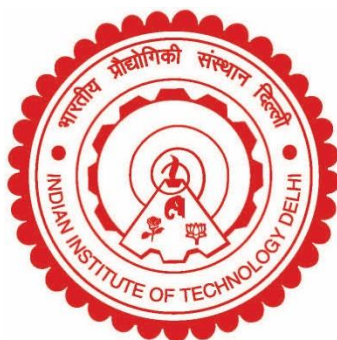


STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS

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STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS

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CERTIFICATE

This is to certify that the thesis entitled “**STUDIES ON THERMAL PERFORMANCE EVALUATION OF BOX TYPE SOLAR COOKERS**” being submitted by Mr. Alok Singh to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy** is a record of bonafide research work carried out by him. He has worked under our supervision and his thesis has attained a standard required for a Ph.D. degree of this Institute. The results presented in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

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(Alok Singh)

ABSTRACT

The present study aims at providing relevant insights into the thermal performance of box type solar cookers primarily focusing on the effect of absorber tray temperature on the value of First Figure of Merit (F_1). The focus of the study is on thermal characterization of the box of the box type solar cooker - The booster mirror has thus been considered as external to the box for augmenting the solar radiation. Experiments were conducted on a control (reference) solar cooker during different periods of the year for the above purpose. A simple correlation (in analytical form) has been developed for the top heat loss coefficient (U_t) of box type solar cooker that is able to capture the variation of F_1 with absorber tray temperature. From the study presented in the thesis it may be inferred that the value of F_1 be determined for moderate temperature (absorber tray temperature in the range of 110-120 °C) conditions and the same can then be used for determining the value of Second Figure of Merit (F_2). The proposed correlation can be used to scale up/down the values of F_1 for use in calculating the values of second figure of merit (F_2) besides deciding a representative value of F_1 for characterization of the box type solar cooker. For the case of control cooker, the correlation for U_t was verified with the values obtained through experiments.

Experiments were also performed on the control cooker to study the variation in the values of F_2 . It was noted that if the values of F_1 obtained at T_p of 110-120 °C are used for calculation of F_2 , the variation in the values of F_2 is reduced. For this purpose, the values of F_1 as obtained in the present study for moderate temperature were used. Despite variation in the time required for heating water up to a certain desired temperature during different periods of the year, the values of F_2 were reasonably stable indicating the suitability of the existing approach for its determination. Studies performed on the control cooker to decide the termination temperature (T_{w2}) indicated that the same should preferably be 10 °C below the boiling temperature of water: between 85-90 °C.

In order to study the applicability of the proposed correlation for U_t for commercially available family type box solar cooker, experiments were conducted on five different designs of the same. It was observed that the proposed equation is able to predict the trend of variation in U_t (specially with respect to absorber tray temperature) for these box type solar cookers.

सारांश

वर्तमान अध्ययन का उद्देश्य बक्सनुमा सौर कुकर के उष्मीय कार्य निष्पादन में प्रासंगिक अंतर्दृष्टि प्रदान करना है, जो मुख्यतः अवशोषक ट्रे के तापमान के, प्रथम फिगर ऑफ मेरिट (F_1) के मान पर पड़ने वाले प्रभाव पर केंद्रित है। इस अध्ययन का मुख्य उद्देश्य बक्सनुमा सौर कुकर के बक्स का उष्मीय अभिलक्षणन करना है – इस कारण बक्सनुमा सौर कुकर में लगे दर्पण को उपलब्ध सौर ऊर्जा के अभिवर्धन में प्रयुक्त मानते हुए बक्स से बाहर समझा गया है। उपरोक्त उद्देश्य के लिए वर्ष की विभिन्न अवधियों के दौरान एक संदर्भ सौर कुकर पर प्रयोग किए गए। बक्सनुमा सौर कुकर की ऊपरी सतह के ऊष्मा ह्रास गुणांक (U_t) के लिए एक साधारण सहसंबंध (correlation) (विश्लेषणात्मक रूप में) विकसित किया गया है जो अवशोषक ट्रे तापमान के F_1 पर प्रभाव को प्रदर्शित करने में सक्षम है। इस शोध ग्रंथ में प्रस्तुत अध्ययन से यह निष्कर्ष निकलता है कि किसी बक्सनुमा सौर कुकर के लिये F_1 का मान निकालने के लिये अवशोषक ट्रे का तापमान 110-120 °C के मध्य होना चाहिये और इन्हीं परिस्थितियों के लिये बक्सनुमा सौर कुकर के द्वितीय फिगर ऑफ मेरिट (F_2) का मान भी निकालना चाहिये। बक्सनुमा सौर कुकर के अभिलक्षणन हेतु F_2 के प्रतिनिधि मान को तय करने के अतिरिक्त प्रस्तावित सहसंबंध का उपयोग F_2 का मान निकालने के लिये आवश्यक F_1 के मान का उचित निर्धारण करने के लिये भी किया जा सकता है। संदर्भ सौर कुकर के लिये U_t के प्रस्तावित सहसंबंध का प्रायोगिक सत्यापन भी किया गया है।

F_2 के मान में भिन्नता का अध्ययन करने के लिए संदर्भ कुकर पर भी प्रयोग किए गए। यह देखा गया कि यदि F_1 का मान 110-120 °C के अवशोषक ट्रे तापमान पर निकाल कर F_2 का मान निकालने के लिये प्रयोग किया जाय तो F_2 के मानों में भिन्नता बहुत कम हो जाती है। इस उद्देश्य के साथ वर्तमान अध्ययन में F_1 का मान मध्यम तापमानों पर निकाला गया है। वर्ष की विभिन्न अवधियों के दौरान एक निश्चित वांछित तापमान तक पानी को गर्म करने के लिए आवश्यक समय में भिन्नता के बावजूद, F_2 के मान इसके निर्धारण के लिए मौजूदा दृष्टिकोण की उपयुक्तता को इंगित करते हुए यथोचित रूप से स्थिर थे। टर्मिनेशन तापमान (T_{w2}) तय करने के लिए संदर्भ कुकर पर किए गए अध्ययनों से संकेत मिलता है कि इसे अधिमानतः पानी के उबलते तापमान से 10 °C कम होना चाहिए: 85-90 °C के बीच।

U_t के लिए प्रस्तावित सहसंबंध की प्रयोज्यता का, व्यावसायिक रूप से उपलब्ध पांच पारिवारिक बक्सनुमा सौर कुकरों के लिये भी अध्ययन किया गया। प्रस्तावित सहसंबंध इन कुकरों के लिये भी U_t की भिन्नता (मुख्यतः अवशोषक ट्रे तापमान के साथ) को समुचित रूप से प्रदर्शित कर सकता है।

Table of Contents

	Page No.
Certificate	i
Acknowledgements	ii
Abstract	iii
List of Figures	xi
List of Photographs	xiv
List of Tables	xv
Nomenclature	xviii
CHAPTER-1: INTRODUCTION	1
1.1 Solar cooking.....	4
1.2 Overview of existing test standards for box type solar cookers.....	6
1.2.1 Test method of Bureau of Indian Standards	7
1.2.2 Test Standard (ASAE S580) of American Society of Agricultural Engineers	9
1.2.3 Test Standard Proposed by European Committee on Solar Cooking Research (ECSCR)	11
1.3 Review of literature on box type solar cooker	14
1.3.1 Test methods and parameters for thermal performance characterization of box type solar cooker	15
1.3.2 Testing of box type solar cooker and its design variations.....	17
1.3.3 Miscellaneous thermal performance related studies on box type solar cookers	20
1.4 Problem Justification.....	30

1.5	Outline of Proposed Work.....	33
1.6	Publications	37
CHAPTER-2: MATERIALS, METHODS AND EXPERIMENTAL RESULTS.....		38
2.1	Introduction	39
2.2	Parameters influencing thermal performance of a box type solar cooker.....	39
2.3	Parameters affecting the first figure of merit, F_1	40
2.3.1	Overall heat loss coefficient, U_L	41
2.4	Computation of optical efficiency	41
2.5	Computation of glass cover temperature.....	42
2.6	Details of cookers and experiments conducted	43
2.6.1	Control Cooker.....	43
2.6.2	Family type box solar cookers	46
2.6.3	Study of perimeter to area ratio (P/A) and combined bottom and side heat loss coefficient of family type box solar cookers.....	48
2.6.4	Instrumentation and measurements.....	49
2.7	Results and discussion pertaining to control cooker	52
2.7.1	Optical efficiency.....	52
2.7.2	Experimental determination of first figure of merit F_1 of control cooker.....	53
2.7.3	Effect of absorption of solar radiation in glass covers of control cooker on their temperature	55
2.7.4	Comparative study of methods for computing outer glass cover temperature ..	59
2.7.5	Heat balance of control cooker	62

CHAPTER-3: STUDY OF SEASONAL VARIATION IN THE VALUE OF THE FIRST FIGURE OF MERIT (F_1) AND VARIATION OF TOP HEAT LOSS COEFFICIENT (U_t) OF BOX TYPE SOLAR COOKER.....75

3.1	Introduction	76
3.2	Variation in experimental values of F_1 in summer and winter.....	76
3.3	Estimation of top heat loss coefficient of a box type solar cooker approximated as double-glazed flat plate solar collector	82
3.3.1	Computation of convective (h_{cp1}) and radiative (h_{rp1}) heat loss coefficients from absorber plate to inner glass cover.....	82
3.3.2	Computation of convective (h_{c12}) and radiative (h_{r12}) heat loss coefficients from inner glass cover to outer glass cover	83
3.3.3	Computation of radiative (h_{r2a}) heat loss coefficient from outer glass cover to ambient	84
3.3.4	Computation of top heat loss coefficient (U_t).....	84
3.3.5	Approach suggested Samdarshi and Mullick (1991) for estimating Glass cover temperatures.....	85
3.3.6	Approach suggested by Akhtar and Mullick (2007) for estimating Glass cover temperatures.....	86
3.3.7	Comparison of the values of outer glass cover temperature (T_2) obtained from experiments on the control cooker with those from analytical equations for double glazed flat plate solar collector.....	87
3.4	Exploring the possibility of capyuring the seasonal variation in experimental values of top heat loss coefficient ($U_{t,exp}$) of a box type solar cooker by using analytical equations for U_t of a double-glazed flat plate solar collector.....	91

3.4.1	Determination of U_t from experiments for F_1	91
3.4.2	Determination of U_t from analytical equations for flat plate solar collector by Samdarshi and Mullick (1991).....	93
3.4.3	Comparison of $U_{t,exp}$ with $U_{t,anl}$	93
3.5	A simplified equation for top heat loss coefficient (U_t) of a box type solar cooker .	97
3.5.1	Equation for top heat loss coefficient (U_t)	99
3.5.2	Correlation for outer glass cover temperature (T_2)	100
3.5.3	Comparison of values of U_t obtained from the proposed equation with those obtained from numerical solution	101
CHAPTER-4: COMPARISON OF VALUES OF TOP HEAT LOSS COEFFICIENT OBTAINED FROM EXPERIMENTS FOR F_1 WITH THE VALUES OBTAINED FROM PROPOSED EQUATION.....		112
4.1	Introduction	113
4.2	Comparison of U_t from proposed equation (Eq. 4.1) (using experimental values of T_2), with U_t from experiments	115
4.3	Comparison of U_t from proposed equation (Eq. 4.1) (using values of T_2 from proposed equation (Eq. 3.28), with U_t from experiments.....	115
4.4	Comparison of values of U_t as obtained from analytical equation (Eq. 4.2) (using experimental values of T_2) with the values of U_t from experiments	116
CHAPTER-5: STUDY AND ANALYSIS OF THE VARIATION IN THE VALUES OF SECOND FIGURE OF MERIT (F_2) AND STUDY OF HEATING CURVES OF CONTROL BOX TYPE SOLAR COOKER		123
5.1	Introduction	124
5.2	Variation of different parameters obtained during test of F_2	126
5.3	Variation in second figure of merit F_2 of control cooker and its analysis.....	128

5.3.1	Selection of termination temperature for computation of F_2	130
5.4	Heating curves of control box type solar cooker.....	135
CHAPTER-6: STUDIES ON DIFFERENT FAMILY TYPE BOX SOLAR COOKERS		140
6.1	Introduction	141
6.2	First figure of merit, F_1 of family type box solar cookers.....	144
6.3	Comparative study of different parameters of box type solar cookers, used in experiments	148
6.4	Results and discussion.....	149
6.4.1	Applicability of the proposed equation for U_t , for family box type solar cookers	149
CHAPTER-7: CONCLUSIONS AND RECOMMENDATIONS		163
7.1	Conclusions	164
7.2	Recommendations for future work.....	166
REFERENCES		167
BIO-DATA OF THE AUTHOR		184

List of Figures

	Page No.
Figure 1.1: Schematic diagram of a control box type solar cooker	5
Figure 2.1: A schematic diagram of the box type solar cooker (control cooker) used in experiments	44
Figure 2.2: U_{b+s} of solar cookers vs. Perimeter to area ratio of cookers	49
Figure 2.3: Optical efficiency of control cooker on different days of experiment	53
Figure 2.4: First figure of merit F_1 of control cooker for different days of experiment	55
Figure 2.5: Comparison of T_1 (experimental, considering absorption, and no absorption of radiation in glass covers)	58
Figure 2.6: Comparison of T_2 (experimental, considering absorption, and no absorption of radiation in glass covers)	58
Figure 2.7: Comparison of experimental and theoretical [using samdarshi and mullick (1991) and by akhtar and mullick (2007)] values of T_2	60
Figure 3.1: Seasonal variation in experimental values of F_1 , for control cooker	79
Figure 3.2: Seasonal variation in experimental values of F_1 , for cooker 1	79
Figure 3.3: Seasonal variation in experimental values of F_1 , for cooker 2	80
Figure 3.4: Seasonal variation in experimental values of F_1 , for cooker 3	80
Figure 3.5: Seasonal variation in experimental values of F_1 , for cooker 4	81
Figure 3.6: Seasonal variation in experimental values of F_1 , for cooker 5	81
Figure 3.7: Comparison of $T_{2,exp}$ and $T_{2,anl}$ (by flat plate collector correlations by samdarshi mullick, 1991)	89
Figure 3.8: Comparison of $U_{t,exp}$ and $U_{t,anl}$ (using analytical correlation by samdarshi and mullick, 1991)	94

Figure 3.9: Comparison of $U_t(ns)$ and $U_t(eqn)$ for different values of absorber tray temp. (t_p)	103
Figure 3.10: Comparison of $U_t(NS)$ and $U_t(eqn)$ for different values of ambient temp. (t_a)	103
Figure 3.11: Comparison of $U_t(NS)$ and $U_t(eqn)$ for different values of wind heat transfer coefficient (h_w)	104
Figure 4.1 : Comparison of $U_{t, exp}$ and $U_{t, anl, proposed eqn}$ (using experimental T_2)	117
Figure 4.2: Comparison of $U_{t, exp}$ and $U_{t, anl, proposed eqn}$; $t_2, proposed eqn$ (using T_2 from eq. (3.28))	117
Figure 4.3: Comparison of $U_{t, exp}$ and $U_{t, anl, kumar et al.}$ (using experiment t_2)	118
Figure 5.1: Variation of different parameters for control cooker obtained during test of f_2 with time of the day on 10 march	127
Figure 5.2: Variation of different parameters for control cooker obtained during test of f_2 with time of the day on 08 june	128
Figure 5.3: Comparison of theoretical values of ' τ ' with experimental values of ' τ ' (summer + spring) for the control cooker	137
Figure 5.4: Comparison of theoretical values of ' τ ' with experimental values of ' τ ' (summer) for the control cooker	138
Figure 5.5: Comparison of theoretical values of ' τ ' with experimental values of ' τ ' (spring) for the control cooker	139
Figure 6.1: First figure of merit F_1 of cooker 1 for summer and winter	145
Figure 6.2: First figure of merit F_1 of cooker 2 for summer and winter	146
Figure 6.3: First figure of merit F_1 of cooker 3 for summer and winter	146
Figure 6.4: First figure of merit F_1 of cooker 4 for summer and winter	147
Figure 6.5: First figure of merit F_1 of cooker 5 for summer and winter	147
Figure 6.6: Variation of T_p (no load and load) and T_w during a day, while testing F_2	149
Figure 6.7: A comparison of $U_{t,eqn}$ and $U_{t,exp}$ for cooker 1	150

Figure 6.8: A comparison of $U_{t,eqn}$ and $U_{t,exp}$ for cooker 2	151
Figure 6.9: A comparison of $U_{t,eqn}$ and $U_{t,exp}$ for cooker 3	151
Figure 6.10: A comparison of $U_{t,eqn}$ and $U_{t,exp}$ for cooker 4	152
Figure 6.11: A comparison of $U_{t,eqn}$ and $U_{t,exp}$ for cooker 5	152

List of Photographs

	Page No.
Photograph 2.1: Control cooker	44
Photograph 2.2: Family type box solar cookers used in experiments (cooker 1, cooker 3 and cooker 5)	47
Photograph 2.3: Family type box type solar cookers used in experiments (cooker 2 and cooker 4)	47
Photograph 2.4: Instrumentation used for conducting experiments on box type solar cookers	51
Photograph 5.1: Experiment for second figure of merit f_2 on control cooker	125
Photograph 6.1: Experimental setup for experiments on family type box solar cookers	143
Photograph 6.2: Experiment for second figure of merit f_2 on cooker-1	144

List of Tables

	Page No.
Table 2.1: Details of control cooker used in experiments	45
Table 2.2: List of family type box type solar cookers used for experimentation and their nomenclature	46
Table 2.3: Details of family type box solar cookers used in experiments	46
Table 2.4: Perimeter to area ratio of cookers	48
Table 2.5: Optical efficiency of the control cooker	54
Table 2.6: Measured values of different parameters for determination of f_1 of control cooker	56
Table 2.7: Experimental and computed values of the temperatures of the glass covers of the control cooker	57
Table 2.8: Measured value of absorber tray and glass cover temperature along with estimated value of outer glass cover temperature of control cooker	61
Table 2.9: Individual heat transfer coefficients and heat loss flux assuming radiative heat losses from outer glass cover to ambient (T_a)	65
Table 2.10: Individual heat transfer coefficients and heat loss flux assuming radiative heat losses from outer glass cover to sky (T_s)	66
Table 2.11: Heat loss flux assuming absorption of solar radiation in glass covers and radiative heat losses from outer glass cover to sky (T_s)	67
Table 3.1: Measured values of T_2 as against the values obtained using analytical correlation by samdarshi and mullick (1991)	90
Table 3.2: Measured values of u_t and other parameters as against the values of U_t obtained the correlation by samdarshi and mullick (1991)	95
Table 3.3: Range of variables for the validity of the proposed equation for U_t ,	98

Table 3.4: Values of U_t and T_2 from numerical solution and proposed analytical equations for varying T_p values (other variables kept constant)	104
Table 3.5: Values of U_t and T_2 from numerical solution and proposed analytical equations for varying T_a values (other variables kept constant)	105
Table 3.6: Values of U_t and T_2 from numerical solution and proposed analytical equations for varying h_w values (other variables kept constant)	105
Table 3.7: Values of U_t and T_2 from numerical solution and proposed analytical equations for varying ε_p values (other variables kept constant)	106
Table 3.8: Values of u_t and T_2 from numerical solution and proposed analytical equations for varying L_1 values, (other variables kept constant)	106
Table 4.1: Range of values of variables for which eq. (4.2) is valid	114
Table 4.2: Results of the calculations made for U_t from experiments ($U_{t,exp}$) and from eq. (4.1 ($U_{t,anl, proposed eqn}$) by using T_2 from experiments	119
Table 4.3: Results of the calculations made for U_t from experiments ($U_{t,exp}$) and from eq. (4.1 ($U_{t,anl, proposed eqn}$) by using T_2 from proposed eq. (3.28)	120
Table 4.4: Experimental observations of no load test and the results of the calculations made for U_t from eq. (4.2 ($U_{t,anl, kumar et al.}$) and T_2 from experiments	121
Table 5.1: F_2 and other parameters for different days of experiment for water heating temperature range of 60-80 °C	131
Table 5.2: F_2 and other parameters for different days of experiment for water heating temperature range of 60-85 °C	131
Table 5.3: F_2 and other parameters for different days of experiment for water heating temperature range of 60-90 °C	132
Table 5.4: F_2 and other parameters for different days of experiment for water heating temperature range of 60-95 °C	132

Table 5.5: F_2 and other parameters for different days of experiment for water heating temperature range of 60-80 °C	133
Table 5.6: F_2 and other parameters for different days of experiment for water heating temperature range of 60-85 °C	133
Table 5.7: F_2 and other parameters for different days of experiment for water heating temperature range of 60-90 °C	134
Table 5.8: F_2 and other parameters for different days of experiment for water heating temperature range of 60-95 °C	134
Table 5.9: Average values of F_2 for different range of water heating temperature	135
Table 6.1: Values of various parameters of different box types solar cookers	149
Table 6.2: Experimental and computed values of different parameters for cooker 1	153
Table 6.3: Experimental and computed values of different parameters for cooker 2	154
Table 6.4 : Experimental and computed values of different parameters for cooker 3	155
Table 6.5: Experimental and computed values of different parameters for cooker 4	156
Table 6.6: Experimental and computed values of different parameters for cooker 5	157

NOMENCLATURE

A = Aperture area (m^2)

C_p = Specific heat ($\text{J kg}^{-1} \text{K}^{-1}$)

C_R = Heat capacity ratio $= (MC)_w / (MC)'_w$

F_1 = First Figure of Merit for box type solar cooker ($\text{m}^2 \text{KW}^{-1}$)

F_2 = Second Figure of Merit for box type solar cooker

F' - Heat exchange efficiency factor

h_c = Convective heat transfer coefficient ($\text{W m}^{-2} \text{K}^{-1}$)

h_r = Radiative heat transfer coefficient ($\text{W m}^{-2} \text{K}^{-1}$)

h_{cp1} = Convective heat transfer coefficient between absorber plate and inner glass cover
($\text{W m}^{-2} \text{K}^{-1}$)

h_{c12} = Convective heat transfer coefficient between inner and outer glass cover ($\text{W m}^{-2} \text{K}^{-1}$)

h_w = Wind heat transfer coefficient ($\text{W m}^{-2} \text{K}^{-1}$)

h_{rp1} = Radiative heat transfer coefficient between absorber plate and inner glass cover
($\text{W m}^{-2} \text{K}^{-1}$)

h_{r12} = Radiative heat transfer coefficient between inner and outer glass cover ($\text{W m}^{-2} \text{K}^{-1}$)

h_{r2a} = Radiative heat transfer coefficient between outer glass cover and sky ($\text{W m}^{-2} \text{K}^{-1}$)

I = Intensity of solar radiation on the aperture of the solar cooker (W m^{-2})

I_b = Intensity of direct (beam) solar radiation on the aperture of the solar cooker (W m^{-2})

I_d = Intensity of diffuse solar radiation on the aperture of the solar cooker (W m^{-2})

I_s = Average intensity of solar radiation at stagnation (Wm^{-2})

k = thermal conductivity of air ($\text{W m}^{-1} \text{K}^{-1}$)

K = Extinction coefficient of glass (m^{-1})

l = Length of absorber tray (m)

L_1 = Air gap spacing between absorber plate and inner glass cover (m)

L_2 = Air gap spacing between inner and outer glass cover (m)

$(MC)_w$ = heat capacity of water in pots (JK^{-1})

$(MC)'_w$ = heat capacity of water including the pots and certain portion of the cooker interior
(JK^{-1})

Nu = Nusselt Number

Pr = Prandtl Number

$\dot{Q}_b''$ = Bottom heat loss flux (Wm^{-2})

$\dot{Q}_t''$ = Top heat loss flux (Wm^{-2})

$\dot{Q}_c''$ = Convective heat loss flux (Wm^{-2})

$\dot{Q}_r''$ = Radiative heat loss flux (Wm^{-2})

R^2 = Coefficient of determination

Ra = Rayleigh Number

T_a = Ambient temperature ($\text{K}/^\circ\text{C}$)

T_{as} = Average ambient temperature at stagnation ($\text{K}/^\circ\text{C}$)

T_p = Average absorber tray temperature ($\text{K}/^\circ\text{C}$)

T_{ps} = Average absorber tray temperature at stagnation (K/ °C)

T_s = Effective black body sky temperature (K/ °C)

T_1 = Temperature of inner glass cover (K/ °C) $(=(T_{1i} + T_{1o})/2)$

T_2 = Temperature of outer glass cover (K/ °C) $(=(T_{2i} + T_{2o})/2)$

T_{1i} = Temperature of inner surface of inner glass cover (K)

T_{1o} = Temperature of outer surface of inner glass cover (K)

T_{2i} = Temperature of inner surface of outer glass cover (K)

T_{2o} = Temperature of outer surface of outer glass cover (K)

T_{mp1} = Mean temperature of absorber tray and inner glass cover (K)

T_{m12} = Mean temperature of inner and outer glass cover (K)

T_w = Water temperature (K/ °C)

T_{w1} = Initial water temperature (K/ °C)

T_{w2} = Final water temperature (K/ °C)

U_L = Overall heat loss coefficient ($Wm^{-2}K^{-1}$)

$(U_L)_{exp}$ = Overall heat loss coefficient from experiments ($Wm^{-2}K^{-1}$)

$(U_L)_{th}$ = Overall heat loss coefficient from theory ($Wm^{-2}K^{-1}$)

U_t = Top heat loss coefficient ($Wm^{-2}K^{-1}$)

$(U_t)_{exp}$ = Top heat loss coefficient from experiments ($Wm^{-2}K^{-1}$)

$(U_t)_{th}$ = Top heat loss coefficient from theory ($Wm^{-2}K^{-1}$)

U_b = Bottom heat loss coefficient ($Wm^{-2}K^{-1}$)

U_s = Side heat loss coefficient ($\text{Wm}^{-2}\text{K}^{-1}$)

$U_{(b+s)}$ = Combined bottom and side heat loss coefficient ($\text{Wm}^{-2}\text{K}^{-1}$)

V_w = Wind speed (ms^{-1})

Greek letters

ρ = Mass density (kg m^{-3})

α_p = Absorptivity of absorber tray

ε_p = Emissivity of absorber tray

σ = Stefan-Boltzmann constant

ΔT_p = Difference of absorber temperature during time interval $d\tau$

θ_1 = Angle of incidence (degrees)

θ_2 = Angle of refraction (degrees)

ε_g = Emissivity of glass

ν = Kinematic viscosity of air

δ = Declination angle (degrees)

ϕ = Latitude of place (degrees)

ω = Hour angle (degrees)

η_0 = Optical efficiency

μ = Refractive index

n = day number (with $n=1$ for January 01)

τ_{12} = Time period to increase water temperature from T_{w1} to T_{w2} (s)

τ_{boil} = Time required to boil water (s)

Subscripts

i = Inner surface of glass -cover

o = Outer surface of glass-cover

p1= Absorber tray to inner (first) glass-cover

12 = Inner glass cover to outer glass-cover

2a = Outer glass cover to ambient

2s = Outer glass cover to sky