Sunwise Cooperative: Affordable Solutions to Thermal Discomfort

ABT 212: Path to Zero Net Energy

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EXECUTIVE SUMMARY

The Sunwise Cooperative is an 8-bedroom, 2-bathroom passive solar home located in West Davis which houses ten residents. The residents are currently experiencing thermal discomfort in the winter and the summer. A thermal comfort survey of the residents found that the individual rooms are slightly more uncomfortable than the communal spaces during these seasons and that the summertime is the most uncomfortable season.

Two site visits were conducted to determine if there were aspects of the home which contribute to the residents' discomfort. There are several doors with gaps at their bases, most of the windows are single-pane, many of the thermal curtains for the windows are either inaccessible or in need of repair, the ceiling fan is inoperable due to the noise it produces while in use, and the thermal storage pillars are not currently utilized by the residents.

The authors conducted research to compile no-cost, low-cost, medium-cost, and high-cost solutions to suit an immediate budget of $500 and a potentially larger budget in the future. The authors consulted with Hammond + Playle Architects, LLP to ensure that the passive solar features of the home are optimally utilized. The authors also conducted a literature review to assess the efficacy and cost of each solution, and lastly, rated these solutions using an evaluative matrix according to the factors which matter most to our client.

These methods produced the following results. The authors created an infographic on optimal utilization of the thermal storage pillars. This infographic can be posted in the house somewhere near the thermal storage pillars for the residents' reference. The authors also recommend that the residents implement thermal curtain repair/replacement where the curtains are inaccessible for opening and closing or otherwise in need of repair as well as installation of a thermal liner on the conventional curtains. The authors recommend door stoppers for the gaps underneath the doors to prevent heat loss due to air leakage. The authors also recommend fan maintenance and/or replacement for the ceiling fan on the second floor for heating and cooling purposes.

TABLE OF CONTENTS

1. PROJECT BACKGROUND

1.1. Client Background

The Sunwise Cooperative is a cooperative housing located in West Davis. It is a 8-bed, 2-bath, 2-story passive solar house with ten occupants. These residents are currently full-time Davis students, although this housing option is available to non-student applicants as well.

The Sunwise Cooperative is owned and managed by the Solar Community Housing Association (SCHA). The SCHA is a non-profit organization based in Davis, CA which provides cooperative housing for people with low income. Our point of contact for this project (who will be referred to as “the client” in this report) is one of the ten residents of the Sunwise Cooperative.

1.2. Problem Statement

The ten residents of the Sunwise Cooperative have expressed thermal discomfort in the winter and most especially in the summer. Although the Sunwise Cooperative has amenities to control the thermal comfort of the house, many of these amenities are currently inaccessible or inoperable. The single ceiling fan in the house creates significant noise, and is therefore not utilized by the residents in the summer. Most of the thermal curtains which cover the windows of the home are both inaccessible and inoperable; many of the rods which hold the curtains are broken, some of the curtains’ inner and outer layers are beginning to separate from one another, and the curtains which cover the largest windows are difficult to reach from the balcony of the second floor. Additionally, the doors have large gaps at their bottom, and the wood-burning stove leaves ash over the living room area when operated.

2. METHODOLOGY

2.1. Identifying scope

The original proposal of the project suggested that the main problem was energy efficiency, so the team analyzed the Sunwise Cooperative energy bills. From this analysis, their energy usage was below the average for California households. Also, the Sunwise Cooperative is a passive solar house, and there is no central heating or cooling system. Improving appliances' efficiency is not a crucial solution for residents` discomfort. So the team concluded that energy efficiency was not the problem.

Following a couple of site visits to look at the house amenities and gain a better understanding of the client's needs, as well as a thermal comfort survey conducted among the Sunwise residents, the team identified that the primary problem is the residents’ thermal comfort in the winter and most especially the summer.

The team will make recommendations to improve the efficacy of the heat transfer in and out of their space to provide a more comfortable home. The client specified a budget of $500 for immediate remedies. However, more expensive solutions were also considered for the client's future consideration since the budget is subject to change. Thus, the suggestions provided to the client are evaluated based on cost and efficacy.

A summary of the images collected during site visits and utility bill analysis can be found in Appendix A, Figures 1-4.

2.2. Research

The current budget of the client was utilized as a guiding factor for conducting research. The authors first researched no-cost solutions to ensure that the current amenities of the house are optimally used to maximize their capabilities to provide thermal comfort. Then, low-cost solutions were researched. This phase of research incorporated repairs and small retrofits. Lastly, high-cost solutions were researched in case the implementation of no-cost and low-cost solutions prove ineffective to solve the client's thermal discomfort.

For each of these categories, a literature review was conducted to evaluate the efficacy of each solution against their respective costs. The authors also consulted with Hammond + Playle Architects, LLP to ensure that the passive solar features of the home are optimally utilized.

In addition, multiple information included in this report was obtained from "Energy Saver", which is a website from the U.S. Department of Energy that serves as a consumer resource on saving energy and using renewable energy technologies at home.

2.3. Equity

This project aims to equitably provide thermal comfort. The Sunwise home is an affordable housing option for people with low income since it is cooperative. It is also affordable in that the home has no central heating or cooling system, so the residents' utility bills are inexpensive. Affordable housing should not imply uncomfortable housing; it is imperative that this project considers the client's current budget, the potential increase in utility bills for the residents, and all of the rebate opportunities available for larger retrofits (if deemed necessary by the client).

3. RESULTS AND DISCUSSION

3.1. Thermal comfort survey results

Seven of the ten residents of the Sunwise Cooperative responded to the thermal comfort survey created by the authors. The survey asked for resident feedback on when and where they experienced the most thermal discomfort and if they were concerned about their utility bills. They were also given the opportunity to express any additional concerns in a short answer format.

All of the respondents stated that utility bills were not a concern. All of the respondents agree that summertime is the most uncomfortable season in the house. Two of the respondents mentioned that the windows are poorly insulated and that there is a draft from the gaps in the doorways in the wintertime. One of the respondents also commented that they are unsure whether or not the thermal storage pillars are helpful. Nearly all of the respondents commented that their personal rooms were the most thermally uncomfortable compared to the communal spaces.

Thus, it can be concluded that thermal discomfort in the winter, but most especially in the summer, is the main issue for the residents.

3.2. No-cost solutions: Optimal use of passive solar home amenities

The Sunwise Cooperative has thermal storage pillars located immediately adjacent to the windows on the south side of the house. The residents are unsure if the thermal storage pillars work, and they are not sure how to operate them to benefit from passive cooling in the summer and passive heating in the winter. The authors consulted with Hammond + Playle Architects, LLP to identify best practices to optimize the utilization of the thermal storage pillars since this company specializes in passive solar heating and cooling and performs and advises the installation of such thermal storage pillars.

Findings from this consultation are threefold; the proper operation of the thermal storage pillars require proper utilization of the adjacent windows and their corresponding thermal curtains. These findings are summarized in an infographic (see Figure 5, Appendix C) which was delivered to the client for residents' reference.

Before these steps in Figure 5 can be taken, there are prerequisite steps which should be taken. Firstly, the thermal storage pillars should be filled with water. The efficacy of thermal storage pillars relies on these pillars being filled with water; since water has a high specific heat capacity, it provides substantial thermal mass to be used for heat storage. The client must determine if the thermal storage pillars are filled with water, and if they are not, then to fill them. Secondly, the windows and thermal curtains adjacent to the thermal storage pillars should be made accessible to the residents. This is discussed further in Section 3.3.1. and Section 3.3.3., respectively.

As shown in the infographic referenced above, the proper operation of the thermal storage pillars in the summer consists of the following steps:

1. Open thermal curtains and windows at night to benefit from convective cooling of the pillars and of the indoor space. This will cool the pillars overnight.
2. Close the windows and thermal curtains during the day to block out the radiant heat. Then, the thermal storage pillars will cool off the house during the day from the cooling acquired the night before.

Conversely, in the winter, the thermal storage pillars should be utilized with the following steps:

1. Open the thermal curtains during the day to benefit from the radiant heating of the thermal pillars and of the indoor space. This will heat the pillars during the daytime.
2. Close the thermal curtains during the night to help with insulation so as to discourage heat transfer from the house to the outside via the windows. Then, the thermal storage pillars will heat the house during the night from the heating acquired during the day.

In addition, the Sunwise Cooperative has a ceiling fan installed on the second floor over the stairway, which can improve thermal comfort all year long when it is appropriately used. Based on information obtained from "Energy Saver", ceiling fans should be operated in a counterclockwise direction during the summer to push cold air downward. Whereas in the winter, it should be operated in a clockwise direction while set on a low speed with the aim of moving warm air from the ceiling to the living levels of the space [1]. However, the ceiling fan is currently unused because it creates significant noise when operating; lack of maintenance may be the reason for this noise. More information regarding maintenance/replacement of the ceiling fan is presented in section 3.4.1.

Additionally, the client has expressed concern about not being able to utilize the wood-burning stove for heating in the wintertime on no-burn days. However, according to the Sacramento Metropolitan Air Quality Management District, "those living in homes where a wood burning device is the only source of heat may be considered for an exemption from Sac Metro Air District Rule 421 by completing an Exemption Request" [2].

Cleaning rooftop solar panels is another option. However, one study found that the estimated improvement by cleaning solar panels is approximately 1% [3]. Nevertheless, cleaning solar panels will be an option for reducing energy bills without additional money. It is generally recommended to clean solar panels every 6 months to a year.

Based on the inspection of the house and interviews with the client, most of the current house amenities, i.e. almost all the thermal curtains and the ceiling fan, are inaccessible and/or inoperable; therefore, some repairs become necessary in order to use these amenities as optimally as described above. A more detailed description of these repairs is discussed in the following subsections.

3.3. Low-cost solutions

3.3.1. Curtains

According to the Department of Energy (DOE), about 30% of a home's heating energy is lost through windows. In cooling seasons, about 76% of sunlight that falls on standard double-pane windows enters to become heat [4]. Thus the importance of using adequate window covering to prevent this.

As mentioned earlier in this report, the Sunwise Cooperative has thermal curtains in the communal spaces, but some of these curtains are currently inoperable. After one of the site visits, the residents mentioned that the thermal curtains of the lower half of the big south window were taken out sometime; thus it would be recommended to put them back in place so that they can be operated. Additionally, the residents pointed out that the curtain located in the right upper half of the big south window is inoperable

and that it might be broken. After analyzing close-up photos of the curtain rod and videos of the curtain rod, the authors concluded that the curtain rod is only out of place. They anticipate that this will be an easy repair, as it is very likely that the curtain rod just needs to be inserted back into the support's holes.

Also, it is presumed that the curtains in the rooms are conventional ones, so for a more effective thermal insulation, the authors recommend installing thermal liners in the conventional curtains. They recommend getting the thermal liners from Amazon which cost starts from $9 for a 2 panel set [5]. These liners are not only inexpensive but also easy to install.

3.3.2. Doors

According to the Department of Energy (DOE), air leakage accounts for 18-20% of heat loss during the winter [6,7]. This is consistent with the feedback we received from the residents on the thermal comfort survey. The DOE recommends caulking and weatherstripping doors to prevent air leakage; this can save homeowners considerable energy used for heat transfer. Insulation in the doors is also an important part of preventing unwanted heat loss or gain (the DOE recommends R5-R6 for doors). Although it is apparent from our site visit (see Appendix A for images) that some of the doors provide poor insulation; in consideration of the client's budget, the authors recommend door stoppers at the base of each door to prevent as much air leakage as possible. The authors recommend these door stoppers from Amazon which cost $16 for a pack of two [8]. These are customizable and easy to install; the residents may cut the door stoppers to the appropriate length for each door.

3.3.3. Windows

According to several window manufacturers, double-pane windows offer 18% more insulation than single-pane windows in the summer and 24% more in the winter. Triple-pane can offer even greater insulation than double-pane, but they are much more expensive and much more difficult to install. Additionally, triple-pane windows are heavier than double-pane windows, and may be less accessible to the residents. This is not desirable, since the residents will need to easily open and close windows for temperature control as well as proper thermal storage pillar operation.

The appropriate installations should be made so that the residents are able to access the windows to easily open and close them. The authors recommend that the client consult with the window vendors to request this, particularly for the south side windows that are immediately adjacent to the thermal storage pillars, since this is necessary for proper thermal storage pillar operation.

3.4. Medium-cost solutions

3.4.1. Fan

To solve the noise issue on the ceiling fan, maintenance should be performed. Below are some tips on how a homeowner can perform maintenance to their fan. This information was obtained from some home warranty companies' websites [9,10]:

- Vacuum and Dust the Fan.

- Tighten Screws.
- Clean the Fan Motor.
- Lubricate Ceiling Fan Bearings

Also these companies recommend maintenance should be done at least once a year.

If the residents decide to hire a professional to perform fan maintenance, especially because of the current noise issue, the cost could vary between $50 and $200 [11], depending on what needs to be fixed. Also, there's the possibility that after the inspection, the professional suggests replacing the current ceiling fan for a new one, either because of the cost or infeasibility of the repair. In this scenario, the cost of buying a new one can vary between $90-$110 [12,13], plus the installation cost which for California may vary between $180-$350 [14]. For this second scenario the total cost is then expected to be $270-$460.

3.5. High-cost solutions

3.5.1. Governments incentives and benefits of a mini-split heat pump

Government incentives include programs supported by the federal government, state government, and other utilities. It is supported by a tax credit or through a low-interest loan program. Most program application criteria are based on household income.

The Inflation Reduction Act enables homeowners to be able to claim a 30% amount of tax credit on energy-efficiency home improvements. The Inflation Reduction Act of 2022 includes two provisions authorizing $8.8 billion in rebates for Home Efficiency Rebates and Home Electrification and Appliance Rebates. Another federal government-level program is the Department of Energy's (DOE) Weatherization Assistance Program (WAP) [15]. It is the nation's single largest residential whole-house energy efficiency program. However, this program is focused on low-income households to improve the energy efficiency of their homes. [16]

Most state-level programs are also focused on financial support to prospective households. Property-assessed clean energy (PACE) [17] programs allow property owners to finance energy efficiency, water efficiency, and renewable energy projects on existing and, in some cases, new residential and commercial structures through a voluntary special tax assessment on the property. In California Yolo County, 1) California First, 2) HERO, and 3) Ygrene programs are available [18]. These programs are similar kinds of financial support programs under PACE. From the Ygrene support date, 31 households used Ygrene, and the average cost was $17,748 [19]. However, PACE is not a government incentive or subsidy program.

PG&E, the utility company, also has rebate programs. The California Golden State Rebate Program provides rebates for Electric heat pump water heaters and room air conditioners. However, they offer few products. For example, the room air conditioner rebates money is $20 [20,21].

The government incentive applicable to the Sunwise cooperative is the federal government's tax credit that can be received while installing a mini-split. In the case of Air-Source Heat Pump - Split Systems, 30% of the total cost, up to a maximum of $2000, can be supported. In the case of Ductless Air

Conditioning (mini & multi-split) Systems (AC only), 30% of the total cost, up to a maximum of $600, can be supported. Supportable items are ENERGY STAR-certified equipment with SEER2 [22] > 16. If it is installed in a quad-zone, the product cost is in the range of US$ 4,100-4,900 [23], and in the case of a triple zone, it is in the field of US$ 2,900-3,200. In addition, labor costs (more than 1,000 dollars), a California state permit [24] for new HVAC installation, and HERS test [25] costs ($250) are required. And as a new heat pump is installed, the electricity bill will increase. Generally, the energy star certified Mini split heat pump's hourly electricity consumption is 2.4kw~3.0kw based on 48000 BTU [26].

4. RECOMMENDATIONS AND CONCLUSION

The evaluative matrix developed by the authors evaluates the no-cost, low-cost, medium-cost, and high-cost solutions (Table 2, Appendix B) considering the factors listed in Table 1 in Appendix B. These factors were chosen and weighted in accordance with interviews conducted with the client as well as feedback from the residents. The solutions were scored according to each of the factors and their respective weights. The three highest ranking solutions on the corresponding evaluative matrix (Table 3, Appendix C) are suggested for implementation by the client:

1. Curtain repair and/or adjustment
2. Door stoppers
3. Fan maintenance and/or replacement

Repair of the thermal curtain located on the right top half and installation of the one that belongs to the lower half of the big south window are expected to be easy tasks. For both of them, residents can simply place the curtain rods back into the support’s holes.

In addition, to further insulate the rooms, thermal liners can be installed in the conventional curtains. A 2-panel set can be found on Amazon starting from $9. Residents can install them themselves.

Door stoppers can be found on Amazon for around $16 for a pack of two. Each door stopper’s length can be customized by the residents to fit each door, and the residents may install the door stoppers easily on their own.

Maintenance of the ceiling fan is recommended to eliminate noise. This can be performed by a professional or by residents. If the fan is not able to be repaired, it may be necessary to replace it. The cost of buying and installing a new fan can be expected to be as high as around $460. Also, regular cleaning and lubrication of the ceiling fan is recommended to be performed at least once a year. Residents can perform this maintenance, especially cleaning of the fan blades.

Additionally, implementation of all the no-cost solutions is recommended.

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APPENDICES

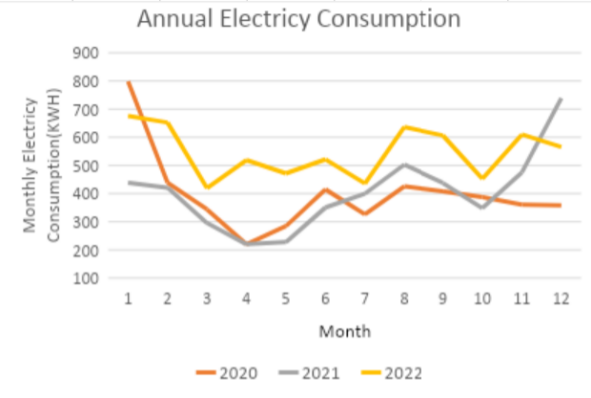
APPENDIX A: SUNWISE COOPERATIVE SITE VISITS AND SCOPE IDENTIFICATION

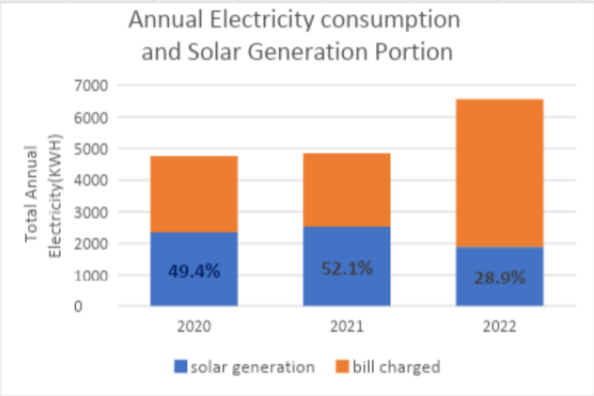
Figure 1. Sunwise Cooperative has several thermal curtains. Some thermal curtains or curtain rods are in need of repair.

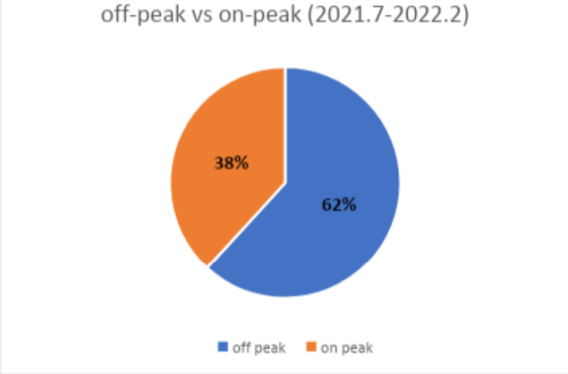
Figure 2. Sunwise Cooperative thermal storage pillars.

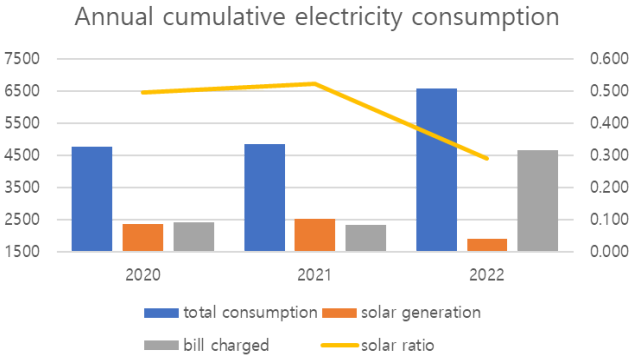
Figure 3. Sunwise Cooperative solar panels.

Figure 4a,b,c,d. Electricity bill analysis shows that solar electricity production decreased in 2022. The authors suggest that the residents regularly hose down the solar panels every few months to ensure higher solar electricity production. Otherwise, the Sunwise Cooperative consumes a lot less electricity than an average California 10-occupant residence.









APPENDIX B: EVALUATIVE MATRIX SUPPLEMENTAL TABLES

Table 1. Factors considered in evaluative matrix per client interviews and residents' feedback from thermal comfort survey. These factors were chosen and weighted in accordance with resident feedback from the thermal comfort survey.

F1	Product and installation cost
F2	Increased utility bill/maintenance cost
F3	Ease of installation
F4	Ease of regular use
F5	Thermal comfort: personal room (cooling)
F6	Thermal comfort: communal space (cooling)
F7	Thermal comfort: personal room (heating)
F8	Thermal comfort: communal space (heating)

Table 2. Legend utilized in an evaluative matrix to refer to all no-cost, low-cost, medium-cost, and high-cost solutions. Low-cost, medium-cost, and high-cost solutions were compiled for comparison via an evaluative matrix. The three highest ranking solutions are suggested for implementation.

LOW-COST SOLUTIONS	
L1	Curtain repair and/or replacement
L2	Door stoppers
L3	Upgrade window replacement: double- to triple-pane

MEDIUM-COST SOLUTIONS	
M1	Fan maintenance and/or replacement

HIGH-COST SOLUTIONS	
H1	Mini-split heat pump

APPENDIX C: CLIENT DELIVERABLES

Table 3. Evaluative matrix which scores the no-cost, low-cost, medium-cost, and high-cost solutions in accordance with the factors in Table 2 and their respective weights. The three highest ranking solutions are circled in red.

		CRITERIA																
		F1	W1	F2	W2	F3	W3	F4	W4	F5	W5	F6	W6	F7	W7	F8	W8	TOTAL
RECOMMENDATIONS	L1	5	7	10	8	8	5	9	7	10	10	10	9	10	8	10	8	568
	L2	9	7	10	8	9	5	10	7	10	10	10	9	10	8	10	8	608
	L3	1	7	10	8	3	5	9	7	7	10	7	9	7	8	7	8	410
	M1	3	7	7	8	5	5	10	7	8	10	10	9	8	8	8	8	470
	H1	1	7	3	8	2	5	9	7	10	10	10	9	10	8	10	8	454

Figure 5. Following consultation with Hammond + Playle Architects, LLP; the authors created the following infographic for the residents to reference for optimal operation of the thermal storage pillars. Intended for print and posting near the thermal pillars.