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TRNSYS models of Evacuated Tubular Collectors

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Contents

1 Introduction

This document shortly summarizes the inputs, outputs and parameters for four TRNSYS [1] models developed within the project “Sustainable Arctic Building Technology for the 21st century - Evacuated Tubular Collectors”.

The TRNSYS models describe:

- All-glass evacuated tubular collectors (TRNSYS Type 232)
- Heat pipe evacuated tubular collectors with curved fins (TRNSYS Type 238)
- Heat pipe evacuated tubular collectors with flat fins (TRNSYS Type 239)
- Collector row shadows and reduction of view factors (TRNSYS Type 240)

The theory behind the TRNSYS is more detailed described in [2], [3], [4], [5], [6], [7] and [8].

2 TRNSYS TYPE 232: All-glass evacuated tubular collectors

2.1 Description

The collector is based on a number of parallel-connected double glass tubes, which are open in both ends. The tubes are closed end annuluses and the outside of the inner glass wall is treated with an absorbing selective coating.

The collector fluid is floating from bottom to top inside the inner tube where also another closed tube is inserted with the purpose to fill out a part of the tube volume so that less collector fluid is needed. Further, it ensures a high heat transfer coefficient from the inner glass tube to the collector fluid.

Fig. 1 shows the design of the evacuated tubes and the principle of the tube connection.

For the theoretical investigation of this collector principle, traditional collector theory cannot directly be applied, as the absorbers are tubular. Therefore, to theoretically determine the collector performance, following must be taken into account:

- Solar radiation from all directions can be utilized (also from the "back" of the collector).
- Shadow effects from adjacent tubes.

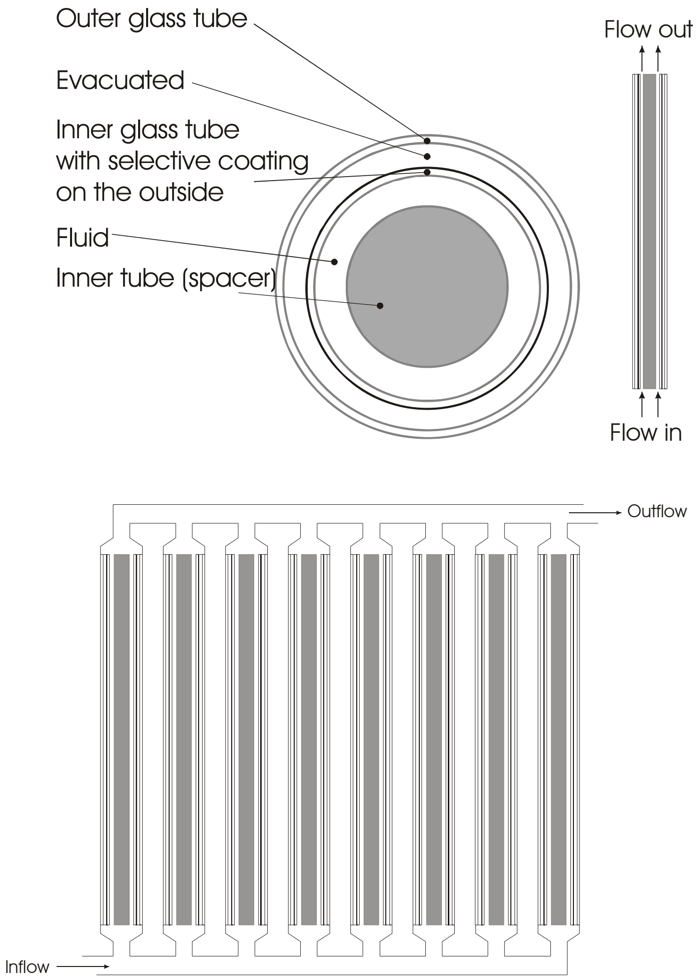


Fig. 1: Design of the evacuated tubes (top) and the tubes connected to a solar panel (bottom).

In this model, a collector theory for the collector performance is implemented. Flat plate collector performance equations are integrated over the absorber circumference and the model determines the shades on the tubes as a function of the solar azimuth.

The following sections describe the necessary parameters, inputs and outputs for the model.

2.2 Parameters

No.	Parameter	Description
1	no	Number of tubes (-)
2	rc	Glass tube radius (m)
3	rp	Absorber tube radius (m)
4	c	Tube centre distance (m)
5	beta_s	Collector panel tilt (°)
6	F_Az	Collector panel azimuth (-)
7	Kdiff	Incidence angle modifier for the diffuse radiation (typical 0.9) (-)
8	eta_0	Start efficiency (-)
9	k_0	Heat loss coefficient (W/(m2*K))
10	k_1	Temperature dif. dependence of the heat loss coefficient (W/(m2*K2))
11	U_mani	Heat loss from manifold tube (W/mK)
12	p	Angle dependence of the tau-alpha product (typical 3-4) (-)
13	Cp	Heat capacitance of the fluid (kJ/kgK)
14	Ceff	Effective heat capacity of the collector including the fluid (kJ/K)
15	L	Pipe length (m)
16	Day1	Day of year when simulation starts (-)
17	SHFT	Shift in solar time hour angle (°)
18	lat	Latitude (°)

2.3 Inputs

No.	Input	Description
1	Tin	Fluid inlet temperature(C)
2	Mfl	Fluid mass flow rate(kg/h)
3	Tamb	Ambient temperature(C)
4	IGlob	Global irradiation on a horizontal surface(kJ/hm2)
5	IDif	Diffuse irradiation on a horizontal surface(kJ/hm2)
6	Albedo	Ground reflection coefficient(-)
7	Theta_p	Angle of incidence of beam radiation on collector plane(degrees)
8	Zenith	Solar zenith(degrees)
9	Az	Solar azimuth(degrees)
10	Fsha_col	Not used (-)
11	Ashadow	Not used (-)

2.4 Outputs

No.	Output	Description
1	Tout	Fluid outlet temperature (°C)
2	XIN(2)	Fluid inlet temperature (°C)
3	Qout	Energy production from collector panel (kJ/h)
4	Angle1	Start angle with incidence of beam radiation (°)
5	Angle2	Stop angle with incidence of beam radiation (°)
6	Az	Solar azimuth (°)
7	q_angle	Strip angle with incidence of beam radiation (°)
8	qb	Absorbed beam radiation on absorber (kJ/h/(m^2))
9	qr	Absorbed ground reflected radiation on absorber (kJ/h/(m^2))
10	qd	Absorbed diffuse (from sky) radiation on absorber (kJ/h/(m^2))
11	qloss	Heat loss from collector tubes (kJ/h)
12	qmani	Heat loss from manifold heat exchanger (kJ/h)

3 TRNSYS TYPE 238: Heat pipe evacuated tubular collectors with curved fins

3.1 Description

This model describes a heat pipe evacuated tubular collector. The absorber fins in the evacuated tubes are curved and the fins have selective coating on both sides. This means that solar radiation from all directions can be utilized.

An illustration of the evacuated tubes is given in Fig. 2. The tubes are connected to a heat exchanger manifold pipe where condensers for all tubes are placed.

The TRNSYS model takes solar radiation from all directions into account.

Due to the curved fin, the irradiance varies along the fin as the incidence angle varies along the fin. Further, due to the cylindrical tubes, depending on the position of the sun and the distance between the tubes, the tubes will be able to cast shadow on each other as illustrated in Fig. 3 and the solar irradiance can vary along the fin.

With this variation in the solar irradiances along the fins, the traditional fin efficiency cannot be applied. Therefore, the heat transfer processes in the fin are solved in detail.

This model works together with TRNSYS Type 240.

The following sections describe the necessary parameters, inputs and outputs for the model.

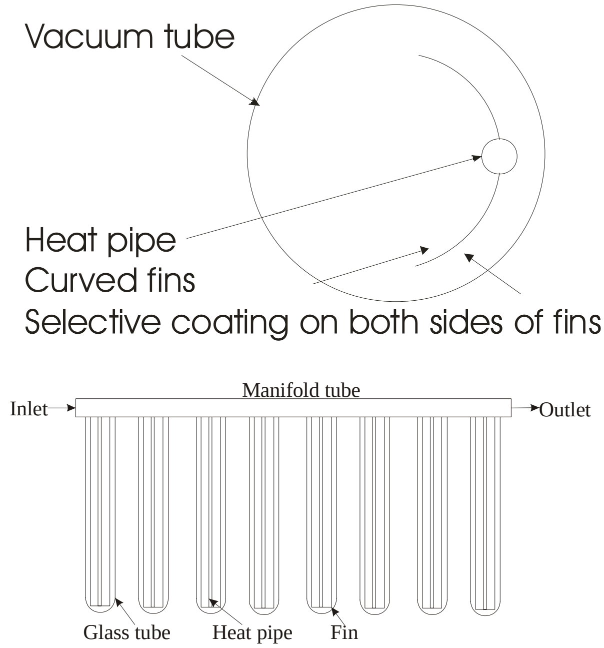


Fig. 2: The investigated evacuated tubular heat pipes.

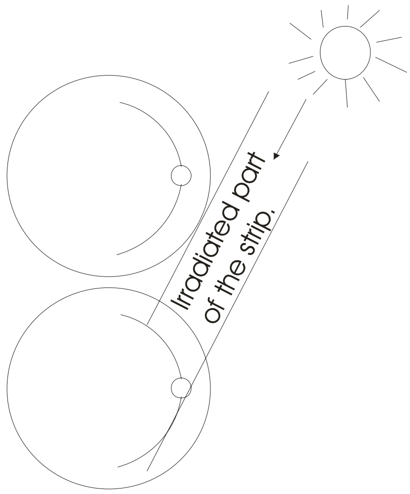


Fig. 3: The irradiated part of the fin for a given position of the sun.

3.2 Parameters

No.	Parameter	Description
1	no	Number of tubes (-)
2	rc	Glass tube radius (m)
3	rp	Absorber tube radius (m)
4	c	Tube centre distance (m)
5	beta_s	Collector panel tilt (°)
6	F_Az	Collector panel azimuth (-)
7	Kdiff	Incidence angle modifier for the diffuse radiation (typical 0.9) (-)
8	taualpha	Effective transmittance - absorptance product (-)
9	k_0	Heat loss coefficient (W/(m2*K))
10	diskr	No of discretizations (-)
11	U_mani	Heat loss from manifold tube (W/mK)
12	p	Angle dependence of the tau-alpha product (typical. 3-4) (-)
13	Cp	Heat capacitance of the fluid in the manifold tube (kJ/kgK)
14	Ceff	Effective heat capacity of the collector including the fluid (kJ/K)
15	l	Heat Pipe length(m)
16	Day1	Iteration stop criterion (must be smaller than 0.00001) (K)
17	SHFT	Shift in solar time hour angle (°)
18	lat	Latitude (°)
19	stripang	Angle of strip (°)
20	lambda	Conductivity of strip material (W/mK)
21	delta	Thickness of strip (m)
22	rhostrip	Density of strip (kg/m3)
23	Cpstrip	Heat capacity of strip (kJ/kgK)
24	TevapLow	Lowest evaporation temperature (°C)
25	UAmani	Manifold heat exchange rate (W/K)
26	MassFluid	Mass of the fluid inside the heat pipe (kg)
27	CpFluid	Mass of the fluid inside the heat pipe (kg)

3.3 Inputs

No.	Input	Description
1	Tin	Fluid inlet temperature (°C)
2	Mfl	Fluid mass flow rate (kg/h)
3	Tamb	Ambient temperature (°C)
4	IGlob	Global irradiation on a horizontal surface (kJ/hm2)
5	IDif	Diffuse irradiation on a horizontal surface (kJ/hm2)
6	Albedo	Ground reflection coefficient (-)
7	Theta_p	Angle of incidence of beam radiation on collector plane (degrees)
8	Zenith	Solar zenith (degrees)
9	Az	Solar azimuth (degrees)
10	red_Shade	Part of tube shaded by neighbour row [from type 240] (-)
11	Fc_sol_front	View factor from the collector front plane to the solar on the ground [from type 240] (-)
12	Fc_sol_back	View factor from the collector back plane the solar on the ground [from type 240] (-)
13	Fground_sky	View factor from the ground between two rows to the sky [from type 240] (-)
14	red_c_s_front	Reduction of view factor Col-sky-front due to rows [from type 240] (-)
15	red_c_g_front	Reduction of view factor Col-ground-front due to rows [from type 240] (-)
16	red_c_s_back	Reduction of view factor Col-sky-back due to rows [from type 240] (-)
17	red_c_g_back	Reduction of view factor Col-ground-back due to rows [from type 240] (-)

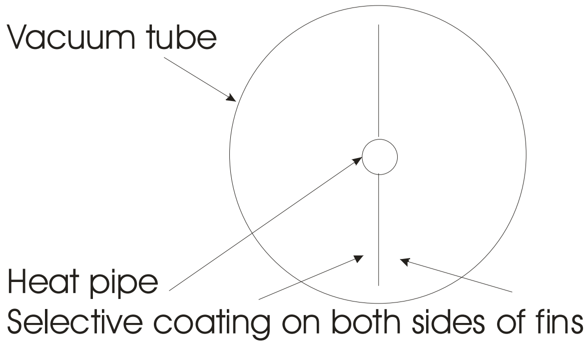
3.4 Outputs

No.	Output	Description
1	Tout	Fluid outlet temperature (°C)
2	XIN(2)	Fluid inlet temperature (°C)
3	Qout	Energy production from collector panel (kJ/h)
4	xPbfront	Absorbed beam radiation on absorber front side (kJ/h/(m²))
5	xPbBack	Absorbed beam radiation on absorber back side (kJ/h/(m²))
6	Az	Solar azimuth (°)
7	q_angle	Strip angle with incidence of beam radiation (°)
8	xPdiffront	Absorbed diffuse radiation on absorber front side (kJ/h/(m²))
9	xPdifback	Absorbed diffuse radiation on absorber back side (kJ/h/(m²))
10	Qmanifold	Energy from 1 tube delivered to manifold heat exchanger (kJ/h)
11	Tfluid	Average temperature in manifold heat exchanger (°C)
12	qmani	Heat loss from manifold heat exchanger (kJ/h)
13		

4 TRNSYS TYPE 239: Heat pipe evacuated tubular collectors with flat fins

4.1 Description

This model describes a heat pipe evacuated tubular collector. The absorber fins in the evacuated tubes are flat and the fins have selective coating on both sides. This means that solar radiation from all directions can be utilized.



An illustration of the evacuated tubes is given in Fig. 2. The tubes are connected to a heat exchanger manifold pipe where condensers for all tubes are placed.

The TRNSYS model takes solar radiation from all directions into account.

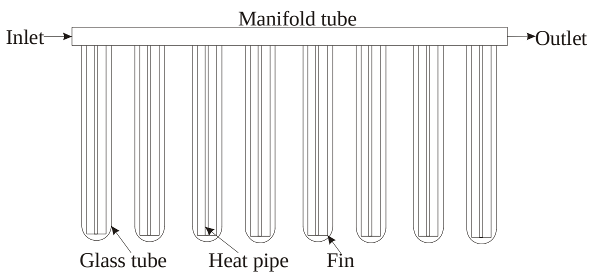


Fig. 4: The investigated evacuated tubular heat pipes.

Due to the cylindrical tubes, depending on the position of the sun and the distance between the tubes, the tubes will be able to cast shadow on each other as illustrated in Fig. 3 and the solar irradiance can vary along the fin.

This variation in the solar irradiances along the fins means that the traditional fin efficiency cannot be applied.

Therefore, the heat transfer processes in the fin are solved in detail.

This model works together with TRNSYS Type 240. The following sections describe the necessary parameters, inputs and outputs for the model.

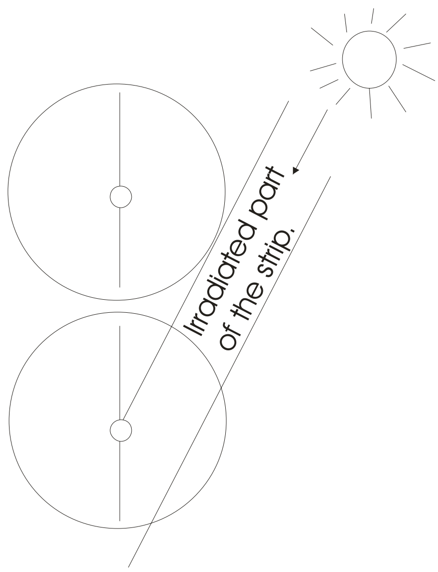


Fig. 5: The irradiated part of the fin for a given position of the sun.

4.2 Parameters

No.	Parameter	Description
1	no	Number of tubes (-)
2	rc	Glass tube radius (m)
3	rp	Absorber tube radius (m)
4	c	Tube centre distance (m)
5	beta_s	Collector panel tilt (°)
6	F_Az	Collector panel azimuth (-)
7	Kdiff	Incidence angle modifier for the diffuse radiation (typical 0.9) (-)
8	taualpha	Effective transmittance - absorptance product (-)
9	k_0	Heat loss coefficient (W/(m2*K))
10	diskr	No of discretizations (-)
11	U_mani	Heat loss from manifold tube (W/mK)
12	p	Angle dependence of the tau-alpha product (typical. 3-4) (-)
13	Cp	Heat capacitance of the fluid in the manifold tube (kJ/kgK)
14	Ceff	Effective heat capacity of the collector including the fluid (kJ/K)
15	l	Heat Pipe length(m)
16	Day1	Iteration stop criterion (must be smaller than 0.00001) (K)
17	SHFT	Shift in solar time hour angle (°)
18	lat	Latitude (°)
19	w	Fin width – both sides of fin (m)
20	lambda	Conductivity of strip material (W/mK)
21	delta	Thickness of strip (m)
22	rhostrip	Density of strip (kg/m3)
23	Cpstrip	Heat capacity of strip (kJ/kgK)
24	TevapLow	Lowest evaporation temperature (°C)
25	UAmani	Manifold heat exchange rate (W/K)
26	MassFluid	Mass of the fluid inside the heat pipe (kg)
27	CpFluid	Mass of the fluid inside the heat pipe (kg)

4.3 Inputs

No.	Input	Description
1	Tin	Fluid inlet temperature (°C)
2	Mfl	Fluid mass flow rate (kg/h)
3	Tamb	Ambient temperature (°C)
4	IGlob	Global irradiation on a horizontal surface (kJ/hm2)
5	IDif	Diffuse irradiation on a horizontal surface (kJ/hm2)
6	Albedo	Ground reflection coefficient (-)
7	Theta_p	Angle of incidence of beam radiation on collector plane (degrees)
8	Zenith	Solar zenith (degrees)
9	Az	Solar azimuth (degrees)
10	red_Shade	Part of tube shaded by neighbour row [from type 240] (-)
11	Fc_sol_front	View factor from the collector front plane to the solar on the ground [from type 240] (-)
12	Fc_sol_back	View factor from the collector back plane the solar on the ground [from type 240] (-)
13	Fground_sky	View factor from the ground between two rows to the sky [from type 240] (-)
14	red_c_s_front	Reduction of view factor Col-sky-front due to rows [from type 240] (-)
15	red_c_g_front	Reduction of view factor Col-ground-front due to rows [from type 240] (-)
16	red_c_s_back	Reduction of view factor Col-sky-back due to rows [from type 240] (-)
17	red_c_g_back	Reduction of view factor Col-ground-back due to rows [from type 240] (-)

4.4 Outputs

No.	Output	Description
1	Tout	Fluid outlet temperature (°C)
2	XIN(2)	Fluid inlet temperature (°C)
3	Qout	Energy production from collector panel (kJ/h)
4	xPbfront	Absorbed beam radiation on absorber front side (kJ/h/(m^2))
5	xPbBack	Absorbed beam radiation on absorber back side (kJ/h/(m^2))
6	Thetafront	Incidence angle on absorber front side (°)
7	q_angle	Not used (-)
8	xPdiffront	Absorbed diffuse radiation on absorber front side (kJ/h/(m^2))
9	xPdifback	Absorbed diffuse radiation on absorber back side (kJ/h/(m^2))
10	Qmanifold	Energy from 1 tube delivered to manifold heat exchanger (kJ/h)
11	Tfluid	Average temperature in manifold heat exchanger (°C)
12	qmani	Heat loss from manifold heat exchanger (kJ/h)

5 TRNSYS TYPE 240: Collector row shadows and reduction of view factors

5.1 Description

The purpose of the collector row model is to get information of the influence of the distance between collector rows on the thermal performance. The model calculates in detail:

- <u>Shadows on the ground caused by the collector rows:</u> The shadows on the ground depend on the length, azimuth and tilt, of the collector, and on the solar zenith and solar azimuth. The aim is to find the position of the solar part on the ground (= ground area irradiated with direct solar radiation) and thus to find the view factor to the solar part on the ground from the collector front side and back side (see Fig. 6). These view factors are important in order to correctly calculate the ground reflected direct solar radiation.
- <u>Shadows on the collectors caused by the collector rows:</u> Determination of these shadows is important in order to correctly calculate the direct solar radiation on the collectors (see Fig. 6).
- <u>Reduction of view factors from collector to ground and sky due to the collector rows:</u> The view factors to the ground and to the sky from the collector will be reduced due to the collector rows, compared to if there were no neighbour rows. Therefore, reduction factors for the view factors are important in order to correctly calculate the ground reflected direct solar radiation.
- <u>Reduction of view factors from ground to sky due to the collector rows:</u> The view factor from ground to sky will also be reduced due to the collector rows, and this will influence the diffuse radiation on horizontal.

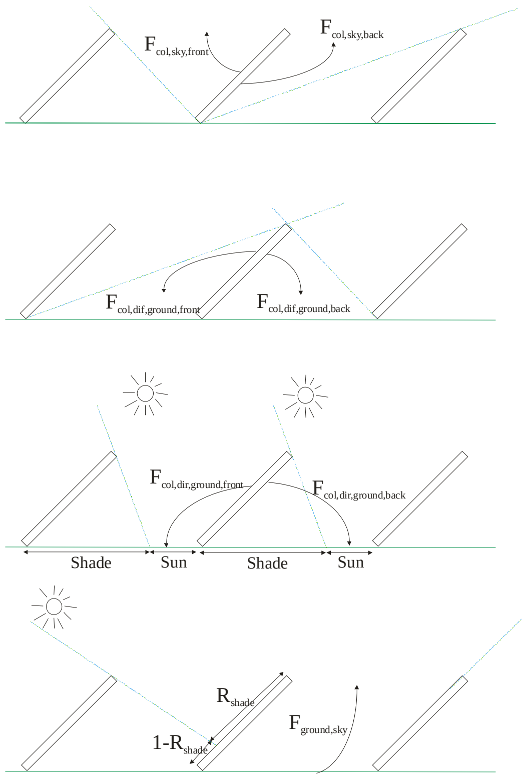


Fig. 6: An illustration, based on three collector rows, of the view factors calculated in the model.

This model works together with TRNSYS Type 238 and Type 239. The following sections describe the necessary parameters, inputs and outputs for the model.

5.2 Parameters

No.	Parameters	Description
1	tilt	Collector row tilt (°)
2	F_az	Collector row azimuth (°)
3	L	Tube length (m)
4	dist	Distance between collector rows (m)

5.3 Inputs

No.	Input	Description
1	Zenith	Solar zenith (°)
2	Az	Solar Azimuth (°)

5.4 Outputs

No.	Output	Description
1	red_Shade	Part of tube shaded by neighbour row (-)
2	Fc_sol_front	View factor from the collector front plane to the solar on the ground (-)
3	Fc_sol_back	View factor from the call-back plane the solar on the ground (-)
4	Fground_sky	View factor from the ground between two rows to the sky (-)
5	red_c_s_front	Reduction of view factor Col-sky-front due to rows (-)
6	red_c_g_front	Reduction of view factor Col-ground-front due to rows (-)
7	red_c_s_back	Reduction of view factor Col-sky-back due to rows (-)
8	red_c_g_back	Reduction of view factor Col-ground-back due to rows (-)

6 References

[1]	Klein, S.A. et al. (1996)	*TRNSYS 14.2, User Manual.* University of Wisconsin Solar Energy Laboratory.
[2]	Shah L.J., Furbo S., Antvorskov S. (2003)	*Thermal Performance of Evacuated Tubular Collectors Utilizing Solar Radiation from All Directions.* In Proceedings of the ISES Solar World Congress, Gothenburg, Sweden, June 14-19, 2003.
[3]	Shah, L.J. & Furbo, S. (2004)	*Vertical evacuated tubular collectors utilizing solar radiation from all directions.* Applied Energy, Vol. 78/4 pp 371-395, 2004
[4]	Shah L.J. & Furbo S. (2004)	*New TRNSYS model of Evacuated Tubular Collector with Cylindrical Absorber.* Proceedings, EuroSun2004, Freiburg, Germany, Vol. 1, pp. 355-364. ISBN. 3-9809656-1-9.
[5]	Shah, L.J. & Furbo, S. (2005)	*Modelling Shadows on Evacuated Tubular Collectors with Cylindrical Absorbers.* Journal of Solar Energy Engineering, Transactions of the ASME. **In press.**
[6]	Shah L.J. (2005)	*Evacuated Tubular Collectors.* Proceedings, Energy-Efficient Building, Vol. 1, pp.87-102. Symposium in Sisimiut, Greenland, April 12-14 2005
[7]	Shah, L.J. & Furbo, S. (2005)	*Utilization of Solar Radiation at High Latitudes with Evacuated Tubular Collectors.* In Proceedings of the North Sun 2005 Congress, Vilnius, Lithuania, May 25-27, 2005. **In press.**
[8]	Shah, L.J. & Furbo, S. (2005)	*Theoretical Investigations of Differently Designed Heat Pipe Evacuated Tubular Collectors.* In Proceedings of the ISES Solar World Congress, Gothenburg, Orlando, Florida USA, August 7-12, 2005. **In press.**

7 Acknowledgement

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