assumption that the key to condensation was thermal mass. An excess of mass can actually prevent an object from being able to cool to the dew-point temperature. While thermal mass can be an important quality in inducing condensation, it is not the best factor. The structures did result in some moisture collection, it was largely due to the large amount of stone and concrete employed in their construction, which happened to cool below the dew-point at night, resulting in condensation. Subsequent attempts were made to "revive" this lost technology, all resulting in the same bafflingly futile results. (Nikolayev et al. 1996, 19-35)

However, the failures of these early prototypes should not discount the potential offered by condensation methods. More recent prototypes have been more successful in identifying surfaces that are much more efficient in inducing condensation. (Beysens et al. 2003, 1-11) The physical properties of the surface are most important in determining whether or not condensation can occur, and the rate at which condensation is possible.

"The water vapor content of the air increases with the dew point temperature, while the radiative cooling potential is larger at low dew-point temperatures and low relative humidities." (Nilsson and Niklasson 1995, 93-118) Warmer air has the potential to hold larger quantities of moisture, and it loses this ability as it cools. The strategy in aerial condensation is to ensure that the condensing surface can reach and fall below the saturation point, resulting in the formation and subsequent collection of that condensation. This is easier said than done – particularly in arid environments where the difference between the ambient temperature and the dew point temperature is often too large to be feasible, even with a surface that is thermodynamically optimized to shed heat as much as possible. However, this does not mean it is beyond the realm of possibility, such as introducing a Peltier thermoelectric unit.

Regardless of environment, the time of the day that dew formation is most prone to occur is the early morning, when the ambient temperature is at its lowest and the relative humidity is typically at its highest. “In arid locations, the most favorable conditions for dew collection persist in the late night and around sunrise.” (Nilsson 1996, 23-32) However, even if dew formation is most likely to form in the morning, it is not a guarantee that it will form. If the ambient temperature does not fall below the saturation point associated with the local relative humidity, condensation will not be observed. There are some seasonal variations in this pattern. Specifically, in the Mojave Desert, the most frequent time that condensation would conceivably occur would be in the mornings during the Winter and early Spring before the daytime temperatures become far too hot. Condensation in the summer is essentially impossible due to the large difference between ambient temperature and the dew-point temperature (i.e. the surface cannot be cooled enough to allow dew to form. Consult Table 3.1 for environmental data for Las Vegas).

Given that there is no clearly defined legal impasse on moisture collected through atmospheric water condensation, it represents an alternative to rainwater collection in areas where such an option is not allowed. In areas where rainwater harvesting is permitted, atmospheric water generation still serves as a viable supplemental source of additional water. Ultimately, AWG systems obtain water that was otherwise inaccessible, reclaiming it to either be directed to a cistern for greywater purposes or redirected back into the civil supply, which is a net benefit.

Unfortunately, all of the technologies discussed above tend to have limits on their applicability in certain areas. Specifically, desalination has no use in a region that is not adjacent to an ocean or brackish source of water; likewise, fog collection is useless in an area that never experiences fog events. In other regions, the law prevents the use of certain technologies. The most important thing in designing strategies for water collection is to accurately assess the environment in which it is to be implemented and to aim for synergetic pairings of strategies when possible. Also, Atmospheric Water Generation systems are at the mercy of relative humidity. Again, successfully meeting the global demand for water requires innovation and the utilization of every possible effort to collect water.

Condensation

Water collection methods that employ condensation of vapor are by far the least-utilized strategy, largely due to the inherent inefficiency of the technology. A few companies have developed large-scale AWG devices that run off of powerful engines to provide water in emergency situations. (Ambient Water 2016) Nevertheless, while large quantities of condensate are unlikely to be collected with current technologies, save for specific environments that favor the conditions needed for condensation to occur, even a meager addition of condensate magnified in scale over numerous areas has the potential to create a significant impact. Furthermore, condensate is considered potable (Maestre-Valero et al. 2011, 84) and there is no production of concentrated, hypersaline wastewater discharge in the process. (Wetterau, ebrary, and American Water Works Association 2011) This has the benefit of making it a very environmentally sensitive option, particularly in comparison to desalination or rainwater collection, which can typically only be used for graywater applications, such as irrigation. The required conditions for dew to form are aptly summarized by Beysens in the following statement:

> "Dew is fundamentally a result of a phase transition, in which water vapor is transformed into liquid when it comes in contact with a surface. The primary condition for the formation of dew is that the temperature of the surface on which condensation takes place be lower than or equal to the dew-point temperature. The two most critical aspects of phase transition, in the case of dew formation, are the nucleation of the liquid phase and the nature of the droplets' growth." (Beysens 1995, 215-237)

In arid, desert environments, and those areas suffering prolonged drought conditions, dew can be a more frequent and dependable means of supplementing the water supply (Richards 2004, 76-94) and can even help to mitigate the consequences of prolonged, intense drought conditions. (Maestre-Valero et al. 2011, 84) Following this logic, it becomes a very sensible option to turn to a condensation-based system for generation of potable water in the absence of other viable methods, such as desalination or groundwater mining. Unfortunately, the significant problem with condensation is finding favorable conditions for it to form. Condensation will only form at or below the dew-point temperature, making it difficult to attain in arid environments, where the dew-point temperature is significantly below ambient temperature, year-round in most cases (consult Table 3.1 for climate information regarding Las Vegas, NV and Oceanside, CA).

Condensation forms as an adiabatic process. Latent heat stored in the water vapor is essentially converted to sensible heat, meaning that the air temperature rises a modest amount when water vapor condenses on a surface. (Lechner 2009) Surfaces that are cooled to the dew-point temperature for a particular relative humidity and ambient temperature will condense water from the surrounding air-film, typically in a dropwise fashion. (Khandekar and Muralidhar 2013) This is readily apparent in the typical morning dew observed on grass or glass window panes. The problem with relying on condensation in this manner is keeping the surface cold and maintaining that temperature, which requires energy to maintain the heat transfer, or the system will eventually equilibrate and no additional condensation will form. As mentioned, condensation is adiabatic, but the heat released to the surroundings as water transitions from its gas phase to its liquid phase, warms the air film in contact with the moisture and therefore the surface of the condenser, making further condensation more difficult. In the case of this study, the thermoelectric units employed require a current to generate the Peltier effect, but if electricity is continuously applied to the system, it will continue to transfer heat from its hot side to its cold side.

There are essentially two methods collect water from the atmosphere: namely direct vapor absorption and dew formation. (Agam and Berliner 2006, 572-590) Desiccation is the primary method of collecting water vapor through direct absorption, but it will not be considered for this study as removal of absorbed vapor from the desiccant can be quite difficult, even though its often easier to accommodate desiccation in environments where dew formation is unlikely to occur due to environmental constraints. (Agam and Berliner 2006, 572-590) There are a number of ways to achieve dew formation, but the primary two of interest in this study are radiative cooling and refrigeration. Radiative cooling is an entirely passive method – that is requiring no energy to lower the temperature of the surface – but it is most viable in regions where the humidity is fairly high and the temperature difference between ambient and dew-point is as small as possible. Additionally, it is most useful in areas where the incident wind moving over the surface is not too high. Refrigeration, on the other hand, is beneficial in any environment regardless of temperature or humidity, but it is also an active system, requiring energy input in the form of work to be able to cool air or a surface in contact with the air in order to form condensation.

Radiative cooling is a method by which interplanetary space is essentially used as a limitless heat sink for the absorption of long-wave radiation emitted by a body from earth through clear sky. (Hu et al. 2015) Thus, for our purposes, it was initially thought that this could be incorporated into the water collection apparatus as a means of preventing a surface from becoming too hot to facilitate condensation. For this to be achieved, a high albedo is critical, but far from the only feature relevant to cooling a surface. (Nilsson and Niklasson 1995, 93-118) Specifically, a surface that allows short-wave radiation to be reflected and long-wave (infrared) radiation to be absorbed, is ideal, such as the zinc-sulfide doped plastics that are utilized by Nilsson et. al. Early concepts designed in this study attempted to reconcile the potential from radiative cooling with the desert environment, however these attempts were abandoned after it became clear that the effectiveness of such a cooling strategy would be greatly limited. The data found by Hu et al. indicate an optimized radiator that was recorded as being able to cool at an intensity of 47.2 W/m^2, directly cooling a surface at 25 °C (77 °F) to -1.9 °C (28.58 °F). (Hu et al. 2015) Cooling capacity of this magnitude should be sufficient for a cooled surface to reach below dew-point, even in the Mojave Desert, however, radiative cooling requires exposure to the open sky to function properly. This would mean that for a large percentage of the calendar year, ambient temperature outside would likely all outside the maximum temperature range to obtain the cooling capability necessary to form condensation.

Fortunately, surfaces can be optimized to radiate heat extremely efficiently, even particularly in arid desert environments, such as Iran (Farmahini Farahani, Heidarinejad, and Delfani 2010, 2131-2138), however the system discussed by Farmahini is partially active in that it utilizes an additional apparatus to chill water that is used to provide evaporative cooling to a space during the day. Nevertheless, this indicates that increasing the likelihood of that they might be able to reach dew point may very well lie in combining a handful of systems, rather than utilizing one single system or method. This most likely has to be accomplished by providing some method of additional cooling capacity, which would require energy input. Ultimately, failure of the system to be entirely passive is not a total shortcoming. Producing water that costs less energy is the purpose of testing the device. Also, it is likely that other physical properties of the environment must also be taken into consideration to develop a truly thermodynamically efficient surface. After all, none of the regions in which the studies researched are exactly similar to either the Mojave Desert or the coastal sage-scrub that Oceanside is characterized by. Part of the effort of this study is to characterize a predictive equation that can estimate the potential performance of a device.

Additionally, these early design efforts in the project revolved around acquiring doped plastic materials, similar to those described by Nilsson (Nilsson, Niklasson, and Granqvist 1992, 175-193) or other unique materials, such as a cadmium telluride material (Benlattar et al. 2005, 10-15), copper thin films (Benlattar and Oualim 2013, 391) or calcite and hematite. (Vazquez, Arias, and Sanchez 2006, 667-673) However, in most cases the cost and availability of these materials reduced their viability in the experiment, prompting other avenues to be investigated. The study conducted by Vasquez led to an attempt to utilize a titanium-dioxide (TiO_2) coating on an early prototype to help facilitate radiative cooling, but met with poor results. In light of the aridity of the environment in Las Vegas, radiative cooling alone is insufficient to generate condensation without specialized foils or films. Nevertheless, in environments where the prerequisites for condensation to occur are met, radiative cooling can provide a large amount of water over a relatively small surface area. For example:

> "If the upper side of the cover has a high solar reflectance and a high IR emittance most of the absorbed power from the sun will be emitted as thermal radiation towards the sky and the temperature of the cover will be close to that of the ambience." (Nilsson, Niklasson, and Granqvist 1992, 175-193)

This readily indicates that successfully managing the thermal properties of any designed surface can significantly reduce the amount of heat that it retains throughout the day, owing to sky cooling. Specifically, this would allow the surface to approach the hours of the morning closer to a temperature amenable to condensation. Regardless, if the ΔT between the condenser surface and the ambient temperature is too large, even the emission of large quantities of infrared energy would not be sufficient to allow for condensation. This suggests that for the Mojave Desert, as well as other regions that fall within a similar Köppen Climate classification (Peel, Finlayson, and McMahon 2007, 1633-1644), a system that is at least partially active in nature ("active" denoting that the system requires some energy input to function properly). This is only useful if a purely passive system is desired. For purposes of this study, an active system was designed with the intent that total power consumption would be within the capabilities of a standard high-efficiency solar panel (approximately 200W).

> "Water is held within the soil matrix by adsorption to particle surfaces and/or by capillarity in the pores. The relative humidity within such pores is thought to be the greatest factor influencing the ability to draw in moisture from the air. Specifically, high relative humidity in the pore is governed by capillarity and low relative humidity inside the pore is governed by physical adsorption directly onto the surface." (Agam 2006, p.4)

Dew cannot be formed on a surface if that surface has a temperature greater than the ambient dew point temperature. While this usually indicates that vapor condensation is impossible, water content in the air can still deposit upon a surface through direct adsorption. (Agam 2006) While this may indicate the possibility of successfully obtaining water from the atmosphere in an arid environment, the amounts will likely be small or possibly unobservable, as the absolute humidity is low.

The inability to utilize rainwater collection or fog collection systems in many dry, desert regions (such as Las Vegas) means that, for arid environments, refrigeration is likely the most useful method in collecting water condensation, as it is too hot and too arid to condense water by radiative cooling.(Nandy et al. 2014, 481)) The *Peltier Effect* is a phenomenon that has the potential to shunt large quantities of heat from the experimental surface with a relatively large investment of energy, which will be discussed in greater detail below. However, such amounts of power are likely able to be provided by a high-efficiency photovoltaic panel or array of panels. (Drebushchak 2008, 311-315)

Refrigeration can be successfully achieved through a number of techniques, such as the more common vapor compression refrigeration (VCR) as well as more uncommon strategies such as vapor absorption refrigeration (VAR), solid adsorption cooling (SAC), active magnetic regenerator (AMR) systems, thermoacoustic refrigeration (TAR) and thermoelectric cooling (TEC). (Milani et al. 2011, 2491-2501) Some of these have inherent advantages over other systems. For instance, TEC systems are essentially solid state, with no moving parts, and are essentially noiseless. (Milani et al. 2011, 2491-2501) Specifically, thermoelectric cooling systems will be explored in detail throughout this project.

The hope was that, through the use of parametric design tools and advanced computational modeling, an architectural element can be developed that successfully optimizes a surface in regards to: (1) wettability (specifically hydrophobic and hydrophilic nodes and how they are arrayed with one another); (2) exposure to the sky-dome to allow for optimal radiant cooling and prevent excessive thermal gain during the day; (3) vapor contact angle and (4) surface pore depth. Inputting these constraints into Grasshopper and therefore into Rhinoceros 3D should generate a rapidly evolved and optimized surface that satisfies one or more of these constraints. Unfortunately, the materials used to construct this surface did not possess the ideal characteristics necessary for adequate heat transfer. As such, the material is a very poor choice for encouraging moisture condensation, and should not be investigated further. See the Methods section below for more information about the experimental setup and apparatus as well as information about the materials selected.

Thermoelectric Cooling

One of the methods considered for achieving this *supercooling* would be to utilize the *Peltier effect* in which a thermoelectric apparatus redirects heat from one side of the apparatus to the other as a voltage is applied. The result is a heat flux in which one side of the apparatus becomes colder while the other becomes hotter as the heat is drawn through the assembly. (Okhrem 2011, 123-126)

While this phenomenon is not new, it typically finds applications in cooling electronic equipment, such as the central processing unit for a computer, however it could be useful in cooling a surface to below the dew-point temperature, inducing condensation. Generating condensation in this manner is fundamentally no different than the condensation that forms on the cooling coils of a traditional air-conditioning system. (Habeebullah 2009, 330-345) Although condensation is usually avoided when combined with electronics, in this case, the effect would be positive, as long as precautionary measures are taken to properly shield the electrical components of the apparatus from any condensate that were to form. Such a system would require some power input to allow the thermoelectric units to function, which could conceivably be coupled with a photovoltaic array, taking advantage of the large number of clear days that Nevada has. Solar energy could be captured during the day and released to power the system at night and the early morning when condensation is most easily achieved.

As stated earlier, a large number of water collection methods have been employed in the distant past and the modern era alike. Some of these methods are more efficient than others, obtaining higher yields of water, but each method is often uniquely suited to the environment in which it is applied. For instance, fog nets, while very useful in the Atacama Desert, find little applicability in the Mojave Desert because the environments are not identical. These other systems are either more experimental or provide less yield during their operation. These other systems utilize either collection of fog (a behavior also observed in many organisms), which is also highly dependent on the climate in which it is utilized (for instance, it would be an essentially useless technology in the Las Vegas Valley where fog events are extremely rare, but might be more viable on, say, Mount Charleston, where fog events are slightly more common. Some of the more experimental solutions look to condense water out of the air itself. While such processes are difficult to achieve, there have been many successful studies and prototypes that can condense small amounts of water on a small surface area.

Another advantage of utilizing TEC systems is that the effect can be compounded by employing multiple thermoelectric (Peltier) units. Use of stacked thermoelectric modules can supercool a surface so far below ambient temperature that the water will freeze out of the air. Such a method is known as cascading. While doing so dramatically increases the amount of heat that is generated on the hot side of the semiconductor junction, it likewise dramatically increases the cooling capacity of the system. In arid environments, the dew point is likely at or below freezing temperatures, leading this to be the only avenue to successfully draw water out of the air. (Nilsson, Niklasson, and Granqvist 1992, 175-193) Unfortunately, this would mean that the frost will continue to accumulate on the cooled surface until the electrical current is removed and the heat of the thermoelectric module is no longer dissipated, thawing the frozen condensate and allowing it to drop into a reservoir. TEC technologies also have the potential to be utilized for other purposes as well. Solar Stills are a relatively new idea that seek to couple the renewable energy of the sun to fuel energy-intensive desalination systems. (Esfahani, Rahbar, and Lavvaf 2011, 198-205) Desalination is extremely energy intensive as a process, and utilizing any method that can reduce the amount of non-renewable energy required to produce freshwater from salt-water is an extremely viable technological application.

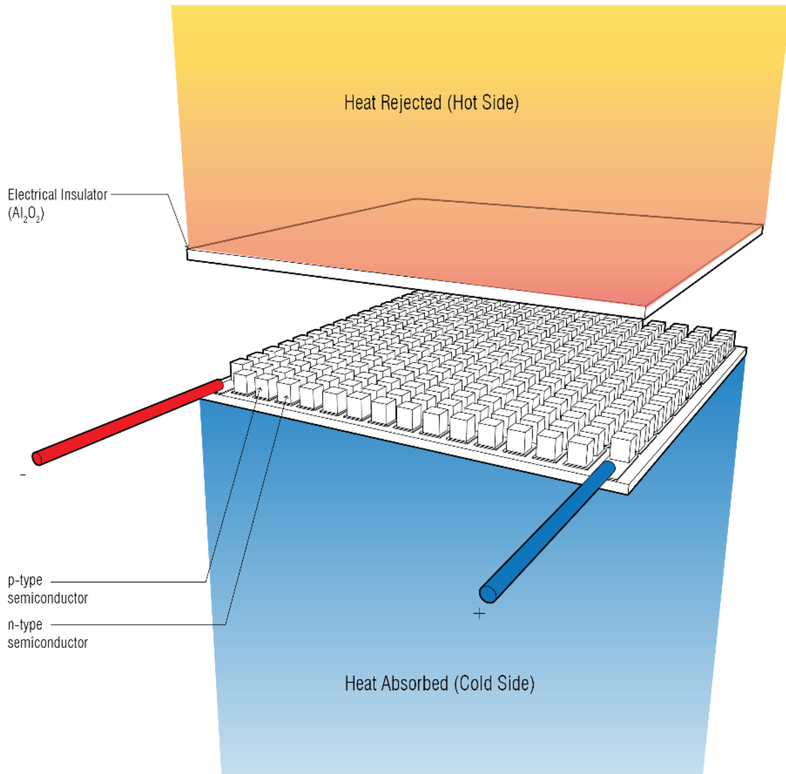


Fig. 2.2: *the Peltier effect in thermoelectric cooling (TEC) applications.*

Additionally, it is possible to employ thermoelectric units inside of ceiling panels to provide a significant amount of space cooling. (Shen et al. 2013, 123-132) However, TEC is not without its drawbacks. The systems are entirely at the mercy of how well they can reject heat, and if they are unable to do so effectively, the semiconductor materials can quickly be destroyed from overheating. (Khonsue 2012) The coefficient of performance is a good way of indicating the overall efficiency of a thermoelectric device, with a higher number corresponding to better performance. (Taherian and Adams 2013, QQ1)

Biological models for adaptations to environmental extremes

For the built-environment to consume less resources, it is argued by the author that biomimetic strategies need to be employed, in some manner. Janine Benyus, in her writings on biomimetic design, suggests that nearly every design problem can be answered with an analogue from the natural world. Specifically, an organism that has developed, through evolution, a means to overcome the problem in question. (Benyus 2002) However, this retools the way that systems must be conceptualized in architectural practice, specifically, it is time that buildings are viewed as open systems rather than as closed systems. Closed systems are finite and unsustainable – they require more resources than they are capable of replacing and they fail to interact harmoniously and synergistically with their surroundings/context. Turning to biological systems – at the micro and macro scales – will allow built forms to behave more sustainably by default. To this end, moisture should not necessarily be seen as an enemy of the built form, but rather as an opportunity, if it is carefully controlled.

Turning to nature for examples of water collection strategies also proves very insightful, particularly in the investigation of condensing water from the air. A number of different organisms throughout the world's arid environments have evolved varying adaptations to water collection or maintain homeostatic water balance, such as the *stenocara* beetles in the Namib Desert of Western Africa. Part of the preliminary studies in this project will involve looking at some of the most successful biological analogues and evaluating the methods by which they either conserve or obtain water from the hostile environments they inhabit. Simultaneous with this study, and tightly integrated with it, is an investigation into the very physics and mechanisms by which water is collected and managed by these organisms. Through this, it is hoped that a prototype system can be developed that is capable of emulating the strategies of these organisms, whether in part or by emulating multiple strategies in parallel.

There are numerous biological models that can be studied to learn the mechanism by which they manage their water reserves physiologically. Some organisms are better at minimizing the amount of water they lose through excretion or respiration, while others have evolved unique mechanisms to extract water from their surroundings. Both methods are worthy of analysis, as the natural world has usually developed particularly efficient ways of approaching otherwise difficult problems.

The first animal is the the Kangaroo Rat, *dipodomys merriami*. This small rodent is capable of concentrating its urine to extremely high levels, which dramatically reduces the amount of water that the animal loses due to normal excretion. (Urity et al. 2012, R720) Research indicates that it is the structure of the kidney of this animal that allows it to achieve this feat. However, this ability to achieve immense osmoregulation is ambiguously related to water management in the built environment. Certainly, further investigation into the physiology of the kangaroo rat would be beneficial, but some of the biological examples discussed below are more useful to the extraction of water from the air.

Second is the Thorny Devil, *moloch horridus*. This creature sports a unique carapace that, upon further study, was found to actually have immensely potent thermal conductivity, exceeding that of most metals that would usually be employed in such applications. (Sinha-Ray, Zhang, and Yarin 2011, 215) It is this feature that allows the organism to thrive in the extremely hot environment of the Australian outback, and also serves to allow the reptile to absorb water directly from a variety of sources, such as rainwater, water trapped within the soil matrix proper as well as any small bodies of water that might be happened upon. (Sherbrooke 1993, 270-275) It is the mechanism of capillary action that allows the skin of the lizard to "drink." (Ask Nature 2016)

While this latter phenomenon is extremely applicable to our concerns with water collection, the thorny devil is actually much more useful as a case-study of the importance of thermal conductivity of materials (which is discussed in more detail below). Sinha-Ray et al. discovered that applying a layer of nanomaterial to a surface in a manner that mimics the natural formations of the skin of the thorny devil significantly improved the ability of the surface to be cooled. Essentially, this could be considered a form of electroplating. Specifically, they found that, depending on the metal used in the application, thermal conductivity upwards of 0.6 kW/cm^2 could be achieved. This is probably one of the most relevant biological sources of inspiration for the study, as using metal with a specific surface area and geometry exploits the thermal conductivity of these materials to rapidly cool a surface. However, for the purposes of this study, the intent is to use that cooling to dissipate latent heat in the air with the hope of condensing water. While the nanofiber aspect of the study is beyond the reach of this investigation, it does offer additional paths to consider upon revisiting the design of the thermoelectric apparatus and might accommodate a more customized condensing surface.

Third is the Namib Desert Beetle *Stenocara gracilpes*. This remarkable insect exhibits a fog-basking behavior that allows it to obtain water from moisture-laden wind borne from the sea adjacent to the desert. This is achieved by an intricate, interlacing array of hydrophilic bumps and hydrophobic pores that exist on the exoskeleton of the dorsal side of the beetle. (Lawrence and Parker 2001, 33-34) Numerous studies have been undertaken to both characterize this ability and identify the mechanism of action by which it occurs; other studies have been undertaken to apply this effect to a field where it is sorely needed: water management. Specifically, one study by Lee et al. (2012) focused on the evaluation of biomimetic surfaces as applied to inducing moisture condensation, but concluded that the interspersing of hydrophobic and hydrophilic regions had no significant effect on condensate yield. (Lee 2012)

Additionally, White et al. determined that it is an extremely complex matter to characterize the mechanics of drop nucleation and the associated mechanics, even across a variety of geometrical configurations and materials. They employed PTFE, Aluminum, Titanium and carbon nanotubes (CNT) with a variety of hydrophobic and hydrophilic formations, but their data could only weakly support any relationship to condensation formation at best. (White, Sarkar, and Kietzig 2013, 826-836)) This would suggest that the simple relationship between hydrophobicity and hydrophilicity modeled by Lawrence is flawed, but it is also important to remember that scale is a significant factor as well. The samples constructed by White et al. were a little over $1cm^2$ in dimension, which, while approaching the scale of the *stenocara gracilpes* beetle itself, may not be an entirely accurate approximation.

Hydrophobicity and Hydrophilicity

Probably the most useful features of the biological models discussed above are the hydrophobic and hydrophilic characteristics of the *stenocara* beetle, the lotus and the common cactus spine. This serves as a way of enhancing water collection, and while the chemical aspects of the condensing surface beyond thermal conductivity are beyond the scope of this study, preliminary tests with aluminum condenser fins were coated with Rust-oleum *Never-Wet* spray to assess if water shedding was improved. Droplet formation was enhanced, but overall water collection was not necessarily easier to collect.

The latter design parameter would be further subdivided into two possible assemblies: a passive apparatus and an active apparatus. The term *active* implies some investment of energy is necessary for the system to function as intended. In arid regions, such as Las Vegas, the dew-point temperature is far below ambient temperature for condensation to form readily. Application of energy in some part could act to bring the temperature of the condensing surface below dew-point temperature, creating condensation. For deployment in regions where the relative humidity is higher, such as coastal areas, the physical characteristics and the thermal properties of the materials utilized should be sufficient to result in adequate moisture collection.

Organisms tend to exhibit very effective and often simple solutions for the problems their environment presents to them. That said, there can be much for humans to gain by emulating or at least understanding the adaptations exhibited by specific creatures. For instance, there are a number of desert organisms that feature very useful physiology and behavior that pertains directly to water collection or management. Of the organisms discussed above of, the creature that drew the most research interest initially was the Namibian desert beetle *stenocara*, whose carapace features very specific arrangements of hydrophilic and hydrophobic surfaces. (White, Sarkar, and Kietzig 2013, 826-836)) In turn, these surfaces effectively act as a potent locus for heterogenous nucleation of water and subsequent shedding of the condensed water via hydrophobic action. (Carey 1992)) While the beetle uses the chemical composition of its carapace to collect water from seaborne fog rolling into the desert from the Atlantic Ocean, the mechanism by which it does this is just as applicable to the Mojave Desert as it is the Namibian Desert (Zhai et al. 2006, 1213-1217)), despite the different in fog patterns and relative humidity. That is to say that there is still water vapor present in the atmosphere of the Mojave Desert, though it is a more arid environment altogether and finding a method of extracting this vapor is more difficult.

> "In the afternoon the equivalent water column is often higher than the daily average value due to evaporation from the ground and open water surfaces, and it is lower at sunrise due to condensation during the night. Also the vertical distribution of the vapor is different from day to night so that the highest T_{dp} at the ground is measured in the morning and the lowest in the afternoon. This contradiction is caused by the fact that the dew point hygrometer is positioned at the ground, whereas some of the water vapor during the day has been moved from the ground to higher altitudes, due to the heating of the sun [adiabatic cooling]. However, the *total* amount of water vapor in the atmosphere is approximately constant in areas with little rain and dewfall. The absorption of solar and thermal radiation by water vapor in the atmosphere is similar regardless of the vertical distribution of the moisture, but the temperature of the vapor at different altitudes is different and thus also the radiance. The only dew point temperature that may remain constant for several days is the night-T_{dp}. This is the value we have used when calculating atmospheric properties for both night and day." (Nilsson and Niklasson 1995, 93-118)

In the earliest stages of this research project, the largest amount of attention was directed to radiative condensation as the mechanism to generate water. At the time, coupled with biomimetic design principles and parametric design efforts, it was thought that these principles would be lead to the development of an effective system for collecting moisture in an arid environment. The earliest prototypes quickly led to an abandonment of this objective, as it proved to generate no observable moisture, even in the season when the difference between the dew-point temperature and ambient temperature was at a seasonal low.

Thermal Conductivity

Thermal conductivity is defined as:

> "The ability of a substance to conduct heat. Good thermal conductors, like good electrical conductors, are generally materials with many free electrons, such as metals. A poor conductor, called an insulator, has low conductivity. Thermal conductivity is expressed in units of joules per second per metre per kelvin (J s^{-1} m^{-1} K^{-1}). For a block of material of cross-sectional area *a* and length *l*, with temperatures T_1 and T_2 at its end faces, the thermal conductivity λ equals $Hl/at(T_2 - T_1)$, where *H* is the amount of heat transferred in time *t*." (The Hutchinson Unabridged Encyclopedia 2015))

With the primary effort of this project being to cool a surface in order to facilitate the formation of condensation upon that surface, it stands to reason that this process would best be encouraged through the use of highly thermally conductive materials. Thermal conductivity values for the following materials were taken from Powell et al. (Powell, Ho, and Liley 1966): copper, aluminum, silver, gold and diamond (values listed are in W m^{-1} K^{-1} at 300K. Table data from the National Bureau of Standards was originally recorded in W cm^{-1} K^{-1} and values were modified to be consistent with the values obtained for Helium II and carbon nanotubes listed below):

Copper: 398
Aluminum: 237
Silver: 427
Gold: 315
Diamond: 900 (type I), 23,500 (type IIa), 13,500 (type IIb)

Other materials, well-beyond the scope of this project, exhibit thermal conductivity vastly superior to the materials discussed above. For example, carbon nanotubes have been recorded with thermal conductivity up to 3,180 W m^{-1} K^{-1}. (Kim et al. 2001, 215502) Additionally, Helium-II is recorded as exhibiting thermal conductivity well beyond 100,000 W m^{-1} K^{-1}. (Hampel 1969, 678) The extremely high thermal conductivity of diamond makes it an excellent choice for cooling applications, and the same can be said of silver. Obviously, silver, gold and diamond are not economically viable for a small research project such as this (for that matter, neither are carbon nanotubes or Helium-II), but copper and aluminum are both readily available and are conveniently manufactured in shapes a large surface area to volume ratio (specifically, heat sinks intended for managing heat flux).

For the construction of the test apparatus, detailed below, copper and aluminum were selected as the materials to investigate, mainly due to their viable thermal conductivity values and how readily available they are in a variety of shapes and structures. A variety of total surface areas were tested during the course of the experimental study and the clarification relationship between the sensible heat, latent heat, thermal conductivity, relative humidity and total surface area was attempted.

03 | METHODOLOGY

Again, the primary intent of the project is to synthesize and apply this research into the direct fabrication of a novel building envelope system. Preliminary readings and research from the previous semester have already suggested that condensation is the means by which water is most readily accessible in arid environments. This thesis will investigate the mechanics of condensation and developing a surface that could be applied to an architectural envelope system for the express purpose of bolstering the structure's ability to collect water. Specifically, the surface in question should be optimized for rainwater catchment if deployed in locales where such collection is permitted. Consequently, where rainwater harvesting is not an allowable method of water collection, such as Nevada, the surface would be designed to facilitate water condensation upon its surface (and the subsequent collection of the condensate). Such an approach would not violate any existing water rights and would not technically intercept water from recharging the groundwater supply in the region.

An apparatus was developed that could allow for two different experimental samples to be evaluated simultaneously, recording ambient temperature and humidity data as well as data within the device itself. Two air wells were constructed from extruded 0.1625” thick transparent polystyrene and numerous custom 3D-printed parts to create a rigid frame. Atop of each well a computer case fan was fastened to a 3D-printed frame, allowing for air to be drawn in to the system, providing a continuous source of humid air. An aperture was cut out of the polystyrene via laser-cutter, allowing two 3A Velleman thermoelectric modules, stacked on top of one another, to be mounted onto the exterior of the air well. The thermoelectric units were mounted in just such a manner as to allow the cold side of the thermoelectric unit (a ceramic plate) to protrude inside the well, allowing an experimental surface to be mounted flush across the inside polystyrene frame and the thermoelectric unit. The hot side of the thermoelectric unit was anchored with a layer of thermal paste to an Evercool CPU heat sink so the heat generated by the 3A units could be effectively discharged, preventing damage to the assembly. The thermoelectric units installed on the first prototype of the condenser apparatus were thermally sealed with silicone, but this dramatically reduced the ability of the devices to operate correctly and the final version of the instrument did not feature thermally sealed Peltiers.

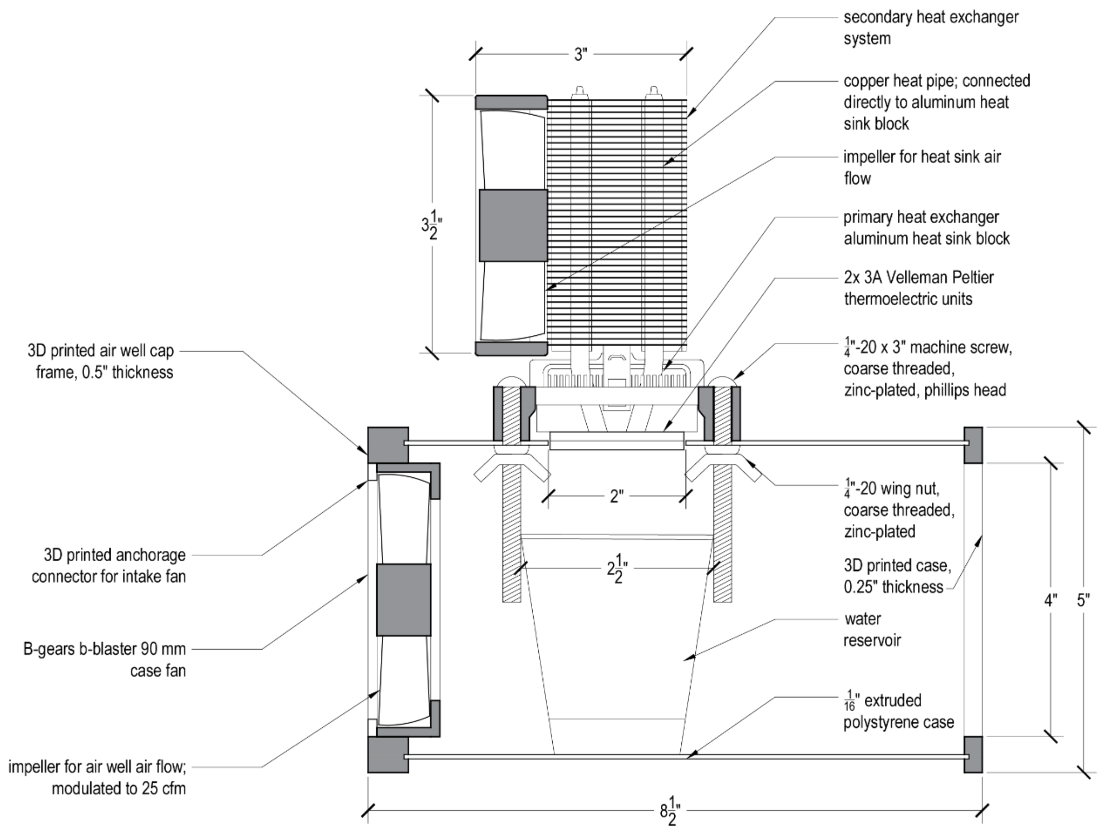


Fig. 3.1: *Schematic cross-section of the test apparatus and its assembly.*

Each air well had a HOBO data-logger from Onset Corporation placed inside to measure the air temperature and relative humidity inside each air well. An additional sensor was placed between each air well during each experiment to allow a comparison between environmental data outside and inside the air wells. An Ex-Tech Thermohygrometer was placed beside the air wells to monitor the ambient temperature, dew-point temperature and relative humidity in real-time.

The four thermoelectric units, the CPU cooling unit, the case fans, and a fan-speed controller were connected to a 600W Thermaltake PC Power Supply to ensure that a continuous source of power was available to the components. The total amount of power consumed by the apparatus is estimated at 77 W, based on manufacturer specifications. At five hours of run-time, this is estimated at 0.45 W·h of energy (refer to Ch. 4 for all of the energy calculations relating to the system and its performance).

Fig. 3.2: Image of the fully constructed prototype.

A series of condenser surfaces were affixed to the thermoelectric unit's cold side. Two materials were employed for the condensing surfaces: aluminum and copper. The aluminum surfaces consisted of a small Raspberry Pi heat sink measuring, a larger heat sink measuring and a smaller heat sink measuring. The copper surfaces consisted of another Raspberry Pi heat sink measuring, and a flat 14 gauge copper plate measuring 4" x 4". See the diagrams below in Fig 3.2.a-e for more information about the surfaces employed. During each test, a plastic container was placed beneath the condenser surface in order to collect condensed water that would drain off due to gravity.

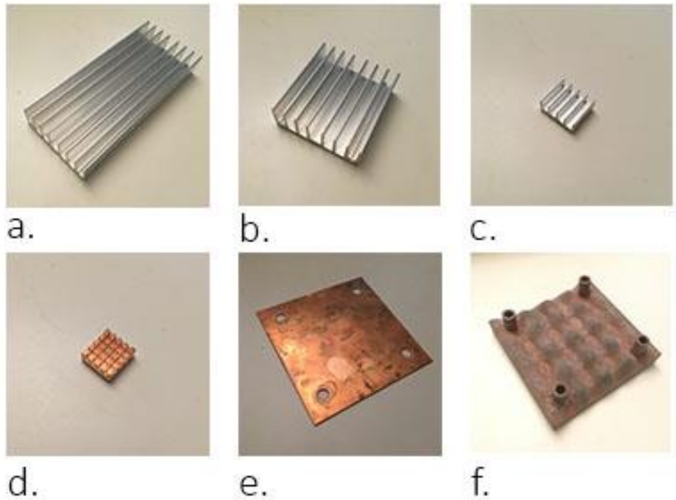


Fig. 3.3: *Photographs showing the various experimental surfaces used during the study.*

The largest aluminum heat sink possessed a surface area of 68.4 in^2, while the second largest aluminum heat sink had a surface area measuring 31.7 in^2. The small Raspberry Pi aluminum heat sink had a surface area of 4.56 in^2 (arrayed as four units together). The small copper Raspberry Pi heat sink had a surface area of 1.92 in^2 (arrayed as four units together on the TEC surface) and the 14 ga. copper plate had a surface area of 16 in^2.

The beginning of each test was begun with a brief temperature verification for each thermoelectric unit. Prior to attaching the experimental surface, the units were allowed to run for one minute to ensure that each thermoelectric unit was reaching the anticipated temperature range. Each test interval was 300 minutes (5 hours), in which the thermoelectric devices were allowed to run uninterrupted. After the time had elapsed, the power source was shut off and moisture was collected from the plastic vessel beneath each condensation surface using a syringe and measured in a 5mL graduated cylinder. If the condensation froze onto the condensing surface, measurement was delayed until the ice thawed enough for the frozen condensate to fall of the surface and melt entirely. Residual moisture on any surface was also collected using a syringe and added to the remaining volume in the plastic vessel to ensure that as much moisture was accounted for as possible.

Due to the nature of the thermoelectric units, moisture that formed on the side of the unit as it cooled below dew-point has the potential to infiltrate into the semiconductor junction of the assembly, which can create a thermal short, dramatically reducing the ability of the device to function. (Nandy et al. 2014, 481) To avoid this occurrence, a blow-drier was used to dry out the thermoelectric units after each test had been run and the moisture had been collected from each surface.

Typically, condensation is not encouraged in the built-environment. Moisture and buildings do not typically mix well, and as such, water-proofing and vapor-retarding are methods commonly employed at various stages of construction. (Grondzik et al. 2010) However, if carefully integrated, a thermoelectric condenser system could be synergistically combined with various wall assembly systems to protect the apparatus from excessive heat and provide a channel through which to conduct air and to collect condensate.

The experiments outlined in this method constitute a battery of schematic prototypes that are intended to *induce* condensation on an optimized surface and collect the potable water (Nikolayev et al. 1996, 19-35). The materials and the characteristics of the surface are manipulated in such a way as to compare the effects these properties have on the ability to condense moisture.

The limiting factor in these experiments is a handful of environmental factors in the Las Vegas Valley, which are not favorable to condensation. Specifically, the aridity of the valley is not conducive to forming condensation naturally, as the dew-point is consistently below freezing temperatures, apart from a narrow margin in the summer when monsoon storms become a frequent occurrence. Additionally, the difference between the ambient temperature and the dew-point temperature is so large that only a large amount of supplemental cooling could bring a surface to the freezing or sub-freezing temperatures required to induce condensation. Even if condensation can be induced, it can only occur as frost-condensation, which will be markedly more difficult to collect than liquid water.

Oceanside, California	Period	1	2	3	4	5	6	7	8	9	10	11	12	Year
Avg. Monthly Temp. (°F)	1953-2010	63.9	63.8	63.8	65.0	66.5	68.4	72.1	74.0	73.5	71.4	68.2	64.9	68.0
Avg. Ann. Precip. (in)	1953-2010	2.17	2.14	1.67	0.98	0.20	0.08	0.03	0.07	0.26	0.45	1.02	1.26	10.33
Mean Monthly RH (AM) (%)	1996-2010	75.0	78.0	84.0	79.0	76.0	75.0	76.0	78.0	78.0	76.0	74.0	75.0	77.0
Mean Monthly Dew-Point Temp. (°F)	1999-2011	41.5	44.1	47.4	48.4	53.6	57.2	61.3	61.4	58.3	53.3	46.7	40.7	51.2
Las Vegas, Nevada	**Period**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Year**
Avg. Monthly Temp. (°F)	1937-2010	45.8	50.7	56.9	65.0	74.7	84.3	90.6	88.5	80.7	67.9	54.3	46.0	67.1
Avg. Ann. Precip. (in)	1937-2010	0.52	0.58	0.44	0.20	0.15	7.00	0.43	0.43	0.31	0.26	0.36	0.40	4.15
Mean Monthly RH (AM) (%)	1996-2010	55.0	50.0	44.0	35.0	31.0	24.0	29.0	35.0	34.0	38.0	46.0	54.0	40.0
Mean Monthly Dew-Point Temp. (°F)	1950-2002	25.0	27.0	28.0	27.0	32.0	35.0	43.0	42.0	39.0	29.0	26.0	21.0	31.0

***Table 3.1**, Regional Climate Data adapted from climate tables provided by the Western Regional Climate Center, an arm of the Desert Research Institute* (WRCC 2016)

First of these limiting factors is the relative humidity. For condensation to occur, the surface temperature must be less than the dew-point temperature. Second, is the difference between ambient temperature and the dew-point temperature, which in the Mojave Desert, particularly in the summer season, tends to be so prohibitively large, that cooling a surface to the dew-point would be impossible without substantial artificial means (i.e. refrigeration or some sort of active chilled system integrated with the condensing surface – the energy investiture of which would be disproportionate to the amount of water extracted from the atmosphere).

Lastly, wind flow and turbulence is a problem in facilitating adequate condensation on a surface. In their radiative cooling condensation experiments, Nilsson et. al. determined that an approximate wind velocity of no greater than 1 m/s (3.3 ft/s) was optimal in order to facilitate the condensation of water on their radiator. The Las Vegas Valley is prone to strong, persistent winds throughout the year, and such strong winds would prevent water from nucleating on a condensation surface. Therefore, the instrument constructed for this study encloses the condensing surface inside a polystyrene chamber to protect the surface from intense winds. A common computer case fan is attached to the top of the experimental air well, allowing air to be drawn in. The fan operates at a default speed of 78 cfm, which corresponds to approximately 10 ft/s. To avoid the inhibition of condensation on the surface, a fan controller dials the speed down to 3.3 ft/s.

The area of the cross-section of the air well was calculated as:

4.375” x 4.375” = 19.14 in^2 which can be converted into 0.13 ft^2

Therefore:

$$3.3\,\frac{\mathrm{ft}}{\mathrm{s}}\left(\frac{60\mathrm{s}}{1\ \mathrm{min}}\right) = 198\,\frac{\mathrm{ft}}{\mathrm{min}}$$

$$198\,\frac{\mathrm{ft}}{\mathrm{min}} \times 0.13\ \mathrm{ft}^2 = 25.4\,\frac{\mathrm{ft}^3}{\mathrm{min}}$$

Using the installed fan controller, the air speed of air circulating through the air well was brought down to 25 cfm, keeping the total air velocity to below 1 m/s. In one of the early Las Vegas outdoor trials, one air well had its fan running while its counterpart did not in order to test the effect of wind velocity on condensation formation. However, it was found that both condensers generated 0.5 mL of condensate. All further experiments were run with both fans operating at 25 cfm.

Combined with a thermoelectric module that is capable of chilling the surface to a temperature that will yield condensation.

As such, the first battery of experiments shows unimpressive results in terms of water collection. This is largely due to dialing in the ideal settings for the apparatus, properly wiring the componentry together and determining proper placement. In all experiments, the experimental AWG was placed on either the shaded North side of a structure or otherwise protected from any direct sunlight. Additionally, once satisfactory wiring arrangements were identified (specifically, the wiring of the thermoelectric units into the power source), those connections were maintained throughout the entire study.

The intent is that trends might become visible which could then be extended to either additional environmental locales or undergo more controlled laboratory settings. Further investigation would be needed to clearly assess the psychrometric performance of the prototype and its ability to adequately generate useful quantities of water.

In regard to the application of biomimetic principles to the atmospheric water generator system developed for this study, the *Stenocara* beetle serves as a useful model. The arrangement of hydrophilic and hydrophobic surfaces on its carapace optimizes water collection and shedding, while the natural “bumps” that form serve to expand the overall surface area upon which condensation is capable of forming through dropwise action. A final test piece was constructed by modeling an experimental surface in Rhinoceros 3D that was inspired from the beetle carapace. The surface was 3D-printed using a Prusa Mendel i-III, with 1.75mm Copper/Poly-lactic acid filament from ColorFabb. The filament actually has copper interwoven into the plastic proper, but ultimately only about 30% of the filament is actually copper, according to the manufacturer’s website. Unfortunately, the equipment necessary to experimentally determine the thermal conductivity of the Copper/PLA material was not available, and as such this value was not calculated. However, experimentally, the biomimetic surface developed from this material did not form any condensation after a 300-minute test interval. This lackluster performance of the experimental surface led to its exclusion from a larger test battery.

Attempts were made to secure a direct-metal laser sintering (DMLS) surface made from aluminum, but the cost for a relatively small print was too expensive for the budgetary constraints in this project (approximately $365 for a 4 in^2 print). If additional funding could be secured in the future, laser-sintered pieces featuring customized geometry could be attainable, likely offering compelling data. Other avenues worth exploring are in silver surfaces, which sports a much higher thermal conductivity than either copper or aluminum (though at considerably higher cost per unit weight) and precious metal clay, which could be sculpted into any variety of shapes or forms.

04 | RESULTS / DISCUSSION

Of the experiments undertaken in Oceanside and Las Vegas, the more successful experiments took place in Oceanside. All of these experiments resulted in significantly higher volumes of condensate collected, and fewer instances of frost formation on the surfaces. The average Relative Humidity across all experiments in Oceanside was 65.3%, with an average dew-point temperature (Td) of 53.4 °F and an average ambient temperature of 62.7 °F, whereas the respective values for Las Vegas were 21.8%, 35.05 °F and 74.56 °F. This indicates that the experimental surfaces required much less cooling to reach the dew-point in Oceanside (approximately 9.3 °F on average versus 39.51 °F). This large difference explains why the condensate yields are so much higher in Oceanside than Las Vegas.

Prior to the main battery of tests, two initial trials of the thermoelectric units were conducted with no experimental surface attached for purposes of assessing the average surface temperature of the cold side of the thermoelectric units.

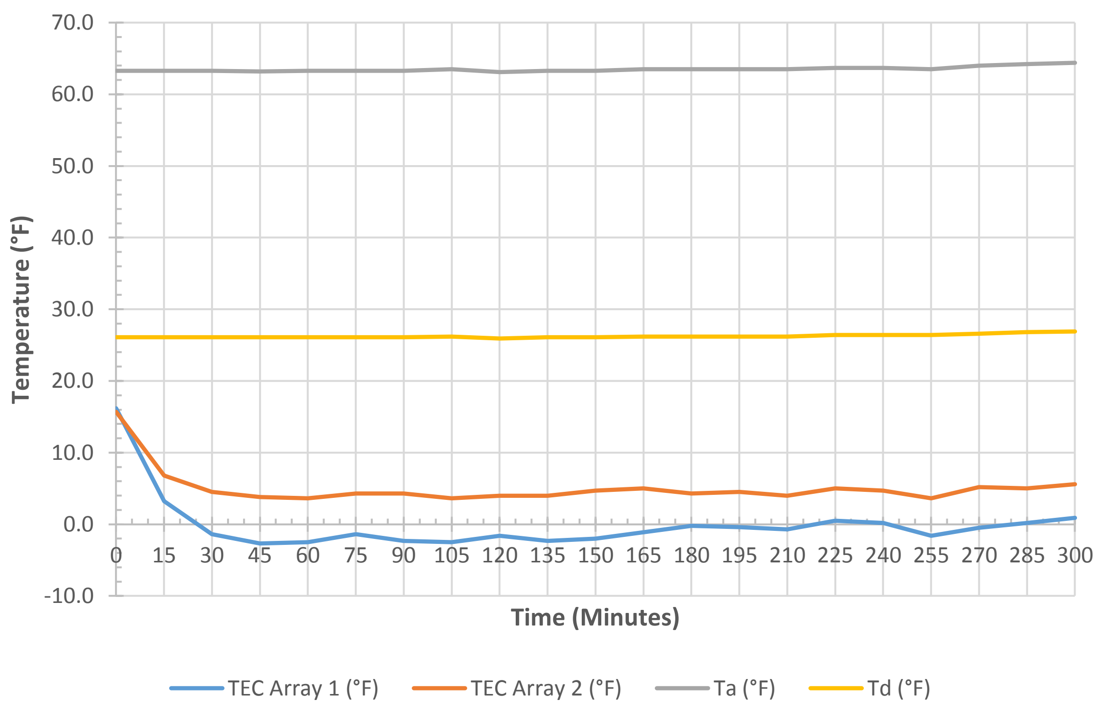


Figure 4.1: *Temperature measurements 1*

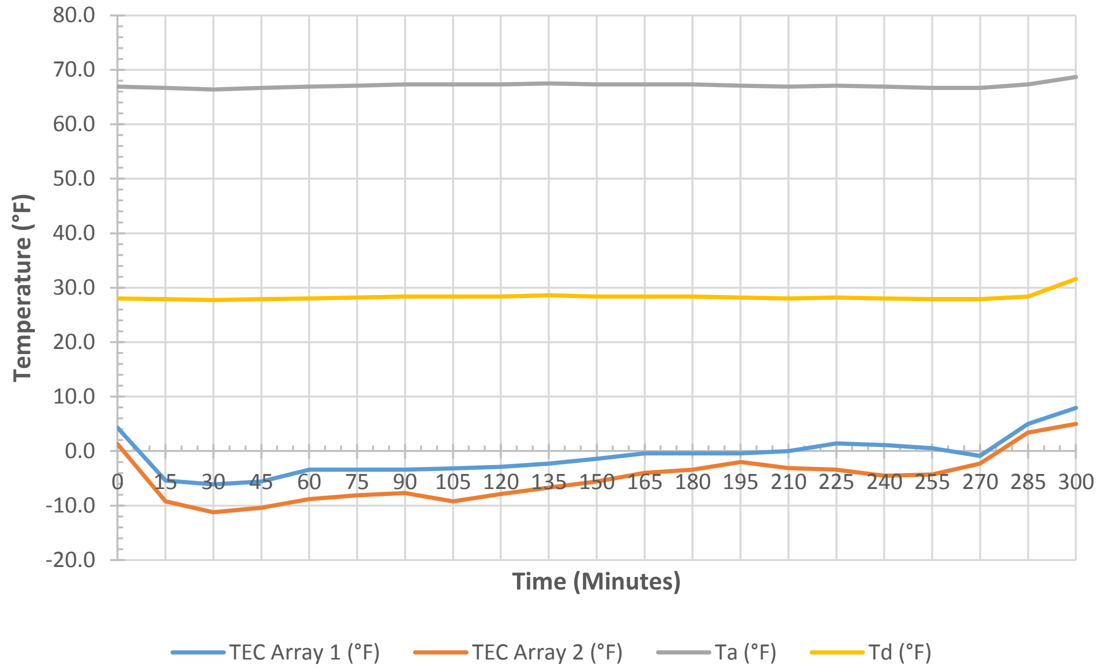


Figure 4.2: Temperature measurements 2

The intent was to assess the performance of the prototype in two areas that exhibit very different levels of humidity in an effort to identify a predictive model for the amount of water that could be theoretically collected in a given environment. It was found that the performance of the machine was significantly improved in Oceanside, where the humidity was much greater than that of Las Vegas. Additionally, it was found that a larger surface area was more conducive to condensation formation when the humidity was higher and the dew-point much easier to reach. In Las Vegas, a larger surface area resulted in less than ideal cooling of the material, preventing condensation from forming efficiently if at all.

The average condensation collected in Oceanside, CA was 11.8 mL over 8 tests, while the average moisture collected was 0.4 mL in Las Vegas over 12 tests. The average humidity in Oceanside was 65.3% during the 8 tests run, which does help explain the additional moisture collected. Furthermore, the only way to condense water out of the air in Las Vegas is to freeze it out of the air, as the dew-point temperature is consistently less than the freezing temperature of water.

In general, it seems that copper and smaller surface area works better in an arid environment, as tests involving copper surfaces were the only successful tests in Las Vegas. Both copper and aluminum seem to work in humid environments, but Aluminum seems more efficient, particularly as it is able to be fashioned into shapes with larger surface areas. Furthermore, it seems that Aluminum is favored in more humid environments because less cooling is required to reach the dew-point temperature, which is consistent with the lower thermal conductivity of aluminum compared to copper (237 W m^{-1} K^{-1} vs. 398 W m^{-1} K^{-1}). The efficiency of this device in an arid, desert region seems to be very poor.

In terms of water condensate collected, the most effective condensation surface was the Aluminum heat sink measuring 5.9" x 2.6", provided with 10 ft^3/min of air flow and high external humidity in Oceanside, California. The total condensation yields for aluminum (Table 4.1) and copper (Table 4.2) are listed below in chronological order:

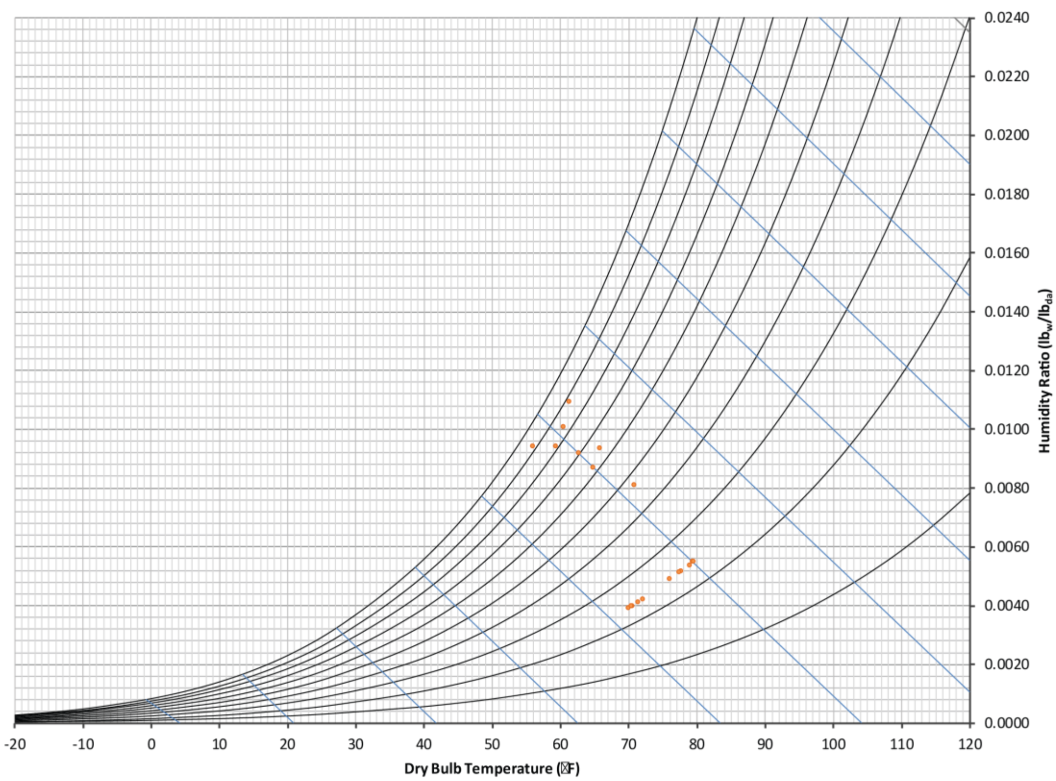


Fig. 4.3: *Psychrometric Chart for the experimental data points, indicating the climatic conditions during each trial. The chart used is meant for climatic conditions at sea level, but ASHRAE standards indicate that it is also usable up to elevations of 2000 ft. above sea level.*

T_a (°F)	T_d (°F)	RH (%)	Surface Area (in^2)	Condensate (mL)	Wet Bulb Temperature (°F)	Enthalpy (Btu/lb)
76.06	36.55	23.9	1.92	1.4	54.7	23.6
78.94	38.91	23.8	1.92	1.8	56.5	24.8
79.49	39.48	23.9	1.92	1.2	56.9	25.1
77.45	37.72	23.9	1.92	1.3	55.6	24.2
79.62	39.58	23.9	1.92	0.5	57.0	25.1
76.06	36.55	23.9	1.92	0.8	54.7	23.6
78.94	38.91	23.8	1.92	1.3	56.5	24.8
79.49	39.48	23.9	1.92	0.5	56.9	25.1
79.62	39.58	23.9	1.92	0.1	57.0	25.1
70.49	31.4	23.4	16.0	0.0	50.7	21.2
62.76	52.86	70.2	1.92	6.6	56.9	24.3
70.89	49.56	46.9	1.92	6.3	58.3	25.2
61.35	57.6	87.7	1.92	14.2	59.0	25.8
60.43	55.34	83.5	16.0	14.8	57.3	24.7
65.79	53.31	64.4	16.0	5.2	58.3	25.2
59.32	53.51	81.4	1.92	12.9	55.9	23.7
56.04	53.63	91.6	1.92	14.0	54.6	23.0
Average Moisture Collected (mL): 4.9						

Table 4.1, yield for copper condensation surfaces

Ta (°F)	Td (°F)	RH (%)	Surface Area (in2)	Condensate (mL)	Wet Bulb Temperature (°F)	Enthalpy (Btu/lb)
70.62	31.51	23.4	68.4	0.0	50.8	21.3
71.14	32.27	23.5	68.4	0.0	51.3	21.6
77.75	37.85	23.8	68.4	0.0	55.7	24.3
69.6	32.2	25.0	31.7	0.0	50.6	21.2
70.52	31.43	23.4	4.56	0.0	50.7	21.2
70.49	31.4	23.4	4.56	0.1	50.7	21.2
71.14	32.27	23.5	68.4	0.0	51.3	21.6
77.75	37.85	23.8	68.4	0.0	55.7	24.3
77.45	37.72	23.9	68.4	0.0	55.6	24.2
69.6	32.2	25.0	31.7	0.0	50.6	21.2
62.76	52.86	70.2	31.7	4.9	56.9	24.3
70.89	49.56	46.9	31.7	0.0	58.3	25.2
61.35	57.6	87.7	31.7	26.9	59.0	25.8
60.43	55.34	83.5	4.56	16.8	57.3	24.7
65.79	53.31	64.4	4.56	12.1	58.3	25.2
59.32	53.51	81.4	31.7	16.6	55.9	23.7
56.04	53.63	91.6	68.4	22.8	54.6	23.0
Average Moisture Collected (mL): 5.9						

Table 4.2: *yield for aluminum condensation surfaces.*

Initially, two of the major relationships of interest in this study were those of condensation collected and the ambient latent heat in the air (expressed as the wet-bulb temperature) and that of surface area as related to condensation collected. The charts below depict the collected data and the trend-line associated. Linear relationships between the data were assumed.

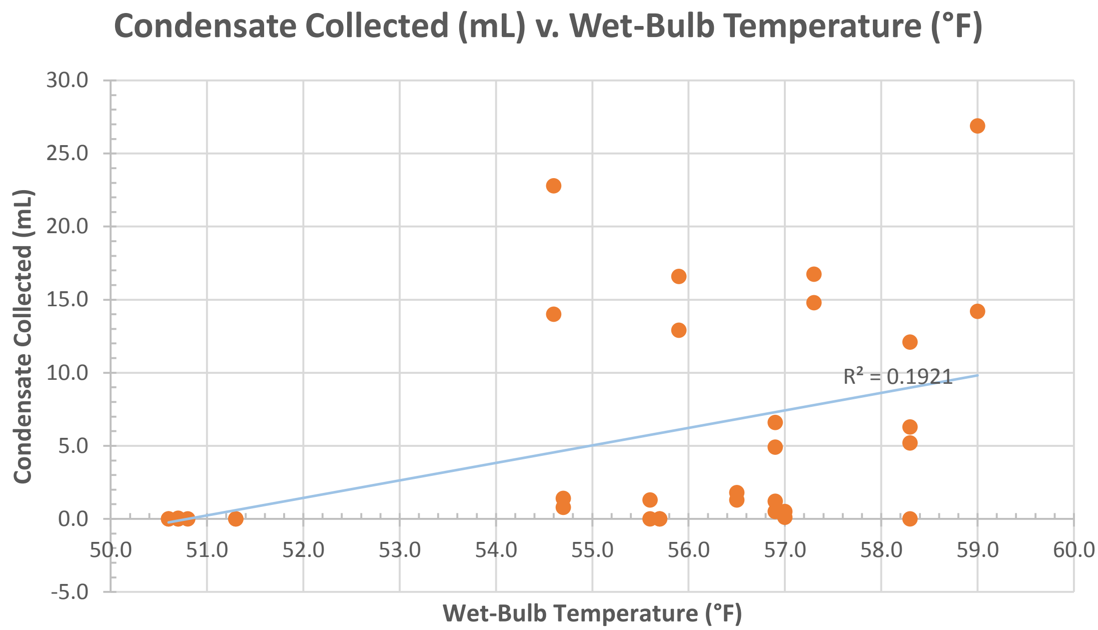


***Fig. 4.4**: Condensate Collected versus Wet-Bulb Temperature.*

With an R^2-value of 0.19, this regression line does little to explain the variability observed in the data. Specifically, there is not a clear relationship between Wet-bulb Temperature itself (that is to say, the latent heat present in the air during the experimental trial) and the amount of condensation formed. Already, this indicates that there is no single variable that governs the amount of condensation that one could expect to collect in a given environment, however, the relationship between surface area of the metal condenser and the amount of water collected was characterized.

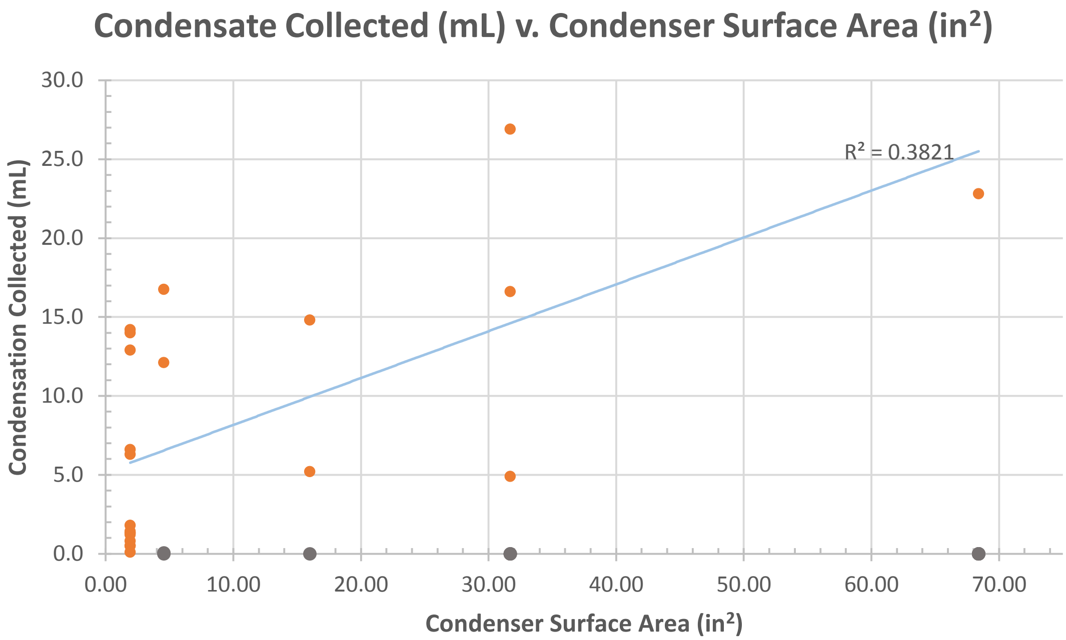


Fig 4.5: *condensate collected versus condenser surface area.*

For construction of this chart, instances where no water was collected on the condenser surface (regardless of environment) were excluded in order to create a trend-line with a clear relationship between surface area and condensate yield. These data points are still included on the chart (marked in gray), for reference. Specifically, instances where no water was collected could have been attributed to either incorrect wiring of the thermoelectric units, which would be a false negative (type II error), or due to ambient environmental factors, but it is impossible to differentiate. However, experimental data, indicated by the grey points in Fig. 4.4, indicate that instances of where no water could be collected occurred for each variety of condenser surface. As the ANOVA analyses indicate below, a p-value of 0.79 for aluminum surfaces and 0.98 for copper surfaces indicate that the ANOVA is not statistically significant for the data collected.

The trend-line crafted for the relationship between surface area and condensation collected possesses an R^2 value of 0.38, which, while a stronger fit than the relationship between condensation collected and Wet-bulb temperature, still does not adequately explain the variability between the data points collected in both Oceanside and Las Vegas. Therefore, surface area itself does not have a statistically compelling effect on condensate formation.

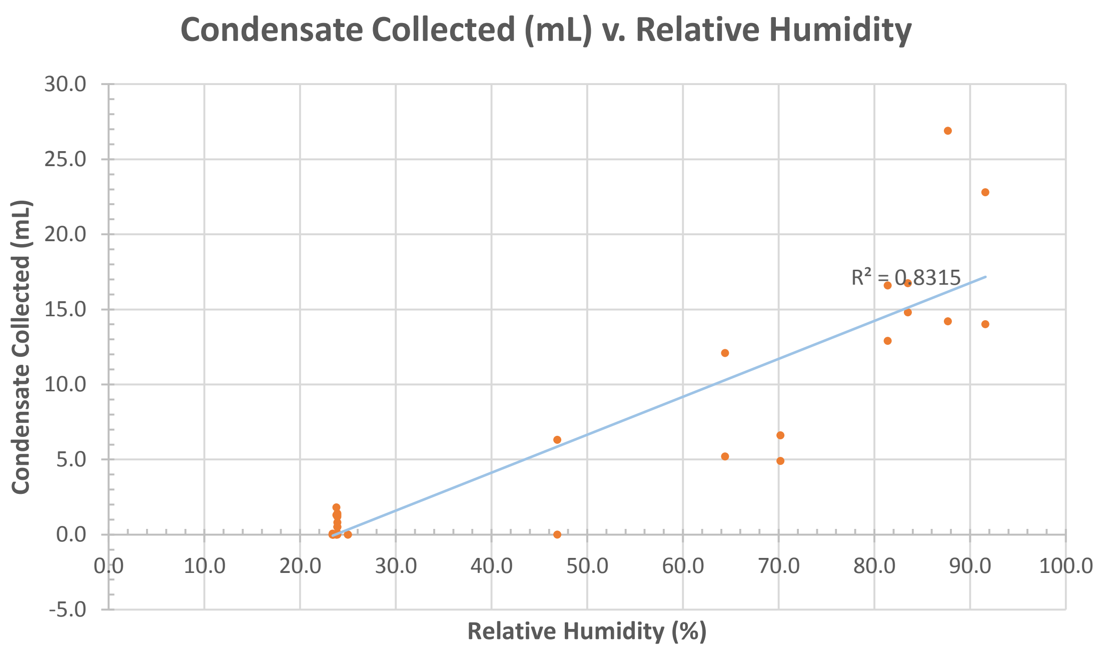


Fig. 4.6: condensate collected versus relative humidity.

Comparison of the condensate volume to the ambient relative humidity presents a more compelling fit, with an R^2 value of 0.83, indicating a compelling correlation between relative humidity and expected water to be collected. Logically speaking, a larger relative humidity simply means that there is a larger humidity ratio, and therefore more water available to condense per unit of air volume. For this analysis, the average humidity during each T = 300-minute test interval was used and compared to the total condensate associated with each condensation surface during each experiment.

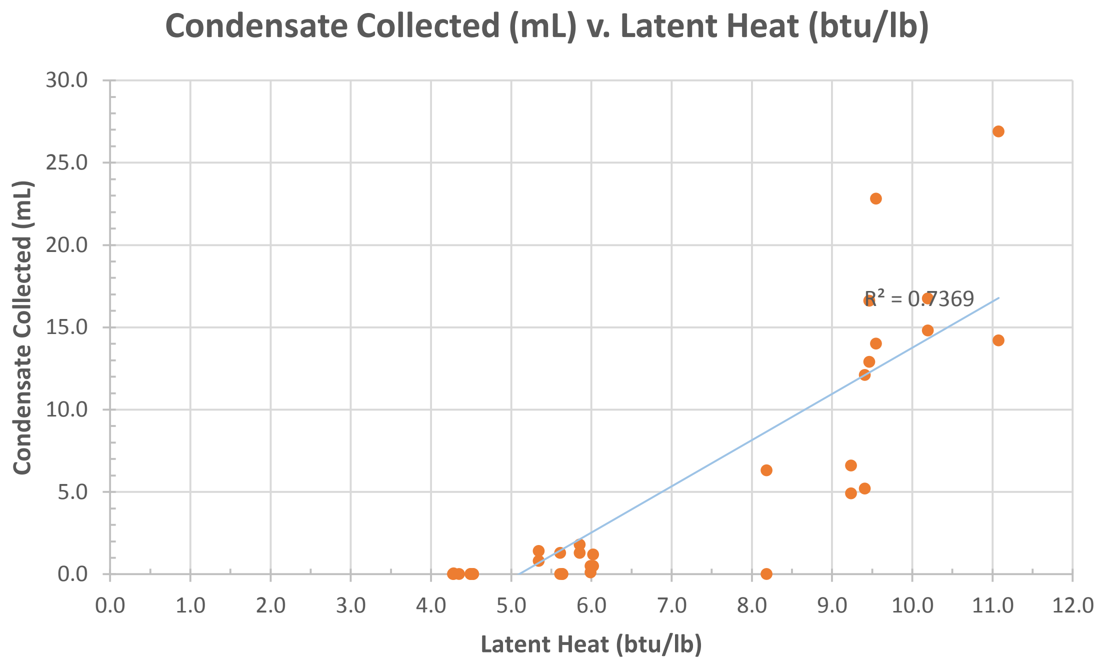


Fig. 4.7: *Comparison of latent heat to condensate yield.*

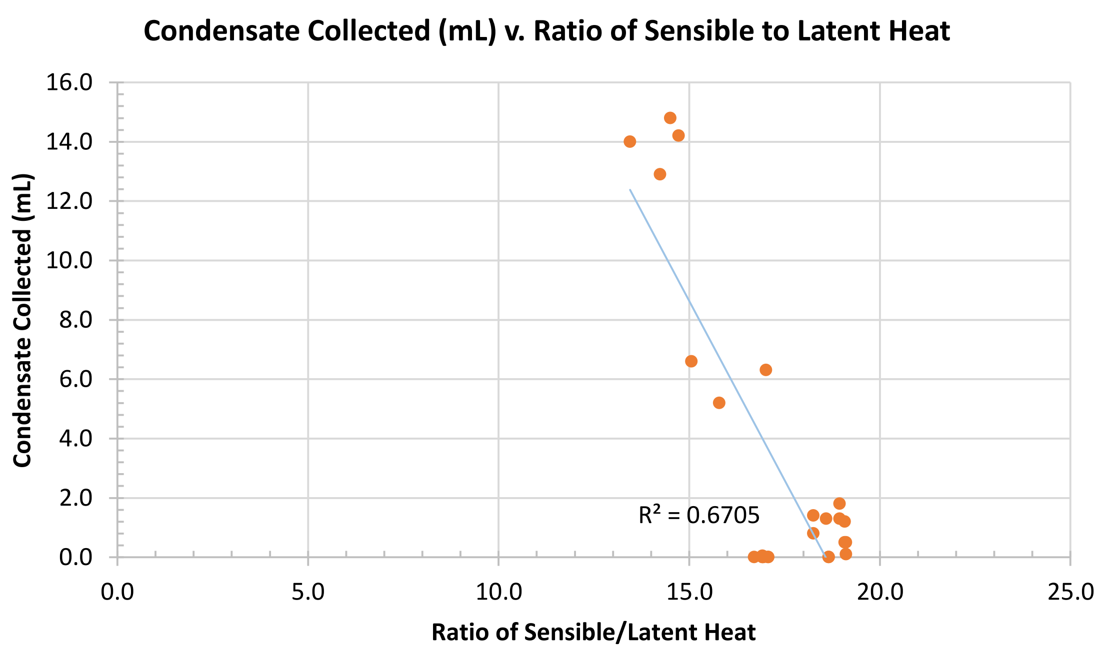


Fig. 4.8: *Condensate collected compared to the ratio of sensible to latent heat.*

Figure 4.6 shows that the relationship between the ambient heat in a mass of air and the condensation that can be formed from it can best be represented by a trend-line with an R^2 value of 0.73. This suggests that the latent heat content of the year in btu/lb is more significant than the wet-bulb temperature and the surface area. Additionally, Figure 4.7 reveals that another strong relationship can be found between the ratio of sensible to latent heat content in the air mass, resulting in a trend-line with $R^2 = 0.67$. These values suggest that both variables could be welcome additions to the predictive equation meant to be developed through performing an ANOVA on the experimental data. However, due to the redundant nature of these two variables, it is likely a wise decision for future analysis to include only the ratio of sensible to latent heat, rather than also including the latent heat itself as another variable. Lastly, these last two variables were assessed after the initial ANOVA was performed, and time constraints prevented an additional ANOVA from being completed. Future efforts should include assessments of experimental data involving this ratio as it has the second strongest relationship to condensate after relative humidity (RH).

In an effort to explain the variability between data points, a multiple regression analysis was applied to the data collected for condensing surfaces of either aluminum or copper. As a broad rule, multivariate analyses tend to be more vulnerable to contravention, as the initial assumptions and definitions in the model are more complex. (Grafen and Hails, 2002) In this case, it was assumed that the dependent variable was water condensate (`COND`) with independent variables Ambient Temperature (`TAMB`), Dew-Point Temperature (`TDEW`), Relative Humidity (`RH`), Wet-Bulb Temperature (`TWET`), Condenser Surface Area (`SA`) and Enthalpy (`ENTH`). This decision was made largely as there was no way to precisely regulate or control the environmental variables, and it was assumed that condensate yield would be largely influenced by these factors, and certainly not the other way around.

Therefore, the ANOVA table constructed is based off the following text formula:

```
TAMB, TDEW, RH, SA, TWET, ENTH = COND
```

The following tables were calculated for an ANOVA regression analysis of the data for both copper and aluminum surfaces. As the two materials have a different thermal conductivity, the data points were separated into two separate analyses for aluminum and copper, respectively.

Regression Analysis: condensation collected from copper condensation surfaces

Model Summary:

R	R^2	Adjusted R^2	Std. Error of the Estimate	
0.97	0.95	0.92	1.59	

ANOVA:

	Sum of Squares (SS)	df	Mean Square	F	P
Regression	474.90	6	79.15	31.17	0
Residual	25.39	10	2.54		
Total	500.29	16			

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients			
	β	Std. Error	β	t	P	
Constant	-196.16	219.9	0.00	-0.89	0.39	
TAMB	0.72	1.24	1.10	0.58	0.58	
TDEW	-1.91	1.86	-2.87	-1.03	0.33	
RH	0.81	0.58	4.04	1.41	0.19	
SA	0.03	0.12	0.03	0.28	0.79	
TWET	7.77	9.62	2.65	0.81	0.44	
ENTH	-9.82	13.57	-1.95	-0.72	0.49	

Coefficient Correlations

	TAMB	TDEW	RH	SA	TWET	ENTH	
	TDEW	1.55	-0.77	0.56	0.11	6.93	
	RH	-0.77	3.45	-0.91	-0.10	-16.88	
	SA	0.56	-0.91	0.33	0.05	5.22	
	TWET	0.11	-0.10	0.05	0.01	0.68	
	ENTH	6.93	-16.88	5.22	0.68	92.49	

Table 4.3: *ANOVA table for aluminum surfaces.*

Regression Analysis: condensation collected from aluminum condensation surfaces

Model Summary:

R	R^2	Adjusted R^2	Std. Error of the Estimate	
0.98	0.96	0.94	2.30	

ANOVA:

	Sum of Squares (SS)	df	Mean Square	F	P
Regression	1328.12	6	221.35	41.79	0
Residual	52.97	10	5.3		
Total	1381.09	16			

Coefficients:

	Unstandardized Coefficients		Standardized Coefficients			
	β	Std. Error	β	t	P	
Constant	-45.59	61.84	0.00	-0.74	0.48	
TAMB	-1.42	1.37	-1.00	-1.04	0.32	
TDEW	-3.49	1.14	-3.94	-3.06	0.01	
RH	0.86	0.28	2.56	3.04	0.01	
SA	0.00	0.03	0.00	-0.02	0.98	
TWET	0.66	3.46	0.23	0.19	0.85	
ENTH	9.51	4.97	1.75	1.91	0.09	

Coefficient Correlations

	TAMB	TDEW	RH	SA	TWET	ENTH	
	TDEW	1.86	1.03	0.27	-0.02	-1.72	
	RH	1.03	1.30	-0.02	-0.01	-2.95	
	SA	0.27	-0.02	0.08	0.00	0.14	
	TWET	-0.02	-0.01	0.00	0.00	0.04	
	ENTH	-1.72	-2.95	0.14	0.04	11.95	

Table 4.4: ANOVA table for copper surfaces.

The initial results are promising and seem to indicate that if more data were collected, two objectives could be accomplished: (1) a surface that is mechanically optimized for water collection and shedding and (2) the selection of a material and size for the collector that is ideally tailored to the psychrometric characteristics of the environment in which the system is to be deployed. Furthermore, the relatively large p-values associated with the test variables for both the aluminum and copper datasets suggest a lack of experimental power. Initially, given the small time-frame through which testing was able to be performed, it was assumed that the total sample size would be small. Further investigation could be improved by increasing the size of the dataset from which the trends and relationship are extracted.

Given that a statistical power of 80% is appropriate for the study and a 95% confidence interval is desired (α=0.05), we can infer the following relationship to estimate a reasonable experimental sample size: (GraphPad 2009)

$$\frac{\sqrt{p \ \times (1-p)}}{n} \leq \alpha$$

Therefore:

$$\frac{\sqrt{0.8 \ \times (1-0.8)}}{n} \leq 0.05$$

Solving for *n* leaves us with n ≥ 64. Providing a dataset with 64 or greater for the suite of copper condenser and aluminum condenser tests alike should be an ideal starting point to bolster the validity of this experimental inquiry and further refine the predictive statistics associated with the datasets.

Additionally, a system powered with the components found in the experimental instrument used in this study has the capacity to be powered entirely through passive means, specifically by means of a high-efficiency photovoltaic panel. While the efficiency of the system is low in terms of mL water condensed per kW·h of energy consumed, if the system can be effectively powered by a limitless energy source, the cost of water becomes free once the cost of the photovoltaics and the water generation system are paid for.

Furthermore, the total power requirements of the system are well-within the capability of a standard photovoltaic cell. The power supply utilized in this study was capable of providing 600 W on demand, but the total requirements of the four thermoelectric units, two CPU cooling fans, two case fans and the fan control unit amounts to 77 W. In each experiment, five hours of operation results in:

$$5 \text{ hrs } \times 77 \text{ W} = 385 \text{ W} \cdot \text{h} = 0.39 \text{ kW} \cdot \text{h}$$

Currently, a reasonable output of 200 W could be expected from an efficient photovoltaic unit. This would mean that in the same five-hour interval, one solar panel would output 1 kW·h, meaning that two of these prototype condensation systems could be comfortably supported by one photovoltaic panel. Coupled with the installation of a battery for storage, the condensers could be run at night, when the humidity is higher, the ambient temperatures are lower and the dew-point is much easier to reach. A future test with a more automated, computerized system could potentially accomplish this.

If the prototype were to be installed inside a wall cavity, there is the possibility of using the cooling capability of the thermoelectric modules for supplemental space cooling, in addition to providing water condensation. If the performative aspects of the system were coupled together in such a fashion, the energy investment becomes more palatable.

The initial data collected from inside the air wells suggested that the thermoelectric units might significantly lower the internal temperature of the air circulating through the system. If this observation were true, the system could then be utilized not only as a water-collection apparatus, but also as a potential avenue for space conditioning. Pairing functions in such a fashion helps to justify the capital costs associated with designing and installing the system, as well as the costs of actually generating any water. Two Student's t-tests were performed on the temperature data collected by the HOBO data-loggers placed within and adjacent to air well 1 and air well 2. The first t-test was designed to compare the means of all ambient data collected to the means of all of air well 1 (the left half of the table below) and air well 2 (the right half of the table below):

t-test, Mean Temperature Differences between Air Wells and Ambient Conditions			
Ambient v. Air Well 1		**Ambient v. Air Well 2**	
Mean Difference ($\bar{x}_d$)	2.09	**Mean Difference ($\bar{x}_d$)**	2.53
Standard Deviation (s)	3.89	**Standard Deviation (s)**	4.06
Variance (σ)	15.12	**Variance (σ)**	16.46
n	405	**n**	405
df	404	**df**	404
t	2.09	**t**	2.53
p	0.04	**p**	0.01

Table 4.5: t-test results for air-temperature in Air Wells 1 and 2 compared to ambient temperature.

The t-test indicates that the thermoelectric cooling produced by the Peltier units do have a statistically significant effect on the interior air temperature. The test statistics for both conditions have a significance that places them within a 95% confidence interval, allowing us to conclude that the null hypothesis is rejected. For Air Well 1, the Peltier assembly produced a mean difference from ambient of 2.09 °F, whereas the Peltier assembly in Air Well 2 produced a mean difference of 2.53 °F. While this is not a large amount, it should be noted that the t-test was to measure an overall observable effect on temperature. The actual experimental conditions varied widely, as indicated by the extremely large variances (σ) of 15.12 in Air Well 1 and 16.46 in Air Well 2. The most likely explanation for this is that the majority of the experimental trials were undertaken outdoors in both Oceanside and Las Vegas. Specifically, the temperature values from Las Vegas would be the most likely to influence this variance, as the total capacity of the surfaces to cool hot incoming air would be much less than, say, in Oceanside where the incoming air is much more humid and cooler.

The second t-test was meant to compare the means of the ambient data-logger and those of Air Well 1 (the left half of tables 4.7 and 4.8) and Air Well 2 (the right half of tables 4.7 and 4.8), but separated by the geographical region in which the tests were undertaken (Table 4.7 lists the analysis of the data collected from Las Vegas and Table 4.8 lists the data collected from Oceanside). Analyzing the data by region helps to more clearly explain the relationship between humidity and temperature modulation:

t-test, Mean Temperature Differences between Air Wells and Ambient Conditions			
La Vegas, Nevada			
Ambient v. Air Well 1		**Ambient v. Air Well 2**	
Mean Difference ($\bar{x}_d$)	3.37	**Mean Difference ($\bar{x}_d$)**	4.01
Standard Deviation (s)	4.53	**Standard Deviation (s)**	4.64
Variance (σ)	20.51	**Variance (σ)**	21.51
n	237	**n**	237
df	236	**df**	236
t	3.37	**t**	4.01
p	0.00087	***p***	0.00008

Table 4.6: t-test results for Las Vegas temperature data.

The p-value associated with the test statistics for a t-test of the data collected in Las Vegas indicates an exceptionally strong significance. Therefore, there is a much more visible difference between ambient air temperature and the air temperature inside either air well. The average relative humidity in Las Vegas during all of the experimental trials was 21.8%, which is quite arid, particularly when compared to the experiments run in Oceanside. Dry air by definition contains less moisture, and is therefore cooled more easily than air that contains more water, mainly due to the high specific heat of water. (USGS 2015)

t-test, Mean Temperature Differences between Air Wells and Ambient Conditions			
Oceanside, California			
Ambient v. Air Well 1		Ambient v. Air Well 2	
Mean Difference ($\bar{x}_d$)	0.29	Mean Difference ($\bar{x}_d$)	0.44
Standard Deviation (s)	1.41	Standard Deviation (s)	1.39
Variance (σ)	1.98	Variance (σ)	1.92
n	168	n	168
df	167	df	167
t	0.29	t	0.44
p	0.77	p	0.66

Table 4.7: t-test results for Oceanside temperature data.

The data from Oceanside indicates the opposite effect, with an average relative humidity of 65.3%. The p-values associated with this data do not satisfy the experimental condition of $p < 0.05$, meaning the null hypothesis cannot be rejected. The temperature data for Oceanside indicates that the thermoelectric assembly does not significantly cool the air inside the air wells. This is likely attributed to the higher relative humidity, which would prevent the air from being cooled as easily as in Las Vegas. However, in the milder climate of Oceanside, active space conditioning is not nearly as necessary for thermal comfort as it is in the warmer seasons in Las Vegas. Therefore, the synergy of having space-conditioning as well as water-generation is significantly less appealing.

Finally, one last t-test pertaining to temperature differences was undertaken to compare the condensate yield between copper and aluminum condensers, in an effort to determine if and which material was more effective at forming condensation.

t-test, Mean differences between collected condensate from condensers of different materials Copper v. Aluminum	
Mean Difference ($\bar{x}_d$)	-1.01
Standard Deviation (s)	4.61
Variance (σ)	21.26
n	17
df	16
t	-1.01
p	0.16

Table 4.8: t-test comparing the condensate yield between aluminum and all copper surfaces.

Analyzing the datasets in this fashion results in a p-value of 0.16, which is much greater than $\alpha = 0.05$, meaning that the null hypothesis (H_0) – that there is no difference between the efficiency of condensate yield when comparing aluminum surfaces to copper surfaces. Rather, this does not necessarily preclude the possibility of a superior material, but more data would be required to make that determination.

Another factor of interest was the mean difference between relative humidity of the inside of the air well versus the ambient relative humidity. Any significant differences reinforce the potential of the device to act as a dehumidifier when paired with a normally humidifying cooling mechanism, such as a swamp cooler or the like.

The first pair of t-tests assess the mean differences for data collected in Las Vegas and found that there was no significant mean difference, with p-values of 0.49 for Air Well 1 and 0.43 for Air Well 2, respectively. The data were tested with a power of $\alpha = 0.05$.

t-test, Mean Relative Humidity Differences between Air Wells and Ambient Conditions			
Las Vegas, Nevada			
Ambient v. Air Well 1		**Ambient v. Air Well 2**	
Mean Difference ($\bar{x}_d$)	-0.03	**Mean Difference ($\bar{x}_d$)**	-0.18
Standard Deviation (s)	0.19	**Standard Deviation (s)**	0.21
Variance (σ)	0.04	**Variance (σ)**	0.05
n	12	**n**	12
df	11	**df**	11
t	-0.03	**t**	-0.18
p	0.49	**p**	0.43

Table 4.9: t-test results for mean relative humidity differences in Las Vegas.

The second pair of t-tests serve to assess any significance in the humidity data collected in Oceanside, CA. Analysis indicates that there is no significant difference in relative humidity between ambient conditions and conditions inside either Air Well 1 or Air Well 2 (p-value = 0.63 and 0.92, respectively). Data were tested with $\alpha = 0.05$.

t-test, Mean Relative Humidity Differences between Air Wells and Ambient Conditions			
Oceanside, California			
Ambient v. Air Well 1		Ambient v. Air Well 2	
Mean Difference ($\bar{x}_d$)	0.35	Mean Difference ($\bar{x}_d$)	1.48
Standard Deviation (s)	2.08	Standard Deviation (s)	2.18
Variance (σ)	4.33	Variance (σ)	4.76
n	8	n	8
df	7	df	7
t	0.35	t	1.48
p	0.63	p	0.66

Table 4.10: *t-test results for mean relative humidity differences in Oceanside.*

Lastly, a brief analysis of the water collected was performed in order to assess an estimated yield in a given time-frame under specific environmental parameters. Out of all of the experiments performed, the best-performing condenser surface was the array of four small copper heat sinks, run in Oceanside during the evening. This particular experiment resulted in the collection of 26.9 mL of water over a 300-minute interval. This could also be expressed as:

$$\frac{26.9\ \mathrm{mL}}{300\ \mathrm{min}} = 89.7\frac{\mathrm{\mu L}}{\mathrm{min}}$$

Assuming *ceteris parebis*, this assembly would presumably collect 1 gallon of water in 704.2 hours, or 29.3 days. Note that 1 gallon = 3.79 L

$$3.79\mathrm{x}10^6\ \mathrm{\mu L} = t\left(89.7\frac{\mathrm{\mu L}}{\mathrm{min}}\right)$$

$$t = \frac{3.79\mathrm{x}10^6\ \mathrm{\mu L}}{89.7\frac{\mathrm{\mu L}}{\mathrm{min}}} = 42{,}251.95\ \mathrm{min} = 704.2\ \mathrm{hr}$$

Obviously this rate indicates that there is great need to improve the rate of condensation, or to improve the efficiency of the surface's ability to shed water that forms upon the surface. Nearly one month to collect 1 gallon of water is far from an acceptable delivery time, but another strength to the system is operating in parallel with multiple condensers. The above example is derived from the condensation rate of one condensation surface in one experimental air well.

For example, if thirty of these devices were operating simultaneously, the condensation rate would be expected to be thirty times greater, all other things remaining constant (and assuming that the systems did not dehumidify the air inside the channel so significantly as to impede the ability of each condenser to function. If this rate were thirty times greater, the time to condense 1 gallon of water would also be reduced by thirty-fold, bringing our calculation of 29 days to 0.97 days (23.28 hours). Additionally, assuming that our calculation for the power requirements above hold constant, each pair of condensation surfaces could be expected to consume 77 W of power. This is assuming that no greater efficiency of either the rate of condensation or the consumption of energy can be achieved. With this, we can conclude that ten of these assemblies, or five pairs to be precise, would require:

$$15 \text{ pairs } \times \ 77 \text{ W} \times \ 23.28 \text{ hours} = 26{,}888.4 \text{ W} \cdot \text{h} = 26.89 \text{ kW} \cdot \text{h}$$

One photovoltaic panel outputting 200 W for the same time period would generate 4.76 kW·h. This means that 5.6 (6) photovoltaic panels outputting 200W over the same time interval (that is, for 23.28 hours of solar exposure – so not continuous days. The system cannot generate power without the sun providing energy) would be capable of providing the required 26.89 kW·h necessary to condense 1 gallon of water. Taking the national average electricity cost per kW·h of $0.996 (EIA 2016a), 1 gallon of water would cost:

$$\$0.0996 \ \times 26.89 \text{ kW} \cdot \text{h} = \$2.68$$

The cost to produce one gallon of water in this regard is quite high, compared to the cost of water produced from desalination, which can range anywhere from $2.50 to $5.00 per 1000 gallons (Bienkowski 2015), though the total costs can widely vary depending on the region of installation and the local resources available. (Yangali-Quintanilla et al. 2015, 2437-2445). This means that nearly a thousandth of the cost to produce one gallon of water from thermoelectric refrigeration. It should be noted that the $0.0996 used in the calculation above is an average across all sectors, including residential, commercial, industrial and transportation uses. (EIA 2016a)) However, desalination plants carry a large price-tag. For instance, the Carlsbad Desalination Plant in Carlsbad, California cost nearly $1 billion to construct (Poseidon Water 2016), meaning that the infrastructure required to utilize desalination to supplement the municipal water supply is a significant investment. There are improvements to the technology in development that have the potential to lower the costs of desalination facilities by approximately 31% (Yangali-Quintanilla et al. 2015, 2437-2445), such as seawater osmotic dilution (SOD) and forward osmosis (FO), which also promises lower initial capital costs and shorter payback intervals on a project. It should also be noted that desalination consumes a tremendously larger quantity of energy to generate water. If 1000 gallons of water were to be generated through this method of thermoelectric refrigeration, it would cost:

$$26.89 \left(\frac{\mathrm{kW \cdot h}}{\mathrm{gallon}}\right) \times 1000 \text{ gallons} = 26{,}890 \text{ kW} \cdot \text{h} = 26.89 \text{ MW} \cdot \text{h}$$

Traditional water treatment infrastructure can typically produce 1 m^3 (264.2 gallons) of freshwater for about 1 kW·h of energy input. Reverse osmosis desalination facilities can create the same volume with approximately 3-10 kW·h or roughly 200 million kW·h/day (Bienkowski 2015). While this is a much more generous output of freshwater for the amount of energy utilized, a passive, less-energy-intensive method of producing potable water would allow that energy to be used for other purposes while simultaneously preventing the accretion of hypersaline residue commonly associated with reverse osmosis processes. Furthermore, little investigation has been done on the effect of desalination plants on marine environments and biota. (Yangali-Quintanilla et al. 2015, 2437-2445)) If the environmental risks of desalination are significant, then the cost of any alternative method of water production, no matter how high, is justifiable.

For comparison, in their experimental study on thermoelectric condensation, Tan and Fok collected approximately 50 mL of water on a condenser surface area of approximately 89.4 in^2 (579.6 cm^2) over a 3-hour interval with an average relative humidity of 77% — easily the most successful case in their study. (Tan and Fok 2013, 96-103)) Additionally, the system drew roughly 124W which puts it closely in line with our system which drew 77W. They measured the yield of their prototype 7.29 kW·h for a single L of water over a 58.8 hour period of operation (or 27.6 kW·h/gallon), whereas for our prototype, a period of approximately 704 hours would be required to generate 1 gallon of water from 54.2 kW·h. This would amount to a total cost of $5.39/gallon. This cost goes down significantly if more units are run in parallel at the same time, requiring more wattage in total, but operating for less time. To make the cost more palatable, the total volume needs to be increased significantly to even begin to offset demand overdrafts. From the data above, 26.89 MW·h would be required to condense 1000 gallons, which, at the going national average of $0.0996 /kW·h, would cost about $2,678. The prototype discussed by Tan and Fok condenses water more effectively, but it draws more power to do so. Obviously the trade-off in question is that if the condensation rate is too low, then a less-effective system will draw more energy in the long-run with the same volume of condensation as the result.

Beyond the application to wall or roof assemblies for the envelope or structure of a building, there is also potential for providing agricultural or site irrigation. Regardless of whether it is intended for agriculture or landscape, water provided for plants is the largest drain on available freshwater, as outlined in Chapter 1. If this experimental system could be refined and its condensate yield could be improved, it would help offset some of the strain placed on both groundwater and municipal reserves. If this system were coupled with rainwater collection infrastructure or other means of greywater collection, the impacts on the total freshwater available to the developed and undeveloped world would be significantly boosted. Ultimately, in face of ongoing drought conditions, cities and settlements need to turn to every available option for obtaining water that *does not* require groundwater mining. Ecosystems are only further destabilized by removing an excess of groundwater, and such a resource needs to be more carefully stewarded. Coupling this system with either a photovoltaic array or another passive means of providing energy could allow water to be generated without incurring significant costs or CO_2 emissions. After the initial capital costs of the renewable energy system are paid for, the water essentially becomes produced for free. Lastly, the thermoelectric array could also be installed directly at a waste-water treatment plant to add collected condensate directly into the municipal reservoir, allowing it to be treated on-site before being added into the grid.

The data collected and evaluated offer insight into the performative capabilities of an atmospheric water generation system. Preliminary analysis suggests that it is possible, with further data collection and compilation, to construct a predictive formula for estimating the amount of water that could be generated from a particular assembly in a specific environment. Using this formula, it would be possible to optimize the collection mechanism by solving for a particular variable. For instance, the surface area of a condenser surface could be optimized for an environment with a particular average relative humidity, average dry-bulb temperature, average wet-bulb temperature, average enthalpy and average dew-point. Using this information, it would be possible to estimate the power necessary to generate 1L of water and the amount of time required to do so. Having the ability to design a system with a finely tuned water production method would prove to be immensely useful in the continued evolution of this concept.

05 | CONCLUSION

Atmospheric water generation represents a potentially inexhaustible supply of supplemental water income to meet end-use demands. However, the technology is fraught with design parameters that require careful optimization in order to adequately provide reasonable volumes of water at a comparable price to other methods such as desalination.

The results from this study suggest that there is a strong link between the ratio of sensible heat to latent heat in the air and the amount of condensate that one could anticipate to collect. The volumes of water collected throughout the study indicate that atmospheric water generation is not an exceptionally efficient method of collecting water, but there are many characteristics of the prototype that could be further optimized to improve yield. Specifically, the area of the cross-section of the air-well designed for the system could be reduced so as to minimize exposure to ambient air. Also, the thermoelectric units and the design of the heat sinks used as a heat exchanger could be specifically tailored to the amount of heat that needs to be dissipated. For this project, pre-fabricated heat sinks were employed, and the most readily available thermoelectric units were utilized.

In general, the data indicate that areas with higher relative humidity are more hospitable to this form of technology, specifically in that larger volumes of water can be generated. The statistical analysis indicates that in arid environments AWG does significantly cool the air inside its air wells compared to the ambient temperature; however, in neither environment does the device act as a true dehumidifier. Overall, this indicates that for synergy to be obtained between the device and another system, its performance metrics in terms of energy consumed, water produced and time needed to generate a reasonable amount of collected condensate all need to be improved. Unfortunately, this means that the application of the device in arid environments is marginally useless. Furthermore, it means that if the device is to be lauded on its ability to synergize with other systems and functions, then this is too a shortcoming at the present stage in the research. Specifically, the system cannot significantly cool the air running through the air well. It fares better in arid environments, but for practical space cooling, a few degrees difference between interior and exterior temperatures is not ideal for, say, Las Vegas, an area with a very large number of heating degree days. Furthermore, the device does not act as a dehumidifier, doing little to reclaim moisture that might be introduced to an interior environment by another method of space cooling, such as a swamp cooler. Improvements could be made that allow the device to function more effectively in secondary capacities, but this would require a significant amount of preliminary research. However, as the primary intent of the study was to assess the feasibility of utilizing TEC units for atmospheric water generation, it can be considered a success. The study also laid the groundwork in characterizing the relationship between environmental data and the amount of water that can be potentially collected.

The data also indicate that the volume of water collected, compared to emerging alternative technologies, such as desalination, are not cost-effective. The power required to generate 1000 gallons is enormous, and the time to condense that amount of water is equally enormous. If the devices were implemented in a large number, the power required would still be large, but the rate of condensation and the amount of condensation collected would be improved tremendously. Additionally, more thermally efficient materials can be employed to utilize more favorable thermal conductivity values.

Additionally, the voltage applied to the thermoelectric units was 4.9V, significantly less than the 15.4V that they are designed to accommodate. This was due to the fact that power was supplied to the thermoelectric units through a 600W PC power supply, and the only rail capable of connecting to the thermoelectric Peltier units was the 4.9 V rail. Boosting the voltage supplied would increase the amount of heat that can be dissipated which in turn would likely improve the overall condensate yield for the system. However, it is possible that increasing the supplied voltage could paradoxically lower the coefficient of performance of the system. (Taherian and Adams 2013, QQ1)) As far as the selection of the thermoelectric units is concerned, choosing a unit with more thermocouples will also increase the ability of the unit to transfer heat effectively. Another way to improve the efficiency of the system is to design a more effective method of collecting the water that condenses on the heat sink. Gravity action was utilized in this study –

meaning that as droplets condensed, they would eventually fall into a collector when their size was sufficient. Regardless, developing a way to more adequately power the system as well as assess the Coefficient of Performance of the thermoelectric device would be extremely beneficial in improving overall performance.

Computerizing the system would allow it to more efficiently regulate the exact amount of energy it needs to provide to the TEC in order to cool the surface to below ambient temperature. The temperatures recorded on the surfaces of the TEC units indicate that they are capable of dropping well below the dew-point temperature, and the most thermally conductive material, copper was able to be cooled to below the dew-point temperature even for an arid environment such as Las Vegas. Utilizing silver or other materials might allow the temperatures to drop so low that the amount of electricity needed to be supplied to the system can effectively be less over a similar collection interval employed during the testing. Control could be regulated by an Arduino system linked to a hygrometer that can assess what the dew-point temperature currently is and then provide an amount of power to the TEC necessary to dissipate enough heat to allow the system to reach that temperature. During the tests, the system ran at constant voltage, meaning that it was always consuming the same amount of electricity. Electricity savings would be a significant advantage in improving the palatability of this device.

With improvements to the basic mechanics of the apparatus, it could easily find ready use inside various building systems, as outlined at the end of the previous chapter. However, as with integrating any new type of system into the existing repertoire of building technology, there would be a handful of issues to resolve before widespread use of this system were to occur. Introducing moisture into various parts of the building envelope needs to be done carefully and should not disregard the potential to cause damage to the building and its components. Furthermore, introducing any new mechanical system with moving parts and pieces in turn introduces new failure modes for those systems. Adding a thermoelectric AWG system to a building would likely require periodic maintenance and monitoring for performance, in spite of the relatively solid-state nature of the technology. Fortunately, this makes it no more complex than most other building systems.

Nevertheless, if AWG systems were integrated with either the wall or roof structure of buildings, the devices could be utilized in just such a synergistic manner. The following two drawings illustrate a schematic assembly diagram of how the device could be integrated into the roof structure of a small train station.

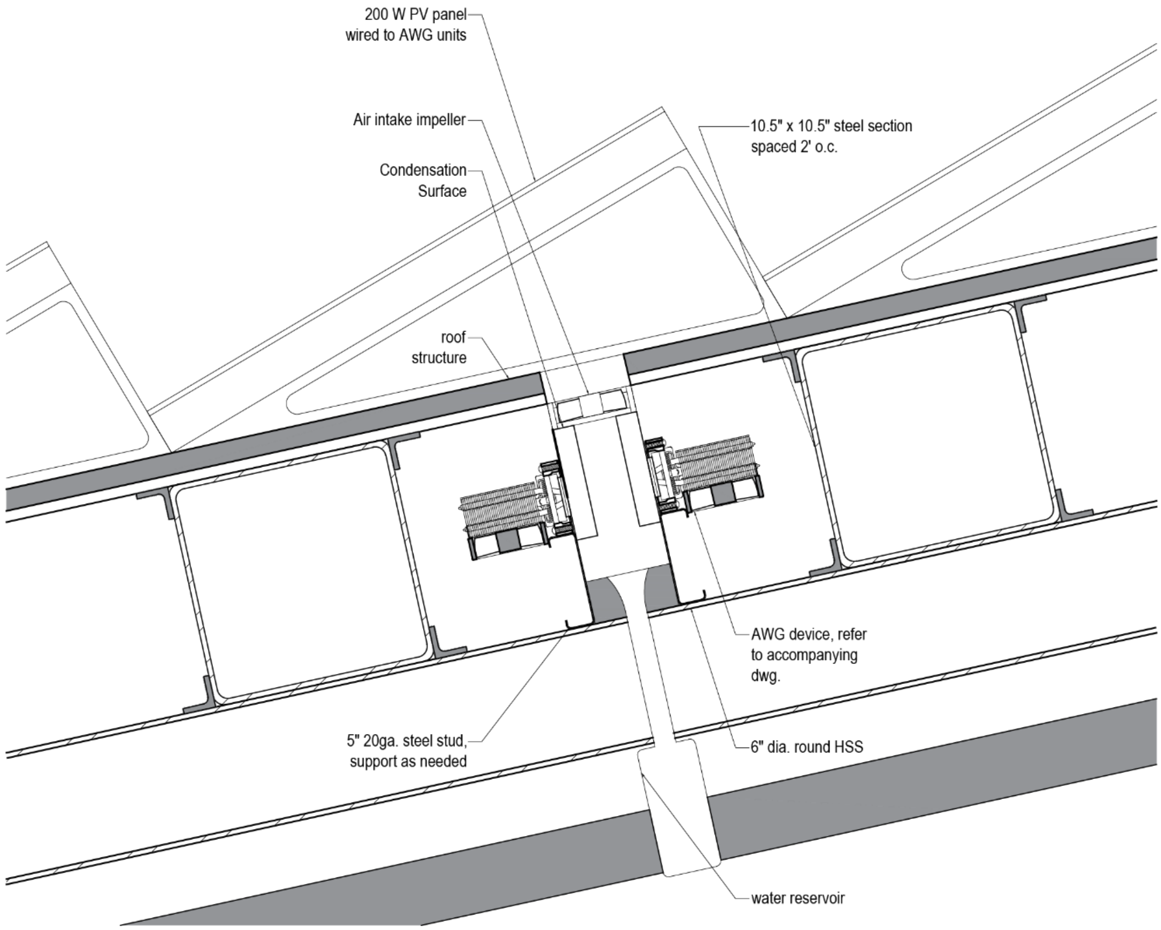


***Fig. 5.1**, schematic drawing illustrating the integration of thermoelectric AWG system into the roof structure of a building.*

The potential for thermoelectric AWG systems is not limited to just buildings. There is a significant interest in developing atmospheric water generation systems for extraterrestrial applications, such as for the future Mars missions. (Tan and Fok 2013, 96-103) Using a system known as WAVAR, it would be possible to extract moisture from the Martian atmosphere using a zeolite-based apparatus. (Adan-Plaza et al. 1998, 171)) However, the creation of psychrometric charts for the Martian atmosphere (Shallcross 2005, 1785-1796) could prove useful in assessing whether or not thermoelectric cooling could be a useful addition or modification to the WAVAR process, which is well-beyond the scope of this paper. However, the Martian atmosphere possesses different chemistry than our own atmosphere, which in turn gives it different physical properties which would require their own considerations. The WAVAR system, however, was developed for the NASA Reference Mission to Mars and might not be a part of the current Mars Mission being developed for the 2030s. (NASA 2015)) After all, the Martian atmosphere is extremely arid, featuring an average moisture content of 0.03% per volume of air; furthermore, the saturation point for such dry air mass is around 200 degrees Kelvin (~99 °F), which requires the dissipation of a significant amount of latent heat in order to produce moisture. (Carr 1996)

Fig. 5.2*, Schematic section illustrating the roof structure upon which the AWG could be integrated as a means of water collection. A particularly large roof area translates to more PV power that can operate additional AWG units, leading to more water collected.*

The original hypothesis asserted that surface area and thermal conductivity would be critical in potentially predicting the amount of water that could be collected in a given environment. The data clearly show that larger surface area does not necessarily indicate a larger amount of water collected. The largest collected volume of 26.9 mL was attributed to the 31.7 in^2 aluminum surface and not its larger counterpart. However, the R^2 values associated with the data indicate that relative humidity and the ratio of the sensible heat to the latent heat of the air are most important. The analysis at present suggest that high thermal conductivity does not necessarily correlate to larger volumes of water collected. Using the device in an arid environment unilaterally guarantees that it would be unsuitable in using for routine water collection. However, better thermal conductivity could be critical in managing the energy consumption of the system, particularly if the system were to be regulated by a centralized computer. Additionally, comparing condenser materials in a high-humidity environment or a humidity-controlled chamber would yield more useful results. Constructing the analysis for this study might have been better served by comparing condensate collected to various parameters one single material at a time, rather than comparing all data points at once. This would have leveraged a more accurate assessment of whether or not copper or aluminum was an effective choice in a particular environment. As it stands, it is likely that the data for one collector confounds the other; or worse, the data from Las Vegas confounds the data from Oceanside. A humidity-controlled chamber would likely be the most sensible option in pursuing further research as it would allow all environmental characteristics to be controlled with more precision. Unfortunately, this is one such side-effect from testing the AWG device outside the laboratory setting.

Climate change represents a tumultuous set of decisions that must be made regarding our water policies and usage. The answers to these matters are by no means clear, but a consensus has essentially been reached that to do nothing is the costliest option, in terms of monetary expense and environmental damage. It has been argued throughout this paper that synergy is critical – that is, systems that can serve multiple purposes, and the thermoelectric condensation method discussed in detail is one such system. Additional research is needed to better clarify the relationships between the variables and metrics evaluated in this study; and with further investigation, a better model could be designed to assess the potential to condense water out of the atmosphere. There are also other physical phenomena worth considering in the aim to produce water with little energy invested, such as magnetocaloric elements. The potential for technology to passively fold additional water into the total available supply worldwide is an important benchmark, and could, if the technology were made more efficient, represent an important stabilization wedge for climate change, if paired with more efficient water sources such as desalination and rainwater harvesting.

06 | REFERENCES

Electric power monthly. in U.S. Energy Information Administration [database online]. 2016a [cited 03/14 2016]. Available from https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

LEED credit library. in U.S. Green Building Council [database online]. 2016b [cited 03/18 2016]. Available from http://www.usgbc.org/credits/new-construction/v4/water-efficiency.

Ackerman, F., and E. A. Stanton. 2011. *The last drop: Climate change and the southwest water crisis.* Somerville, MA: Stockholm Environment Institute, .

Adan-Plaza, S., M. Hilstad, K. Carpenter, C. Hoffman, L. Elias, M. Schneider, and R. Grover. 1998. Extraction of atmospheric water on mars for the mars reference mission. *Lunar and Planetary Institute Contribution Series*(955): 171.

Adeyeye, Kemi. 2014. *Water efficiency in buildings: Theory and practice*Wiley, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwrV09b8IwED1RWOhUUlChjeQ_kCpxnDheQY26dEMwotg-S11cKcD_xzaOhCq6dbQs-ezF7z7fAyjpe579-hO0LIuOKpXXou40cqQceaMLrLiumMn_n2HIIbuoShfMP9SN59RfR5gOuRdfXqI8CAe5CMf5NEJE-qdhHZqi7SAeH8CmfYIJ-gmEGYzQJvB4wxiYQLLz7SthhpZ8xbL4M6R75zH2BAMdhJ-lJN-WyCh4fZxD2n5sN5-Zt3SI-ZrDcPWiXMDY_lh8AaKMMZqyhjHp_H_BZZMrajTSrtaGKbmExf0zVn9tvMLUYT-7ZhPeYHzqz5he33wBohZ7xA.

Agam, N., and P. R. Berliner. 2006. Dew formation and water vapor adsorption in semi-arid environments—A review. *Journal of Arid Environments* 65 (4): 572-90, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1Lb9NAEB6hCgQS4hEohIe0Bzi68b683mNLU3HhBueV17sWiUSoYvd140fwC_klzNjrNKQgDr1Z8TiyvZOZbzbzfQMgxUGe7cQEro3XgRehVrzBrB-159rXqkZA3VjudxSGjraaLFMmGCJ8H7vTJ7P0bmeni8Wsb1Iib8o1pSVJtHON2ZaEH4-PNv8r0JScsamRrLc4w8uDJVan-GM_TzstJGSp_pWuUvy-S9yRs_bvWUtShD55DGPP1NiackMw6YYA5C2e-wk8SlCWHQ52T-FOXE3g3ryXwb6awP78mkOHZimItBO4nwavf716Bp-O4wXbEChZtQrsAtHvmp1XWBiwKrTf131QY4sVa-O3RUZvj23T8379-HnIBgbOc_hyMv_84WOWJjxkteBSZ54H6aNVlTGxUJZG5njblI3RAYFjEAKLsYoXMYgmYNoslcVqKdjCmoAHpZH78LAiJsCq6xmD4SWwaPPohQpGNWiE5VDEi3lpTBBYuuZ-CrNxRd3poOjhxla3pRt9gMZzapdbhz4wBTsuvPtjVRymnf9e-4I8xVG46NZV7bhFCFUaUU7h_eA8m7sQrhUud1IiRi0QdknlussOv2HHjkhuiMvzKbzb9rrN-V7EyBQk7keQ_NUtbv81PLjec3oDe936LL6FPfLc39ZaLZw.

Ambient Water. Systems. in Ambient Water [database online]. 2016 [cited 3/25 2016]. Available from http://www.ambientwater.com/en/systems.

Ask Nature. Grooves gather water: Thorny devil. in Biomimicry Institute [database online]. 2016 [cited 3/25 2016]. Available from http://www.asknature.org/strategy/3f47ec0d4343c94f82e19e103ac20c34.

Benlattar, M., E. M. Oualim, M. Harmouchi, A. Mouhsen, and A. Belafhal. 2005. Radiative properties of cadmium telluride thin film as radiative cooling materials. *Optics Communications* 256 (1): 10-5, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1Lb9QwEB6hikqVUKEU2qUg-QDHtH5lvTm2lIpzBWfLr0AQ-1A2K_Xnd8ZJVmULQoJrYkeJPflmxvrmGwAlz3mxgwmiNL6MYhqDFjV6_VR6UfqgAwbUdSX8jsLQ1QOS5eAJeoTP2D1cuRjW9mLVNFTxi4k5qVGV5JWz_meJ3paEH6-vtthMzb57oUZe0OixmC4zvparjhgk_TnL9Jwr9SdnNaD3U6oc2ax_77MU4e_NcxgZUyMx5ZFc0iP5x__46hdwOASy7LIfdwRP0uIl7GdCaVgfw-0tiR4QlrIVnfe3JNzKljULLs6bzZxR9cqmbWJi3fdmwerm55y5NWu308KS-gl9YxhS93_JK_h68-nLx8_F0L-hCJi1yCIp6SpntNdJOVfGmawwdTc8hco7Y6qkNA9BI2zgUk85WpMWwjivSM5c10m9hmeOeP6LLtcDxlNgqeLJSx2NrqOWmOwkWUcxMyZKTEy5n0Ax7phd9XoddiSy_bD9DlPrzdISn0-pCZhxW-0va27Rpfxl5glZgSUg6FoXrKBgccorPoEPvWFs30DatbTcSoPRZ87gjO3uOnzCzjjKpnGQmMD7hxa1vZ_liRQ6GUVxhnzzzy9_BgdZgzafJb2Fva7dpHewRzZ5DxjtH9I.

Benlattar, Mourad, and El Mostafa Oualim. 2013. RADIATIVE PROPERTIES OF COPPER THIN FILM AS RADIATIVE COOLING MATERIALS. *Journal of Science and Arts* 13 (4): 391, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1Nb5wwELXanCpVVdPPbRPJx0SICGPWNoceyGa3QdoNUZbmGg3GKKnIttqQ_9_xmq-0qnrvETNY4GfGb8bPNiE8PAn833wC2AnOQkodiamOFVdRWUIVigr5go64ebrDUC9dHcr-B-CvkrM0ydPrObZudjm_ypHwWW3PLLvEKy8_Ty-8RbpcecnaG2xnWba0iatVgvw2TZbrv7DWzhfYfHuybXpGvkITKL1Ts6mhaaCX_M5rdBvIQCvwMrt-836cZmCDYM11jGuo4fYOHAUei0bsUjcnh4TH5vbHthWS2E5-0aUzR-adnnC35F63KhLnelUU-fHUHeByYnZlYSCUbycCn_hrPuqX0cj58pgNo1qvNUSnFSKpklix3U39vrzTzRez8b-tn2OoruQoDP_uIibOXZzevdAfw_RuKM1fk1dt89PEgb1PnpnNG7LfQvFAj9q9w4_fkq89onRAn2YL6tCnFn1q0afJmg62Lfq0R_8dyRfzfHbut2dl-D-VVS8qzvBbZCAKZjgrpChiBWVsNMiqwCiUh0xogFIFUMJUMg1MYCxZQWxUYIC_Jy8tflahZpV45UdCKwmSF3KKdMbSThGrIK6QzmFIqgQINiGHXbPcQGETc7p5wFBS7o5ICMWEfOjvl3V9MwAxIQf9nfbPGT_46R8VfyYvhh56QPaa7aM5JHt2_7FfM5lgYg.

Benyus, Janine M. 2002. *Biomimicry: Innovation inspired by nature*Perennial, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4CdjMRU0zSjJFPT5BSTRGCLzjLNzMIgJSnVEFgjp5lR_4QhY2BTyBJ0FjezmQXoTH0nRDVtZGBhaWFkCemkmYE2owLbINDDeGB80MoukHVIlY2bIAMLaAOCEANTap4wAzfSgYEiDFxOmfm5mbmZyUWVogyybq4hzh66IP3x0FGYeJiDKozEGHgTQavX80rAu9xSJBgUEo0SzYwME02TjcyTTYyBgZMEWn-ZnJJqYmaRAqxjJRnEsBsmhUtCmoELfG8JeLBAhoE1DZiYU2UhfgIA0s9wHA.

Beysens, D. 1995. The formation of dew. *Atmospheric Research* 39 (1): 215-37, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV3dS8MwED9kT4L4NWV1Cn0Q0Ye6Jm1m86jTKQPf9h7SNIGBbMN16J_vXb-cG0MY9KXpNfRy4e5y3O9XgIjfh8GaT5DOpmGchbafcMcli0QYap5hfq6TJLLrDEN1cyE1WVaRoPTwhe-uRnrV2vbmk0mPSEUSqmmJAh08ImA1BlvifXx--u35qPJhFA5IusbSsX6vGbuV4q6YIxhti1WruSiBR5aLLWGLvPnwCOr-hLo3ZYMxaYMBcnfFj-

GwSmX9x1LsBPbs9BS8d8zCZ59Fsd6_8QcfE0yJi7s2tHFP-g1a0p85P7NfZzAevowHb0H1V4bAcBazwFktRCRcxEwiXWyE1UTazjhPhbUyjLThluC0TKJTZ2mqUzzDkJE1F8ZF53CgqXl_mhcgv6wDPnMyNKipNqHBqYROnXWp0XgWktyY2IOgtoOalyQcqu5OI_0VLYDCq1gCNfLgoTaW-rOKCuPEP292a9sqnVKxyeQLhYKSQLwedEpzN1-B3hDzVymFB9frj9SCK-Je5TJOqAqh8u8cxVb3SSNM5MNi_EoekpL0i50V6MJ-CbqnItEltPLPpb2CFu20H1y7DhU.

Beysens, Daniel, Irina Milimouk, Vadim Nikolayev, Marc Muselli, and Jacques Marcillat. 2003. Using radiative cooling to condense atmospheric vapor: A study to improve water yield. *Journal of Hydrology* 276 (1): 1-11, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1LT9wwEB4hLiAhoJTHQiv5wIEeAvEjL27lpf6Acrb8SruHsmiTpeXfM-Mk7LK0qgS3KBlb8Xg0D3vmGwApTtNkSSfwrLCZ57l3itdo9UNmeWadcuhQ1xW3SwhDFwtJlr0l6DR81N39m7Oet2f34zFV_ArB80qh0JIdp_LfDK0tAT9eXcx1s5RqwA8n6nlNTzdDfHmSyi9xkqT8l7Va9EapfGTW_N1wKVK6N1swpE0N2SmvMJNeYUC-Y-nbsNl7s-xrR_cBVsLdDqz1jdV_Pn6E25iSwKaEgECKlbkJdQn6wdoJPlL33SYw0_6aNARvMHbswWBAcM4Mi7i3RDaOxx6B_UaveMoeKeNuF25vrr9ffkv6Tg6JoyvnRllambLmeeZNXqHNVDWGMeirecsLa1IM73nupFPe4UeUEBms4UUQdRAVD5Xcgw1DGf93bawM9AfAQkXDlC9U7ZXAsAepPS-LwgsMUVM7gtNh6_R9h9yh5yltyDJNPNOp1JFruhxBOWywfsF5jdblf0OPBoHQxtIZlWsbTe0OqZHJCI47GXn-D6EboSMua0n3YGWm2z_tCPaXyAhcT8miwAkWZev5OznopUT3QsRLmsO3L-AI1mOWYjxb-gSr7XQWPsMqiecTD0QgbQ.

Bienkowski, Brian. Desalination is an expensive energy hog, but improvements are on the way. in Public Radio International [database online]. 2015 [cited 03/14 2016]. Available from http://www.pri.org/stories/2015-05-15/desalination-expensive-energy-hog-improvements-are-way.

Brean, H. New straw at lake mead up for prestigious engineering prize. in Las Vegas Review Journal [database online]. 2016 [cited 3/25 2016]. Available from http://www.reviewjournal.com/news/nevada/new-straw-lake-mead-prestigious-engineering-prize-photos.

Bronstert, A. (Axel), and SpringerLink (Online service). 2005. *Coupled models for the hydrological cycle: Integrating atmosphere, biosphere and pedosphere*Springer, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4D1oBmw6WxhkWKWlGRkYZhmkJKYYmSWCGzOWqYYgveMUfmEIWNjc2B1Diycmc0sQGfqO0GraehZmoYm5mbQrR7AChzYrmaHj4KA-aDbVkDW8SDKTjdBBtZU0A4EIQam1DxhBk7oNeUZlcIM7O7ge3grRRg0nfNLC3JSUxTAN9kUKwCbngrAppxCRmVKEaw4U0iuBKYJUQZZN9cQZw9dkD3x0NGaeJjDTYzFGFjy8vNSJRgUTI2TDNLSDE1SkhOTTFJTLZIsDVITLVITzSyMDBOTDQwlGcSwmyGFS0KagQt8Bil4LEGGgaWkqDRVFuJjANxCec0.

Campbell, Richard G., and National Business Institute. 2005. *Fundamentals of water law in nevada: Protecting water rights, use and quality*National Business Institute, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrEwxNzZNMUwzNUpJNDNOAtX6qaZKhaVKySTKwQZ1maZhE_ROGjEAnrYF2ATObWYDO1HcC3YzOAjKBB1EcugkysID2FAgxMKXmiTA ou4F2X0AO1S9WyE9TKAe294oUchLLFTLzFPxSyxJTEkUZZN1cQ5w9dEFGxUPHWOJh1lkaiTHwJoLWpueVgPewpUgwKKRaGgD7ryYp5iZpKSZGwAZ6qlFaiqGFuXmKEbAzZZAkySCG3TApXBLSDFzgl0TBQwEyDKxpQPemykK8BwBf3mu7.

Carey, V. P. (Van P.). 1992. *Liquid-vapor phase-change phenomena: An introduction to the thermophysics of vaporization and condensation processes in heat transfer equipment*Hemisphere Pub. Corp, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwrV09C8IwED38mNTBr-JXoeBcaZMmraticXB0L2mToosoqL_fu1axiG7OB5fkSO5dwr0XAM4WnvuRE_CSoYzIWSpEpgOFFd0yl5GnU-MjIufy_wpD9K8PF2Ed6jIiTf1VyAv5RzzcMsKsTSQvRHvOEEPFU4mnYiy0oF52EvSnsdvvRBp3oUFshB7UzKkPrYp64ADmu-PldtTuXWEN7ZwPiEduyeN1qHGLpBXUEOx4s19vXXKcPN9qkte0PWZBR1GP--lacOH0CBzFlGS-EhkLs4BjCFPq0sy0CWSkEYnHYH13NvllmGIQivZTeIKYQTPHLW_scrEPTE16Ew.

Carr, M. H. (Michael H.). 1996. *Water on mars*Oxford University Press, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrEyzN0wwTTQwTU9KSEw3Tkk0NLRKB9T7owknjZHPTFBPqnzAESmjA3gszA7OZBehMfSfQzegsIBOQ6g83QQYW0J4CIQam1DxhBgnHYtD4c35upYKaApgNGV4oFmZgdwdftFspwsAbDmwEFink5yn4Arueogyybq4hzh66IJPjoUMu8TDbjYzEGFiA3fhUCQYFsySTNGBuSgZma2OTFGMDixTT1BTLxOSUJItE80QzC0kGMexmSOGSkGbggqwhBg0IyDCwpgETbKosxJMAWDdsdA.

Christensen, N. S., and D. P. Lettenmaier. 2007. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the colorado river basin. *Hydrology and Earth System Sciences* 11 (4): 1417-1434.

Craig, Robin Kundis. 2009. Water supply, desalination, climate change, and energy policy. *Pacific McGeorge Global Business & Development Law Journal* 22 (2): 225, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1bS8MwFD64PYki3u-SJ1-6ypre1gcfxlCGIoKb-DjaJJWCFum6_29Oki6tsD_gY1NoT_KFc8t3TgB8ejd0_-gEL4yzkHsRZ4GXS6svwswLMxYw6VDniZd1Owyti03s2H8A_iPFvodLvK1TLSAXyxSrbhWLQz6zr0J6qcKU_DbsTaFrAH9sm2DjsRrWnvPCdPrc0bcEWMa82juWeuQ0t6E1guIBR5UWn4bHXZTO86rkRTffoAhV1EanXb4IOsdGDpXAbUQxLUT1MUdLvSZ-5PqJ0ftCjVE_TjClGbV1MqWtvUfbClaXSXcbZ48nT_NZd1hZaOn6RBQ9zlvso_7NC1bfi9J9n_VkkD7CUP1t-trYbbyMjWoOgpbRGOkda13n-7BnFpCMNb4HsCXKQ-jJaR6BRphohAekje-AGHSJRndAJLZEY0s0tsdw8_gwn0xd_OsCt1ldpWyxnoR_Arsplj2UtSqP5GdARDIUGQ14HOQ8oDL2EzTn3iiOOZVx-jA7h9MNX7vY-OYSti3uV9Cvq5W4hj629_oFiI449A.

D'Odorico, Paolo, Abinash Bhattachan, Kyle F. Davis, Sujith Ravi, and Christiane W. Runyan. 2013. Global desertification: Drivers and feedbacks. *Advances in Water Resources* 51 : 326-44, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV3JTsMwEB2hnkCIfSlQKQc4BsWOk9TcgFLxAXC2vMQHDqVqU-DzmXGbqE1bCaTcEsWOx555Ez-_AUj5fRK3fALLCpM5ljsrmMeoX2aGZcYKi4DaS2ZaCkNsy4Z-lGZp9_Wt6SAFEbN4EN0MZWuF4LQyh4OnxhWj6222EViR9FclXhvfsxKe2k6a5ETt53g23RylAnN6eAj1YYCairlmkLQm-Pj37zyCgwVSjR7nUsYdsrRCewt6ReeQjyvGBC5kvb0iXQU7PwQDSaB7hHpkYs8xkdDJ_nP4H348vb8Gi_qL8SWY9Ycc2-8N8xIxFCJc17azGSGa0SA3ic6R-_gSOnUSiGEtCUvCik1mjaXpTCFT89hXxNPf1SF83zuEqJSJpjLC1cI7wTHZKXk3rF-UTiOiWViupDU46_Gc70NVRPRPlQzJIqGRCUMr7QLF2QnRSuymmirUpYjzsq47EKvNp3Shn4d2WqqMCJnQY-ZbbmfC9L8x9504W5u76YrXE2xWdXHNI9qPCHaU9VPhT1oPYe4GLFVji3cLk-U5j6looFhKwPIvvr_V1_DLg-VOehv0A10qsms7EGH5tgvWUoFpg.

Doron. Chand baori. in Wikipedia [database online]. 2003 [cited 3/25 2016]. Available from https://commons.wikimedia.org/wiki/File:ChandBaori.jpg.

Drebushchak, V. A. 2008. The peltier effect. *Journal of Thermal Analysis and Calorimetry* 91 (1): 311-5, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV1LS8NAEB6kCAqi1geND8hBL2JKspvs4yjF4lHwcV2SfVyUUmwK_nx3sk0bWwW95TDJsLPDTOb1DQAlwzRZswmpaxbe29TyzLhKOl5YgwtSBDE5bXC1uwhDZJnJmLwN2wJlY7c7o2-S0wQTbYJSluAIH7oqjNefXlewuzINlZfXB4Q-b-uaP33hm2faxqGQ-axTH_3FM6GVHR9A22jctp9sgCJtgDz-42yHsL_4PY3vgj71YctOjmBn1G6FO4a-16v40b7X3p3GoRnkBF7G98-jh2SxVyHRGfN20YeEXLOscow6V2iGA_G60FTnmfYXUhqBQQoCEXJHMmsLUwkuWMkqKawPeOgp7JXYfz-pmzk9M4A4rwix1JTUaJlrLmRROGud1FYTRkoWwU0rXDUNOBpqhZiM51X4iOdVMoLrIP4lKVEzolLlrzH31plnhKn6s45gsEbXlEWlD5MiuG1l2-GHbDA5qxZiDPymxiHHdfJmQWd4R2Yqa2gjuOoqwZIWHUtBhJA4-ZTzsz9-7hx2Q_8JpnQuoFd_zO0l9FBpvgAy4-zR.

Esfahani, Javad Abolfazli, Nader Rahbar, and Mehdi Lavvaf. 2011. Utilization of thermoelectric cooling in a portable active solar still — an experimental study on winter days. *Desalination* 269 (1): 198-205, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1LTsMwELVQVrDg_ykfaQ5AaWLn4yxboOIAdG3ZsYOCQlK1RYgdh-CEnARP4qDSChYgZWU5luKxZt44b94QwuiV31_xCVIG2seaTR6FLFE-D8OIB3GS-ErFVCcrCkOjJZKliwSth298txsZuL0dTIsCK35RqiwOgybqpVhfHtlYj8KPN6Ov_wrUNZfHi0Gc3ekQNYwvbeaybNleSPiK6U-xyuuIc867jndIx4vq6CdrokhrIo__-LZdsu3gKgzbeXtkw1T7ZGtJxPCA1JNFUbpqTqhzQET5VLftdYoMshrbAj1AUYGEBuyr0oBs3CzMMbEG62XKEj7e3mFYwXLLAWjEb8Gu-4KyFjPQ8nV-SCbj2_vru75r49DPKEuwE2SQ-0xzE0RKRkYzhfqlWR7Q3PjGbj2XQagTw1MukzTTFFW4qJQ2lZJhYCg7Il5VV-aEQE5TnysLMS3oscgn4kxnFnHkKqLS5vm6Ry47g4lpq9YhOhrbo2jsK9C-OGjt2yNxZ1TxzRTCxpPfXzzGIyDQCSxmMhM2ibXALGLh6V-XPCOb7XU1PufEW8yezQXx8Px8Anla_MQ.

Farmahini Farahani, Moien, Ghassem Heidarinejad, and Shahram Delfani. 2010. A two-stage system of nocturnal radiative and indirect evaporative cooling for conditions in tehran. *Energy & Buildings* 42 (11): 2131-8, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1Lb9QwELZQT0WI8iZQJB_gmF2vvYntYx9U3Clny7HjshXarHZT4Od3vjyWZVuEBLcoGSsPT76Z8cx8ZkzJicj3MMEjwVlpHeZlEaxRZh6jT7JM5C-Euar3GIZOd4osB0vQI3yH3cOZ6fBtp6vFYvpZKFI9cKPjH59Z9JcXZG1B_Hh-usXmsuhCMAjnkP7V0zO9noBsYPEtDvVeoDZUf7JW-_ANotHQrG4299qvDoIvjthYPDXWqNxhTrrDBPkfH-AJezz4tPykl3vKHtTLZ-zhDtPhcxZOePujyckVvap5zx7Nm8SXDTIYGLwGRwKgl_tl5Eik4zl4_d13RMu4EBpsMHTFyc2mY6Ta8cuQLLsv5LJfcG-XHy8PPuUD_s75AEGM5cpWuGlriiSLUg3qplXWs9SFX1IUora2xilr0QqDFjlE7xZUxiZgrfGBPWSPfLoA1i2Xb9gfM140l6rShdkg-ErldYIm8gHoTjKlL6cZWwyTqhb9Xwebix0u3aDBjhogBPIzKuMmXHa3W8z4cjm_G3oK6iJA1S0ax-cVBT-0guUGTseNcf5Cmtaod04Ay42S6iYsQ-9Nm0fUbqNdMJpjT5krbWQrv3Z0g325ICwFATajL3fVcPt9W41lZy4uemYjt78-8u9ZYd9IQVWo47ZQbu-qd-xA6jyLb6NNck.

Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandea, T. E. Bilir, M. Chatterjee, et al. 2014. *IPCC, 2014: Climate change 2014: Impacts, adaptation, and vulnerability. part A: Global and sectoral aspects contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change.* Cambridge, UK and New York, NY, USA: Cambridge University Press, .

Field, Richard, Marie L. O'Shea, and K. K. (Kee Kean) Chin. 1993. *Integrated stormwater management*Lewis Publishers, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrEwzSwBfepxqkmhumpCVZppmbpqaALkixMEoxMQafq03lE4YMQUdjWVowMzCbWYDO1HcyNwYf_2huDCyNge0U6OE7MD5oJRfIeB5E2ekmyMAC2nAgxMCUmifMwI10QKAIg4In7DSHFAXQMsbcciCzSCEXvmZFlEHWzTXE2UMXZGo8dCwmHuYsYyMxBt5E0Br2vBLwXrcUCQYFkyQjo1TjlETjlGRLk2RzC0tT07TU1DTL5NRkIzOjRDNJBjHshknhkpBm4IIs0AMNGcgwsKYBk3SqLMSnAIE5dV4.

Fisher, J., and F. Ackerman. 2011. *The water-energy nexus in the western united states: Projections to 2100.* Somerville, MA: Stockholm Environment Institute, .

Gandhidasan, P., and H. I. Abualhamayel. 2012. Exploring fog water harvesting potential and quality in the asir region, kingdom of saudi arabia. *Pure and Applied Geophysics* 169 (5): 1019-36, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV1Zi9RAEC5kQRBE13PjrtCIgohZ0leOx2XZwUdxPR7bviKDmAyTDOj-equSSVxn9kEf0xRdSVV3HamvqwGkOM3SHZvAdeF04Hnwitfo9aN2XDuvPAbUdcXdTochMf_JaL6fTgXKwW7PR99oKxN-ggBBiqdXaIXJVVG-fvl5riMUhR4DYClTpbWc6po3zfCXZ9q1z9RJ1LerTXetYnqzrxqqtov7MEGPJ0DKXpukvbaP__G1h3BvG7Cys3GFPYBbsXkItwfgqO8ewdcZxMcW7Tf2BUPXNaMLh6h7Bw6-b3vCI-EMtgls7Njxiy0bhoEnO-uWa_YhEiT6LaPbVUL7g7U1u7SbsESW1i3tY_i0uPh4_i7d3tqQesHzKhWVi7Vzwce8LLnlyjrrMa_LRAy5l8Jp6SpUv7P4LHhduxyDRiWDtHks0aM-gbuW0P1NP5wCDEfAYpVFJ1QoVB2UwBQnijrwsiiCwHQ0cwm8mVRnVmOXDjP3Yx5kZ1B2hmRnrhJ4Sso1tIP7tfUGk0aJhq7MEjiZ9G22W7kjDJwoCl4plcCrcQ3MPITphMlMqcqcDvBirmr6n30CRzt0MldoObVEDi8mBf-ZBBkYfEMUntEGXzGB1_tEiui42WqbyMwq1Am8vL4EZ_Ih1ZVon6shiH_2L2yP4Q6NjWjOEzjo15v4HA5ovf4GCDweVg.

Global Water Partnership. What is water security? in Global Water Partnership [database online]. 2012 [cited 3/25 2016]. Available from http://www.gwp.org/en/The-Challenge/What-is-water-security/.

GraphPad. How can I determine the needed sample size for an experiment to be analyzed by two-way ANOVA? in GraphPad Software [database online]. 2009 [cited 03/14 2016]. Available from http://www.graphpad.com/support/faqid/1038/.

Grondzik, W., A. Kwok, B. Stein, and J. Reynolds. 2010. *Mechanical and electrical equipment for buildings, 11th edition*. 11th ed. Hoboken, New Jersey: Wiley, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4CVmEVakpFRslkSsM9lbJZkbJ5iATosLc00JcnELI36JwyB5v-MTc2YGZjNLEBn6juBbkZnAZmAVH-4CTKwgPYUCDEwpeaJMAj6uro6KRgahngouLp4goaIRBlk3VxDnD10QRrjoSMq8TDDLY3EGFiAvfRUCQaFVAujFHNg58ciydDYJAVIAzOSSRIwdQOraGOLZGNJBjHsZkjhkpBhYE0DJsFUWYizAVzCXD0.

Gross, Matthias, 1969, Rüdiger Mautz, and Ebooks Corporation. 2014. *Renewable energies*Routledge, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwrZ1LC8IwDICDj4uenA98gn9gUpu1666Kw7N4l7mlRw-i-PdN5kQRvXlsC2kKeZBAvgKgXqjwIyZY50yMmpTJTaLzbEkuQ946KuuNKr8m-DNhiA0ziRDrULdOmPqrV5pmJ5UByrj8OAjZKHWidIV_eq6F4S_XvSWbtANNkgmEAGp06kL7jRjYg2DHsekm405z4UUL46EPs3SzX29DEXSo2jGHp2aIA2hwiU9DmFPGnuBYUUpM5IW5RoVH6-O8yLggwBEMvssY_zqYQItTe_RoFkyhcTlfafZ40h0rMG5q.

Habeebullah, Badr A. 2009. Potential use of evaporator coils for water extraction in hot and humid areas. *Desalination* 237 (1): 330-45, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1Lb9QwEB6hnkCI8m4oSD7AjaXxK3GOFKi4lHGAszXxQw0qm9UmW_j59eSxWrYtB7jG44NnRjOfnc-fAaR4ly_2akLkXqJXETFiroIqROkCj46eutW1xD2FodMdkuXUCcYKP9Tu6cvJ5NuTVdPQjV-SKisUIaCi0qQQqlO3JeHHj6fb_wpielyeDgbJetYhGhhfPnR4MdErSclT39ar9os3yYy6drXpbuxeQ0E-O4SZOjUzVK7pJl3TgfyP5T-EBxOiZe9Hu0dwJywfw70dncMn8OVr2xMrKZltusDayMIlDgLK7Zq5trnoWMLO7FfCvWuWusV6vG3BmiU7b3uGS8_ONz8bz5Ao9E_h-9mnbx8-L6Z3HBaO5O4X0qDXKvhoEljS0RAGC1hGL5QzQbm65mlLX2FlVJQhASZvypCHoHTQpqqDfAb3kfj-y364F-iPgBWVqCvHdch1UHVtkGTphTMRJRp0OoO3c-jsatTtsDOh7YcdIj29wMltinQGxRxe-4fHbeosf5_4nJLBUjkg79gUhSpB2qrM4HjOD4t1N7iuSzstkoDk-uZRkQZLfttcOqdKaC_P4M2YbtuVCdsJm1tt0n6Xm9IU3Pa_-wyO9uzokE-S4k8Gr3cTdWtADbKQSik9bJZf_KtbjuHu-NuNzqpewkG_3oRXcECpfgU8J0AH.

Hampel, C. A. 1969. *Encyclopedia of the chemical elements*American Association for the Advancement of Science, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE9KMks0NDJKB7dOUlERgmzzNPNU4KQ0oCprFMgNv-EY6YQh-tA5CbDhEvCuwuEzOyS8AbQnR9k8Dr6mAHwvgClktXozcJoVmb0T_H3SWDXi1HaKUgU_sIEUnflWiI2QdAWxZAbJ50PIQehwxpDaAFIEGoNsbjQyMkYo1M8g1O6jHVXsGB6EKQmpFQwtgI87SUg10dHluSmZyiW1qnm5oMLCWBJ30A7nTAeexyNCKEamKDxFk4AZt-1CAzJUIMTCl5gkzsENu6qwUZhCCeqpYQQN6ULemCIMqclAr-KcpAINaARbUCrCgFmVQdnMNcfbQBVkZDzoMIw-

02iY9sbS4OB7mD2MxBt5E0GaDvBLwpsQUCQYFc4PUtETDREuLVNM0k2QTy0RgK9fSxAK0KSLNMs3EQJJBBp-RUvilpRm4EPEsw8BSUlSaKsvAAjpeCwA-fw5F.

Helmreich, B., and H. Horn. 2009. Opportunities in rainwater harvesting. *Desalination* 248 (1): 118-24, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV1NT9wwEB1VnFpV0C8gUKQcyq0LtmPH8bG0Rb310kq9WY4dl0UorHazoj-_M06y2i4sB3rNOJEyk8y8Z4-fAQpxxiYbOYErXavAy-Alj1j1G1VzVXvpEVBHw-sNhaGLtSbLoRL0GT7l7uHK-eDb89l0Sjt-SaqsRLpC-yvVL9pZjdWWhB-_XKzWFcRwuDxNDNLoUYcodXyFZuFuhvZKdcYIEz9cqzaTN8mM-tvZcrGlelHmvdyDsXdqbFG5J5x0TwjyP97_FewOkDb_1I97Dc-a9g28WBM6fAun32eE85dt0m_Np21OJ1PcIc6d51dunqQ-2t_v4Ofl1x-fv02GAxomvhBMT2QdjUFAWTjmo5dFlEguTfTG-VqGwLEOuKiVccZpaSSGGxGJKQ1yqMoJFYt9eOmokb_t0oa_cAh5YxiSfRm0jEEKZDONiIFXWgeBzJPVGXwcY2JnvSCHHTvVrm0K4XC0prIYwgzKMW72H09aLBmP33hAUbb0n3dz59FWGVVpUWVwMgbeupompHy3sOh6Aqfc6EftRooMjh-wC-SSpeZqixVZOmLTLdZCGlbIEp982n-HK88IuxCWWZ1UiCpSpbfdny6Dw41xiDoLgqosgw_rX_BqQFqiRu7MRZJYOnqqW4_heb8eR5NY72Gnmy-bE9ihX-Av5O5FQg.

Hodges, Andrew, Kristiana Hansen, and Donald McLeod. 2014. The economics of bulk water transport in southern california. *Resources* 3 (4): 703-20, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV1BS8MwFH7IQPQiOhWnE3JVqCRN0ibgxcmK4FXxWJI0AVE62dzBf-9L1lWcu3hMKCF9L3n5voT3PQCe39BsIyYUWnBeNLwIUc_Nx2zMUodY5kGJIA3fUBi63vqgz5GfR0ntdKu9QB4el2vMHhc0kanHqr9diWqXKlVKy2mpM52X3Rvl1jF-nUlJuv9PZE7HTXUIBx1OJHcrxx7Bjm-HsDtNGtNfQ9hbJxQvjuEWXU36NpkFMlm-v5EXRJFz0ouXk9eWpHp5ft6Sn4ysE3iupk_3D1lXFCFzjEuV-VCY0itqPQK3XJuGcmMCNqgoTSmDCs5ZLYxrEHv5gHG1kBw5GDNWBeEKfgqDdtb6MyCNDVY4Zg1iJOEEtYqxRvGAPSanTo3gam2W-mOlfVEjZ4gmrDdNOIJJtFv_XVStTh3ou7rbBDUzwioTkFIyjYGj0YLhBBzl-Gs4qhzBeG31uttKixr5nGSFzKk6_8d8LmAfoU2SZKR8DIPP-dJfwiBqVH0Dj3S_aQ.

Hoell, Andrew, Martin Hoerling, Jon Eischeid, Klaus Wolter, Randall Dole, Judith Perlwitz, Taiyi Xu, and Linyin Cheng. 2016. Does el niño intensity matter for california precipitation? *Geophysical Research Letters* 43 (2): 819, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V3LbtQwFLVgJCQ2qLwEtJWyYjMKxK_YlkCowDBdlDa068pxrtFIaTLqlEU3_Se-gR_j-pHJtEV8AFIWkaPIUXxyXzn3mBDO3lTlLZvAayOdVh79A96DSbSTdSO1A2-t0p7dVBjaMoSmsf9h4T8PsJkvOlzj8BP8Ix2iJEQfuRfnUU0zUgt3mrLWQeFincW6bzH9ljCsx6UcWXq5B2gbjSdS5Px4gG5iGUZ5gjAW5LR-TESdfr5YYUYNI5MebX1nAw136EamcC5C0FiEyE3dfyk2puLZREuKlteIUjOVZa-TsTUCx6q06-1ojZNoU0Yd2zGtOpnWOyY_ScjiQ8nlV3S9tGKTa9sSDrmRGBcbIenrIKl-3q7c5Xvoy9Pv9zFf1yFrvw65eHbh6NfTVov5oXPHBE71dneiO_47BiUne-RRziaKo4SCx-Qe9E_Ig2XcrfkKzyK_122ekncBFcWiK76tfv8aii0iioSIApFQTIgobiDiwzNy-mVx8um4zBtnlGtKFS2FB-5bPOqmVc5UVcukYxowuve1BBDOWqBVI1ojdcMk1JpjGmsaYMIzMPw5mfVDDy9I4SVzFfe1ajDyttRarzhYA9roVjguX5KD8RWc5Y9gc0ZVLRTGmqx-9e_L--ThhKYDMru8-AmHZBaUxP4AoOhXIQ.

Hoerling, M., and J. Eischeid. 2007. Past peak water in the southwest. *Southwest Hydrology* 6 (1): 18-9.

Howard, G., and J. Bartram. 2003. *Domestic water quantity, service level and health.* Geneva, Switzerland: World Health Organization, .

Hu, Mingke, Gang Pei, Lei Li, Renchun Zheng, Junfei Li, and Jie Ji. 2015. Theoretical and experimental study of spectral selectivity surface for both solar heating and radiative cooling. *International Journal of Photoenergy* 2015 , http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwfV09a8MwED1KlhZK6SdJmoKWjm4lWbLssQkJmZMUshnrw9mcko-h_753ttOmoXQ1SAKfdHpP0nsHEMsXHp3kBKGN1V4k3ilR4q4ftBXaOuUQUJeZsCcOQ89_X-jj3odkXehXMkk3pCzHvEtTeTZdHtKvStK4qaiCCSZJ5LIV5Z20bS36f-NKEoLst8ePuSbXcNUiQ_bWhPIGzkJ1C-ejQ0G2O1gvfkSHrKg8Gx-58zN6EPjJ1iWjivJ0fMHmdYmbujgEm-83ZeECQ4jKhhgcNidKy6aEGKtV3duMXAoo-bHRmir5rO7hfTJejKZRWy8h8tJwFRlkyRYXIW7bLjU-cF5yqzXdVHqd8WBckdlQSB90rLRVyiAc4aSkdUmBVCZ-gMuC3tVXu1p_57vAArazUnmjSq8kkosgSy9SY3BIYbjtwZD-Y_7ReGPk5FZdf8CY5e3kzwPSYJF6I6XLVMFjm2SZIw1s7BBwKt-DwSEKebuEtjn2TjJ9TDk96DaR-R4FOViCmdqY_v8tH-GCYt4cmQygs9vswxN0yKnqC4pEv6w.

Joustra, Caryssa M., and Daniel H. Yeh. 2015. Framework for net-zero and net-positive building water cycle management. *Building Research & Information* 43 (1): 121-32, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1LT9wwELaAUxGqeFVsuyv5wA0FZRwnzh56aFFpJY7AoafIrwgObBGkquDXM37lAUiVOHLMOna89ufxzHjmMyEFO86zZzIBSqFKA5XRHFrc9W2poFSaa1So2yWoKcPQWmIYGn57DxN_msKtfAThynbZo7374w8J3EOI0nIh6_FC7KN_0hEl6gdsJwaz9tEw6bQ3vZri9DxgYibT-CQf1VvnOomRJA_393Lwtv62V0NOe8yJiO4GKL27YTBOp3FK0ZPoXFgsilEb5CivqowXIfk5CdrAxzQBVJCaEN57Ic1j-CO275p3cXjlMT7ksT9TnuxY4BjTb8y17r7aVXZ5vo7meO2M8vz7Wb9Do1HsQ1tTx1NKpeNcf-VjE5VlQmg7MUteU1z8fn6xTT5G84J-C7DYIWt2tUs2R6STe-RnDxCKn6AJIBQBQscAoQkg1AOEeoDQASD75PL0x8XJryxep5FpVAIhU_hvoNA5M1aj7iJrVD4LXklVcimMaN1qVJJrACtQsWatlNzIGkCbpWVoCHwiW9KlXaw6n55pDgi1y9wqxo3greEMbU_LWgO1EIYJELmakSwNXXMb6FMaSKy0cagbN9RNGOoZEePxbTrvtmrDHTP_qblIU9FI5bCuO6xRoXkBRbHMZ2Tel8fV6opRMKEFUGP1w_H09Z31BE6s9qdguBV-fnP_vpAPw3Kak43u7q9dkA1HmvYEPm2bCw.

Kelkar, P. S., V. A. Joshi, M. H. Ansari, and U. Manivel. 2003. Performance evaluation of reverse osmosis desalination plants for rural water supply in a developing country – A case study. *Environmental Monitoring and Assessment* 89 (3): 243-61, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwjV1LaxRBEC4kEFDE6GriJBH64MHLxn7No48h2eBNia9j09MPCOLusjMB9yD4H_yH_hK75rXDbgI5V1fPzG5N1VfTVV8BCH5Gp1s-gYZm4L2nPmculCrkqXc4IKXgToqGV3vMMESHLxnzH2f9AWXjt8fUPBH8Sxw5GGNM9MEYqDBb__xtQ7qbt_AXub0zkaktap-R_l34EslD7WJ5W40OSe8JT-hyrw6gb4Toa1B2mJF2mB4f_IDP4VmHUMl5a1Iv4JGfT2B_1rBbryfwZMRgOIHD2aZRLip1nqJ6Cb8_bToSyGygFCeLQK49loJ48rH6uahuKhJTX4NtwY0chyjVFYmq5BoZQcj3CIZXpBkuiY3c2LI5dDnRbCjvl6tyb8_f8k5uYgRmWBh5PoVfL2afbn4MO1GPUyXPAKGKXPOsVBwaUIRaAyRhVVoIoHZMjjOSim5dzn3JnjrqKW8FJ7lzHgrmTWZOISnBlsC5nXTOuheA5El5144I5xV0uaFStPgfVDWW55xkyVw0v_n2pT4YcnWFaZCeRpT9XukEfCJaFgJnN4hVUjHHwEiGyt3PqHSecSmPBVKJHDUWphetowieFHBKUretiY3SLiuuKYakRTPlMikrn_VcYOtZSIXyKPDE3jfW9Nm84gqGY4blbozHZ1iBzWleulCAu92NLBgsVMrlBb98nh3Y-MflmOegMfL-MtEzeOH73gCj9viSCwPOoW9enXr38Aevi__AVqBR-c.

Khandekar, Sameer, and Krishnamurthy Muralidhar. 2013. *Dropwise condensation on inclined textured surfaces*Springer, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwrV1NSwMxEB2sIlg96GqxaiEnb5U1H5vN1Wrx4s172SYTWJCtZLv4982kWypib0IOCYF8HWYmw3tvAAR_yKe_bELuU8F7zFE_Or80Xit0VCCl5E6KpKv9zwpD0giptRrAoChJU_-pd9Mp95Ico0w8LxLClFLzrfxTPyZkF213urO183M4QmIgXMABNhkMfygGZjB-i0HuKqRcOLtns486RpxplMFxQnPa9hLEc1h9ftUtsvjbjYZlg9hhsdUNUSHRMQJ8dCF22i54gmVdwWT-8j57ndJ5Fn1WZ7G9oBIjOKsIDd-sE2vOXQOTS85RuEo4a6TVpVHKI3pj0fKCV8UYRn8vdrNv4hZOeCoEQcmHOzhchw4nmyf6BkDvjNs.

Kibert, Charles J. 2013. *Sustainable construction: Green building design and delivery*. 3rd ed.John Wiley & Sons, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4CVmEVakpFRslkSsM9lbJZkbJ5iATosLc00JcnELI36JwyBjk0xtDBjZmA2swCdqe8ErabBJbQ5-CYm8AZ1cwNLAxMTU2PYYTxQPmhlF8g6HkTZ6SbIwALagCDEwJSaJ8zAjXRgoAiDRDBiv5NCcj7i9FdRBlk31xBnD12QafHQMZl4mPNMjMQYWID9_FQJBoVUC6MUc5BokqGxSQqQBmZFkyRg_gBW8sYWycaSDGLYzZDCJSHNwGUEvr0BNGIgw8CaBkzRqbIQjwEAlRZwYw.

Kidron, Giora J. 1999. Altitude dependent dew and fog in the negev desert, israel. *Agricultural and Forest Meteorology* 96 (1): 1-8, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwpV3db9MwED-hPQ1NA8Y-CpvkB4RAWtbGjlNnb93GBA_wAkh9sy72uao0dVOaAn8-tpN0Xcc0abwlzsWJz6e7s333OwDBTwbJmk5wqRVoM4focJBRlvOhodSZUOpWlgLXEIbOVoIsW0vQaPiou9uWfsvb_s102v_uXZeA7eXtbTzdGofMam9tA_DjxdnyXIEPG_Q9T5wE6tucnqaH2PihKD7GTpLxg9Yq5Iws5v-0VlEhX76ALlSqi0i5h5N0D_fxP4b7ErZbD5aNGrpX8IxmO_B8NKlaFA_agd5X74pfV3HHnr1n51dT7xfHu9dwOgoZvwtLrKu_W_ur3wxnlrnrCZvOmPdJ2Tea0C_mV8VU1cfsy7xCutqFn5effpx_TtoCDolJlUoTEbJu0QknBmXKuRkaQ46syaXLnFSiRBTWL1ExlJ0p89Ii2UxKRynJIcpc7MEWhkD_WR0TAu0BsLzgZWFSSQNJWVkqDHj03CiHAhUa2YOTbsb0TQPYoVci2XKlA9t0UejIOD3ugermVd9hvvZG5bFX9xs5WH6JF5n3B1Peg3frT_Sc6wjFKvxg_SpX139qT7YqP0vi6MnzTAUN66X2zdN_8S1sNkATYdPoEDbqakFHsBFk8C-h8hVf.

Kim, P., L. Shi, A. Majumdar, and PL McEuen. 2001. Thermal transport measurements of individual multiwalled nanotubes. *Physical Review Letters* 87 (21): 215502, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV3NT8MgHP3FLDExMX5_1I-Eg9d2tLACR11c9OBl0XNDKZzMZlyn_778aNfNz8xrS5sW6ONR3nsAsCyh8RdMcJkRlBrPT6tKe07uhGWl80dxFSsPhu_VhKH-zwv6KWV9FEaO7RuaXRIpkgwpNkIwrtAF-8i4A-I0yxsgZqhCoKI18Px6l09D01_jUYDS0S4spPcLzcm3JKRvyY7rvtAe7LSElFw3PWgfNuzkADaDMNTMDuHG9yOP3c-kS0EnD8vfijMydeS-83SRYOd9x-1ZKuJxe1rPSzs7gqfR7ePwLm73XYi1ny_lsbPOcsN45dmY9l-01UxS7XleyTiVynCrJDdSKDflcs1t6ZQrU1cqpqUZyIodw7ZGff6kDj6-

6hSIoNbpVCtpB44brrQnhopL9BH4qzmNIFnUffHS5GwUYX5CWbFSQ4UURVNDEZw0LbQsngqWMy4juFptsu58yAZCyWyOw0AeQbpOsWEblY4RAfXZf5_yHLaCaC2o_y6gV7_O7SX0sIN8AG867L4.

Lawrence, Chris R., and Andrew R. Parker. 2001. Water capture by a desert beetle. *Nature* 414 (6859): 33-4, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3Z3Ni9QwFMCDLgiCiLvqWncXehBRhq5NkybpwYOI4kH2sM7iMeRzEdzZYdtB_e_NS9KOHRf_AK99JVPypu8jfe_3ECLNaV3t2ATumPUc6OkholDaCOcoswRw4G2HnZ0ThqaZeNtr_4PivyrgHhq1jt8GQnSpFtbBN_eFdm74Piv9OVMjUSQdBUBx4-L8dBF7oaey3QgggMuf1Y_YHDg7KsC5Z26qpIhr3n6-NZb2J1x1cg7JIlLOKsqyV8wmk6bGz_zfYCJDvZMNTGCLv0xzArGTFmaJ12LrfqaiwOBDeRe8JcMvAXt-Zb-Z4a1bVRdf7oacWkBmfX623Nbv7CC2R7IwEW_GH5nc7JySOssiABFrrteb_tbII0YZy0foYU4PyndJrfvojlsdoHuxTNf0B2g_m-K-fJV54a8fozJqvMwaL_WvUpVJ42XS-BN08fHD8v2nKg--qC4bxrsqZJnWYG5MU5POa0WYE0Y0vtZtTUxI8aimqrUaa2wEDQGxEYpZTRjx3nrfkqfogYIGidUQGyntM1QarzhrQzBH6xCQGKJF3SmhSMc4FDn6Ap3AXklggqyg6OhSbfpewjD6EARzUaDDLPfXw40yM0naXrlOgBQ57n-Bjsf9lkrD0Z0ZetnUlHKOG1ago0mcX6CZ9DBpaFoWYyZCOF0X6EVS2SRpZN_IyLltaRdyRiyHn0NYYOc2OLsLGQ4OC_yp6kme6FEwUBUChe75vx__CN3fvmTHaG-42bgTtAcYtN-iO4nb.

Lechner, Norbert. 2009. *Heating, cooling, lighting: Sustainable design methods for architects*. 3rd ed.John Wiley & Sons, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4CVmEVakpFRslkSsM9lbJZkbJ5iATosLc00JcnELI36JwwBE6qhOej6YWYzC9CZ-k7mxuAN6ebgXdSWxrDDd6B88Dl8ebDL4sFlppsgAwtow4EQA1NqnjADN9IBgSIMUh6gJl1euo5Ccj7odh0gIwfUmwayRBlk3VxDnD10QebFQ0dh4mEOMjISY2AB9uxTJRgUUi2MUsyBHSaLJENjkxQgDcx8JknAHAGs1o0tko0lGcSwmyGFS0KagQsy3QEaI5BhYE0DpuFUWYjXAJoSbIw.

Lochhead, James S. 2001. An upper basin perspective on california's claims to water from the colorado river: The law of the river. *University of Denver Water Law Review* 4 (2): 290, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1dS8MwFA1zT6KIX8OvwX3Sh1FZs9Rugg9lKkMEYR_4ONIkZYOtHV1lf9_ktl1bnX_AtzaFkPaEe3OSc08J6dD7tvUjJtiO6zvSfpCC2YHO-srxbccXTOgFddCz_arDUC0XWRZt_wF4L2xNVitTQ8LXKBHfVlOag4GiFgt36sWCz5do8rDhxi5xW23S10Ex5jJqDY1wI1d_LPgmFxXEpr28tK1KPJ5VqO9an9jr70OI90jMZtn0QqFutgWb7z-gAIsWbHVX5-V4Sm2rw1In3jzgstK8ouXgmf44tGqK7fXfxqNqM2Zf1xA1vf65NRbpSzkXyZMKrcloT_PvrmHhw8HHlnmb8lo0zs1Gk-XfgyKBjo_JUUYBwEuhOyE1FZ6SPf2NzsjMCwHBAwQPSuBBFEIB3t0aUuggiQChAwMdaGQghw4Qukds08BBFOAlAndOmq8v4_7AMgOcmsmWxFxM89ftNMghN7UPYYI1kvKCgOq1lU-ZdFkgGdUEUNFA2l3XlVST9bZ_SRq7O7v668E12S-gviH1JP5STVI3Dl_fyBk9EA.

MacDonald, Glen M., and B. L. Turner. 2010. Water, climate change, and sustainability in the southwest. *Proceedings of the National Academy of Sciences of the United States of America* 107 (50): 21256-62, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV1Nb9QwEB2hqgckhChQGlokX6iK1F38lcRB6gEhKn4AiKPl2I5YqaSrTSoBv54Zx9ll98g1ie1kxp68Sd48Ayi55IuDmNB0seU68FgZ2clGqJJzJwPic2eMiocKQzOLjEiWe1TFZb_6keiW2a6btN_asqO8kQ6FG0XTVFSX4_393c36Z2oX_1xOFyYhItfSRwQ_YtwWvDFzhr8V6jVT2YrE6K2lnuWAavV-

3bthyRvSS6GsKekIY4JR503e5pdaDu0TvZE0U7HZHn49ZF8eUwHKw_BvacztM3iaESn7OD3qCTyK_XM4yWt-YFdZmPrdC_jwHYHp5pr5uxXi3MimouFr5vrAhrkQi7i2v9mqZ4gs2UAb9JEYw0v4dvv566cvi7z3wsJLUZmFVk6FRvmydd5JRBlCBtfpqvQhVKXT6DMTjBQt2rqVMpKsmqgi5x49LUuvTuGJI45-P6ZavnAGTHQN9z4G57nXiKRc28Wu9Q5TnkZ6rwu4mq1o15PWhk3_yGtlyYh2Z_sCXpGVLa1CcqaVSZhMSVHAaTL8tgeMSWWFaWEBRepk13NtS27x1V1WBZzP7rF5DQ-WoIxuRIOD1Xse23ZB0tz7Z3B6JonuPAsLeDv5dnc3dpCW29ogMq4RrOrajr_GAs4OrlNVklKrzev_HvwcHsvMvRH6Ao7GzUN8A0ck0_UXl8IZIQ.

Maestre-Valero, J. F., V. Martinez-Alvarez, A. Baille, B. Martin-Gorriz, and B. Gallego-Elvira. 2011. Comparative analysis of two polyethylene foil materials for dew harvesting in a semi-arid climate. *Journal of Hydrology* 410 (1-2): 84,

Maupin, M. A., J. F. Kenny, J. K. Lovelace, N. L. Barber, and K. S. Linsey. 2014. Estimated use of water in the united states in 2010. *U.S. Geological Survey Circular*(1405): 56.

McKinsey & Co. 2009. Charting our water future: Economic frameworks to inform decision-making. , 10.4324/9780203132937, http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/charting-our-water-future.

Milani, Dia, Ali Abbas, Anthony Vassallo, Matteo Chiesa, and Dhia Al Bakri. 2011. Evaluation of using thermoelectric coolers in a dehumidification system to generate freshwater from ambient air. *Chemical Engineering Science* 66 (12): 2491-501,

Nandy, Aditya, Sharmi Saha, Souradeep Ganguly, and Sharmistha Chattopadhyay. 2014. A project on atmospheric water generator with the concept of peltier effect. *International Journal of Advanced Computer Research* 4 (2): 481, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1Ba9swFBZtT4XRbmtL06ag0y7BJZZlyzr0EMbWwo7J2DHI0hPJaJLSqIf9--lJsmOyQqHHXS3bSPbnp_eev_c9Qgp2O872bMLYhob3MAaRG9tIK0ow2CClZoYXQVe7pzB00HKHd8f-hxc_QfI_ZlfwP8DErTZbVA5Y6tEvhYKIUWfaR9opBRv61oXSxUCHg0eH9SdR1Ljvuf6bOmz92JZF0DaI6Nh8Oy6Ad_UVGnLTJfBRKHq1HE3VotsXpv6eygA8je4xifq4d-7WLRSyA5zzcb5Z_Ensn5SxyPmOWRWj2HfONxhF73HIzPtccZOGdEyITMjYgKS16rwHXtaz0Dx2iNkT2S545S1tzWT-BSXXV2ap3R2ss5_TQx_P16IXq_-ObnXBQjfnbj6v7OW44c4-kpO0RDqJkPhEDmD9mZy2q6TJip-RHxOaEEI3a9pDCA0IoR1CKCKEeoTQhBC6sTQhhEaEnJPZ92-zrw9Z6qmRPdUVzwyvGJTjXGnOTNX4mMWHuxoaDbkQ2rDSaGbrprbK--kgmG2EtCjBXXPOpXeVL8gHhaUXaxdKNM0lobxhDAqjCqMl16KWZWkBrNSgWcVUNSA37ZOZqwYTeNpt5z7SKFA0WvABGXbj6TvqD1-9cfk1Od6BbEiO3PML3JAjVCP7CzpGd54.

NASA. NASA releases plan outlining next steps in the journey to mars. in National Aeronautics and Space Administration [database online]. 2015 [cited 3/25 2016]. Available from http://www.nasa.gov/press-release/nasa-releases-plan-outlining-next-steps-in-the-journey-to-mars.

Nikolayev, V. S., D. Beysens, A. Gioda, I. Milimouka, E. Katiushin, and J. -P Morel. 1996. Water recovery from dew. *Journal of Hydrology* 182 (1): 19-35, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV1LT8MwDLYQF5AQ78d4SD1wgENZkiYNPfKa-AFMHKOmScQu08SKgH-P3TYDNhAS19RtYyf1I7U_A2TigqVzOoErbZXjuaskD2j1vbJc2UpW6FCHgts5hKGYXEhJlp0laDV8o7u7kX4n2_5kNKKqbsHzAt19hgasoPJyhcaWcB9vrz9Vc5bJCB9O1LGWjuf92dhZoc6bZ6T6N1v11Rel4pGX6c9mS5JqHmxAzE-IuSkLiEkLCJD_Z3wT1jtXNrlqybZgyY-3YaXrqv70vgP7j-jIPicUc-MH855QKUvi_OsuDAd3Dzf3adeIIa34pRZpUI4F4VBx-lKossLgtSwvnctl4YOWVmkW6Hec5KxkTlTOKptlWbDBKe9Rp-7BWkkJ--O6KexzB5D4gmFQL52WwUmBUYsXweHbtBMYYTLbgzTK3kxa4A0TM9KIZ0NMm0KZhm2je6DjAplvkjNoG_648yiupyktHTBV9dRQhbnIM96Dg3aJP2eBPg2FlbIHp3OXhJkK0-CtMk4d3JSp32ok-7o3ZsQEOJwPh4paBOC8Dv_NwBGstrnkdDB0DMv184s_gWXaXR_s9Qjk.

Nilsson, Torbjörn. 1996. Initial experiments on dew collection in sweden and tanzania. *Solar Energy Materials and Solar Cells* 40 (1): 23-32, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV07T8MwELZQJxDijVoekgcGGEJsx45riYVHK5hpZyuJbSlLqGiq8vPx5dGWFoTU1Tkn8fl0d7a_-4xQxO5JsOYTqJCpMDQ2GafOR30rUirSjGc-oXaKpmsMQy24EECWTSSoPXzlu5uWsNFtOMnzkCgorOJ9JarDJaD_FD7YAu_jy9PCNbO4OmYG4QCk21o6GoeLtlsl7qp3BNGfsQoqRmbT32MVB_87PEQtKKEFpGzQJG3QPm4_2iN00OSv-LEWO0Y7tjhBeyushqfo4Q0ASV5oeXvAFH8U2Ng5BrOrwF8Fzgv8Prfe7eGkMHjkc9SkyJMzNB4ORs-vQXNJQ5DBDdUBi61jsXAqcVyoiMssNSyhMqLOMSKdcC4hKYmTiFkirCGqL0gqiXGRcpSL6BztJwDmL8qq6M90EbaK-AU_N5I7w5lf0VjmDO1LaZhffZK0h4J2XvSkJuXQLVoNVKNBN1oJXWlHRz0k28nTPxSsfdz4p2e3nuvld7wN-RHwuIdu1h4xPWW6YluF80YpqC6_Si-2aiQLYaAbjscDARm773Gx9S9eot0aSQ7bQleoU37O7DXqgJl9A-TSCSM.

Nilsson, Torbjörn M. J., and Gunnar A. Niklasson. 1995. Radiative cooling during the day: Simulations and experiments on pigmented polyethylene cover foils. *Solar Energy Materials and Solar Cells* 37 (1): 93-118, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV1LT8MwDI4QJxDijTYeUg4c4FDWJW0e3HgNzhOcoyxpp0pjm-gmsX-P3ccYGwhp19ZNU8f97Db2Z0I4uwmDJUywuMHZk9JFInZacRV5b1MmUogXXMSTJYahOrkQkywrT1AifIHd1ZFWpdvWOMtaocbCqkhhn--KXTIGZ4u8j4_3c2hmothmRuEApetaurZozY9d6ei6GCNgf_oqrBiZ5r_6qgJ-O3ukzkmo81FWWJJWWB_Xf9h9sluFr_SuFDsgG8nwkGwvkBoeEddFugNEUepG2BKoT8taSAqxJvV2dkvz7L3qGpZTO_T0u81ATkdDOs76BVWop-PRYJaAKYFrxNHgtaPpKBvkx-St8_T68BJUrRwC19ayHTgVMuctIBrMOnZMpSny9iciVFomWknPYh71lOXChdzyNFHWIo9OLL30ivMTsmMx5X84KUoDfYPQVFrJezIGd4thkdAq1CmEG_DJpIQV7SYJ6tUz45K6w9Q5bahBgyo0OjKFEg1rElkvsfmxDga8yz9XNkqLmN8HUJLBdGLVJJfLp0zODHKyMohMsczZTD4nILZoSnNhJCWOu88QxRXB_enaUzwjW2UxPv48Oieb k49pckE20Rq_AN9pFo4.

Nilsson, Torbjörn M. J., Gunnar A. Niklasson, and Claes G. Granqvist. 1992. A solar reflecting material for radiative cooling applications: ZnS pigmented polyethylene. *Solar Energy Materials and Solar Cells* 28 (2): 175-93, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwnV1LT8MwDI7QTiDEG208pBw4wKH0kS5NuI3HhIR2Ai67REmbTpPQVm2dBP8euy-NDYS0a-q2qWvZX2L7CyEsuPWcFZ-gMcFpoigOeTeWgokwSXQa8BTwQhwyu8IwVBcXYpFlFQlKD1_47mrErXTrZuOx60lsrAoFRHtc5gywsRqCLfl-Pt43rjngRZoZhR2UrnvpfO42Y9cyuCme4Qz-jFXYMbKY_xqrCjfc3yd1TUJdj7LGkrTG-rj5xx6QvQq-0l4pdki27OSI7CyRGh6TYY_Ocb1M4XswJwCDFGBxYekUIDKdIR0CelkaT_HIoBFdzqLf0eHklWbjUcEWmtBs-vFlwZogOtoT8t5_ent4dqoTHJzYByTl2NC30teeAZgVSaO1NSngka5JfRYbP4w9jhxgXEvci2IGLhjhpcJyj7FEG3ZKdjVW-k_yoiMwaROaRjpiJoIHCkRDXApPpoAyYKUkuOZ-hzj1T1NZydih6lI2VJxCzSkZqEJ3atAhUf1n1Q_1Kwgq_9zZLg2heQ-ALZxFl3fI1eolNQ8UUrFi6zAXQqr8MwexZQtqhJGLOHi5B9-IGNw723iK52S7rC_GPaML0spnC3tJWmiE35sOFGQ.

Okhrem, V. G. 2011. Thermoelectric cooling by the peltier effect. *Applied Physics*(5): 123-6, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1LS8QwEB5EL4KIorK-MCcv2qVN2m1z8CDiAxQUXL0ubTKBRbddlnrw39tJ-nJx_4DXFtrwzXRmks73DYDgQ99bigm-sQPv0cc40CaTJo5Q04CUhOtQWF3tnsJQO9a1u_ZPDL-YFW68zVRdqKKwjHMqMyuXeMHPkggmro-jX5o29ajtCe1a4J8_Kmtbp3kf3vfPCCxTrjkjcGHNthrLMOlZNOqFrcBxfusMGPA_xKmXkkbbyidi-tnHZXhOWuUzPVXlFebe22uVFknqh_bJj0_NJx5ECanh2G1wsyYSaVXF_KtuQLd5arwD23VFzq4dkruwhvkeXP5GkdUosuybVSiyGkXmUNyHs7vb8c2D514wmTsFj0m7aH4AWylRCfLSUg71AFiYcY5Cp0IrGao4kVFkEI1UqPiIp6NDGKx63NHqW8ew2VnmBDZM5WR4CuukmvUD1ZgA3A.

Olson, Reuel Leslie. 1926. *The colorado river compact*. 1st ed.the author, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrEwxNzZNMUwzNUpJNDNOAtX6qaZKhaVKySTKwQZ1maZhE_ROGDEGXSoAON2U2swCdqe8EuhmdBWQCUv3hJsjAAtpTIMTAlJonwiAFjBoFYIcdGPgp-QpBoIURCuCl4Mklogyybq4hzh66IBPioUMr8TBbzIzEGHgTQUvS80rAW9dSJBgUUi0NgN1WkxRzk7QUEyNguzzVKC3F0MLcPMUI2IcySJJkEMNumBQuCWkGLmCDDDoCIMPAmgZMoamyEF8BAAfdaEY.

Park, Kyoo-Chul, Shreerang S. Chhatre, Siddarth Srinivasan, Robert E. Cohen, and Gareth H. McKinley. 2013. Optimal design of permeable fiber network structures for fog harvesting. *Langmuir : The ACS Journal of Surfaces and Colloids* 29 (43): 13269-77, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1LTxsxELYAIRUJVQUKpA_JB8Ql2na9a2fXhx7QirYSB5ASzsjrRxKJJAiSShV_nvFjbZ5_gEMOee5mPJqZb_zNZ4TK4keePYsJhFUtU2SgJCUGsr5mLWGtpBIKasNJ-1RhaO0-LHx67T0s_DkEgZndenHcDMdohuir3YiUsfyQ_txTv_teO3YFgNuRDc1i3J-IW6e7EfJZGpQez1bTyOO9CATrs_-LRdZMErewmUzEMnS1wUk0JMJxaq4O7W7RP3EXeq5TpeD2Yzs6Dop4sncYkQgNCeKobaFr4eOWVT2taIhbOsRVQKms9jIAXeBNX1p1Yk0hjAJE9ge4hJwMz_1hLy8CPpQosK7XglqtNm5SVut28p8lu0hBLCt7HCGj9NhqrM_UVC5_6Xl2OVwHAF9bGH_SDJN8c-mBVPfXOo2qgvyM135Uw2zakaLV3evFjJt9Gn1CHwPkwCfeVXbQmp7vog9Nd9LfHvoTXAZ7l8ELg6PLYOcyOLgMTi6DwWXgMcbJZT6j0e_TUfM3CwdsZDdQF2dayVbzuiZCUDlQqgIorjVUNDnPlZLMyIHVi6SypKouBABzzoSQZc6lRQGs3Efbws5hzJduXlMdIqx5rtuCqooaRQsAo7owCgxdqaIiVd720IE30tWNV1O5gpqRM7hyDx16q8V34hL10NFjO8YPWEAPBX3BmYMqX97-ha9oK7nqN7QBxtLf0YaVLHsAgOh3mQ.

Peel, M. C., B. L. Finlayson, and T. A. McMahon. 2007. Updated world map of the köppen-geiger climate classification. *Hydrology and Earth System Sciences* 11 (5): 1633-44, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1La9wwEBYllxZK6bvbB_jQ9tDFxdbDtg45JOmmW8q2Jd495GRkPboLya5JHEj-fUey_NpD6bmnBa0wRjMefd9I8w1CBH-Owr2YEBnX8F5HOo2VKblJmVa2QUqGFSVOV3ugMNSVovRj_4PhV5Ul8WrqtFCnl6JqrwF831WV3oZf9cZW-sqLDYBVDb8An-19od5EHqvOz7-cuWMmJ0E1A-Q7n-bn-XK2aFNTeR9Ym8P-Pmt9utleiDtfznXcZZgXciHWzeDyaJRxSPsrPz9_zc5-fDtZ5aNS50H4BJIbAoby4tbNWBKlIUSBbBRz44FvsUEABXhIBpsxkDna71Tt6fzeBtZdK4wcY2IAYh30_WjV0y_VRtaHsLqr3AoNkCRrebdn5VmWNEfi_tVHAMX1cbAqsnJX3Vz_BZwsH6NHnkIER43pn6B7evsU3ffd7Nd3z1DrAoFzgQBcINiZAFwgGLlA4F0gGLvAc7Q6nS1P5qFvkxFKe4YWliaJMI9kGiW6ZIpTTmhJicliiQU3SQpbmGHGGKujZIBfKiJtVwKAeobwRJAX6KGw5RTb2pVdqlcooCXGmihBlORUphlnzGhtuNQSJ1gkE_SpXaSiamRRCqCTQAdosYYtGohlYU1pu5ymE3Rsl7GbaBXN3cDu6nfhv5MiVnGqMiGtwCHlMS6lYMJYNcSYM1xmE_ShMUL3GFxc4yIqCIP4YVUY06yob-sJerk3jwIljmHOBL0fWq_7f89rXv_btDfoQZPmt9m4t-igvrrR79CBFUH7A9U1jaI.

Poseidon Water. The carlsbad desalination project, located in san diego county, CA, at the encina power station, will provide 50 million gallons of desalinated seawater per day. in Poseidon Water [database online]. 2016 [cited 3/2 2016]. Available from http://poseidonwater.com/our_projects/all_projects/carlsbad_project.

Powell, R. W., C. Y. Ho, and P. E. Liley. 1966. *Thermal conductivity of selected materials.* National Institute of Standards and Technology, NSRDS-NBS 8.

Rhoades, Alan M., Xingying Huang, Paul A. Ullrich, and Colin M. Zarzycki. 2016. Characterizing sierra nevada snowpack using variable-resolution CESM. *Journal of Applied Meteorology and Climatology* 55 (1): 173-96, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V3PT9swFLZYT1zQYCC6UcknJFSl1I0dNwcOVdppF6QJKEJcLMd2BKJLp64DwV_Pc-z8KnDYdddYcpy8L-9979n5HkLhaDAMNnwC5zFTacbVmGQQEeNYRxzsk9FQaSrphsLQVtlIpr72Pxg-qSSYXwq1bYh7KwnO7FFq2b_Ml0-QJT_03VGBa8iU7b9Tga3iu6X0k5lXzf-Ysp4D016uavWmZHEPxLdVoL-4W0rtXNBkYTeEavz4CvUNLOC5DJwwMF8swCdXxxXrIuutXL08K9deO7E9hvxkvlZBmrUK717ZOBhT99f0wDSvhS2f7KR7W9hzDpa4xic-VhPXDfdtGOBWMQPCVhJMA2JPJ7JoQOqQV27zb0TC6nxikRlxJuwMYioIE3YGQY6tHvsvfa_WZyYP5pefINkfF-n_5GcZ_ynlhbxz9azV5jg73VxRmwy1uUBBcK4-ox1vZjxxiNpFWybfQ92GqfExbhj6C5q2kYYd0rBDGi6Rhguk4XeQhi3S9tH8--wq-RH4phyBIgyyMSMhqeY0ZbEKtWFGc5VJpUeSkhHQ-RDyBSIpl5woCuxfAp9lJmahygwbZqkKD1AnX-bmEOFQZxEQSprKNKNDyeUQ3EHEU0hRKLgF3kUn5dsRv532ivjIMl3UK1-fkKmtEqr1H0G4lcuMIM3poqNq3H-szeGv_3Crb2i7xvYR6qxXf00Pdaz82SskBY1g.

Richards, K. 2004. Observation and simulation of dew in rural and urban environments. *Progress in Physical Geography* 28 (1): 76-94, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwjV3NT9swFH-aENLQEBtlhVIm-YB2GOpI7DhOjtXUihuHsXP0_CU4LFRJKrb_Hr80_aDlUOXi6D0llv1s_36233sAgv-MRltzgo-tQJt4RI9R4pKUK-NibyjVrdQCtyIM3bx_oB-4xS0dCQReFVj4bBa4T0XYKCyBZNy_pwrSVip9QECqb9ddtZYsvOtPyQfkHn97urTTqzTz7D0j1neMNmJe7QTx3Gf6n-Bkw56svHCVk7hgyt70J-sPd2CsBvqdQ8-dunRH__34NO9cVh2r2cwvtervVyGpWX1098uCxh79sy6F_ZUsooCerTieaWxZJsudV_hz3Ty8Otu1KViGBnOWw88KVKNaZrFKUfvtfeifTSKLBGcUEsomUCHjOKJ1TbRLkAnmxuLqbSiD8dIV_bLpnXtsxfA0pzr3MTSRdIlWmdIkeW5yTwKzNDIAfxYdlkxW4TeKFrKksfFTjMOYLjs1AI17RKZpg68RkUEUDal3Riti4BsKTmXjAbwnaxgn59cL-xkpcqLmhdBPUu4ImjIi-ZfM4DzLbXQRkpIpcIHNu1rJSekneU8lZSeIhKX-1ZoCEeLm0S0JXQFB001d9_ggCzyFWa6CNA.

Ruckriegle, Heide. 2013. The colorado river compact: Effective or obsolete? *University of Denver Water Law Review* 17 (1): 172, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1bS8MwFD64PYki3u-SJ19GpcnSywSRMZXhi7BVfBzNpSJiC6X7_-Y0Xbtu7g_4mkJ66BfOOV_65QtAn925zkpOoF4gPEV9JTlNTNXXnqCekFyahjoZUNF2GKqv6mzG_gvwI5PS8lhlvQnKLqzQXJabgFa_gXKhLO9lwgRguuYVdV9brPGkU5zjI0Y7xfXfCZO5_DZ0-9PKkkvbrOWdBLzVYeCwhnf-NflyZmTU6XPrqVunzmBtidg8SO19PG1_6-HoNZq2h20h9f0Qjej5Ldqd_6gvWTzo1HmfdgyXDpFRT8ZvNYvGo7KlCW4VT1VLd5qiF-3DXtXOk6GF4QC2dHoIHfOVjoAZIMgCCFICQSog7kkNA8lysoDh8RhuXp6j0djBV81wCRR5LGd15P0T2I3xSEJalEcX1RkQPXC1YFwFPFGcGV6mWaJoGASKGQ7tinM43TDbxcYnl7DdIHcF3SKf62voovXWL2QdFy8.

Seager, Richard, Mingfang Ting, Isaac Held, Yochanan Kushnir, Jian Lu, Gabriel Vecchi, Huei-Ping Huang, et al. 2007. Model projections of an imminent transition to a more arid climate in southwestern north america. *Science* 316 (5828): 1181-4, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV07T8MwED6hSkgsvCnhIXmEIRDbieNMCFVUMCAxsAc_pUptWkoY-PfYjlNe6sBsKU50l7vPd5_vA6DkKkt_xQSXB5mDzpxrJiXh2GZaaMKEg7OVxuHO2PcJQ30lw5MsA0sw9PQdXJJTc-3pVIzS8mbxmnr1KN9ljVIaLhR7wNwx-9bO3o0Tfr7dnfHKJg7K4x_JKYbojqa4HoCGRDTegZ4x3BNQ_oxF-jPm8b9ftwvbEaWi286t9mDDNPuw2elWfuzDXowIb-gijq2-PIAXL6s2RU9dacd7M5pbJBr0MJs5KNu0KOTFQBFD7RwJ9DhfGrfHRKPRdOKQs0GTBgVNvzi_AYWuEopdpUN4Ht89j-7TqN-QKkqLLPXHX5ZX1lSlKqVQDhsqZTQ1VpFM5YwrqnPDuM2IlQURVWHzMteWa5NjWdEjGDTzxhwDKqjMrMW5VkLmxnBZZUZwIxgnWKgMJ3DR261edFM66nC6IayOJq6jiRMYervW_v9tl0LV2GFUXLpTXQJHwRqrJ_SmSOCst30tpK9AqfatJpgWlQeoCZyulmMA-LE67Lzl68UciPMaYSfr9juFra6CXKSkOINBu3w35zDwjvQJnfAAwQ.

Shallcross, David C. 2005. Preparation of psychrometric charts for water vapour in martian atmosphere. *International Journal of Heat and Mass Transfer* 48 (9): 1785-96, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwrV1LT-MwEB4hBCskxGOXR3lIPrDSXgqO7TTJkacQpz3sni3btaUikVZNePx8ZpyksC2XFVxyiC3LmRnNfM7MfAaQ4pT353xCEbzlasj9IBdBFIlMOTdiiPjc5Ln08wxDF--KLNtI0Hj46LvbN2etbM8moxF1_JKpJdEoU1kQ_2eK0ZaIH68uZnmFjDetO-SbafY3-PVW8TW6J__3gKC1jqDRR75QdUosn3Rt7seBq_XkK9RF8lh9HL9iJvdmE7rqqa5IZYE6aYEK8hMS2IKNFtSy82beNiz58jusxuJSV_2Au99T31CMj0s2DixWWBNNAt0OwKjvq64Ygmf2jMB3yp7MBBdko5JFjgNTMhTXuCL-A78Df2-

u_1ze9ts7HPpOSCn6w1xyG_AYZG1QCQbkEJTNAm7QEdpJvPFWUTJImsLicUqk1qe5DAqf2SBIuQvrhmr9yzr2BA73gSWh4A7lYRx3ChGZscEH6wwenQrhnOpB0WlKTxrODt0Vs93rRS3TVZwKj0IatdyDy061-h-5awwx_7HKHlmFJieB404Tr55S6O968LMxlNnOhK6ExnUzRKaUhs4SXb_UuMLcPELWQmWDHpy8t7DZeENlJGQWEzbi4Es-5BDWIldt_Od0BMv19NEfwzLZ6yv6wjE.

Energy Policy Act of 1992, Sec. 123. Energy Conservation Requirements for Certain Lamps and Plumbing Products, (1992): 123, https://www.ferc.gov/legal/maj-ord-reg/epa.pdf.

Shen, Limei, Fu Xiao, Huanxin Chen, and Shengwei Wang. 2013. Investigation of a novel thermoelectric radiant air-conditioning system. *Energy and Buildings* 59 : 123-32, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV3JTsMwEB2hnODAvpRF8g-kJF6yHNkKHwBny44dKagkKCp8PzNZoLQggZRTIo2icWy_57x5AyD4NApX1gRjYhdRzWampEhtlEmpsjhJ08jahLt0xWHo8pcf-p0wizwBqjm5fMa8O8rr6tal5NTAYHZ7_bkQJ6rjW5FAopQi1fsq4Pk5yretKRjFccNWM9uBUWk_SkzWjI_WjBz_-v67sD3gT3bVfzB7sOHrfdhaciU8gPsl742mZk3JDKubdz9nBBZfmr5zTlWwtvM1WDBTtSHSalcNh7ust4c-hKfZ3ePNQzj0WwiLWGUiNFFmVelkab1SRsXWIz8RKUI-orG5tcI5Q357yjrh8S7OX8RzluPDMndeHEFQN7U_AVbyHIMhFkR0ghAFo7sCoUFpFTdIyN0EpmOq9Wtvq6FHvdmzHjKkKUMaL8zQBI5pQDRNu0VrCo0LkSTjneT0v6HOYJN3PS1IfnMOwaJ98xcQ0Ch-AB7bxKE.

Sherbrooke, Wade C. 1993. Rain-drinking behaviors of the australian thorny devil (sauria: Agamidae). *Journal of Herpetology* 27 (3): 270-5, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV09T8MwELVQJSQWvhFflTzCEIjj9GyzoIpSwUwnlsrOnflQSUqAgX-PnaQglQExe4ns6O6d3_N7jMnsLE2WagK6YgAKwJoCNFiNCEYKTwrIWFmoJYehRahjFFk2KsGG0w9wyc3oPEwcocury_lrEsOjIsnaJWmEShzwsm5fMHxzCVna1eMwdoX-JpaVh7GRjDfYgsBfCEh-2Rr9smn859dtsvUOZPJh-1dssRUqt9nqfdVcoe-w20jqJKO6jU3gnUVi_cYrzwMe5D_3H3zyWNXlJx-F9jnjJ3fRg8he8OGDfXlCS6e7bDK-nlzdJF2kQvJsMkggN2lOAycUCu_AUqpcPnCqAJI6RQ_WygC5DQoCrbxGMuQUSk82IB9Aucd6ZVXSPuNWK42ZLDSBz1EY7RCEVQ4zKAhzfcD6zd5M561rxjRMG1F0Pu026PCP9SO21moLo5zrmPXe6w_qs148jS8eRrKD.

Sinha-Ray, S., Y. Zhang, and A. L. Yarin. 2011. Thorny devil nanotextured fibers: The way to cooling rates on the order of 1 kW/cm2. *Langmuir : The ACS Journal of Surfaces and Colloids* 27 (1): 215, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V3JasMwFBRpLu2ldN9B9-DWtmwthR5KaOmhpyYl9BQUSW5NEylkoeTvq8XOBv2Bgi-2sMEa8_Tm-c0IAJTextFWTJADkWOCMWcCU8yplJihpFAEK8aRIJsOQ426_ra69j-ANxO9cGqoctjSXBvX2zF3beaF6w6Z1p0cP9wnnsIYr0h3lhH1r4OWN-R0eWTS-u7ZNxKjdD2LfeX6czQvgwmF16a0O-seFNP5pPCtXkE0NxyaUi5z906pv3j0xhcbhddl4XqZWn9YFh_8DSplhFwVW-0R6gOqiqeWneY0yP_rgFudrX9YdfTMN6L6eGRxSZ3IKWZbftl-BV4OOZv0kSzF7EHp6L2zYzk4dUzcvv3KgRllzFs_h3u2aIRfTbsHYL_iAfAx4HcIGkofgd12vf3eMegEHKHHEa7jCAOO99DOPLQowpmBFYrQowiN9mMeRWgKmMDv3p3F8AR0n5-67Zeo2gEjGpM8idhA4kHMGZI5UShx7J0khVBpbJN2gZiiNh4LTuJcZpZLYc6nqWFUspJiFOBTkFTG63OAeSUUJkiQRUuMpkwah-dcDKQKRZKZvQCnIXp6I-Dy0m_nqjLP0euwN4K9GvQnE3m6gY0nQ_YL3YpQPg.

SIO. The keeling curve. in Scripps Institution of Oceanography [database online]. 2016 [cited 3/25 2016]. Available from https://scripps.ucsd.edu/programs/keelingcurve/.

Skoloff, B. Much of U.S. could see a water shortage. in Truthout [database online]. 2007 [cited 9/9 2015]. Available from http://truth-out.org/archive/component/k2/item/74044:much-of-us-could-see-a-water-shortage.

SNWA. 2015. *Water resource plan 2015, ch. 3: SNWA water resource portfolio.* Southern Nevada Water Authority, .

Suau, C. 2011. FogHive : Fog collection and sustainable architecture in the atacama coast. *Materials Architecture Design Environment (MADE)* 6 : pp. 31-40.

Taherian, Hessam, and William L. Adams Jr. 2013. Coefficient of performance improvement in small thermoelectric refrigerators. *ASHRAE Transactions* 119 (2): QQ1, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V09T8MwELWgEwyIbwpF8oBYUFDSpHE6MEQVqKAOqB8SW-XYDsrQBDXt_-fOcVIHCYmZJYMTRZEvvnv3zn5HiN9_dJ0fPiHxJSrX8QHnEND4QIiAg3mUFygpXO63FYaabbu7sf9g-FGhtCyEKfJ_WScDMs0gaEIQeY5yhXVpRICromqHo_WcU0jYla6-lzZ0jWfjafxcqaFXpyEaOD7neIqwolLH2FNltdsGYLgcw-s8TLQ3elvbbAN2fmCtnRt1GaneU4rVBgS3lWOaNp9oBpD8j7O1MyqwAG8Y5lppsXaDLf_sOQjKWv7Z-NTMypNbutkfr6w9WIVnBqEXwEl4jyLqK5mJzZPKncVsHzL0SOfs8XtTcArMma76A36L0DqKzo_JkckXaFzZ-YTsqfyUHFoqkmdkYlmcFim1LE4ti9Msp9ritG1x2rL4OVm8PM9HY8c0yXA-PUDrjpQRSyFpDWQ4ZO7QDZUSMooAnChPDT3FpJLgd1PsJxf1BSDcEFALSxQPJKT2ff-CdPIiV1eEhoOED9MUQifWXgduwhKRuIEnUhXKvvS75A7nZGnao8KlRAKp_OTbslw2890ll_oxXCibNRf2nV49m0uzYsolhFwGIN1j3vXf3n9DDnZ_Zo90NuutuiUdlB_7BobAbyk.

Tan, F. L., and S. C. Fok. 2013. Experimental testing and evaluation of parameters on the extraction of water from air using thermoelectric coolers. *Journal of Testing and Evaluation* 41 (1): 96-103, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1Bb9MwFLYmdhlCCAZoBSb5wLhMGYlrp_GBQ1QFgVS0Q1I4Ro4dS5VYO3VB2s_nPdtp0m4HzrsmVpvGX9_73vN73yNkyq7i6MAmQJChWmFZI4Q2XAGjkzbNYtO0CXhkm-4rDB31U7eGa09h44uxZn-FIhqhDbHYCXu7wjeFZVmorRnOCy6L-24bJofD_d8K5RNd90m-2l760gIA1fZm40fnrDQYk82fUEH_WDFRUVaYC0MBq-JXvlgO6TCXKvDEeTH4QWeYy_k4EYFDIfYSEU7Hobye7z79Zw6E_Ee-KMf2V4LVl354yVXrTa7kIpoJLxnc22QvhrWHPW9gZTpy1YmTR3joBQRzA66rgmFrcBKLwdn1B_wHPnBXmYgxInBkZFHIBD-jAPuNWenua7uOliX4eqCEWU-7g8fPenHn8OtCHyg8xpfRQ6AYrd7c_r17lOM4N129Ii9DIEJzD6DX5Khdn5LnI3nKN2Q7hhINUKIAJTpAiW4sHaBE4QJAiQ5QwvsOShShRAFK1EGJ7kOJBii9JctvRTX_HoUZHZFKgPVEEgg2MFpt2kbbJpZmyrTNWoYipIJxJaZqxpVttLGZSA3nChU48TBfxtLqmL0jLxT2cqw71_NpzghVTKUsUUKzmeZTMBUNViPDV_A0M8A4J-

TCv8j61iuy1Ky-Y3VcZxh9gxNKk6zu7rsJOTtYh9MWJIeYZUI-jbdgt-Bg-9__37IP5GT4Q3wkxxYMSHtOnqEi2j86nJGX.

The Hutchinson Unabridged Encyclopedia. 2015. *Thermal conductivity*, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE4CdjMRU0zSjJFPT5BSTRGCLzjLNzMIgJSnVEFgjp5mhnTAEu-0KGttYrt0ALeQGlsrQ6zcyUnOA4ZaXkaoPajXlAqMIyAOdlwq-gAFYQAMrXVDPzDiqDpbYgOnY0MTcwBS02cscWGdZAtsVhtAzoGB8I9RzO8ElqpsAQznyWQoVlZgHIGEc6EgdfwgycMJPnxViYErNE2EQgapTQFYnyiDr5hri7KELti8eZDSw1x1vBO5OGBsZizHwJoKWz-eVgLfZpUgwKCQaJZoZGSaaJhuZJ5sYA2MnCbQANDkl1cTMIgVYyUsyiGE3TAqXhDQDF7BtYQoZrZBhYCkpKk2VZWABhREA0xmkow.

U.S Bureau of Reclamation. 2007. *Final environmental impact statement: Colorado river interim guidelines for lower basin shortages and coordinated operations for lake powell and lake mead.* http://www.usbr.gov/lc/region/programs/strategies/FEIS/Chp4.pdf: .

Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Bain Project Act of September 30, 1968 (P.L.. 90-537), (1970): .

U.S. Census Bureau. Nevada: Quick facts. in U.S. Census Bureau [database online]. 2016 [cited 04/1 2016]. Available from http://www.census.gov/quickfacts/table/PST045215/32.

UNESCO. 2014. UNESCO world water assessment program. *African Journal of Food, Agriculture, Nutrition and Development* 14 (6): 12, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1NT4MwGH6jnLwYv51f6UUvBrPRMsrBA5kjehmHbfG4FNrqEsWEsP8vLV0pJvsDciwplPdp3o_m4XkBcPA09P_4hLwoxoIRHsYUD5lqjyNHMsZCUhFgqXtPOApDtg1pN_YfgF_OpvNJZlgy70yJICZWflP9GKD4WG5O2rYKKh-d3DQ1RJzkozLaHPrcc7aV7jcEZss3cs8ORsSy0AzpSCt7ZBvFaS8-eytoveGYEj_Erba6dZfE2Rau7zN06J6k9VuW9gd15Gxquqi5mglK3_ybr4v6WZT-cr7fFM802hbGbTwlYahFwOxiTPB00oDFERwaG6Gktfsx7InyBAYva1GjB2REVr-QNdQp3Ld4II0H0nigDg9krHEGd-l0MXn11TtXCvy6YsXKfgI-B6_8KcUloDCPMM8ZDWImSU5jJnIe00CGvCkyA8wHcLHjIVc771zDQQfcDXh1tRG34CmtrV8QKxLJ.

———. 2014. *Water and energy: Facts and figures.* UNESCO, .

Urity, Vinoo B., Tadeh Issaian, Eldon J. Braun, William H. Dantzler, and Thomas L. Pannabecker. 2012. Architecture of kangaroo rat inner medulla: Segmentation of descending thin limb of henle's loop. *American Journal of Physiology.Regulatory, Integrative and Comparative Physiology* 302 (6): R720, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V1Lj9MwELaWnrggYHkuSD7BoUqVxInjIHFoEYgjYrdcy_iRKqJxqqZ7gF_P2HEerLR_gGucHOz5NJlvxjMfISxdxdEdn6ClynnBOZSKCw5Ca16ypDIFNyUwVfw7YehiUB-bnv0Phl_PSwMYCv4CuweMj5do66VX2nIFdWSeXpWnM_smtB_5wFH78U66b6Kq7fJQN9In-411F4-Lbnlo2-M8pB1rPrMhFD5f4hP2KzSgV7tv-3r9MJ7CXVgKLXXj9PHpqwEG21MQLfhRW9zBZgJyB3UQVgZtxpT25gS3fUL poHE_Yw4csX3-

E3oeQ4YpdGWEhIe7OcKivuVzZYKTRgKNzC6ee3EWpzO4zn3y98K3200_i2OD5nZxUZH3Onx3Jm6PS27_ja7V-aOx0fb6AVJ74cn-5nrqvWWZ02IavrmfqPj_8c1j8igwDbruEfKEXBj7lFyuLZqi-U3f0W_jaV-Sn3PQ0LaiA2gomoZ60NAAmg90Dhn37gQZ6iBDHWTccw-Z9x11gHlGtl8-33z6GgXtjWjvB1PkqkwBMvQzotJ5AnEOXElXBJexYZBJhjwakG9igC1BVaVKJFlJmbmcB6Qxe04WtrXmJaEgCqFTpoThVaaTUkjNEyikTrkyOhOvyNVwZLuA1G6HUbu7gcxw9UV_irtjP35lNxz163tXrsjDCThvyOJ8ujVvycINKPsLRud74A.

US DOI. Warren H. brock storage reservoir. in U.S. Department of the Interior, Bureau of Reclamation [database online]. 2014Available from http://www.usbr.gov/lc/yuma/facilities/Brock/yao_brock.html.

USGS. Specific heat capacity of water. in U.S. Geological Survey [database online]. 2015 [cited 3/25 2016]. Available from http://water.usgs.gov/edu/heat-capacity.html.

Vazquez, A., J. Arias, and R. M. Sanchez. 2006. Calcite and hematite minerals: A promising application as dew water collectors. *European Journal of Physics* 27 (3): 667-73, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwjV1LS8QwEB5UEATx_agPCKJepNqkSdt4E1E8edJzyKsg6O5iV_TnO0m767orsrcEhjRNpplvOjNfAHJ2maVTZwIVpRGOFs5yWqPV98JQYSy3CKhrSc0Uw9DoZrmX_qAzBJfYjIH9wEeXIswpr9Bpz7Ebi_fQqsbarcdxBAEtV8vr3Yl3BTP4Uf0xxC-jtIiPCsShtj_4aP62R3k4S-_XYVQoPko6maFCmqF2nOuNNmCtg6PkptWfTVjwvS1YjmmhttmGx1v9ahGUEt1zpKV3xc7bS6Sqbq6JJgj1BS0f2QiFE50Q5z_JJ8IZN9JULUYG2h24Pn-7un2Ie1uYEgtLSqZmooKW3lbahmo6wyvfS090zLnWYXIsaBGGBc476S0hfBCO2-ZYMZYpxmin11Y1SFTvzeMFX1uH4iXGXrz3JW8dpyhu-JZ7WhVlo6ha5mZBC5Ge6EGLeOGipHyqlJhqVRYKsVKhS0qEzjBdRwLzgqogasTOJ8U-m-0s3bbx7JMNUxlKs8LXqA3z2Whhl_DBPam5HheoJWXIoHTSX35mVgLjhAMRFR9MO-MDmGl_ekTUiyPYGn4_uGPYSko2DcDtvi4.

WEF. 2015. *Global risks 2015.* Geneva, Switzerland: World Economic Forum, .

Wetterau, Greg, Inc ebrary, and American Water Works Association. 2011. *Desalination of seawater*. 1st ed. Vol. M61American Water Works Association, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwY2AwNtIz0EUrE1INzM3Nk5MsjUG3FVokgqo1M2PjZLMUkyQjYzOzFOqfMAQ6Sd3S3JiZgdnMAnSmvhPoZnQWkAk8iOLQTZCBNRW0qUCIgSk1T5iBG-kQQBEGCWDXLxG0LRYURAr5aQpA48uBLcAiUQZZN9cQZw9dkHHx0HGWeJiVFcZiDCzAvnuqBINCqmGSqWGihalFshHoHJgkYO1rngjMZYbmKQZJJhapkgxi2M2QwiUhzcAFGdYEIRkGlpKi0lRZiMcAhOZoqA.

White, Beatrice, Anjishnu Sarkar, and Anne-Marie Kietzig. 2013. Fog-harvesting inspired by the stenocara beetle - an analysis of drop collection and removal from biomimetic samples with wetting contrast. *Applied Surface Science* 284 : 826-36, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwlV1LT9wwELYQ4tCqKn2zLUhzaI9BsZ2HfaTQVe_A2XLsMaUSWZQE0d565txf2F9Sj7NZLS-pPUZORok9Hs9k5vuGMSn28-yOTchDaniPOdbch0aHukRPDVKU8IVMvNrrDEP7jyT0U2GWjeFjT-

yDXCb2TU5Y8qIQtC3nR59XOYQYC8iR2VsTLkhMwLlHhNw6mJbmeYugIVf9w4dSsszzbTaVZE-
VJ_f4kO7xO_7jZ71gz5deKRyMavSSbWD7ij1d4yp8zW7mi7Psm-
0SLUd7Buct5ejRQ_MTohMJx9H5judiZ6FBjAr459fvgxbskvMEFgF8t7gE0rtU_UVjHjq8WERdB0K5AFEBnF8Q
qhJ6S6zFPdBvYrjGVJwNqaze9sMbdjr_cnL4NVs2cshcdAeqDEvrJRdBKO98jrYppYuWJjhecK-
9DmXDvQtS1aGyIXdaFbrOnfSVsAodyrfsmaWC_3ZIwEC_w6BohEDprfROF65WuiwDYtAOnYiPVTOWTctpLkf
iDjNVtH0342QbmmxDbTh5PWPvaM0N7ev4Lc7IooxCuRAz9mlUg5UcYXphcqOi8ZOqkhRDDT-
GKOHOfSXRL_I6n7GP6_qzGqeAlOA5qkr5sPf_-cof2BO6GpGRu2xz6K5wj22S3v0FjfoM8w.

WRCC. Comparative climate data tables. in Wesern Regional Climate Center [database online]. 2016 [cited 3/25 2016]. Available from http://www.wrcc.dri.edu/climatedata/tables/.

Yangali-Quintanilla, Victor, Lars Olesen, Jesper Lorenzen, Christian Rasmussen, Henrik Laursen, Ebbe Vestergaard, and Kristian Keiding. 2015. Lowering desalination costs by alternative desalination and water reuse scenarios. *Desalination and Water Treatment* 55 (9): 2437-45,
http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V09T8MwELWgEwyIT1EokncUSGo3Tg
YGPoVEF0QRY-QkttShKWoaIfj13NlOm7RISIysSc6tLi_2u7PvHSGsf-
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foRxvn_ztEjnAfPFXsLmDIP783WhZuRf_vR7LSLUksldowVm6R7tkh0XpNBrC649sqGKfbLdkK48IM81zGgTRN
TAjKaftAGz9hMAGmpgRg3M6AJmh-T14X50--i59hxe1vdj4QV9XyJf5CrVkodhpATLgX37gzQKpNQQijMtQ1-
kAquvmZ_LcMBEnqoAODww3SPSKaaFOiaUM6YGOk4ZyzTPeZQGoY6wb5qWMUT4WZd4ta-
Sd6vCkgRO3Lb2bYK-
Taxvu0Q0HZrMDdi0xdkvlr3a94n7qMFAQFQDXFiIkz8PfEq2ll9Bj3Tms0qdkQ6Kpn0Db2igIQ.

Zhai, Lei, Michael C. Berg, Fevzi Ç. Cebeci, Yushan Kim, John M. Milwid, Michael F. Rubner, and Robert E. Cohen. 2006. Patterned superhydrophobic surfaces: Toward a synthetic mimic of the namib desert beetle. *Nano Letters* 6 (6): 1213-7,
http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMwjV3NTtwwEB4h1ANVRQuINBQkq9DjQv
wT2-ltWYG4UCEtXLhEju2IldifhqwEb8Oz8GSMk91luxS0l8ixHUvO2OP57PE3AJwdxq0FncAcIg1T6KQ--
MsRkdEcoUVsaeJ9Ku0Cw9D-Gwf6jB4NbmO0uYX4Gy6sJzx48bU73ReeXV4HZcV5jKgo1WJKJjT_5T9L0Gzd-
RCugYzv_rsA1Tr29DNMo3BNnUxeUR-9onJ8rwdfYH1idZJ2M0w2YMUPNuHjHBfhV7i-
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XE4SzvqzIsfc4Frfg6vTksnPWmgReaFlKpWwp45QMkRKU154XXqTOGZsY6RVOWJyxhdHKxIKqHAFY7pUqjOJ
OSysd1S7m3-CTCQ76g6q-yOe-
A0msTphNU694giaaSVUhhU4ZM5Y7TEXwcyqUbNQQbWT1ATmj2eyPRbDdiOulilSKJppF8KuR36yEZXcsizP
OlUCtxNGSzKr7CltYqCdEUEo6jeBgXvCz8poSCHG05iElI6DLVOtMGNYDs0C1s0zffsBas70Tdnh2YbUqx34PVs
PQegY9H_ii.

Zhou, Yuan, and Richard S. J. Tol. 2005. Evaluating the costs of desalination and water transport. *Water Resources Research* 41 (3): W03003,n/a, http://unlv.summon.serialssolutions.com/2.0.0/link/0/eLvHCXMw3V07T8MwELagCyyIp1oekhemKqGJ8_LAgFABMdJWlVgqO3YoEiQVSYRY-O2cEztJi_gDbFGcWIn96fOd7-4zQsS1R9YGJwgRsJhysB_COACQxAAlhytrNgbfrDqaoKMw1OgrtPf-w8SPtX63LoOKs7xO1xAyZ6r6tjAJyJ9MCSQWRt28a6bOqyaztZ83-XkNR5RAC8_LrGziNXX51nBiDx_t4TR7W9tN8Kt0qtb3bMJE9zJbGaCA9ashoklUqZqSOq3WljVvUs-zQlqfSmKItVa00gAiHZacA7NUyga_CXzkKv1TNYPzp0obh7YLlQnOb6xfTVbh2ltKOf1dvMbFtUyt2WQb3PJIOeffyuXWUSYwHkOTgaB-SBdGwDdcdftShstL2TFcOhbIdB_tadcB39RTfoC2ZHqIdkxleQ7X-kT75dcRiloYYIABrmCAswR3YYABBriCAW5gcIxmd-Pp7YOlT8mwmOOFrsXBqfSpcGni-ySgIiHSpaOEcBFQlyeEeY7wwogLSaMEpiniDiMJd6ifeMINODlBvTRLZR9hj0UhC1gopdKN9JU2lYxZKDh0FHAmB6gPA7FY1Tooi-4YDdClGZ2mvcpvcOnac6d_d3GGdltEnqNe8VHKC9RTsmI_0z5VZw.

Zibold, F. I. 1905. The role of underground dew in water supply of feodosia. *Trudy Opytnyh Lesnitchestv* 3 .

CURRICULUM VITAE

Adam J. Bradshaw

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Areas of Interest

- building science and technology
- energy performance and modeling
- natural ventilation for tall buildings
- innovative water conservation measures in the built environment

Education

University of California, San Diego
B.S., General Biology 2008

University of Nevada, Las Vegas
M.Arch, Architecture, May 2016

Employment and Experience

Spring 2016 – Present	Steelman Partners. Las Vegas, Nevada Project Coordinator
08/2015 – 04/2016	Assemblage Studio. Las Vegas, Nevada. Graduate Assistant, Structures 1 and Structures 2
Fall 2014 – Present	University of Nevada, Las Vegas. Graduate College, College of Fine Arts Graduate Assistant, Structures 1 and Structures 2

Scholarly and Professional Memberships

U.S. Green Building Council, Nevada

AIAS

Tau Sigma Delta, Architectural Honors Society