Successful Cost-Effective Green Implementations

Ramiro Olivarez III

Abstract

Concerns of rising temperatures are growing due to climate change, pushing us to find alternative strategies to mitigate it. This paper focuses on cost-effective green implementation design strategies to combat rising temperatures for homeowners who cannot afford the newest technologies. With increasing temperatures, this paper aims to answer which strategies will best optimize comfort levels to avoid a crisis event where temperatures are unbearable and air conditioning and heating units or the power stops working, making the home indoor climate uncomfortable and unsafe. Our current residential building stock accounts for 21% of energy consumption, and a majority of that energy is to create indoor comfort conditions . This study uses Tucson, Arizona, climate data gathered as a case study. Data collected included sample population habits of making their indoor home climate comfortable, climate data and design strategies gathered by Climate Consultant, a computer software, and an interview. The data was used to find the most successful, cost-effective green design implementations. This paper will assert financially friendly green design implementations, such as cost-effective overhangs or trees to maximize shading in the summer but allow sunlight in the winter, weatherstrips, and double-pane windows for those with financial constraints to help them avoid rising temperatures with no working mechanical systems.

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Introduction

In Southern Arizona, a reasonable assumption we can infer is our average current home building stock is not prepared to protect occupants if our power, air conditioning, and heating units stop working. When power and our mechanical systems stop providing comfortable conditions, the average homeowner may not have alternative solutions to keep them comfortable. Not to mention our homes coupled with commercial and office buildings lend to immense gas emissions, which is “a catastrophic effect on global climate” (Crichton et al., 2006). Moreover, new green building constructions are suspected to be a solution; however, they are “...inadequate to overcome the negative impact of existing buildings” (Jagarajan et al., 2017). Research shows that new green implementations do work in mitigating climate change. However, evidence and knowledge lack the determination to sway owners to want to green retrofit their buildings. Limited studies have found “success factors of implementing green retrofitting in existing buildings” (Jagarajan et al., 2017). This research will assert cost-effective green implementations that are practical for the average homeowner to obtain and protect them from events of no electricity or mechanical systems that provide indoor human thermal comfort. Research has found, “The state’s [Arizona] average temperature is projected to increase by more than 10 degrees Fahrenheit by 2090” (“Could Arizona Be Unlivable by 2050?,” 2018). Summers in Tucson, AZ, is already unbelievably hot. Research conducted in 2020 found an “…average high temperature was 104.0° and ranked as the 4th hottest July ever” for Tucson, AZ (Diggs, 2020). If the projected temperature upswing continues as projected, not to mention the already unbearable temperatures for some, it is now paramount to seek answers to rising temperatures and problematic mechanical systems used to combat higher temperatures.

Moreover, increased energy-consumption is used to combat rising temperatures. Energy consumption is overly used to create indoor human thermal comfort. Studies show that “sustainable retrofit decisions are commonly based on maximizing energy savings to recover initial upfront costs within an acceptable period of time” (Menassa & Baer, 2014). The challenge of green retrofitting homes from a stakeholder's perspective is based on the “decision often made based purely on short-term economic grounds” (Menassa & Baer, 2014). Due mainly to economic reasons, “consequences for energy demand and for CO2 emissions will be disastrous” (Hirst, 2013). According to Chidiac (2011), through green retrofitted buildings, energy consumption can be reduced through energy retrofit measures by changing tangible objects. Green retrofitting “…is a process that reaps the benefits of the embodied energy and quality of the original building in a sustainable manner” (Bullen & Love, 2011). Green retrofitted buildings have proven to reduce energy consumption, reducing costs, improving health while simultaneously reducing greenhouse gas emissions combating climate change. Benefits of green retrofits have been identified; however, it is important to find which ones are financially friendly.

This study will not explore new green technologies because they may be impractical to obtain and be financially expensive for average homeowners. Instead, this study is searching for practical, cost-effective green implementation designs the average homeowner can achieve. One article found, “The greenest building is the one that already exists” (Adam, 2019). With this initial premise, finding tangible, financially friendly green implementations to the average home can be achieved. Additionally, it will benefit those with financial limitations by retrofitting their homes and perhaps making their home more survivable during the event of no cooling or heating units during the summer or winter months. The idea that newer is better than old is false in this sense, which makes green retrofitting an interesting topic. By finding cost-effective green implementations for average homeowners, they can save money in the long-term and protect themselves in a catastrophic crisis while indirectly mitigating climate change.

Research Question/Objectives

Due to the pressing matter of rising temperatures brought about by climate change, it is imperative to find optimization strategies to reduce gas emissions. Moreover, finding sustainable alternatives that allow homes to remain at comfortable indoor temperatures during the summer and winter months is just as important. Therefore, to encourage homeowners to use green implementation techniques within their current structures is necessary. To convince owners of green retrofit implementations, we must answer:

-What will happen to the residents if power is unavailable for a given amount of time?
-What would happen to home occupiers in the summer/winter months if the power, A.C. unit, or heating units stopped working?
-Would they have an alternative living situation in the event of no cooling/heating?
-Would they be able to remain thermally comfortable in uncomfortable temperatures?
-What are the successful green implementation strategies to use in our current home building stock to avoid such situations?
-Finally, what are cost-effective optimizations for an average homeowner to use?

Many people do not have an answer to the above questions. Nor do their finances allow them to move into a new sustainable house. Alternatives are needed to save those "stuck" in situations where their homes may prove unsafe.

Literature Review

Climate change is an impending crisis that will bring adverse effects to all living inhabitants of planet Earth. Our current building stock is both the problem and a solution to climate change. Crichton, Nicol, and Nicol (2006) list a few questions that can be answered with our approach to buildings:

1.) Will my home get so hot this summer that I won't be able to stay in it?
2.) How long could I survive in this building without air conditioning?
3.) Will we survive?

The overall theme of the questions can be formed into, can we make our building better? Climate change and our building stock go together. Crinchton et al. (2006) suggest that our buildings need to be reexamined. Many contribute to climate change; however, the leading contributor is our current building stock. According to the U.S. Energy Information Administration, our current commercial and residential buildings account for 39% combined of energy consumption in 2019. The residential sector accounted for 21% of energy consumption (*Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA)*, n.d.). Building designs need to be redesigned and green retrofitted to combat this crisis. Jagarajan, Asmoni, Mohammed, Jaafar, Mei, and Baba (2017) sees massive obtainable building retrofitting's as an effective strategy in enhancing sustainability. Furthermore, sustainable retrofits bring benefits to the three pillars of sustainability; economic, environmental, and social. Jagarajan et al. (2017) note that a problem arises with “green retrofitting is not winning its place at the forefront, even with the growing concerns of stakeholders over environmental, social and economic aspects.”

Hirst (2013) further identifies the Primary source of climate change. Hurst (2013) argues that “Achieving the necessary level of carbon reduction within the buildings sector is a monumental global challenge.” Mitigation of our gas emissions will enable us to combat climate change. Hirst (2013) notes that climate is a challenge that will not be easy to undertake, but the building sector is the solution. Through further analysis, “Several studies suggest green construction can result in significant economic savings by improving employee productivity, increasing benefits from improvements in health and safety, and providing savings from energy, maintenance, and operational costs” (Ries et al., 2006). Green construction on current buildings shows that economic benefits can be seen. All prior problems are seen all over the globe.

For example, Australia is trying to attain carbon neutrality by the year 2020. Again we see “The problems faced by policymakers to determine which buildings have the optimum adaptation potential are to be identified…” and will help them reach their goal (Wilkinson et al., 2009). Wilkinson, James, and Reed (2009) see the existing office building stock in Melbourne, Australia, as the solution. Green implementation solutions are simple in theory but convincing the policy and stakeholders is the real problem. These concerns can be overcome by presenting success factor solutions to the stakeholders. Menassa and Baer (2014) also notice stakeholders’ concerns with benefits associated with green retrofit implementations within current buildings. Menassa and Baer (2014) state, “most studies did not take into account the important role that different stakeholders can play in determining the type and extent of any retrofit measures, or develop methodologies that integrate social, environmental, economic, and technical concerns.”

Many stakeholders have competing objectives. Mohamed and Alauddin (2016) have identified owners and practitioners as the main culprit to avoiding green implementations. Owners simply lack the knowledge needed regarding green implementations. The authors have identified that stakeholders are the critical component of making green implementations a reality. The solution is to make the green implementations a benefit to the stakeholders. However, five main criteria have been identified to give that knowledge. Expanding stakeholder’s knowledge of “economic, environment, social, legislative and architecture” will influence the decision making (Mohamed & Alauddin, 2016). For example, according to a review on green roofs, many buildings can benefit from green implementations. Similar to Australia and the United States, the U.K. does have a problem with their current building stock. A case for green retrofitting can be made to the stakeholders’ who “The case for retrofitting existing buildings is therefore reviewed and it is found there is strong potential for green roof retrofit in the U.K.” (Castleton et al., 2010).

Creating a sustainable energy performance can be achieved through our buildings. Studies have found “…green buildings has been transformed to a sensible and practical resolution to alleviate the CO2 emissions and diminish the building sector energy consumption” (Ghaffarian Hoseini et al., 2013). GhaffarianHoseini, Dahlan, Berardi, GhaffarianHoseini, Makaremi, and GhaffarianHoseini (2013) found, “…research findings are recommended to be taken into consideration by architects, engineers and developers for the development…” further demonstrating that stakeholders are the main reason as to if green implementations are made. Menassa and Baer (2014) conclude that the best way to bring sustainable green implementations is to show stakeholders the success factors, i.e., reduce costs, save energy, and following the correct policies. Making green implementations a reality in building retrofits will be done by showing stakeholders' success factors in buildings from documented data. Green retrofitting a building "…is a process that reaps the benefits of the embodied energy and quality of the original building in a sustainable manner" (Bullen & Love, 2011). Here we found that different geographical locations have similarities in that owners are not submitting to sustainable alternatives to combat climate change. The best way to combat it is through green retrofitting our current buildings. However, to achieve this, we need to convince the stakeholders who ultimately decide whether to retrofit a building. This decision can be achieved by showing them positive benefits that ensure their comfortability and possible financial savings.

Research Design & Methods

Study Area

The study area analyzed the hot and arid climate of Southeastern Arizona homes, particularly in Tucson, AZ. Due to the increasing temperatures felt across the world and especially in hot and arid climates, Tucson is seen as an ideal case study. Further cementing Tucson as an area of study is data showing an increase by more than 10 degrees Fahrenheit by 2090, adding to current uncomfortable conditions ("Could Arizona Be Unlivable by 2050?," 2018). Four (4) data measures were conducted over the course of this analysis:

- **Measure 1** identified homeowner survey responses to various home questions. Notably, this survey sought to find homeowners dwelling factors and the occupant's responses to having a plan if they do not have tools to provide indoor human thermal comfort. Finally, it sought to find their knowledge in the subject of green retrofitting their home and willingness to apply green retrofits. Questions this measure asked can be found in Appendix A. One study found that a homeowner does not have alternative plans because they "decided that he would rather do nothing than pay prices that he thought were unfair, particularly when there was uncertainty about how effective some of the recommended measures may be" (Wolfe & Hendrick, 2012). Analyzing the survey, coupled with Wolfe & Hendricks (2012) findings, helps infer design strategies gathered in measure 2.
- **Measure 2** identified and analyzed climate data for Tucson, AZ, through Climate Consultant (2020). Climate Consultant (2020) is a computer software database containing various climate data points for a geographical location. Furthermore, it recommends specific green design strategies pertinent to the location requested. Results gathered showed the current climate data and green design strategies that can be applied to homes to provide indoor human thermal comfort.
- **Measure 3** interviewed Omar Youssef, Ph.D., to seek green design solutions to answer the research questions. Furthermore, the interview sought to find whether design solutions coincided with Climate Consultant. Based on the research questions, interview questions sought to identify if successful cost-effective implementations exist and are practical. Moreover, the questions were developed to identify whether research an average homeowner conducts on their own is practical. A list of interview questions can be found in Appendix B.
- **Measure 4** concluded the research by finding tools and green design implementations that are financially friendly to homeowners so they can apply them to their homes and avoid crisis-like events with no power to supply comfortable temperatures in the summer and winter months.

Discussion and Results

Survey

This study electronically sent a survey to a random sample homeowner population. However, due to limitations and Covid-19 restrictions, only twenty-three (23) random homeowners responded to the survey. Through these small sample responses, it is determined that a majority of their homes in Southern Arizona are at most fifty (50) years old or newer. Similarly, Phoenix, AZ, which is 114.3 miles northwest of Tucson and in a hot and arid climate, sees most homes were built after 1970, further corresponding with the survey (*Phoenix Arizona Housing Market Data Real Estate Research*, n.d.). Their homes, however, are not sustainable nor properly adequate to supply indoor human thermal comfort if their power stops working in the summer or winter months. Consequently, such an occurrence might prove a crisis for some homeowners.

According to the survey conducted, 62.50% or 15 survey participants answered no to having an alternative living situation if their air conditioning or heating unit quit working, illustrated by Figure 1, below.

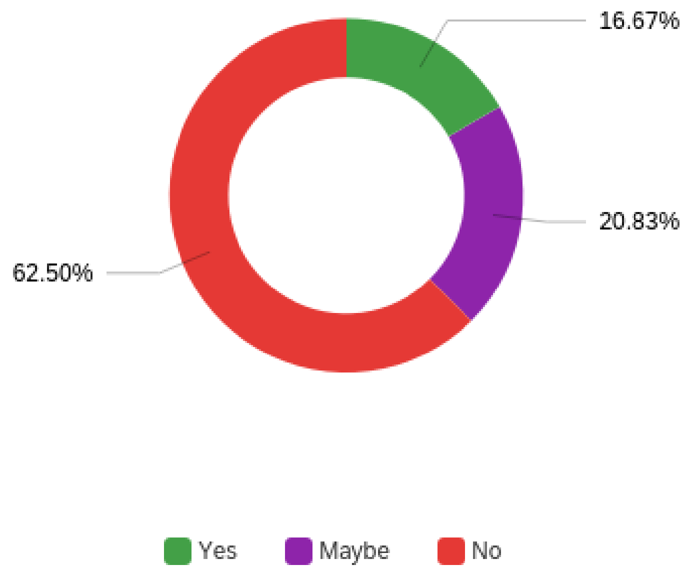

Figure 1 – 62.50% of participants answered no to having alternative living plans with no ac or heating units available

This survey further found that only two (2) dwelling households have received any sustainable enhancements. Of those same participants, 75%, illustrated by Figure 2 below, worryingly had no answer to “If your air conditioning unit or heating unit stopped working, would your residence still be comfortable to reside in, particularly during the summer or winter months?” Not shockingly, 91.67% of the participants answered yes to using their A.C. unit a lot in the summer, and 50% use their heating unit in the winter.

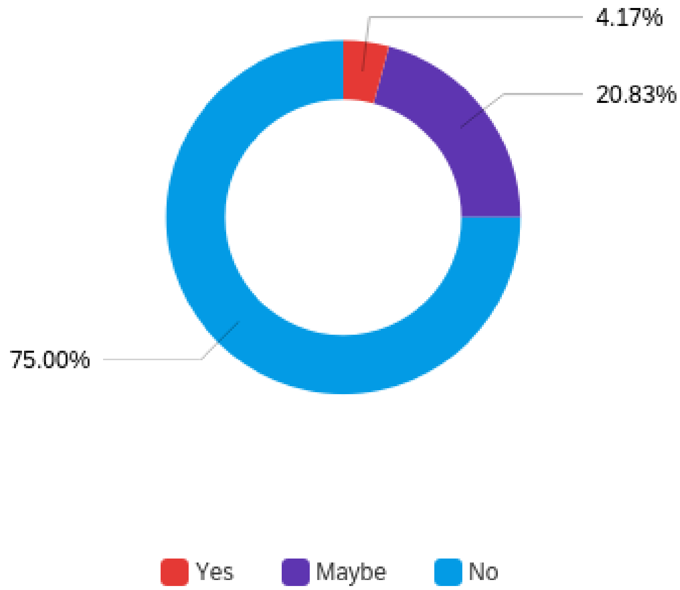

Figure 2 – 75% of participants answered no to living in a comfortable residence with no A.C. or heating unit

Likewise, every participant paid either an average or very costly amount on their monthly bills. Interestingly, four (4) participants have an alternative plan to remain thermally comfortable within their dwelling household without the need for an air conditioning or heating unit. More hopeful is the sample population had a combined 79.17% alternative area of residence to stay in if their homes reached a point where it cannot keep them thermally comfortable, illustrated by Figure 3 below. This survey is designed to make the participants think about situations of having no ac or heater during the summer or winter months.

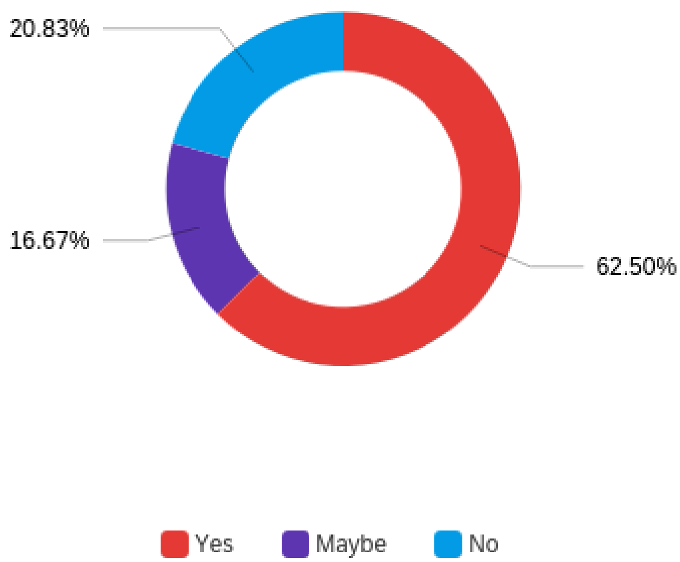

Figure 3 – Yes and maybe participants have a combined 79.17% alternative area to stay in if their homes were too uncomfortable to reside in

The second half of the survey strategically asks participants questions about adding sustainable design improvements to their dwelling units. In no surprise, sample participants all answered "Yes" with one (1) "Maybe" to make their home's energy-efficient now or in the future. During my interview, Dr. Omar mentioned that ordinary people often think of green retrofits, based on no fault of their own, as solar panel additions. However, this survey asked participants whether they would add green retrofits such as trees for shading, wall insulation, energy-efficient windows, or other improvements. Every participant answered with either a "Yes" or "Maybe." This survey found that most participants are aware that green retrofits provide financial, health, and sustainable benefits.

Moreover, some are aware of financial incentives to reduce energy consumption. Every participant from this sample needs an option or green implementations to avoid the disastrous event of no working mechanical systems to supply indoor human thermal comfort. To find these implementations, this study determined it is paramount to find successful green implementations to avoid the situational crisis questions.

Climate Consultant

Finding successful green implementations begins with a thorough understanding of enhancements recommended by a climate consulting program known as Climate Consultant developed by Liggett and Milne (2020). Climate Consultant (2020) is a free application for users whose objective is to:

> Show you a variety of graphic representations of hourly climate data for your chosen location, and to help you see visually the unique overall patterns and subtle details that characterize each different climate that would otherwise be lost in tables of numbers.

> Climate Consultant seeks to translate outdoor conditions to indoor comfort, [and] makes generalized assumptions about building design (Liggett & Milne, 2020).

Designs suggested by Climate Consultant (2020) are based on The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard 55. ASHRAE Standard 55 makes its suggestions for thermal comfort:

> Based on dry bulb temperature, clothing level (clo), metabolic activity (met), air velocity, humidity, and mean radiant temperature. Indoors it is assumed that mean radiant temperature is close to dry bulb temperature. The zone is which most people are comfortable is calculated using the PMV (Predicted Mean Vote) model. In residential settings, people adapt clothing to match the season and feel comfortable in higher air velocities and so have wider comfort range than in buildings with centralized HVAC systems (Liggett & Milne, 2020).

Calculating based on the above information, Climate Consultant (2020) provides average climate data gathered over the previous years. Climate Consultant (2020) for this study will utilize climate datum from Tucson Intl AP 722740 (TMY3) and be analyzed through a psychrometric chart.

Psychrometric Chart

Psychrometric charts are a graphical representation of the thermodynamic properties of moist air. Notably, these charts are useful in understanding the relationships between thermal conditions of the environment. For this study, the chart will tell the climate temperature and layout of what should be done to provide optimized indoor human thermal comfort enhancements.

Psychrometric charts require only a minimum of two-axis points to label a climate point on the chart. Having two-line points intersecting will give the information to determine the element's different points. Every point on the chart represents the properties of air at a particular temperature and moisture level. Below, Figure 4 illustrates a psychrometric chart. This chart's goal is to have temperature points in the comfortable zone highlighted by the blue box in Figure 4. For example, suppose a temperature point lies to the right in the green section of the comfort zone. In that case, that suggests a design strategy of fan-forced ventilation cooling should be considered to move conditions left into the comfort zone. The next section will show the varying temperature plots that are not located in the chart's comfortable zone for Tucson, AZ. For this study, it is important to identify design strategies to make the temperature within the comfort zone. Moreover, it is important to find low budget solutions for those that have financial constraints.

Psychrometric Chart – Summer Months

With this basic understanding, this study will first analyze the psychrometric chart for the month's May through September. These months are chosen to be analyzed because Tucson is located in a hot and arid environment and hotter throughout a typical year in general. Examining the chart for these months identifies many different temperature indices.

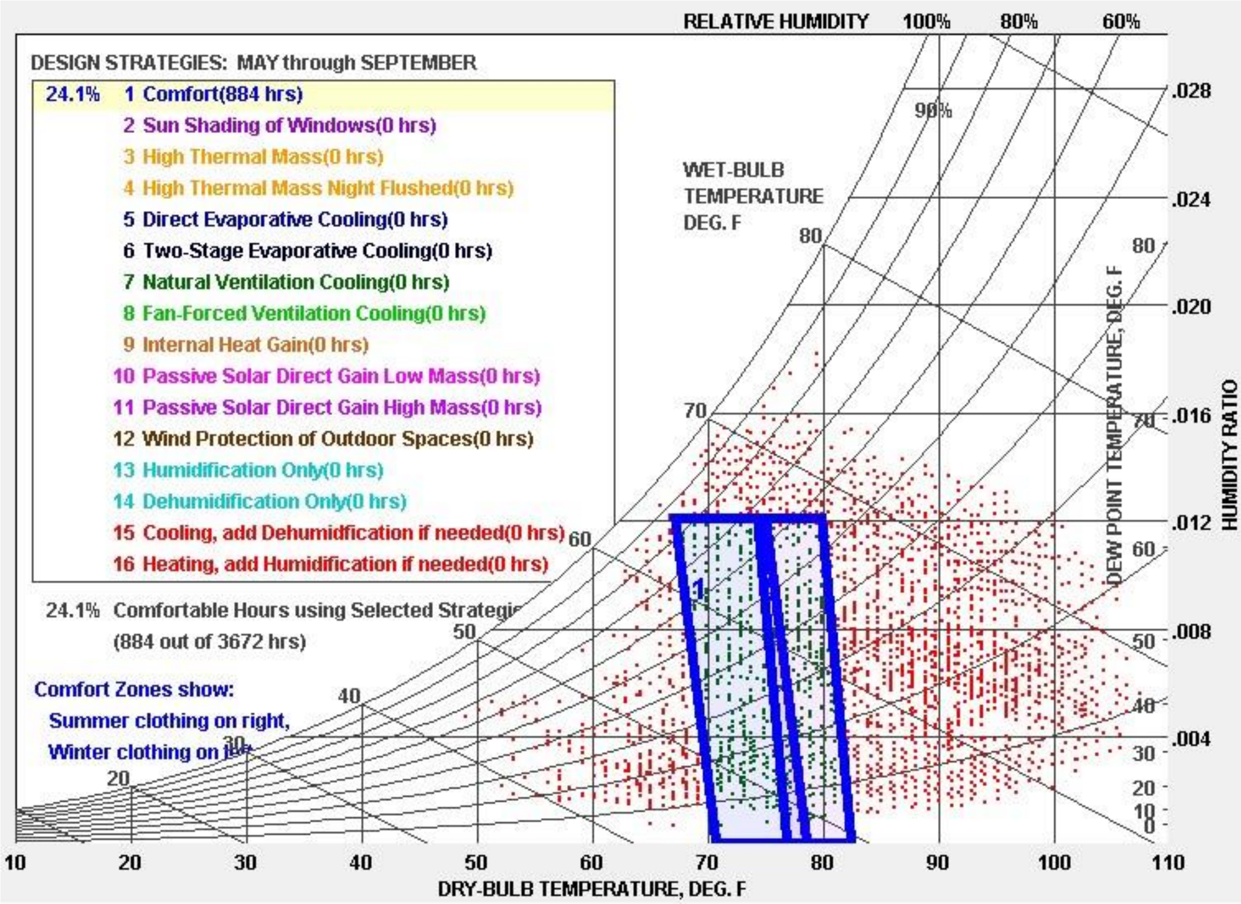

Figure 4 – Hot Tucson Months (May through September)

According to the psychrometric chart in Figure 4, only 884 hours or 24.1% of the time, the indoor climate is comfortable enough for an average homeowner not to require any resources to supply indoor human thermal comfort. During these five (5) months analyzed, 884 hours of human thermal comfort roughly converts to only 36 days of comfort. Consequently, these calculations determine that about four (4) months of this time are uncomfortable living in a household. Climate Consultant (2020) illustrates in Figure 5 that only 24% of the time, an indoor climate is comfortable in this time range, while 76% it is not.

Figure 5 – Summer indoor comfort condition percentages

Climate Consultant's best design strategies (2020) are identified for optimized indoor human thermal comfort to maximize comfortability. In Figure 6 below, the psychrometric chart illustrates optimized design strategies.

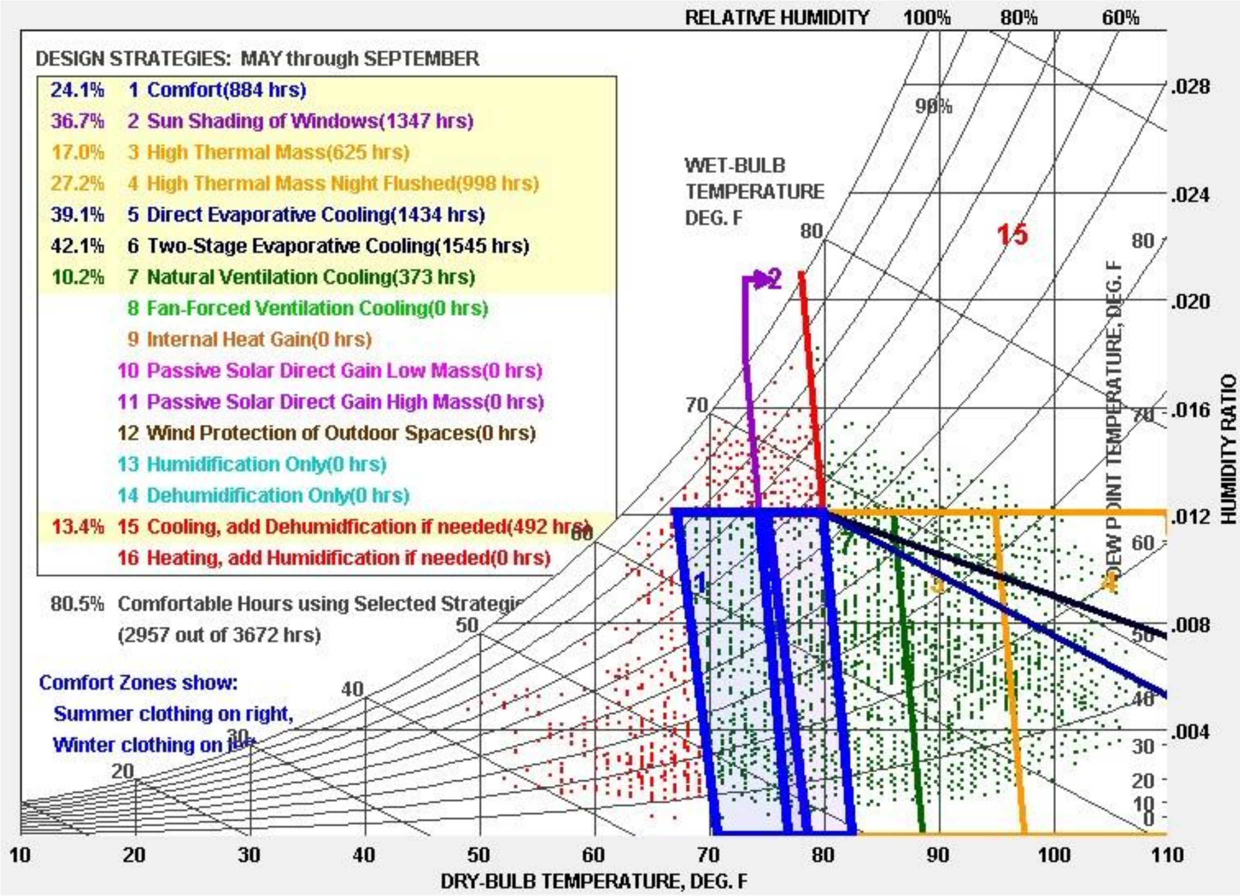

Figure 6 – Summer months with optimized strategies included

Applying and analyzing these strategies in Table 1 below will optimize indoor human thermal comfort. The table's left column illustrates the design strategies. The second column demonstrates the hours required from each strategy to optimize the indoor comfort levels. Likewise, the third column demonstrates the percentage needed for each strategy for maximized indoor comfort levels.

First, applying "Sun Shading of Windows" for a total of 1,347 hours will maximize shade and reduce solar heat gain. Maximizing shade will lower sunlight entering the dwelling structure, reducing external heat gains. Shades can be maximized through various objects placed in front of a window. Climate Consultant (2020) recommends a couple of prominent implementations. First, planting and growing trees, if not already in place, can provide adequate shading. However, "Trees (neither conifer or deciduous) should not be planted in front of passive solar windows, but are OK beyond 45 degrees from each corner" (Liggett & Milne, 2020). To reduce watering, encourage good growth, and have minimum maintenance, we should use native trees, or mesquite trees in Tucson's situation. It is important to note that trees are not an immediate payback due to time required for tree growth. Trees are considered more of a medium to long-term payback optimization. Secondly, installing overhangs will provide adequate summer shading. To mitigate solar heat gains, shading is a top priority; however, other design strategies will also enhance indoor human thermal comfort.

Table 1 Summer Design Strategies

May through September Strategies	Hours	Percentage
Comfort	884	24.1
Sun Shading of Windows	1347	36.7
High Thermal Mass	625	17.0
High Thermal Mass Night Flushed	998	27.2
Direct Evaporative Cooling	1434	39.1
Two-Stage Evaporative Cooling	1545	42.1
Natural Ventilation Cooling	373	10.2
Cooling, add Dehumidification if needed	503	13.7

Climate Consultant (2020) supplies a myriad of design strategies to enhance indoor human thermal comfort. Climate Consultant (2020) states that maximizing high thermal mass material (tile, slate, brick, adobe, or stone) for a combined 1,623 hours will "…feel naturally cool on hot days and can reduce day-to-night temperature swings." Utilizing "Direct Evaporative Cooling" and "Two-Stage Evaporative Cooling" for a total of 2,979 hours with an evaporative cooler can provide a cooling capacity, assuming water is available, which can reduce or lower the need for air conditioning. "Natural Ventilation Cooling" is also encouraged with a need of 373 hours. If a household is constructed with open plans, the household's interior will promote natural cross ventilation and eliminate or reduce the need for an air conditioner. This can best be promoted by opening windows on windward sides and consequently needing to open the leeward windows to ensure fresh air flow is entering the space and adequately leaving the space. Figure 7 below, according to Climate Consultant (2020), illustrates the various wind directions buildings receive. As illustrated, Tucson receives throughout the summer months winds primarily from the Southeast and roughly the same hourly winds from the East, South, and North. According to Figure 7, little to no winds are received from the Northeast direction.

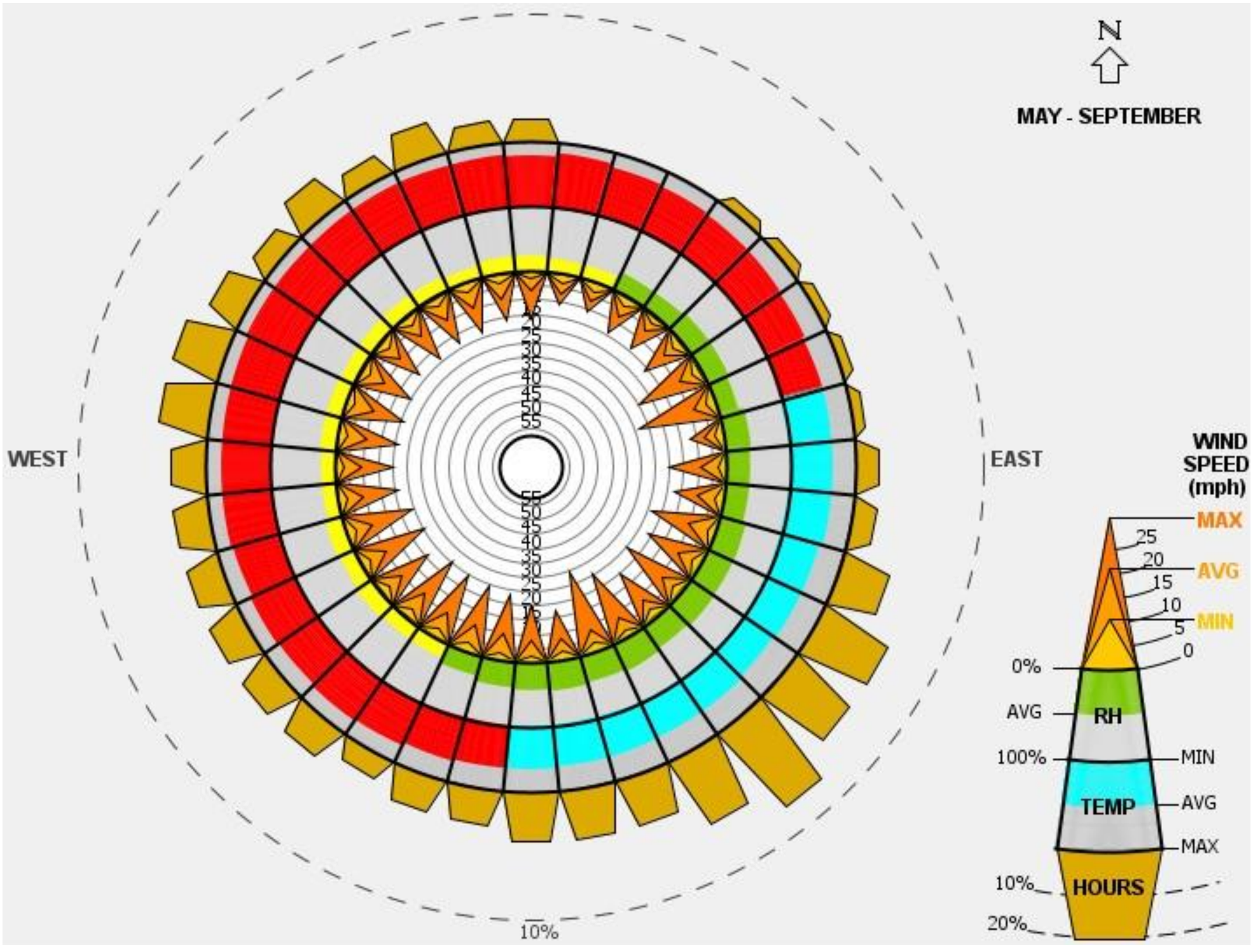

Figure 7 – Summer wind speed & receiving directions

Based on the illustration, natural ventilation is a viable design implementation that should be acted upon. Finally, adding "Cooling" for an encouraging time of 503 hours will make indoor conditions more tolerable. This can be achieved by providing, for example, water sprinklers, fountains, misters, etc., in front of a window that benefits from wind ventilation. The water will humidify the wind, cooling the air flowing through natural ventilation indoors. By applying the green design strategies, indoor comfort levels increase to 81% and reduce non-comfortability to 19%, according to Climate Consultant (2020) illustrated by Figure 8 below.

Figure 8 – Optimized summer indoor comfort condition percentages

Psychrometric Chart – Winter Months

Additionally, winter months (November-March) design strategies need to be identified. Due to Tucson's hot and arid environment, it receives little to no snow throughout the year, and for these reasons, these months are chosen. Moreover, Tucson begins to see reduced solar heat gains in November and receive heat gains earlier in the year in March as opposed to, for example, a state like Illinois. With these constraints of winter effects felt in different months than in other locations, Figure 9 illustrates the various datum points of winter weather Tucson experiences on average.

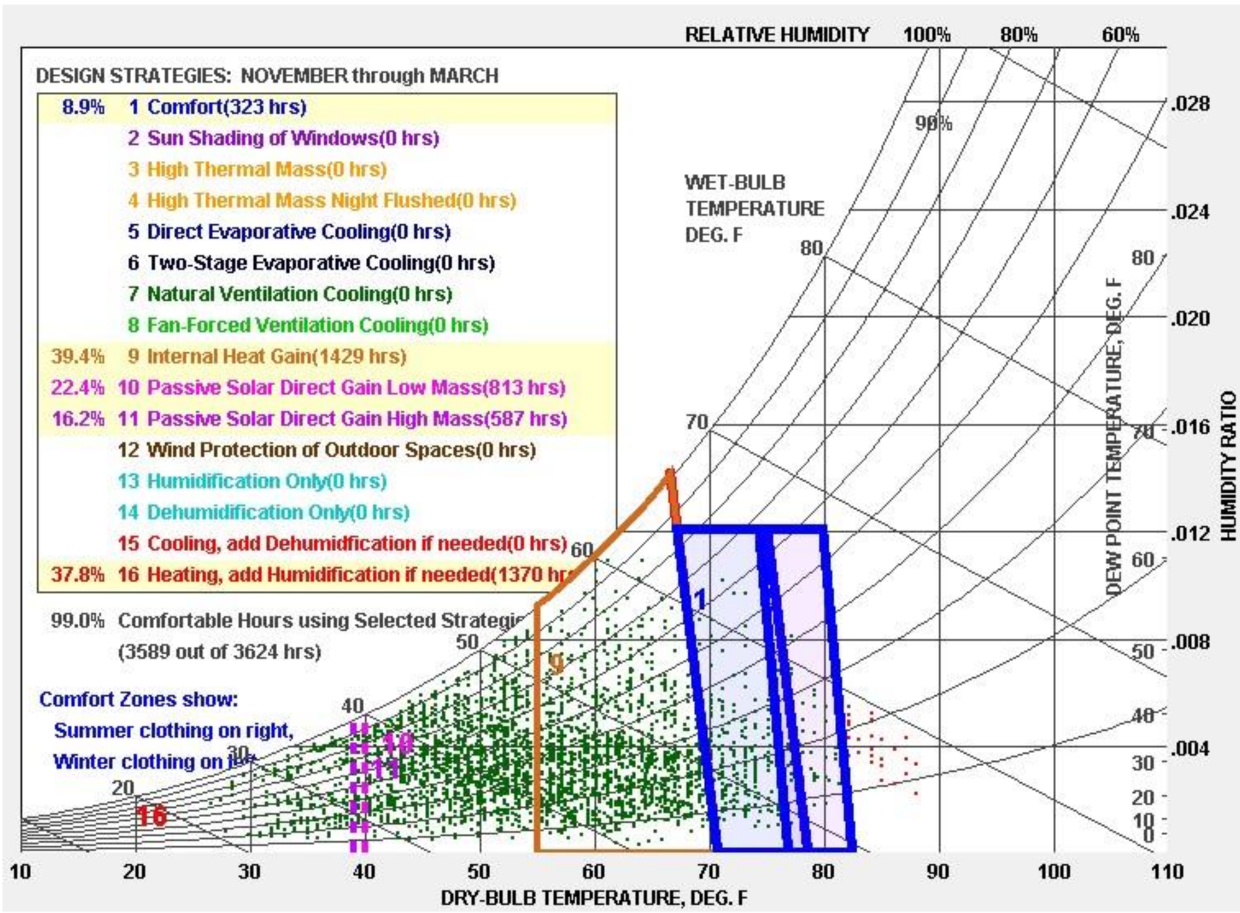

Figure 9 – Cold winter months (November through March)

During these winter months, only 323 hours or 8.9% or 9% rounded up of the time is the climate comfortable as illustrated by Figure 10 below. According to the winter psychrometric chart, design strategies are recommended and further identified in Table 2. Applying and analyzing these strategies will optimize winter indoor human thermal comfort. The table's left column illustrates the design strategies. The second column demonstrates the hours required from each strategy to optimize the indoor comfort levels. Likewise, the third column demonstrates the percentage needed for each strategy for maximized indoor comfort levels.

Figure 10 – Indoor winter comfort condition percentages

During these five (5) months analyzed, 323 hours of human thermal comfort roughly converts to only 13.46 days of comfortability. Consequently, these calculations determine that about four and a half (4.5) months of this time are uncomfortable to reside in a dwelling household. Different design strategies for winter are prioritized to maximize comfort and encourage comfortable indoor human thermal comfort consistently. Analyzing Table 2 below, for the more prominent design strategies of a 10% need or higher, first shows a need for "Internal Heat Gains" for a total of 1,429 hours. Increasing interior heat gains does not require any alteration to someone's human behavior within their home. Internal heat gains simply are acquired from home appliances such as plug-in loads and equipment loads.

Furthermore, inhabitants (human or pet) provide internal heat gains too. Internal heat gain is a great heating source and sees "Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well-insulated (to lower Balance Point temperature)" (Liggett & Milne, 2020). Utilizing "Passive Solar Heat Gain Low & High Mass" for a total of 813 & 587 hours can sufficiently provide warm temperatures during the winter. Passive solar heat gains can be maximized through fenestrations such as windows and doors. Different floor materials like "tiles or slate (even on wood floors) or a stone-faced fireplace provides enough surface mass to store winter daytime solar gain and summer nighttime 'coolth'" (Liggett & Milne, 2020).

Specifically, for winter, home structural material will release warm sunlight garnered during the day and release it at night, maximizing indoor human thermal comfort. Furthermore, double pane windows also contain warm temperatures during winter. Double pane high-performance glazing (Low-E) windows are best utilized on the north, east, & west façades; alternatively, for the south façade, clear double pane windows are suggested for maximum solar heat gain. By applying the green design strategies, indoor comfort levels increase to a staggering 99% and reduce non-comfortability to 1%, according to Climate Consultant (2020) illustrated by Figure 11 below. However, not including heating with humidification will reduce indoor comfort to 61%, according to Climate Consultant (2020) in Figure 12. Removing heating with humidification is researched because it can require a furnace, which is more expensive than any other implementation in the cost-effective table, discussed in the successful green implementation cost-effective table section.

Figure 11 Optimized winter indoor comfort condition percentages

Figure 12 – Optimized winter indoor comfort condition percentages without heating with added humidification

Table 2 Winter Design Strategies

November through March Strategies	Hours	Percentage
Comfort	323	8.9
Internal Heat Gain	1429	39.4

Passive Solar Heat Gain Low Mass	813	22.4
Passive Solar Heat Gain High Mass	587	16.2
Heating, Add Humidification if Needed	1370	37.8

Additional green enhancements include other simple improvements for homeowners. Firstly, Climate Consultant (2020) suggests adding "Extra insulation (super insulation) might prove cost-effective and will increase occupant comfort by keeping indoor temperatures more uniform." To best enhance insulation, homeowners should purchase products based on R-values. Particularly, R-values purchased should be higher. Larger R-values will increase insulation efficiency and help prevent heat from leaving the home structure. Climate Consultant (2020) further suggests insulation implementations by "Insulating blinds, heavy draperies, or operable window shutters will help reduce winter nighttime heat losses." Each recommended result is taken and explored based upon both achievabilities of financial constraints and implementation.

Every suggestion taken to show green retrofit enhancements is taken based on cost-effectiveness. Many other green techniques can be implemented, but not many households can financially afford the newest technology or renovations. Climate Consultant's (2020) chosen green enhancement recommendations are cost-effective and achievable. According to Climate Consultant (2020), implementing every consideration can provide 99% indoor human thermal comfort, but not all options are financially viable or can be physically implemented without major renovations. Nonetheless, the results explored will provide tolerable conditions for indoor human thermal comfort. However, computer programs are not always correct and only offer limited insight into the situation. It is not actually in the geographical location and only has objective opinions. To confirm what Climate Consultant (2020) has suggested, an interview was conducted with Omar Youssef Ph.D., Assoc. AIA at the College of Architecture, Planning, Landscape Architecture at The University of Arizona to reaffirm or add further successful green implementations.

Interview

In an interview with Omar Youssef, Ph.D., questions with the idea of finding successful green retrofit implementations were asked. Additionally, finding answers that are cost-effective and correspond with Climate Consultant (2020) was paramount. Questions and answers must revolve around Tucson and the surrounding Arizona geographic location. Overall, the vast majority of successful green implementations did correspond with Climate Consultant (2020) regarding sites itself; primarily, the outdoor microclimate. In my interview, I found in general, yes, there are successful practical green retrofit designs for an average homeowner with limited financial spending. However, many building factors need to be considered before implementing green solutions. Considerations stressed regarded home conditions, orientation, climate, and material. For example, if wider façades of buildings are east or west facing, it will be more challenging to find shading to lower solar heat gain. In the case that east and west façades are wider, according to Dr. Omar, the shading should be more focused on the areas of the building where the inhabitants are often in. Alternatively, if the north and south façades are wider, it will be easier to maximize shading to reduce solar heat gain.

Similarities found with Climate Consultant (2020) did revolve around shading regarding summer design strategies. The most cost-effective, as seen above, was optimizing the outdoor microclimate. Some of the best ways to maximize shading include trees. Once located and tall enough, trees will diffuse the solar radiation, lowering external heat gain entering windows or hitting outside walls. He noted that trees work best primarily on east and west façades.

Furthermore, Dr. Omar noted that utilizing water efficiency, such as greywater to the outdoor microclimate, will show benefits. Directed greywater from roof gutters, water faucets, and laundry machines to the optimized outdoor microclimate can lower costs on using extra water to grow the plants. Additionally, if using water efficiently, the water, as found in Climate Consultant (2020), can provide evaporative cooling from the outside wind. Researching how to efficiently use water to optimize the microclimate will be key to avoid creating puddles or other water bodies that bring the unwanted possibility of mosquitoes or other negative effects.

Similarly, overhangs will provide adequate shading to block solar heat gain in the summer while allowing it to enter in the winter, allowing the building material to absorb heat in the day and release it at night. When asked what design implementations all homeowners should implement, Dr. Omar provided three answers, all being "shading," particularly for newer homes. Shading is found to be key to providing tolerable indoor human thermal comfort in hot and arid climates. Figure 13 below, according to Climate Consultant (2020), illustrates why shading is a priority for homes.

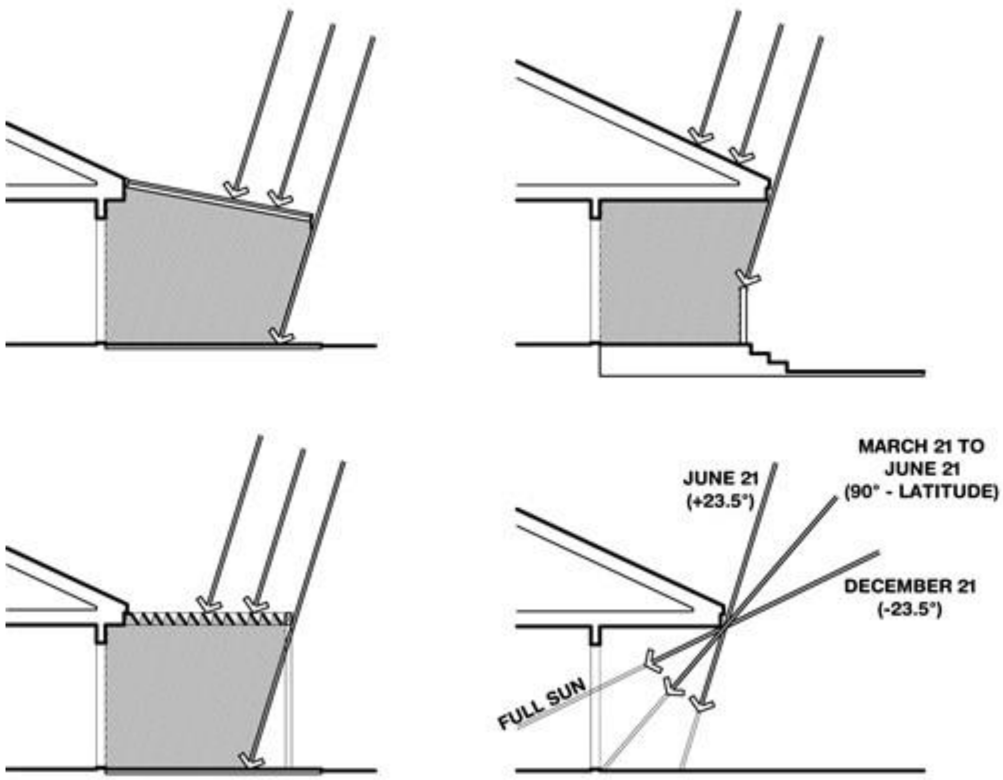

Figure 13 – Sample overhang image demonstrating shade importance for both summer & winter

With older homes, which, as the survey found, some people do reside in, more efficient double-paned windows should be implemented, and all buildings should have a lighter or white coated paint. A white paint coat is relatively cheap and self-doable and will reflect the solar radiation.

Alternatively, trees planted will lose their leaves in the winter allowing direct solar heat gains to enter the building. As stated above, properly design overhangs will allow solar heat gains to enter the building as well. One other cost-effective winter implementation not identified in Climate Consultant (2020) found in the interview is weather stripping. Implementing weather strips in thermal bridge areas or open-air spaces typically found in fenestrations will reduce heat in the winter or cool air in the summer from escaping the building.

This interview also found a free tip to reduce spending. Homeowners can apply a thermostat setback, which, according to Climate Consultant (2020), is to "Lower the indoor comfort temperature at night to reduce heating energy consumption (lower thermostat heating setback)." This, in turn, will save money by simply consuming less energy through heating and cooling. Dr. Omar also noted that opening the windows during a more chilly yet tolerable day will allow solar radiation in, heating the structure, and closing all windows at night will help contain the heat within the home.

Bonus Cost-Effective Recommendations Found

All these design strategies are successful green implementations in Dr. Omar's experience; however, he stressed two key facts that need to be explained. First, education on the topic of successful green implementations can make a huge difference in efficient indoor human thermal comfort. Many of the design strategies recommended above can be successfully implemented simply by understanding the topic. Knowing that shading can reduce external heat gains can be learned by exploring the internet. Planting trees will produce shading and have been utilized for all of human history. Secondly, it was found that Climate Consultant (2020) will provide successful green implementations for indoor human thermal comfort. However, financially, not all the options are appliable nor achievable, and thus not mentioned. 100% indoor human thermal comfort cannot be achieved. To this point, Dr. Omar mentioned that all the design solutions would only create conditions tolerable to indoor human thermal comfort. Conditions inside homes in the summer may only be reduced to temperatures in the 80 degrees Fahrenheit range at most. For these recommendations to be successful, home inhabitants will need to tolerate higher temperatures and probably change their day-to-day habits. Unplugging equipment not in use will use less energy, reducing costs, and internal heat gains, which can be felt in the summer and winter. Cost-effective green implementations found can be successful or failures entirely dependent upon the building factors and human activity. Knowing these green implementations can be successful, allowed for further research to be identified for cost-effective implementations.

Successful Green Implementation Cost-Effective Table

Table 3 categorizes successful green implementation designs based on a financially friendly, cost-effective scale for the summer and winter months. This table does not provide specific types of double pane windows or overhang brands or sizes. Every dwelling includes different factors, making it difficult to provide the best cost-effective models. Many model brands are found through Home Depot, a common hardware store in Southern AZ, providing reasonable example solutions and prices that can be bought.

The purpose of this table is to propose financially friendly material prices any homeowner can buy. There is a plethora of brands and materials homeowners can buy at varying prices. This table conveys that energy-efficient materials can be bought for less and provide tolerable indoor human thermal comfort. The implementations column conveys the green implementation design type. Next, the cost column conveys the friendliest cost for each implementation coupled with a citation of a specific brand researched. Next, column three conveys the price savings and energy savings occupants might gain from applying the green implementation design strategies. Finally, the last column conveys the use of each implementation and the corresponding benefits.

Table 3 – Implementation cost-effectiveness table

Implementation	Cost	Price savings or Energy Savings	Use
Mesquite Trees	At Tucson Clean and Beautiful – $25.00 (*Velvet Mesquite | Tucson Clean and Beautiful, Inc.*, n.d.)	"A well-planned landscape can reduce an unshaded home's air conditioning costs by 15-50 percent." (*Landscaping101_finalv2.Pdf*, n.d.)	Provide shading to diffuse solar radiation on Western & Eastern elevations of a home. Increase evapotranspiration benefiting natural ventilation. Chances are, in Southern AZ, a Mesquite tree is already growing in your yard and will provide its seeds for occupants to grow. It is important to note that trees need to be tended to and will take time to grow
Window Overhangs	At Home Depot, Most window overhangs price range between $30 to $400	Shading can reduce heat loss through windows by 40% or more, equating to about 20% heating energy savings. In cooling seasons, cellular shades can reduce unwanted solar heat through windows by up to 80%, reducing the total solar gain to 15% or less when installed with a tight fit. (*Energy Efficient Window Attachments*, n.d.)	Shading over windows or doors on Southern, West, & East elevations will reduce solar heat gains. Alternatively, properly angled overhangs will welcome winter solar heat gains. Window size is paramount, and identifying size dimensions will infer which overhang will maximize summer shading
Double Pane Windows	At Home Depot, double pane casement windows prices range between $150 to $2000.	An Energy Star certified double-pane window can save $27–$197 on average (*Benefits of ENERGY STAR Qualified Windows, Doors, and Skylights*, n.d.)	Double pane windows are energy-efficient and will diffuse and lower solar heat gains in the summer and retain heat gains in the winter
Misters	At Home Depot – $8.07 (*SPT 3/8 in. Outdoor Cooling/Misting Kit with 12 Nozzles-SM-3812*, n.d.)	Will enhance the natural ventilation, which can save 10%–30% of total energy consumption (*Natural Ventilation | WBDG - Whole Building Design Guide*, n.d.)	Will cool the natural air ventilation temperature flowing through the occupant household. Can water surrounding vegetation
Window Weather Strips	At Home Depot – $12.73 (*Frost King 62 in. x 210 in. Polyurethane Extra-Large Shrink Window*	Estimated Annual Utility Bill Savings (%): Total House - 6% Heating and cooling only - 9%	Reduce thermal bridge areas in fenestrations or infiltrating & exfiltrating areas

	Insulation (2 per Pack)-V75/2QPD2, n.d.)	(*Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating*, n.d.)	
Door Weather Strips	At Home Depot – $12.49 (*Frost King 3/4 in. x 1/2 in. x 84 in.White Elite Lifetime Door Weatherseal Replacement-ES184W*, n.d.)	Estimated Annual Utility Bill Savings (%): Total House - 6% Heating and cooling only - 9% (*Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating*, n.d.)	Reduce thermal bridge areas in fenestrations or infiltrating & exfiltrating areas
Evaporative Cooler	At Home Depot – $371.23 (*Search Results for Evaporative Cooler at The Home Depot*, n.d.)	"A/C systems costs $1.13 per hour to run whereby the Evaporative cooler cost is only $0.26 per hour." (*Evaporative Cooling*, n.d.)	Reduce or lower the need for air conditioning. Important to set in most used rooms
Internal Heat Gains	Does not increase the price with normal internal habits	N/A	Normal human behavior in a dwelling household (i.e., using an oven, laptop, dryer, etc.) will increase internal heat gains in the winter
2 x 4 Wall Insulation	At Home Depot – $23.48 (*Owens Corning R-13 Pink EcoTouch Kraft Faced Fiberglass Insulation Continuous Roll 15 in. x 32 Ft.-RF10 - The Home Depot*, n.d.)	15% reduction on heating and cooling costs (or an average of 11% on total energy costs) by air sealing their homes and adding insulation in attics, floors over crawl spaces, and accessible basement rim joists. (*Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating*, n.d.)	Insulation with a higher R-Value will increase occupant comfort by keeping indoor temperatures more uniform and efficient
2 x 6 Wall Insulation	At Home Depot – $34.98 (*Owens Corning R-19 EcoTouch PINK Kraft Faced Fiberglass Insulation Continuous Roll 15 in. x 39.2 Ft.-RF40 - The Home Depot*, n.d.)	15% reduction on heating and cooling costs (or an average of 11% on total energy costs) by air sealing their homes and adding insulation in attics, floors over crawl spaces, and accessible basement rim joists. According to Energy Star. (*Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating*, n.d.)	Insulation with a higher R-Value will increase occupant comfort by keeping indoor temperatures more uniform and efficient
Fans coupled with light fixtures	At Home Depot – $49.97	15% reduction in air conditioning energy use and	Provides circulated air enhancing indoor human thermal comfort

	(*Unbranded Hugger 52 in. LED Indoor Brushed Nickel Ceiling Fan with Light Kit-AL383LED-BN*, n.d.)	the cost of running the ceiling fan is minimal (*Saving Energy With Ceiling Fans*, n.d.)	
Thermostat setback	Free (if already included in-home)	According to energy.gov, you can save 10% a year on heating and cooling by simply turning your thermostat back 7°-10°F for 8 hours a day from its normal setting. (*Thermostats*, n.d.)	Save money by consuming less energy through heating and cooling

Conclusion

Green retrofitted buildings, whose benefits are not generally among public knowledge, can make noticeable differences in financial gains while combating climate change. In Southern Arizona, particularly Tucson, the temperature is very hot during the summer months. In 2020, Tucson broke numerous records for the hottest July, August, September, and October on record and 108 days over 100 degrees (*National Weather Service - NWS Tucson*, n.d.). Similarly, during the winter months, while not frigid, the temperature does become cold enough to require a heating unit. To mitigate uncomfortable indoor temperatures, large amounts of energy is consumed contributing to climate change. A primary cause of this is the lack of knowledge on how home occupier's energy consumption contributes to climate change.

The survey sample population primarily understood that financial savings, health, and sustainable benefits could be achieved by adding green implementations. Figure 14 is a graph illustration showing that above half of the sample population understands the benefits.

Moreover, homeowners can implement various design strategies to improve their indoor human thermal comfort further. This study found that successful green implementations are not primarily mechanical system enhancements, but they include design strategies. A cross-analysis of surveys, climate consultations, an interview, and price comparisons identified impactful and affordable successful green implementations. Due to the above reasons, this study proceeded to find solutions for different temperature ranges. A few questions underpinned the solutions sought:

- What will happen to the home occupiers if power is unavailable for a given amount of time?
- What would happen to home occupiers in the summer/winter months if the power, A.C. unit, or heating units stopped working?
- Would they have an alternative living situation in the event of no cooling/heating in their home?
- Would they be able to remain thermally comfortable in uncomfortable temperature situations?

This study found, in general, through a homeowner/renter sample size, occupants do not have green implementations, let alone successful green implementations. Not surprisingly, it found that their air conditioning and heating units are used a lot during their respective summer and winter months. In general, most participants noted that their homes would not be comfortable to reside in during the event that the air conditioning or heating units stopped working or worse if the power supply stopped working for an extended time.

Interestingly, results showed that most participants did not have a plan without a working air conditioning or heating unit in such an event. More promising, at the very least, is the sample survey takers possibly had an alternative location to reside in, to avoid the situation indirectly. If the survey gathered more answers, it may be reasonable to speculate that the results would show they do not have an alternative option to avoid discomfort in their homes. The survey found that every participant was at least open to making their home more energy-efficient. Perhaps it was because the survey made them think about a possible crisis or because they found out through the survey about financial savings by finding passive cooling and heating techniques. The survey responses allowed this study to find alternative, financially friendly, successful green implementations for residents negatively impacted by such a crisis.

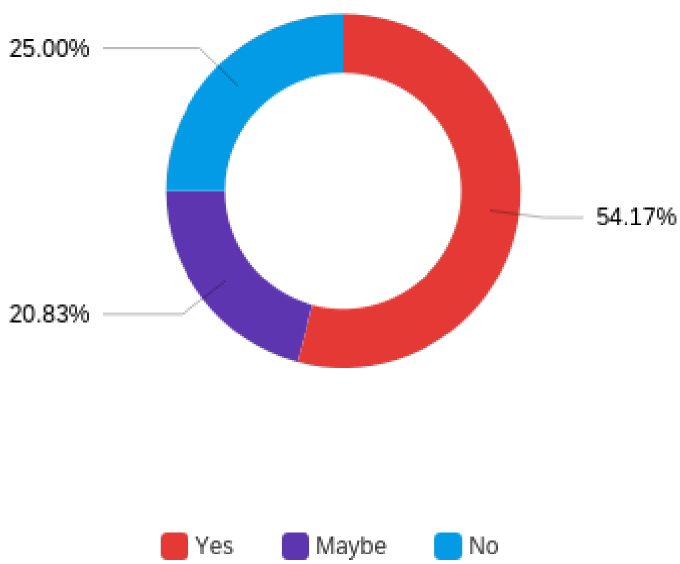

Figure 14 – 54.17% of participants are aware of some benefits of green implementations

Finally, what are cost-effective optimizations for an average homeowner to use from the research? An average homeowner can undertake various retrofits. However, there are always financial limits for the best possible outcomes for the above questions. It was imperative to find home optimizations to the following problems:

- What are the successful green implementation strategies to use in our current home building stock to avoid such situations?
- What can be added to homes to cool or heat the structure?

Climate Consultant (2020) found viable solutions to make homes tolerable for those with no mechanical systems to provide indoor comfort. Using sun shading of windows, two-stage evaporative cooling, natural ventilation cooling, and cooling can provide 81% comfortable indoor temperatures during the summer months. In the winter, internal heat gain, passive low & high mass gains, and adding humidification are recommended to provide 99% indoor comfort levels; however, that comfort level is reduced to 61% of indoor comfort temperatures by not including heat coupled with humidification due to high prices such as furnaces.

Coupled with Climate Consultant (2020), my interview with Dr. Omar Youssef found similar recommendations to the underpinned question:

- Will these changes be an alternative for A.C./heating units?

Recommendations included optimization implementations such as weather strips, external shading, and lowering thermostats. However, it should be noted that all the recommendations require a homeowner or renter to be comfortable with higher temperatures during the summer and lower temperatures in the winter. If a resident is unwilling to accept these changes, then it is unlikely these techniques will reduce energy use and loads. Tolerable indoor conditions can be achieved with education on how to optimize one's own home. Moreover, it will be an alternative to A.C./heating units if the occupants can tolerate higher or lower temperatures in the different weather seasons.

Knowing that tolerable conditions can be maximized, this study went through thorough research of what can be bought for reasonable to low prices to find recommendations to:

- How does this indirectly help them financially while providing comforting temperatures?

The research found that optimizing occupant homes can reduce energy consumption, consequently lowering billing prices. This may be achieved by implementing native trees & window overhangs for shading, weather strips to maintain indoor temperatures, evaporative coolers & misters to cool the air, and optimize natural ventilation through window openings. Being educated and adjusting occupant's home features to optimize these suggestions in their respectable seasons should bring tolerable indoor human thermal comfort conditions to occupant homes.

Limitations & Recommendations

This study incurred limitations worthy of addressing due to the Covid-19 pandemic. First, contacting large populations to gather quantifiable survey responses was limited to electronic means of sending and receiving the survey and responses. While convenient, electronically sending surveys limited the potential of larger population responses. Secondly, in-person observational analysis of green retrofitted homes was not possible. Gathering a personal in-person observational opinion on how green implementations benefited homes would have allowed direct research on how the varying implementations performed versus theoretical. Furthermore, analyzing an actual home's direct financial savings was not viable either. Researching how green retrofit implementations benefit the home residents and, ultimately, its impacts on climate change is a young subject. Quantifiable data in the long-term regarding financial savings and carbon gas emission reductions only extend a short time.

Home green retrofits are an ever-evolving subject. As technology changes, climate change mitigation techniques change too. Further research to support green implantations would include physically analyzing a green retrofitted home and the different design implementations from lower to higher cost implementations. Identifying what is implemented, its price and its effects would help cement solutions to recommend house owners who cannot afford higher-priced technology. As time progresses, research will determine the direct impact green implementations have on humans and the planet.

Appendix

Appendix A. A list of measure 1 survey questions asked

1. Has your residence had any sustainable improvements?
2. If your air conditioning unit or heating unit stopped working, would your residence still be comfortable to reside in, particularly during the summer or winter months?
3. Do you use your air conditioning unit a lot during the summer months?
4. Do you use your heating unit a lot during the winter months?
5. Do you have plans if the power were to go out and you could not cool/heat your home in the summer/winter months?
6. Do you have the option to stay elsewhere?
7. Would you now or in the future want to make your dwelling energy efficient?
8. Are you aware of the financial, health, and sustainable benefits to making your dwelling more energy efficient?
9. Would you add trees near your building structure to increase shading on your structure and reduce heat?
10. Would you implement more efficient insulation?
11. Would you implement energy efficient windows?
12. Are you open to adding other sustainable retrofit implementations to improve your dwelling?
13. Are you aware you could possibly receive money rebates for consuming less energy?

Appendix B. A list of interview questions asked

1. Are there practical green retrofit ideas an average homeowner with limited financial spending can implement to their homes to provide indoor human thermal comfort?
2. What are successful green retrofit implementations?
3. Of those successful, what are green implementations that a homeowner could implement that are considered more practical to implement?
4. What areas should a homeowner focus on first when considering green implementations?
5. What are more important components of a façade to focus on?
    a. East, west, or south elevations?
6. What are further important components of a façade to focus on?
    a. The insulation, shading, combination of both, or another factor that people overlook?
7. Because these are successful green implementations, do you believe using these designs as passive techniques could sufficiently provide indoor human thermal comfort in the event that their cooling/heating units stop working in the summer/winter?

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