BUILDING SIZE FIXED REFLECTOR CPC TROUGHS and BOWLS for FOOD PROCESSING FACILITIES

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Abstract

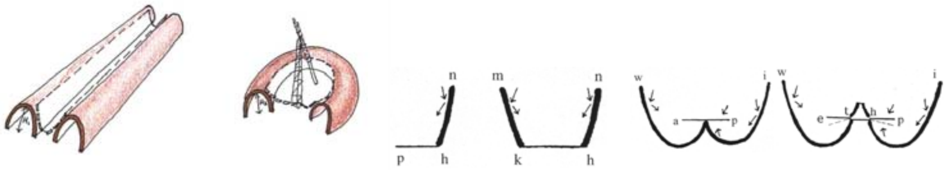
Building integrated stationary concentrating building size reflectors for solar thermal food processing applications and facilities in non-seismic regions are schematically presented for: water distillation, drying, cooking and refrigeration. Fixed mirror concentrating collector technologies are: nonimaging (NI) CPC type *troughs* for low concentrations (E-W horizontal for equatorial tropics, and N-S inclined for higher latitudes); and solar *bowls* (fixed spherical segment reflector with two axis tracking linear receiver) for mid to high beam imaging concentrations. Fixed flat glass laminated silver mirror segments are supported on stabilized excavations, masonry structures (vaults, domes, etc.) or manufactured substrate panels. Targets for the NI CPC troughs are: walk-in stills; dryer with "seashell" type concentrator; global glazed type ovens (HotPot^{TM}, etc.); and thermal flat plates/evacuated tubes (ET) transverse to troughs. Main materials and structures are compressed stabilized earthen blocks (CSEB), flat glass laminated silver mirrors, and masonry vaults and domes with up to 15m/50ft spans and rises.

1. Introduction

Continuing studies are of architectural structures with integral concentrating solar thermal collectors for non-seismic global applications that begin with the active collector technologies and reflector optics as basis for exploration of architectural collector elements [1-4]. Building size fixed mirror solar concentrators are nonimaging CPC type troughs and solar bowls for applications up to mid temperature (~80C/176F to 250C/482F). An intention is to present schematic building integrated possibilities with troughs and bowls that can be reviewed for selection of engineering evaluation and architectural design development advance.

A building structures emphasis is with masonry forms (vaults, domes, etc.) composed with compressed stabilized earthen blocks (CSEB) technology. Sunlight, local raw earth (mixed with small amounts of stabilizer compressed into building blocks) supporting fixed reflecting mirrors is presented as a potential part of sustainable energy economic development for many people in the non-seismic developing regions. Reflector technology emphasis is with flat glass laminated mirrors technology with reference to the successfully demonstrated Auroville solar bowl concentrator [5-6]. Small portable solar cookers (30cm/12"o.d. HotPot^{TM}) with building size fixed NI CPC type reflector concentrators are considered for mid size solar kitchens. Global glazed type ovens are studied because out-gassing (from insulation, paint, glue, etc.) is a concern with large reflector augmented box cookers.

Building integrated solar collector *troughs* and *bowls* are project parts of a more comprehensive research program initiative of Building Integrated Micro CSP (Concentrating Solar Power) being developed for international collaboration.



a) b) c) d) e) f)

Fig. 1- BUILDING SIZE FIXED REFLECTOR CPC TROUGHS and BOWLS for FOOD PROCESSING FACILITIES: a) CPC trough; b) solar bowl; c) one sided CPC; d) CPC; e) involute; f) split involute.

2. Background

Thermal reflecting involute troughs patented in 1967 [7] were later adapted for reflecting solar concentration by Meinel; and secondary cusp mirrors between heat transfer fluid pipes were reported [8]. Nuclear light concentrator optics and technology were applied to nonimaging (NI) CPC solar applications by Winston [9]; and advanced with flat-plate bifacial receivers and "sea shell" concentrators by Rabl [10]. Building integrated fixed curved exterior reflector one-sided troughs have been built [11]. Nonimaging CPC type reflectors augmenting water stills and cooker studies have been reported [12,13,14, 32].

Mouchot in France (c1860) and Adams in India (c1877) developed glazed type solar ovens. The CooKit reflector panel type cooker with a plastic bag pot glazing is in part attributed to Bernard at Lyon U., France [15]. The HotPot ™ by SHE Inc is a global glass glazed type oven currently being marketed that is manufactured in Mexico with World Bank support.

Evacuated tube (ET) collectors are: all-glass Dewar type with vacuum in a double glass tube, and vacuum inside a single glass tube. There can be less Dewar type tubes with external augmenting/concentrating reflectors, and an increase of more than 25% absorbed energy is reported with a diffuse white flat reflector behind spaced tubes [16]. The 1911 US patent by Emmet assignor to the GE Corp., applied for June 1, 1909, includes: a vacuum chamber formed by a double walled glass tube, similar to Dewar flask type ET now mass produced, and reflector troughs external to the ET, similar to CPC troughs [17]. Prototype single glass wall about 2" diam. ET were built and tested in the USA with interior silvered reflectors and alternative pumped fluid interior conduits [18].

Solar bowl R&D [19-21] includes: US DOE 1970-80s Crosbyton Solar Power Project (CSPP)[22]; the French Pericles Project; a 10 m. diam. bowl built at IIT Haifa c1979 [23]; and R&D in Egypt [24]. A "dirt bowl" was considered in the CSPP of excavated shaped compacted earth substrate for concrete and glued flat glass mirror segments [22]. A 15m/49ft diameter solar bowl (4m/13ft receiver) designed and built by Auroville in India is reported to produce 140-150C, 2-3 bars steam, and the Auroville team says the bowl can be larger [5,6].

Compressed stabilized earth block (CSEB) technology is established and developing at the Auroville Building Centre, Earth Unit, designated as the UNESCO Chair for earthen architecture in India [25]. CSEB technology can form vaults with up to 15m/50ft spans and rises according to UNESCO Auroville architect Satprem Maïni.

3. Exterior Reflector Troughs

Exterior nonimaging (NI) CPC type fixed reflector troughs for low concentrations (E-W horizontal for equatorial tropics, and N-S inclined for higher latitudes) supported by masonry vault buildings and stabilized excavations have been schematically developed. Truncated NI-CPC trough types include: 1-sided CPC, CPC, involute, and split-involute (Fig.1c-f). A reference ratio of 1.66 is CPC trough inlet to outlet width. A "seashell" trough, termed by Rabl [10], food dryer study reference is trough inlet width to outlet width (Wi / Wo) equals 3 (Fig. 2c).

Studies include: walk-in stills (Fig. 2ab); dryer with "sea shell" concentrator (Fig. 2c)[31]; outdoor solar cookers with global glazed type ovens (30cm/12"o.d. HotPot™, 'fishbowl' [30], etc.)(Fig. 2e-i); mid size solar interior cooking kitchens with short thru-wall lintel spans for the global glazed type ovens (Fig. 2jk) and thermal flat plates or evacuated tubes (ET) transverse to the linear axis of the troughs (Fig. 2d&q).

Walk-in basin stills with exterior CPC reflector augmentation for the equatorial tropics (0-25 deg lat.) has a CPC outlet width (S in Fig. 2b) of at least 3m/10ft to permit interior access through an airtight door at the trough end (Fig. 2a-b).

A "seashell" trough is composed of circular and parabolic segments. A masonry vault supports the parabolic side, opposite the circular side under cabinet dryer inlets. An upper level platform provides access to the dryer tray doors, and floor levels are related to the gutter line at the trough bottom that is above ground level for gravity flow rain collection (Fig. 2c).

A CPC trough has 1-sided ET (or flat-plates) with small clearance (under access flap) for ET manifold placement (Fig. 2q), and split-involute (two "seashells" back to back) troughs have large clearance area for placing two-sided Dewar type ET onto manifold fixed extending U tube absorbers (Fig. 2t-u). A "seashell" trough circular segment under a 1.72m/5.6ft wide receiver (and trough radius) is formed with six flat glass mirror segments each about 49cm/19" x 1m/40" (Fig. 2d).

NI reflectors at 1-sided CPC outlets with cooks working outside have ovens on an E-W axis involute reflector (Fig. 2e-h). A precast concrete base lower part of the involute stabilizes oven holders and drains (Fig. 2i). The involutes reflect to oven bottoms.

It would be the mason's job to position the CSEB blocks with acceptable accuracy for the nonimaging concentrator substrate. This method implies that the CSEB masonry is formed as a substrate for the nonimaging (NI) optical configurations so that the laminated flat glass mirror segments could be tiled directly onto the cement milked CSEB. Moulds for CSEB may be developed to be fitting with the NI optical configurations. For example, a plain block (24x 24 x 9cm/9.5x9.5x4inches) is produced with the AURAM™ Press 240 [25], a single mould manual press.

Mirrors may be glued to injection molded involute bio-plastic substrates, and a three-oven NI reflector moulded substrate would be near bathtub size. Individual cooker carts lined up adjacent to a fixed one-sided CPC reflector wall have the concern of tipping loaded ovens during movement (Fig. 2l). This presents an optical thermal design comparison question between: an involute trough with 3 ovens close together in a line, or NI square inlet involutes for each oven cart.

Adjustable end of trough reflectors have less importance for longer troughs, however building designs and site limitations are likely to be influences for shorter troughs. Adjustable trough end lightweight fabric-reflector studies include fail-safe rip away connections (low test fish line loops, etc.) to avoid high wind damage.

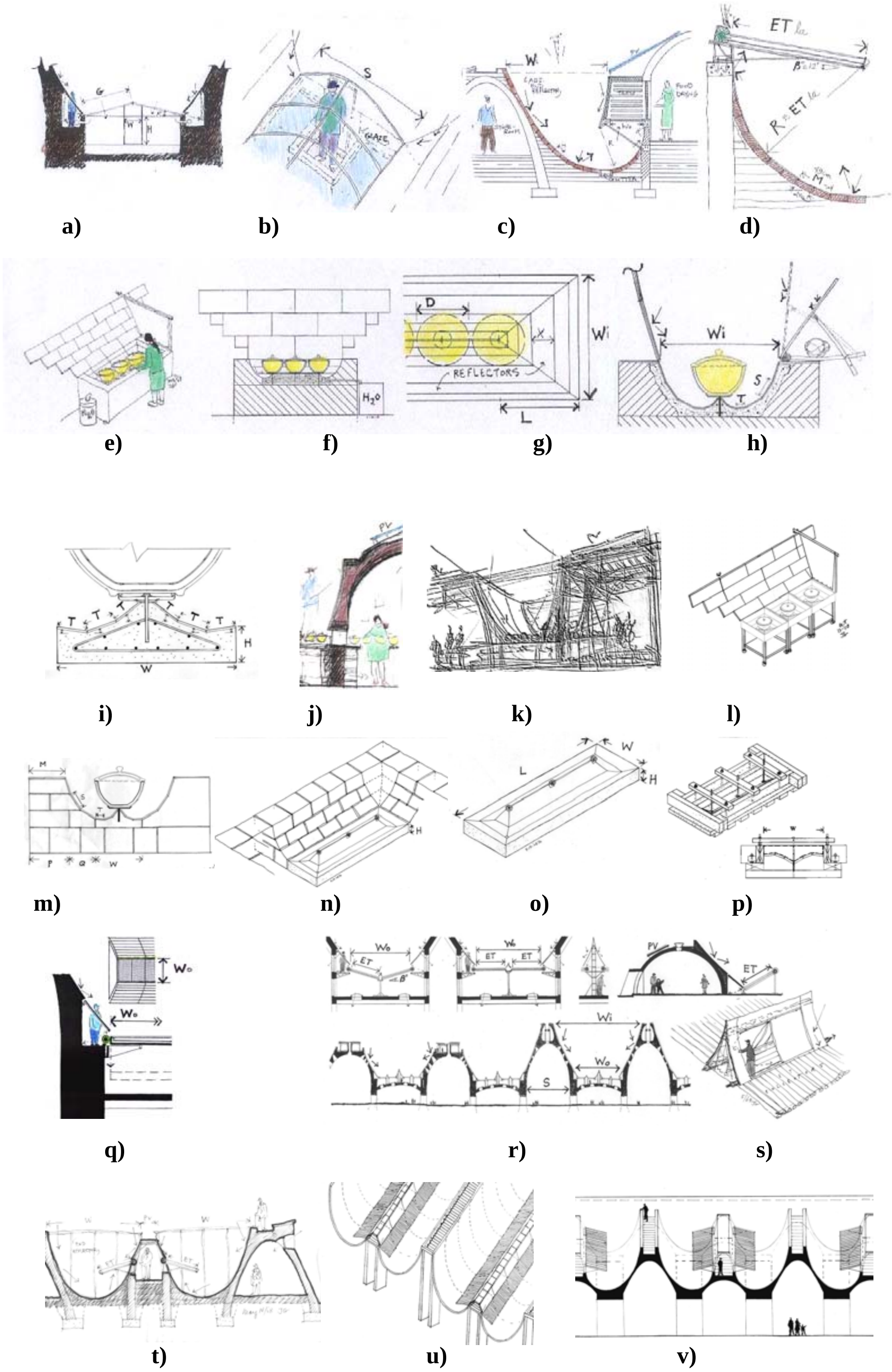
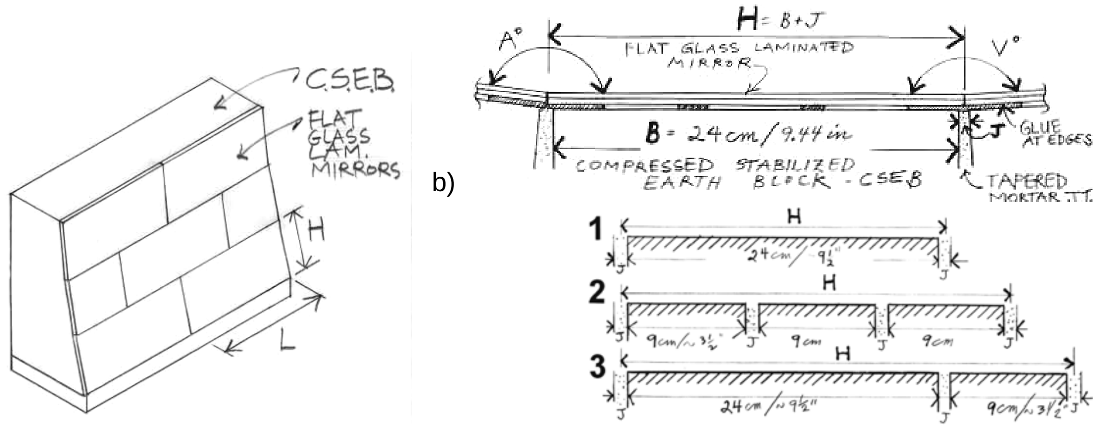


Fig. 2- Nonimaging (NI) CPC type building integrated reflector troughs: a-b) walk-in still; c) "seashell" dryer; d) circular trough under ET; e-i) one-sided CPC and involute for global glazed type ovens; o); j-k) thru wall kitchens with global glazed ovens on sliding trays; l) augmented oven carts; m-n) CSEB involute; o-p) precast base for oven holders and wood form; q) section at reflector flap over ET manifold; r-s) CPC, vaults and ET possibilities; t) split involute with masonry vaults; u-v) ET and split-involutes NS inclined



a) c)

Fig. 3- Flat glass laminated mirror CSEB test wall: a) small test wall; b) section of flat glass reflector glued to masonry; c) CSEB masonry course sizes with selected block and mortar joint sizes.

A reflector segment dimension of flat glass silver mirror adhered with full coverage glue to low cost glass is an optical design factor for flat faceted NI CPC troughs. Flat glass laminated mirrors would be tiled directly to CSEB masonry when formed accurately enough to be a NI CPC trough substrate. Preferred NI CPC trough optical-thermal studies would be correlated with CSEB masonry course construction configurations and dimensions, with architectural coordination. The NI CPC troughs are tiled with larger flat mirror segments that approximate the ideal NI trough curvature. An existing reflector technology now being field tested in India of glue laminated flat glass mirrors is considered for several NI CPC exterior trough-building configurations sized in accord with CSEB masonry course dimensions. Small square slightly trapezoid laminated mirrors (15cm/6in) spot glued to a concrete cement substrate have been in the Auroville solar bowl for more than 9 years, with reports of only minor degradation, and a small percentage of damaged mirror elements, that are replaceable according to Harper. Flat reflector segments for NI CPC troughs are much larger than flat segments for bowls.

Common low cost glass glued with thin silicone sealant coatings to a CSEB sample received from the Auroville, India, UNESCO architect appears to bond well. The width of flat mirror segments (H in Fig. 3c) for troughs with masonry course dimensions based on typical CSEB AURAM™ Press 240 [25] block sizes and 1cm/0.5in mortar joints are nominally:

#1: H= one 24cm block plus one joint = 25cm/10in.
#2: H= three 9cm blocks plus three 1cm joints = 30cm/12in.
#3: H= 24cm and 9cm blocks plus two 1cm joints = 35cm/14in.

A materials only (from Pondicherry) 2005 cost estimate for 30.5x 76cm/12x30in laminated flat mirror segments was IRS 56.2/sq ft (3mm glass mirror, glue full coverage, 2mm plain glass)[26]. Glass that can be cut to large sizes was less costly than smaller limited sized fired clay tiles.

An exterior reflector wall test facility (Fig. 3a) for: weather testing and to gain experience and cost data is suggested for the non-seismic regions (wall of existing building, or new wall/building) with solar access (not shaded by buildings, trees, etc.) to verify dimensional relationships between rectangular mirrors and CSEB/mortar joint sizes and details (edge conditions, mason guide, etc.).
It is suggested to begin with construction of the CSEB test section, allow time for mortar shrinkage [27], and cut to fit laminated glass mirrors.

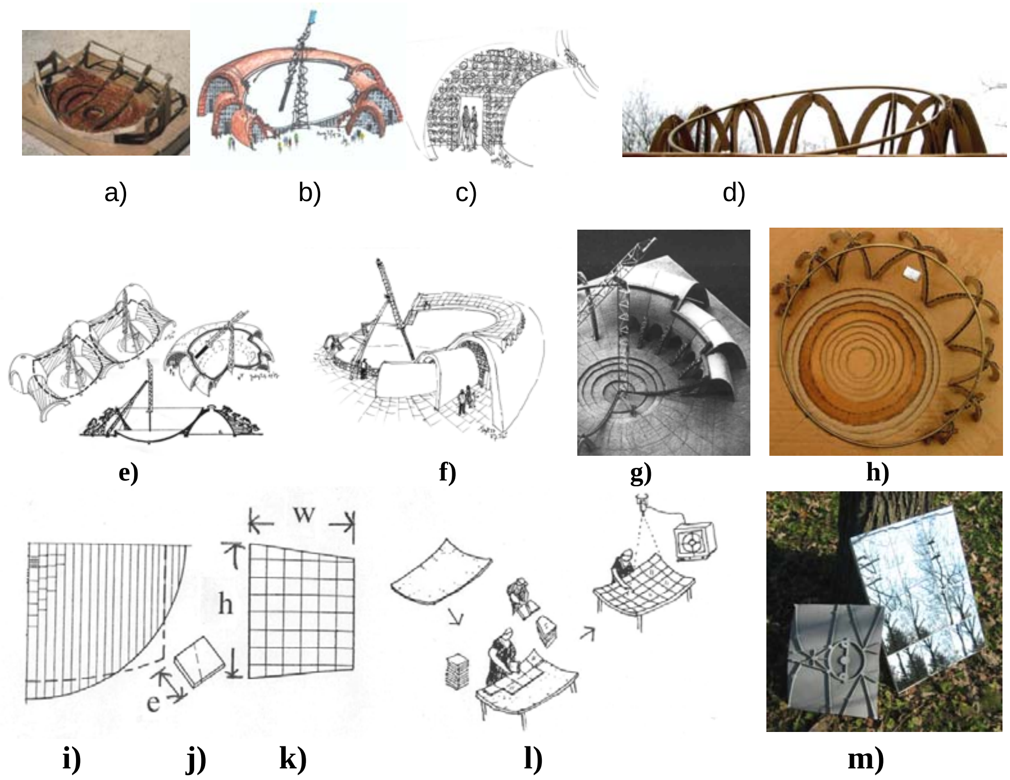


Fig. 4: Building Integrated SOLAR BOWL - fixed spherical segment reflector with two axis tracking linear boiler: a) square bowl rim; b-c) serrated rim bowl on curved vaults; d & h) crescent plan with intersecting masonry domes, e-g) solar bowl rim types supported on masonry vaults and domes; i) paving pattern with set of trapezoid reflector panels, j) elemental flat mirror segment sized for receiver, k) trapezoid reflector panel, l) workshop panel fabrication sequence, m) mock-up reflector panel studies.

4. Bowls

Solar bowl architectural schematic studies are presented for mid-size process heat applications with various rim configurations and masonry compression structures (arches, domes, vaults)(Fig.4). A circular rim 60 deg. semi-rim angle bowl with masonry arches/domes/vaults with 15m/50ft rises and 50m/164ft rim diameter has inclination around 17 deg. from horizontal, and radius of curvature of Rc = 28.8m/94.7ft (Fig.4d&h). A square rim bowl with 55 deg. E-W semi-rim angle has radius of curvature Rc = 11.4m/37.5ft with a tubular receiver length (0.5Rc) of 5.7m/18.7ft (Fig. 4a) [19,20,21]. Larger bowl collectors with shallow rims may have less than full-length receivers. A set of rectilinear and trapezoid reflector panels has some compatibility with a parallel strips bowl paving pattern and the square rim configuration (Fig.4a). Students at the U. of Minnesota circa 1960s constructed a masonry saddle vault (Fig. 5).

To reduce on-site work solar bowl advance requires workshop production with precise adhesion of small flat glass mirrors (sized in accord with the receiver) to spherical segment substrate panels. Panel technology similar to molded communication dishes with bio-materials sheet-molding composites has potential radius of curvature commonality with reflector facets for tracking parabolic large dishes, for example the 87.7m2 USA dish/Stirling facet radii are: 15.21, 15.65, 16.26, 16.94, and 17.73m [28]. A standard spherical substrate panel with flat glass reflector facets for solar bowls may be effective enough for an enlarged Scheffler dish concentrator as well [29].

5. Comments

Building integrated fixed large reflector *trough* and *bowl* solar concentrators with masonry structures (vaults and domes with up to 15m/50ft spans and rises) appear feasible for non-seismic regions. If these large architectural solar concentrating collectors were included in projects they would have to be part of initial architectural and site design. Building integrated fixed nonimaging CPC troughs with evacuated tubes, and solar bowls with tracking elevated tubular counterweighted receivers, can supply mid temperature (~80C/176F to 250C/482F) process steam for solar food processing facilities.

Fixed reflector bowls and troughs supported by CSEB masonry structures and stabilized excavations would have less embedded energy than metal supports for reflectors.

Building materials emphasized are compressed stabilized earthen blocks (CSEB) and flat glass silver laminated mirrors. The reflector facet width of flat glass silver mirrors (adhered with full coverage glue to low cost glass) is an optical design factor for faceted NI CPC troughs. Masonry vaults and CPC troughs can have sympathetic form relation.

CPC troughs can proceed with large area flat mirror facets with reference to the glass mirrors laminated to glass reflector technology successfully demonstrated for 9+ years in the Auroville solar bowl. A large bowl with tracking and compact steam distribution compared to several smaller dishes, may be durable with locally manufactured and repairable parts, whereas broken imported evacuated tubes (ET) cannot be repaired.

However, maintenance demands at elevated two-axis tracker pivots for heavy counterweighted tubular boilers for solar bowls are a concern, likely to be more demanding than for nonimaging troughs with lightweight evacuated tubes that can be easily carried.

A project is schematically outlined for moulded plastic (bio-plastics, recycled plastics) spherical substrate panels for gluing flat glass mirrors for: solar bowls and possible an enlarged Scheffler concentrator. Construction of compressed stabilized earth block (CSEB) flat glass laminated mirror facets test walls are suggested for selected non-seismic regions.

Fig. 5 The straight-line generated masonry saddle vault constructed by Prof. V. Michelson's architecture students at the U. of Minnesota circa 1960s. Photo by Francis Bulbulian.

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