Manufactured Homes: Accessibility, Resilience, and Enhanced Quality of Life in Three Extreme Climates

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ABSTRACT: This paper asks what can we learn from homeowner modifications of manufactured homes about addressing resilience, accommodation, energy savings, occupation, and flexibility? The authors identify retrofits which decrease heating and/or cooling requirements; provide long term accessibility as owner's age; plan resilience in the face of extreme weather; and enhance quality of life aligned with local culture. Three rural extreme climates in Louisiana, Arizona, and Colorado provide data on a wide range of solutions tailored to the particularities of climate conditions. The resulting assessment identifies categories of modifications and retrofits and associated typologies, for example homes on piers, unconditioned porch or carport additions, conditioned additions, envelope modifications, and changes to provide ADA accessibility.

Quantified assessment through energy and structural modeling evaluates the effectiveness of the homeowner designed retrofits observed in Louisiana, Arizona, and Colorado. The results of assessment reveal that homeowners decreased EUI through simple passive methods adapted from agricultural, aquacultural, and industrial architecture. Energy modeling simulation on case studies for observed retrofit roof assemblies showed up to a 28% decrease in EUI in Louisiana, and 58% decrease in EUI in Arizona. These same retrofits produce large exterior covered occupiable spaces which provide an extended period of thermal comfort by over 20%.

While the paper primarily focuses upon assessment of heating/cooling mitigation through roof assembly retrofit, it also discusses: structural changes through the addition of piers, super structure, and lifting systems along with accessibility and circulation changes, all due to accommodation of FEMA base flood height elevation in Louisiana; window retrofits, window shading, and understory/crawlspace protection and skirting to both provide resilience during climatic events, but also to mitigate heat transfer in manufactured homes in Arizona and Colorado; and heating/cooling source retrofits and augmentation in all three locations.

KEYWORDS: affordable, retrofit, manufactured home, energy modeling

INTRODUCTION

In 1974, the Department of Housing and Urban Development (HUD) began regulating manufactured housing to assure "quality, durability, safety, and affordability." Today, both HUD and the Department of Energy are funneling research funds to the manufactured home industry to design new sustainable homes and to find retrofit solutions to increase energy efficiency and resiliency. Instead of looking to designers or industry leaders, this paper proposes looking at three communities to investigate modifications that homeowners and tradespeople make to their own existing manufactured and modular homes. To produce a range of modifications, this paper investigates homes in rural communities in three different extreme climates.

This paper identifies retrofits which decrease heating and/or cooling requirements; provide long term accessibility as owner's age; planned resilience in the face of extreme weather; and enhanced quality of life aligned with local culture. This includes extensions of unconditioned living space to make it possible to comfortably increase occupancy for extended family members during short-term or long-term living arrangements, or to accommodate rural living patterns. Analysis of these retrofits also reveal decision making based on phased installation, cost control, and designs specific to the particularities of a region's climatic conditions.

This paper asks what can we learn from in situ modifications of manufactured homes from homeowners about addressing resilience, accommodation, energy savings, occupation, and flexibility?

1.0 CONTEXT

Manufactured homes serve a fundamentally important role as affordable housing. Data reveals how that affordability is achieved. Contemporary single wide manufactured homes range in size from about 74 to 130 m2 in floor area, while double wide manufactured homes average 213 m2. (Clayton Homes 2023) Manufactured homes typically have 2 to 3 bedrooms that have an average size of 16 m2 (larger for primary bedroom, smaller for other bedrooms). By contrast, new stick-built homes in 2023 averaged 232 m2 in floor area, with bedrooms averaging 21 m2. 2.5

people reside in the average home (Korhonen 2023). Manufactured homes typically have between 2 and 3 bedrooms, a distribution that aligns with the average occupancy count; in contrast roughly 80% of new stick-built homes have three or four bedrooms, above the average occupancy. (Wade 2021)

Through calculation, single-wide manufactured home average 45% the floor size of a new stick-built home, and a double-wide manufactured home averages 90% the size. In 2023, manufactured home sales were nearly equally divided between single and double wide, with the result that by inhabitable space, manufactured homes are on average 70% the size of stick-built homes. A single-wide is roughly the same size as an average home in 1920 (which had an average occupancy rate of 4.3 people), while today a contemporary stick-built home is 230% the size of an average 1920 home. Stick-built homes in the United States average over 200% the size of European and Canadian housing. (World Population Review 2024)

Manufactured homes cost less to build than stick-built homes per square meter. Labor costs are more stable, since construction is inside and not subject to vagaries of weather. Engineered construction processes limit excess unused materials. Manufactured homes do not contend with costs associated with slab or foundation work. Manufactured homes also favor cost efficient 2x4 construction with limited insulation. The contemporary construction cost of stick-built homes averages $2700/m2 (Grupa 2023) while manufactured homes average $754/m2 (Hazen 2023), though hidden costs like delivery, site preparation, and structural support are additional for manufactured homes.

Both stick-built homes and manufactured homes average energy costs of approximately $180/month. (DOE 2022) (Durani 2023) It is here where an inefficiency for manufactured homes becomes apparent. With the smaller building footprint, this means manufactured home energy costs may be as much as 50% more than stick-built homes. One source of explanation may be the thinness of the envelope assembly and minimal insulation.

With a focus on affordable housing, home equity not only speaks about the value of a home but access to home ownership across the entire population. Manufactured homes are important to rural America, providing the convenience of delivery in lieu of onsite construction. Manufactured homes serve populations disproportionately threatened by environmental disasters due to affordable land ownership in areas adjacent to coasts and in low-lying areas.

Increasingly federal agencies like HUD, USDA, and DOE are investing in manufactured homes as an important way to provide affordable housing for the US populace. These agencies also are steadily supporting new strategies for retrofitting existing manufactured homes, largely driven through engineering solutions developed by building science researchers and industry. The authors feel it is important to also investigate solutions designed by homeowners, analyzing affordable, effective, and easily managed remedies that are tailored to the specificity of local climate and associated cultural awareness.

2.0 FIELD STUDY AND DATA COLLECTION

The authors selected locations in three rural extreme climates to collect information on a wide range of solutions tailored to the particularities of climate conditions. Data from this field study revealed modifications by homeowners that align with agricultural, aquacultural, or industrial building practices common to rural locations, with corresponding material, structural, and detail selection. Unlike tight fit or optimized architecture, these design modifications rely on loose coupling and layering to provide resilience, protection, and flexibility of intended use. Additionally, solutions are often low tech, give preference to passive systems, and may have a sacrificial layer. The solutions provide the capability for mechanically trained self-reliant homeowners or community members to install and repair, rather than relying upon outside technicians who are less available in these underpopulated locations. In some cases, this means highly regionalized solutions appear, differing from one community to the next, based on localized experience and knowledge, including experience gained from local employers. Modifications may exhibit phasing, and the utilization of applications and technologies for other industries being converted to provide the same utility in service to the manufactured home.

Documentation of these modifications provides a taxonomy of solutions that could be utilized in less harsh environments, or in more populated areas, or as a basis for kits that could be purchased by homeowners, for DIY installation.

2.1. Case study 1: Louisiana

Vermillion and Cameron Parishes, along the south Louisiana coast contain small communities like Erath, Delcambre, and Pecan Island. In the face of climate change and due to federal regulation, manufactured homes have been raised an entire floor height to protect from coastal flooding and tidal surge during hurricanes. Lafayette, the closest metropolis is between 30 and 60 miles from these communities. A second site, in Catahoula Parish, is Larto Lake, a remnant oxbow lake from the Red River, that is now fed by the Red River's flooding. To prevent seasonal flooding, many homes are raised a full story above ground. These homes often have extended porch and balcony systems similar in typology to additions witnessed in Vermillion and Cameron Parishes. Alexandria, the closest city, is 45 miles away. While Larto Lake is inland far enough that it is not susceptible to hurricane force winds, it does have the same hot humid climate as the Vermillion and Cameron Parish sites, absent the cooling breezes from the coast.

2.2. Case study 2: Colorado

Cooperativa Nueva Union is in Leadville, Colorado, the highest incorporated city in the country (10,158 ft). This manufactured home community recently benefited from Colorado's HB20-1201 law, purchasing the park's land from its long-term owner. Temperatures average in the teens for winter months, with typically ten feet of snow fall each Winter and Spring. Modifications consider snow load, extreme cold, and wind. Homes have had multiple owners and modifications are incremental. Denver, the closest metropolis, is 100 miles away.

2.3. Case study 3: Arizona

Roosevelt Lakeview Mobile Home Park is located near Phoenix, on Forest Service Property. The homes were first purchased for tradesmen who were resurfacing one of the world's highest masonry dams with concrete; today, the park is mainly used for summer part-time residency. In 2012, after an intensive fight, the Forest Service agreed to renew the park's long-term lease based upon a plan that included specific rules for retrofit and modification of homes. These rules govern retrofits, including carport construction, standardized window shading techniques, skirting details, utility use requirements, and landscaping regulations. Temperatures average above 100 degrees three months per year, and average rainfall is sixteen inches. Phoenix, the closest metropolis is 106 miles away.

3.0 ASSESSMENT PROCESS

The assessment of data followed a mix of qualitative and quantitative processes. The authors first selected three locations that described extreme climates in the United States: humid, sub-tropical; hot, semi-arid; alpine subarctic. The authors surveyed rural locations to find communities of manufactured homes that had been retrofitted to adapt to the local climate, including documenting communities near to each other but exhibiting differing adaptation methods. Once selected, the authors documented the homes through photography and some owner interviews.

The authors entered the next phase of assessment, identifying categories of modifications and retrofits and associated typologies, for example home on piers, unconditioned additions – porch or carport, or conditioned additions, envelope modifications, and changes to increase accessibility. Categories of retrofit primarily addressed energy cost savings, resiliency / hardening, and accessibility / occupancy accommodation. The authors then reframed the research to look at corresponding elements within the retrofits, so that they could be isolated for analysis:

- Roofs, porches, decks, and carport (unconditioned, covered space)
- Piers, super structure, and lifting systems (structural changes)
- Accessibility, circulation, and conveyance (accessibility)
- Wall assembly and exterior cladding (envelope)
- Window retrofits and window shading (envelope – glazing)
- Understory/crawlspace, underfloor membrane, and skirting
- Heating/cooling source retrofit or addition

This paper qualitatively describes the retrofit innovations that the authors found for each element in the subcategories, and how the homeowners address climate while also aligning with cultural identity and accommodation. To develop a method for quantitative analysis, the authors selected one manufactured home case study in Louisiana and in Arizona to study roof, porch deck, and carport condition as an initial test of analysis method. To evaluate effectiveness the authors and their graduate assistants constructed digital models in Revit, and then the authors analyzed the models in DesignBuilder in conjunction with thermal comfort analysis for the sites. The resulting data is presented below. It identifies innovations, misconceptions, and opportunities for improvement.

As mentioned earlier in this paper, the energy consumption of manufactured homes is higher compared to single-family homes primarily due to inadequate insulation and the use of materials that are not suitable for different climates. In Arizona, the average Energy Use Intensity (EUI) number for manufactured homes is 104 kWh/m2 while in Louisiana, it is 70 kWh/m2. These numbers are significantly higher than the EUI values for single-family homes. For single-family homes in Arizona, the EUI ranges between 38-73kWh/m2, and in Louisiana, it ranges from 63-73 kWh/m2 based on home wall structure (NREL 2024). To investigate the impact of certain modifications on energy consumption and EUI numbers in manufactured homes, a building energy simulation was conducted using DesignBuilder for both the Louisiana and Arizona locations.

In the next phase of research, the authors plan to return to the communities, further identify stakeholders, and complete additional surveys at the scale of analysis of retrofits to envelope assembly bolstered by forensics. With this additional data, the authors will refine digital models and corresponding energy analysis, while adding structural analysis. A future stage of research envisions developing a program that identifies test homes, placing sensors and collecting utility information, to compare homes that have not been modified with those that have. This added layer of information will be used to validate the data generated from the energy modeling. The authors observed non-modified similar homes in each location, allowing for comparison of data.

3.1. Roofs, porches, decks, and carport

In the two hot climates of Louisiana and Arizona this study identified many added roof configurations hovering above the manufactured home's original roof, and the corresponding heat absorption and transfer. (fig 1 & 2)
In Louisiana, typically these roofs were positioned 9-12 inches above the existing roof, supported by either wood or steel beams and rafters, clad with metal deck but without a layer of OSB or plywood sheathing. Open air circulates between the two roof layers, and the original asphaltic roof is protected from sun and extreme heat degradation and leaks. The construction methods of these roofs ally with agricultural and aquacultural building methods of barn and shed construction. It could be argued that the principles also follow that of contemporary rain screens in commercial architecture, with the added benefit of providing air circulation at the building's hottest location.

In Arizona, the authors again witnessed adding metal roofs on top of the asphaltic shingles, but in this case the space between roofs is smaller than witnessed in Louisiana, and gables close off the space between the metal roof and the original manufactured home roof, creating a liminal attic space. The author's also noted extension of the roofs to create large carports and spraying white polyurethane insulating foam onto the metal standing seam which covers the asphaltic shingles.

Quantified results of energy modeling simulation conducted for Louisiana indicate that adding a metal roof over the asphalt roof can bring down the EUI number by around 13%, reducing it from 101 kWh/m2 to 88 kWh/m2. Introducing a 12-inch air cavity between the two roofs can lead to an additional 15% reduction, bringing the EUI number down to 75 kWh/m2. A similar study conducted in Arizona showed that adding a metal roof over the asphalt roof can reduce the EUI number by 30%, lowering it from 130 kWh/m2 to 100 kWh/m2. Additionally, the inclusion of a 4-inch polyurethane foam insulation on top of the metal can reduce the EUI number by another 28%, taking it down from 100 kWh/m2 to 73 kWh/m2.

In addition, extending the roofs to cover the carport area also impacted energy consumption in the study. In Louisiana, this modification resulted in a 2% reduction in annual energy consumption, while in Arizona, it led to a 5% reduction. By extending the thermal comfort zone for occupants, the larger roof can contribute to a more comfortable indoor environment, potentially reducing the need for excessive cooling and improving overall energy efficiency.

Roof material selection and color further yield temperature reduction, with a corresponding heat load reduction for HVAC in conditioned space. Conventional roofs can reach temperatures of 65°C or more on a sunny summer afternoon. Under the same conditions a reflective roof could stay more than 28 °C cooler (US Department of Energy 2023). Solar reflectance from a cool roof in air-conditioned residential buildings can reduce peak cooling demand by 11–27% (US EPA 2014). Additionally, an efficient total roof system can lower the energy required for cooling a Louisiana home by 30 percent or more (Davison, Heinberg, and Williamson 2010). While metal roofs may cost $108 sq/m (ASHI 2023), which is double in price compared to asphalt roofs, they are long lasting, needing replacement after 40-80 years in comparison to asphaltic roof replacement every 15 years in the hot climates of Arizona and Louisiana. To further evaluate this comparison, the team will calculate LCA of the standing seam with rolled asphaltic shingles in the next phase of research to relate purchase cost with overall environmental cost.

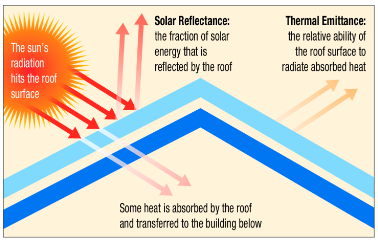

Figure 1: Solar reflectance, thermal emittance, heat absorption and transfer from solar radiation interacting with the surface of a roof. Source: (Mohan Rawat, R.N. Singh 2022)

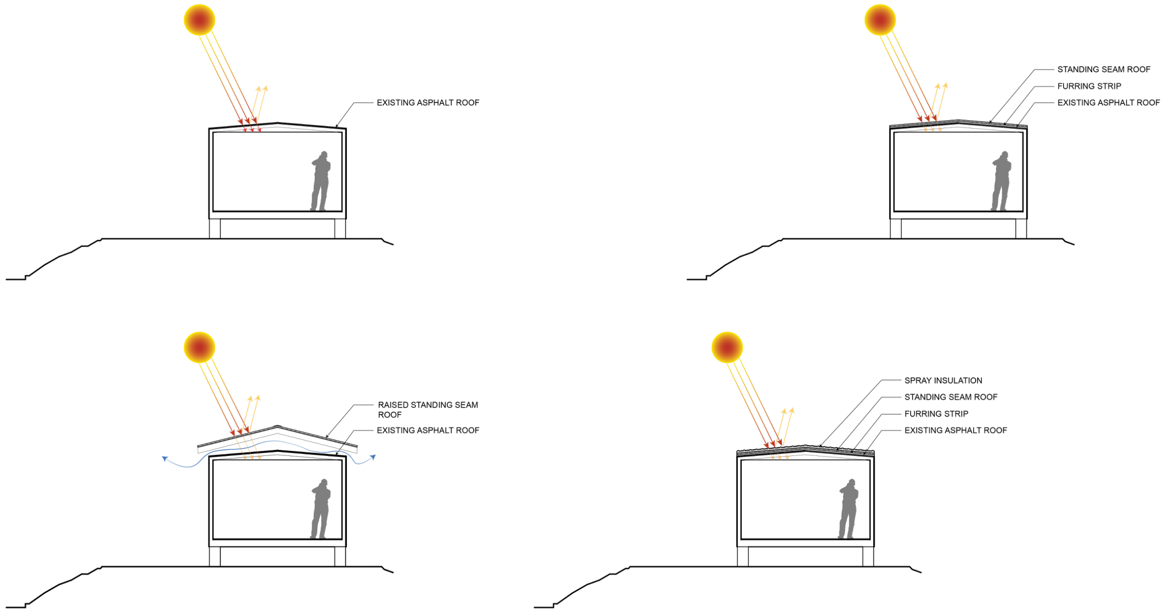

Figure 2: Solar reflectance, thermal emittance, heat absorption and transfer from solar radiation interacting with the surface of a roof for four conditions: asphaltic roof, LA and AZ; standing seam metal roof installed on top of asphaltic roof, LA and AZ; standing seam metal roof with .3-meter air gap, LA; standing seam metal roof installed on top of asphaltic roof with additional .1 m of white spray foam insulation on top of standing seam. Source: (Authors 2024)

It is important to note that the extended roof can provide additional benefits beyond energy consumption. One of these benefits is the increased shading area, which can enlarge the occupiable outdoor environment to incorporate unconditioned porches and carports. With manufactured homes providing on average 30% less conditioned living space than stick-built homes, these covered, unconditioned spaces deliver extended living space for a large part of the year in Louisiana and Arizona. Of the attached porches we observed usable square footage increased by at least 50%.

In Louisiana, residents' experience uncovered thermal comfort 8% of the year, predominantly during September, and October with an average of 3 months (Dec to Feb) of temperature below thermal comfort during the year. During the warmer months, residents experience uncovered thermal comfort as low as 2% in Jun and 0% for July and Aug for activities during waking hours. Covering a porch, while allowing cooling breezes through screens lengthens external thermal comfort by 20%, specifically during morning and early evening hours. Ceiling fans provide an additional 10% thermal comfort during this same period. Additionally, porch spaces are sheltered from rain, and often screened to provide protection from insects. (fig 3 & 4)

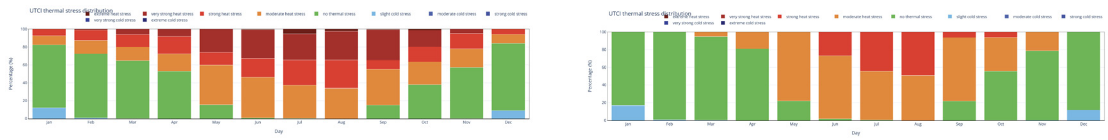

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Figure 3: Thermal Stress distribution for outdoor thermal comfort in Louisiana, a) with sun and no wind b) with no sun and no wind. Source: (Betti 2003).

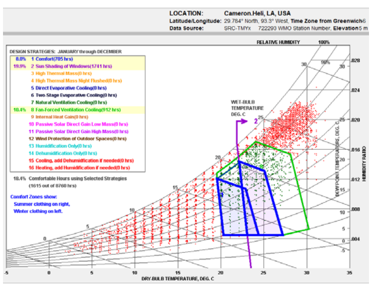
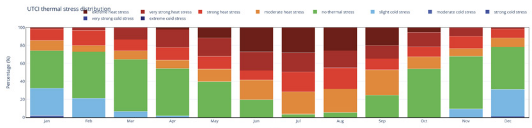


Figure 4: Psychometric Chart for Louisiana thermal comfort zone and best strategies to expand the comfort zone. Source: (UCLA Energy Design Tools Group 2019).

In Arizona's hot dry climate, thermal comfort is also extended through porches and carports. Uncovered thermal comfort for Arizona is 10% throughout the year, with an average of 5 months (Jan to March, Nov, and Dec) of temperature below thermal comfort. During the warmer months, such as July, residents experience uncovered thermal comfort only for 3.5% compared to October with 30%. Covering a porch, while allowing cooling breezes through screens lengthens external thermal comfort by 23%, specifically during morning and early evening hours in the summer. For example, shading strategies can expand the comfort level from 3.5% to 42% in July. (fig 5 & 6)



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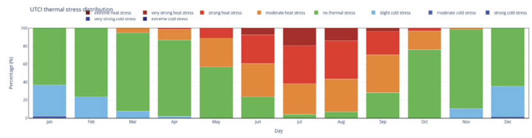

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Figure 5: Thermal Stress distribution for outdoor thermal comfort in Arizona, a) with sun and no wind b) with no sun and no wind- Source:(Betti 2003).

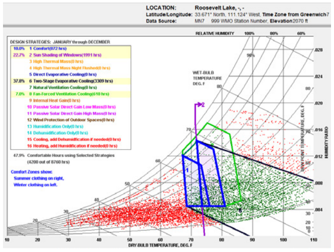


Figure 6: Psychometric Chart for Arizona thermal comfort zone and best strategies to expand the comfort zone- Source: (UCLA Energy Design Tools Group 2019).

These covered spaces also protect homeowners' belongings. The paint lifespan for a car, boat, or four-wheeler parked in the sun is roughly half the length of being protected. As a result, an unconditioned carport significantly extends the value of automobiles and equipment. The authors recognize that shading of porches impacts daylighting. In future calculation iterations, the authors will refine models to consider increase in utility cost to light interior spaces might offset decreases in utility cost due to reduction in solar thermal load.

3.2. Piers, superstructure and lifting systems

In the face of climate change and due to federal regulation, manufactured homes have been raised an entire floor height to protect from coastal flooding and tidal surge during hurricanes in Louisiana, in alignment with FEMA establishing base flood elevation height. In some cases, raising homes or roofs accommodates RV parking beneath the roof, or home itself. Residents have redesigned the areas underneath the manufactured homes to provide dedicated spaces to embrace all facets of Creole and Cajun heritage: cleaning fish and game, working on equipment, and gathering for meals, music, and dancing.

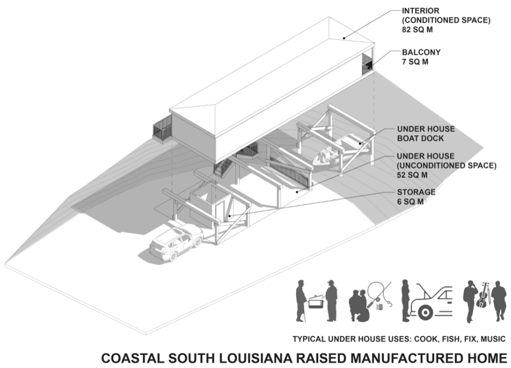
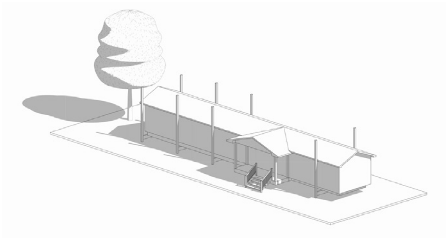


Figure 7: Covered spaces under the manufactured homes are used in culturally relevant ways. Source: (Authors and GAs 2024).

In Cameron and Vermillion Parishes, construction draws from aquacultural architecture using primarily wood piling supporting wood structure clad with uninsulated standing seam roofing. In some cases, piers are reinforced concrete masonry units. Larto Lake, 120 miles north of the coast in Catahoula Parish, contends with seasonal flooding from the Red River. Many houses are also raised a full story above ground. Unlike Vermillion and Cameron parish, all support structure is steel. Several homes have the added capability of being further elevated using a hand winching system, an adaptation of dock winching systems seen along the lake's shore.



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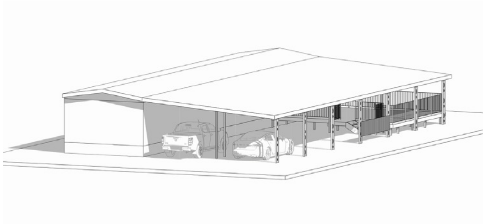

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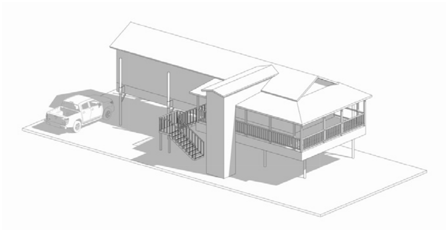

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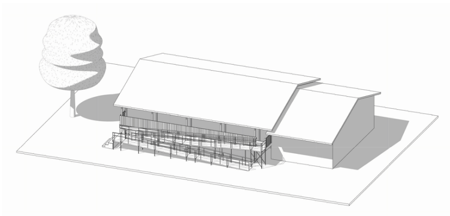

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Figure 8: Typologies accommodate climatic conditions and accessibility. a) hand winching system to raise a home above flooding in Louisiana b) extensive carport in Arizona c) home with mechanized lift in Louisiana d) ADA ramp in Louisiana. Source: (Graduate Assistants Salomon Rodriguez, Rachel Helminger 2024).

3.3. Accessibility, circulation, and conveyance

In Cameron and Vermillion Parish, changes to FEMA base flood elevation marks the built environment, as houses built during different decades are built to different heights. Nearly all homes in these flood prone areas are raised to a height that affects ADA accessibility. This is especially relevant as this rural, independent populations tends to prefer to age in place. The authors observed a range of resultant solutions, from electrified lifts to ramping. In Louisiana, wood ramps rot, and algae grows on the surface, making them hazardous. Further investigation will reveal whether the commercial sector is adequately serving this population with products that accommodate the situation while also acknowledging the climatic conditions.

3.4. Wall assembly and exterior cladding

Many of the homes observed retained original vinyl or metal sheathing. Some portion of this siding was covered in mold, algae, or rust. Additional research will focus on where retrofits have occurred. One area of observed solutions is retrofitting exterior wall assemblies to stucco in Colorado. Stucco is seen as a vernacular material, and tradesmen are used to working with it. Given the interest by the DOE on retrofitting with prefabricated panels, analysis of stucco performance could provide useful data on benefits of sealing assembly, and insulative properties of layers within the retrofit assembly.

3.5. Window retrofits and window shading

Window replacement represents a substantial cost. In lieu of this retrofit, the authors witnessed a variety of low-tech passive solutions that decreased heat gain. In Arizona, the authors documented a range of shading interventions, from awnings to louvered partitions, and including some coverings that could also be lowered and locked to provide security when homeowners travel. In Colorado storm windows are extensively used, adding an extra layer of material to prevent air leakage.

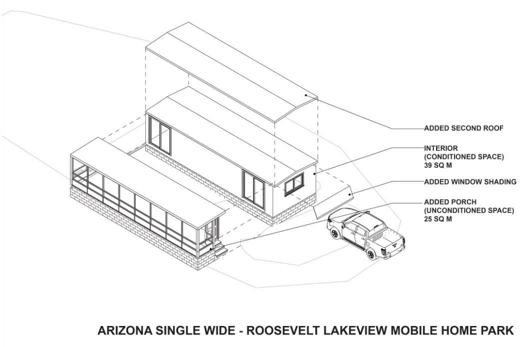

Figure 9: Homeowners have also retrofit skirting systems and added varied methods to decrease heat exchange through windows. Source: (Authors and graduate assistants 2024).

3.6. Understory/crawlspace, underfloor membrane, and skirting

Many observed modifications sought to harden and protect the undercarriage vapor barrier and associated insulation. Homeowners sought a variety of skirting options that attempted to obviate wear and tear, especially plastic skirting that becomes brittle in sunlight, and can be chewed by animals seeking protection which can result in related damage to vapor barrier and insulation. Homeowners also sought to replace the lack of permanence that skirting portrays, often retrofitting with more permanent protective materials. Homeowners seek to deploy sheet goods to decrease breeze. There also seems to be a perception that skirting with mass, like stone, brick or concrete, provides thermal protection against temperature change. In Arizona, vernacular materials like stone also give the visual perception of connection to the ground, and perceived benefit of using local materials. Unfortunately, DIY solutions are fully sealed, exhibiting a lack of understanding of the need to provide ventilation to prevent condensation and rot. One unique solution was observed in Larto Lake, where clickable metal ceiling planks were installed along the underside of the home, exhibiting ease of installation, flexible access to MEP infrastructure, breathability, while resisting unwanted impact.

3.7. Heating/cooling source retrofit or replacement

Modifications include replacement of and supplementation to original HVAC units. In Louisiana and Arizona, some homeowners replace window units and inefficient HVAC units with mini splits. Manufactured homes' efficient floor plans, in conjunction with the ability to establish zones that can be turned off when unoccupied make mini splits particularly well suited to this housing type. The authors plan to investigate how the addition or retrofit of mini splits affects existing ducting, and if abandoned ducting is being retrofit to decrease heat/cold transmission. In Colorado, the addition of wood burning stoves to offset utility costs, also provides a resiliency solution. The forests are choked with beetle kill pine in Lake County, and burning it is seen as a method to mitigate fire danger in the summer. Finally, when homeowners replace window units there is a corresponding increase in daylighting, and the opportunity for sealing gaps created by the propped windows. In the future, using comparative modeling, the authors plan to evaluate the resulting gains in efficiency.

CONCLUSION

This paper is a first phase of research, documenting homeowner modifications to manufactured homes through photographs, digital modeling, and initial computational analysis. These modifications do not adhere to climate tightened engineered solutions, and yet our calculations reveal they are effective, while being low cost, and easily installed. Phases of research beyond this paper will include homeowner interview, collection of data on utility use, manufactured model # identification and sourcing of original design specifications, further documentation on any specific modifications beyond what was initially observed, with a particular focus on modifications to sealed off crawl spaces, changes to exterior envelope, roof conditions, and/or hvac/mini split retrofits.

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