BUILDING-INTEGRATED NONIMAGING CONCENTRATOR THRU-REFLECTOR-WALL (TRW) SOLAR COOKER-KITCHENS CONSTRUCTION STUDIES PREPRINT

Joel H. Goodman, Dodgeville, Wisconsin, 53533, USA, email: joelhgoodman3@hotmail.com

ABSTRACT: Clean cooking energy is needed for about the 2.3 billion people that use solid biomass (wood, charcoal, and dung), kerosene, coal, etc. in developing regions mainly in the Torrid Zone. Building-integrated two-stage nonimaging concentrator thru-reflector-wall (TRW) solar cooker-kitchens conceptual constructional studies are presented with: fixed reflector walls, three-sided CPC-type funnel parts and E/W lightweight portable vertical reflectors manually re-positioned at noon for small-large cookware with cooks in kitchens without mechanical tracking, forced fluid loops and electronics. Site-built and prefabricated parts TRW kitchen building studies include: small houses, mid-large size buildings, pergolas, trailers/food carts, and for commercial food processing with various structural forms and materials (fired-clay, masonry, ferrocement, fiberglass, etc.). Portland cement damage to reflectors (flat glass silver mirror and aluminum) is discussed, and a R&D proposed project outline includes: test stands, student projects, optical-thermal ray trace studies and development of simulation design-aid tools. Conceptual and schematic design studies indicate potentials and extent of construction formation required for building-integrated nonimaging solar concentrating TRW indoor cooking systems for comparing to PV electric cooking systems. TRW type projects started in 2023 at the U. of Tarapaca, Arica, Chile, and the U. of California-Merced.

Keywords: building-integrated nonimaging concentrator, two-stage nonimaging concentrator, thru-reflector-wall (TRW) solar cooker, solar concentrator conceptual construction studies, tropical solar cooker-kitchen buildings, clean cooking energy.

1. INTRODUCTION

Humane sustainability depends on clean energy for cooking, food processing, water, etc. Clean cooking energy is an urgent priority in tropical areas with diminishing wood fuel and unaffordable fossil fuels. The need for and benefits of solar cooking in the developing world have been documented by several organizations e.g., about 2.3 billion people use solid biomass (wood, charcoal, dung, etc.), kerosene or coal for cooking; and heat is largest energy end use for about 50% of total global energy consumption according to the International Energy Agency [1]. Direct solar thermal cooking with concentrated sunlight heating cookware is proposed to be evaluated with building-integrated thru-reflector-wall (TRW) nonimaging reflector concentrators that collect diffuse and direct solar radiation. However, integrating these solar cooking concentrator systems in the built environment requires modifications to building design and site planning. Nonimaging concentrators "allow greatly relaxed optical tolerances" [2 p1] without tracking, fitting with conventional building construction tolerances. Conceptual and schematic studies are presented that indicate constructional designs required for TRW cooking systems with fixed reflectors supported on kitchen building walls and adjacent funnels mainly for the

Torrid Zone and near tropical latitude locations for various sizes and types of cookware. Kitchen cookware doors enable cooks to work inside of kitchens with large and heavy cookware too cumbersome to conveniently carry to outside solar concentrators in bright sunlight. TRW solar kitchen building studies are mainly without: mechanical tracking of reflectors or receivers, heat transfer fluids, plumbing and pumps and associated electronic control systems. The TRW nonimaging optical-thermal configuration is a building-size two-stage reflector concentrator with fixed cookware. The first stage has two parts: an EW-line large trough (one-sided kitchen wall trapezoidal-shape reflector or two sided) and an E or W (E/W) lightweight portable vertical reflector repositioned at noon; and a second stage horizontal inlet aperture funnel with three Compound Parabolic Concentrator (CPC) type reflectors and vertical reflector cookware door side. TRW kitchen building site-built and prefabricated constructional studies with various structural forms and materials for low and high seismic risk locations include: small houses, mid-size community, institutional, cafeterias, and restaurant buildings, open-air pergolas, trailers and food carts, and for commercial food processing. Studies include: flat glass mirror tiles and aluminum reflectors supported on masonry, concrete, ferrocement, wood walls, bamboo, recycled plastic and rigid foam with methods to block ion exchange damage by Portland cement to back-silver flat glass mirrors. TRW proposed R&D project notes include: test stand measurements of instrumented cookware targets, funnel construction options, student projects, comparative evaluation of flat and CPC-shape reflector trough kitchen walls, kitchen building designs, optical-thermal ray trace studies and development of simulation design-aid tools for the tropics. A TRW type test stand construction and measurements were started about November 2022 in Pandharpur, India (17.76˚ N) [3]. The presented TRW conceptual kitchen building designs for the tropics appear to be novel by integrating two-stage nonimaging reflector solar concentrators with cooks working in the kitchens. A research gap addressed in the proposed R&D project outline is empirical work to justify TRW building designs and demonstrations investment. The main research method has been to produce TRW conceptual and schematic building designs integrated with associated solar concentrating technology configurations that are references for proposed empirical evaluations. An aim of TRW solar cooking is to reduce stress due to climate-change warming on people living in the tropics.

This article of building-integrated nonimaging concentrator solar cooker-kitchen studies mainly for the Torrid Zone is an addition to previously reported studies of building-urban-integrated reflector concentrators that include: spherical bowls [4]; architectonic studies with selected concentrators [5]; small heliostats systems on long span hanging roofs [6]; and building-integrated interior tubes and nonimaging reflectors (BITNR) [7].

2. DEVELOPING TRW SOLAR COOKER-KITCHEN STUDIES

The TRW nonimaging two-stage reflecting concentrator that collects direct beam and diffuse insolation is initially being developed for building-integrated solar cooking applications for the tropics and near tropical locations, and higher latitude locations for seasonal applications. Diffuse solar radiation related to location can be substantial according to NREL [8]. Solar concentration can elevate cooking temperatures and reduce cooking times. Cooks, working in kitchens, avoid bright sunlight without mechanized tracking mirrors or receivers or pumped fluid loops. Standalone concentrating solar cooker appliances require frequent manual adjustment. Large area trapezoidal reflectors on building walls sloped according to latitude location avoid reflector support wind-tolerant structures required for tracking concentrators. There is a correspondence between sloped reflector walls for equatorial latitudes and linear vault building structures e.g., masonry vaults with compressed stabilized earth blocks (CSEB). Nonimaging CPC reflectors can deliver moderate concentration with stationary reflectors and receivers [2]. The TRW first stage concentrator parts are: a large fixed trapezoidal reflector EW-line trough (one-sided kitchen wall reflector or two sided) and a portable E/W lightweight vertical reflector repositioned at noon stowed when not in use; and second stage horizontal inlet aperture three-sided CPC-type funnel reflector with cookware door in a vertical reflector funnel side part of the kitchen wall. Kitchens may have single or multiple cookware doors and funnels. Cooks working in the kitchen avoid frequent trips in bright sunlight to adjust exterior standalone concentrators and attend cookware. Large and heavy cookware can be rolled in-out of the cooking zone that would be unmanageable for exterior focus standalone tracking concentrators and beyond limits of window-mounted solar cookers. However, there are solar access requirements for TRW kitchens that significantly influence kitchen building and site plan designs (Fig. 1).

Building-integrated large nonimaging concentrators are part of a wider research area of building and urban integrated solar concentrators. Cities and towns have high densities of people per land area with related buildings and energy consumption, and solar concentrators that deliver higher temperatures increase potential applications (cooking, food processing, water purification, etc.). Building-integrated solar concentrators in cities and towns are feasible however special design, installation and care for safe operation are required.

3. BACKGROUND

Conceptual building-integrated TRW nonimaging concentrator solar cooker-kitchens and related process heat application studies by the author began in early 2000 with glazed outlets of building-size CPC reflector troughs for the tropics [9]. Afterwards glazed insulated box type solar cookers and process heat receivers rolling/sliding in-out under unglazed outlets of building-integrated large CPC cooking zones were considered [10]. The glazed insulated box cookers occupied substantial kitchen space and required longer span structural lintels and had toxic outgassing from insulation and sealants considerations. Glazed cookware, e.g., the Hotpot TM (no longer manufactured in Mexico), was considered in c2005 with shorter lintels over cookware doors [5, 11, 12]. Building-integrated large CPC slight curvature troughs were considered for kitchen reflector walls for equatorial tropical latitudes with ordinary and involute second stage concentrator CPC type funnels. Current studies include vertical reflector kitchen walls for higher and near tropical latitudes, and higher latitude locations for seasonal applications. Flat kitchen wall reflectors reduce construction complications and cost of slightly nonimaging-curved kitchen wall reflectors. Building-integrated fixed large CPC reflector unglazed troughs with E&W reflectors for the equatorial tropics were discussed in 2003 with Prof. Bill Beckman, then Director of the U. of Wisconsin Solar Energy Laboratory and he commented: *"…buildings like this have never been built and it looks like it has some potential…about a concentration ratio of 2 to 2.5…". At a later meeting in 2004: "…about a 20% increase per side of ordinary CPC…".* Prof. Beckman did not comment about the E/W portable reflector repositioned at noon.

CPCs are widely reported in the literature and books [13, 14]. Thermal outward reflecting involute-cusp troughs by Trombe [15] were "rediscovered" and adapted for reflecting solar concentration [16]. A "double cusp" reflector concentrator for receiver tubes called a 'planar' collector by the Meinels was derived from a 'space radiator' used to reject heat from a spacecraft [17]. Winston and Hinterberger discussed Meinel's "cusp concentrator" presented at the 1974 NSF review [18]. Origin of stationary nonimaging CPC type optics 1966 references are: empty conical and parabolic-toroid funnel studies [19, 20]. Parabolic empty CPC trough and refractive filled concentrator R&D were advanced at the U. of Chicago [13, 2]. CPC troughs were developed and tetsed at RAC, Ooty, south India [21]. Involute CPC trough prototype sections for tube receivers were produced with a 3D printed mold and laid-up fiberglass by hand and compared to vacuum deposition of aluminum reflector of automotive headlight reflectors [22].

Architect Lambeth's c1974 Strawberry Fields Apartments East (Springfield, Missouri, Lat. 37.11˚N) combined a building-size exterior fixed upper curved nonimaging stainless steel reflector (top one-sided trough) to augment flat-plate solar thermal collectors [23] and a conceptual sketch is in Lambeth's earlier book [24]). The 1972 Yokum Lodge by Lambeth has a curved fixed reflector over an exterior door to melt snow [23]. The Heliothermic Housing project (not built) for Mount Demavend, Iran, had roof top solar thermal collectors augmented with lens reflectors [24]. Lambeth's 1974 solar module cabin in Washington County, Arkansas, has twenty-foot-tall E&W hinged reflector walls opened on sunny winter days to reflect solar to interior stone walls. Similar hinged reflector walls are on his 1976 mobile home study [23]. A vertically curved masonry wall construction has slight curvature at the second level made with special bricks in the first phase of the Monadnock Building in Chicago by Burnham and Root in 1891 has a somewhat similar profile to CPC shapes [25]. Sawtooth-shape roof structures and collectors with one-sided reflector V troughs have been built [26]; and the US National Agricultural Library in 1985 had reflector augmented evacuated tube collectors [27].

Solar cookers were designed and tested by Maria Telkes in the1950's. A folding-two step and fixed three step flat asymmetric reflectors augmented box cookers in India [28, 29]. A 'Through the Wall Solar Cooker' with glazed interior reflectors and exterior reflectors was patented by Kerr in 1987 [30]. A through the wall solar cooker called "SunGenius Built-in Solar" with an exterior reflector was installed and marketed in South Africa. Building-integrated thru-wall solar cookers with large area flat reflector troughs were demonstrated in Sudan (convective air) and southern Ethiopia (with VTR361 vacuum tubes and electric back-up) for "injera" flat bread baking machines in the kitchen [31]. Flat-plate collectors augmented with vertical kitchen wall reflectors and fixed E&W flat reflectors heated oil that naturally flowed thru the kitchen wall for indoor cooking with and without storage installed in Tiger Kloof, South Africa; and the collector system was installed in an elementary school in northern Chile. About 250 solar cooker systems were reported to be installed in several locations [32]. Preliminary construction studies of a building-integrated roll in-out large Tolokatsin type solar cooker has precast concrete wall elements with an oval cooking vessel (250 liters / 67 gallons per batch) opening and thermal insulation details not fully resolved [5]. Scheffler concentrators thru kitchen wall fixed focus solar cookers have mechanized tracking of an exterior parabolic dish-segment reflector with frequent reflector shape adjustments [33]. A thru building wall box-type double-glazed solar cooker with E&W fixed sloped augmenting reflectors was tested in Nigeria [34]. A building-integrated box type solar cooker for cooking in the kitchen was reported with a horizontal asymmetric CPC fixed trough reflector and double-glazing covering a step absorber plate and cookware for ~28˚ latitude, Adrar, Algeria [35]. A TRW-type student engineering semester project was started at the U. of Malaga, Spain (Carrillo Andrés 2022 personal communication).

Flat glass mirror segments glued to precast reinforced concrete funnel appliances are manually positioned on an azimuth pivot concrete base with a two-piece (top and bottom) glass enclosed cookpot [36]. A solar box cooker with inner reflectors on four sides with three steps was investigated in Mexico [37]. Temperature distribution CFD studies in a glazed box cooker with stepped interior reflectors indicate higher temperatures above the cook-pot [38]. Unsuccessful autoclave experiments with a standard Fenix solar box cooker that reaches temperatures above 130˚C at midday were reported [39]. Vertically trapezoidal shaped solar box cookers with triple glass covers, interior polystyrene insulation, exterior reflectors, and a plaster slab under a black absorber plate were tested in Abidjan, Ivory Coast, Africa, from February 1999 to September 2000 [40]. The Mexican Tolokatsin standalone solar cooker appliance has a glazed involute-CPC metal reflector, cylindrical absorber cookware, and an exterior augmenting CPC reflector trough. Autoclave experiments based on a Tolokatsin solar cooker receiver with added cover had temperatures about 160˚C for about two hours however it must not be hermetically sealed because of dangerous pressures [41]. An exterior flat inclined reflector for a double-glazed box-type solar cooker appliance with interior stepped reflectors significantly decreased boiling times at Tanta, Egypt, (~31˚ latitude) [42]. A student project at the Pondicherry Engineering College (PEC), S. India, studied the optical-thermal properties of CPC solar box cookers with and without end-wall reflectors with physical truncated models with a 32˚ half acceptance angle sloped ~12˚ (Fig. 34). Undergrad students designed and fabricated an aluminum reflector funnel solar cooker standalone appliance (Fig. 35). A pressure cooker used as a medical autoclave with a solar parabolic reflector dish in Huamba, Peru (12.77˚ S latitude) was a student project [43]. A solar cooker appliance on four wheels with an adjustable (about every ten minutes) parabolic segment glass mirrors reflector under an insulated cook-pot was developed by Roger Bernard, originator of the CooKit solar cooker [44-46]. Efficiency was improved for a flat plate solar dryer with N&S fixed augmenting flat reflectors in India [47]. A shallow satellite antenna parabolic reflector dish and a small deep reflector parabola funnel concentrating solar cookers were experimental compared and rated for establishing usefulness in urban areas [48]. The Clausson small Copenhagen Solar Cooker appliance has four reflector panels that double-curvature bend. A community-size solar box oven for baking at the SOS Children's Village in Mamelodi, South Africa funded by the Embassy of Switzerland can bake “80 loaves of bread in 40 minutes on a good day”, [ ] https://www.sos-jamaica.org/news/latest-news/blogs/south-africa-delivering-daily-bread. accessed March 8, 2024.

Reverse flat plate collector (RFPC) configurations [49] integrated with TRW-type configurations for higher than tropical latitudes e.g., ~30-40˚ latitudes are a research issue. A Telkes solar cooker design had a reverse-shape in an insulated box with exterior funnel reflector [29 p34]. A RFPC with horizontal flat-plate absorber above a curved reflector was reported in 1975 [50]. A RFPC with extended nonimaging reflector was called a “sea shell” by Rabl [51]. A RFPC study with asymmetric CPC-type reflector was for water desalination [52]. A RFPC with absorber under a cookpot in the kitchen with nonimaging reflector inlet outside thru a vertical kitchen wall was reported [53]. An agricultural crops dryer study had a reverse absorber above a glazed reflector [54].

Fixed spherical solar bowl collectors had aluminum reflectors glued on sprayed and shaped polyurethane rigid foam. The Steward house building-integrated bowl in Colorado had 4 inch/ 10.1cm sprayed high density polyurethane foam cut to spherical shape with a router on a radius arm [55, 56]; and a demonstration and testing bowl in Haifa had 10cm thick 30 kg/m2 high density foam [57, 58].

4. TRW CONFIGURATIONS

The TRW nonimaging two-stage concentrator two-part first-stage has a large fixed trapezoidal wall reflector (one or two-sided trough) and a portable vertical E/W lightweight reflector repositioned at noon, and second-stage horizontal inlet funnel reflector with cookware door vertical reflector kitchen wall part so that cooks in the kitchen can slide/roll cookware in-out of the cooking zone. A three-sided CPC-type funnel optical configuration may be ordinary or involute and the ordinary CPC-type funnel is favored for initial development (Fig.1). The cookware target is for all reflections and direct radiation (beam and diffuse). Reflector design factors include: cookware specifications, latitude location, site characteristics and building construction methods and materials. Reflector materials considered are: flat glass silver mirrors, anodized aluminum, and stainless steel in the funnel under the cookware. Main reflectors are: trapezoidal kitchen wall with cookware door area (with opposite side trough option), vertical E/W portable and 3-sided CPC-type funnel. A three-sided CPC-type funnel part plus a vertical cookware door kitchen wall part forms a full funnel with cookware base tray/grill at countertop level. A kitchen wall reflector and opposite side reflector can form an EW-line building size CPC trough, symmetric for equatorial latitudes and asymmetric for higher latitudes. Cost-performance tradeoffs to construct inclined or vertical slightly curved parabolic segment or flat reflector walls are research issues. Vertical flat trapezoidal reflector kitchen walls are studied for higher and near-tropical latitudes for construction cost reasons. A cookware door limits cookware sizes and maintenance access to inside a funnel with a sealed glazed cover. Latitude influences ideal shape of reflectors and seismic hazard risk influences building structure construction. Cookware specifications and site location information (latitude, seismic risk, construction methods, etc.) are beginning aspects of TRW solar cooker-kitchen designs. Building-integrated building-size nonimaging reflector concentrator configurations may have only stage-1 reflectors, an option for several of the presented building configurations i.e., Figure 24q and Figure 30a, d.

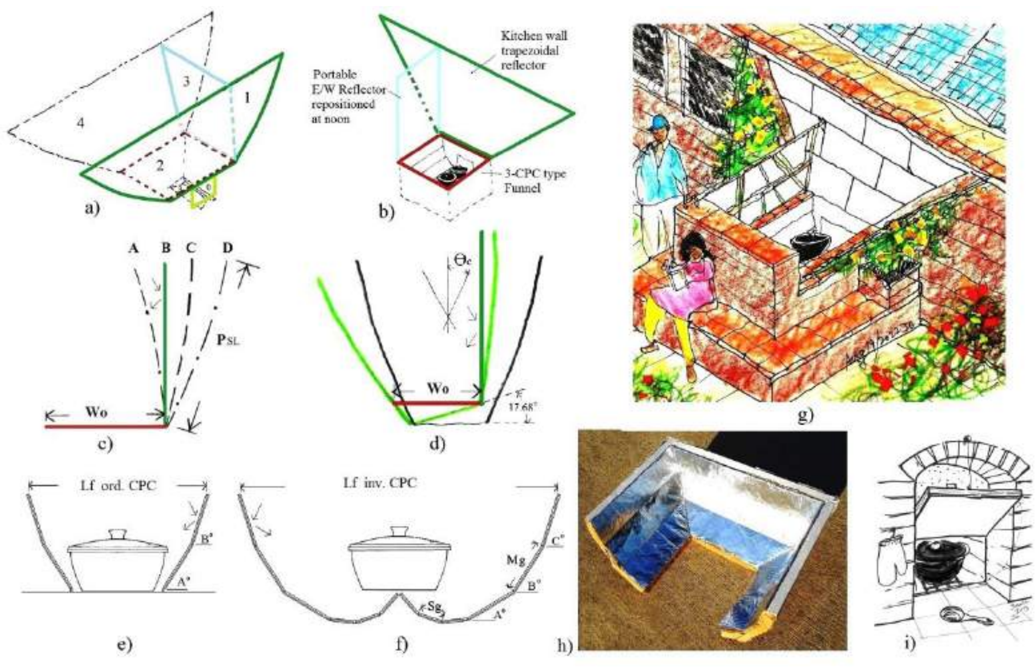

FIGURE 1. TRW Configuration Diagrams: a) TRW reflector parts: 1. Kitchen wall reflector side of a nonimaging trough, 2. Funnel reflector with horizontal inlet and door in vertical side, 3. east or west vertical reflector repositioned at noon, 4. nonimaging reflector trough side; b) isometric drawing with one-sided nonimaging trough kitchen wall reflector; c) south-north section illustrating kitchen wall reflector options; d) vertical kitchen wall reflector compared to ordinary CPC rotated to a high tropical latitude; e) ordinary-CPC-type diagram; f) involute-CPC-type diagram; g) TRW solar kitchen building with vertical kitchen wall reflector one-sided trough illustration; h) three-sided ordinary CPC-type reflector funnel part; i) cookware door view from inside of kitchen.

4.1 Cookware/Receivers

Cookware specifications are a beginning part of TRW solar cooker-kitchen design as targets for direct and reflected solar rays (beam and diffuse) influencing: tray/grill sizes, reflector shapes and sizes, cookware door and associated kitchen wall construction. Cookware and receiver targets considered include: single and multiple black/dark cookpots of different sizes (uncovered and directly glaze covered), sheet metal black cubic ovens, evacuated tubes, glaze domed absorber coils (with air or liquid fluid loops), etc. Enameled steel black pots or black painted locally available pots may be used. Studies with the HotPot TM glass glazed cookpot began c2005 [11]. The Hotpot TM funded by the World Bank is no longer made by Energia Portatil S.A. de C.V.in Monterrey, Mexico. Recent studies are with the Haines TM solar cookpot (5 liters/5.28 quart stainless steel with tempered glass lid with steam release); and Granite-Ware TM porcelin-steel canner pots (14.6, 20.3, 31.2 liters /15.5, 21.5, 33 Quarts). Three large cookpots directly above a ridged involute reflector on a wheeled rack are illustrated in Figure 4 with a reflective stainless-steel curved nonimaging involute shape reflector/trivet under a grill and cookware approximating an involute CPC with an ordinary CPC-type funnel. Locally fabricated sheet metal cubic baking ovens painted matt black could temporarily slide thru a cookware door. A small glazed-insulated solar box cooker that fits thru a cookware door could slide in-out of the cooking zone of an ordinary-CPC type funnel. Thermal storage e.g., xylitol may be added to a box cooker or black absorber plate [59-62]. A Tolakatsin [68] type solar cooker may be adjacent to a TRW wall opening (Fig. 26h). Additional application receivers may include glaze covered absorbers for heating air or water and medical autoclaves [41, 43]. A solar heat receiver study has inverted Pyrex-type clear glass bowls insulating black absorber coils with active fluid loops (forced air or pumped liquid), and the space between four inverted circular bowls is close to a square for a mirror (Fig. 29h). The tallest cookware/receiver top should be well below the horizontal funnel inlet to avoid horizontal wind losses. More than one cookware/receiver may be in a linear funne (Fig. 2-5).

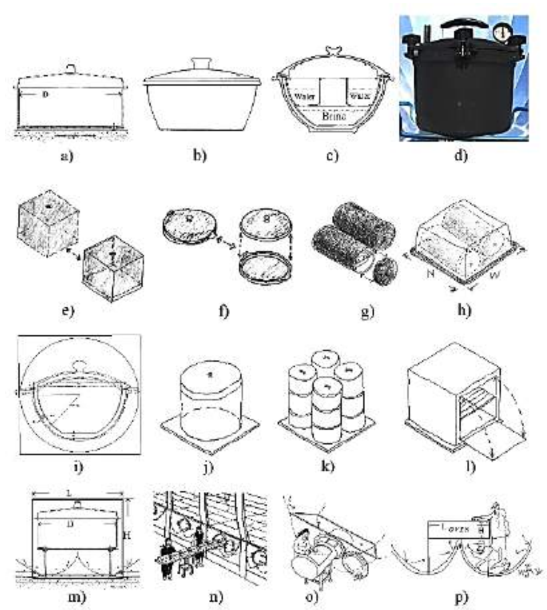

FIGURE 2. Thru-Reflector-Wall (TRW) solar cooker-kitchen cookware options: a) metal cook pot with metal top; b) stainless steel 4.5qt. cookpot with tempered glass top and steam outlet Haine's TM; c) glazed metal cookpot with glass top HotPot TM no longer made; d)

medical autoclave (modified pressure cooker) [43]; e) black metal oven lid on tray; f) metal pan with black metal lid; g) black metal cylinder cookware; h) cylinder cookware on covered tray; i) metal pot above involute reflector rack; j) multiple small cookware on long tray; k) large volume cookware; l) large metal oven above involute reflector; m-n) evacuated cookware with five tube rack; o) large evacuated cookware with two tube rack; p) large evacuated tube cookware with involute reflector rack.

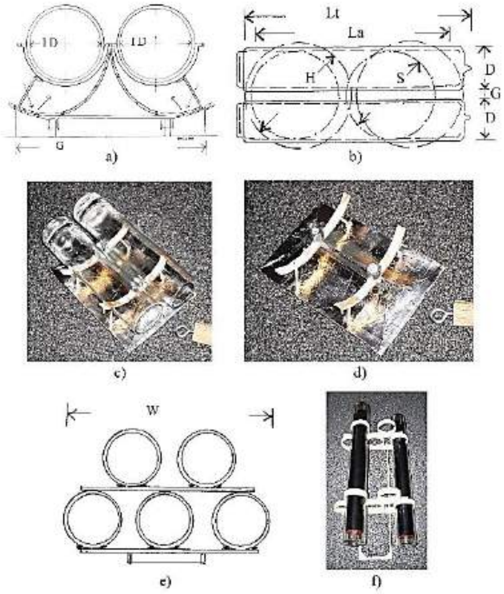

FIGURE 3. Thru-Reflector-Wall (TRW) Evacuated Solar Cooker Tubes Studies: a) section drawing of two large diameter tubes on an involute reflector rack; b) drawing comparing two evacuated tubes with cylindrical cookpots; c-d) photos of two tube involute reflector rack sketch model; e)section drawing of five small diameter tubes on a rack; f) photo of five small diameter tubes rack sketch model.

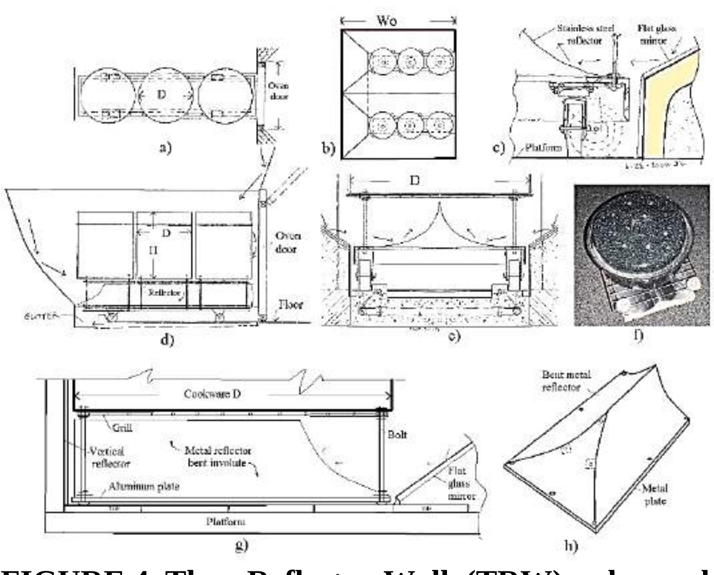

FIGURE 4. Thru-Reflector-Wall (TRW) solar cooker-kitchen large cookware / receiver options rolled in-out: a-b) plan view of three large cookware/receivers per slot; c) detail of tray wheel; d) N-S section drawing of three large cookware/receivers; e) section drawing of ridged involute stainless steel reflector on cart under cookware/receiver; f) mock-up model of cookpot

on grill above involute metal reflector ridge (e.g. stainless steel) on wheeled tray; g) section at curved reflector under grill and cookware; h) involute curved reflector requiring some fabrication skill.

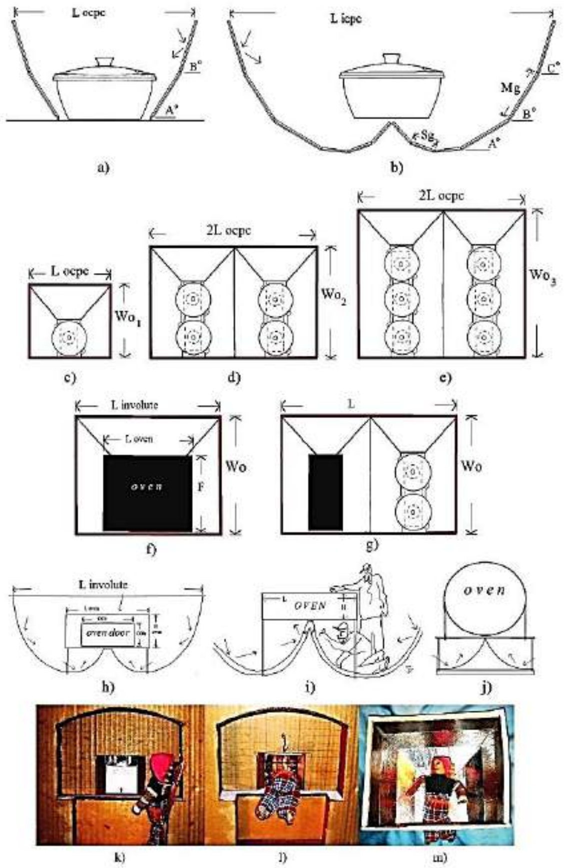

FIGURE 5. Thru-Reflector-Wall (TRW) Funnel Target Rectangle (TR) Options with Interior Reflectors (flat glass mirrors or aluminum reflectors): a) ordinary CPC approximated with flat glass mirrors; b) involute CPC approximated with flat glass mirrors; c) one cook-pot in a funnel-box; d) two cook-pots in each of two linear funnels; e) three cook-pots in each of two linnear funnels; f) cubic oven in funnel-box; g) TR with a linear cubic oven and two cook-pots linnear funnel; h) cubic oven in involute CPC; i) maintenance access under oven; j) involute under cylindrical oven; k-m) cookware door maintenance access to sealed covered funnel-box interior.

4.2 TRW Nonimaging Reflectors

Main nonimaging reflector parts are: a) fixed kitchen wall trapezoidal reflector with cookware door(s) (one or two sides of an EW-line linear trough); b) three-sided CPC-type funnel (ordinary or involute) with horizontal inlet that contains the cookware; and c) east or west (E/W) portable vertical reflector repositioned at noon (Fig. 1). The upper first stage reflectors concentrate reflections into a horizontal inlet target rectangle of the funnel(s) (glaze-covered or uncovered). The three-sided funnel reflectors are CPC-type segments continuously curved or approximated with flat/stepped reflectors designed to avoid corrosion, ion exchange damage and tolerate heat. The trapezoidal kitchen wall reflector may be flat or a CPC trough side.

4.3 Kitchen Wall Reflector and Cookware Door

A kitchen wall reflector has two parts: an upper reflector (trapezoidal shape, etc.) above the funnel, and a lower vertical part with reflective cookware door funnel side. A kitchen wall fixed trapezoidal reflector above cookware door(s) may be vertical or inclined and CPC slightly curved related to latitude location and construction costs. At ~23.5˚ latitude a trapezoidal wall reflector could be near vertical, and at 0˚ (equator), ~23.5˚ from vertical. An ordinary CPC-type trough for equatorial locations, when rotated about 16˚-23˚ has a vertical kitchen wall flat reflector near to curvature of a CPC-type side (Fig. 1-d). A vertical kitchen wall trapezoidal reflector above a vertical funnel reflector side with cookware door is in the same vertical surface plane with a horizontal straight-line between them. Tradeoffs between flat and CPC-type curved/segmented reflector walls are research issues considering performance and construction costs proposed in the R&D project outline notes. If funnel E&W side (Wo) is ~0.6m /2ft maximum distance (K) between parabolic segment and straight-line chord is only ~25mm /1" (Fig. 6a-b). A flat vertical kitchen wall trapezoidal reflector at low seismic hazard risk locations is a suggested base-case. Kitchen wall reflectors may be flat glass mirror tiles or aluminum. Mirrors from retired large one-axis tracking trough CSP systems may be effective for TRW kitchen wall reflectors. A two-sided EW-line nonimaging trough could be symmetric for equatorial latitudes and asymmetric for higher latitudes, with a partial side opposite the kitchen wall reflector option. A partial reflector side on masonry construction of an outdoor seating area is illustrated in Figures 1g and 10f-g. Higher latitude locations outside the tropics with overhanging reflectors may have better annual performance with added construction cost considerations. Augmenting planar reflectors have been evaluated [63]. TRW type test stand measurements with a two-sided E&W CPC-type funnel, vertical 'kitchen' wall reflector, portable E/W reflector, and covered instrumented cookpot in Pandharpur, India, (17.76˚ N lat.) was reported [3]. Reflectors (flat glass silver mirrors, aluminum) adhered to Portland cement (masonry walls, ferrocement, reinforced concrete lintels, etc.) have corrosion considerations.

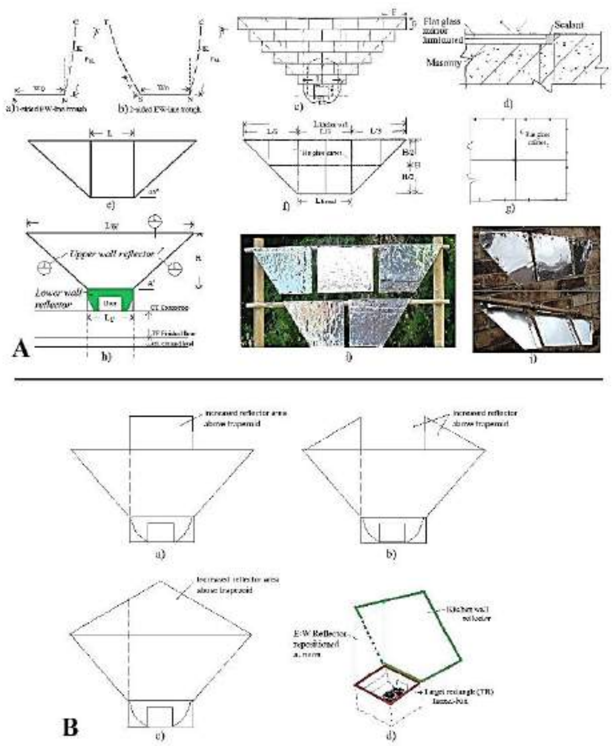

FIGURE 6. TRW Kitchen Wall Trapezoidal Reflector Studies: **A** a-b) diagrams of one-sided and two-sided nonimaging reflector wall troughs; c) elevation of trapezoid reflector wall with flat mirror rectangular tiles; d) detail of flush laminated flat glass mirror tile in masonry relief; e) wall with aluminum reflector trapezoid; f-g) wall with large flat glass mirror tiles and masonry

screws/washers at clipped corners; h) elevation with vertical mirror and door in funnel-box; i-j) reflector facets supported on horizontal poles; **B** a-d) kitchen wall reflector area options above trapezoidal reflector.

4.4 TRW Funnel

A typical TRW funnel has: a horizontal rectangular inlet (glazed or unglazed), three-sided CPC-type reflector (with flat steps or curved), a separate adjacent vertical fourth side reflector kitchen wall part containing a cookware reflective door, and a drain. It is a second stage nonimaging concentrator sized in accord with cookware target(s). Funnel shape may be ordinary or involute CPC-type (Fig. 7a-b). The funnel inlet is target for the nonimaging first stage reflector parts (kitchen wall reflector and E/W portable vertical reflector repositioned at noon). Linear funnels can contain multiple or linear cookware and single or multiple funnels can form a horizontal target rectangle. Cookware is below the funnel inlet to avoid horizontal wind losses. An ordinary CPC (o-cpc) type funnel is a less complicated construction and is suggested for initial TRW solar cooker-kitchen testing and demonstration buildings. Involute CPC (i-cpc) funnels generally have larger inlet areas with reflections hitting the cookware bottom with potential for higher and faster cooking temperatures (Fig. 7a-b). Glaze covered or uncovered funnels have a range of temperatures and rain and wind environments on reflectors/supports. A horizontal funnel cover may be temporary unsealed or sealed. A low-cost unsealed cover is with polycarbonate film and bamboo frame (Fig. 22t). Cookware glass covers may be too cumbersome for cooks. Glazing covers for flat-plate solar thermal collectors have been evaluated [14]. An uncovered funnel has more heat loss, debris collection and cleaning access for food spills, bird droppings, etc. with cookware door details that block rain and insects. Sealed covers have a slight slope away from the kitchen wall and cookware door sized for maintenance access to all areas in the funnel (Fig. 5k-m) and reflectors, supports, insulation, adhesives, etc. would require non-toxic toleration of concentration and heat. Three-sided CPC funnels U-shape in plan may be prefabricated as three or five glued pieces or one piece (Fig. 7p).

Cookware (glazed and unglazed) on a black tray or grill can slide in-out of the cooking zone. A dark tray with upturned edges could contain spills and ease movement of cookware in-out of the cooking zone. A grill slid on ledges above a reflector has reflections on cookware bottoms and an oversized drain for extreme rains is at the reflector level below the kitchen countertop level. A grill/trivet supporting cookware above a reflector base plate has reflections on cookware bottoms with an ordinary CPC (o-cpc) type funnel reflector. A rack with ridged involute reflector under a grill slid or rolled in-out of the cooking zone is for large/heavy cookware (Fig. 4). Performance difference between an involute reflector and simplified curved reflector under receiver tubes was 15% more for the involute [64, 65]. Box cookers with interior reflectors studies have been reported [37, 38, 42]. Sealed covered box-cooker with interior reflectors temperature distribution CFD studies [38] indicate reduced heat loss and higher temperatures above the cookpot. This suggests improvement with the cookpot raised on a grill/trivet above a reflector base plate. A covered sealed funnel-box could have electric booster heating [66]. TRW type test stand empirical studies in Pandharpur, India, have an ordinary two-sided (E&W) CPC-type funnel with aluminum reflectors [3].

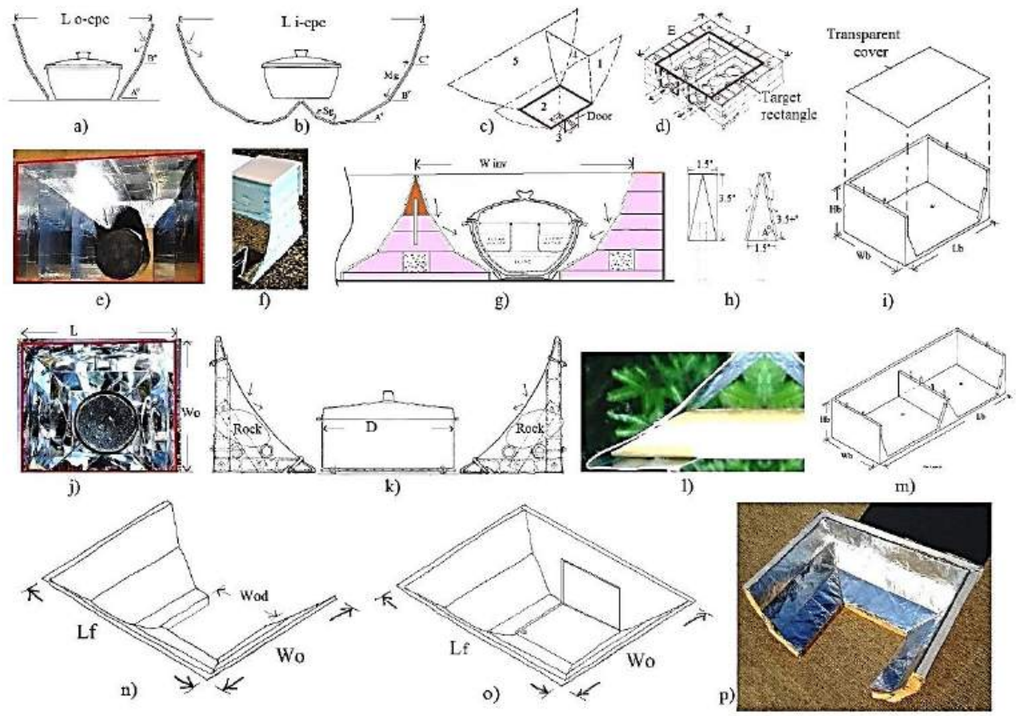

FIGURE 7. Thru-Reflector-Wall (TRW) Funnel/Box Studies: a) ordinary CPC approximated with flat glass mirrors; b) involute CPC approximated with flat glass mirrors; c) 'horizontal' funnel-box inlet outlined; d) TR with two linear funnels; e) funnel-box with flat mirror segments; f) model of flat glass mirror segments adhered to rigid foam; g-h) section drawings of ridged reflector between two linear funnels; i) isometric of ferrocement funnel box with glazed cover; j) plan view of uncovered funnel-box with bent aluminum reflectors; k-l) bamboo/wood supported aluminum reflectors; m) isometric of ferrocement box for two funnel-boxes; n) mass produced 3 side CPC-type funnel; o) 3 side CPC-type funnel adjacent to vertical kitchen wall reflector with cookware door; p) mock-up model photo of 3-sided CPC nonimaging optical element funnel part.

4.5 Portable E/W Vertical Reflector

A portable vertical reflector at the east or west (E/W) side of the funnel horizontal inlet manually repositioned at noon is a first-stage part of the two-stage nonimaging concentrator configuration. An easy-to-handle portable reflector placed in the early morning at the sunset side and repositioned manually at noon to the sunrise side increases collection and reduces solar-spillage made with lightweight aluminum reflector-flap facets attached to bamboo pole frame horizontals (Fig. 8 h-i). A sloped flat or slightly curved kitchen wall reflector has an E/W reflector shaped to avoid gap losses between the kitchen wall reflector and E/W reflector. An E/W portable vertical reflector has extended N&S enlarged reflector area at equatorial locations fitting with sloped kitchen wall reflectors. Extended reflector-flaps are cut to approximate kitchen wall 'stepped-curvature'. A symmetrical E/W reflector has reflector material only on one side and both sides if asymmetric. The lightweight E/W portable reflector is stowed when not in use and may augment LED lighting in buildings. TRW kitchen buildings ideally would be in a wind protected area with surrounding buildings, fence, and/or trees and shrubs to reduce horizontal wind on the portable E/W reflector and protected areas are a consideration to avoid vandalism. Relaxed mechanical tracking of E&W large reflectors in horizontal wind protected courtyards for large TRW buildings appear feasible (Fig. 12 and 25). Greenhouses used for drying during the summer months with an interior north or south reflector may benefit with an interior portable E/W vertical reflector [67]. E/W reflector references are: boosters [68, 69, 16 p159]; and tracking [70]. An E/W portable reflector for a house made of split bamboo and two poles and lightweight reflector facets (aluminum, etc.) would be much less weight than a head-load of wood (Fig. 8).

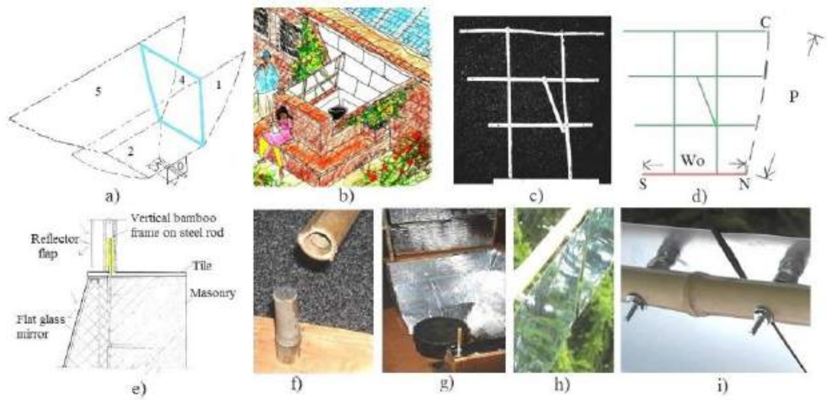

FIGURE 8. TRW East or West (E/W) Portable Reflector Repositioned at Noon: a) diagram of reflectors outlining E/W portable; b) illustration of TRW solar cooker; c-d) rigid bamboo frame with one triangulated corner; e-f) detail of vertical bamboo support with masonry funnel g); model of funnel with E/W reflector; h-i) aluminum reflector facets bolted to horizontal bamboo.

5. TRW KITCHEN BUILDING TYPES

Kitchen buildings and application types mainly for the tropics of various sizes include: small houses (Fig. 9); community mid-size kitchens (Fig. 12); restaurants and cafeterias (Fig. 11), commercial kitchens, open-air PV pergola kitchens (Fig. 13), trailers and food carts (Fig15), stepped multi-level housing, and supplemental schematics. Demountable funnel reflectors (e.g., bent aluminum) about the size of wheel barrow tubs, may be of interest for food carts and emergency medical trailers (Fig. 15). Bamboo structures with aluminum reflectors for solar cooker open-air kitchens are considered for proof-of-concept testing and demonstrations (Fig.14).

Small house TRW schematics in Figure 9 illustrate types of construction materials. The solar kitchens have convenience of cooks working in the kitchen buildings however there are solar access requirements for the kitchen buildings and site plans. Therefore, it is important to study house cluster and site planning before finalizing individual TRW solar cooker kitchen house plans (Fig. 10). Glare and disturbing reflections related to reflector shapes and reflectivity are a research consideration. Bamboo frame triangular trellises on both sides of funnels are considered with solar tolerant plants e.g., lightweight vegetables and flowering vines (Fig. 24a-b). The small TRW house studies have a one-sided reflector trough kitchen wall and the mid-large size TRW kitchen building studies generally have two-sided reflector trough walls that may be large CPCs (Fig. 11). Multiple EW adjacent glued fired clay funnels and glued top fired clay ridge have glued flat glass mirrors (Fig. 11f-g). Relaxed mechanically tracking reflector 'wings' in E&W courtyards surrounded by building prevents horizontal wind loads on the 'wings'. Each wing reflector has a linear actuator drive and associated controls (Fig. 12) [7].

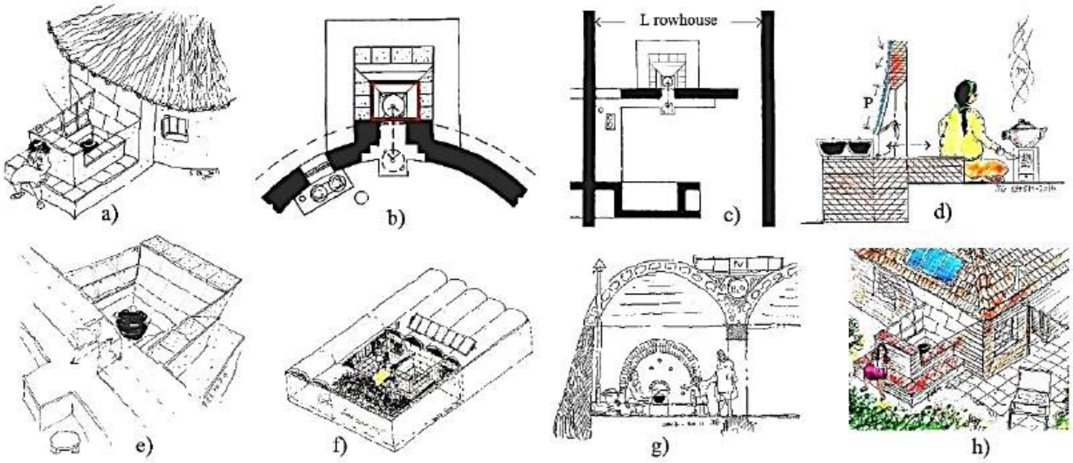

FIGURE 9. Thru-reflector-wall (TRW) Small House Types a-b) small house with circular plan; c) TRW added to small row-house partial plan [71]; d-e) drawings with cook-pot funnel-box and low countertop; f-g) house with roof vaults; h) small house with tile roof.

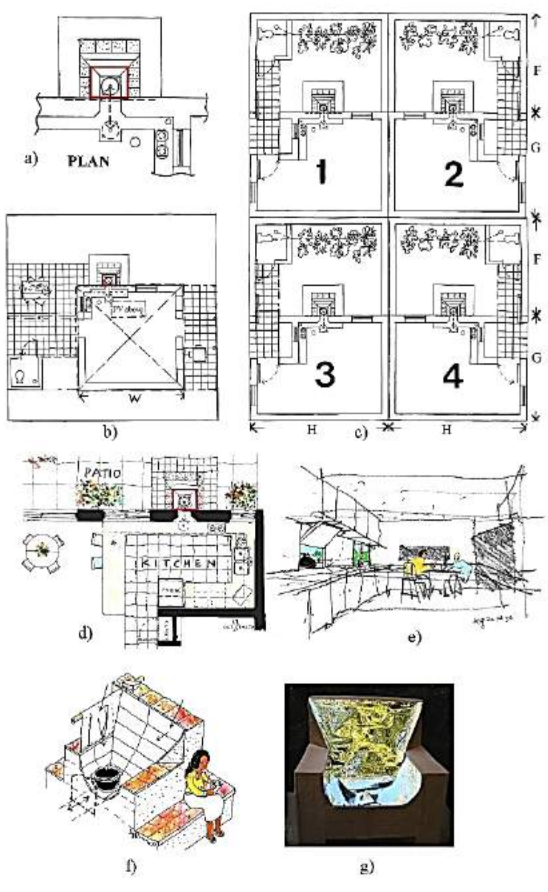

FIGURE 10. Thru-Reflector-Wall (TRW) solar kitchen house cluster planning: a) partial low cost kitchen plan; b) house-site plan; c) four house plan cluster; d) kitchen plan with terrace; e) TRW kitchen interior sketch; f-g) exterior view and sketch model of augmented nonimaging reflector funnel concentrator.

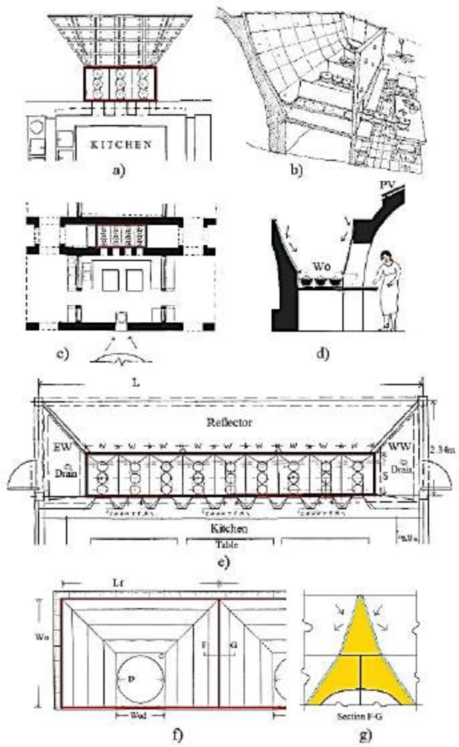

FIGURE 11. TRW Mid-Large Size Kitchen Studies: a) kitchen partial plan with three linear funnels and large CPC trough side with tensioned-cable reflector facets; b) sketch of multiple funnel-boxes and large CPC trough side with laminated flat glass mirror tiles supported on a masonry vault wall; c) kitchen plan with four linear funnels and Scheffler option; d) section of building-integrated CPC vaults and three cookpot funnel; e) plan of multiple funnels in CPC trough with E&W tracking 'wing' reflectors; f-g) plan of EW adjacent glued fired clay funnels and glued top fired clay ridge with glued flat glass mirrors.

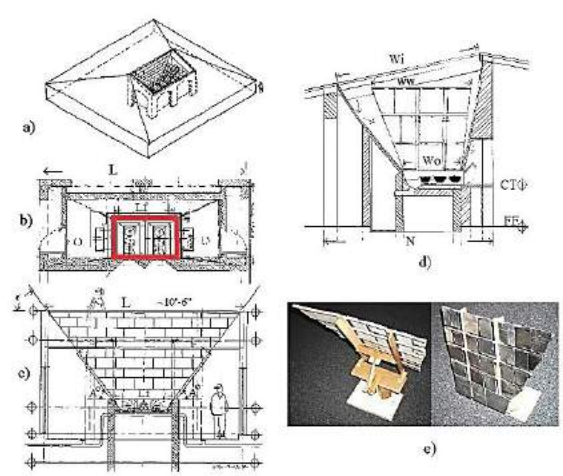

FIGURE 12. TRW mid-size community kitchen studies: a) isometric of TRW concentrator surrounded by kitchen building; b-c) plan and section of TRW solar cooker with E&W reflector 'wings' utility horizontal-wind protecting courtyards; d) building-integrated large CPC trough and tracking reflector 'wing'; e) model photos of tracking 'wing' reflectors.

Open-air TRW kitchen studies have pergola columns and/or a masonry wall supporting kitchen wall reflectors. N&S pergolas supporting a nonimaging reflector trough may be structured with existing buildings or standalone structures (Fig. 14 d-e) . Solar access is with surrounding buildings and trees that block horizontal wind loads. Bamboo open-air kitchen constructional studies began with: an EW-line ordinary symmetrical CPC reflector trough for equator locations, and a sloped CPC asymmetrically truncated trough for about 12˚ latitude locations. The three main reflector parts may be supported on bamboo with funnel(s) on a platform secured with weights, etc. (Fig. 14i). Kitchen wall reflectors would be stowed before storms. A vertical portable E/W bamboo poles frame has small thin aluminum reflector facets-flaps (~0.020 inch / 0.5mm) bolted to horizontal bamboo poles that bend by the wind and still reflect into the nonimaging funnel (Fig. 21). Bamboo open-air kitchens are site built with local materials (bamboo, rocks, etc.) and minimum imported materials (reflectors, cement, metal connectors, etc.). Reflector facets are sized according to standards and postal / transport economic limits. Standard aluminum reflector width is ~1205mm / 47.44 inches. Pergola columns support demountable horizontal bamboo poles with bolted metal reflector facets and a horizontal bamboo lintel with diagonal corner bracing. Stainless steel wingnut bolts secure horizontal bamboo reflector facet poles to bamboo columns for quick detachment during strong winds, storm forcasts and night stow. Bamboo truss-columns are anchored to foundations with moment-rotation resistance for storm winds. Aluminum reflector facets bolted to horizontal bamboo shade cooks and bend in strong winds. Bent-over perimeter edges adds stiffness to aluminum facets and avoids sharp metal edges with 3-ply layers at the bolt connections. Funnel top reflector rim and ridge-tops align with the top of the horizontal lintel bamboo pole that stays in place all the time (Fig. 14n). The countertop is at the funnel base plate level for cookware/trays to slide in/out of the cooking zone. Oven door(s) and countertop are at the more vertical side of the EW-line trough for better head clearance in the kitchen. An EW bench extension to a funnel platform provides access for changing the E/W portable reflector at noon. A low-cost bamboo open-air kitchen pergola with aluminum reflectors is for proof-of-concept testing and demonstration (annual or seasonal) in the equatorial tropics. Demountable vertical bamboo frame with aluminum reflector facets, reflector facets bolted to horizontal bamboo poles, bamboo lintel and oven door details are illustrated in Figure 14.

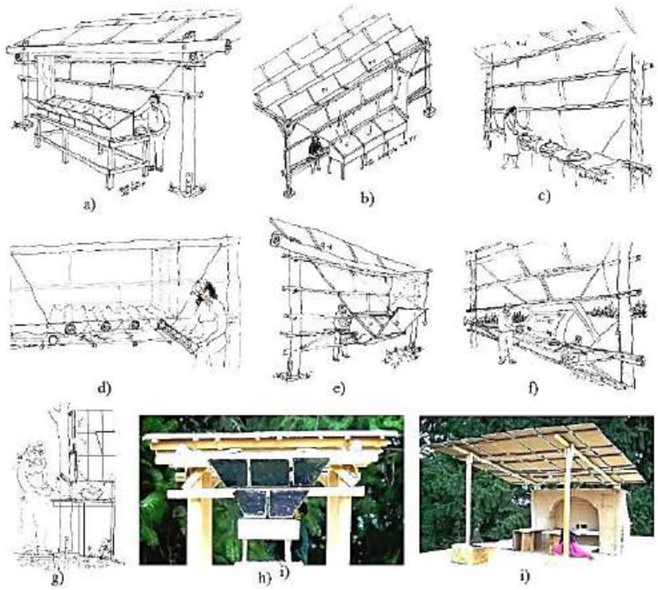

FIGURE 13. TRW Pergola Open-Air Kitchens: a-h) horizontal poles and aluminum reflector facets temporarily bolted to PV pergola vertical columns for various solar cookers (box-cookers, evacuated tube cookers, large ovens, etc.); i) masonry wall with fixed reflectors and cookware door partially supporting a PV pergola roof.

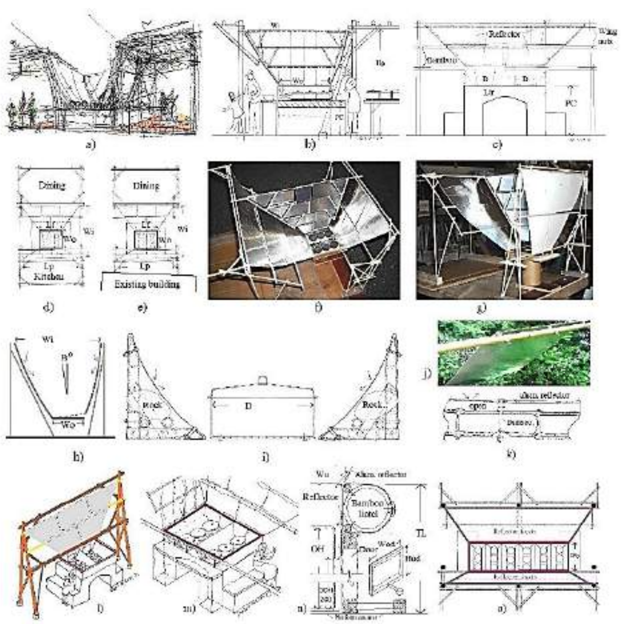

FIGURE 14. TRW Bamboo Cooker-Kitchen Studies: a) perspective sketch; b) south-north section; c) west-east section at TR; d-e) plan options; f-g) sketch model photos; h) nonimaging trough diagram for equatorial 8-12˚ latitude locations; i) wood/bamboo supporting funnel reflectors; j-k) aluminum facets bolted to bamboo; l) demountable horizontal bamboo poles with reflector facets temporarily supported on a bamboo frame; m) isometric of target rectangle with two linear funnels; n) detail of bamboo lintel supporting cookware door; o) plan with multiple linear funnels and multiple cookpots.

TRW trailer/food cart studies have detachable lightweight aluminum reflector involute funnels (about wheel barrow tub size) and hinged reflector flap drains attached to a reflector wall and removed when the trailer is moved. The funnel has a ridged reflector base-bracket with grill bolt-posts that supports loaded cookware cantilevered from the trailer wall. Four different quadrant shapes form the nonimaging second-stage concentrator involute funnel. Three CPC-type stepped-bent aluminum reflector parts (approximating curvature) and one flat vertical panel with door opening are assembled with pop-riveted tabs and attached to a grill reflector bracket tempoarily structured to the trailer/cart wall. The reflector covered base-bracket (e.g., lightweight wood) reflects upwards to the cookware bottom. A small full size funnel mock-up model with three-steps was fabricated with lightweight anodized aluminum reflector sheet (0.020 inch thick) with a scissors, pliers, and clamps. Cut-out and bent quadrants were clamped together and tabs were bolted (Fig. 15). The reflector panel patterns were adapted from a four identical panel standalone solar cooker appliance student project (Fig. 35) TRW trailers/food cart student projects demonstrating proof-of-concept may lead to TRW building integrated applications in tropical regions and disaster relief trailers for: water distillation, autoclaves, hot water and cooking. A campus food cart with vertical trapezoidal reflector wall during high solar angles in the temperate zone could indicate performance for some tropical latitudes, and is a proposed student engineering project.

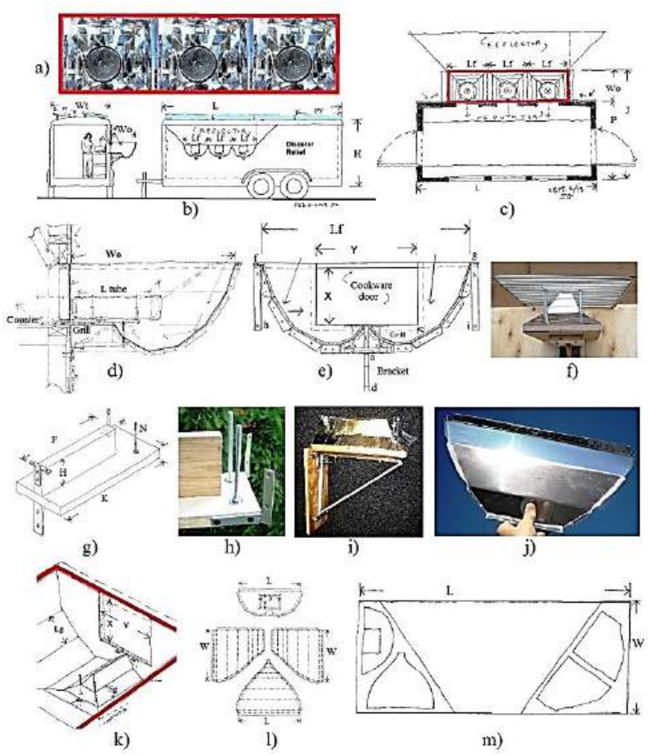

FIGURE 15. Thru-Reflector-Wall (TRW) Trailer/ Food Cart Studies: a) plan view of three nonimaging involute CPC-type funnels; b) section and elevation of TRW trailer; c) plan of TRW trailer; d-e) section drawings of reflector funnel; f) image of grill above involute reflector; g-h-i) involute bracket funnel support; j) phot of one part of bent anodized aluminum reflector funnel ; k) isometric of funnel; l) diagram of four parts of reflector funnel; m) reflector parts cut out of an anodized aluminum sheet for a one funnel prototype.

6. REFLECTOR MATERIALS

Main reflector materials considered are: flat glass silver back mirrors (monolithic and laminated) and anodized aluminum sheet (with requirements to avoid corrosion, ion exchange damage, tolerate heat, etc.) for trapezoidal kitchen walls, funnels and vertical E/W portable. Flat glass silver mirrors and aluminum reflectors may be glued to: masonry, Portland cement, fired clay, gypsum, wood, metal, plastic etc. Anodized aluminum reflectors for outdoor concentrators were considered suitable [72, 73] however coatings can be damaged by abrasive cleaning and some cleaning chemicals. Bird droppings left on aluminum can cause damage and be difficult to clean. A reflector plate under cookware may be reflective stainless steel with a drain. Ion exchange damage to silver glass mirrors from Portland cement in masonry blocks/bricks, mortar, ferrocement, reinforced concrete, plasters, etc. is a concern and barriers considered are: laminated glass, fiberglass, rigid foam, etc. Large flat glass laminated mirror tiles adhered to masonry building structures could be durable and easy to clean with added lamination or barrier costs. Prefabricated small flat glass mirrors glue laminated to plain glass for an exterior bowl concentrator are in India [74]. Kitchen wall trapezoidal reflectors are flat glass mirror tiles or aluminum on masonry, ferrocement, corrugated siding and wood with perimeter details to withstand strong wind and rain storms, e.g., flush with wall so that wind cannot get behind the reflectors. Kitchen walls with Portland cement would have laminated flat glass silver mirrors or barrier to block ion exchange damage. Funnel reflectors (glaze-covered sealed or unsealed) have heat tolerance considerations. Portable E/W vertical reflectors are flexible thin aluminum flaps bolted to bamboo poles, stiff-enough to not bend too much to cause damage and still solar-collect in a nonimaging funnel. Adhesion enhancement for gluing reflectors is by painting glass mirror backs with clean small sand in the paint, and scratched-backs of aluminum reflectors.

Flat glass silver mirrors can have over 90% reflectivity [75] and the edges must be well coated with laquer-paint to avoid silver corrosion. The Australian big dish has 93.5% reflectivity glass mirror facets. Silver glass mirrors have protective paint dried at 118˚C / 244˚F. Low thermal conductive typical glass can crack with fast temperature changes and thin glass can crack at about 150-200C / 302–392F. Laminated silvered-glass reflectors were reported suitable for uncooled 2D secondary Fresnel concentrating collectors [73]. Flat glass monolithic mirrors glued to Portland cement, even small amounts in CSEB masonry, need an ion exchange damage barrier (Authier 1996 letters). Glue lamination of flat glass mirror segments to an ion exchange barrier substrate may be with: plain flat glass, fiberglass, plastic, rigid foam, etc. A research issue for monolithic glass-silver mirrors in a glazed covered funnel is heat tolerance of mirrors and adhesive toxic outgas near cookware. Oven adhesives presumably have solved the toxic issue but hot mirrors and mirror adhesives appears to be a research issue. The mirrors would be uncooled secondary concentrating reflectors [92].

Communication in 1996 with Dr. Bernard Authier, leader of the PERICLES French solar bowl project by C.N.R.S. Marseille, was: “ I have no report on adhering silver-glass mirror to concrete but the conclusions of all the duration tests conducted in France were negative. In fact, the alkaline ions cross all kind of glues and varnishes and attack the silver even when protected by copper“ (B. Authier June 1996 personal letter). “I fear the few alkaline ions of the fired clay tiles will attack the coating of the silver mirror but I am not sure. Try it… we did not succeed to find a coating protecting the silver from ion migration when the mirrors are stuck on cement supports.... our best solution was to use double face adhesive tape pads at the four ends of each mirror to allow the air to go behind the back side of the mirror” (B. Authier, Sept.1996 pesonal letter). The south India Auroville solar bowl flat glass mirrors (about 15.24cm / 6x6 inches slightly trapezoidal) were glue laminated with clear flat glass [74] and damaged mirrors are regularly replaced. Small solar cooker funnel appliances have been constructed with flat glass mirror segments glued to precast reinforced concrete [36].

Flat glass silver mirrors for flat-stepped walls and funnels can approximate nonimaging CPC-type slight curvature with standard size reflector tiles. A Portland cement ion exchange barrier may be a resilient material glued to a wall structure as substrate for screwing/gluing flat glass mirror tiles. Prefabricated glue laminated tile options are with: flat plain glass, fiberglass and FRP (fiber reinforced plastic), rigid foam, etc. Rigid foam e.g. polyurethane has moisture absorption concerns and exposed edges covered to avoid shrinkage by sunlight. Reflector facets bolted to corrugated wall materials may have insect nesting in covered corrugated gaps. Laminated flat glass mirror tiles could be glued/screwed to masonry and ferrocement walls and a CPC-type test section of compressed stabilized earth blocks (CSEB) has been suggested [12]. Heat tolerance of monolithic and laminated flat glass mirror funnels is a research issue.

Laminated flat glass with PVB resin interlayer for windows and skylights is an expensive energy intensive (heat and pressure) product. The plastic interlayer distributes and absorbs impact loads from hail and rocks. Laminating flat glass mirrors with heat and pressure was demonstrated for heliostat facets that included 1/8” silvered float glass mirror PVB laminated on 1/8” float glass by McDonnell Douglas. “The second-surface laminated mirrors withstood the laboratory environmental and desert exposure tests quite well”; and 3-mm float glass silvered mirror polymer bonded to 3-mm float glass by Martin Marietta. “After 16 years reflectivity is essentially the same as when the mirrors were manufactured.” 3mm mirror on 3mm float glass PVB autoclaved and 0.7mm Glaverbel mirror on 5mm float glass were laminated with Glaverbel adhesive by SKI. Glass mirrors laminated to glass “will most likely be able to achieve a 30 year life without replacement and without loss of optical performance” [76]. Another glass-mirror facets for tracking heliostats reference is the ATS heliostats that had flat mirror square facets 1.22m per side,1-mm silvered glass bonded to 3-mm glass that were evaluated from 1986-1992 at the National Solar Thermal Test Facility in Albuquerque, New Mexico. “The ATS mirrors…no evidence of corrosion or debonding of any kind” [77].

Recycled parabolic trough curved glass reflectors (~1.6m x 1.7m facets) salvaged from large one-axis tracking solar thermal power stations may be used for TRW kitchen wall mirrors. Secured curved reflector facets to approximately curved masonry or ferrocement TRW kitchen walls could have a sealed perimeter. The one-axis curved parabolic mirror segments may not align perfectly with an ideal TRW CPC design however the performance is likely to be satisfactory. Buildings have been constructed with exterior flat and curved reflector facades e.g., The Depot Museum in Rotterdam has a convex bowl-shape façade of large glass laminated silver mirrors on large prefabricated panels bolted to a concrete building structure [78]. Anodized aluminum is considered for funnels, trapezoidal walls (flat and curved) e.g., screwed to masonry walls, and portable E/W reflector thin flaps spring-bolted to bamboo poles (Fig. 21b). Anodizing is said to be a non-toxic process with a stable chemical finish that is heat-resistant. Aluminum reflector screwed to a well cured dry Portland cement masonry wall may have a perimeter adhesive bead to block wind. Aluminum reflector sheet can be glued to CPC-type bent-steps or continuously curved substrates of Portland cement, gypsum, wood, rigid foam, plastic, etc. and aluminum ~ 0.020 inch / 0.508 mm thick or less can be cut with a scissor, easy to make holes, and can be bent to fit. The cookware door side and funnel vertical wall area may be aluminum reflector to tolerate heat with a glaze-covered funnel. However, damage can result when aluminum is in contact with uncured wet Portland cement. Well cured for several weeks dry cement pH drops to near neutral 7 as alkali salts become bonded within but alkali can migrate to aluminum in wet climates. A barrier of thick bituminous paint or silicon caulk gap is recommended. Anodized aluminum reflector sheet glued to well-cured and painted Portland cement is considered feasible (K. Kinster, Lorin Industries Inc. March 3, 2023 email). An anodized aluminum sample .5mm / 0.020" glued to precast concrete after 13 years indoors appears to be undamaged (Fig. 22s).

7. TRW BUILDING CONSTRUCTION STUDIES

This section discusses construction, fabrication, structural and materials aspects, and associated dimensioning for the three main reflector parts: trapezoidal kitchen wall and cookware door part; three CPC-type funnels; and portable E/W vertical repositioned at noon for selected building / structure types. Reflector shapes and dimensions would be based on: optical-thermal engineering analysis for selected cookware targets, test stand results, site latitude, local building construction materials and methods, etc., all parts of the proposed R&D project notes. Construction details of kitchen buildings would be part of site-specific design taking into account soils and foundation requirements, seismic resistance, wind and roof loads, countertop height, floor to ceiling height, etc. Cookware that slides/roll in-out of the cooking zone determines sizes of cookware doors and lintel structural spans. There are reflector shape similarities for some configurations, e.g., a house near ~23.5˚ latitude and a trailer with vertical trapezoidal reflector. The funnel/box may be prefabricated or site-built with materials and methods options. Solar cooker appliances in place of funnels may be used e.g., a solar-box and Tolokatsin [41] (Fig. 26). Dimensions are preliminary estimates for study of construction feasibility.

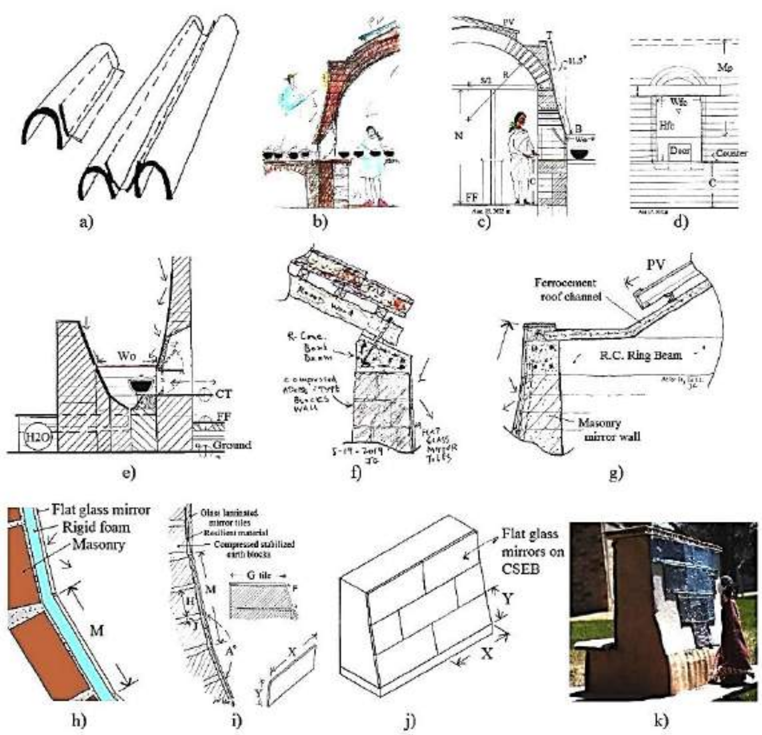

FIGURE 16. TRW Exterior CPC building structure studies: a) one and two sided CPC EW-line troughs supported on masonry vaults; b-c) section studies of masonry vaults with flat glass mirror tiles; d) interior elevation drawing of lintel on masonry wall above cookware door; e) section drawing two sided asymmetric CPC trough; f) tile roof above CSEB wall at nonimaging

reflector trough inlet; g) ferrocement channels roof structure on masonry nonimaging reflector trough wall; h,I,j) full size test section of flat glass mirrors adhered to a curved masonry wall with ion exchange barrier; sketch model of reflector test wall.

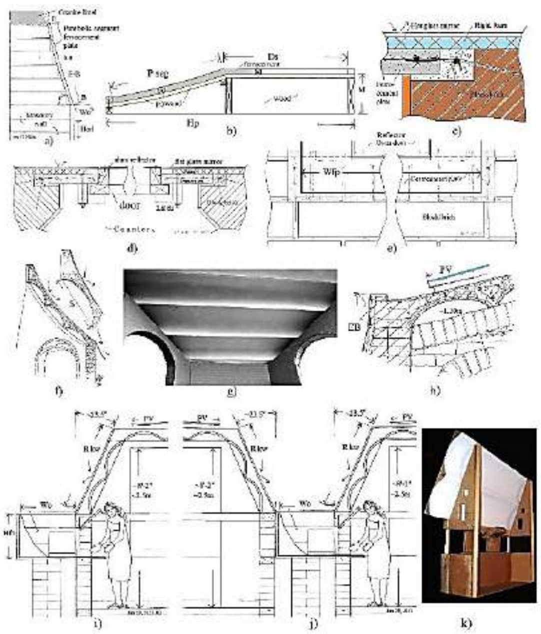

FIGURE 17. TRW Construction Ferrocement Studies: a) section at CPC shape ferrocement wall; b) CPC shape ferrocement wall panel mold; c) Glue laminated glass mirrors or glass mirrors glued to thin rigid foam glued to masonry with cement plaster; d-e) ferrocement panel details at masonry wall and cookware door; f-k) TRW kitchen building structure studies with ferrocement channels.

7.1 Kitchen Wall Reflectors

A vertical or sloped kitchen wall reflector (flat or slightly curved) side of a building-size nonimaging EW-line trough with opposite second side reflector option could form a large CPC trough. Slightly curved CPC-type construction has cost-performance tradeoff research issues. Two reflector kitchen wall areas are: an upper area trapezoidal shape and a lower vertical funnel side with reflector cookware door. Kitchen walls supporting fixed trapezoidal shape reflectors (flat glass mirrors, aluminum) may be masonry, ferrocement, wood, corrugated siding/roofing, bamboo, etc. A slightly curved CPC-type shaped reflector substrate wall could be constructed with a mason's guide or prefabricated ferrocement panels for screwing/glueing reflector. The trapezoidal angle A is a design variable (Fig. 6). Kitchen wall reflector slope, influenced by latitude location sun angles, may be vertical at ~23.5˚ latitudes and sloped about 23.5˚ for equatorial locations. A sloped kitchen reflector wall should have convenient reach to cookware door and head clearance in the kitchen. A sloped wall/roof pyramid constructed with CSEB masonry is the Sri Karneshwara Nataraj Temple, Pudhukuppam, south India [79 p141. A partial reflector trough side above the funnel opposite the reflector kitchen wall integrated with outdoor seating forms an asymmetric two-sided trough (Fig. 1g). Reflector kitchen wall construction details are part of site-specific building design taking into account: reflector material, cookware door, lintel, soils and foundation requirements, wind and roof loads, seismic resistance, etc.

Kitchen reflector walls sloped ~23.5˚ from vertical for equatorial locations have more complicated construction for masonry walls and vault structures, than for vertical walls at ~ 23.5˚ latitude locations. However, there is a geometric-shape correlation between building- size nonimaging CPC-type fixed reflector troughs for equatorial and near equatorial tropical latitudes and linear vault building structures e.g., masonry vaults (Fig. 16). Load bearing adobe-type walls in the tropics often are tapered, wider at the bottom, for structural stability and a slight parabolic curvature could coincide with CPC shapes. Locations at near ~23.5˚ latitudes suitable for vertical kitchen wall trapezoidal reflectors with low seismic risk could avoid construction complications. Trapezoidal reflector angle A (Fig. 6) determines reflector area extending to E&W. An angle A of ~45˚ has earlier and later higher cooking temperatures with more reflections missing the funnel at midday however, these reflections may increase plant growth and food production with sun tolerant-enough vegetables (green beans, etc.) on trellises (Fig. 1g). Modular standardization of reflector facet shape(s) influences trapezoidal reflector dimensions and angle A. Aluminum reflector on masonry has perimeter aluminum strips cement screwed into cement strengthened mortar joints and glued to prevent wind from getting behind the reflector. Reflectors with 45˚ angle A could avoid waste (Fig. 6). A curved prefabricated ferrocement kitchen wall (a CPC trough side) has a lower vertical cookware door area with parabolic curved shape wall plate segments (Pseg) and rectangular perimeter anchored to a top horizontal reinforced concrete frame for seismic resistant construction. The ferrocement plate dimensions are about: Wfp and Hfp = 0.76m / 30in (Fig. 17) feasible with existing low-cost technology and molds. A schematic design with horizontal ferrocement channels sloped kitchen wall and laminated glass mirror tiles is illustrated in Figure 17 suitable for some seismic hazard locations [80]. Higher latitude locations than 23.5˚ may have overhanging reflector walls. Overhanging linear reflector constructed building structures include: thermal flat-plate booster at Strawberry Fields Apartments East, Springfield, Missouri, Lat. 37.11˚N [23] and at the Chicago Riverwalk. An undeveloped idea for TRW solar cooker-kitchens at about 30˚-40˚ latitude locations may have an integrated reverse flat plate collector (RFPC) configuration below a glazed cookware box (Fig. 27g). Beginning TRW-type BISTIC test stand measurements at 17.76˚ latitude in India started with a vertical trapezoidal flat reflector wall [3].

A reflective (aluminum) cookware door in the lower vertical kitchen reflector wall part and vertical funnel side has insulation options. Wood door frames must be protected from damaging concentration. If the funnel is uncovered or temporarily glazed covered with an unsealed cover the cookware door details should block water during rain/storms and insect entry into the kitchen. If the funnel has a sealed cover the cookware door details may be less demanding but large enough for maintenance access (Fig. 5k-m). A rectangular cookware door size coordinates with construction materials e.g., masonry course dimensions and lintel. The kitchen countertop height sets the level for the cookware to enter the door to the cooking zone determing the amount of construction to support the cookware loads in the funnel above ground level. Lintel structural design factors include: cookware door size and span dimension, wall construction materials (e.g, masonry dimensions), door swing clearnce, etc. Lintel design may be different for a vertical or sloped reflector kitchen wall. A heated wood lintel could expand and CSEB masonry shrinks when heated. A wood lintel may be suitable for an uncovered funnel and a covered funnel is likely to require a precast concrete lintel. A precast concrete lintel for masonry walls has wood cast-in or bolted for cookware door top hinge screws. A masonry wall with a relieving arch could also influence lintel design e.g., a precast concrete lintel sized for CSEB illustrated in Figure 16. A cookware door lintel with an arch above in a masonry wall would be a less complicated precast reinforced concrete element than a precast lintel directly supporting masonry (CSEB, fired bricks, granite, etc.). An arch may be a relieving arch or a large span arch for sloped masonry kitchen walls.

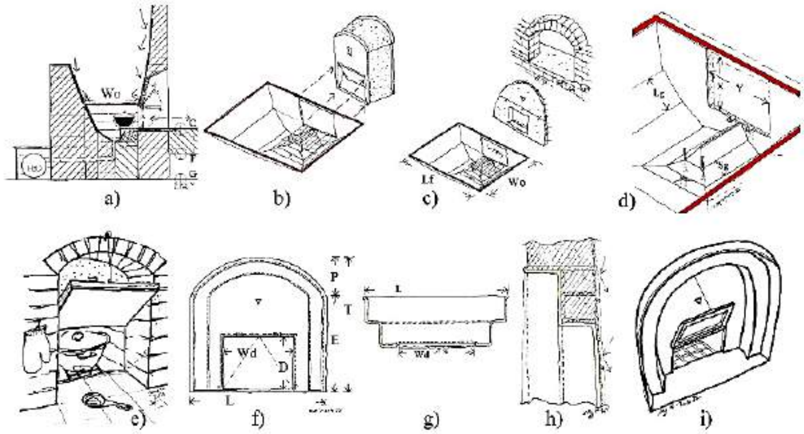

FIGURE 18. Thru-Reflector-Wall (TRW) solar cooker prefabricated cookware door frame and funnel-box set studies for masonry walls: a) south-north section at masonry wall; b-c-d) masonry CPC oven door fame parts; e-i) CPC oven door frame studies; j) target rectangle; k-l) sheet metal reflector parts; m) flat segments forming CPC involute.

Prefabricated cookware door frame and funnel set studies for masonry kitchen walls were started c2014 for distribution to local workshops for flat glass mirror tiling and then to builders (Fig. 18). A funnel mass-production manufacturing reference is wheel barrow tubs. Funnels with few reflector segment widths simplify glass mirror cutting and number and sizes of stepped sloped flat segments. An injection molded process for the SolavoreTM Sport (formerly SOS Sport) solar box cooker by Paul Funk (no longer manufactured) was made with resin and 1000 tons pressure reinforced with glass fibers to prevent heat degradation and crushing. Because of expensive tooling and fossil-energy intensive manufacturing study shifted to low-energy manufacturing processes and site-built cookware door frames with lintels and relieving archs for masonry walls and prefabricated ferrocement funnel-boxes and fired clay funnel parts that could be made in local workshops with flat glass mirrors (Fig. 19).

7.2 TRW Funnel/Box Construction Studies

Three-sided CPC funnel parts (with or without cover glazing) on a platform or in a box site-built or prefabricated with drainage have construction materials and methods options. A funnel part with three ordinary CPC-type reflector sides [83] is initially favored and discussed with flat glass mirrors or aluminum reflectors. Funnels, sized for selected target cookware that pass thru the cookware door, have considerations that include: temperature limits, toxic outgas of funnel materials, vapor, insulation and maintenance aspects. Drainage, with access for cleaning food spills, should block insect entry and is oversized to compensate for record breaking rain extremes with possibility for rain water storage, less a factor for funnels with sealed covers. Cookware is well below an uncovered funnel horizontal inlet rim to avoid horizontal wind losses. Prefabricated funnel-boxes have an open side that fits adjacent to a kitchen wall vertical part with cookware door (Fig.19a). Funnel construction for mass production include: fired-clay, fiberglass, bent metal, casting/ramming molds, rigid foam, 3D printing, injection molding, etc. A fired-clay 3-sided CPC funnel fixed to a platform with backsides filled with local masonry supports top rim edges and portable E/W reflector rods. The fired-clay 3-sided CPC-type funnel part may be mass-produced and locally produced as a U-shaped part and also as five or three separate parts glued to form the U-shape. Considerations include: expansion coefficients, reflector and adhesive heat tolerance and outgas. Wood, bamboo, or foam must be protected to avoid concentration that could smoke, ignite, or shrink them. Temperatures inside a sealed funnel, indicated by temperatures in box-cookers with stepped CPC-type reflectors, are a research issue, suggesting performance improvement with a reflector base plate and trivet for reflections on cookware bottom [38]. Construction precision is not required for effective nonimaging concentration [2]. Funnel reflector material and construction options include: monolithic and laminated flat glass mirrors adhered to substrates (fired clay, masonry, gypsum, ferrocement, plastic, resin, etc.); and metal e.g., aluminum curved or stepped. Test stands may have bamboo supporting bent metal reflectors. Stepped reflectors approximating curved CPCs may have multiple segment widths and studies have only one or two reflector segment widths to simplify glass mirror cutting. Flat glass mirror segments have acute angles to cut. Compact stackable funnel products are a shipping economy volume consideration.

Prefabricated funnel platforms or funnel-boxes would be supported independently or with kitchen wall extensions. Three-sided CPC funnel reflectors are secured on platforms (reinforced concrete, masonry, etc.) and in ferrocement boxes [80] to withstand extreme wind loads. A funnel-box may be a type of side door solar box-cooker with interior CPC-type reflectors adjacent to a kitchen wall cookware door. CPC-type reflector funnels robust enough may not need a containment structure. A vertical bamboo frame E/W portable reflector is supported at E&W platform edges or at funnel/box rims. Reflectors in a funnel-box may be support on: fired-clay, rigid foam (high temperature nonflammable), or lightweight cement or gypsum. Vermiculite and perlite aggregates withstand high temperatures and insulate with expansion considerations and locally sourced lightweight natural materials (i.e., coir fibers, etc.). A 3-sided CPC funnel bolted/glued on a platform requires self-supporting rigidity. A ferrocement funnel-box has an open side adjacent to a vertical kitchen wall cookware door (Fig. 18a). Funnel support under large/heavy cookware loads may be masonry with drain access clearance and independent separate foundation for seismic risk locations. The funnel cookware base is at countertop level so cookware can easily slide-roll in-out of the cooking zone. Masonry course vertical dimensions of the kitchen wall and funnel-box may be coordinated. Reflectors on masonry with Portland cement require an ion exchange barrier (full curing and protective paint, lamination, etc.).

A ferrocement prefabricated funnel-box study has three vertical sides and one open side with three CPC-type reflectors around cookware at countertop level coordinated with cookware door in the kitchen wall. Ferrocement E&W rims support the E/W vertical portable reflector (Fig. 19). A drain for extreme rains slightly down-slope from the cookware door at a corner of the cookware support is about 1” diameter. The kitchen wall vertical reflector area around the cookware door would be heated in a covered funnel-box and therefor the reflector would be heat tolerant. A prefabricated ferrocement ordinary-CPC type funnel box study (Wfb) adjacent to a cookware door has 3-4 CSEB masonry courses tall (Hfb) and 1-2 blocks wide, placed adjacent with a small gap to the cookware door (Fig. 18). A sealant filled small gap between the kitchen wall reflector and funnel-box on an independent support/foundation may avoid damage from some minor seismic movements. Casting identical prefabricated ferrocement boxes requires mold design and fabrication (metal or wood) to place reinforcement wires/mesh for masons to press on cement paste, and removal for wet curing, and a finalized design is required for mold investment. A protype funnel for testing may be with precast reinforced concrete and laminated flat glass mirrors [36]. Three sided CPC-type funnels with stepped flat glass mirror segments (monolithic or laminated) or bent/curved aluminum have fabrication options: fired-clay, injection molding, cast/rammed binder-aggregates in molds, 3D printing, rigid foam blocks, etc. A three-sided ordinary CPC-type funnel with a square absorber plate/tray is favored for initial development.

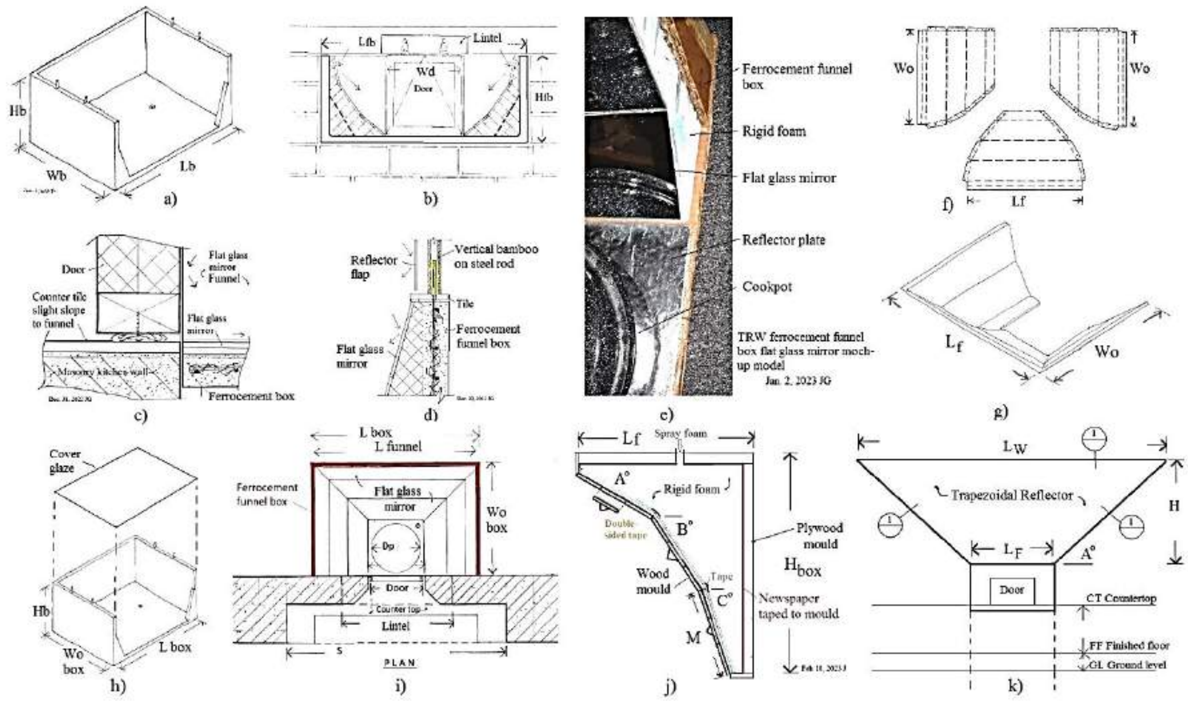

FIGURE 19. TRW Prefabricated Ferrocement Funnel-Box with Flat Glass Mirrors or Aluminum Reflectors Studies: a) isometric with open side; b) EW section viewing cookware door; c) detail section at cookware door and countertop; d) section at E and W rim with extended rods for portable reflector; e) photo of flat glass mirrors glued to rigid foam; f) CPC-type aluminum funnel parts; g) 3-sided CPC funnel isometric; h) glazed cover above ferrocement box; i) plan of kitchen wall at cookware door and funnel; j) CPC funnel mold for rigid foam; k) elevation of cookware door and kitchen wall trapezoidal reflector.

7.3 Funnels with Three-Sided CPC Part

Materials and methods of fabrication for three-sided CPC-type four-sided funnels are discussed. Manual casting/ramming funnel/parts for gluing flat glass mirrors or aluminum (curved or stepped) reflectors in press-molds have material options e.g., manual/machine formed clay for firing, precast binder and lightweight aggregate, Portland cement or gypsum with coir, vermiculite, perlite, etc. Fire resistant and heat tolerant gypsum melting temperature is a consideration for sealed covered funnels. Vermiculite is fire resistant with high thermal insulation value and Perlite is about 1/10th the weight of sand. A set of two standard size CPC-type prefabricated pieces/blocks can form a three-sided CPC–type funnel part by gluing pieces/blocks together on a platform. Three CPC-type funnel parts could have one (‘U-shape) or two (linear and corner) molds sized according to masonry (CSEB, etc.) dimensions (Fig. 20B). Precast lightweight concrete funnels may require top E&W rims strong enough to support a portable vertical E/W reflector. Molds (e.g., wood, plastic, bent metal) require accurate reflector shape design and require skillful fabrication work. A three-piece funnel part permits a different CPC contour for the side opposite the cookware door than the E and W sides with same CPC contour. A five-piece funnel may have all three CPC sides with the same contour. Fired-clay flat surfaces for gluing flat glass mirrors may require thicker clay to hold flat-shape when removed from molds and handled to kilns/fire.

Fired-clay funnel part production options include: one-piece with one mold, three-pieces with three molds, and five-pieces with two molds (Fig. 20D). The clay when removed from the molds until completed firing must maintain flat surfaces for gluing flat glass mirrors. When fired-clay pieces are glued together misalignment at joints could require flat glass mirror joints with associated mirror cutting and un-level mirror surfaces and edges, likely acceptable for large funnels. Sketches of two clay molds, a corner mold and 'rectangular' mold, are illustrated in Figure 20. Back support clay ribs would be formed as needed. Clay forced extrusion molding with a die and evacuated plug-mill may have one acceptable contour-shape for all three of the CPC funnel part sides. It would be a trade-off between optimum optical-thermal design and manufacturing economy. A preliminary die study has three equal flat reflector tier-steps (AB, BC and CD with angle P about 20˚ (Fig. 20C). A continuous stiff-mud extrusion may be immediately straight-line cut (perpendicular and 45˚) into the CPC-type three side shapes with edges sloped for glue joints. A one-piece 3-sided CPC-type part mold (U shape in plan) for hand forming clay may be wood, metal or 3D printed. Stiff clay could be self-supporting off a mold with open flat vertical side with possibility for compact packing. Test stand funnels could be made with modified similar fabrication engineering mold drawings. Local clay composition and nearby kiln sizes are research areas with possible funnel production at operating pottery kilns.

Injection molding (clay, plastic, etc.) in a mass-production factory with high tooling costs may be a three-sided CPC-type reflector large optical element substrate as one piece (U shape in plan) or five or three parts to be glued together. Considerations include variable shrinkage for high temperature (about 1,500F / 815C) fired-clay and heat tolerance and out-gas for plastics. The Solavore Sport TM solar cooker (no longer in production) was produced with energy intensive injection high pressure (1000 tons) molded resin glass fiber reinforcement that prevented heat degradation and crushing.

Funnel reflector metal supports with formed steel or aluminum by stamping, drilling, and bending could have heat tolerance without outgas. Corrosion coating and expansion coefficients are considerations for gluing flat glass mirrors to metal substrates. Stamping of individual (1, 3 or 5) metal formed panels have: waste-scrap, compact stacking for economical packaging and shipping considerations (Fig. 20-A). The TRW trailer/food cart application has cantilevered bent aluminum three-sided CPC-type funnel reflectors (about .5mm / 0.020") with a drainage flap (Fig.15). Three bent-stepped metal panels with tabs bolted or pop riveted with sealant forming a U-shaped CPC-type assemble could be fixed in a funnel-box and back-filled with insulation. Watertight sealant/gaskets at tab pop-rivet edges could avoid water seepage and insects into the box. A three-sided CPC funnel and a one-sided CPC kitchen wall trapezoid cut out of a standard rectangular aluminum reflector sheet are illustrated in Fig.15m. A standalone unglazed four-sided aluminum reflector solar cooker appliance student 2015 project was intended to be preparation for a thru-reflector-wall (TRW) campus food cart/trailer project (Fig.35).

Prefabricated CPC-type shaped rigid heat tolerant foam glued into a funnel box (site-built masonry or prefabricated ferrocement) are for gluing reflectors (monolithic flat glass mirrors or aluminum). Polyurethane rigid foam blocks, made by pouring a well-mixed two-part mixture into a paper lined robust form with heavy top enclosure to withstand expanding foam outward pressure could be cut and glued to form a three-side CPC-shaped (U shape in plan) for gluing reflectors e.g., monolithic flat glass mirror segments. Expanding foam adhering mirrors in a mold could reduce adhesive cost. Rigid foam cut/glued to form CPC-type shapes would avoid optical shape tooling costs. Rigid foam needs to be covered to avoid slow shrinkage by sunlight and foam toxic outgas is a concern in sealed glazed covered funnels. Rigid foam moisture absorption from masonry or ferrocement could damage silver glass mirrors that may require waterproof seal-coating. Polyurethanes are mostly made from fossil resources and renewable chemicals are being researched. Rigid foam glass insulation made from recycled glass may have toxic outgas and attack copper and silver [82, 83]. Typical spray foam polyurethane degrades at about 93°C / 200°F); and special polyurethane products for temperatures from 150°C (300°F) to +200°C (392°F) are reported to be permitted in fire resistant building construction. Marketed polyurethane foam insulation sandwich panels for walls and roofs are allowed for fire-resistant construction (e.g., Icynene TM foam insulation). HCFC-free high-temperature polyurethane that may be costly and difficult to source in small quantities is available e.g., from Puren Gmbh, Germany. Sprayed polyurethane rigid foam had glued aluminum reflectors in spherical solar bowl collectors [55, 57]. Polystyrene is combustible with temperature limits (~80°C / 176°F) and may only be suitable for test stands with uncovered funnels. Rigid polyurethane blocks made with a wood mold and taped newspaper lining can be cut into sheets and sloped shapes. Sprayed polyurethane foam in forms that contain flat glass mirrors directly sticking the mirrors to the expanding foam could avoid glue costs. Mirrors held in place with double-sided tape and the edges taped could block foam passage between mirrors (Fig.19j). A manufacturing process reported for linear involute CPC troughs has polyurethane foam supporting aluminum reflectors in Mexico [84].

3D printed CPC-type funnel parts for gluing monolithic flat glass mirrors or aluminum reflectors may be: self-supporting hollow blocks glued/snapped together and fixed to a platform or a whole U shape in plan three-sided CPC-type part fixed in a box. Heat tolerance and outgas are significant material considerations. 3D printed prototypes are of interest for molds and test stands for gluing flat glass mirror segments for less mold investment.

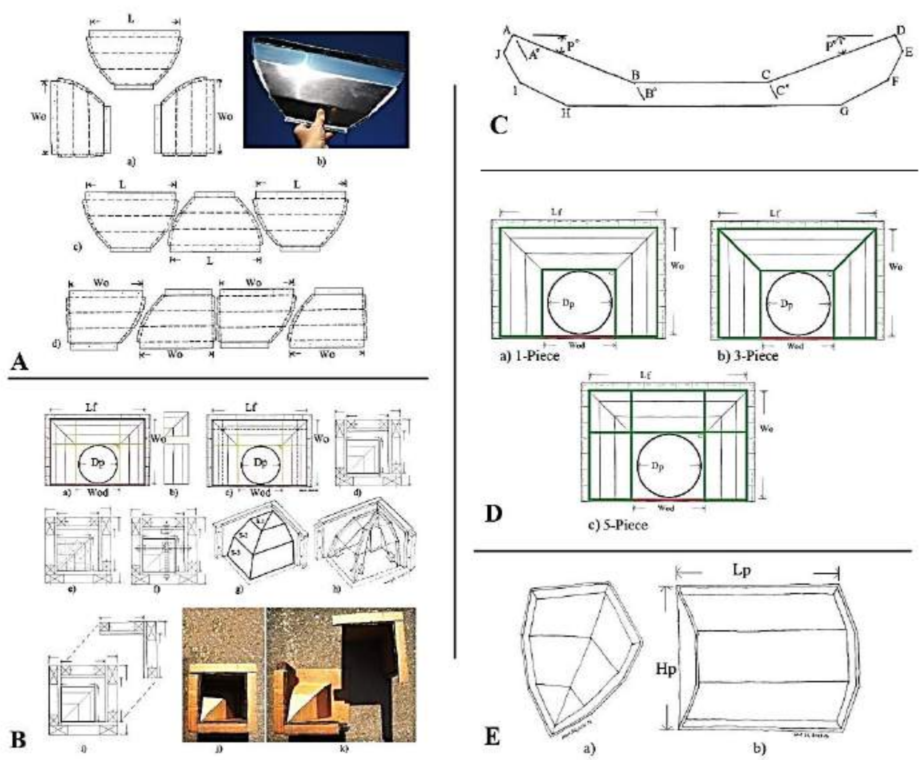

FIGURE 20. TRW Three-Sided CPC-type Reflector Funnel Construction Studies: **A**- a-d) Stamped, drilled, and bent metal panel studies; **B**- a) Plan of ‘U’ shape funnel with two CPC-type block types (corner and linear); b) Corner and linear blocks; c) plan with tensioned tie rods; d-e) corner block wood form plan; f) corner block wood form plan with two-way junction sleeves; g-h) isometric sketches of corner block wood form; i) drawing of two part wood form; j-k) model of two part corner block wood form; C- clay CPC-type funnel-side contour extrusion die shape for pugmill; **D-** a) one piece funnel with one mold; b) three piece funnel with three molds; c) five piece funnel with two molds; **E**- molds (only 2) for press clay sketches for five piece funnel part; a) corner mold; b) ‘rectangular’ mold.

7.4 Portable E/W Reflector

A TRW lightweight portable E/W reflector is important for morning and afternoon solar collection however it requires daily manual placement and stowing with theft and vandalism considerations. The E/W reflector stowed in the evening and when not in use could be a decorative augmenter of LED lighting in buildings. The TRW E/W reflector facets bend or reposition with spring-hinges (for large systems) by the wind to avoid wind damage. Small E/W reflector facets may be metal reflector or reflector film adhered to bendable material (i.e., plastic). Moving reflector facets by wind still nonimaging concentrate into the funnel. A portable E/W reflector frame may be with bamboo poles bolted and glued to maintain rigidity. Reflector facet bending or repositioning for large E/W reflector systems permit access for cleaning of ‘wing’ reflectors when horizontal or near horizontal. Because a portable E/W reflector is important for morning and afternoon solar collection, and has a comparative small reflector area, more costly high reflectivity material may be justified. A TRW test stand with about a 20cm/8inch diameter cookpot could have an E/W reflector rectangular perimeter of only about 46cm/18 inches wide and 51cm/20 inches tall.

A vertical portable E/W bamboo frame study has lightweight aluminum reflector-flaps bolted to horizontal bamboo poles, with two verticals, three horizontals and a short diagonal triangulated pole that provides rigidity (Fig. 21c-d). Vertical rods/bolts at E&W rims of a funnel-box or structural platform support the two vertical bamboo poles (Fig. 21f) or an E/W reflector can be hung with top horizontal pole supported at the kitchen wall and opposite partial trough reflector (Fig.1g). For equatorial locations e.g., 0°-15° latitudes with a sloped kitchen wall reflector (one-sided trough) the E/W portable vertical reflector is enlarged extending N&S to fit close to the sloped reflector wall symmetrically so that reflector material is only on one side. Horizontal poles can fit with flat or curved kitchen wall reflector shapes with reflector-flaps cut to fit. Reflector-flaps bend/rotate by wind loads reducing possibility of damage by gusts, and flapping reflections at low wind speeds can enter the nonimaging funnel. Reflector-flaps with spring or rubber washer bolted thin aluminum should not flap too much to miss the funnel in mild wind speeds (Fig. 21b). Standard size reflector-flap facets can be pre-cut with holes, and a frame with smaller diameter bamboo poles has more reflector area. Thin reflector facets with longer vertical dimension bend more by horizontal wind. A wind protected area is preferred to avoid extreme wind loads. A lightweight E/W portable reflector repositioned at noon is easily handled to storage and for morning setup. Bamboo treatment to avoid insect nesting has toxicity considerations.

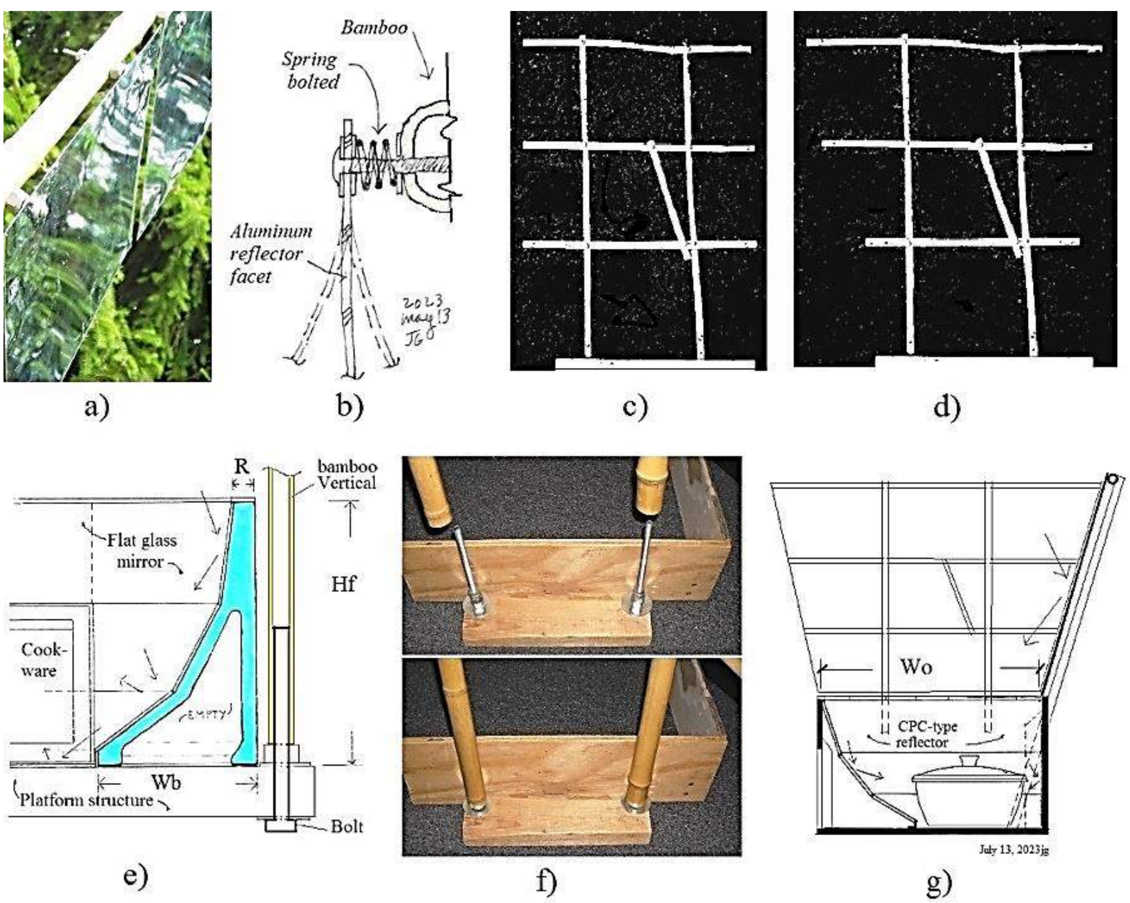

FIGURE 21. TRW E/W portable vertical reflector: a) aluminum facet bolted to horizontal bamboo; b) spring-bolt detail; c-d) rectangular and trapezoidal vertical bamboo frame with triangulated diagonal; e) vertical bolts at E&W extended structural platform to support vertical bamboos; f) vertical bolts at E&W funnel-box supporting the two vertical bamboos; g) drawing of trapezoidal shape symmetrical E/W portable reflector.

7.5 Test Stand Studies

Modest cost small TRW test stands can indicate performance potentials, identify problems and provide experience for design-engineering of full-size TRW building-integrated concentrators. Test stand design is much different than kitchen building design with many site-specific construction detail considerations (reflector durability, water and insect blockage at cookware door, seismic resistant construction, countertop funnel alignment, etc.). A cookware door is not required for test stands. However, TRW building designers would require recommended shapes and sizes of TRW reflectors and parts. Considerations for reflectors and adhesives in a covered uncooled funnel secondary concentrator include durability, corrosion and capacity for concentration and heat. Selected cookware/receiver testing includes: baking ovens (locally made with black thin-metal), glass domed forced fluid coils, evacuated tubes (ET), autoclaves, etc. Proposed R&D studies include: evaluations of each reflector part and sum of all reflectors, unglazed and glazed funnels, and measurements (speeds of cooking temperatures, etc.). A smaller instrumented cookware target will proportionally have smaller reflector areas and associated cost considerations for test stand project budgets. Wood test stand parts that receive concentration should be covered to avoid smoking/igniting. TRW test stands and demonstration buildings are intended to be constructed with a minimum of imported materials.

A base-case configuration is for comparative measurements of: reflector shapes and sizes, glaze uncovered and covered funnels, ordinary and involute CPC-type funnels, etc. A suggested base-case has: an ordinary three-sided CPC-type unglazed horizontal inlet funnel, one-sided trough trapezoidal flat 'kitchen wall' reflector, and vertical symmetrical E/W reflector repositioned at noon. A vertical flat 'kitchen 'wall reflector test stand is considered suitable for high or near tropical latitude locations (about 15°-27° latitudes), and seasonal applications at higher latitudes for performance indications at some tropical latitudes. A hinged trapazoidal upper 'kitchen' wall reflector would be for testing sloped options e.g., vertical, ~11°, and 23.5°from vertical, with associated E/W portable trapezoidal extended reflector areas for sloped 'kitchen' walls. Funnel cover testing includes: outgas and temperature limits of materials in the funnel, condensation, etc.Test stands can be sized for door exits to outdoor wind protected testing areas.

A three sided CPC funnel test stand reflector may be stepped-bent aluminum (about 0.5mm/0.020") parts bolted or pop riveted tabs for screwing to a wood box. Reflectors may be adhered to rigid foam (with temperature limits, etc.) or rammed/cast materials that require design and fabrication of mold(s). A plywood test stand funnel box study with cutouts in three vertical sides has places for stabilizing weight and useful plywood for other purposes. Thermal storage may be added to insulated funnels under cookware base plates. An unsealed temporary glazed funnel cover with narrow split-bamboo rectangular frame and polycarbonate film would have small shading losses at the 'kitchen wall' reflector (Fig. 22t). Test stand substitute stainless steel reflector under instrumented cookware may be flat glass mirror or aluminum for an involute under a grill. A CPC-type involute for large and multiple cookpots on wheeled trays can be tested in an ordinary-CPC-type funnel with an involute-tray without wheels. An aluminum plate with four corner bolts extending upward supporting a grill above an involute-shape reflector is illustrated in Figure 22 j,k,l.

Low sun angle testing began ~December 2022 for the TRW-type test stand at Pandarpur, India, (17.76° N lat.) with two CPC-type reflectors in a plywood funnel-box and vertical trapezoidal reflector 'wall' [3]. A TRW-type test-stand funded project started ~Sept. 2023 at the U. of Tarapaca, Arica, Chile (18.47° S lat.) (A. Sagade Aug.1, 2023 personal communication); and a TRW 3-sided CPC-type fired-clay funnel and test stand undergrad student project started September 2023 at the U. of California-Merced.

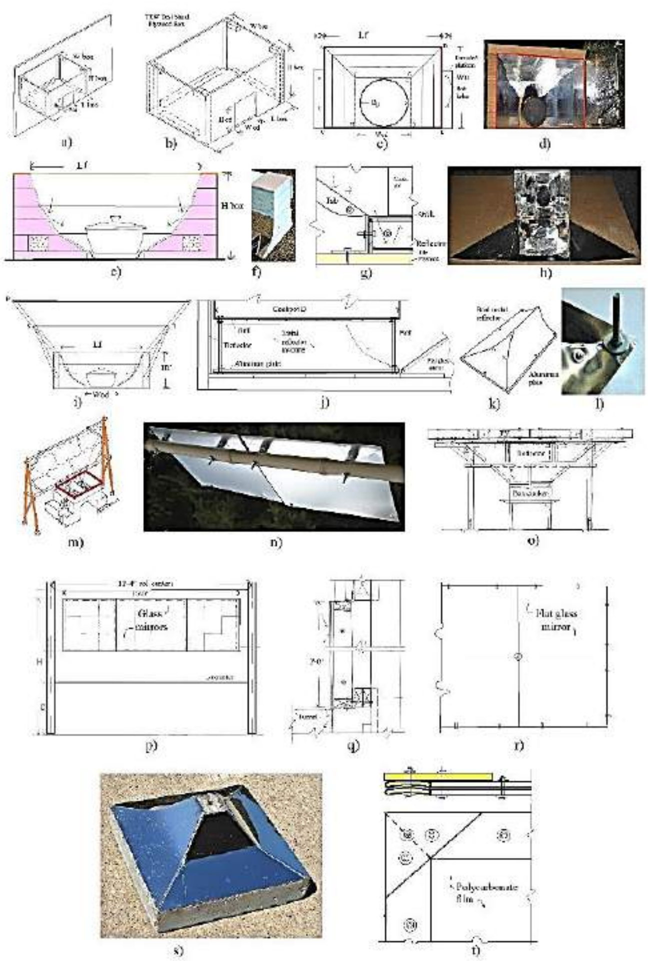

FIGURE 22. Thru-Reflector-Wall (TRW) Solar Cooker Test Stand Studies: a-b) wood funnel box layout; c) plan of funnel; d) funnel mockup cardboard scale mode; e) section of funnel box with rigid foam; f) mockup model of flat glass mirror glued to rigid foam; g) detail section of metal reflector at reflector under grill; h) funnel and trapezoid wall reflector sketch model; i) test stand with folding trapezoid reflector horizontal poles; j,k,l) involute reflector under grill details; m) bamboo supports for trapezoidal reflector with two linear funnels; n) aluminum reflectors bolted to horizontal bamboo; o,p,q) wood pergola frame suporting vertical reflectors; r) flat glass mirror clipped corner for bolting; s) aluminum reflector glued to concrete; t) polycarbonate film split bamboo frame cover detail.

7.6 Testing and Demonstration TRW Building Studies

A small low-cost masonry house in the tropics study has a three-sided ordinary-CPC type funnel part with horizontal inlet aperture, flat trapezoidal kitchen wall reflector (inclined according to site latitude) and vertical E/W portable reflector with a temporary transparent unsealed funnel cover. Cookware on a dark tray (with edges to contain spills) defines the cookware door size and lintel. Cookware options include: large diameter cylindrical cookpot, multiple smaller cookpots, and a cubic black metal oven. A flat glass mirror three-sided CPC-type funnel is in a box or on a platform. Flat glass mirror tiles or aluminum form a trapezoidal reflector shape on the kitchen wall above the cookware door. Construction materials and methods influence cookware door and funnel size e.g., with compressed stabilized earth blocks (CSEB) standard shapes and sizes. The funnel base and countertop are aligned for cookware to slide in/out of the cooking zone. The funnel platform or box is independently structured on a foundation separate (width of a sealant gap) from the kitchen building for seismic risk locations. A seismic resistant masonry study has a horizontal and vertical grid of a reinforced concrete frame integrated within the walls. CSEB block openings are forms for a concrete vertical frame, e.g., at the cookware door sides, cast with steel reinforcement extending from a precast concrete horizontal lintel above the door (Fig. 23). Reference is the AUM house at Mundra, Kutch, Gujarat, by architect Satprem Maini. A small testing and demonstration TRW kitchen building (about 2.5m x 2.5m / 8ft x 8ft) may be later enlarged with an addition to form a house for evaluation by live-in residents cooking for an extended period about one year and documenting the experience (Fig. 23l). Another testing/demonstration building idea is with a Tolokatsin solar cooker appliance from Mexico modified to fit with a trapezoidal reflector wall and portable E/W vertical reflector (Fig. 26h).

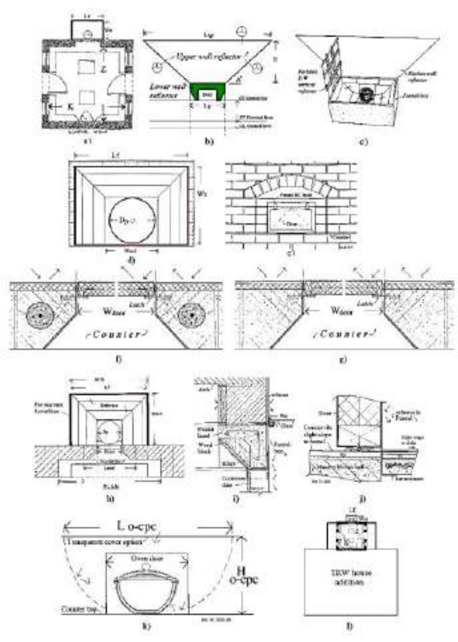

FIGURE 23. TRW Testing and Demonstration Small Kitchen Masonry Building Studies: a) plan; b) schematic elevation; c) isometric; d) plan view of funnel-box; e) interior elevation of cookware door, lintel and relieving arch; f) plan of cookware door area with seismic resistant concrete frame; g) plan of cookware door area for low seismic risk locations; h) plan of funnel-box, cookware door and countertop; i) section of precast reinforced concrete lintel; j) section at bottom of cookware door; k) elevation of cookware door indicating CPC funnel; l) Plan of TRW testing and demonstration house addition.

8. SUPPLEMENTAL STUDIES

Supplemental studies have building-integrated building-size nonimaging CPC-type reflector concentrators (exterior and interior) for a range of building types and sizes, building components and applications (cooking, drying, hot water, process heat, etc.). Medical autoclave temperatures (121°-134°C) may be attained for an alternative to toxic chemicals now used in rural applications to clean medical instruments by visiting doctors and dentists. Large monolithic flat glass mirror rigid foam panel-tiles are for large exterior nonimaging structures with Portland cement in the tropics for various process heat applications. Building integrated walk-in basin stills with large exterior nonimaging CPC reflector troughs were studied in c2006 [5, 12] and continued with a 2021 walk-in still student projects (Cardenas, Cesar, James Waters, Oscar Mora, Sebastian Sena, Basin still with ETFE, Final Report, Dec. 6, 2021, undergrad senior design engineering project, professor Samah Ben Ayed , New Mexico State University, Joel H. Goodman sponsor). A restaurant schematic has multiple solar cookers, funnels and fixed azimuth orientations (Fig. 25). A large involute CPC ship for the equatorial tropics has PV and wind turbines structured on the top rim deck. The glass mirror CPC reflector collects rain stored in large tanks. CPC ship movements that would cause losses for imaging concentrators may have negligible effects. Applications include: hospital ship, habitat for floating wind farm crews, a university, a small town, process heat industries, OTEC, and hotels (Fig. 30g). A building-integrated solar thermal nonimaging concentrator configuration useful for air heating and drying (Fig. 33f) is similar to the BITNR [7] studies except a flat plate shape air collector is the target, and testing can be done in a greenhouse. Previous nonimaging architectonic BITNR studies with evacuated tube receivers are references for glazed walk-in size air receivers and ovens [7]. ETFE glazed heated volumes for interior cookware targets are large enough for maintenance workers to enter (Fig. 33f) [85, 86]. "The (ETFE) membrane is 95% translucent and can have a life expectancy of over 30 years. It performs very similar to glass, without the high weight and cost. Glass structures can exceed $300/sf and ETFE (being flexible and lighter weight) can come in under $150/sf (surface area) …" (E. Jarvie, Pfeifer Structures Inc. May 2021 personal communication). Vertical façade collectors have cable-supported tempered glass (Fig. 33c) [87, 88]. Building interior cookers and nonimaging reflectors (BICNR) for high latitude locations include ETFE single layer and vertical glass-cables glazing configurations that have E&W tracking interior 'wing' reflectors augmenting large EW-line CPC troughs. The BICNR-ETFE may be considered for 30°-40° locations with dust storms or snow. Interior reflector nonimaging concentrators [89, 90] and vertical glass-cable glazing are discussed in the BITNR publication [7]. Additional studies include: building-size CPC trough solar dryers (Fig. 24 i-j), i.e., with tray-racks on an EW-line conveyer belt with only E and W insulated rack doors (Fig. 24j); CPC augmented walk-in basin stills (Fig. 24 e,f,g); TRW with Tolokatsin type solar cookers and medical autoclaves (Fig. 26); building-integrated big 'scoop' funnel solar cooker (Fig. 28); fluid coils (air, liquid) in inverted glass bowl targets (Fig. 29h); large CPC commercial ovens (Fig. 31); suspended cable/net Large CPC trough reflectors (Fig. 32); walk-in CPC and 'wings' augmented air heater with ETFE glazing (Fig. 33f); and hotel kitchen ovens (Fig. 33).

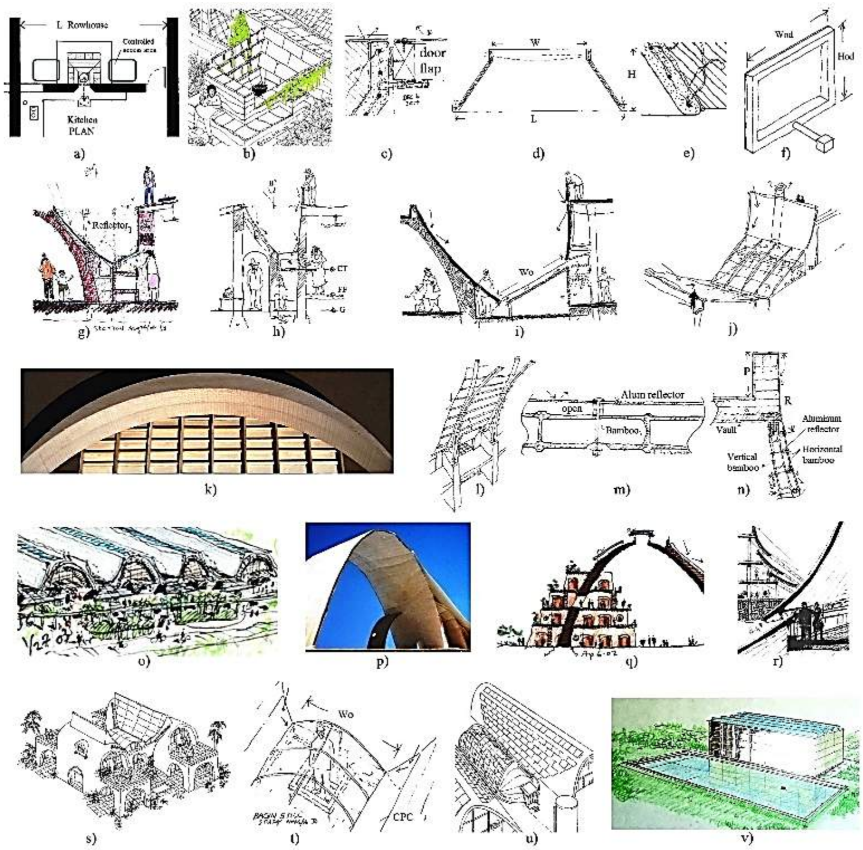

FIGURE 24. Supplemental Studies: a) row house plan showing reflections at E&W areas; b) trellises at E&W areas; c-d-e) ferrocement details at cookware door; f) cookware door; g-h) section drawings with vertical kitchen wall reflector; i-j) large CPC dryers; k-n) bamboo kitchen wall studies with aluminum reflector; o) multiple TRW nonimaging troughs for equatorial latitude locations with low seismic risk; p)sketch model of large vault for supporting fixed reflectors; q)large vault supporting fixed reflectors with multi-level housing; r) serrated fixed reflector trough side; s-t-u) reflectors on building vaults augmenting ETFE walk-in basin stills; v) building-integrated reflector façade augmenting adjacent salt gradient solar pond.

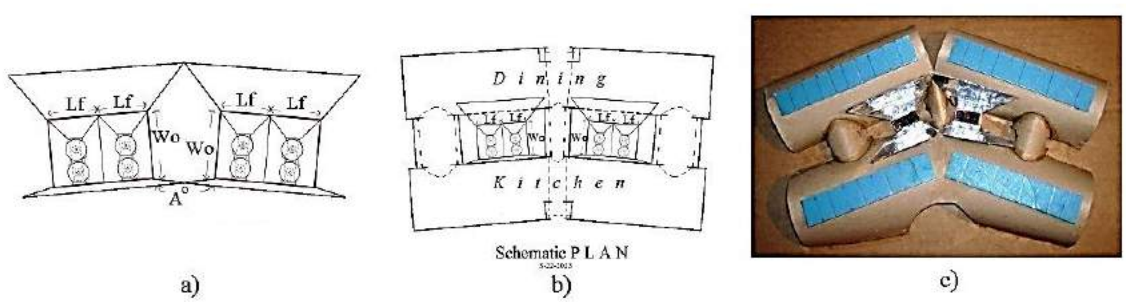

FIGURE 25. TRW building with kitchen and dining room with multiple solar access orientations: a) diagrammatic plan of nonimaging troughs and target rectangles (four cook-pots each) with different solar access orientation azimuth angles; b) schematic building plan with cook-pots in target rectangles protected from horizontal wind; c) photo of sketch model with tracking east and west reflector ‘wings’ in wind protected courtyards .

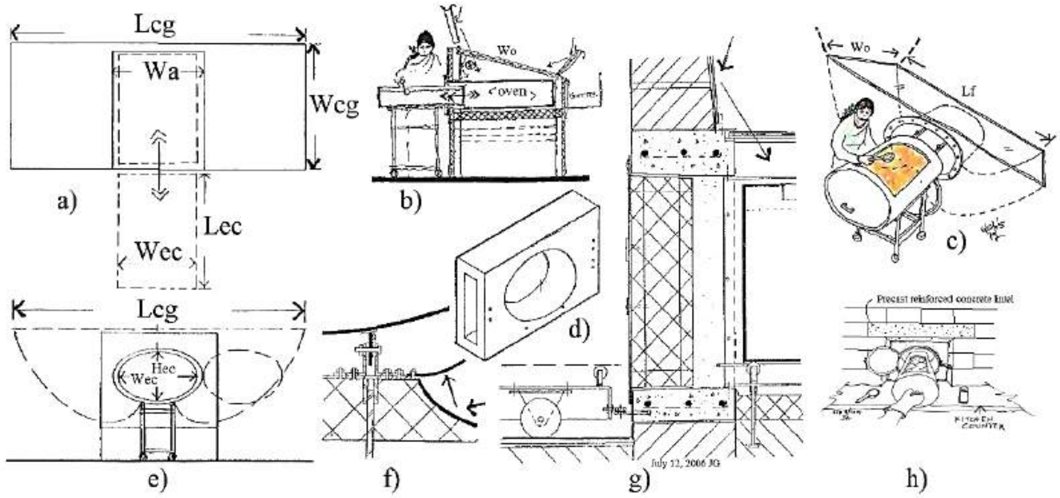

FIGURE 26. TRW with Tolokatsin type solar cookers: a-g) building-integrated construction studies for an enlarged Tolokatsin type solar cooker; h) kitchen view of TRW masonry wall with opening for Tolakatsin TM solar cooker.

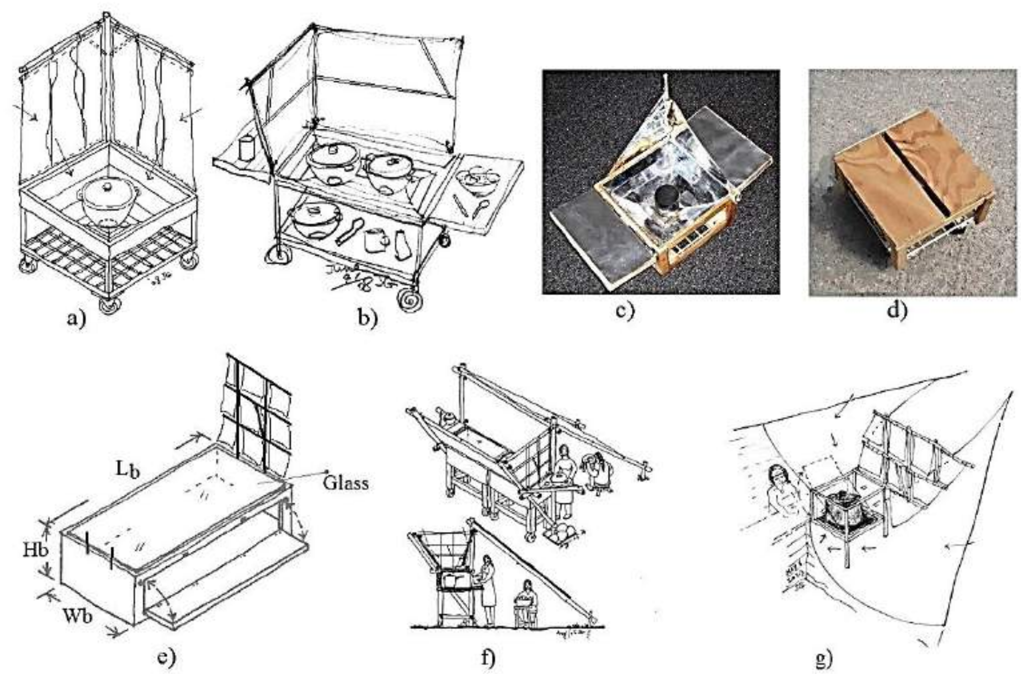

FIGURE 27. Supplemenat Studies a-d) solar cooker cart with nonimaging reflector funnel; e) box-cooker with side door and portable E/W vertical reflector for use with trapezoidal reflector wall f) shed TRW outdoor kitchen with side-door box-cooker; g) TRW for 30°-40° latitudes with reversed glazed receiver base study.

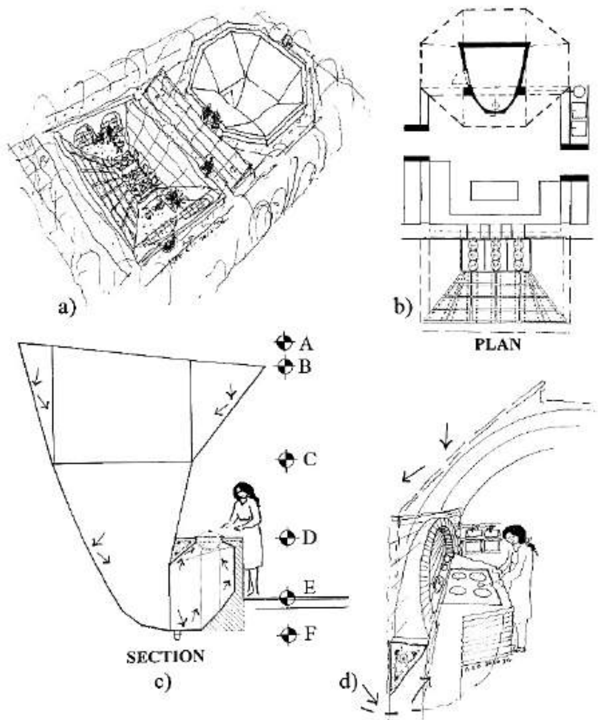

FIGURE 28. Building-Integrated Nonimmaging Big Reflector ‘Scoop’ Funnel Solar Cooker.

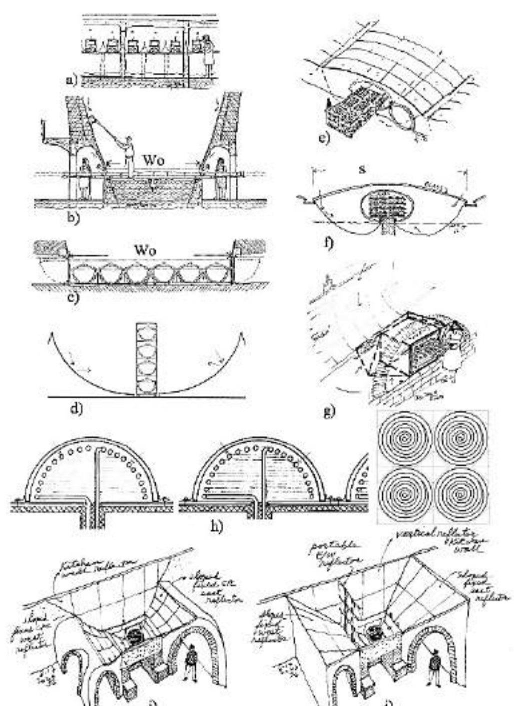

FIGURE 29. TRW Supplementry Studies: a,b,c) N&S cookware doors with large CPC trough commercial cookers; d) vertical multiple cookware rack; e-f) large cookware trays in glazed CPC ovens; g) building-integrated “sea shell” cooker; h) TRW targets of fluid coils (fanned air, pumped fluid) in inverted Pyrex type glass bowls for drying and hot water applications; i-j) E&W fixed reflectors.

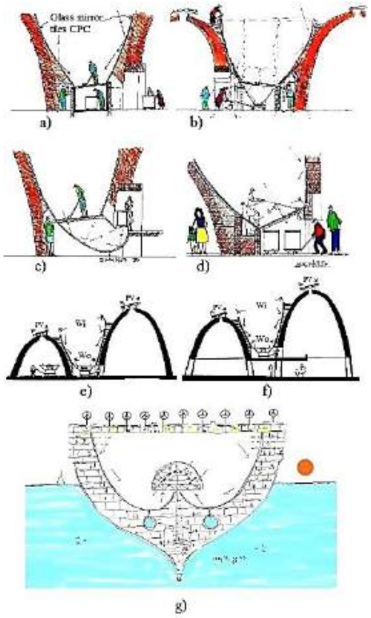

FIGURE 30. Building-Integrated Nonimaging Concentrators Suplementary Studies: a-f) Buildig-size unglazed CPC troughs for process heating applications at equatorial tropical locations; g) CPC trough ship.

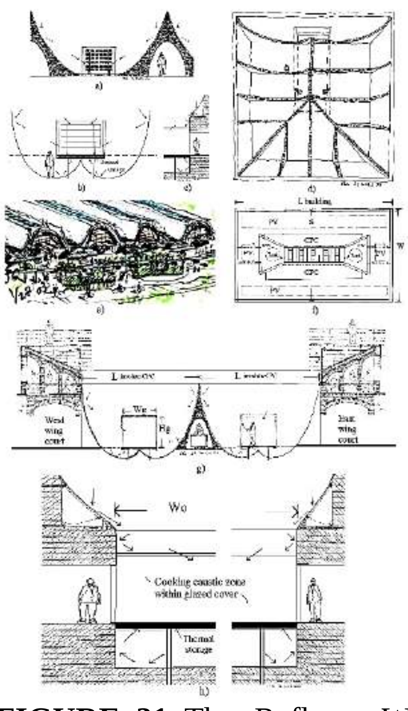

FIGURE 31. Thru Reflector Wall (TRW) large CPC glazed walk-in for maintenance ovens: a) E-W section of ordinary CPC; b) E-W section of involute CPC; c) partial section of kitchen wall reflector one side of an ordinary CPC for equatorial tropical locations; d) masonry foundation walls for a large involute-CPC TRW plan view sketch; e) sketch of large multiple CPCs building; f) diagrammatic large CPC building plan for equatorial locations; g-h) section drawings of large involute CPC building for commercial bakeries.

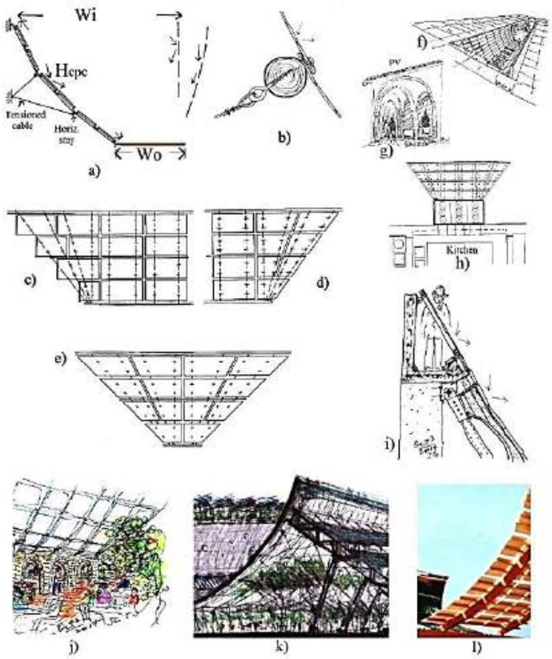

FIGURE 32. Building-Integrated Suspended Cable/Net Large CPC Trough Studies: a-b) cable net supported facet detail studies c,d,e) reflector facets supported on tensioned cable-nets; f-g) sketches of building-integrated large cable-net CPC; h) partial kitchen plan with cable-net CPC side and three linear funnels with multiple cookware; i) top rim of large CPC tension structure; j,k,l) schematic studies of building-integrated large CPC tension structures.

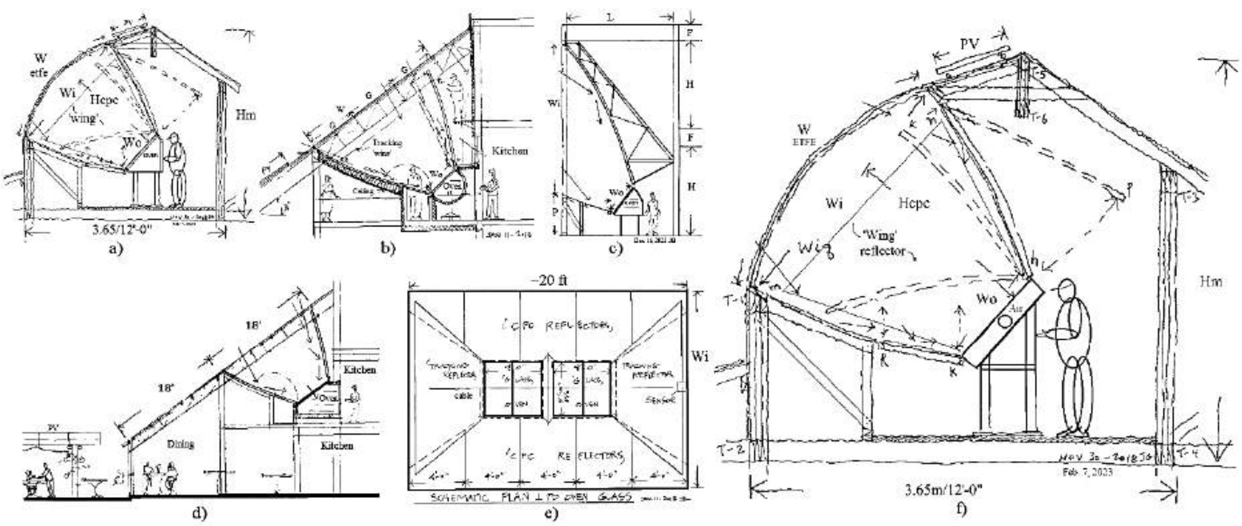

FIGURE 33. Building Interior Solar Ovens with Nonimaging Reflectors with E&W Tracking Reflector 'Wings': a) interior oven with large CPC EW-line trough, tracking E&W 'wing' reflectors and ETFE single layer arched cover roof glazing; b & d) hotel kitchen oven; c) section drawing of interior solar oven for high latitude locations with vertical tensioned cable glass façade glazing; e) interior ovens with large CPC EW-line trough, tracking E&W 'wing' reflectors; f) walk-in CPC and 'wings' augmented air heater with ETFE glazing.

9. TRW SOLAR COOKER-KITCHENS R&D PROJECT PROPOSAL NOTES

A R&D project outline includes: optical-thermal analysis, three-sided CPC-type funnel reflectors, test stands at selected tropical latitudes, glazing funnel cover options, fixed azimuth orientation options, survey of interest for design-engineering projects at universities, technical colleges and research centers, and design and cost estimates of testing and demonstration kitchen buildings for selected cookware sizes and latitude locations. Proposed studies are: for high latitudes (~15° to 2°4+) with a vertical kitchen trapezoidal reflector wall, and equatorial latitudes (~0° to15°) with sloped kitchen trapezoidal reflector walls; durability of reflectors, adhesives, and insulation, and, and ion exchange barriers. Test facilities and demonstration buildings in non-public areas could measure glare and disturbing reflections.

9.1 R&D PART-1: Surveys for TRW Solar Cooker Interest

Participation surveys of interest to universities, colleges, research centers, architects and existing tropical pottery-kiln and glass mirror cutting operations include: engineering/design projects, test stands, testing and demonstration building design and construction. TRW-type test-stand projects began in 2023 at the U. of Tarapaca, Chile, and at U. of California-Merced. Previous related student projects were in India and U. of Wisconsin-Platteville.

9.2 R&D PART-2: Test Stands

This work includes: optical-thermal ray trace studies, testing plan, test stand design and fabrication, measurements documentation, and publication of results. Comparative tests are: funnel with and without cover glazing, and cookware base plate black absorber or reflector. Three-sided ordinary CPC-type funnels with flat glass mirrors are favored for initial testing with selected instrumented cookpots and ovens as a base-case for low seismic risk locations, with flat trapezoidal kitchen wall reflector, and vertical portable E/W reflector. Intentions are to provide references for reflector shapes and sizes for proof-of-concept test facilities and demonstration kitchen buildings designers. Funnel clay molds for test stands may be sized for airplane carry-on bag sizes (22” x14” x9”).

9.3 R&D PART-3: Funnel Design and Construction

This work is comparative evaluation of three-sided CPC-type reflector funnel construction and material options (locally hand built, mass produced, etc.), design development, and prototype fabrication, and cost estimates. Included are: design of tooling (with dimensioned drawings and specifications of molds), evaluating clay compositions and mixtures of binders and aggregates, comparing metal stamping, illustrated construction sequence of recommended designs, instructions for local workshops, and documentation. Compare: mass production manufacturing of three-sided CPC-type reflector funnel as one ‘U’ shape in plan part and three-five separate pieces with material options (fired-clay, recycled plastic, bio-plastic, etc.) as substrate for gluing flat glass mirror monolithic segments; and silver-glass mirrors to aluminum-glass mirrors [91]. Consider durability and cost of metal reflectors [92]. Molds may be sized for airplane luggage. Consider: heat storage options for uncovered funnels, glaze covered funnels (temporary and permanent), and covered cookware [60-62]. Consider funnel optical shape, production costs and transport logistics [93, 94].

9.4 R&D PART-4: Cookware and Receiver Survey
Survey cookware and receiver options for funnel sizing and manufacturing study related to local cookware and cooking used in selected tropical regions.

9.5 R&D PART-5: TRW Simulation Computer Model
Development of simulation design tools for test stands and solar cooker-kitchens with monthly and annual solar resource. Computer models include: ray trace analysis and reflector characterizations for selected locations, latitude ranges and whole Torrid Zone. Variables include: sloped flat or CPC-type curved reflector walls, cookware and funnel cover options. The NREL SolTrace advanced ray trace program may be used available for free [8]. The TRW simulation model is intended to be compared with TRW test stand measurements, and a beginning of a design aid for architects.

9.6 R&D PART-6: Testing/Demonstration Full Size Facility
Full size testing facility design and cost estimate based on test stand results with selected existing marketed cookware. Development of a testing plan (for at least one year) outlining types of cookware, foods to be cooked, and methods of evaluation. This work includes environmental impact assessment, lifecycle impacts, and policy/regulatory issues.

9.7 R&D PART-7: Conceptual Design of TRW building types
This work is to indicate extent of TRW building type possibilities in rural and urban environments. Conceptual and schematic design studies of TRW kitchen buildings and applications of various sizes include: small houses; community kitchens; restaurants and cafeterias, commercial kitchens, open-air PV pergola kitchens, trailers and food carts, stepped multi-level housing, food processing facilities, etc.

9.8 R&D PART-8: Preliminary Design of a Small TRW Testing/Demonstration Kitchen Building
A site-specific small TRW building design and preliminary cost estimate is based on selected cookware dimensions, cookware door clearance height and width and related wall construction design. It may be a new building or remodeling/addition of an existing building. The phase-1 small kitchen building design has a phase-2 addition/remodeling to form a small house for residents to perform continuous (about one year) testing and documentation of cooking selected foods, cookware, operation and maintenance, etc. Building design may proceed with best available location-specific nonimaging reflectors characterization. An aim is for TRW solar kitchen building projects in representative latitude tropical and near tropical locations with high and low seismic risk with local construction materials and methods.

9.9 R&D PART-9: Design Development of Small TRW Testing/Demonstration Kitchen Buildings
This architecture and engineering work is to develop selected preliminary designs for specific sites with construction documents, specifications and cost estimates by project architects and engineers.

9.10 R&D PART-10: Construction of TRW Testing/Demonstration Buildings
Documentation includes: construction team descriptions; materials and equipment specifications; step-by-step construction, and costs.

9.11 R&D PART-11: Small TRW Building Evaluation

Evaluations include: cooking in the small TRW kitchen buildings for an extended period of testing (at least one year), with selected foods, cookware, operation and maintenance, and documentation; and kitchen building construction and costs.

9.12 R&D PART-12: Student Projects

All the R&D parts have possible student projects to be included in surveys to research and educational programs. Completed student projects include: CPC solar cooker study student engineering project at the Pondicherry Engineering College, Pillaichavady, south India in 2006 partly funded by the Foundation for World Education (FWE) (Fig. 34); and solar cooker appliance undergrad student project at the U. of Wisconsin-Platteville in 2015 intended to be preparation for a TRW trailer food cart project (Fig.35). A TRW-type test stand project with three-sided CPC-type funnel by Dr. Sagade has been funded at the U. of Tarapaca, Arica, Chile (18.47° S) (A. Sagade Aug. 1, 2023 personal communication); and a TRW fired-clay three-sided CPC-type funnel manufacturing and test stand two semester student project began in 2023 at U. of California-Merced.

FIGURE 34. Compound Parabolic Concentrator (CPC) solar cooker study student engineering project at the Pondicherry Engineering College, south India in 2006, partly funded by the Foundation for World Education (FWE) (Rapaka, E. V. K., *Report No.3: Study on the optical and thermal properties of a compound parabolic concentrator with and without end-wall reflectors for Pondicherry region*, Oct. 9, 2006, Dept. of Mechanical Engineering, Pondicherry Engineering College, Pillaichavady, Pondicherry, India).

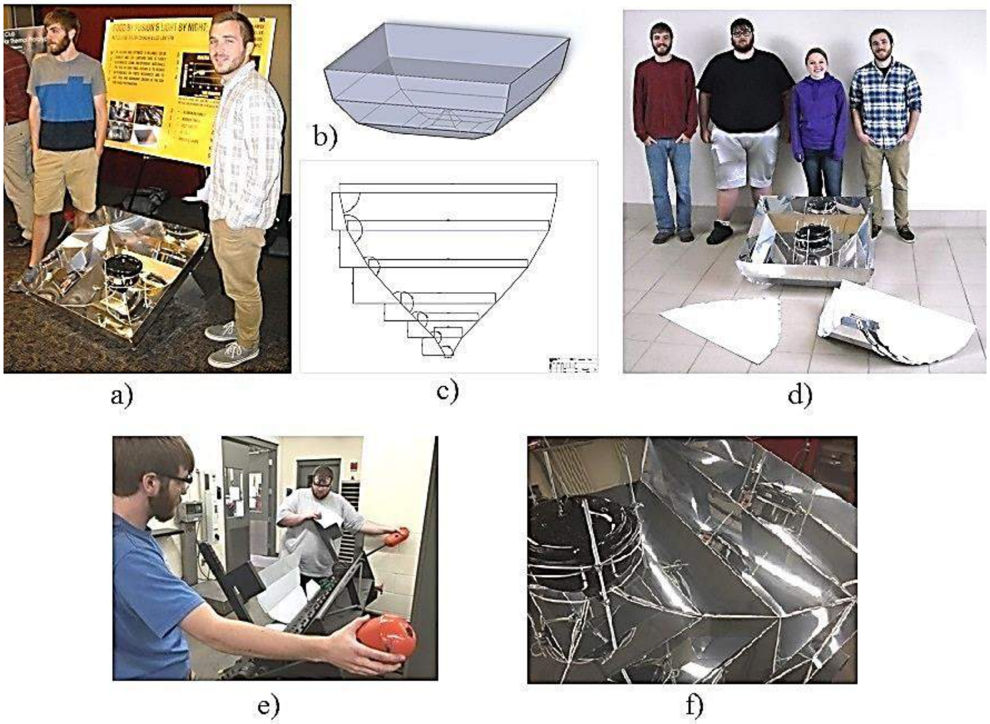

FIGURE 35. Solar cooker appliance project at the University of Wisconsin-Platteville, May 2015, involute CPC aluminum stand-alone cooker appliance: a) mid-term poster presentation, b-c) design drawings, d) final presentation, e) bending aluminum reflector fabrication, f) four quadrants assemble (Hayes, Andy, Chaz Keller, Hayley Gigous, and Nathan Kahle; Reflective solar cooker- food by fusion, light by night, PACCE project May 2015 final report, Renewable Energy Systems, U. of Wisconsin-Platteville, D. Ress Faculty advisor, Joel H. Goodman sponsor, 1997.

10. COMMENTS

Building-integrated two-stage nonimaging concentrator Thru-Reflector-Wall (TRW) solar cooker-kitchens conceptual and schematic design and constructional studies (since c2000) mainly for the Torrid Zone and near tropical locations are presented. A two-part first-stage basic concentrator has: a large fixed wall(s) trapezoidal reflector(s) EW-line trough and a portable E/W lightweight vertical reflector repositioned at noon; and second-stage horizontal inlet three-sided CPC-type part plus vertical side with cookware door funnel reflector. A cookware door in the funnel vertical side kitchen wall enables cooks in the kitchen to slide or roll in-out cookware to the exterior cooking zone. The integration of nonimaging reflector two-stage concentrators with building structures combine wide solar CPC angular acceptances and conventional construction tolerances for applications in tropical locations without: mechanical tracking, fluid loops, pumps and electronics. TRW kitchen building studies include: small houses; community kitchens; restaurants/cafeterias, commercial kitchens, open-air PV pergola kitchens, and trailers/food carts. Building-integration with nonimaging reflector optical shapes and associated building structure and construction factors are discussed e.g., flat and curved parabolic segment reflector performance and construction cost tradeoffs and glass silver mirror ion exchange damage by Portland cement. Proposed R&D project notes include: test stand measurements, computer modelling ray-trace and design tools, demonstration kitchen building designs and construction, and performance and cost evaluations. Building-integrated fixed large CPC reflector unglazed troughs with E&W reflectors for the tropics were discussed in 2003 with Prof. Bill Beckman, then Director of the U. of Wisconsin Solar Energy Laboratory and he commented: "…buildings like this have never been built and it looks like it has some potential…about a concentration ratio of 2 to 2.5…", and later "…about a 20% increase per side of ordinary CPC…". He did not comment about the E/W reflectors repositioned at noon. Measurements of a TRW type test stand called BISTIC with a vertical 'kitchen' wall trapezoidal reflector and two-sided CPC-type funnel began about November 2022 in Pandharpur, India, (17.68° N latitude). A TRW-type funded (4 million Chilean Pesos) project began in 2023 at the U. of Tarapaca, Arica, Chile (18.47° S latitude); and a TRW 3-sided CPC-type fired-clay funnel part and test stand undergrad student team project started September 2023 at the U. of California-Merced (37.30° N latitude). TRW nonimaging optical-thermal empirical evaluation studies are needed for demonstration building construction designs.

11. REFERENCES

[1] IEA (2023), SDG7: Data and projections, IEA, Paris https://www.iea.org/reports/sdg7-data-and-projections, accessed Oct. 15, 2023.

[2] O'Gallagher JJ. Nonimaging optics in solar energy. Cham: Springer; 2008. https://doi.org/10.1007/978-3-031-79420-9

[3] Sagade Atul A., Narayani A. Sagade, Basim Belgasim, M.A. Tawfik, Swanand Kulkarni, S.K. Shulka, Building integrated innovative non-imaging concentrating solar collector for clean cooking under low sun elevation, *Sustainable Energy Technologies and Assessments*, Volume 57, 2023, https://doi.org/10.1016/j.seta.2023.103234.

[4] Goodman, Joel H., *Solar Concentrating Architectonics*, Design Arts Grant #91-4259-0121, U.S. National Endowment for the Arts, Final Report, 1993.

[5] Goodman, Joel H., Architectonic studies with selected reflector concentrating solar collectors, *Journal of Green Building*, 2007, Vol. 2 Number 2, Spring, College Publishing, pp 78-108, https://doi.org/10.3992/jgb.2.2.78.

[6] Goodman, Joel H., "Small heliostats CSP systems on long-span hanging roofs", *Journal of Green Building*, 2019 Spring, Vol. 14, number 2, p219-242, https://doi.org/10.3992/1943-4618.14.2.219

[7] Goodman, Joel H., Building interior tubes and nonimaging reflectors (BITNR) studies, 2020, Spring, *Journal of Green Building*, Vol.15 Number 2, p213-248, https://doi.org/10.3992/1943-4618.15.2.213.

[8] NREL SolTrace advanced ray trace program, *NREL Technology Brief*, 8-1994, NREL/MK-336-6702, https://www.nrel.gov/csp/soltrace.html.

[9] Goodman, Joel H., Selected building integrated active solar energy structures, In: *Proceedings of International Solar Energy Society Solar World Congress*, Gothenburg, Sweden, June 14-19, 2003.

[10] Goodman, Joel H., Solar cooking kitchen studies with building size nonimaging reflectors, In: *Proceedings of ISES Solar World Congress, Orlando*, Ed: D.Y. Goswami et al, Aug. 2005. DOI:10.3992/1943-4618.15.2.213

[11] Goodman, Joel H., Architectonic studies with building size nonimaging reflectors", invited, In: *Proceedings of the World Renewable Energy Congress IX*, Ed: A. Sayigh, Florence, Italy, Aug., 2006.

[12] Goodman, Joel H., Building size fixed reflector CPC troughs and bowls for food processing facilities, In: *Proceedings of the International Solar Food Processing Conference, ISES*, Jan. 2009, Indore, India.
[13] Winston, Roland, Principles of solar concentrators of a novel design, *Solar Energy*, 1974, Vol.16, p89-95.
https://doi.org/10.1016/0038-092X(74)90004-8.
[14] Duffie, John A. and William A. Beckman, *Solar Engineering of Thermal Processes*, 1980, Wiley. https://doi.org/10.1002/9781118671603
[15] Trombe, Felix, CNRS, *U.S. Patent 3,310,102*, 3-21-1967.
[16] Meinel, Aden B. and Marjorie P. Meinel, *Applied Solar Energy an Introduction*, Addison-Wesley Pub., 1976, https://www.osti.gov/biblio/7338398.
[17] Steadman, Philip, Energy, *Environment and Building*, 1975, Cambridge U. Press, p80.
[18] Winston, R. and H. Hinterberger, Principles of cylindrical concentrators for solar energy, *Solar Energy*, 1975, 17, 255, https://doi.org/10.1016/0038-092X(75)90007-9.
[19] Baranov, V. K. and G.K. Mel'nikov, Study of the illumination characteristics of hollow focons, *Soviet Journal of Optical Technology*, Vol: 33, No.5, September-October, 1966, p 408-411.
[20] Hinterberger, H. and R. Winston, Efficient light coupler for threshold Cerenkov counters, *Review of Scientific Instruments,* Vol: 37, 1966, pps 1094- 1095 (Received 1 March 1966).
https://doi.org/10.1063/1.1720428
[21] Jayaraman, S., K. Perumal and V. Balasubramanian, Development of compound parabolic concentrators in India, *Energy and Environment into the 1990s, WREC-1,* Reading UK, Sept 1990, Ed: A.A.M. Sayigh, p 844-848, Pergamon Press, Oxford.
[22] Ferrari, David, Ninad Mohan Dharmadhikari, Cameron Stanley, Leesa Blazley, Ahmad Mojiri and Gary Rosengarten, Prototype design of a low-concentration roof-mounted solar thermal collector for industrial heat production, *Proceedings of Asia-Pacific Solar Research Conference*, 2016.
[23] Hunbae and C. Lambeth, 1993*, Sundancing, The Art and Architecture of James Lambeth*, Miami Dog Press.
[24] Lambeth, James and John D. Delap, *Solar Designing*, 1977, privately published.
[25] Anderson, S and G. Fenske editors, *Aalto and America*, 2012, Yale U. Press.
[26] Shurcliff, William, *Solar Heated Buildings of North America: 120 outstanding examples*, Brick House Publishing Co., 1978.
[27] Bellamy, Glenn, An evacuated tube solar system for the National Agricultural Library, *Proceedings of 9th Biennial ISES Congress, Intersol 85*, Vol. 2, Montreal, 6-1985, p1033-1037.
[28] Mannan, K.D., Cheema L.S., Development and testing of solar cooking devices at P.A.U. Ludhiana, In: Proceedings of Alternative Energy Sources, 6th International Symposium, Miami Beach, Dec 12-14, 1983, Ed: Veziroglu, T. N., Springer-Verlag.
[29] Garg, H.P., *Advances in Solar Energy Technology*, Vol.3, 1987, Springer Nature.
[30] Kerr, Barbara, Trough Wall Solar Cooker, *US Patent 4,655,196*, April 7, 1987.
[31] Grupp, Michael and Hannelore Bergler, Advanced solar box and flat plate cookers", In: *Advances in Solar Cooking, Proceedings of the First World Conference on Solar Cooking*, Stockton, California, June, 1992, ed: Edwin Pejack, p 87-95.
[32] Schwarzer, Klemens, and Maria Eugenia Vieira da Silva, Solar cooking system with or without heat storage for families and institutions, *Solar Energy*, 75, 2003, p35-41, DOI:10.1016/S0038-092X(03)00197-X.

[33] Munir, A., O. Hensel, and W. Scheffler, Design principle and calculations of a Scheffler fixed focus concentrator for medium temperature applications, *Solar Energy*, Volume 84, Issue 8, August 2010, p1490–1502, DOI:10.1016/j.solener.2010.05.011.
[34] Aremu, A. K., C.A. Ogunlade and A.D. Oladapo, Design and experimental testing for a building integrated box type solar cooker, *Journal of Multidisciplinary Engineering Science Studies (JMESS)*, Vol. 5 Issue 3, March 2019.
[35] Harmima, A., M. Merzouka, M. Boukara, and M. Amara, Design and experimental testing of an innovative building-integrated box type solar cooker, *Solar Energy*, Volume 98, Part C, December 2013, p422-433, DOI:10.1016/j.solener.2013.09.019.
[36] Ruivo, Celestino Rodrigues, Concrete funnel cooker: useful permanent outside device for slow cooking, In: *Proceedings of University of Algarve-Portugal, CONSOLFOOD 2016 Conference*, January 22-23, Faro-Portugal.
[37] Terres, Hilero, Arturo Lizardi, Raymundo López, Mabel Vaca, Sandra Chávez, Mathematical model to study solar cookers box-type with internal reflectors, *Energy Procedia 57*, 2014, p1583–1592, doi: 10.1016/j.egypro.2014.10.150.
[38] Terres, H., S. Chávez, A. Lizardi, A. Lara, J. Morales, R. Rodríguez, C. Ruiz, M. Reyes and E. Andrade, Analysis of a solar cookers box-type with inner reflectors by using CFD, September 2022, In: *Journal of Physics Conference Series, p2307*, 2022, DOI:10.1088/1742-6596/2307/1/012001.
[39] Martinez, Alexis, Onell Morales, Richard Komp, Solar autoclaves for sterilizing medical instruments in remote health clinics, In: *Proceedings of Orlando ISES Conference, 2005.* Ed: D.Y. Goswami et al, Aug. 2005, DOI:10.3992/1943-4618.15.2.213
[40] Touré, Siaka, Modibo Sidibé, Wanignon Fassinou, Aboudramane Gbané, Hassan Salami, A performance study of two solar cookers experimented in Abidjan (Ivory Coast), Laboratoire d'Energie Solaire, Université de Cocody 22 BP 582 Abidjan 22, Ivory Coast, In: *Proceedings of World Renewable Energy Congress VIII (WREC 2004)*, Denver, Ed: AAM Sayigh.
[41] Mora, Eduardo González, Eduardo Armando Rincón Mejía, Daniel Moreno Lawrence, Using a new solar sterilizer for surgical instruments as a solar oven for cooking, In: *Proceedings of CYTEF 2016 − VIII Congreso Ibérico | VI Congreso Iberoamericano de las Ciencias y Técnicas del Frío Coimbra-Portugal*, 3-6 May, 2016.
[42] El-Sebaii, A.A., Thermal performance of a box type solar cooker with outer-inner reflectors, *Energy*, Vol. 22, No. 10, pp 969-978, 1997.
DOI: 10.1016/S0360-5442(97)00027-3.
[43] Duffy, John, Village empowerment: service-learning with continuity, Engineering Program, University of Massachusetts Lowell, In: *International Journal for Service Learning in Engineering*, Vol. 3, No. 2, Fall 2008, p1-17.
[44] Bernard, Roger, *Le Soleil a Votre Table*, Editions Silence, Lyon, 1987a.
[45] Bernard, Roger, A handy solar cooker, *SunWorld*, Vol. 11, Number 2, 1987b, p49-50.
[46] Cogni, Francesca, file no.3 article editor, Solar open source, solar cookers, *Domus magazine 891*, Italy, April, 2006, p52-57.
[47] Maiti, Subaran, Pankaj Patel, Kairavi Vyas, Kruthika Eswaran, and Pushpito K. Ghosh, Performance evaluation of a small scale indirect solar dryer with static reflectors during non-summer months in the Saurashtra region of western India, *Solar Energy*, 85, 2011, p2686-2696, DOI:10.1016/j.solener.2011.08.007.
[48] Sagade, Atul A., Xabier Apaolaza-Pagoaga, Celestino Rodrigues Ruivo, Antonio Carrillo-Andrés, Concentrating solar cookers in urban areas: establishing usefulness through realistic

intermediate temperature rating and grading, *Solar Energy,* 241 (2022), 157-166. https://doi.org/10.1016/j.solener.2022.06.007 (IF: 5.742).
[49] Kienzlen, V., Gordon, J. M., and Kreider, J. F., The reverse flat plate collector: A stationary, nonevacuated, low-technology, medium-temperature solar collector, *In: ASME Journal of Solar Energy Engineering,* February 1988; 110(1): 23–30. https://doi.org/10.1115/1.3268232
[50] Sakuta, K., T. Tani, S. Sawata, T. Tanaka and T. Horigome, Comparison of solar concentrators, *Energy Development in Japan*, Vol. 1, 1975.
[51] Rabl, A., Comparison of solar concentrators, *Solar Energy*, 18, 93, 1976a, https://doi.org/10.1016/0038-092X(76)90043-8.
[52] Collares-Pereira, Manuel, and Antonia Joyce, A CPC type collector applied to water desalination, In: *Proceedings of optical materials technology for energy efficiency and solar energy conversion XI*, France, SPIE, International Society for Optical Engineering, Vol: 1727, 1992, p 269-275.
[53] Norton, B., P.C. Eames, Y.P Yadav, and P.W. Griffiths, Inverted absorber solar concentrators for rural applications, *International Journal of Ambient Energy*, Taylor & Francis, July 1997, p115-120. doi: 10.1080/01430750.1997.9675269.
[54] Goyal, R. K., and G. N. Tiwari, Parametric study of a reverse flat plate absorber cabinet dryer: a new concept, *Solar Energy,* 60.1 (1997): 41-48. DOI:10.1080/01430750.1997.9675269.
[55] Steward, W.G., P.S. Caruso. JR., J.F. Kreider, and F. Kreith, Experimental evaluation of a stationary spherical reflector tracking absorber solar energy collector, In: *Proceedings of ASME Tech. Div. Dec. 5, 1976 Meeting*, NY, NY, 76-WA/HT-10, 6 pages.
[56] Kreider, Jan, and Frank Kreith, *Solar Heating and Cooling*, Revised first edition, McGraw-Hill, 1975.
[57] Grossman, Gershon and Eliezer Fruchter, Development of a spherical reflector/tracking absorber solar energy collector, In*: Israel Journal of Technology,* Vol. 17, 1979, pp. 5-11.
[58] Grossman, Gershon, Chapter 9, Israeli Section of the ISES, 2005, ed: Karl Boer, published by ASES, *History of ISES Vol. 1*, p216.
[59] Di Nicola, Giovanni, Gianluca Coccia, Alessia Aquilanti, Sebastiano Tomassetti, Mariano Pierantozzi, Experimental testing of a solar box cooker with thermal energy storage based on xylitol, *Proceedings of Third International Conference CONSOL FOOD 2020*, *Advances in Solar Thermal Food Processing* 22-24 January 2020, at U. of Algarve, Faro, Portugal.
[60] Anilkumar, B. C., Maniyeri, R., and Anish, S. (May 18, 2023). Performance prediction model evelopment for solar box cooker using computational and machine learning techniques, *ASME. J. Thermal Sci. Eng. Appl.* July 2023; 15(7): 071011. https://doi.org/10.1115/1.4062357
[61] B.C. Anilkumar, Ranjith Maniyeri, S. Anish, Optimum selection of phase change material for solar box cooker integrated with thermal energy storage unit using multi-criteria decision-making technique, *Journal of Energy Storage*, Volume 40, 2021, 102807, https://doi.org/10.1016/j.est.2021.102807.
[62] Anilkumar BC, Maniyeri R, Anish S. Design, fabrication and performance assessment of a solar cooker with optimum composition of heat storage materials, *Environ Sci Pollut Res Int.* 2021 Dec;28(45):63629-63637. doi: 10.1007/s11356-020-11024-3.
[63] Grassie, Stuart L. and Norman R. Sheridan, The use of planar reflectors for increasing the energy yield of flat-plate collectors, *Solar Energy*, Vol. 19, pp 663-668, 1977. https://doi.org/10.1016/0038-092X(77)90027-5.
[64] Wang, Ping-Yang, Shuang-Fei Li, Zhen-Hua Liu, Collecting performance of an evacuated tubular solar high-temperature air heater with concentric tube heat exchanger, *Energy Conversion and Management*, Volume 106, December 2015, Pages 1166-1173.

https://doi.org/10.1016/j.enconman.2015.10.058.
[65] Wang, Pin-Yang, Hong-Yang Guan, Zhen-Hua Liu, Guo-San Wang, Feng Zhao, Hong-Sheng Xiao, High temperature collecting performance of a new all-glass evacuated tubular solar air heater with U-shaped tube heat exchanger, *Energy Conversion and Management*, January 2014, 77, 315–323. https://doi.org/10.1016/j.enconman.2013.08.019.
[66] Nandwani, Shyam S., Design, construction and study of a hybrid solar food processor in the climate of Costa Rica, *Renewable Energy*, Volume 32, Issue 3, 2007, Pages 427-441, https://doi.org/10.1016/j.renene.2006.01.019.3
[67] Sethi, V.P. and Sadhna Arora, Improvement in greenhouse solar drying using inclined north wall reflection, *Solar Energy*, Volume 83, Issue 9, 2009, Pages 1472-1484. https://doi.org/10.1016/j.solener.2009.04.001
[68] Tabor, H., Mirror boosters for solar collectors, *Solar Energy*, vol. 10 -3, 1966, pp111-118.
[69] Tabor, H., Some reflections on mirror concentrators, Solar Institute of technology, Athens, (1966), p227-241, in *Selected reprints of papers by Harry Zvi Tabor*, Ed: M. Prince, 1999, Co-publisher ISES and Balaban.
[70] Mueller Solartechnik, Zebre Pil Kaar 2 solar cooker, *Solar Cooker Review*, March 2007, p13.
[71] Curtis, William. *Balkrishna V Doshi*, Rizzoli 1988, (Atira Housing).
[72] Fend, Thomas, Gary Jorgensen, Harald Küster, Applicability of highly reflective aluminum coil for solar concentrators, *Solar Energy*, Volume 68, Issue 4, 2000, p361-370. DOI:10.1016/S0038-092X(00)00027-X.
[73] Fernández-García, Aránzazu, Diaz Franco, Raquel, Martinez, L. and Wette, Johannes. (2014). Study of the effect of acid atmospheres in solar reflectors durability under accelerated aging conditions. *Energy Procedia*, 49. 10.1016/j.egypro.2014.03.177. DOI:10.1016/j.egypro.2014.03.177.
[74] Guigan, Gilles, John Harper, et al, Auroville Centre for Scientific Research Trust (CSR), *Auroville Solar Bowl Concentrator for Community Scale Steam Cooking*, May 2008 Report, funded by the Government of India, Ministry of Non-Conventional Energy Sources (MNES).
[75] SERI, *Silver/Glass Mirrors for Solar Thermal Systems*, SERI/SP-271-2293, DE85000537, June 1985
[76] Stone, K.W., Radtke, C.W., Blackmon, J.B, , Status of glass reflector technology for heliostats and concentrators, In: *Proceedings of the 28th Intersociety Energy Conversion Engineering Conference*, Vol. 2, Atlanta, American Chemical Society, Aug 8-13, 1993.
[77] Strachan et al, February 1993, *Testing and evaluation of large-area heliostats for solar thermal applications*, SAND92-1381-UC-235, Contract DE-AC04-76DP00789.
[78] Abrahams, Tim, Dec. 2021, *"Bowled Over*", Architectural Record magazine, p68-73.
[79] Maini, Satprem, *Auroville Architecture*, Prisma 4th edition, 2011, p141.
[80] Baetens, Tency and Gilles Guigan, Fabrication and specifications of ferrocement doors, *J. of Ferrocement*, V-20, No.4, Oct. 1990, p357-365.
[81] Winston, R., 1977, *Radiant Energy Collector*, US Patent 4,002,499
[82] Goyal, Krishan, *Foam glass from waste glass*, M.S. thesis in ceramic engineering, U. of Utah, Aug. 1975.
[83] Giovan, M. and M. Adams, *Evaluation of cellular glasses for solar mirror panel applications*, JPL Pub., 79-61, DOE/JPL-1060-24, June 15, 1979.
[84] Martínez-Manuel, Pedro R., Luis M. Valentín-Coronado, Iván Salgado-Transito,Manuel I. Peña-Cruz, Fernando Martell-Chávez, J. Gonzalo Carrillo-Baeza, Carlos A. Pineda-Arellano, Optical evaluation of 3D printed CPC by coupling photogrammetry and ray tracing analysis,

Journal of Applied Engineering Science, Vol. 20, No. 4, 2022, Paper number: 20(2022)4, 1033, 1282-1292, DOI:10.5937/jaes0-37918.
[85] Fortmeyer, R. and C. Linn, 2014, *Kinetic Architecture*, Unilever Haus by Behnisch Archikten, p118-123.
[86] Dimitriadou, Eleni Anastasia and Andrew Shea, Experimental assessment and thermal characterization of ethylene tetra fluoro ethylene ETFE Foil, *Athens Journal of Technology & Engineering*, Vol. 2, No. 1, March 2015. DOI:10.30958/ajte.2-1-2.
[87] Holgate, Alan, *The art of structural engineering, the work of Jorg Schlaich and his team*, 1997, Publisher: Edition Axel Menges.
[88] Patterson, Mic, *Structural Glass Facades and Enclosures*, 2011, Wiley.
[89] Adsten, M., A. Helgesson, and B. Karlsson, Evaluation of CPC-collector designs for standalone, roof or wall installation, *Solar Energy,* 79, 2005 p638-647. DOI:10.1016/j.solener, 2005.04.023.
[90] T.K. Mallick, P.C. Eames, T.J. Hyde, B. Norton,
The design and experimental characterization of an asymmetric compound parabolic photovoltaic concentrator for building façade integration in the UK, Solar Energy, Volume 77, Issue 3, 2004, Pages 319-327, https://doi.org/10.1016/j.solener.2004.05.015.
[91] Jiping, H. and C. Faquan, Investigation on getting longer lifetime AL/ Glass mirror, In: *Proceedings of ASME-JSME-JSES Solar Engineering Conference, Vol-2*, Honolulu, March 1987, p549-552, Ed: Koichi Watanabe, D. Yogi Goswami, Henry M. Healey.
[92] Christian Hutter, Lucía Martínez-Arcos, Durability of solar reflector materials for secondary concentrators used in CSP systems, *Solar Energy Materials & Solar Cells*, 130 (2014) 51–63.
[93] Rabl, Ari, Optical and thermal properties of compound parabolic concentrators, *Solar Energy*, Vol. 18, pp 497-511, Pergamon Press, 1976b. DOI; 10.1016/0038-092X(76)90069-4
[94] Winston, Roland, Juan C. Minano, Pablo G. Benitez, *Nonimaging Optics*, Elsevier Academic Press, 2005. https://doi.org/10.1016/B978-0-12-759751-5.X5000-3