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Reducing Our Energy Usage and Reliance to Mechanical Air Conditioning through Passive Cooling: Can It Be Done at Home Today?

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Abstract. Today more houses are being built to rely solely on air conditioning as the only means of cooling a home. This research study explored methods available that may help minimize energy consumption and reduce reliance on mechanical cooling through passive cooling while focusing on retrofit options for existing residential buildings and energy saving considerations for new residential construction in the United States of America. The data of this research was collected through literature review, a combination of an online survey and interviews on individuals' experiences with air conditioning, and an interview with an electrical energy provider managing weatherization home improvements.

Keywords: Air Conditioning, Energy, Insulation, Natural Ventilation, Passive Cooling, Residential Construction.

1 Introduction

Today, nearly most of a person's day is spent comfortably sheltered in an air-conditioned box. Air conditioning has become our way of life, it has changed the type of air we breathe, the way we design our homes and has redefined our tolerance to surrounding temperature according to a modern standard of living. For some of us, it is the only life we know. So, what happens when our air conditioning system suddenly fails, when there is a power outage, or when it becomes necessary to shut off the only cooling system our home was built to work with? In most cases, the inside temperatures become too uncomfortable to withstand. The one place we call home can suddenly become inhabitable.

Before air conditioning, most homes were built to provide people comfort according to the climate and geographic location. They were built using vernacular building methods. Today, the ability to keep a home cooled mostly naturally with near zero energy consumption is referred to as passive cooling [1]. Consisting of different non-mechanical methods and some new energy efficient technologies, setting up an existing or new construction home for passive cooling, can improve home energy efficiency, can be something to fall back on when a break from air conditioning is inevitable, can redefine our current standard of living and mostly, it can help minimize the negative impact of air conditioning on the environment.

However, most buildings today and especially the mass number of housing developments emerging every year are designed and built to depend on an air conditioning system for most part of the year. Featuring operable windows is almost always part of residential construction, but is that enough to cover our cooling needs during a power outage or at least cuts back on air conditioning usage during parts of the year?

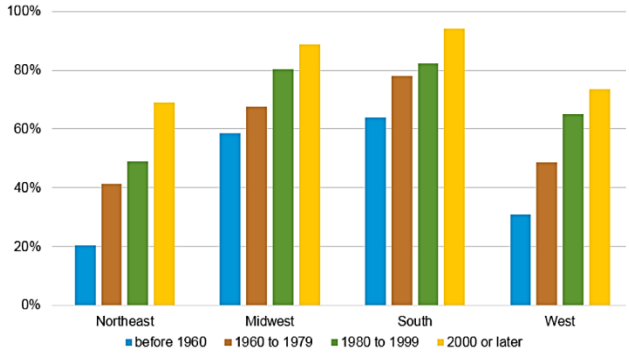

Fig. 1. Most newer homes have central air conditioning. Percentage of homes by year built with air conditioning. 2015 Residential Energy Consumption Survey. [2]

According to the U.S. Energy Information Administration [2], the demand for electrical power was expected to increase in the summer of 2018 alone by 1% with an estimated 3% spending increase. With energy resources depleting and demand growing annually, increase in prices will continue to follow. This tendency also continues to impact the environment. The building sector is currently the 3rd largest contributor to greenhouse gas emission. By 2030, if the industry continue the trend of building with energy consuming systems, the building sector will earn the spot as the 2nd largest contributor to greenhouse gas emissions [1]. As seen in Figure-1, there is an upward increase of air conditioners being installed in all new homes in all four geographic regions of the Contiguous United States. Regardless of the years of research, studies and awareness done on the impact of the environment, people continue to move forward with buildings constructed to comfortably house them on the condition that the air conditioner is running. With this upward increase of new buildings equipped with air conditioning, comes an upward increase in energy consumption, energy costs, and greenhouse gas emissions. So, it has never made more sense to finally adopt alternatives methods to cool a home such as those offered through passive cooling that can help offset these increases in energy consumption.

The purpose of this study is to explore the options available that may help minimize energy consumption and reduce our reliance on mechanical cooling for homes through passive cooling. Some passive cooling methods are more feasible than others, some may require a new perspective of comfort or can only be applied under certain climate or site conditions.

2 Passive Cooling

Passive cooling involves the use of the natural environment to cool a building with no electrical supply. Unless you are using a wind turbine, solar or a water mill to produce electricity, passive cooling options can include using natural breezes, landscapes, thermal masses, insulation, wind towers and other permanent architectural features such as deep overhangs and sun shade devices. During some parts of the year such as the summer season, eliminating the use of electricity all together for cooling purposes may not be a realistic option, but minimizing it with the assistance of passive cooling systems can reduce the cooling load which will allow for minimal energy consumption. The application of mechanical air conditioning systems in this form would be included as a supplement during these intense hot days.

The effectiveness of these passive cooling options varies by climate, time of year and geographic location, but the methodology of passive cooling in respect to combating heat gain and heat rejection can be applied the same regardless of these conditions. The site selected for new construction or where an existing home is already built includes its own unique climate, location, site features or other special conditions which are all context sensitive elements that will drive the selection of passive cooling options appropriate for the site. Considering how each of these passive cooling options vary is crucial as no one site with building combined is ever the same.

There are two key functions that make up passive cooling and help accomplish its goals: 1) heat gain preventive measures and 2) heat rejection corrective measures. Keeping as much heat out as possible and keeping existing cool conditions in, allows for more sensible cooling levels. Heat energy flows through the envelope of the building from outside. A building gets heat energy through radiation and convection, and can also generate heat energy inside through convection. Passive cooling options are more effective if there are efforts taken to try to keep heat energy out of a building. This is also an important factor to consider for a building constructed to solely depend on an air conditioning system. If more effort is taken to prevent heat flow into a building, air conditioners would have to work less, thus consume less energy and cost less. So, the first key function is to prevent (or minimize) heat energy from accessing or generating inside. Second, once heat energy is generated or has entered from outside sources, the key is to get as much of that heat energy out. Heat energy flows into a home and then out of the home, and if more heat is coming in than what is being taken out, then the difference will generate uncomfortable room conditions.

2.1 Heat Gain Preventive Measures

To get a better understanding on how to prevent heat flow, first consider where this heat comes from. Heat can come from the following:

- Conduction through building envelope.
- Solar heat gains. Accounts for 75% of the cooling load in a residential building that occurs through windows, doors and other exterior glazing wall systems.

- Air infiltrations. Can include natural air ventilation during peak summer temperatures.
- Internal gains. Accounts for about 25% of the cooling load in a residential building normally generated by appliances, lights and human body temperature.

1. *Insulation and Thermal Mass:* One of the passive cooling methods that effectively helps keep heat energy out is the application of building envelope insulation. "Many older homes have less insulation than homes built today, but even adding insulation to a newer home can pay for itself within a few years [3]." Today, for the sake of initial cost savings, homes can be designed and constructed to meet just the bare minimum heat resistance (R-Value) insulation standards provided by the International Energy Conservation Code (IECC) or other enforced building codes. Initiatives taken by the owner or designer to increase these values during design appropriate to the climate and geographic location, increase the insulating effectiveness. Increasing the R-Value will slow the flow of heat into a building, but higher R-Values do have their limits subject to diminishing returns. The effectiveness of a properly insulated wall and attic is critical in preventing heat gain thus minimizing energy usage that now even energy companies have taken the role of providing insulation services to low income residence with a goal of increasing their home's energy efficiency.

Electrical companies are now offering programs that either assist home owners improve their home's energy efficiency or reward them for installing qualifying energy saving improvements. City Public Services (CPS) in San Antonio, Texas for example includes a program, Casa Verde [4], which offers an estimated $5,000 in energy efficiency upgrades to each qualifying home amounting to an average savings of 25% in annual energy consumption for each home. These upgrades include attic insulation, wall insulation, air sealing measures, duct sealing, replacing incandescent bulbs with LEDs and other minor repairs that may be needed to make a home safe once its building tightness limit (BTL) has been improved. For wall insulation for example, CPS will conduct an energy and safety evaluation of the home to assess needed energy improvements and send a contractor to make small openings between each wall cavity on the interior side of perimeter walls and install R-19 loose cellulose installation as seen in Figure-2. After interviewing CPS Casa Verde Weatherization Program Manager, Frank Kostusyk, it was interesting to find that nearly 90% of homes that participated in the program had to receive attic insulation as they did not have any. He explained that they begin with a base line of R-0 for a home that does not have insulation and increase as needed targeting R-19 for walls and R-30 for attics. For an attic with a lower R-Value, such as the one shown in Figure-3, additional insulation was added on top of existing batt insulation so that the R-30 can be met. Casa Verde is a program within CPS Energy's Save for Tomorrow Energy Plan (STEP). Based on their annual reports on residential energy improvements, it is determined that envelope measures are the largest contributor to total gross program impacts with attic and wall insulation bringing the largest energy impacts per home. A homeowner that participated

in this program was also interviewed and explained that he has noticed a significant difference in his home. Since adding insulation into both the walls and attic of his home, he has had to run the air conditioner a lot less [4].

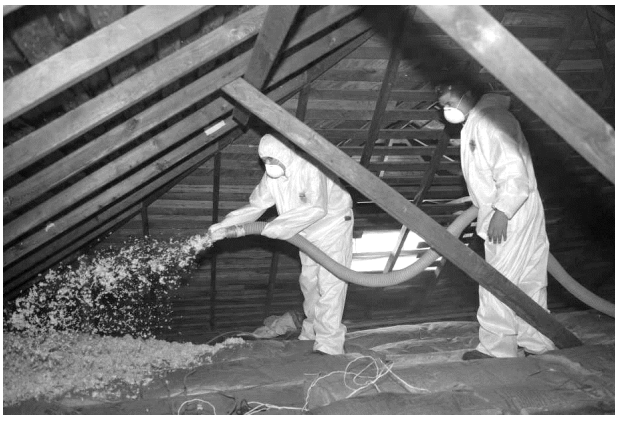

Fig. 2. CPS Wall Insulation installed at a residence's home.

Fig. 3. CPS Attic cellulose insulation on top of existing fiberglass insulation [5].

Prior to building insulation as we know it today, thermal mass or trombe walls [6] were used to slow the flow of heat entering a building. While the R-Value of a concrete wall alone is less than that provided by Polyurethane or Fiberglass insulation, these methods can be added on to an existing building or new construction to assist with keeping heat from entering a building. A trombe wall works by absorbing heat energy from the heated outside air during the day as a heat sink and then expelling the collected heat out at night either through manual or automated controlled vents, or windows.

2. *Shading:* Another important factor in passive cooling preventive heat gain is through proper shading. Shading can be provided through systems built directly on the building or through landscape near the home. It will provide both protection from the sun's rays and allow for cooler ambient air to surround the building. With heat energy flowing through the building roof, exterior walls, and window, shielding these surfaces before direct solar radiation contact can minimize the impact of radiated heat entering the building. "Controlling solar heat gains is a matter of keeping the sun out of the building and off the exterior surfaces" [7]. Before mechanical cooling, buildings were built with deep overhangs, deep porches, and windows strategically placed for ventilation and according to the sun's path. Compared to an exterior wall or roof, windows are impacted the most due to their lack of thermal mass and greater emphasis needs to be considered when protecting them from the sun rays. Whether single or double glazed, their thermal mass is much less than that provided by the rest of the building envelope.

Figure-4 provides an example of a sun shade device that can also be added to an existing house that may have originally been designed and constructed with minimal or no

shading in mind. A retractable device such as this one allows for it to be lowered and raised according to the location of the windows in relation to their cardinal orientation which depending on their location, will receive dissimilar angles of the sun during certain parts of the day and time of year.

Other retrofit options of utilizing shading could include the addition of a deep porch at the front entrance of a house, on the side of the house that is most vulnerable to the sun, or a wrap-around porch for full protection of the first-floor level. Before air conditioning, wrap around porches were a common part of southern architecture serving multiple purposes from protecting the lower level windows from the sun to providing a cool shaded outdoor living/dining space. This option, while providing consistent shading, can end up costing more than individual window sun shading devices, but as a permanent structure, can also add value to a house.

In addition to heat gain acquired through outside conditions, are those generated through inside sources such as human body heat, appliances and light fixtures. While it may appear as minor, replacing incandescent bulbs with CFL bulbs or even better, LEDs, also helps minimize heat gains. An incandescent bulb for example emits more heat and consumes more power. A 100 watt incandescent bulb will produce 10% of that into light, and the rest, 90% into heat. The CFLs on the other hand, will produce 15% of that into light, and the rest, 85% into heat and will last longer than an incandescent. LEDs, while much more expensive, are 90% more efficient than incandescent, producing less heat and cool to the touch, using less energy and lasting longer than both the incandescent and CFL bulb [8].

2.2 Heat Rejection Corrective Measures

The second key function of passive cooling includes implementing corrective measures through heat rejection. That is, removing heat gains. The preventive measures discussed earlier are key as they help reduce heat gains, keep existing cool conditions in and reduce the required cooling load, but for any heat gain that does occur despite these preventive measures, using corrective measures to immediately expel them will help maintain conditions inside a house that can be comfortable enough to live in without air conditioning use or to minimize its use.

Some of these heat rejection measures include the following:

1. Natural ventilation through outdoor breezes and density differences
2. Natural ventilation with supplemental mechanical support (ceiling exhaust fan)
3. Mechanical cooling combined with passive cooling methods (Hybrid of the two)

a) *Natural Ventilation:* Cooling a house using natural ventilation is accomplished by allowing outside air to supply and remove inside air and creating a constant movement of airflow throughout a house without mechanical means. The idea is to use the outside atmosphere as a heat sink under the condition that the interior temperature is already warmer than the outside temperature. To fully take advantage and get the most of natural ventilation, creating a constant

airflow can involve more than simply opening a window or two. Strategically sized and placed windows along with an open internal wall layout can help create a cross flow of air that will aid in displacing warmer indoor air with slightly cooler outdoor air. A channel of openings must exist within the house to allow uninterrupted airflow. For an existing home, this can be done by opening doors inside or through planned demolition of nonstructural walls creating a more open layout. To further accentuate this process, the implementation of a wind tower, ceiling to roof ventilation or any type of vertical chase with an opening terminated at the highest point of the house, can assist with displacing heat not captured by the horizontal flow of air brought by only using windows. Warmer air will rise to the top due to it being less dense than the air surrounding it. Combining this thermal phenomenon with open windows and a vertical chase, it creates a vacuum like force with a natural upward airflow motion referred to as the stack effect. As warmer air rises towards the highest exit point of a house, it pulls in outside or cooler air in. Figure-5 shows a design sketch of a Natural Ventilation System for a building.

Fig. 4. An example of Retractable Window Shading Device mounted to a wall [9].

Fig. 5. Natural Ventilation System for a building including windows and skylights. [10].

b) *Combined Efforts:* To further boost the flow of air inside a home for ventilation and cooling purposes, force ventilation provided by fans, exhaust fans and whole house fans can also be considered to lessen the use of the air conditioner. The inside of an attic if improperly insulated, can easily measure up to 150° on a 100° day thus acting very much like a furnace or a heating pad radiating heat directly into the interior spaces of a house. If insulated, the temperature is reduced, but combining it with a solar exhaust fan can further reduce the attic temperature by removing the hot air normally trapped on the highest point near the ridge of the roof structure. For an existing house built

without a vertical chase such as a chimney for the purposes of the stack effect, a whole-house fan can be installed at the highest ceiling point of the interior space open to the attic space [11]. As required with natural ventilation, with open windows, and an open interior wall layout, the flow of air would be continuous providing a cooling effect and removing warmer air with cooler outside air provided it is less warm outside. Other systems that can also be integrated depending on the climate can include evaporative cooling in dry-hot climates or dehumidification in hot-humid climates.

The conditions can vary as the second law of thermodynamics states that heat will naturally flow from a high temperature area to a low temperature area until both areas are balanced. If the conditions outside are too hot to bare, it would probably not make sense to displace interior air with it. There are parts of the year when ventilation alone can provide plenty of cooling without mechanical means. It is during this time of the year, that taking a break from the air conditioner and letting passive cooling methods take over should be considered. During the summer peak, the time of the year when the temperature outside is significantly greater than it is inside, or during extremely hot and humid conditions, supplemental mechanical support such as dehumidifiers, evaporators and finally air conditioning, may then be needed.

Natural ventilation can be feasible for most part of the year. According to Paula Melton [12-13], the three primary reason to design a building using natural ventilation is for energy savings, occupant satisfaction and indoor air quality. Also, being realistic, she makes note that there are also many reasons why not to. These reasons can depend on the geographic location, current outside air quality conditions, humidity levels and other factors that can impact the comfort level provided using only natural air ventilation and other passive cooling methods. These factors alone should not be a reason to deter from designing and constructing a building with passive cooling systems. The idea again, is not to eliminate mechanical systems entirely, but to reduce it instead and create a balance or harmony between available advanced technology and natural systems that have also progressed as a result of this technology.

Giving up air conditioning altogether is unlikely to happen any time soon. Combining passive cooling preventive measures to lower the cooling load and lessening air conditioning use during parts of the year when the outside temperature is acceptable, will help minimize energy consumption.

Q #	Questions	Response					
1	Nearly everyone today has an air conditioner at home which wasn't the case for everyone growing up. Did you grow up with air conditioning?	Yes	No	Experienced Both			
		14%	73%	14%			
2	Whether or not you grew up with or without air conditioning , if you experienced it in some form or fashion such as visiting family or a friend, how would you describe your experience growing up without it from a comfort standpoint?	Fine, Comfortable Enough		Too Hot, Uncomfortable			
		82%		18%			
3	*What methods did your family use to stay cool before air conditioning?	Natural Breezes (Open Windows)		Fans	Watercoolers	**Building Components	***Other
		68%		82%	27%	27%	36%
4	Are you familiar with passive cooling or any methods like it?	Yes		No			No Answer
		32%		64%			5%
5	*What methods do you mostly use today to lessen the use of your air conditioning?	Natural Breezes (Open Windows)		Fans	Control Thermostat	**Building Improvments	Other
		14%		36%	41%	9%	14%

* Sum does not equal to 100%. Surveyors were given the option to select more than one method of staying cool or lessening use of air conditioner.

** "Building Components/Improvements": Consist of taking advantage of house architectural systems such as overhangs, insulation system, porches, high ceilings, occupy only 1st floor since 2nd floor is hotter, thermal mass, concrete walls, cool ceramic floors, specifically placed windows, attic fan, etc. Or

the installation of any of these listed for building improvement purposes. Items in this list were items provided by those surveyed and were not provided as options to select.
*** "Other" included visiting public spaces, staying outside, pools, clothing selected, acclimating to the heat, or ice blocks added to swamp coolers.

Fig. 6. Survey result summary

With more buildings continually being built to depend on air conditioning for cooling means, and energy consumption and cost increasing as a result, what options do we have to provide relief? The different options and methods available are not new. People have used and relied on these options long before electricity. Many have experienced them, and others simply have not. Transitioning from a solely air-conditioned home regardless of a person's experience with it would likely require accepting, adapting and adopting a new life style and understanding how the system works.

3 Research Data and Analysis

A survey for this research concerning individual experiences with air conditioning and methods of keeping cool was conducted through social media. The data gathered on past experiences with air conditioning is based on individuals from different geographic locations including all regions of the United States, and various locations in Central America and Southern America with most of the respondents now residing in the Southern United States.

According to the survey results as shown in Figure-6, only 14% participants say they grew up with air conditioning compared to the 73% that did not grow up with it. With 100% of the respondents now relying on air conditioning, their non-air conditioning methods of staying cool have also changed. Before air conditioning was prominent, 68% used natural methods of cooling such as opening windows and letting breezes in. 82% of the respondents also used fans, with most of them sharing through individual interviews that they combined natural breezes and fans together to boost ventilation and air movement in their homes. Now that all respondent use air conditioning, the data reveals that natural cooling methods have decreased with only 14% of respondents cooling their homes with natural breezes and 36% still using fans. More is focused on simply controlling the thermostat as a method of lessening air conditioning while still trying to keep their home cool. Seeing how each respondent has moved away from natural methods of cooling and now rely on air conditioning, the question about how they felt growing up without air conditioning was asked. 82% of the respondents felt the conditions at that time were acceptable. Also provided in the survey were individual statements revealing why they feel they have no choice but to use air conditioning today and how hard it would be to go back to natural cooling. Within most of the statements provided, respondents explained the homes they grew up used materials that felt cooler to the touch. Many explained how they didn't know any different, survived with the bare minimum and were fine with it while slowly acclimating to living in air conditioning over time attributing it to new home construction and/or climate change.

4 Conclusion

It may be easier, cheaper and faster to design and build a house that is cooled entirely by mechanical means and repeat that process again until thousands more of the same are built without considering the context surrounding them. Consisting of different non-mechanical methods and some new energy efficient technologies, setting up an existing or new construction home for passive cooling, can help it be more energy efficiency. This can be something to fall back on when a break from air conditioning is inevitable. This can also redefine the current standard of living and mostly, it can help minimize the impact on the environment.

It is also understood that some climate conditions may not allow for natural passive cooling during parts of the year. In that case, efforts in combining some parts of the passive cooling system with mechanical systems can ease the cooling load demand and lessen the energy consumption. Some of these systems, will be more energy efficient than others and some will be better suited for extreme conditions that may require air conditioning during parts of the year. Some of these systems can include natural or forced ventilation for cooling, fans for cooling, evaporative cooling, air conditioning, and radiant cooling. While it may seem minor, making changes to an existing home or adding passive cooling measures to new construction, may make a world of a difference and lessen air conditioning dependency.

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