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LITERATURE REVIEW OF UNCERTAINTY OF ANALYSIS METHODS

(F-Chart Program)

Report to the
Texas Commission on Environmental Quality

Jeff S. Haberl, Ph.D., P.E.
Soolyeon Cho

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ENERGY SYSTEMS LABORATORY

Texas Engineering Experiment Station
Texas A&M University System

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1 Executive Summary

This report reviews the reported uncertainty of F-Chart analysis method by reviewing the published related accuracy of TRNSYS simulations versus measured data, F-Chart predictions versus measured data, F-Chart predictions versus TRNSYS simulations and F-Chart predictions versus other methods. This report begins with a review of the history of the F-Chart method, and includes an example F-Chart calculation. In summary, from the literature it was found that hourly TRNSYS simulations versus measured data were shown to be within 5 to 6%, F-Chart predictions versus measured data showed agreement in the 2 to 15% range, and F-Chart predictions versus TRNSYS simulations were shown to vary from 1.1% to 4.7%. A significant number of studies used F-Chart to assess the accuracy of newly developed methods. In these studies agreement varied from 2.5% to 9%.

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2 Introduction

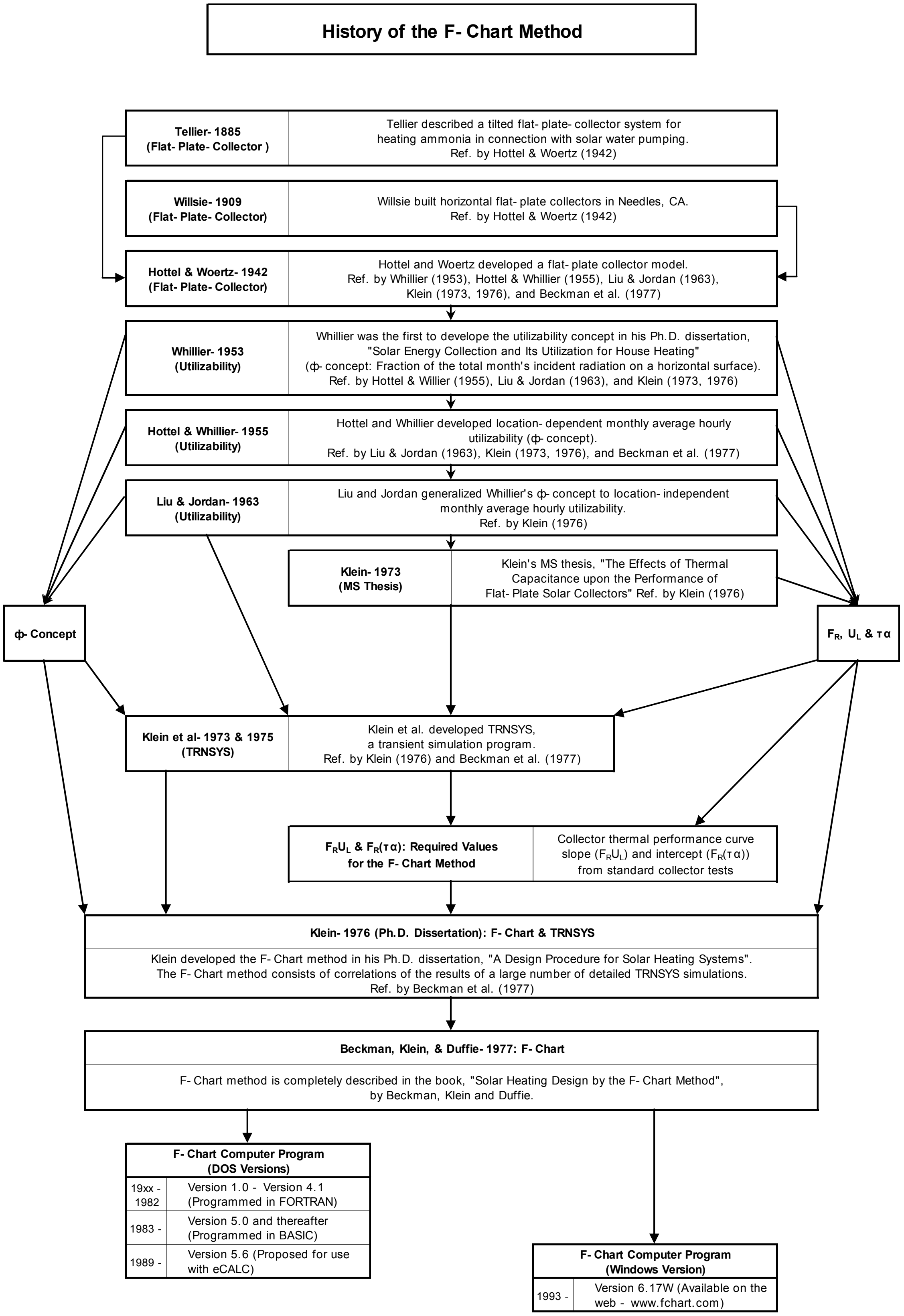
This literature review covers the F-Chart program, which is one of the legacy programs in the ESL's Emissions Calculator (eCALC), a web-based emissions reductions calculator. The eCALC program is a tool for those who want to see how their energy savings has reduced NOx emissions, a by-product made during the burning of fossil fuels. This report includes a brief history of the F-Chart method, its applications, accuracies, basic equations, and an example calculation.

3 History of the F-Chart Method

The F-Chart method is an analysis that is useful for the design of active and passive solar heating systems, especially for selecting the size and type of solar collectors supplying the DHW and heating loads. It was originally developed as part of the Dr. Sanford Klein's Ph.D. thesis, entitled "A Design Procedure for Solar Heating Systems" (1976), Klein et al. (1976a, 1977). Figure **1** shows the history of the F-Chart method with a special emphasis on the values and parameters in F-Chart that are used in the ESL's eCALC. The F-Chart method consists of correlations of the results of a large number of detailed simulations using TRNSYS, a transient systems simulation program by Klein et al. (1973). The first publication regarding the F-Chart method was first published one year after Klein's Ph.D. thesis in the book by Beckman, Klein, and Duffie (1977), entitled "Solar Heating Design by the F-Chart Method."

The F-Chart method requires two values to describe a solar collector: the solar collector thermal performance curve slope (F_RU_L, Btu/hr-ft^2-F) and intercept ($F_R(\tau\alpha)$, %) from standard collector tests. These parameters include the F_R (Collector Efficiency Factor), U_L (Collector Overall Energy Loss Coefficient) and $\tau\alpha$ (Transmittance-Absorptance Product). F_RU_L and $F_R(\tau\alpha)$, were initially introduced by Whillier (1953a,1953b). These parameters were also by Hottel and Whillier (1955), and Liu and Jordan (1963) in conjunction with the development of the φ concept (utilizability), which calculates the fraction of the total month's incident radiation on a horizontal surface.

The φ concept was developed by Whillier (1953a; 1953b), and later used by Hottel and Whillier (1955), as location-dependent, monthly-average hourly utilizability. Liu and Jordan (1963) then generalized the Whillier's φ concept to location-independent monthly average hourly utilizability.



History of the F- Chart Method

Tellier- 1885 (Flat- Plate- Collector)
Tellier described a tilted flat- plate- collector system for heating ammonia in connection with solar water pumping.
Ref. by Hottel & Woertz (1942)

Willsie- 1909 (Flat- Plate- Collector)
Willsie built horizontal flat- plate collectors in Needles, CA.
Ref. by Hottel & Woertz (1942)

Hottel & Woertz- 1942 (Flat- Plate- Collector)
Hottel and Woertz developed a flat- plate collector model.
Ref. by Whillier (1953), Hottel & Whillier (1955), Liu & Jordan (1963), Klein (1973, 1976), and Beckman et al. (1977)

Whillier- 1953 (Utilizability)
Whillier was the first to develope the utilizability concept in his Ph.D. dissertation, "Solar Energy Collection and Its Utilization for House Heating"
(ф- concept: Fraction of the total month's incident radiation on a horizontal surface).
Ref. by Hottel & Willier (1955), Liu & Jordan (1963), and Klein (1973, 1976)

Hottel & Whillier- 1955 (Utilizability)
Hottel and Whillier developed location- dependent monthly average hourly utilizability (ф- concept).
Ref. by Liu & Jordan (1963), Klein (1973, 1976), and Beckman et al. (1977)

Liu & Jordan- 1963 (Utilizability)
Liu and Jordan generalized Whillier's ф- concept to location- independent monthly average hourly utilizability.
Ref. by Klein (1976)

Klein- 1973 (MS Thesis)
Klein's MS thesis, "The Effects of Thermal Capacitance upon the Performance of Flat- Plate Solar Collectors" Ref. by Klein (1976)

ф- Concept

F_R, U_L & τα

Klein et al- 1973 & 1975 (TRNSYS)
Klein et al. developed TRNSYS, a transient simulation program.
Ref. by Klein (1976) and Beckman et al. (1977)

F_RU_L & F_R(τα): Required Values for the F- Chart Method
Collector thermal performance curve slope (F_RU_L) and intercept (F_R(τα)) from standard collector tests

Klein- 1976 (Ph.D. Dissertation): F- Chart & TRNSYS
Klein developed the F- Chart method in his Ph.D. dissertation, "A Design Procedure for Solar Heating Systems".
The F- Chart method consists of correlations of the results of a large number of detailed TRNSYS simulations.
Ref. by Beckman et al. (1977)

Beckman, Klein, & Duffie- 1977: F- Chart
F- Chart method is completely described in the book, "Solar Heating Design by the F- Chart Method", by Beckman, Klein and Duffie.

F- Chart Computer Program (DOS Versions)	
19xx - 1982	Version 1.0 - Version 4.1 (Programmed in FORTRAN)
1983 -	Version 5.0 and thereafter (Programmed in BASIC)
1989 -	Version 5.6 (Proposed for use with eCALC)

F- Chart Computer Program (Windows Version)	
1993 -	Version 6.17W (Available on the web - www.fchart.com)

Figure 1. History Diagram of the F-Chart Method

Flat-plate collector systems are a popular form of solar collector because they are simple to construct and are reasonably efficient. Flat-plate collectors have been used mostly with solar space heating, and domestic hot water. The idea of a flat-plate for collecting solar energy dates to almost 70 years before the utilizability concept was introduced by Whillier to a flat-plate-collector system described and built by Tellier in 1885. In his work, Tellier described a tilted, flat-plate collector system for heating ammonia to drive a solar water pumping system. Horizontal, flat-plate collectors were also used in this country at the turn of the century in Needles, California, by Willsie (1909) to collect heat for operation of a heat-engine with sulphur dioxide as the working fluid. Hottel and Whillier (1942) were the first to develop detailed methods for predicting the flat-plate collector performance, which form the basis for the F-Chart solar analysis system.

The F-Chart method combining all the concepts above was first programmed in FORTRAN for mainframe computers until Version 4 was released from the Solar Energy Laboratory at the University of Wisconsin, Madison (Beckman et al. 1982). Later, F-Chart, Version 5, a microcomputer F-Chart program written in BASIC, was developed (Klein and Beckman 1983). The BASIC version of F-Chart calculates all the same analysis as the FORTRAN version except for those involving heat pumps. In addition, the BASIC version of F-Chart also analyzes passive solar systems and solar-heated pool systems, including pool energy losses. The Windows version of F-Chart, Version 6.17W, was developed by Klein and Beckman (1993) and is available commercially on the Internet web site www.fchart.com. The F-Chart for the MAC is also available.

Version 5.6 of the F-Chart method, which is programmed in BASIC and running in the DOS mode, is the version used with the ESL's eCALC emissions calculator. This version gives identical results as those from the F-Chart Version 6.17W running under Microsoft Windows.

4 Applications of the F-Chart Method

F-Chart can be used to estimate the long-term average performance of the following solar systems:

- ☐ Water Storage Heating
- ☐ Pebble Bed Storage Heating
- ☐ Building Storage Heating
- ☐ Domestic Water Heating
- ☐ Integral Collector-Storage DHW
- ☐ Indoor and Outdoor Pool Heating
- ☐ Passive Direct-Gain
- ☐ Passive Collector-Storage Wall

F-Chart can also evaluate the performance of the collector types listed below:

- ☐ Flat-Plate
- ☐ Evacuated Tube
- ☐ Compound Parabolic Concentrating
- ☐ 1 and 2-Axis Tracking

More features of F-Chart are as follows:

- ☐ Life-cycle economics with cash flow
- ☐ Weather data for over 300 locations
- ☐ Weather data can be added
- ☐ Monthly parameter variation
- ☐ 2-D incidence angle modifiers
- ☐ English and SI units
- ☐ Approved for use in California
- ☐ Versions for Mac, DOS, and Windows

5 Accuracy of the F-Chart Method

The F-Chart method is a carefully constructed correlation that is based on 1,000s (spell out) of simulations with a streamlined version of the TRNSYS program, developed by the University of Wisconsin. Therefore, an assessment of the accuracy of the F-Chart method should include an assessment of the accuracy of the TRNSYS program.

5.1 Accuracy of the TRNSYS Simulation Program

The TRNSYS program, which is a modular differential equation solver, was developed at the Solar Energy Laboratory by the University of Wisconsin-Madison to be a general purpose engineering problem solver (Klein et al. 1973). TRNSYS users can have a variety of outputs from their simulations, including: the calculated solar fraction, auxiliary heating requirement, and many other component-level performance indices. Several validation studies for the TRNSYS program have been conducted since 1976 (Duong and Winn 1977; and Mitchell et al. 1978). System simulations using specially-constructed TRNSYS input files have been compared with experiments for several periods of operation of the Colorado State University (CSU) house I. In these simulations the predicted collector output using TRNSYS agreed with the experimental output within 5%. Furthermore, the heat transferred across the air heater was compared with that delivered by the auxiliary heater and agreed to within 6% of measured values. Therefore, according to these studies it can be concluded that a properly constructed TRNSYS simulation can be a valid and reliable tool for the analysis and design of solar systems (Garg 1985).

5.2 Accuracy of the F-Chart Method

There are several papers in the literature that have addressed the uncertainty of the F-Chart method, comparing the results of F-Chart with those of experiments, TRNSYS simulations, and other methods for which F-Chart was used as a verification tool since the mid-1980's. Figure **2** shows a diagram of the accuracy of the F-Chart method.

5.2.1 F-Chart vs. Measurement

One of the first assessments of the accuracy of the F-Chart methods was performed by Klein as part of his Ph.D. thesis (Klein 1976). In this assessment Klein showed that the values of $F_R(\tau\alpha)$ were 0.663 from measurement data recorded during 1974 in Madison, Wisconsin, and 0.628 from calculation, which is only a 5.3% deviation from experiment.

The values of F_RU_L were 20.5 from experiment data and 19.9 from calculation, which was only a 2.9% deviation from experiment data.

In 1976 Klein et al. compared the results of the F-Chart with the measurement data from Engebretson (1964) on the MIT House IV in Blue Hills, Massachusetts, for the periods of 1959-60 and 1960-61. In their analysis the yearly average value of the solar fraction estimated by the F-Chart method was only 8% higher than the measured values for the 1959-60 heating season and 5% higher for 1960-61.

Fanney and Liu (1980) showed the comparison between experimental and computer-predicted performance for solar hot water systems. Their measurements were from experiments performed at the National Bureau of Standards (NBS) in Gaithersburg, Maryland, for the period of July 1978 to June 1979. Figure 5 in their paper showed that the deviation between the F-Chart values of tilted surface solar radiance based on measured horizontal surface solar irradiance and measured values of tilted surface solar radiance is about 8% in average for the period.

Duffie and Mitchell (1983) performed a comparison study between F-Chart simulation data and measurement data from measurements taken by the NBS and the National Solar Data Network (NSDN) in over 30 cities located different climate regions. Results showed that twenty-two of the thirty cities showed that the simulations matched the measurement within ± 15% of the F-Chart prediction values.

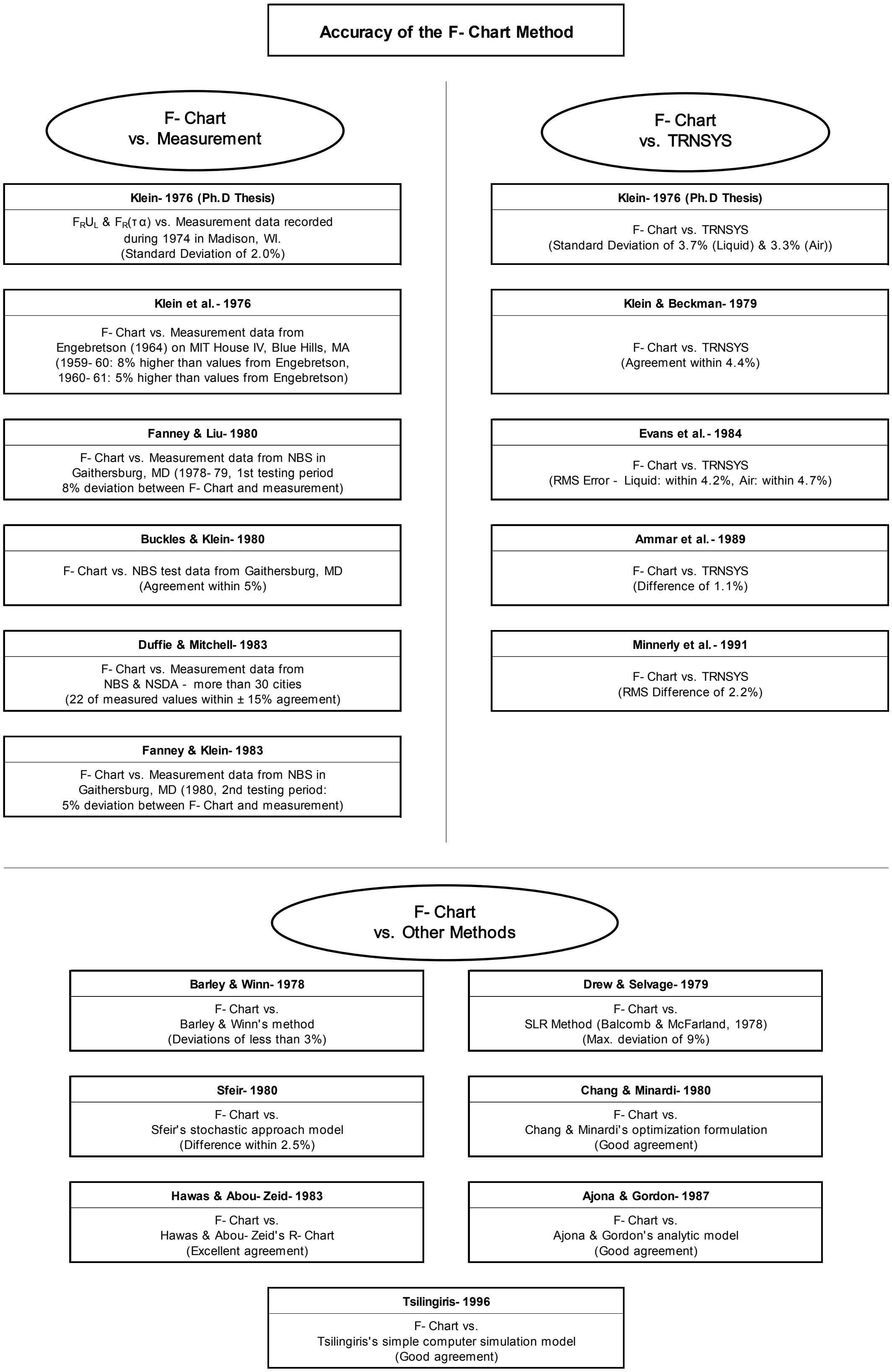
Fanney and Klein (1983) conducted a study of the performance of solar domestic hot water systems at NBS in Gaithersburg, Maryland, for the year 1980. In their study they compared on-site measurements with predictions from F-Chart. Their study showed that the annual solar savings fraction estimated by F-Chart method was within 5 % of the measured value for the five active systems.

In summary, six studies were reviewed that compared solar system performance predicted by F-Chart against data from measurements. These studies showed agreement in the 2 to 15% range.

5.2.2 F-Chart vs. TRNSYS

Klein (1976) compared the prediction results between F-Chart and TRNSYS simulation as part of this Ph.D. work. His results show that the standard deviation between those two methods was 3.7% for the liquid system and 3.3% for the air system.

Klein and Beckman (1979) presented a general design method for closed-loop solar thermal energy systems. In this project they performed a study of the comparison of TRNSYS, F-Chart, and Phi-bar-F-Chart results from six different cities in U.S. and showed that the annual solar load fractions were 0.59, 0.59, and 0.61, respectively, which indicates that the results from the three methods are in good agreement. In the comparison of monthly solar load fractions performed for Madison, Wisconsin, it was shown that the three methods match each other with a difference of only 4.4%.



Accuracy of the F- Chart Method

F- Chart vs. Measurement

Klein- 1976 (Ph.D Thesis)
F_RU_L & $F_R(\tau\alpha)$ vs. Measurement data recorded during 1974 in Madison, WI.
(Standard Deviation of 2.0%)

Klein et al.- 1976
F- Chart vs. Measurement data from Engebretson (1964) on MIT House IV, Blue Hills, MA
(1959- 60: 8% higher than values from Engebretson,
1960- 61: 5% higher than values from Engebretson)

Fanney & Liu- 1980
F- Chart vs. Measurement data from NBS in Gaithersburg, MD (1978- 79, 1st testing period
8% deviation between F- Chart and measurement)

Buckles & Klein- 1980
F- Chart vs. NBS test data from Gaithersburg, MD
(Agreement within 5%)

Duffie & Mitchell- 1983
F- Chart vs. Measurement data from NBS & NSDA - more than 30 cities
(22 of measured values within ± 15% agreement)

Fanney & Klein- 1983
F- Chart vs. Measurement data from NBS in Gaithersburg, MD (1980, 2nd testing period:
5% deviation between F- Chart and measurement)

F- Chart vs. TRNSYS

Klein- 1976 (Ph.D Thesis)
F- Chart vs. TRNSYS
(Standard Deviation of 3.7% (Liquid) & 3.3% (Air))

Klein & Beckman- 1979
F- Chart vs. TRNSYS
(Agreement within 4.4%)

Evans et al.- 1984
F- Chart vs. TRNSYS
(RMS Error - Liquid: within 4.2%, Air: within 4.7%)

Ammar et al.- 1989
F- Chart vs. TRNSYS
(Difference of 1.1%)

Minnerly et al.- 1991
F- Chart vs. TRNSYS
(RMS Difference of 2.2%)

F- Chart vs. Other Methods

Barley & Winn- 1978
F- Chart vs.
Barley & Winn's method
(Deviations of less than 3%)

Drew & Selvage- 1979
F- Chart vs.
SLR Method (Balcomb & McFarland, 1978)
(Max. deviation of 9%)

Sfeir- 1980
F- Chart vs.
Sfeir's stochastic approach model
(Difference within 2.5%)

Chang & Minardi- 1980
F- Chart vs.
Chang & Minardi's optimization formulation
(Good agreement)

Hawas & Abou- Zeid- 1983
F- Chart vs.
Hawas & Abou- Zeid's R- Chart
(Excellent agreement)

Ajona & Gordon- 1987
F- Chart vs.
Ajona & Gordon's analytic model
(Good agreement)

Tsilingiris- 1996
F- Chart vs.
Tsilingiris's simple computer simulation model
(Good agreement)

Figure 2. Accuracy Diagram of the F-Chart Method.

Evans et al. (1985) implemented the F-Chart method in the European climates. In their study they showed that the design method performance predictions for domestic hot water system were within an RMS error of 2.2% of the simulation results. RMS errors of the system performance were estimated to be 4.7% for air systems and 4.2% for liquid systems.

Ammar et al. (1989) investigated optimum parameters for solar domestic hot water systems in Alexandria, Egypt. In their study they compared results from F-Chart and a TRNSYS simulation. They showed that the annual solar fraction predicted by the F-Chart method was only 1.1% different from the value obtained from TRNSYS.

Minnerly et al. (1991) simulated the annual performance of the equivalent simplified system using F-Chart. In their study they showed an RMS difference of 2.2% between the simulated performance of TRNSYS and F-Chart.

In summary, five published studies were reviewed that compared F-Chart and TRNSYS simulations of the same system. These studies showed good agreement, varying from 1.1% to 4.7%, which is slightly better than the results of F-Chart versus measured data. This is expected since the comparison of correlation (which is based on simulations) against a simulation should give better results than either method compared against measured data that contains unavoidable experimental error.

5.2.3 F-Chart vs. Other Methods

Barley and Winn (1978) used the F-Chart method as a verification tool to test the accuracy of a method they developed for sizing optimal solar collectors. In their report they showed good agreement with the F-Chart calculation, showing the deviations of less than 3%.

Drew and Selvage (1979) performed a comparison study between F-Chart and the Simplified Load Ratio (SLR) method developed by Balcomb and McFarland (1978). Their results indicated a discrepancy of 9% solar fraction between the two methods, SLR and F-Chart.

Sfeir (1980) developed a stochastic model for predicting solar system performance. In this study annual solar energy as a function of collector area was compared to the F-Chart results. This study showed that the largest difference between curves generated from the two different methods did not exceed 4% (or 2.5% of the annual load).

Chang and Minardi (1980) developed an optimization formulation for solar heating systems. In their study the results of the optimum collector areas from F-Chart and their model was displayed graphically. Although the graph showed good agreement between the two methods, their published study stopped short of providing any quantitative values for the comparison.

Hawas and Abou-Zeid (1983) developed a general chart (R-Chart) for sizing collectors of solar heating systems and compared their results with those from F-Chart. They concluded that the results of their R-Chart method have a good agreement with the F-Chart method in all cases. However, in a similar fashion as the paper by Chang and Minardi (1980), their paper stopped short of providing any quantitative values for the comparison.

Ajona and Gordon (1987) developed an analytic model for the long-term performance of solar air heating systems and showed the comparison with the F-Chart method. The comparison of results for the annual solar fraction (f) calculated with their analytic model and those corresponding F-Chart results was also presented graphically. However, their paper also stopped short of providing any quantitative values for the comparison.

Tsilingiris (1996) also developed an analytic model for the solar water-heating design. The results from his analytic model were compared with those from the F-Chart method, and the comparison indicated very good agreement between results from his model and F-Chart method. However, his paper also stopped short of providing any quantitative values for the comparison.

In the published literature, the F-Chart method has often been used as a standard to compare new methods against. Although this is of secondary importance to this uncertainty analysis, it is worth noting that F-Chart is so widely used as a standard. In the seven previous studies that were reviewed, agreement varied from 2.5% to 9%, with several studies reporting only graphical comparisons, or qualitative assessments such as “good agreement”, or “excellent agreement”.

5.3 Summary of the Reported Accuracy of F-Chart Method.

The reported accuracy of the F-Chart method has been assessed by reviewing the related accuracy of TRNSYS simulations versus measured data, F-Chart predictions versus measured data, F-Chart predictions versus TRNSYS simulations and F-Chart predictions versus other methods. In summary, hourly TRNSYS simulations versus measured data were shown to be within 5 to 6%, F-Chart predictions versus measured data showed agreement in the 2 to 15% range, and F-Chart predictions versus TRNSYS simulations were shown to vary from 1.1% to 4.7%. A significant number of studies used F-Chart to assess the accuracy of newly developed methods. In these studies agreement varied from 2.5% to 9%.

6 Basic Equations of the *f*-Chart Method

The *f*-Chart method is a correlation of the results of many hundreds of thermal performance simulations of solar heating systems. The resulting simulations give f, the fraction of the monthly heating load (for space heating and hot water) supplied by solar energy as a function of two dimensionless parameters, X (Collector Loss) and Y (Collector Gain). X is related to the ratio of collector losses to heating loads, and Y is related to the ratio of absorbed solar radiation to the heating loads.

Equation 1: $$X = F_R U_L \times \frac{F'_R}{F_R} \times (T_{ref} - \overline{T}_a) \times \Delta\tau \times \frac{A_c}{L}$$

Equation 2: $$Y = F_R(\tau\alpha)_n \times \frac{F'_R}{F_R} \times \frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} \times \overline{H}_T N \times \frac{A_c}{L}$$

where

A_c = Area of solar collector (m^2 or ft^2),
F'_R = Collector-heat exchanger efficiency factor (%),
F_R = Collector heat removal factor (%),
U_L = Collector overall energy loss coefficient (W/m^2-°C or Btu/hr-ft^2-^{o}F),
$\Delta\tau$ = Total number of seconds (SI) or hours (IP) in the month,
$\overline{T}_a$ = Monthly average ambient temperature (°C or °F),
L = Monthly total heating load for space heating and hot water (GJ or MMBtu),
$\overline{H}_T$ = Monthly averaged, daily radiation incident on collector surface per unit area (MJ/m^2 or Btu/ft^2),
N = Number of days in the month,
$\overline{(\tau\alpha)}$ = Monthly average transmittance-absorptance product (%),
$(\tau\alpha)_n$ = Normal transmittance-absorptance product (%), and
T_{ref} = An empirically derived reference temperature (100 °C or 212 ^{o}F).

The F-Chart equations for the fraction *f* of the monthly space and water heating loads supplied by solar energy are the following.

Equation 3: $f = 1.04Y - 0.065X - 0.159Y^2 + 0.00187X^2 - 0.0095Y^3$ **(Air System)**

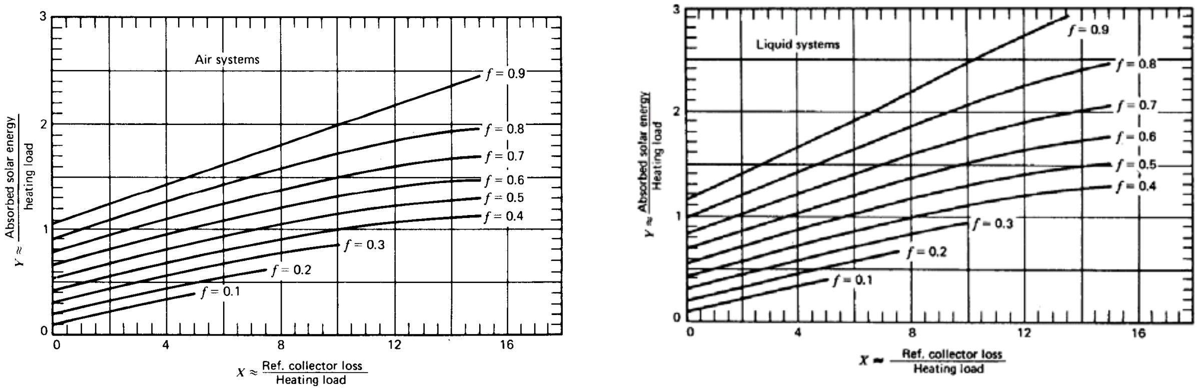
Equation 4: $f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3$ **(Liquid System)**

Figure 3 shows *f*-Chart for both air and liquid systems. The fraction *F* of the annual heating load supplied by solar energy is the sum of the monthly solar energy contributions divided by the annual load.

Equation 5: $$F = \sum fL / \sum L$$

6.1 Example 1: Calculation of Heating Load Supplied by the Solar Energy Using the F-Chart Method (Duffie & Beckman, 1991, p. 691).

One-cover collectors are used for designing a solar heating system for Madison, Wisconsin (latitude 43 °). The values of $F_R(\tau\alpha)_n$ and $F_R U_L$ were determined from standard collector tests as 0.74 and 4.00 W/m^2 °C (0.704 Btu/hr-ft^2-F), respectively. The collector faces south and has a slope of 60° from the horizontal. In January, Madison has an average daily radiation of 11.9 MJ/m^2 (1,048 Btu/ft^2) on a 60° surface and an average ambient temperature of –7 °C (19.4 °F). The monthly heating load for both space and hot water in January is 36.0 GJ (34 MMBtu) and F'_R / F_R, the collector-heat exchanger correction factor, is 0.97. The monthly average to normal incidence transmittance-absorptance product is 0.96. The collector loss, *X*, and collector gain, *Y*, and *f* for these conditions, with a collector area of 50 m^2 (538 ft^2) can be calculated as follows using the F-Chart method, resulting in the fraction of the annual heating load supplied by solar energy.



(a) Air Systems (b) Liquid Systems

Figure 3. The f-Charts for Systems Using Air and Liquid Heat Transfer and Storage Media (Duffie & Beckman, 1991).

<u>Solution for the liquid system:</u>

From Equations 1 and 2 with A$_c$=50 m^2,

$$X = F_R U_L \times \frac{F'_R}{F_R} \times (T_{ref} - \overline{T}_a) \times \Delta\tau \times \frac{A_c}{L}$$

= (4.0) x 0.97 x [100-(-7)] x (31 x 86,400) x (50)/(36.0x10^9) = **1.54**

$$Y = F_R(\tau\alpha)_n \times \frac{F'_R}{F_R} \times \frac{\overline{(\tau\alpha)}}{(\tau\alpha)_n} \times \overline{H}_T N \times \frac{A_c}{L}$$

= 0.74 x 0.97 x 0.96 x (11.9x10^6) x 31 x (50)/(36.0x10^9) = **0.35**

From Equation 4 or Figure 3 (b),

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3$$

$$= 1.029 \times 0.35 - 0.065 \times 1.54 - 0.245 \times 0.35^2 + 0.0018 \times 1.54^2 + 0.0215 \times 0.35^3 = \mathbf{0.24}$$

Yielding an energy delivery from the solar heating system in January of

$$\boldsymbol{f}\mathbf{L} = 0.24 \times 36.0 = \mathbf{8.6\ GJ}$$

The fraction (***F***) of the annual heating load, which is supplied by solar energy, is then determined by repeating the calculation of *X*, *Y*, and *f* for each month and summing the results as indicated by Equation 5. Table 1 shows the results of these calculations for the entire months of the year. From Equation 5, the annual fraction of the load supplied by solar energy is

***F* = 85.9/203.2 = 0.42 (42% from solar energy)**

Month	$\overline{H}_T$		$\overline{T}_a$		L		X	Y	f	fL	
	(MJ/m^2)	[Btu/ft^2]	(°C)	[°F]	(GJ)	[MMBtu]				(GJ)	[MMBtu]
Jan.	11.9	1048.0	-7	19.4	36	34.1	1.54	0.35	0.24	8.6	8.2
Feb	15.5	1365.0	-6	21.2	30.4	28.8	1.64	0.49	0.35	10.5	10.0
Mar	15.8	1391.4	0	32.0	26.7	25.3	1.95	0.63	0.44	11.7	11.1
Apr	14.5	1276.9	7	44.6	15.7	14.9	2.98	0.96	0.60	9.4	8.9
May	15.4	1356.2	13	55.4	9.2	8.7	4.91	1.73	0.88	8.1	7.7
Jun	15.9	1400.2	19	66.2	4.1	3.9	9.93	4.01	1.00	4.1	3.9
Jul	16.3	1435.4	21	69.8	2.9	2.7	14.15	6.01	1.00	2.9	2.7
Aug	16.6	1461.9	20	68.0	3.4	3.2	12.23	5.22	1.00	3.4	3.2
Sep	15.8	1391.4	15	59.0	6.3	6.0	6.78	2.59	1.00	6.3	6.0
Oct	14.9	1312.1	10	50.0	13.2	12.5	3.54	1.21	0.71	9.4	8.9
Nov	9.6	845.4	1	33.8	22.8	21.6	2.18	0.44	0.27	6.2	5.9
Dec	8.5	748.5	-5	23.0	32.5	30.8	1.68	0.28	0.16	5.3	5.0
Total					203.2	192.6				85.9	81.4

Table 1. Monthly Heating Load Calculations Using the F-Chart Method.

The above example demonstrates how the F-Chart program is used in the ESL's eCALC to calculate the energy savings from the installation of a solar thermal system.

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