BUILDING INTERIOR EVACUATED TUBES and REFLECTORS

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ABSTRACT

The Building Interior Evacuated Tubes and Reflectors (BI-ET&R) active solar thermal collector building type is for mid temperature (~80C/176F - 250C/482F) applications in non-seismic snow accumulation regions. A walk-in architectural solar collector has interior fixed nonimaging (NI) CPC type E-W line troughs augmenting transverse evacuated tubes (ET) with monolithic glazing building envelope collector cover. Studies include: small refrigeration and heater facility; large area roof-collectors for additions and new buildings with 10-60^{o} (from horiz.) inclinations; vertical glazed asymmetric NI-CPC for high latitude regions; and verification test facilities. Discussed are selected: structure/construction materials and details; building code requirements; and reflector cost estimates. The BI-ET&R R&D project is outlined; and schematics describe an R&D program initiative of Building Integrated CSP. Studies indicate active solar energy technologies are main organizing factors for building design and site planning.

1. INTRODUCTION

Alternatives for natural gas are of environmental, strategic, and local economic concern. On-site building integrated solar thermal collection has local construction jobs in place of huge payments to distant finite gas suppliers. Solar technology innovations of recent history, evacuated tube (ET) collectors and nonimaging (NI) CPC (compound parabolic concentrator) reflector troughs are integrated within building structure and form. Schematic architectural studies began with selected active collectors and reflector optics as a starting point (1)(2)(31)(32).

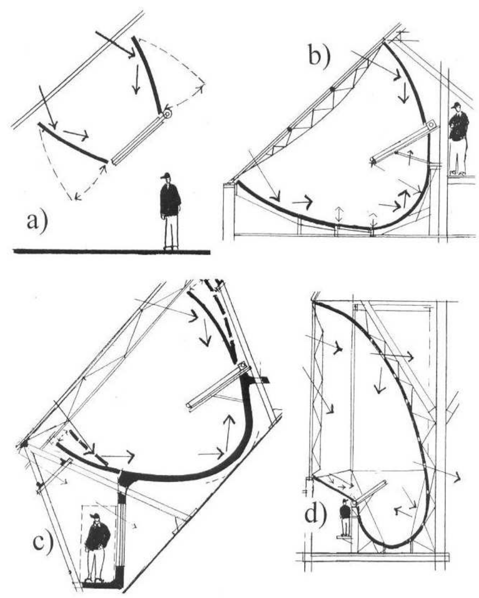

Fig: 1- Building Interior Evacuated Tubes and Reflectors (BI-ET&R) nonimaging CPC type E-W line trough configurations with transverse evacuated tubes (ET), S-N section drawings: **a)** CPC (compound parabolic concentrator); **b)** sea shell and upper reflector; **c)** sea shell and adjustable upper reflectors; **d)** vertical asymmetric.

The BI-ET&R for mid temperature thermal applications (industrial process heat, commercial refrigeration and cooling, district heating, etc.) to reduce natural gas, electricity, and biomass fuel demand, is one type of Building Integrated CSP (concentrating solar power). It is a large walk-in architectural solar collector with daylighting possibilities and a temperature controlled collector buffer space that can melt snow on the outer cover monolithic tempered solar glass building envelope. The interior fixed collector parts are: NI-CPC type reflector troughs and flat-plate arrays of transverse ET. The building structure and solar collector structure are the same with one glazing building envelope part and collector cover as well. Architectural schematic studies of case study configurations include: low rise buildings with wood structures, and large area collector-roof structures with: steel, wood glue-laminates and composite fiberglass structural elements. Influence of ET sizes and related reflector characterizations, to architectural dimensions and urban form are indicated. Selected construction details have been studied to determine feasibility. The BI-ET&R is recommended research that "fits into the AIA's goals and aligns with the 2030 challenge" by the national AIA Center for Building Science and Performance (3).

A multi-phased BI-ET&R research project is outlined with an objective to gain understandings of the potential extent of feasible building configurations that can be reviewed for selection of case studies to be engineering evaluated. Added architectonic schematic studies outline an R&D program of Building Integrated CSP that include: the BI-ET&R; exterior NI-CPC troughs with transverse ET; one and two axis tracking heliostats systems; CPV; and fixed spherical segment concentrators with tracking receivers. There are common research aspects between building interior and exterior ET- reflector configurations (2). Analytical review of these studies in university education programs is suggested.

2. BACKGROUND

NI-CPC type reflector concentrator troughs are a recent history solar optical innovation (27)(28)(29). An asymmetric NI-CPC fixed trough composed of a circular section (under a receiver plate) combined with a parabolic section that can be truncated to fit demand curves was called a "sea shell" collector by Rabl (4). A later asymmetric CPC development is the MaReCo (5). Emmet (1911)(25) and Speyer (1965)(26) developed ET collectors. Lambeth's 1970s fixed curved exterior reflectors were 1-sided (upper) E-W troughs augmenting F-P collectors (33). The 1974 Aachen glazed attic house had 324 interior ET (6). A 1980s Munich housing project had ET in an inclined 2-glazed space (7). Floor reflectors and tubular solar collectors were combined in a walk-in glazed attic 1982 patent (8). Vertical glass walls with minimum frames include: Faguswerk, Werkbund exhibition, Dessau Bauhaus (1911-26); and Breman U. Student Building (9). Constructed large fixed exterior reflector-concentrating curved roof troughs include: a Disney Orlando building (10); Padonia School, Baltimore (11); and the Solargenix Power Roof ™ (34).

A quick calculation for a BI-ET&R configuration had inputs of: SEIDO-1 ET heat pipe; 1.66 CPC trough inlet to outlet (Fig.1a); and 10% exterior glazing-frame losses (transmittance, reflective frame shading) subtracted from ET eff. curve (No. C182-SPF Rapperswil). The CPC outlet is similar to the ET absorber length (about 2m) in transverse position to an E-W line CPC trough. The calculation was 310 W/m^2 with 800 W/m^2 in-solar, for 100C operating output, for the exterior monolithic solar glass aperture (12). However, the glazing-frame losses in some cases may be nearer to 20%.

3. NONIMAGING CPC-TYPE TROUGHS

NI-CPC type E-W line reflector trough configurations augmenting transverse ET flat-plates include: CPC with fixed or adjustable reflectors (Fig.1a); "sea shell" and upper reflector (Fig.1b); "sea shell" and adjustable upper reflectors (Fig. 1c); and vertical asymmetric (Fig. 1d). Schematic dimensional ratios of trough inlet to ET absorber length outlet widths are: 1.66 for CPC (Fig. 1a); 3.6 for "sea shell" (Fig.1b); and 4.5 for asymmetric with vertical glazing (Fig.1d)(5)(30). Augmenting cusp mirrors behind-between spaced bifacial ET reduce ET per unit area. If cusp reflectors between each ET have performance and initial cost advantage, there is a cleaning maintenance concern. Adjustable end reflectors for long troughs have less importance, however building and site designs have limited E-W dimensions.

4. BI-ET&R BUILDING TYPES

Schematic BI-ET&R architectural studies of possible building type case study (CS) configurations include: small refrigeration and heater facility (Fig.2e); building additions (Fig.3a); large area roof-collector buildings (Fig.3b,c,d); vertical glazing and collector for high latitudes (Alaska, Sweden, etc.)(5)(30)(Fig.1 p-s); and "sea shell" type trough verification facility (Fig. 2e-h). Additional configurations include: two stacked CPC rows (Fig.2bc); and closed packed adjacent CPC rows with exterior roof reflector augmentation and reflector flap access gutter (Fig.2d).

CS: Solar Refrigeration (<20 R-tons in summer and cold season heater) is for small commercial food growers for single and double effect (2E) chillers.

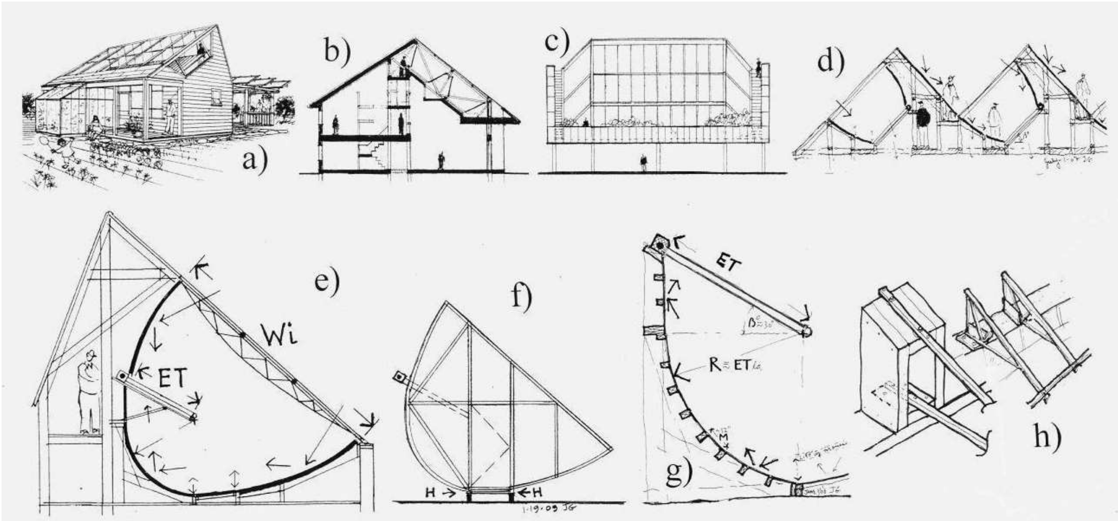

Fig: 2- Building Interior Evacuated Tubes and Reflectors **(**BI-ET&R): **a)** verification testing facility; **b-c)** two stacked CPC rows section and elevation; **d)** closed packed adjacent CPC rows; **e)** "sea shell" trough verification facility section; **f)** adjustable end reflector with door; **g)** reflector circular trough under ET; **h)** manifold and ET support brackets.

A circular trough radius under the ET is similar to ET absorber length, formed with milled or round wood to support reflectors (glass mirrors on milled wood or compacted earth, reflector film taped to back of recycled carpet, etc.). Eight flat 12"/30cm mirror segments can approximate the circular segment (Fig.2g). Cantilevered manifold brackets support the ET (Fig.2h). Adjustable end reflectors hinged under doors (H in Fig. 2f) move under hipped E and W exterior triangular glazing frames.

CS: Building additions with 40-60^o (from horiz.) roof-collector inclinations with independent structure are for adding to existing buildings (Fig.3a,e).

CS: New large area roof-collector buildings with 10-40^o (from horiz.) inclinations (Fig. 3b-c): Fitness facility (pool, gyms, exercise, etc.) with cylindrical hot water insulated storage tank in climbing wall (Fig. 3b) and large halls (Fig. 3d).

CS: Vertical glazed collector building with asymmetrical NI-CPC type trough for high latitude regions has manifold at lower end of bifacial ET (Fig. 5). Maintenance access apparatus to interior reflector and vertical glass is an influence to reflector optical design. Daylighting gaps are between reflector segments adhered to translucent insulation (TI).). The asymmetric trough back has a form relation with a diffusing stretched fabric around a cylindrical storage tank with circular clerestory daylighting above (Fig. 5c).

5. BI-ET&R STRUCTURE STUDIES

Structural configurations for long span roof-collectors are: 3-pin frame with inclined struts (Fig.3e); and inclined beam/arch supported at both ends (Fig.3f). Structural materials considered include: steel, wood, and composite-fiberglass. These have similar top plane exterior glazing support structures with E-W open web 3d trusses and E-W flush monolithic glass on E-W rafters (Fig. 4b,e,f). Interrelated design variables include: inclination angle, ET length, NI-CPC truncation, roof-collector structure depth, vertical daylighting window depth, and E-W non-public access clearance for maintenance workers. Exterior roof-glazing maintenance access possibilities are: N-S inclined access truss spanning on E-W tracks; and access trolley cable driven on main N-S truss-girder tracks (Fig. 3i). A building code requirement is: 0.915m/36"x 2.32m/80"clearance for E-W non-public passage within the collector (Fig.3g-h)(35). Stairs are over the bottom chord for N-S inclined open web girder-trusses (Fig.4a).

A wood glue-laminated structure has main N-S inclined beams that support E-W wood glu-lam beams. The main N-S glu-lams support perpendicular steel columns for the top E-W open web 3d trusses and exterior monolithic glass. E-W stepped glu-lams support access platforms and ET arrays. A vertical interior insulated daylight glazing is hung from the E-W glu-lams (Fig.3g).

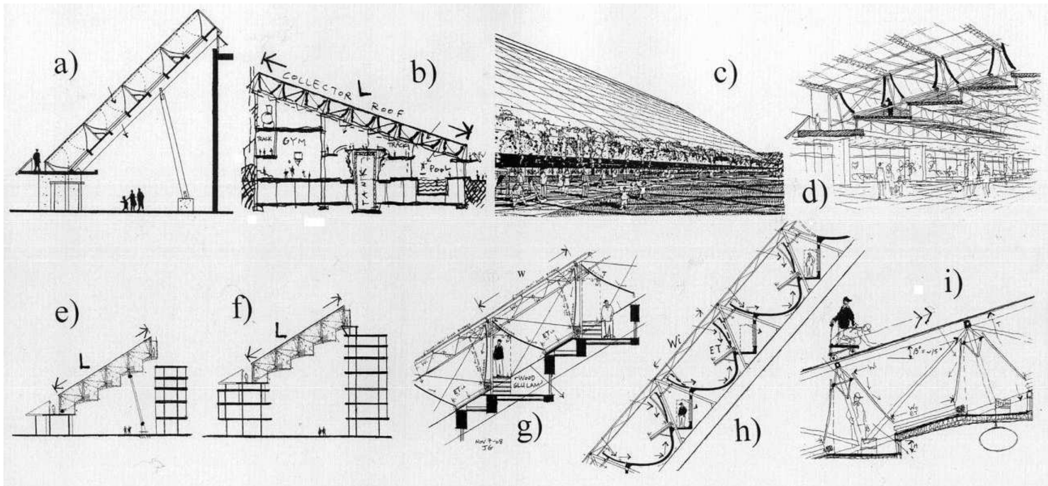

Fig. 3- Building Interior Evacuated Tubes and Reflectors (BI-ET&R): **a)** addition section; **b)** fitness facility with storage tank section; **c)** exterior perspective; **d)** interior cutaway perspective; **e)** 3-pin collector frame with inclined strut supports; **f)** inclined collector beam supported at both ends; **g)** wood glue-laminated bottom structure; **h)** E-W fiberglass reflector substrate channels; **i)** access trolley on N-S tracks.

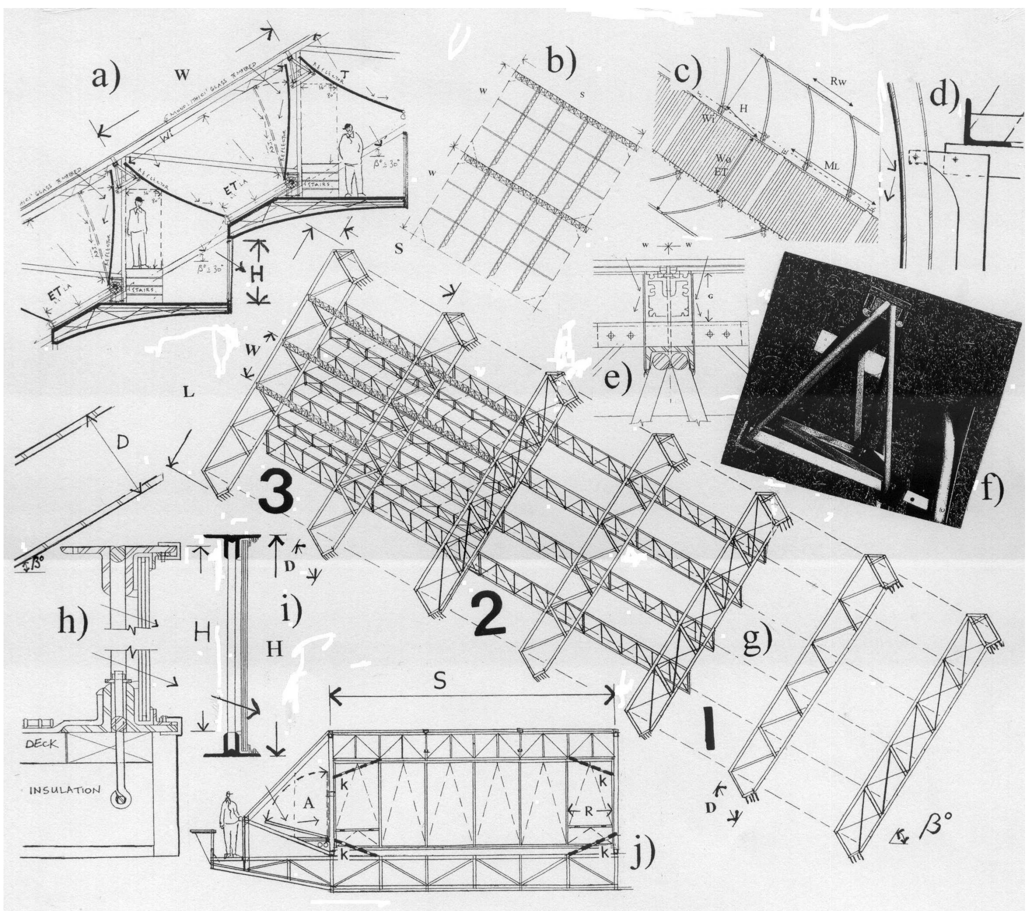

Fig. 4: BI-ET&R Steel Frame Studies: a) N-S section; b) exterior glazing frame isometric; c) ET and CPC collector isometric; d) adjustable reflector top connection detail; e) flush glazing above E-W crossbar; f) top 3d open web truss; g) steel structural members isometric; h-i) sections at E-W clerestory truss; j) E-W section of modular bay.

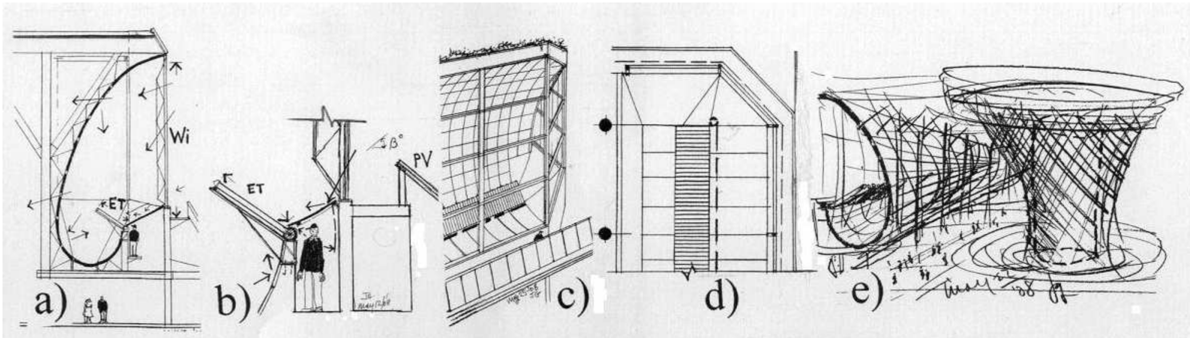

Fig. 5- BI-ET&R for high latitude regions: **a)** section at asymmetric NI-CPC reflector concentrator with vertical glazing; **b)** section with manifold at low end of ET; **c)** exterior perspective; **d)** partial plan; **e)** interior perspective of collector and storage tank.

Fiberglass shell E-W spanning channel beams are fixed reflector substrates supported on main N-S inclined beams (used modified fiberglass wind blades, etc.). The NI-CPC reflector trough has a fixed lower part, and lightweight movable upper reflectors that can have seasonal positions. The fixed E-W channel beam reflector substrate can be semi-automated manufactured with a mandrel (Fig.3h).

Steel frame studies have: main N-S inclined open web girder beams (Fig.4g) with E-W open web trusses hung from the bottom chords (Fig.4h) that form fixed insulated daylight glazing (Fig.4i). Truss diaphragm platforms are supported from the top and bottom of the E-W daylighting trusses forming inclined platforms for the ET, and horizontal platforms for maintenance access. Steps permit E-W passage (36" x 80") thru the truss. E-W racking is restrained with corner braces (k in Fig.4j). Triangular structure at the E-W trough ends provides additional E-W racking resistance (A in Fig .4j). Double-hinged reflectors (R in Fig. 4j) near k-braces permit reflector positioning for cleaning and ET manifold access (Fig.4j). Insulated water-steam plumbing risers and platform-to-platform maintenance access are architectural design concerns for the trough end areas.

6. INTERIOR REFLECTORS

An interior reflector (fixed and movable) material option is aluminum: frames (thin-wall tube) with thin sheets. Estimates for ReflecTech ™ (1.22m/48"/4ft x 2.44m/96"/8ft each sheet) mirror film laminated to 0.032" thick aluminum were $2,351 for 14 sheets ($168/sheet, $5.25/sqft); and $79,330 for 750 sheets ($105/sheet, $3.28/sqft) (FOB Arvada, CO)(13). And for Miro Silver™ 0.016" thick sheets (1.24m/49.21"/4.1ft x 2.43m/96"/8ft each sheet), $2000 for 14 sheets ($143.85/sheet, $4.35/sqft), and $71,224 for 750 sheets ($95/sheet, $2.89/sqft), plus delivery from Westlake Ohio (14). Glass mirrors 12"x12" at Wal-Mart, Dodgeville, WI (2/2009) were $1.70/sqft.

7. BI-ET&R R&D PROJECT DEVELOPMENT

A BI-ET&R research initiative was originated as a 5-year phased project; with a preliminary evaluation project with graduate students for 1-2 years (Fig. 6). Investigations of: existing and new ET (flow in-out one end, heat pipes) with reflector options; storage; distribution; controls; and building structure-form are included for evaluation of mid temperature process heat applications to identify problems, explore the technology influence to feasible new building/architecture configurations, and to define a verification test facility. Phase 1 includes: document previous studies and references; architectural-engineering schematics dimensioned with existing ET/system sizes with NI-CPC characterizations for selected case studies; selected construction detail studies, material/labor cost estimates; and building code issues. An objective is to gain understanding of the potential extent of feasible building configuration possibilities that can be reviewed for selection of case studies to be solar engineering evaluated in Phase 2. A preliminary abstract: "Building Interior Evacuated Tubes and Reflectors (BI-ET&R) research project –Part 1" was reviewed by US DOE (15); and discussed with Chris Early (16) and Jim Kern (US DOE). BI-ET&R project development is currently proceeding by writing and offering design projects to educational programs.

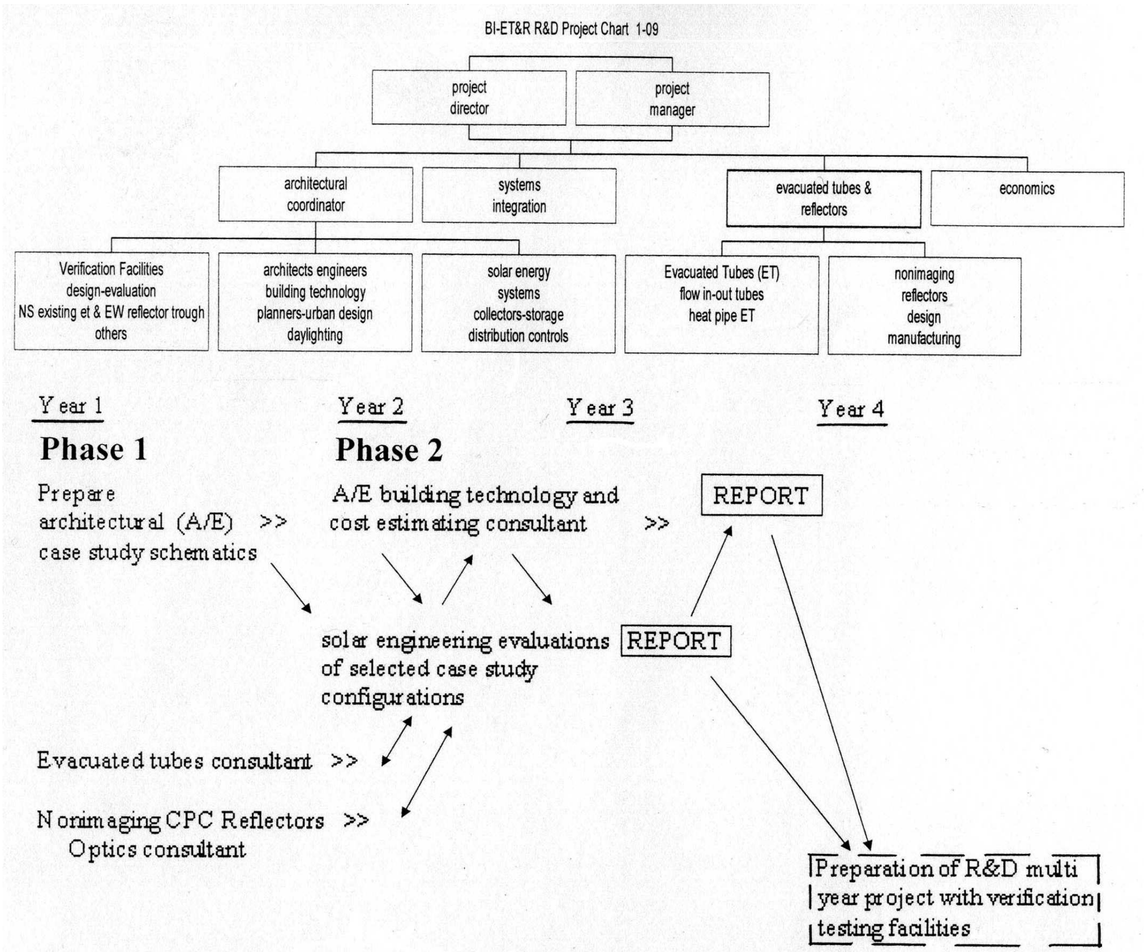

Fig. 6- Building Interior Evacuated Tubes and Reflectors (BI-ET&R) R&D project: organizational preliminary chart for comprehensive multi year (around 5 years) project; and schedule for multi-phased preliminary project.

8. BI-CSP R&D PROGRAM

A Building Integrated (BI) CSP (concentrating solar power) R&D program initiative for global applications and international collaboration has emerged after several studies (1)(2)(22)(24). Architectural schematic studies indicating an R&D program outline of main project parts include: the BI-ET&R (Fig.7a-c); exterior NI-CPC troughs with transverse ET (2)(Fig.7d-f); one and two axis tracking heliostats systems (Fig.7g-j)(17); CPV; and fixed spherical segment bowls with 2-axis tracking linear receivers (21)(23)(Fig.7k-m).

BI solar bowls with excavated stabilized earth (with rain drainage) and masonry structures (vaults and domes) supporting fixed mirror panels may be considered for mid-size industrial process heat mid-temperature applications for non-seismic beam regions (2)(Fig.7k,l,m). References for the BI exterior NI-CPC troughs with tensile structures suitable for water distillation and augmenting ET in seismic regions include; Ulm Medical Academy project (V-III)(18); and the US DOE Sun Wall Competition 2000 winner, a cable beam structure (19)(20).

9. COMMENTS

Architectural schematic studies have been presented for the Building Interior Evacuated Tubes and Reflectors (BI-ET&R) active solar building type for mid temperature (~80C/176F - 250C/482F) thermal process-heat applications in non-seismic snow accumulation regions. The BI-ET&R walk-in architectural solar collector with monolithic glazing has interior fixed nonimaging

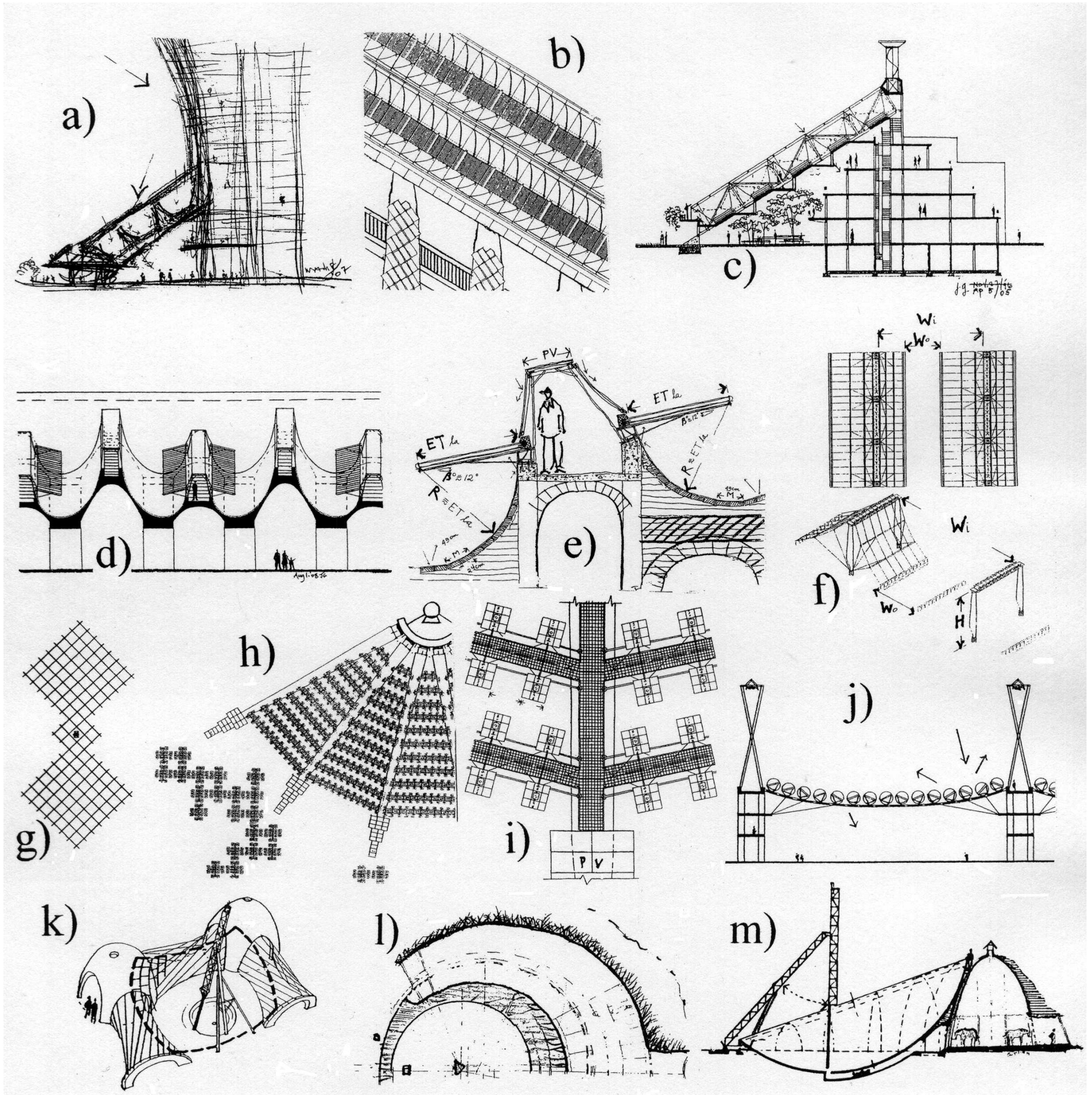

Fig. 7- Building Integrated (BI) CSP R&D program outline: **a-c)** interior (BI-ET&R) NI-CPC type troughs with transverse ET-a) reflector façade, b) 2 row entablature, c) with small wind turbines ; **d-f)** exterior NI-CPC type troughs with transverse ET-d) N-S line inclined, e) E-W line, f) tensioned cable beam/nets; **g-i)** two axis tracking small heliostats systems-g) Vierendeel roof terraces, h-i) 3d trusses and pergolas; **j)** CLFR on sagged roof; **k-m)** fixed spherical segment bowl with 2-axis tracking linear receiver-k) 'square' rim bowl on masonry saddle vaults and domes, l-m) bowl on compacted excavation and curved vault.

(NI) CPC type E-W line troughs augmenting flat-plates of transverse evacuated tubes (ET). The influence of ET sizes and closely related reflector trough characterizations to architectural structures and dimensions has been indicated for selected building type configurations. A multi-phased BI-ET&R research project has been outlined with objectives: to gain understandings of feasible building configurations; identify case studies to be evaluated; and define a testing facility project. R&D is required for new ET systems with efficient heat removal to tolerate reflector augmentation. Schematic architectural studies describe an R&D program of Building Integrated CSP that includes: exterior and interior NI-CPC troughs with transverse ET; CPV; one and two axis tracking heliostats systems; and fixed spherical segment reflector with tracking receiver. Results of schematic studies indicate that active solar energy technologies are main organizing factors that require understanding before starting commercial project design and site planning. Building integration of active solar thermal technologies is a possibility for: development of local construction jobs, reduction of greenhouse gases, and subject of study for elementary architectural, urban design, and town planning education programs.

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