BUILDING INTERIOR TUBES AND NONIMAGING REFLECTORS (BITNR) STUDIES

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ABSTRACT

Building Interior Tubes and Nonimaging Reflectors (BITNR) solar thermal concentrators for mid-temperature applications in snow and dust regions, previously titled BIETR now include non-evacuated tube-receivers. A nonpublic walk-in solar collector space has fixed receiver-tubes with matching involute (rounded W) reflectors forming target-rectangles for augmenting large CPC troughs and relaxed tracking E&W 'wing' reflectors with a glass or solid polycarbonate building envelope collector cover. Reported is a BITNR reflector 'wings' tracker invention by George Helmholz and proof-of-concept development by university undergraduate engineering students. Discussed are: building types, structure, and construction and reflector materials for global applications. BITNR architectural feasibility studies with air and water-steam systems include: small wood frame structures, two-car garages, house size demonstration, long-span atriums, large concourses, towers, additions, and verification-test facilities. Schematic studies indicate integrated solar thermal mid-temperature technologies with building-size nonimaging CPC reflectors are main organizing factors for building design and site planning. BITNR/BIETR undergraduate student mechanical and structural engineering semester projects at the University of Wisconsin-Platteville are reported. A BITNR R&D project proposal is outlined which includes: a greenhouse test facility, evaluation of test stands, and development of a computer simulation design aid for architects.

KEYWORDS

architectural mid-temperature concentrators, building interior big CPCs, building interior receiver-tubes, Helmholz 'wings' tracker, BITNR student engineering projects

1. INTRODUCTION

The Building Interior Evacuated Tubes and Reflectors (BIETR) title became the BITNR (Building Interior Tubes and Nonimaging Reflectors) in 2019 to include non-evacuated receiver-tubes and to more accurately describe the nonimaging reflectors. BIETR notations generally apply to activities before 8-2019, or differentiate between evacuated and non-evacuated tube collectors.

Why building-integrated mid-temperature solar thermal concentrators? After concentrating solar for mid-temperatures, there is diminished lower temperature useful energy, therefore

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to collect only low-temperature energy with active collectors is like "wasting energy" [1], and there is limited active solar collector areas on buildings, site plans, and big city land. And more thermal energy can be stored in a given volume with higher temperatures, for example "five times as much energy can be stored in a given volume at 340C/644F degrees as at 100C/212 F degrees" [1].

Many buildings have large fossil fuel heat applications e.g. industrial process heat (IPH), commercial and institutional hot water, and district heating systems.

The BITNR collector is mainly for large mid-temperature (above 80C/176F) heat applications. A nonpublic non-insulated walk-in solar collector space generally has: fixed receiver-tubes (evacuated or non-evacuated) each with a matching involute (rounded W) reflector trough, forming target-rectangles for large CPC reflectors and relaxed tracking E&W 'wing' reflectors with a monolithic glass or solid polycarbonate cover part of a building envelope. The BITNR collector with minimum shading glazing-frames is an integral part of building structures, different than manufactured thermal collectors attached to the exterior of building structures, often with substantial and redundant structural materials.

BITNR architectural feasibility studies primarily for new buildings include: small wood frame structures, two-car garages (detached and attached), house size demonstration, long-span atriums, large arena concourses, towers, additions, and test-verification facilities. Discussed are: receiver-tube and reflector options, building types, and construction materials. Schematic studies started c1998 indicate interior mid-temperature solar collector systems with building-size nonimaging CPC reflectors are main organizing factors for building design and site planning. Building type application studies are references for: engineering evaluations, testing, and demonstrations required for BITNR development. Most architects and developers would need to see BITNR demonstrations and convincing technical and cost estimate reports before investing in BITNR building design. A BITNR R&D multiyear project proposal is outlined. An aim is to reduce the large amounts of climate-change greenhouse-gas pollution by the building sector. The research method begins with the collector and storage technologies exploring for fitting and sensible building structure and form possibilities. A thesis is: BITNR buildings have aesthetic architectural potentials.

"One of the most difficult tasks of designing active solar systems for buildings is to make the installation aesthetically pleasing. Poor visual designs are the norm and contribute to the failure of solar systems gaining wide acceptance.… We often consider economics as the most difficult barrier to widespread use of solar energy but, in my opinion, the aesthetic quality of solar building design is an even more difficult problem." Professor William A. Beckman, Director of the Solar Energy Laboratory, U. of Wisconsin-Madison (retired), June 1, 1995 [9]

2. BACKGROUND

Studies of building integrated interior reflector solar concentrators by the author began with small two-axis tracking heliostats c1980s [10, 5]. The walk-in collector with EW-line large CPC troughs augmenting fixed receivers studies were started c1998, part of a research project presented in 2000 [12]. BITNR/BIETR studies continued with university undergrad student engineering participation. Studies c1998 included E&W relaxed tracking 'wing' reflectors at large CPC trough ends to increase solar collection, concentration ratios and temperatures, and to avoid spillage. A 'wings' passive PV sensor with counterweighted-gears tracker was invented by George Helmholz c2014.

Compound parabolic concentrator (CPC) is a general term used to describe types of non-imaging reflector concentrator shapes. CPC fixed troughs have solar radiation inlet aperture acceptance angles, and outlet apertures in accord with absorber-receivers e.g. evacuated and non-evacuated receiver-tubes [2]. CPC troughs concentrate beam and some diffuse solar radiation with relaxed construction tolerances and very small efficiency losses due to inaccurate shape [14]. CPC truncation options provide building design flexibility for some building design factors e.g. avoiding unacceptable low ceilings. Kreith and Kreider computer models and testing indicated high efficiencies with relaxed trough construction tolerances at Argonne National Laboratory c1975 [15, 16]. Hour-to-hour annual computer simulation modeling of ±35 deg. CPCs with ±10 deg. misalignment had less than 3% loss for Phoenix, Boston and Miami simulations [14].

A BIETR research project proposal presented to NREL, 6-2006, was reviewed by NETL. US DoE reviewed a BIETR research proposal in 2008 and replied "… current and future proposed funding … none appropriate for your proposed research project …" [103]. A Building Integrated-CSP Research Program solicited idea including the BIETR was presented to US DoE in 2009 [22, 6]. BIETR (now BITNR) research was endorsed by the AIA in 2008 [8]; and part of an invited presentation for WREC-IX[4]. A BITNR poster was displayed at the 11-2019 U. of California Solar Thermal Symposium at UC Davis.

2.1 Historical References

The curved interior ceiling of an18th century greenhouse with vertical glass appears to have low-angle winter sunlight reflected down to plants [24]. Glass walls/roofs references include: the 1851 Crystal Palace [25]; Cologne office building corner stairs c1914 by Gropius [26]; Faguswerk factory, Alfeld-an-der-Leine c1911; Bauhaus architecture building workshop wing, Dessau c1925; and Frei Otto's glass roof house [49]. James Dewar invented a double-wall vacuum-insulating thermal storage vessel c1892. The 1911 Emmet-GE double-walled evacuated tube patent had an interior curved reflector trough with glass cover [27] and this type of evacuated tube was developed and is produced in China. The first M.I.T. solar houses c1939 had building integrated active thermal flat-plate collectors and storage [24]. Flat-plate collector architectural implications were discussed at a 1955 MIT symposium [28]. Lof's 1956 Denver house had air collectors on a flat roof and interior expressive vertical thermal storage tanks designed by James Hunter [29].

Thermal outward reflecting involute-cusp troughs by Trombe c1967 [30] were "rediscovered" and adapted for solar concentration [18]. The origin of stationary nonimaging concentrator optics is referenced [31, 32]. Refractive-filled and empty parabolic trough CPC collector R&D at the U. of Chicago was by Winston, colleagues and students [33, 34]. A Kreith and Kreider computer model predicted CPC performance c1975 [35, 36]. Bifacial concentrators include: a glazed "scoop-shaped" reflector by Falbel c1975 [72, 37, 38, 39]; an unglazed "Sea shell" fixed trough by Rabl c1976 [40, 41]; and by others [42, 43, 44, 45, 46, 47].

Lambeth constructed building-size exterior fixed curved nonimaging EW-line upper one-sided reflector troughs augmenting thermal fixed flat-plates e.g. the 1974 Strawberry Fields apartments [21]. The 1974 Philips Aachen experimental house had 20m2 of 1m long evacuated tubes in the attic covered by monolithic glazing. Interior silver mirror on the bottom half of glass tubes reflected to water U tubes [50, 51]. The c1975 Silo House horizontal trough air collector had exterior top and bottom-walkway reflectors with rock-bin storage [48].

The c1977 Pyramidal Optics system by Wormser had a glazed roof thermal collector with interior reflectors developed with HUD, DoE, and NASA grants [39, 52, 53, 54]. The 1982

Keller patent had a glazed roof collector with an interior reflector [55]. The U. of Wisconsin-Madison c1977 Arlington experimental house had 380 exterior air evacuated tubes roof-mounted, sloped 60 degree for winter heating; with collector area (43.6m2/470 SF) about 40% of the house living area (106m2/1,140SF) [56, 57]. Sawtooth-shape horizontal roof-structures were built with exterior fixed thermal collectors augmented by flat reflectors [58, 59]. The US National Agricultural Library c1985 had a horizontal roof top sawtooth-shape collector with exterior fixed reflectors and evacuated tubes [60]. Evacuated tubes in a two-glazed buffer zone were in Munich housing by Herzog c1980 [61]. A daylighting flat-roof system with fixed reflector troughs and one-axis tracking linear evacuated tubes (with CPC reflectors in the tubes) was tested c1995 [68].

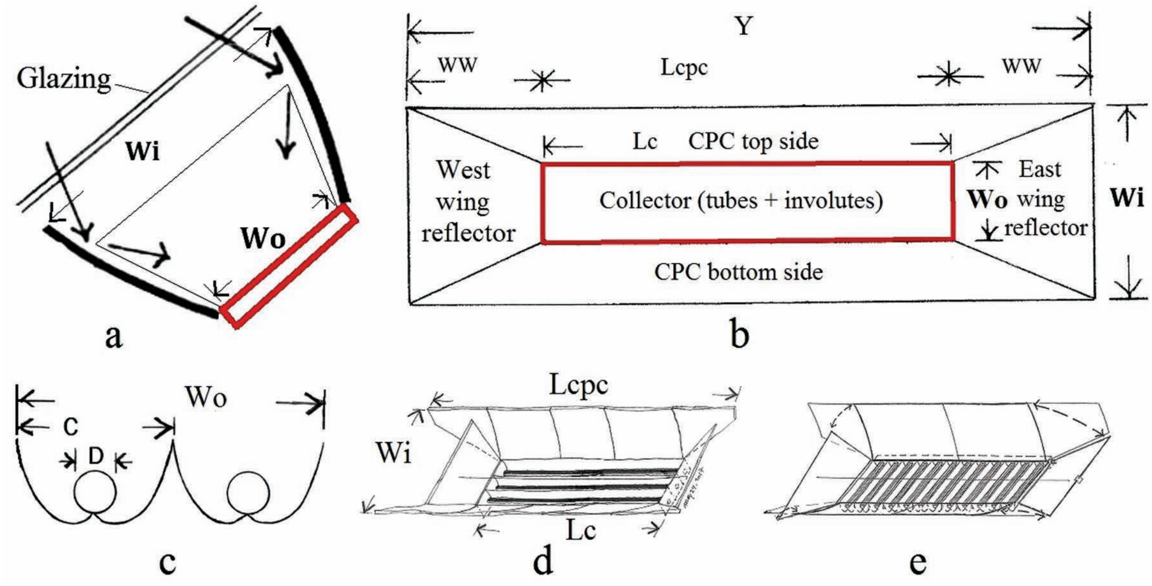
The Sun Wall competition winner (not built) c2000 had PV and thermal panels on cable-beams structured to an existing DoE building in Washington DC [62]. A New York City Jets Stadium Convention Center proposed design (not built) by KPF Architects c2004 was reported to have a large number of interior solar collector tubes in the south façade [63]. Horizontal air all-glass evacuated tubes (70mm/2.75inch OD, 1675mm/5.27ft EAL) in a vertical building facade with PCM storage in Slovenia was reported in 2015 [64]. The Pittsburgh PNC Tower by Gensler Architects, in partial ways, indicates parts of a BITNR atrium building with a large area solar thermal up-draft collector glass roof, and a lobby sculpture similar to a screen 'dressing' for a large insulated storage tank [65]. Building interior large one-axis tracking parabolic troughs with glass rooftop studies by the author were reported in 2002 [13]. Interior lightweight one-axis tracking parabolic reflector troughs with fixed linear receivers hanging from a greenhouse monolithic glass roof structure on the ground by GlassPoint Solar Inc. operated in Oman with high temperatures c2013 [66, 67]. The BIETR (now titled BITNR) 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 [8].

3. BITNR CONCENTRATING COLLECTOR SYSTEM

The BITNR walk-in collector space has fixed receiver-tubes with matching involute reflectors forming target-rectangles for large CPC troughs and tracking E&W 'wing' reflectors all covered by a glazed building envelope part (Figure 1). The target-rectangle inclined, or vertical for high latitude regions, has air and water-steam collector system options including: Dewar type NS-inclined evacuated tube systems e.g. an air system tested in China [73, 74], and the Ritter Solar TM water-steam system; one open-end one glass wall evacuated tube systems e.g. Artic Solar TM; and horizontal or vertical receiver-tubes (non-evacuated or evacuated) systems similar to tubes for one-axis tracking parabolic trough concentrators. The collector system clearances for placement/replacement influence building structure design (Figure 2). Nonimaging reflectors with effective concentration without very high specularity have characterization options (truncation, reflectivity, seasonal adjustments, etc.) which are research issues. Any receiver-collector that could work with the BITNR may be considered, e.g., one-sided and bifacial flat-plates, evacuated flat-plates, concentrator PV electrical/thermal [75], detoxification tubes [76], thermoelectric generators, daylighting for distribution, and hydrogen production.

Heat transfer working fluid system options include: air [82, 23, 107, 80], water-steam, glycol, oil, etc. Air avoids: freezing, liquid leak damage, water-steam pressurized connections, over heated glycol, and air may be better for higher concentrations and temperatures than water-steam. Forced air thru two-open-ended receiver-tubes can have clamped tube connections.

FIGURE 1. BITNR diagrams: a) section at collector and big EW-line CPC; b) plan perpendicular to collector target-rectangular; c) section at receiver-tubes and involute (rounded W) reflectors; d) schematic with EW-line horizontal receiver-tubes; e) schematic with north-south inclined receiver-tubes.



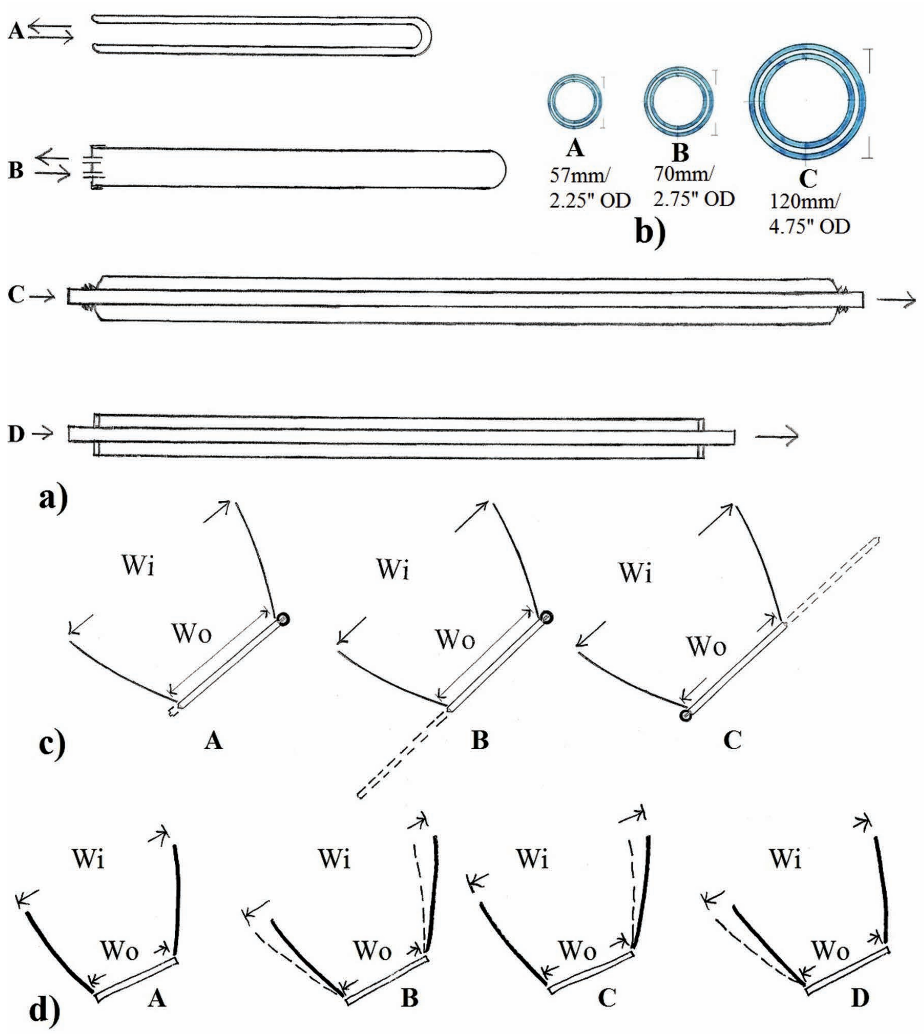
Evacuated glass-metal 4m/13ft long stainless steel absorber tubes for CSP high temperature liquid systems require field welding. A large BITNR modular collector design consideration for water-steam systems is EW spacing of plumbing risers between collector-units. Exterior air evacuated tubes on both sides of a duct-manifold references include: U. of Wisconsin-Madison experimental house [56, 57]; a building with PCM storage in Slovenia [64]; and the Industrial Solar Sun Storm Air collector (Germany).

3.1 BITNR RECEIVER-TUBES

The receiver-tubes are the core of the BITNR solar collector systems, as they are the eventual targets for all the concentrating nonimaging reflectors (involute rounded W troughs for each tube, big CPC trough, and tracking 'wings') and solar radiation that contacts the tubes directly thru the exterior glazing. Fixed receiver-tubes in an involute reflector trough receive solar radiation 360 degrees all around, different than tubular receivers for tracking parabolic trough reflector systems which receive a limited angle of concentrated radiation. Commercialized single glass wall receiver-tube products (non-evacuated and evacuated) for tracking parabolic systems may be considered for BITNR. Non-evacuated tubes will be less efficient for cold climates than all-glass double-wall evacuated tubes. Non-evacuated tubes can be made/repaired locally according to availability of glass tube sizes, and imported Dewar type glass tubes cannot be repaired. Lengths and diameters of manufactured marketed evacuated receiver-tubes are limited.

The receiver-tube length, specifically the effective absorber length (EAL), is a significant variable for BITNR building-structure design. The EAL of NS inclined receiver-tubes establish a target-rectangle E&W side dimension, and outlet width (Wo) of a big EW-line CPC reflector trough. And the big CPC inlet width (Wi) relates to the exterior glazing aperture which is

FIGURE 2. BITNR receiver-tube and CPC reflector configurations.



part of the building design. Multiple horizontal interconnected receiver-tubes and involutes influence the EW dimension of collectors. Receiver-tubes clearance for installation/replacement can influence building design e.g. all-glass Dewar type receiver-tubes may require nearly full tube length clearance to slip on-off of inserts related to insert material flexibility (Figure 2c-A,B,C). Target-rectangles are mainly sized according to standard sizes of: evacuated tubes and glass tubes for non-evacuated collectors. Receiver tube systems with exterior involute reflectors that collect dust and snow may expand market potentials in BITNR collectors. How much added concentration can receiver-tubes tolerate is a research question. Interior bifacial arrays of receiver-tubes are not emphasized in this article because of close receiver-tubes spacing (Figure 8A) [18, page 227].

Initial studies began with Dewar type all-glass evacuated tube water-steam marketed systems e.g. the BIETR was discussed with Ritter Solar TM USA. Evacuated tube heat-pipe systems were considered however contact with manufacturers revealed temperature condenser limits and loss of guarantees with added reflectors, and this is a condenser heat removal research issue. Forced air system studies later included large diameter Dewar type all-glass evacuated solar cooker tubes with matching silicone caps and 300C/572F degrees stagnation temperature (~127mm/5inch OD, EAL = 558–914mm/22–36inch tubes). Air systems with inter-tube insulated ducting and alternative inserts to enhance heat removal were part of undergrad student projects. Studies included single glass wall evacuated tubes e.g. Artic Solar TM, and are continuing with non-evacuated receiver-tubes and the evacuated double glass wall tubes of various sizes.

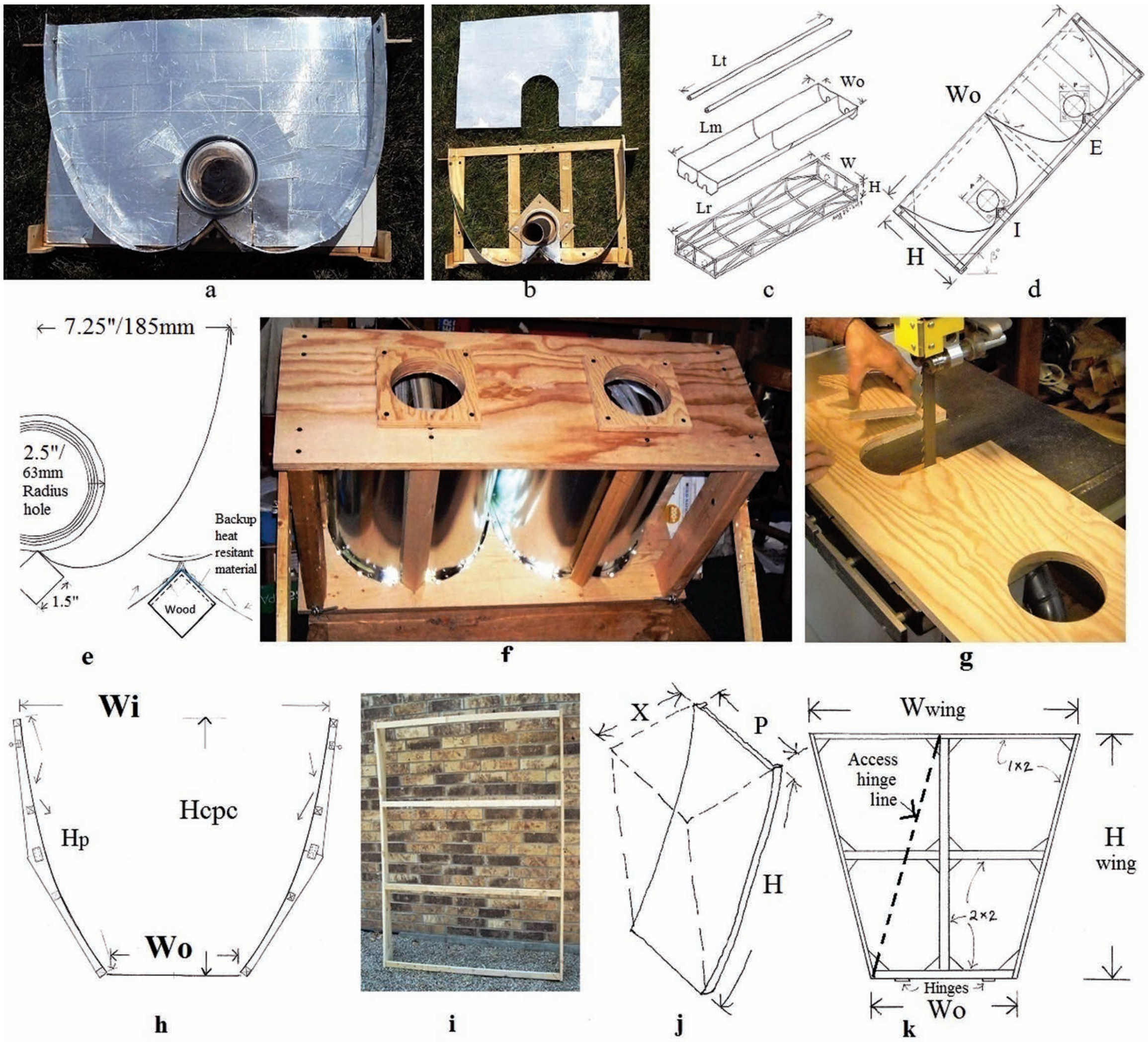
Different sizes (diameter and length) of Dewar-type all-glass evacuated tubes are manufactured in China (Figure 2b). Receiver-tube overheating concern may be alleviated by a control system and/or automated shading devices and is a research issue. Dewar-type tubes can have a silicone cap/gasket at the open end to relieve pressure with spring-loaded fasteners (Figure 14d and k); and the all-glass tubes can be replaced without interrupting the fluid loop ducting or steam plumbing. Un-repairable damage from thermal shock on evacuated tubes on a sunny very cold day is a concern with short duration cloud cover. The all-glass tubes at the open end have the hot selective surface on the inner glass tube outer side close to the rounded glass edge continuous with the outer glass tube in contact with very cold ambient temperatures. And a research question is: would an all-glass tube crack at the rounded edge? Dewar type all-glass evacuated tubes 58mm/2.38inch OD have been tested in an exterior (Shanghai) air heating system with novel inserts at up to about 220C/428F degrees air flow with only stainless steel reflector augmentation from a truncated CPC (without an involute ridge under each tube) reported in 2015 [73, 74]. A BITNR-Air system in cold climates may provide both, refrigeration in the warm season and heat for the cold season, and commercial greenhouses are a case study in the proposed BITNR research project.

Non-evacuated receiver-tubes became of interest: after learning about non-evacuated tube high-temperature concentrators [66, 67, 106], and as a way to locally manufacture and repair tubes. An air study has a glass tube with silicone cushions pressed against reflector metal collar plates with small bolt-posts, held in place by set screwed rings on a metal absorber tube (Figure 14l). An air target-rectangle with three modules of four EW rows of non-evacuated tubes and involutes has twelve 1500mm/59inch long glass tubes. The reflective metal mount-plates are two-bolted to aluminum racks at rack ends and interior where two racks join. Metal reflector sheet attached to racks at the E&W row ends slide out for access to mount plate bolts for installation / replacement (Figure 3). Twisted tape inserts in receiver-tube air systems improve heat transfer removal [77, 78, 79, 81]. A student test stand project with non-evacuated tubes reported an 8.9% increased rate of heat transfer with a twisted-tape insert that they fabricated [83].

3.2 BITNR REFLECTORS

The three main BITNR interior reflector parts generally are: an involute (rounded W) trough for each receiver-tube; a large fixed EW-line CPC trough, and relaxed tracking 'wing' reflectors at the big CPC trough ends (Figure 1). Large CPC trough reflector shape options include: ordinary (both sides symmetric), asymmetric, "sea shell" shape, and one-sided CPC. The large CPC reflector panels have seasonal adjustment (quasi-tracking) options with small hinged flaps on the 'wings'. A vertical configuration for high-latitude regions has hinged vertical tracking E&W 'wing' reflectors (reflector facets on frames with wheels) and a fixed reflector floor (Figure 8). Some building configuration studies have exterior reflector augmentation (Figure 9).

FIGURE 3. BITNR Reflectors: a-d) involute reflectors rack, e-g) two-tube involutes wood case, h) section drawing of big CPC with spliced wood panel frames, i) big CPC reflector panel wood frame, j) CPC reflector panel projected inlet aperture drawing, k) 'wing' wood frame drawing.



3.2.1 Involute (rounded 'W') Reflector Trough

Each receiver-tube has a matched involute reflector (rounded W) trough [34] (Figure 1c). Involute characterization and material specification is a research issue regarding reflector tolerance and durability for concentration intensities. Involute inlet width to absorber receiver-tube diameter ratios of demonstrated and commercialized (e.g. Artic Solar TM, Ritter Solar TM) examples include a wide range from less than three times to over six times the absorber reciever-tube diameter [34, 73]. The involute shape partly determines: E&W low-angle reflections that will reach the receiver-tube absorbers; and collection intensities during the course of a day. Involute reflector troughs for larger diameter receiver-tubes of metal sheet (e.g. anodized aluminum, stainless steel) are simpler to manufacture and easier to clean than involutes for smaller diameter tubes which can be more costly to manufacture. Anodized aluminum reflector damage by cleaning chemicals is a consideration. Interior involute reflector troughs without wind and snow loads and exterior soiling can have a longer service time than exterior reflector material which may be more expensive.

Upward opening BITNR involute reflector troughs accepting concentrating reflections from a big CPC and 'wings' reflectors has a configuration somewhat similar but inverted to involute secondary reflectors tried for linear Fresnel reflector collectors with higher concentrations. For example, the Doha, Qatar, model stadium linear Fresnel system by Mirroxx GmbH had a polished aluminum secondary reflector. Aluminum reflectors at Fresnel reflector receivers that trap rising heat have durability problems according to informal reporting. BITNR aluminum involutes could have better durability because of less concentration, losses thru the exterior glazing-frame, and inverted shape with natural upward heat flow, and this is a research issue. A reference is the silver coated metal reflector sheet in the Absolicon T160 TM tracking parabolic troughs: "… reflectors are in our case protected under glass and can withstand up to 60 C/140F …" [85]. The BITNR involute troughs receive lower solar concentrations than the high concentrations demonstrated on secondary reflectors with heliostats and beam-down systems.

Testing of a simplified exterior stainless steel (2mm/0.07" thick) reflector trough (330mm/13inch inlet width) profile with a flat-bottom (without an involute ridge under each tube) reported in 2015 decreased concentrating efficiency by 15% at Shanghai [73, 74]. Prices in the U.S. are higher for less reflective stainless steel compared to lesser cost for more reflective anodized aluminum sheet. Frame material options for involute ridges under each tube include: wood (38x38mm/1.5x1.5 inch for short tubes) and metal angles equal to the EAL. All wood reflector supports in/near solar concentration caustic-zone hot-spots should be covered with reflector or protecting material because the intensity of nonimaging concentrations can overheat wood to smoke and ignite.

3.2.2 Big CPC Trough

Interior reflector panels for big CPC troughs and tracking E&W 'wings' have lightweight frames (wood, aluminum, recycled plastic, etc.) and lightweight reflector material, e.g. anodized aluminum sheet or thin film on substrates. Thin film reflector material laminated to curved aluminum honeycomb substrates were used in the interior imaging concentrators by GlassPoint Inc. [66, 67]. Dimensional stability of the reflector frames with the temperature extremes and possible humidity, inside a BITNR collector un-insulated space is a consideration however relaxed accuracy and less than perfect specularity may be acceptable for nonimaging concentration. Big EW-line CPC configuration options (Figure. 1d,e) include a big CPC trough reflector with the upper and lower sides fixed all year or seasonally adjusted, e.g. 2x per year. Seasonally adjusted big CPC troughs may have higher concentrations compared to fixed-all-year CPC troughs. A big CPC lower-side reflector fixed-all-year has two parts in some studies: removable lightweight reflector access panels adjacent to the target-rectangle and a fixed reflector part on building structure (Figure 12e). A big CPC reflector panel (4ftx5.5ft, 22SF) prototype wood frame for anodized aluminum reflector sheet (0.020inch thick, $2/SF, 86% reflectivity) had c2012 material cost of $70($3.18/SF) (FIgure 3i). Higher reflectivity anodized aluminum reflector sheet for exterior applications 0.020inch thick in 2019 was about $3.50/SF.

3.2.3 Tracking 'Wing' Reflectors

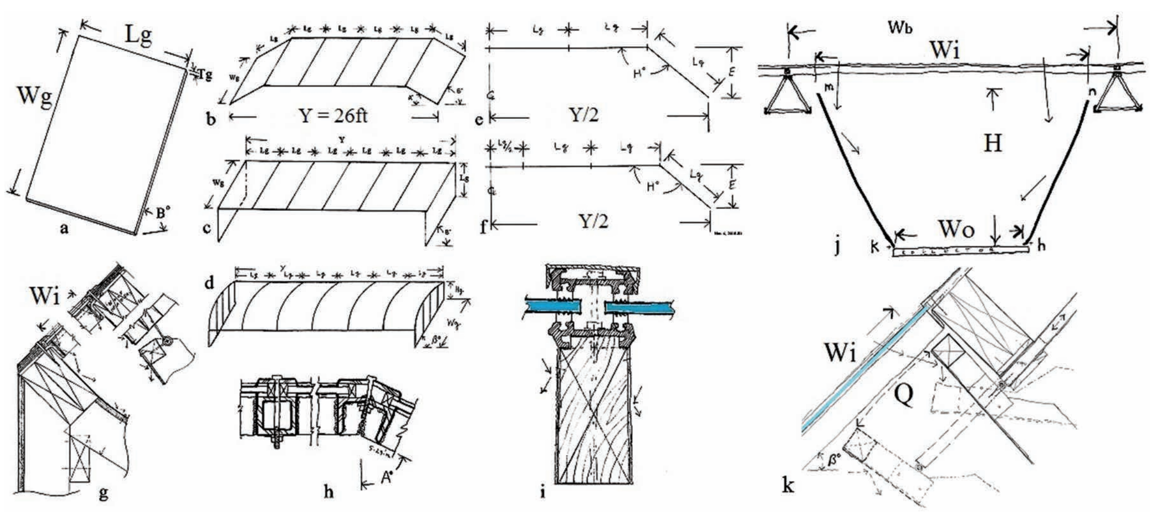
Collection and concentration are increased with tracking 'wings'. Big EW-line CPC troughs without tracking E&W 'wings' have open-end spillage losses with reflections missing the target-rectangle. 'Wing' reflectors hinged at the E&W sides of target-rectangles inclined and vertical are: flat trapezoids (Figure 3k) with inclined hinge lines; and vertical curved segment 'wings' with vertical hinge lines for high latitude regions (Figure 8G). The 'wings' hinge-lines and target-rectangle have the same inclination angle. Areas behind 'wings' with inclined hinge-lines have access space for: maintenance, stairs, and distribution ducts or riser pipes. Flat 'wings' can have small hinged flaps manually repositioned to fit with big CPC seasonal adjustment. The 'wings' with a string-linkage above inclined receiver-tubes only track to near vertical, and a linear actuator drives the east 'wing'. The lowest trapezoid long-edge positions at exterior wall glazing inclined sills are set by the actuator stroke-extension and string length. The string length limit above inclined tubes is a research issue. For long EW-line collector rows beyond the limit of a string linkage, an actuator system at each row end would be required, which may have multi-row inclined linkage. Access to the target-rectangle lower edge and lightweight removable reflector panels is thru a hinged 'wing' part (Figure 3k). At morning start the east trapezoid 'wing' is sloped for low-angle sunlight to enter the big CPC and the west 'wing' is near vertical to avoid spillage, and at the end of a collection day the 'wings' are in converse position. Each reflector 'wing' slants outward similarly at midday. Precise tracking accuracy is not required for nonimaging effective concentration. Additional tracking E&W reflector configurations include: up-and-down, and rotating vertical flaps.

George Helmholz, Small Power Systems (SPS), invented a passive PV sensor-tracker c2014 with: counterweighted small gears on the east 'wing' string connected to a west 'wing' reflector, with a shade-band and three small PV areas (one PV area for return to morning position), and a gear-motor driven spool-cable-spring drive for the BIETR (now called BITNR). SPS fabricated and donated a prototype tracker which was given to students for development [91] (Figure 15d).

3.3 Exterior Glazing Aperture (EGA)

The BITNR EGA monolithic exterior glazing-frame aperture is a weather protecting cover to the interior receiver-tubes and lightweight reflectors in a walk-in collector space, and also part of a building envelope roof /wall. The EGA is coordinated with the nonimaging reflectors inlet aperture e.g. with a big EW-line CPC inlet width (Wi) plus seasonal adjustment (quasi-tracking) (Figure 2d and Figure 4k). The EGA has a structural frame and high transmittance

FIGURE 4. BITNR exterior glazing aperture (EGA) frame configurations.



monolithic tempered flat glass or solid polycarbonate curved and flat sheets. Solid polycarbonate has wavelength dependent transmittance losses [84]. EGA structural frame material possibilities include: wood, steel, and aluminum with applied reflector options to increase collection and reduce frame heating. There is a large distance in the un-insulated collector space between the receiver-tubes and the EGA. Configurations with non-evacuated glass tubes are a type of double-glazing with a large volume and distance between the tubes and EGA.

Sloped, curved, and vertical glass and polycarbonate architectural facades and large area skylights are common building industry products; and commercial greenhouses are designed to maximize plant growth. Monolithic glass greenhouse technology would be less costly than architectural glass envelope and skylight systems. Solid polycarbonate vaults are for hail damage regions; and sloped glazing and E&W hip windows may reduce bird-kills (Figure 4b). The glass-grip top parts of architectural skylight extruded aluminum products purchased separately may be assembled on locally manufacture frame structures (Figure 4i).

Sizing of a typical monolithic tempered flat glass lite is a design variable with glass-grip detail options. Architectural skylight systems with: extruded aluminum frames, serrated extruded EPDM rubber glazing strips to ASTM standards, and certified installers could have large area sloped glass lites typically 6.35mm/0.25inch thick, up to around 3.7m2/40ft2 each, with flush horizontal structural sealant gaps and vertical cap strips. A glass-frame system by local installers with edge trim (e.g.Trim-Lok TM) and four sided cap strips will have a smaller typical glass lite size with a looser glass-grip. A slim reflective stainless steel frame would have little shading, and holes in steel glazing frames would need to be coordinated with prefabricated holes for stainless steel cap strips. Greenhouse systems have optimized transmittance and shading losses to improve produce production. A high-temperature solar-beam only imaging concentrator by GlassPoint Solar Inc. used commercialized glass greenhouses on the ground with around 18% loss by glass transmittance and metal frame shading [66, 67]. The nonpublic walk-in BITNR collector space may be a hardhat area according to governing codes.

Vertical BITNR schematics have vertical exterior glass for high latitude regions (Figure 6b and 8). An EGA with a combined vertical plus top sloped glazing may have better yearly collection. Vertical monolithic glass has less risk of hail damage. However, only vertical glass configurations for 30–50 degree latitude regions would have an annual collection performance reduction. Hail damage trends are a consideration in selecting glazing configurations. Solid polycarbonate vaults could have less damage from large hail stones, may have less frame shading with reflector covered arc rafters, and have a lower handling cost. Solid polycarbonate has greater impact resistance compared to glass and is lighter than glass, around half the weight by volume, for easier handling. The "wave-length dependent" properties and spectral transmittance of glazing materials are considerations [84], for example, the clear solid polycarbonate transmittance loss effect for the receiver-tubes selective absorber coating. Solid clear polycarbonate has transmittance loss at the far infrared wavelengths due to its chemical composition, and is an influence on the performance of the selective surface emittance.

A BITNR-Air two-car garage study with a glass-hips-frame has: a typical glass lite size fitting with the EW-line big CPC trough, 140 degree hip-angle and clearance for tracking 'wings'. Glass lite width options for a 7.92m/ 26ft EW-line BITNR collector with 35.5inch/902mm EAL solar cooker tubes with a 140 degrees hip angle (H) include: 1.46m/4.8ft with six lites, and 1.2m/4ft with seven lites (Figure 4a,b,c,f). The hips slope angle (H) is a site-specific engineering variable and H = 140 degrees was used for beginning studies as it is a standard hip-rafter aluminum extrusion in the architectural skylight industry (Figure 11b).

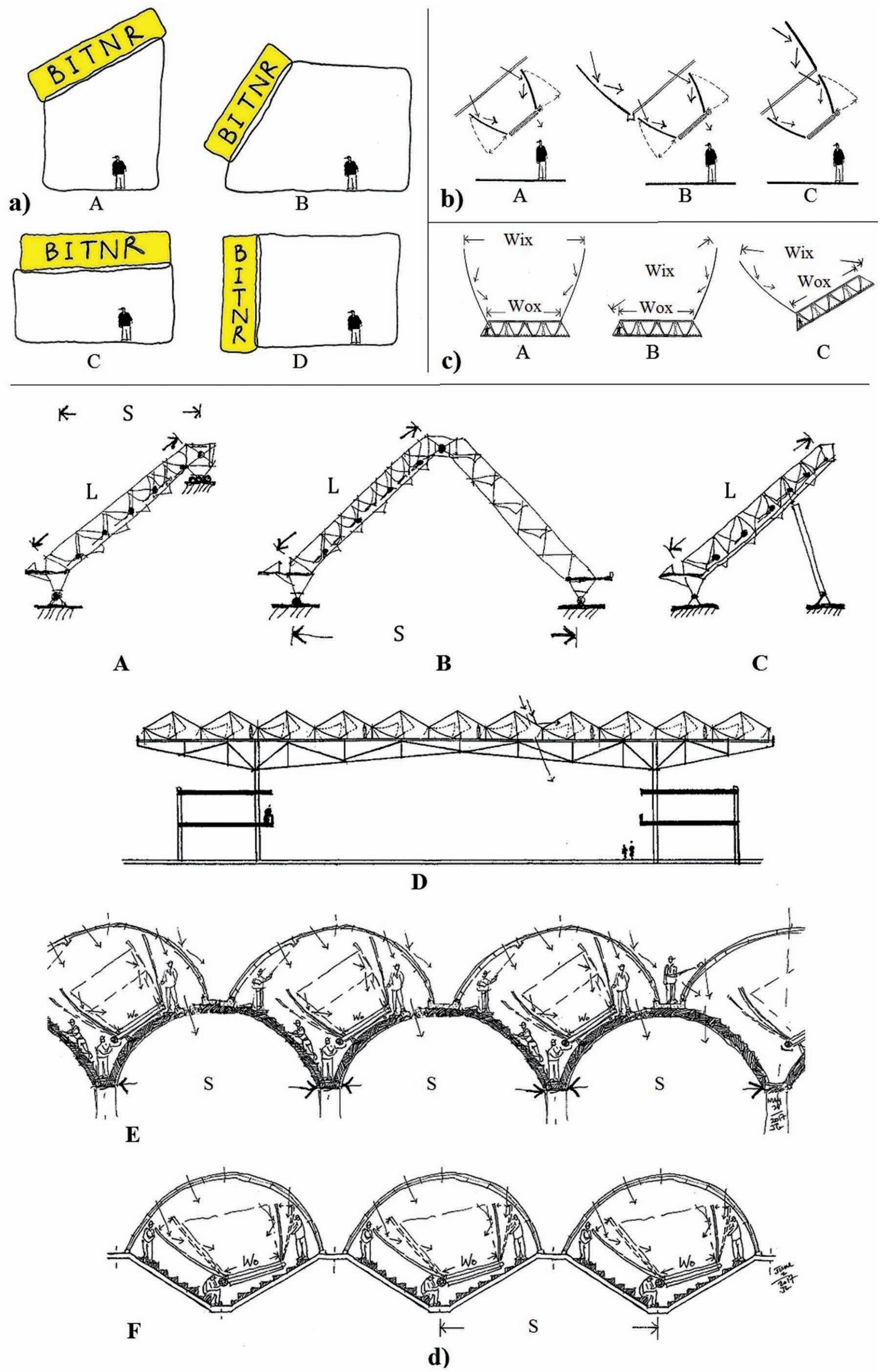
4. BITNR BUILDING-TYPE APPLICATION STUDIES

BITNR building-type feasibility studies include: small wood frame structures, two-car garages detached and attached, house size demonstration, apartment buildings, long-span atriums, large concourses, towers, and additions with possibilities for district heating systems with storage. Additional BITNR building-type case studies include: a greenhouse type structure on the ground or roof connected to commercial greenhouses (vegetables, flowers, etc.) in cold regions for cold season heating and double effect refrigeration during the warm season; restaurants; food and beverage process heat facilities; and a remodeled shipping container collector. Schematic structure studies with conventional construction materials and methods appears feasible which include: trusses (wood, steel), wood laminated beams, and vaults (concrete, masonry). BITNR architectural studies indicate integrated active solar energy technologies with receiver-tubes and building-size nonimaging CPC reflectors are significant factors for building and site design. BITNR/BIETR building-type studies have been developing since c1998 [4, 5, 6, 7, 12, 94, 95, 97].

Fixed target-rectangles are inclined, or vertical for high latitude regions, coordinated with a heat transfer distribution system of insulated pipes/ducts integrated with structure to fit with various building forms. There is most all-weather maintenance access to collectors and distribution systems inside of the thermal buffer space. Different building types have different BITNR collector configurations and dimensions for example EW dimensions of selected building types include: 7.3m/24ft for a two car garage (Figure 12); double-loaded corridor dormitories, hotels and apartments (Figure 10a) are typically around 15–20m/50–70ft and may be multilevel buildings; atrium hotel around 85m/280ft (Figure 7c); hospital double-corridor floors with patient rooms and center multipurpose rooms are around 25m/80ft; arena concourse 152m/500ft (Figure 7b), and big box stores are about 152m /500ft (with about 7.3m/24ft floor to rooftop). The building vertical façade and floor to ceiling dimensions have a BITNR modular framework influence. For example in multifamily buildings (row houses, apartment buildings 2–8 levels+) (Figure 10) apartments typically have a 2.4m/8ft room floor to ceiling height with a 0.5m/20 inch floor-ceiling depth. Some big box stores have a floor to bottom of flat roof structure of around 6.4m/21ft with truss roof structure depth of around 0.91m/3ft. BITNR long-span truss depths coordinate with big and tall EW line CPC reflector troughs [6, 7] (Figure 7). BITNR collector modular assembles can be sized to fit with commonly sized rooms and roof spans. The ratio of a nonimaging CPC trough inlet width (Wi) to the outlet width (Wo) which is also the target-rectangle inlet width can influence roof spans and room dimensions. Larger BITNR systems with walk-in flat-plate solar collector-roofs have integral daylighting possibilities (Figure 7a).

Nonimaging reflectors characterization truncation provides a measure of flexibility for dimensioning architectural and structural designs, coordinating with the limited specific lengths of receiver-tubes and some building dimensions (floor-to-ceiling heights, room sizes, etc.). Access considerations influencing building/structural dimensions include: installing/replacing receiver-tubes and reflectors/racks; sizes of doors, stairs, and elevators; and maintenance of collector system and interior of glazed-roof. Some BITNR configurations have a big horizontal CPC reflector bottom-side fixed with options for the top CPC reflector side (fixed or quasi-tracking) (Figure 12e). Maintenance access to the interior inside of the exterior glazing, condensation, and entry large enough for collector equipment are considerations for all the schematics. Disturbing reflections and glare may be minimized with efficient optical design and building/site design and landscaping.

FIGURE 5. BITNR building integration and structural configurations.



BITNR urban and campus building designs as distributed solar heating stations (water-steam, air) for solar district heating systems with storage are of interest where there are limited land areas for ground-mounted mid-temperature solar thermal collectors. BITNR collectors with short distribution lengths to district heating systems may be sources of income when thermal energy could be sold. And IPH applications at urban industrial sites have high land cost.

Added exterior augmentation fixed building integrated reflectors to BITNR collector studies are illustrated in Figure 9. BITNR long-span collector roofs may be the target for large augmenting exterior reflectors for large buildings. An equatorial latitudes example has a large CPC trough oriented upwards with up- and-down reflector "wings' protected from horizontal wind loads by building around E&W courtyards (Figure 9d-f). Supplemental studies include BITNR buildings combined with small wind turbines (Figure 13a-f), a two-row entablature (Figure 13g), and a BITNR shipping container (Figure 13h).

BITNR Tower studies have collectors integrated in the higher regions of sloped and vertical glass façade tall buildings. Sloped upper façades of towers can have reduced wind load structure. The more inclined BITNR collector rows are below less inclined façade integrated PV modules (Figure 6a). BITNR collectors inside of vertical glass tower facades for high latitude regions can have less frame shading per glass lite area compared to sloped glass façades (Figure 6b). Towers with integrated vertical thermal storage in cores (elevators, stairs, toilets, etc.) could have efficient thermal stratification, perhaps a novel design component for tall building cores. BITNR tower thermal storage may be with rocks [108, 109] and PCM [64] for air systems, and with insulated water tanks with liquid systems; and towers adjacent to small heliostats high temperature collector systems [110] safe high temperature storages are possibilities in tall building cores, atriums, etc. (Figure 6).

BITNR Concourses can be structured independently to an adjacent building or group of buildings with columns or struts, or structurally integrated with an adjacent building (Figure 7b). A reference for a solar collector concourse formed with an integrated structure to an existing building is a project (not built) with cable-beams supporting solar collector panels structured to an existing US DoE building with thermal panels on upper part and PV panels on the lower part [62].

BITNR Long-Span Roof/ Wall System Studies with horizontal collector rows have integral daylighting possibilities. A BITNR inclined long-span system is a large walk-in flat-plate collector with NS inclined open-web-girder depths sized for maintenance access with EW-line big CPC troughs. There is a correspondence between the girder depth and the big CPC height, and combined with daylighting apertures are for inclined atrium roof and wall systems. Modular structural-frame bays have: receiver-tubes with involutes, plumbing/ducts, big CPC and 'wings', all under a glass roof. Typical E&W end modular bays have stairs, heat fluid risers, and clearance for tracking 'wings'. The open-web girders have clearance for EW-line manifolds/ducts at the top or bottom of NS inclined receiver-tubes with EAL that equals the big CPC outlet width (Wo) which is a significant system design dimension (Figure 7a). For horizontal tubes the involute inlet widths define a big CPC outlet (Wo).

There is a measure of dimensional flexibility with truncation of the big CPC and 'wings'. The inclined girders support: top EW 3d open-web trusses with a glass roof; and 2d EW-line trusses (with vertical insulated daylight glazing) for maintenance access collector platforms that form an insulated ceiling (Figure 7a). A few vertical daylight windows can open for infrequent big parts replacement. Seasonally adjusted quasi-tracking (e.g. twice/year when cleaning) EW-line trough CPC reflector side(s) influence NS bay glazing frame spans, passive daylight

FIGURE 6. BITNR Tower studies: a) sloped facade; b) vertical façade.

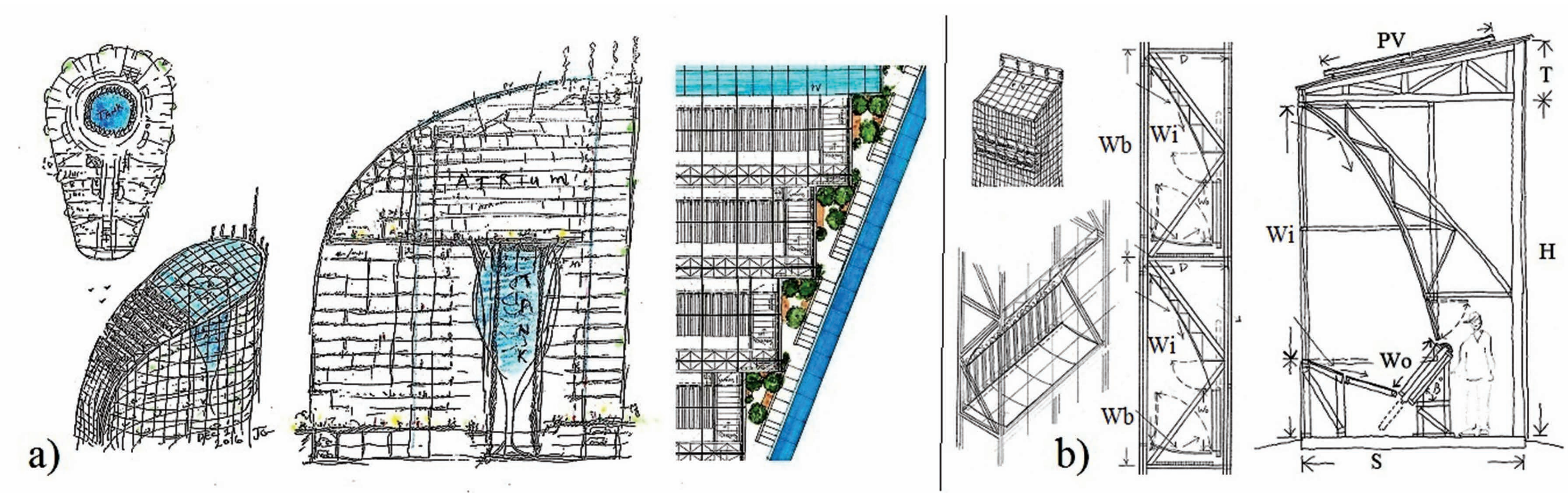
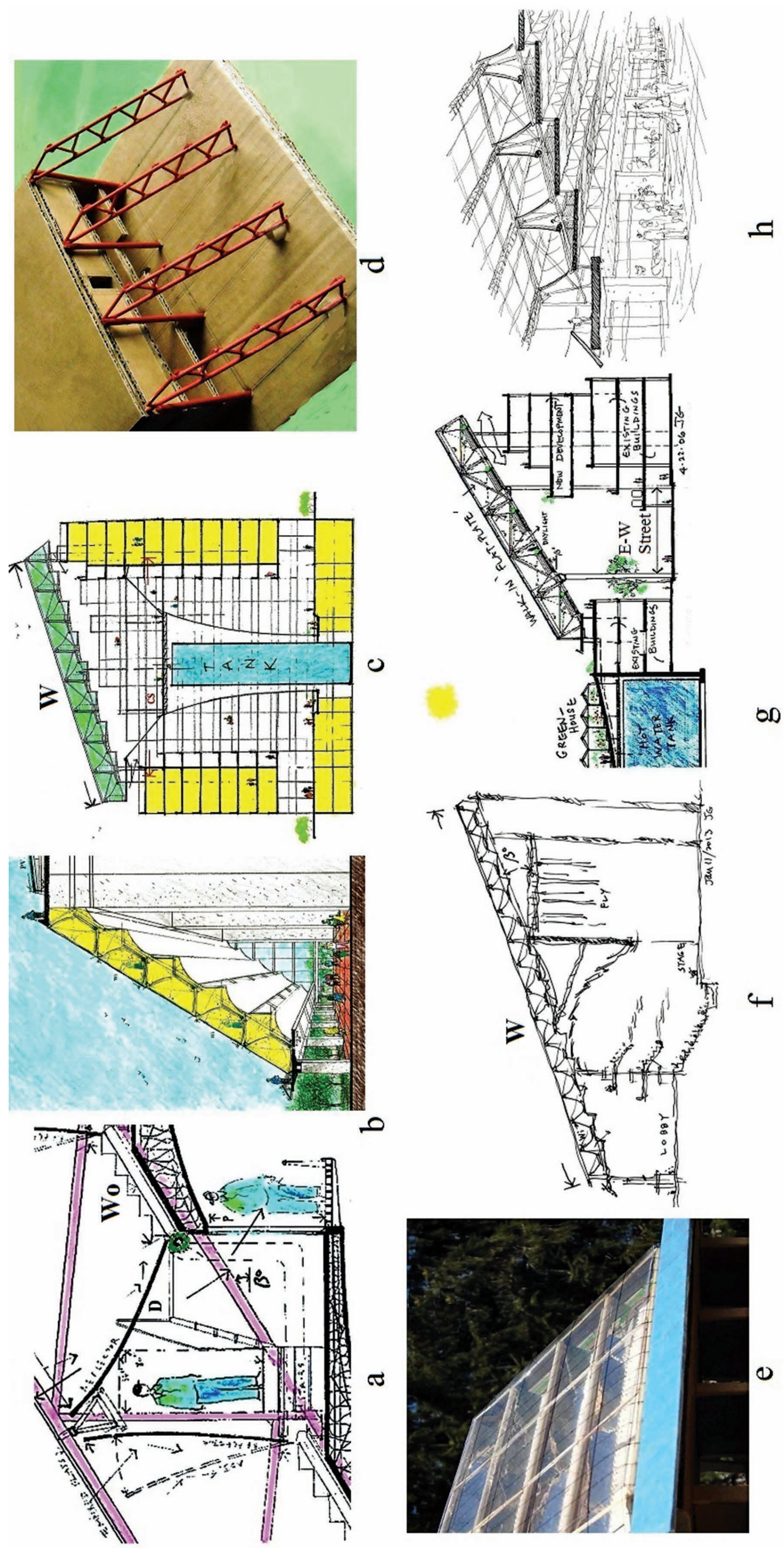


FIGURE 7. BITNR Long-span roof/wall building type application studies.



apertures, and gaps at the 'wings'(Figure 4j-k). Different long-span inclinations have significantly different detail designs. BITNR inclined long-span case studies include: atrium hotel; arena concourse; music hall; and spanning over EW-line streets [6, 7] (Figure 7).

BITNR-Vertical for high latitude regions schematics have inclined or vertical target rectangles with vertical or horizontal receiver tubes and involutes (Figure 8). An inclined target rectangle BITNR-vertical with only vertical glass has an asymmetric EW-line large CPC. The upper CPC-side reflector has a top part fixed to CPC-shaped joists and lower part reflector panels that manually rotate for maintenance access [101] (Figure 8c); and for multilevel residential buildings there are two apartment levels per BITNR module, and horizontal EW collector rows coordinated with apartments and NS-double-loaded corridor total around 18.3m/60ft. This BITNR-Vertical module type may be an integral part of towers, hospitals, dormitories, office buildings, etc.

Another BITNR-vertical collector module for high latitude regions has a vertical target-rectangle and tracking E&W rotating 'wing' reflectors with vertical hinge-lines and a mirror floor. The EGA has a sloped upper part and a lower part vertical 'curve' formed with flat glass lites [26]. Receiver-tubes are vertical or if horizontal clearance for placement/replacement is coordinated with involute spacing and under or over maintenance access catwalk levels. A lightweight electric scissor-lift with soft wheels on a glass mirror floor is considered for maintenance access to the higher collector and 'wings' areas. A lightweight weight screen could be lowered in front of the vertical target-rectangle as an automated failsafe measure. Studies include a production hall, hotels, and apartment building (Figure 8B,D-G).

BITNR Apartment and townhouse building studies intended for solar district heating systems with storage include an apartment building with four BITNR-Air inclined collector EW rows over a commons room and three apartment floor levels with a basement garage option (Figure 10A). This four-row BITNR collector is a proposed structures design project. Studies with long evacuated tubes (around 1.5m/5ft+ EAL) indicate feasibility, and with shorter cooker tubes (900mm/35.5inch EAL) there are some tight clearance considerations e.g. worker access. BITNR structural dimensions seem more influenced by access for maintenance workers and building application dimensions (floor-to-floor heights, etc.), with big CPC reflectors truncation optimization tailored to those dimensions. Current studies have center-line dimensions of 3d top trusses at 2.74m/9'-0" with inclined 2d girder height at 2.43m/8'0" (Figure 7a,d).

A townhouse (two levels) cluster study has one EW BITNR-Air collector row over laundry, thermal storage and mechanical rooms connected to a district heating system. Low sloped roof mounted PV solar panels are above storage sheds with access to the exterior glazing (flat glass or solid polycarbonate vault) (Figure 10B).

BITNR house and garage studies have a large EW-line big CPC reflector trough with two parts: a lower reflector side adjacent to the exterior glazing lower edge with lift-off (for maintenance access) reflector panels adjacent to the lower edge of the target-rectangle of collector tubes and involutes; and an upper reflector side of panels fixed all year or with seasonal adjustment, e.g. two times per year. A NS-inclined receiver-tube EAL influences the large EW-line CPC reflector trough size which in turn influences the size of the E&W tracking 'wing' reflectors. Longer NS inclined receiver-tubes, e.g. around 1.8m/6ft, can have larger EW-line big CPC troughs and 'wings', which can have longer dimensions between 'wings' so as not to miss reflected low angle solar from the east and west. The shorter receiver-tubes (e.g. around 0.6–0.9m/2–3ft long) evacuated solar cooking tubes would have a BITNR collector EW length fitting with house sizes and two-car garage sizes, around 7.3m/24ft east-west.

FIGURE 8. BITNR-Vertical schematics for high latitude regions.

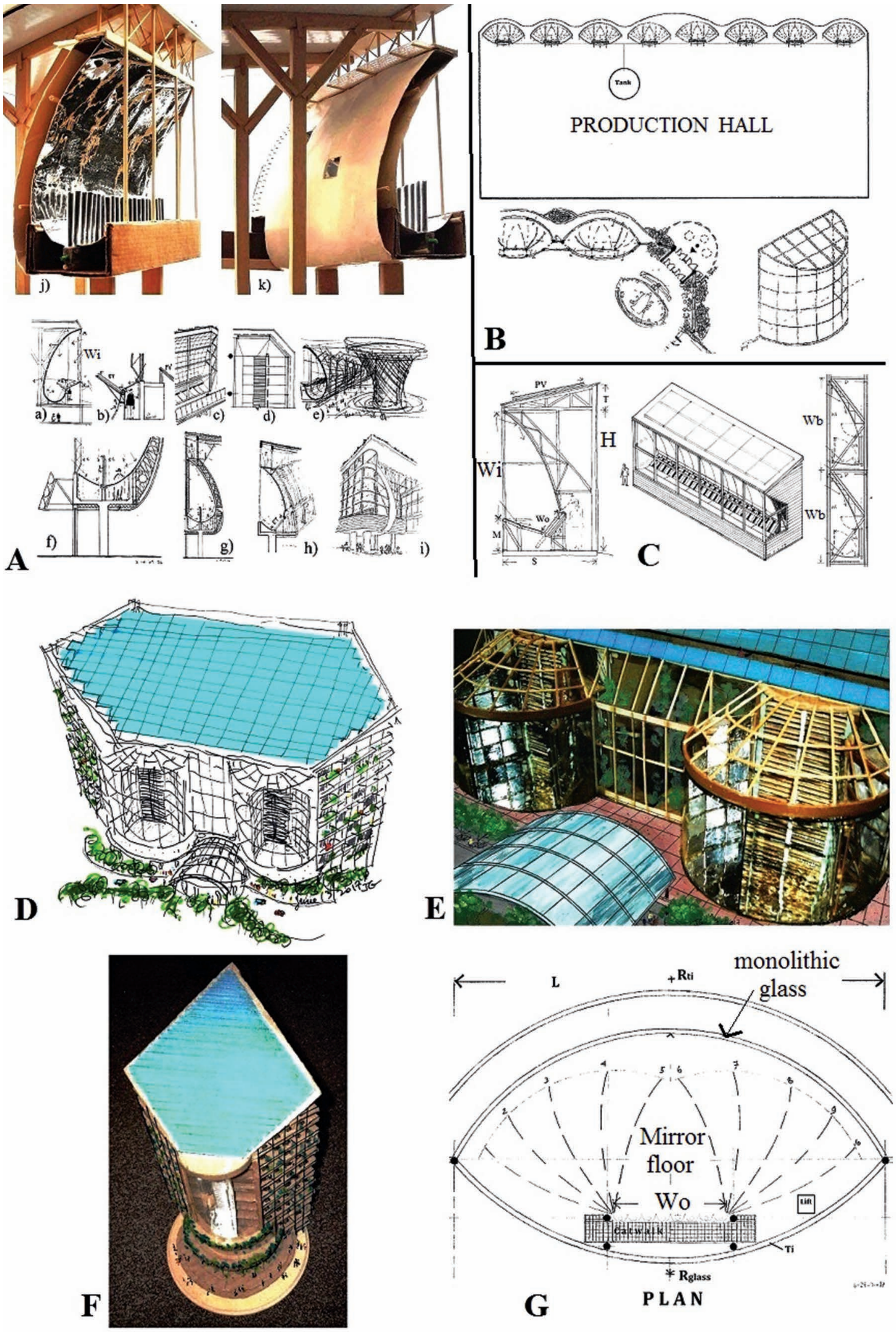


FIGURE 9. BITNR studies with exterior reflector augmentation.

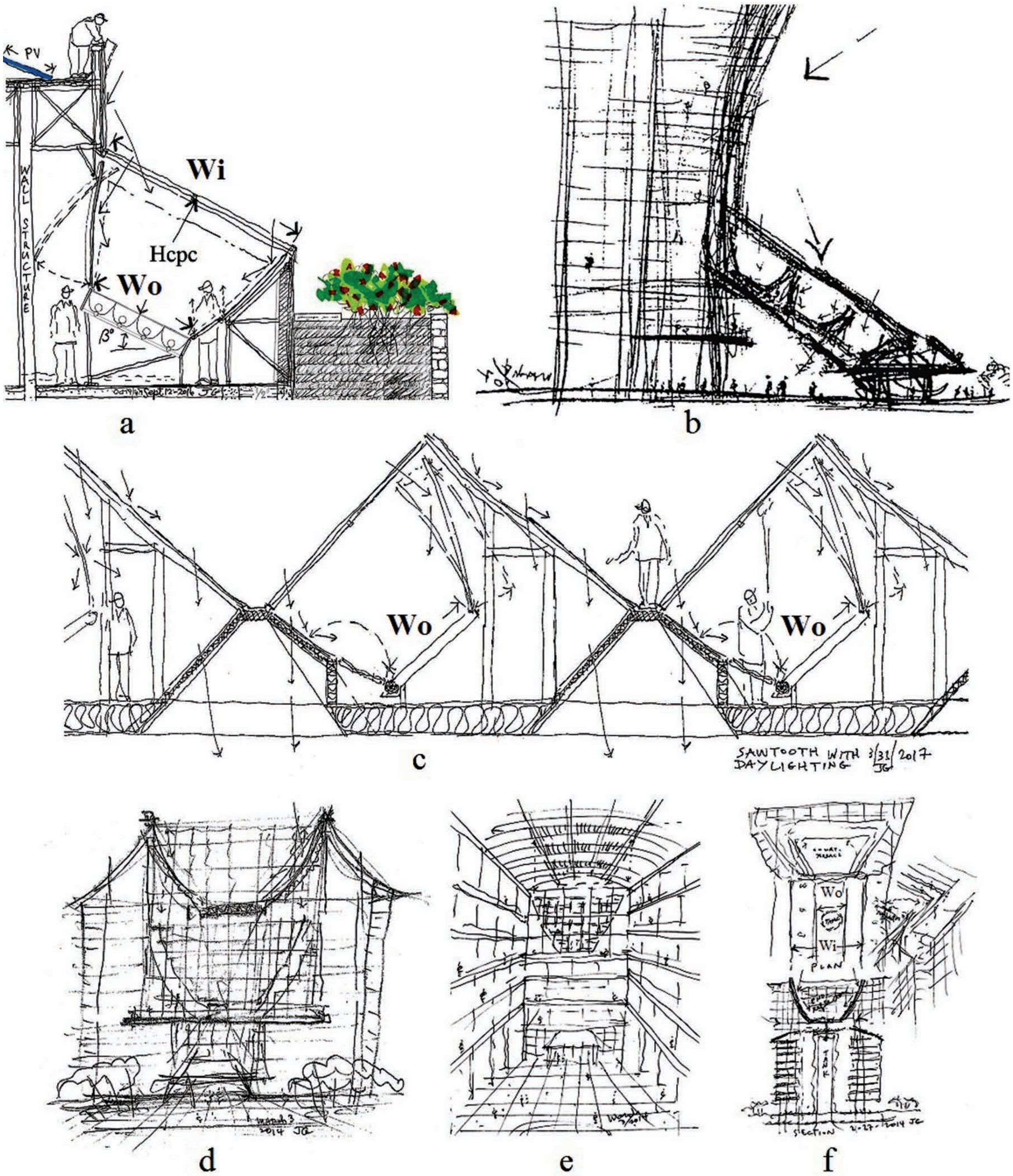


FIGURE 10. BITNR Apartments (three floors) and townhouse building studies.

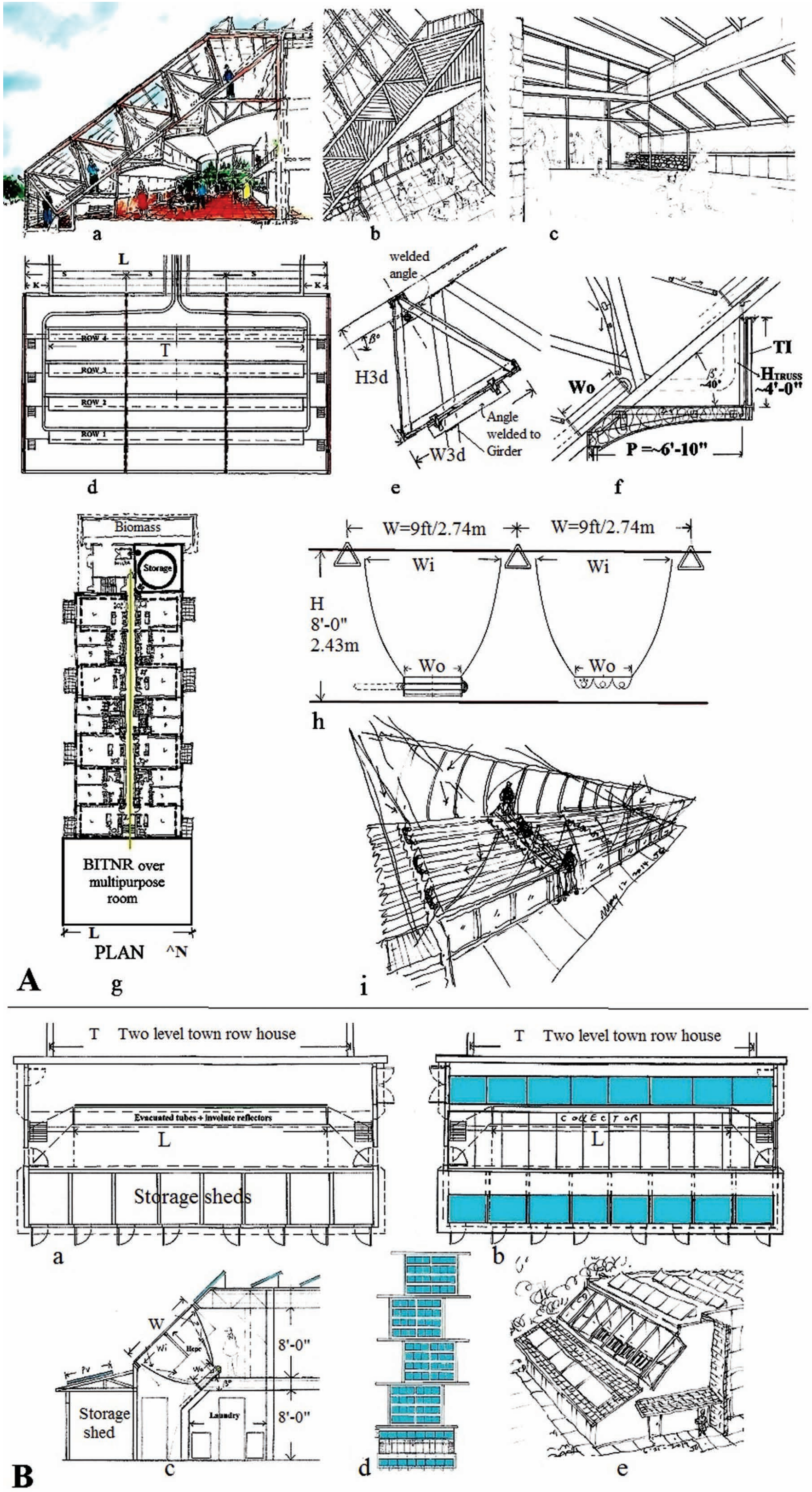
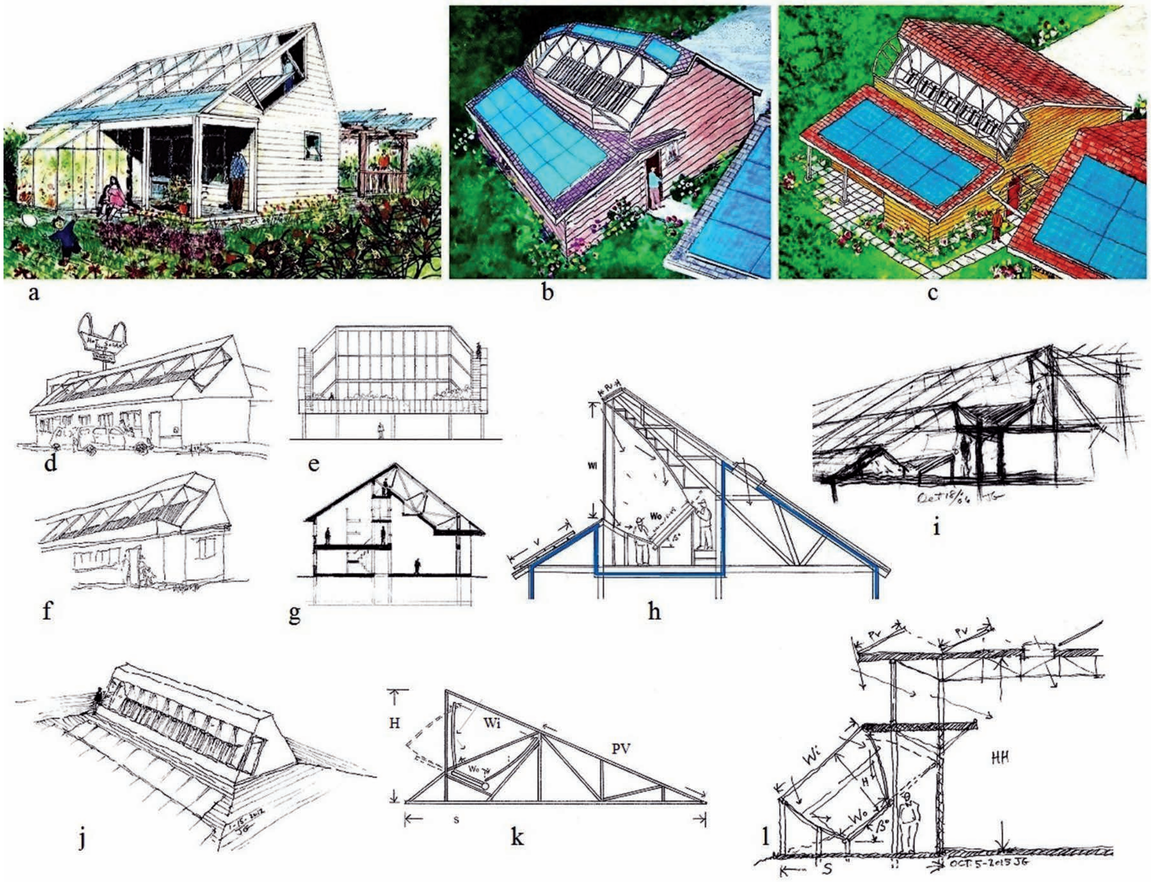
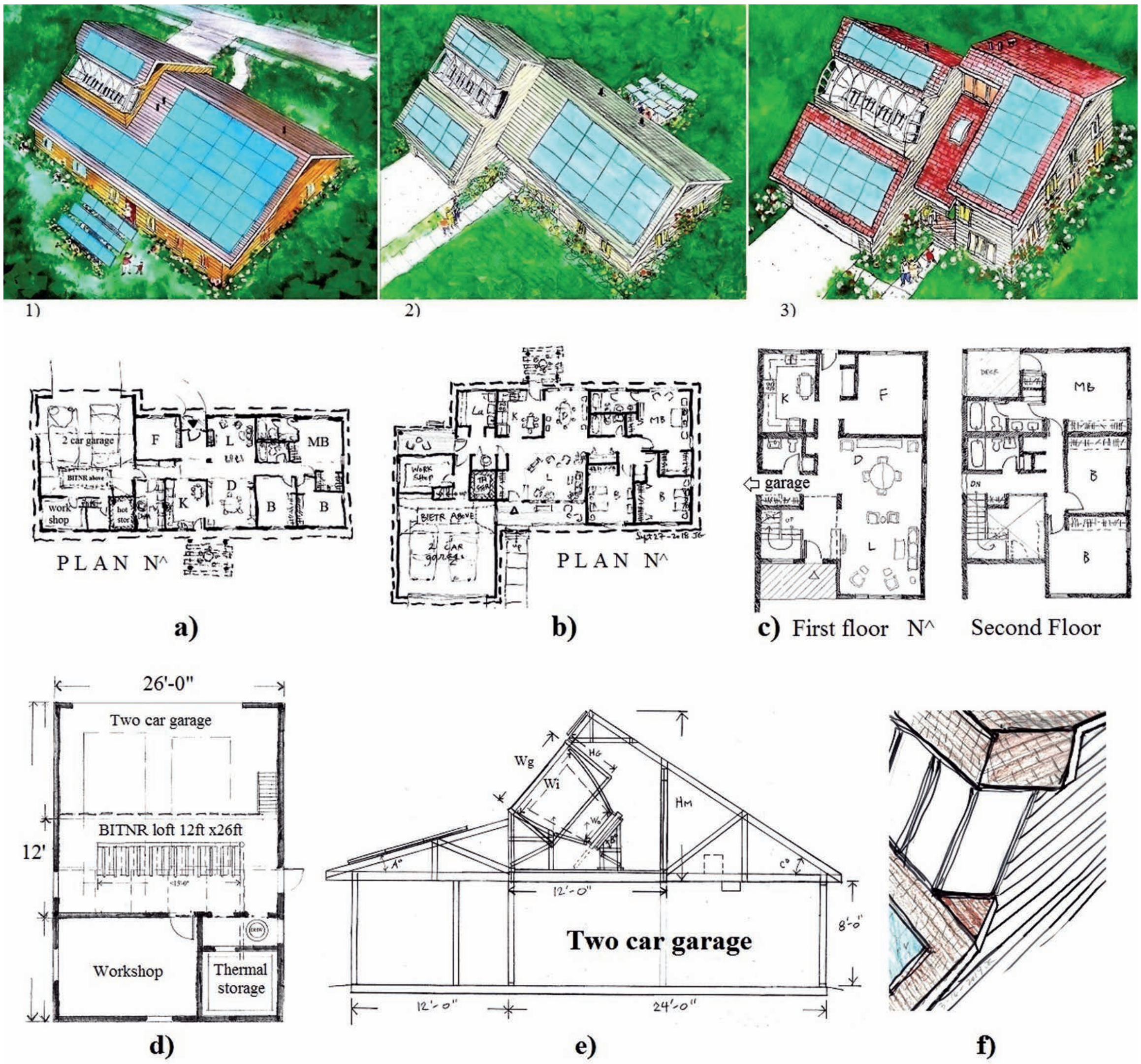


FIGURE 11. BITNR small building demonstration and application studies.



BITNR two-car garages attached to houses were studied to gain understanding of influence to house and site plans. Preliminary house design studies include one level houses with garage entry at the north and south side (Figure 12). If the glazed roof of a BITNR collector on a loft in a two-car garage is damaged (by hail, etc.) water falling from the loft onto cars, bicycles, lawn mowers etc. in the garage would be much less of a problem than when a BITNR collector is above rooms in a house. BITNR collectors above rooms in a house would require very careful glazed roof sealing and a drainage membrane on the BITNR platform, and air heat transfer systems reduce liquid leak damage concerns. A BITNR two-car garage attached to a house has solar access for E&W window (hips or vertical) parts of wall elevations which influence roof shape, house and site planning. Roofs below the BITNR EGA influence the: collector loft level, size of glazing element, and house roof slopes (Figure 12). Many typical house plans with a two-car attached garage have the garage extended out from the house which would permit solar access to E&W BITNR collector windows above the garage if facing the sun. The BITNR collector is more suited for buildings with larger heat demands and district heating systems however a BITNR house would be a modest size demonstration and testing facility and possibility for residential solar district heating systems with seasonal thermal storage. The 'Fantasy' Almere solar house indicated the 3-d massing design influence of a large flat-plate thermal collector and large thermal storage tank integrated with an awkward fit for a small house [105].

FIGURE 12. BITNR House studies: a-c) House plans and perspectives with attached two-car garages; d-f) detached two-car garage with flat glass glazing.

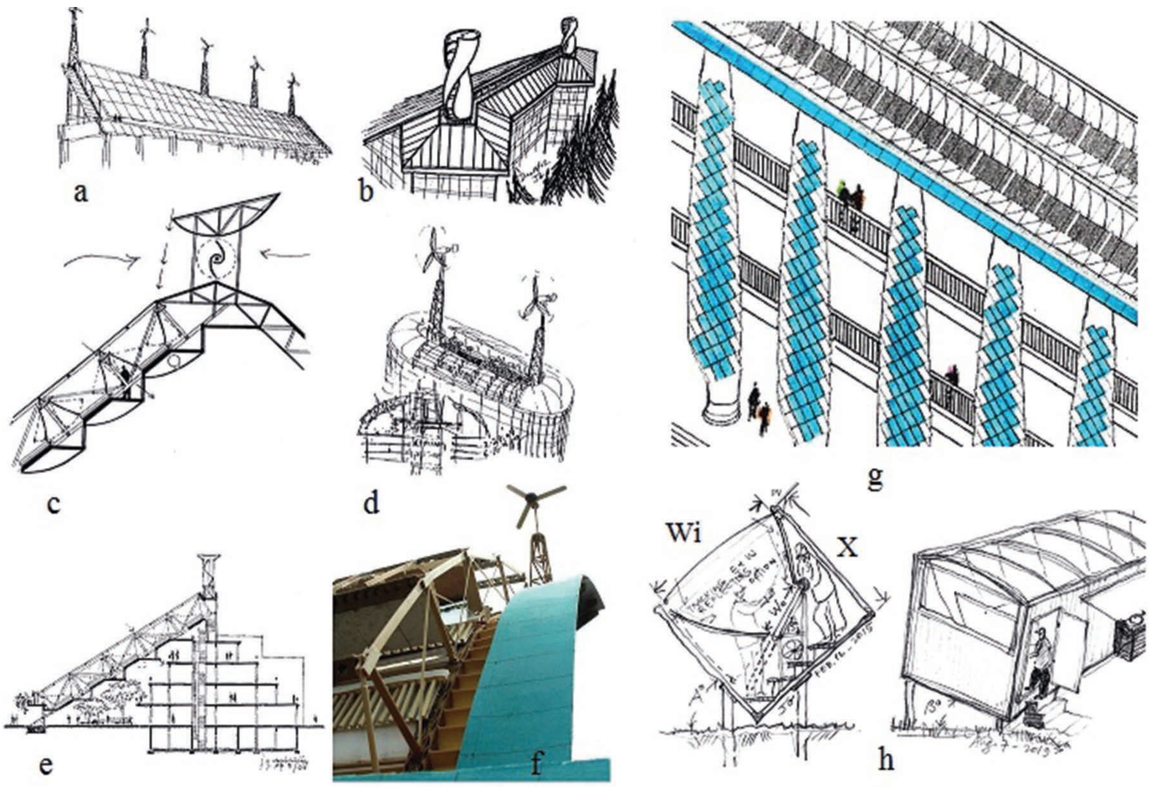


BITNR Small Demonstration Verification Test Building studies have been started with selected receiver-tube collector sizes. A BITNR-Air wood frame building study with twelve 35.5”/900mm long all-glass 120mm/4.75” OD tubes plus matching involutes has around a 4.26m/14ft x 7.31m/24ft plan with big CPC reflector panel wood frames around 4ft x 5.5ft hinge-connected at a top wood header (two 2x6inch) (Figure 16Bg).

5. BITNR-AIR PROTOTYPE TEST STANDS

BITNR-Air test-stand parts were schematically designed and mock-up modeled to gain experience for formulating student engineering projects and used for visual-aids. Wood test-stands with two-four receiver-tubes are intended for testing insert and insulated duct options. Tube inserts e.g. twisted-tapes to direct air flow to hot surfaces in absorber tubes improves heat removal for evacuated and non-evacuated receiver-tubes. Promising tested configurations could

FIGURE 13. BITNR Supplemental studies: a-f) BITNR collectors combined with small wind turbines; g) two-row BITNR entablature above reused wind blades colonnade; h) BITNR container.



then be fabricated for larger arrays with multiple (e.g. six-twelve) tube test-stands and tested with all the BITNR reflectors in a greenhouse. A plywood wood case design to hold sloped large diameter (120mm/4.72" OD) all-glass evacuated solar cooker tubes and matching rounded-W involute reflectors was developed in 2017 (Figure 14).

6. BITNR/BIETR STUDENT ENGINEERING PROJECTS

BITNR/BIETR student engineering projects were written and offered to universities and technical colleges. Selected BITNR/BIETR undergrad mechanical and structural engineering semester senior design projects completed at the U. of Wisconsin-Platteville (UWP) sponsored/mentored by the author are reviewed. And new BITNR engineering student projects being offered to university professors are presented.

6.1 BITNR/BIETR Mechanical Engineering Student projects at UWP

BIETR (BITNR) Atrium Hotel 2005 Project: A glass roof collector (19m/62ft x 61m/200ft) inclined 40 degrees from horizontal was given for a Wisconsin site. NS-inclined open-web steel girder depth is around 2.9m/9.5ft. The big CPC trough (inlet width Wi = 3.69m/12.11ft) has reflector panels top-hinged to 3d open-web trusses. Size collector components for access to the collector space thru doors, stairwells, elevators, etc. Select an evacuated receiver-tube collector system in the market. The insulated fluid loop is water-steam up to 176C/350F degrees, 125psi,

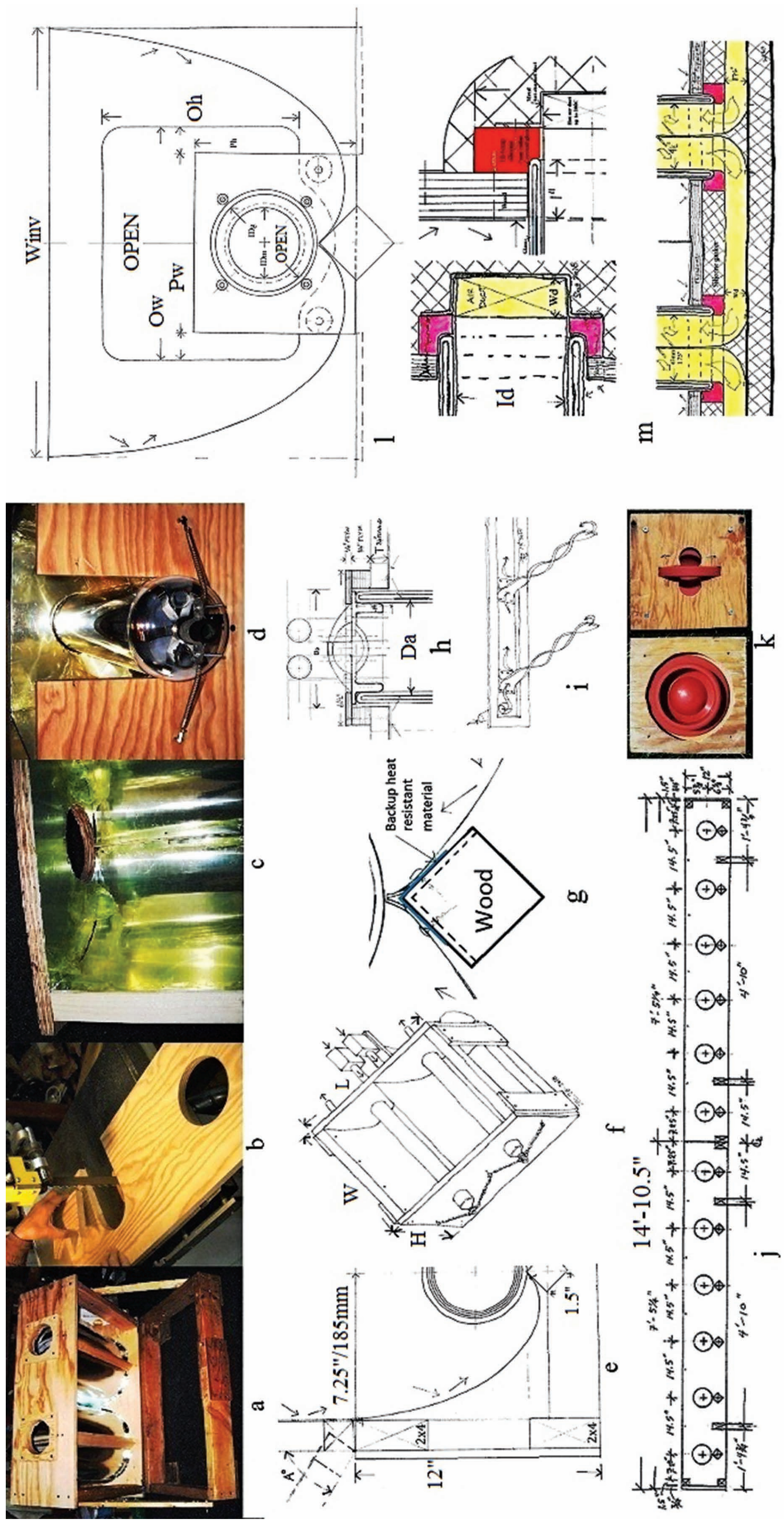


FIGURE 14. BITNR-Air mockup wood test stands with insert and duct studies for evacuated and non-evacuated receiver-tubes.

in accord with local governing codes. The students estimated an area solar concentration factor of 7.3 onto evacuated tubes for a four EW rows array, and proposed a brake-motor drive system at the E&W ends to track 'wing' reflectors. For a 250 room hotel with 60% occupancy, 209 gallons per/day water use per room, with 70% hot water supply rate was calculated to be 915 gallons per/hour. They concluded the solar collector system could deliver heated water up to 140F/60C degrees at the necessary flow rate thru a 2"/50.8mm diameter pipe [86] (Figure 15a).

BIETR (BITNR) tracking 'wings' 2012 project was the first tracking 'wings' project at UWP and students constructed full size 'wing' wood frames sized for NS inclined 1.5m/5ft long evacuated tubes. A linear actuator was first considered with an attached programmable logic controller; and a stepper motor and controller were selected with a downloaded controller program. The linear actuator temperature range was reported to be better suited for Wisconsin temperatures. A tracker rope-pulley system under the tubes was developed. After this project it became evident that a string-cable connecting the 'wings' above inclined tubes appeared feasible to minimize linkage with one actuator [87] (Figure 15c).

During this time the author communicated with people knowledgeable about solar trackers to see if they could supply a 'wings' tracker. An exchange with George Helmholz, SPS, developed and he presented a passive tracker concept invention composed of a PV-sensors shade band (shade band between two PVs, and third PV for return to morning position), counter-weighted gears, and a DC gear motor. Conceptual drawings received in April 2014 included a small gear-motor part of an assemble mounted on the east 'wing' powered by the PV-sensors with cable-spool linkage at the east reflector and spring at the west reflector. Helmholz donated a prototype passive sensor-tracker (Figure 15d).

Air volumetric receiver for 2-axis tracking heliostat reflectors 2013: This was not a BITNR/BIETR project however it had heliostats concentration onto an air receiver with Dewar type evacuated tubes for farm applications. The focus of this project was the design of a small volumetric elevated air receiver and forced air fluid loop [88].

BIETR-Air 2015 heat removal project: Students used all-glass (double-glass Dewar type) solar cooking evacuated tubes (about 5inch nominal OD, 20inch EAL) with silicone caps purchased from Rand Solar. Only about a 25.4mm/1inch diameter duct-tube in-and-out holes could fit in the silicone cap. Duct-tube entered thru the cap at the bottom and extended nearly to the end of the tube interior and warmer forced air exited the cap thru a very short top duct-tube. Each evacuated tube-receiver had an augmenting rounded-W involute reflector which determined the receiver-tube spacing and insulated duct-tube manifold length between receiver-tubes. Testing results were: 20C/68F degrees temperature increase due to the involutes [89] (Figure 15f).

BIETR (BITNR) second tracking 'wings' 2016 project: Students were given the Helmholz invention prototype and they confirmed feasibility by testing and refined the PV-sensor weighted gears and directly connected the DC gear motor with added gears in a large notch in the east 'wing' reflector, with cable spool linkage at the east reflector and spring at the west reflector. They designed and fabricated a working model and reported that the gear motor and gear ratio changes with different 'wing' reflector sizes [90] (Figure 15e and g).

After the Spring 2016 'wings' tracker project the author wanted to compare a design with a direct drive actuator without cable-spool and spring linkage, and custom counterweighted gear-ratio sensor design. The 2016 tracker student final report was reviewed by Helmholz and he suggested to replace the PV with small sensors and develop electronics for an east 'wing' actuator with remote PV-battery power.

FIGURE 15. BIETR(BITNR) undergrad student mechanical and structural engineering semester projects at the U. of Wisconsin-Platteville from 2005 to 2019.

BIETR III (BITNR) tracking 'wings' 2017 project objective was to design a low cost controller and linear actuator for a test stand with 508mm/20inch and 914mm/36" EAL inclined receiver-tubes. The students used small sensors and refined the counterweighted gear-assemble with 3d printing, designed a small electronic controller Arduino circuit board, and selected a DC motor linear actuator for a remote PV-battery system. The students fabricated a full-size working tracking 'wing' system, reduced the size and refined the Helmholz invention with log-scale analog photo-sensors and wrote a program for a PV powered microcontroller to drive a linear actuator [91] (Figure 15h-j).

This sequence of a 'wings' tracker development for BITNR/BIETR buildings with EW-line big CPC troughs and string-cable linkage above inclined target-rectangles appeared to be proof-of-concept and a start for product development.

BIETR (BITNR) 2017 nonimaging reflectors assessment project had a PV flat-plate target-rectangle at the outlet of an ordinary CPC plus 'wings' to measure the light intensity distribution on the PV for extrapolation to target-rectangles of evacuated tubes and involutes. A scaled mockup model was fabricated and individual PV cells were wired to a data acquisition module to read voltages at each PV cell. Testing results indicated that the light intensity distribution was not uniform with noticeable light and dark bands [92] (Figure 15b).

BIETR-AIR six tubes test-stand assessment 2018 project objectives included: evaluate performance by testing and simulations of an air fluid loop with 150degC/302degF output with and without inserts for 6–12 tube systems; estimate output BTUs per/year and per each month; fabricate a six tube wood test-stand; and compare simple payback to propane and natural gas prices with inflation rates. Layout test-stand equipment in a small marketed greenhouse. Assume 20% loss by greenhouse glass transmittance and frame.

The students continued with the 25.4mm/inch diameter in-out air duct tubes limited by the silicone cap size. The evacuated tubes (Rand Solar solar oven) were about 5.12"/130mm OD x 20.62"/525mm EAL, about 66mm/2.6" longer than old tubes from Rand Solar. The 1inch diameter duct-tube length was reduced with a long horizontal center metal fin insert separating entering lower cooler air and exiting upper warmer air. A one tube simulation with the horizontal fin insert with the tube glass inner wall set at 150C deg. had a 34C/93F deg. temperature increase. A six tube test stand wood rack was fabricated and tested with only three tubes because additional tubes were not available. A variable speed blower, controller, and data logger, with an Arduino unit, powered by a PV panel was designed and fabricated [93] (Figure 15 k-l).

BITNR-Air two-tube (not evacuated) test stand project 2019 for IPH and commercial applications e.g. greenhouse refrigeration (absorption) during warm season and cold season heating is to be designed for local manufacturing and repair. Objectives were: design, test and evaluate a two-tube involutes test-stand with inserts (twisted tapes, etc.) for EW horizontal tubes in a target-rectangle; specify receiver-tubes, involute reflectors, and aluminum rack system; tubes have identical air flow with data logger instrumented to record solar radiation at each temperature measurement. Test inserts for improved heat removal, and test identical absorber tubes with and without a glass tube cover.

This BITNR-Air semester project was combined with analysis of a geothermal heat pump system for a Dairy Innovation Hub. The design and fabrication of a two tubes (each 5ft/1524mm long) with involutes test stand had: a wood frame; involutes with 19 degree half-angle and 14.75inch/375mm inlet width; 1.5inch/38mm OD aluminum tubes painted with Solkote TM; 2.2inch/56mm OD, .07inch/2mm glass wall tubes; twisted metal tape inserts;

and one small bathroom fan. A test without glass tubes, with twisted tape inserts compared to no turbulator resulted in 8.9% increase rate of heat transfer. The flow rate without turbulator was 28% higher than with a turbulator. Another test with glass tube compared to no glass tube resulted in a 32.3% increase of heat removal with the glass tube [83].

Observations after this project were: receiver-tube lengths of 8ft/2438mm could coordinate with two standard reflector4ft/1219mm EW lengths of big CPC reflector panels however glass tubes 1500mm/59inch are a standard length. About 12inch/304mm (involute height) x 5ft/1524mm (multiple involute widths) x10ft/3048mm aluminum involute racks could pass thru stairways and doors.

6.2 BIETR/BITNR Structures Student Engineering Projects at UWP

BIETR small test building (STB) structures 2016 project objectives included: design a STB for southern Wisconsin with minimum shading and identical flat glass lites 4-sided supported without intermediate EW glazing bars, with slim wood or metal rafters secured to a wood building frame rough opening. Size glazing elements for: extreme loadings (wind, hail, etc.), deflection, and weather trends. The STB glazing frame EW length is about 22–26ft with E&W hips covering a nonpublic walk-in solar thermal collector un-insulated space. The STB is for testing NS inclined receiver-tubes (less than 1m/3ft long) with a big CPC inlet Wi (less than 1676mm/66"). The inclination angle (about 45deg. from horizontal) is the same for: the NS inclined tubes and involute, glazing frame, 'wings' hinge line, and E&W wall sills. Compare shading losses and frame costs for steel (mild and reflective stainless), aluminum and wood frames from local workshops; and suggest campus STB locations. The student design included a unique EW-line wood truss with NS extensions to support an EW-line two-2"x6" wood header for the glass hips configuration. The big CPC reflector panels hang from the top header. The 2"x6" wood stud south, east and west vertical walls have several custom angle cuts and heights to fit with the hip glazing plan. STB total cost estimate was $12,700 [98] (Figure 15m).

BIETR test facility building 2018 project objective was structural design of a 7.3m/24ft x 18.3m/60ft building plan for testing long receiver-tubes systems (e.g. 2m/6.7ft tubes) augmented with big EW-Line CPC trough and tracking 'wings' options for a campus rural site. Steel and wood structures were compared for supporting glass lites 6.3mm/¼"x 1.5m/5ft x 1.8m/6ft inclined 35 degrees from horizontal with 115mph wind loading. A bolted and welded steel frame on a 152mm/6" reinforced concrete slab, with glass lites was estimated at $145,257. Wisconsin snow loading was a significant factor in sizing the steel [99] (Figure 15n).

BIETR-Air two-car detached garage 2019 project objective was design of a wood structure with rock bin storage. The collector loft roof structure design had wood N-S trusses integrating wood glazing rafters as part of the trusses for supporting flat glass. Glass lites 4ftx7ft x¼" were supported on 1.5" nominal 2"x6" wood rafter parts of N-S trusses. The E&W glass lites were vertical. This was a new framing idea, different than the EW-line truss in the 2016 student project with E&W hip glazing [98]. The construction tolerances and demands on carpenters and wood selection necessary for the installation of the glass lites and durability are a concern that the design may be too exacting for local builders. A pebble-rock insulated storage [109] in the garage was on a 12" concrete slab, thicker than the 6" parking floor [100] (Figure 15o).

6.3 Proposed BITNR Student Engineering Projects

BITNR projects currently being offered to mechanical and structural engineering professors are outlined. Mechanical engineering projects are: BITNR nonimaging reflectors evaluation table top model project; and BITNR-Air four tube test stand projects, one with evacuated tubes and another with non-evacuated tubes. Proposed Structures Projects are: BITNR two-car detached garage with solid polycarbonate vault glazing; and BITNR four-row inclined collector over a multipurpose space.

6.3.1 Proposed Mechanical Engineering Student Projects

The BITNR nonimaging reflectors evaluation project includes construction of a table-top size model to evaluate EW-line CPC trough and 'wings' options with a target-rectangle of small PV cells individually wired to a data logger to fit in a greenhouse. The PV cells target-rectangle represents receiver tubes and matching involutes. Outline a BITNR extended testing project proposal (around 2 years) with descriptions of tests to be performed.

BITNR-AIR four *evacuated tubes* test-stand assessment project is to evaluate performance and cost with a four small all-glass evacuated tubes and involutes with inserts test-stand with a variable speed blower. Based on the four tube test-stand data calculate output for a 16 tubes/involutes array with selected fixed inclination all year and a big CPC and 'wings' in a greenhouse. Estimate output BTUs per year and for each month. Design and fabricate: inserts (e.g. twisted tapes), silicone gaskets, and insulated duct-manifold for the air fluid loop with blower, PV-battery power source, controller and data logger. This project includes fluids analysis and prototype fabrication of gaskets and insulated manifold-duct parts [83, 91, 73].

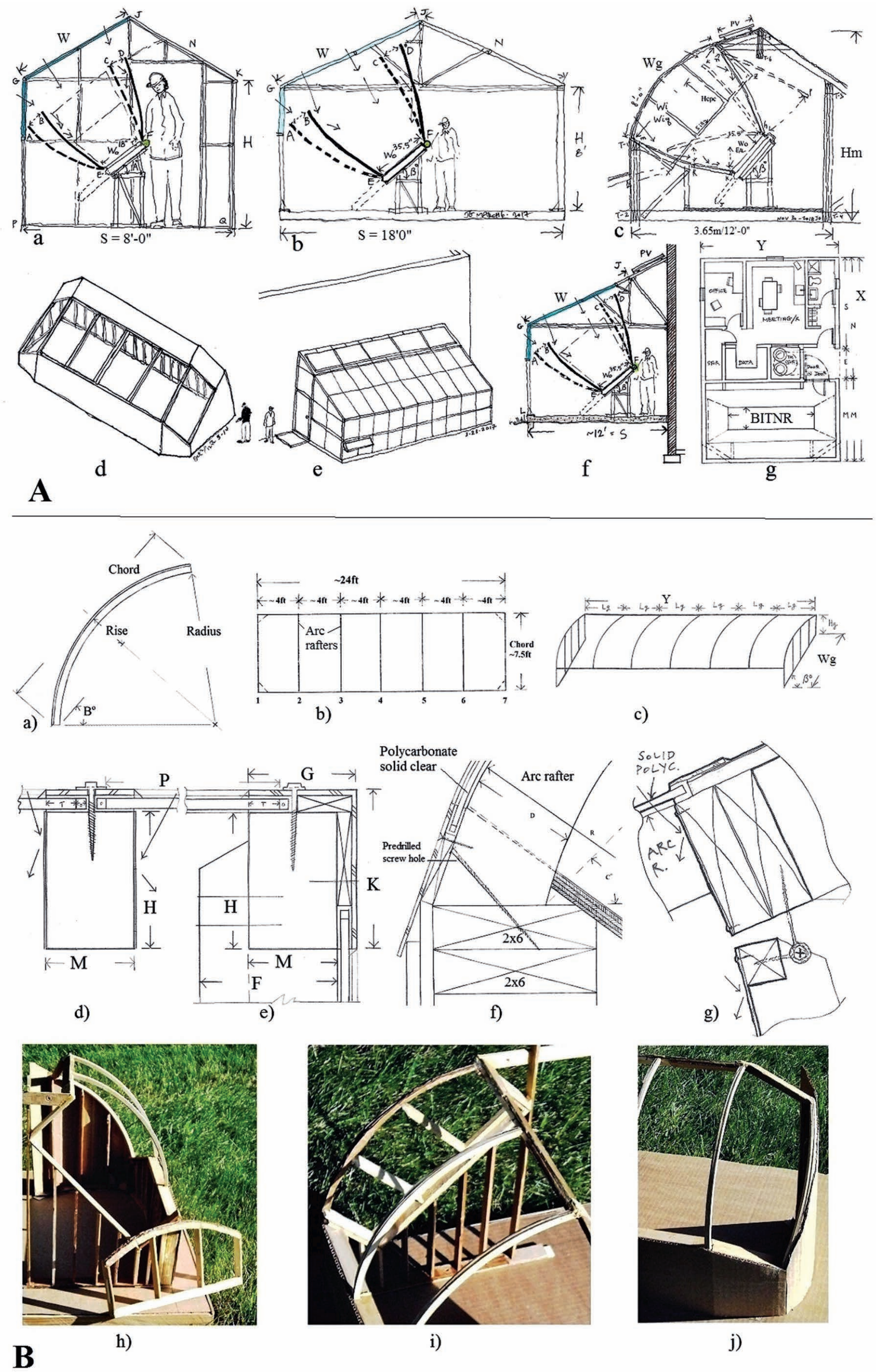
BITNR-Air four *non-evacuated* tubes test-stand project objectives are: evaluate performance and cost for selected tubes and tube inserts and inter-tube ducting by calculations, simulations and testing with a four tube and involutes wood case test-stand for enhanced heat removal, and estimate cost savings for a campus swimming pool heating system. Design and fabricate a four tubes/involutes test-stand with series air circuit flow. Record measurements: in sunlight (W/m2), for air temperature in and out of each tube and air flow rate. Based on the four tube module test stand data calculate temperature in and out and BTUs/month and a typical year for a four module collector (16 tubes) target-rectangle with a big CPC and ''wings' in a greenhouse or with 20% loss thru the glazing-frame, and estimate the total cost. Aims include: 300F/150C degrees for double-effect refrigeration; and do-it-yourself economy [83].

6.3.2 Proposed Structures Student Projects

BITNR-Air two-car detached garage with solid polycarbonate vault glazing project objective is to design a two-car garage with a collector loft covered by solid polycarbonate vault glazing, south side garage door, rock-pebble storage, utility room with hot water tank, and workshop at the north side. Wood arc rafters support glazing sheets (4x8ft x selected thickness) with E&W flat vertical or hip-sloped (gore-shape) windows. Gore-shape hip windows would be above curved walls. Report a comparative study of the E&W glazing options, and select one option for design development. Consider placement/replacement of the BITNR-air collector system (which will be given) and rock-pebble storage tank. The rural site for this demonstration building is near your campus. Polycarbonate solid glazing is of interest because of hail damage trends (Figure 16).

The BITNR-Air four-row inclined collector over a multipurpose space project for a three level apartment building near campus has a steel frame, also intended for other building types. Solar collector dimensions will be given. The main structural elements are: four NS-inclined (around 45 deg.) open-web steel girders (with square/rectangular member sections

FIGURE 16. BITNR testing-verification facilities and small demonstration building studies.



for applying reflector material), four vertical columns independent of adjacent building structure, EW-line top 3d open-web trusses and bottom 2d trusses (Vierendeel for cleaning maintenance and aesthetics) that support wood platforms for collectors and access with waterproof membrane and drainage. The E&W girders support exterior stairways and PV. Lightweight big CPC reflector panels hang from the top 3d open-web truss which is also a daylighting aperture [99, 7] (Figure 10a-f).

7. BITNR R&D PROJECT PROPOSAL OUTLINE

A BITNR R&D proposed project outline is presented [6, 22, 102]. BITNR/BIETR studies and publications [3, 4, 5, 6, 7] have continued privately, with participation by undergrad engineering students and professors at the U. of Wisconsin-Platteville. Project proposal development has included contact with researchers for computer simulation modeling e.g. the AIT offer [102]. At present proposed BITNR R&D project parts are being offered to university engineering programs.

BITNR R&D proposed tasks along multiple paths require extended commitment of researchers, funding, and testing in a greenhouse which is considered a priority. A Phase-1 goal is to prepare for Phase-2 testing for at least one year of a selected BITNR instrumented system in a greenhouse. The SPS 'wings' tracker developed with student projects is considered ready for prototype design, fabrication and extended testing [91]. A greenhouse with generous space around test stands for testing different size reflectors avoids the design complication of fitting a selected BITNR system with a building-structure. Demonstration building design would be in a later phase. A small greenhouse may be reused for other purposes after BITNR testing.

A BITNR R&D proposed multiyear project summary includes PHASE-1: Literature search, Nonimaging Reflectors Evaluation, Receiver tubes review, Select target rectangles, Testing in a greenhouse preparation, and Simulations (performance and economics); and PHASE-2: Testing in a greenhouse (at least one year), Simulations (con't), building applications studies, and Verification facility design.

PHASE-1 BITNR R&D Proposed Project Tasks:

PHASE-1 TASK: Literature search

PHASE-1 TASK: BITNR nonimaging reflectors evaluation

Table top instrumented model assessing CPC and 'wings' reflectors augmentation on selected target rectangles. Select target rectangles and reflectors for simulations.

PHASE-1 TASK: Receiver tube systems review

PHASE-1 TASK: Involute (rounded W) reflector fixed trough characterization

PHASE-1 TASK: 'Wings' characterization and tracker development

Prototype preparation for extended testing in a greenhouse.

PHASE-1 TASK: BITNR testing greenhouse preparation

Prepare for BITNR instrumented system testing in a greenhouse for at least one year in Phase-2. Develop tests stands for estimating

PHASE-1 TASK: BITNR simulations

Begin simulation development for performance and economics for selected TMY data, and front-end design aid for architects. A reference is the F-chart program by Klein and Beckman (U of Wisconsin-Madison).

PHASE-2 BITNR R&D Proposed Project Tasks:

PHASE 2 TASK: BITNR testing in a greenhouse for at least one year

PHASE-2 TASK: BITNR simulations continued

PHASE-2 TASK: Survey for case study applications

PHASE-2 TASK: BITNR building-type application studies

PHASE-2 TASK: BITNR small demonstration building (SDB) design

8. COMMENTS

The main nonimaging interior reflectors in the BITNR (previously titled BIETR) architectural studies are: involute troughs (rounded W for each receiver-tube); large CPC troughs; and E&W relaxed tracking 'wings', all within a glazed glass or solid polycarbonate collector space. Interior reflectors augment target-rectangles containing receiver-tubes (evacuated or non-evacuated) and involutes with air or water-steam systems. BITNR feasibility studies including: towers, concourses, long-span atriums, double-loaded corridor buildings, residential buildings, and two-car garages indicate that nonimaging building-size reflectors augmenting receiver-tube collector systems are main organizing factors for building design and site planning. BITNR buildings with compact heat distribution are for sites where land is costly or not available for ground mounted mid-temperature collectors. Selected BIETR/BITNR U. of Wisconsin-Platteville undergrad student mechanical and structural engineering completed projects are reviewed e.g. development of a 'wings' tracker based on a Helmholz invention, and proposed BITNR student engineering projects are presented. Proposed BITNR R&D project tasks are outlined requiring commitments with a priority for extended testing in a greenhouse.

Durable buildings and infrastructure can last 50–100+years, when it is unlikely that natural gas will be viable. Substantial changes in the building sector are needed for this eventuality, when the economy may be stressed and massive rebuilding would be more difficult. It is unrealistic, in most all cases, for existing durable buildings with large mid-temperature heat demands to be substantially remodeled with reasonable budgets to supply mid-temperature heat demands with solar energy. Changing building structured form and site plans designed for fossil fuels to be remodeled with solar mid-temperature collectors and storage is expensive if feasible. By chance, a few buildings may be retrofitted, and a few solar thermal collectors can usually be placed here and there with high cost and structural duplication, but this is not enough to accomplish climate goals. Solar thermal-mid temperature collectors and storage would need to be a priority for building committees and part of programming, site selection, and conceptual design, spelled-out in contracts with architects and engineers. Research funding is needed to include conceptual design architects and engineers versed in solar thermal collector and storage technologies in education programs. The BITNR (BIETR) research project 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 [8]. The U. of California-Merced Solar Energy Group has expressed interest to computer-model simulations for the BITNR configuration [111].

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