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FCHART PROGRAM DOCUMENTATION

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I. FCHART PROGRAM OVERVIEW

INTRODUCTION

This report presents the program documentation for the FCHART computer model developed at the University of Wisconsin — Madison, College of Engineering. This document highlights and explains the various components comprising the FCHART interactive program.

Specifically, this document includes descriptions of:

- FCHART Program Narrative
- FCHART Program Overview
- FCHART Model Components
- FCHART Thermal Analysis
- FCHART Economic Analysis

PROGRAM NARRATIVE

FCHART is a computer model which calculates domestic water and space heating loads for residential and commercial buildings. This thermal analysis of performance standards of active solar space and domestic water heating systems can be accomplished for either water or air as the transfer fluid. FCHART is also capable of performing life-cycle cost analyses of solar space and water heating of various levels of intricacy.

FCHART is written in the FORTRAN II compiler language and consists of a main program utilizing subroutines and functions. The subroutines and functions are as follows:

- CALC
- ECON

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- YESNO
- READIN
- TAUALF
- RBAR
- CYREAD
- SLREAD
- DDREAD
- TAREAD

A further explanation of each of these routines appears later in this section. FCHART is designed to function on a computer in an interactive mode and is currently available at the FEA/OSI Computer Installation.

The following "data blocks" contain the weather and location data needed to facilitate program operation:

- CITYDATA
- SOLDATA
- DDDATA
- TADATA
- TEXT

These data blocks contain the following types of information:

- CITYDATA - City labels and latitudes
- SOLDATA - Monthly long-term average total solar radiation data (horizontal surface)
- DDDATA - Monthly long-term average degree-days
- TADATA - Monthly long-term average ambient temperatures
- TEXT - Format information

Current FCHART data exists for 126 cities within the United States and Canada. Given the above data criteria, the FCHART model becomes a method one can use in order to design economical solar space and water heating systems for residential and commercial buildings.

FCHART PROGRAM GENERAL FLOW

The program overview for the FCHART model presents a macro level flowchart of the FCHART program. The program overview

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depicts major FCHART routines and processes and how they are associated with the other major FCHART routines and processes. The logical flow and operations of the various FCHART routines combine together to form the FCHART model. Exhibit I-1 on the following page presents the FCHART Program Overview.

FCHART MODEL COMPONENTS

The FCHART model is comprised of a main program, eight subroutines, two functions and four data blocks. The following paragraphs present a description of each of these FCHART program components. A summary matrix of the FCHART model components is presented in Exhibit I-2.

Main Program

The FCHART main program is the hub of the various FCHART program components. The main program controls the logic to process the subroutines, functions and data blocks as well as the logic to control the program interactivity. The main program also specifies those variable values to initialize subroutines for processing. These default values are supplied by the main program unless overridden by user supplied parameters.

The purpose of the main program is to accept the specified information from the four input data blocks and from the user specified parameters such that the thermal and econometric analyses can be processed and outputs can be generated. Therefore, the main program serves as the controlling mechanism for all FCHART subroutines, functions and data blocks.

FCHART Subroutines

CALC - The CALC subroutine is the portion of the FCHART model which performs the thermal analysis. CALC determines the monthly and yearly domestic water loads and space heating loads. CALC facilitates the optimization of the solar collector area such that the present worth of costs with solar over a pre-determined amount of time are minimized. The CALC subroutine also calculates the:

- Percent solar
- Number of degree days
- Incident solar

Exhibit I-1

FCHART Program Overview

Exhibit I-2

Summary Matrix of FCHART Model Components

COMPONENTS	DESCRIPTION
1. MAIN Program	A central program logic controller
2. Subroutines	
2a. CALC	Performs thermal analysis
2b. ECON	Performs economic analysis
2c. YESNO	Accepts user specified parameters
2d. READIN	Reads user supplied inputs and returns values to the MAIN program
2e. CYREAD	Reads city and latitude data for 126 cities
2f. SLREAD	Reads monthly long-term average total solar radiation for 126 cities
2g. DDREAD	Reads monthly long-term average degree-days for 126 cities
2h. TAREAD	Reads monthly long-term average ambient temperatures for 126 cities
3. Functions	
3a. RBAR	Calculates ratio of daily extraterrestrial radiation incidence of a tilted surface
3b. TAUALF	Calculates transmittance-absorptance product
4. Data Blocks	
4a. CITYDATA	Contains name and latitude of 126 cities
4b. SOLDATA	Contains monthly long-term average solar radiation data for 126 cities
4c. DDATA	Contains long-term average degree-days for 126 cities
4d. TADATA	Contains monthly long-term average ambient temperatures for 126 cities

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A detailed explanation of the FCHART thermal analysis appears later in this document in Chapter II.

ECON - The ECON subroutine of the FCHART model performs the FCHART economic analysis. In particular, the ECON subroutine performs a life-cycle cost analysis whereby the present worth of yearly costs with and without a solar system are calculated over the life of the system. A detailed description of the FCHART economic analysis is presented later in this document in Chapter III.

YESNO - The purpose of the YESNO subroutine is to accept user specified parameters for "YES-NO" questions. YESNO sets the IFLG flag to "1" for a "yes" response and the IFLG flag to "0" for a "no" response.

READIN - The READIN subroutine performs the function of free-format card reading. That is, input values specified by the user are accepted regardless of where they might appear in an 80 character card image. This flexible routine foregoes the user from having to "key-in" input values into specific columns or specified fields. This subroutine reads the user supplied inputs and returns those values to the MAIN program.

CYREAD - This subroutine reads and enters into the processing program the city data and associated latitudes for the 126 cities used by FCHART.

SLREAD - This subroutine reads and enters into the processing program the monthly long-term average total solar radiation data for the 126 cities used by FCHART.

DDREAD - The DDREAD subroutine reads and enters into the processing program the monthly long-term average degree days for each of the 126 cities.

TAREAD - This subroutine reads and enters into the processing program the monthly long-term average ambient temperatures for the 126 cities.

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FCHART Functions

RBAR - The purpose of this function is to calculate the ratio of daily extraterrestrial radiation incidence on a titled surface to that of daily intraterrestrial radiation incidence on a horizontal surface.

TAUALF - The purpose of this function is to calculate the transmittance - absorptance product for a solar collector with n glass covers.

FCHART Data Blocks

CITYDATA - The CITYDATA data block contains the names of each of the 126 cities used in FCHART plus their associated latitudes.

SOLDATA - The SOLDATA data block contains, for each of the 126 FCHART cities, monthly long-term average total solar radiation data.

DDDATA - Monthly long-term average degree-days for the FCHART 126 cities is contained in the DDDATA data block.

TADATA - The TADATA data block contains the monthly long-term average ambient temperatures for the FCHART 126 cities.

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II. DESCRIPTION OF THERMAL ANALYSIS

FCHART THERMAL ANALYSIS (CALC)

The FCHART thermal analysis is generated by the CALC subroutine of the FCHART model. The CALC subroutine performs all of the calculations involved in the thermal analysis. The following calculations encompass the thermal analysis:

- Percent solar
- Incident solar
- Space heating load
- Domestic water load
- Degree-days
- Ambient temperature

All of the above calculations are computed by month and year. The solutions to these computations may be obtained in either English or Scientific Units, dependent upon user specification. CALC utilizes certain parameters in order to facilitate the thermal analysis. These parameters and a brief description of them follows:

- XLIST - An array which contains user supplied values that become system parameters
- XLOAD - Contains user supplied (optional) monthly load factors

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- RHO - Contains ground reflectance values
- IU - The unit, in either English or Metric specifications.

The CALC subroutine has the capability to optimize the collector area such that the present worth of a solar energy system is minimized. This optimization is accomplished by an iterative type search routine. In the following paragraphs, a detailed description is presented for the variables calculated for the thermal analysis.

Percent Solar

Percent Solar equals $F(J)$

Where $J = 1, 2, \dots, 12$ for 12 months

and F_{YR} for yearly percent solar

Preliminary values must be computed before percent solar can be calculated.

First, $F1(J) = 1.029y - .065x - .245y^2 + .0018x^2 + .0215y^3$

for a water system,

and $F1(J) = 1.040y - .065x - .159y^2 + .00187x^2 - .0095y^3$

for an air system,

where $X = XDA * \text{Area of Collector}$

and $Y = YDA * \text{Area of Collector}$

and $XDA = XLIST(3) * (T_{REF} - TAMB) * 24 * \# \text{ days in } J^{\text{th}} \text{ month} / TOTLM$

and $YDA = XLIST(4) * S * TARAT;$

where T_{REF} is the reference temperature (100°C or 212°F)

and $TAMB$ is the ambient temperature for month J .

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TOTLM is the total monthly load which is the sum of the monthly domestic water load and the monthly space heating load.

XLIST(3) is FRPRIME-TAU-ALPHA PRODUCT

and XLIST(4) is FRPRIME-UL PRODUCT, both of which are user supplied parameters.

S is incident solar which will be defined later.

TARAT is the ratio of the average transmittance-absorptance product to that at normal incidence.

Second, $F1 = 1.029y - .067x - .245y^2 + .0018x^2 + .0251y^3$

where x and y are defined as before.

Finally $F(J) = [F1 * DWLM(J) + F(J) * SHLM(J)] / TOTLM(J)$

where DWLM is the monthly domestic water load

and SHLM is the monthly space heating load.

Both DWLM and SHLM will be defined later. The yearly percent solar is FYR, defined as:

$$FYR = QUYR / TOTLYR$$

$$\text{where } QUYR = \sum_{j=1}^{12} F(J) * TOTLM(J)$$

FYR is a measure in percent of the total yearly load that can be accounted for by solar.

Incident Solar

The CALC subroutine also determines the value of Incident Solar.

Incident Solar equals S(J) for the 12 months

and equals SOLYR for yearly total.

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The incident solar for the J^{th} month is

$$S(J) = H(J) * DD\text{CONV} * R\text{BAR}(Z)$$

where $H(J)$ = monthly long-term average radiation incident on a horizontal surface

and $DD\text{CONV} = 1$ or $9/5$ (a conversion factor between Celcius and Fahrenheit).

$R\text{BAR}$ is a function which calculates the ratio of daily extraterrestrial radiation incident on a tilted surface to that of a horizontal surface. Some of the input values to $R\text{BAR}$ are latitude, collector slope, azimuth angle, $H(J)$, $R\text{HO}(J)$, and the number of transparent covers.

$$\text{SOLYR} = \sum_{j=1}^{12} S(J) \quad \text{is the total yearly incident solar.}$$

Space Heating Load

Also determined by the CALC subroutine is the space heating load which is SHLM for each month and SHLYR for the year.

$$\text{SHLM}(J) = \text{XLOAD}(J) * \# \text{ days in month } J + \text{XLIST}(9) * \text{DD}(J) - \text{XLIST}(10) * \# \text{ days in month } J$$

where $\text{XLOAD}(J)$ is the user supplied monthly load factors

and $\text{XLIST}(9)$ is Effective Building UA ,

$\text{DD}(J)$ is degree days for month J

and $\text{XLIST}(10)$ is constant daily building heat generation.

Note that either $\text{XLOAD}(J) = 0$ or $\text{XLIST}(9) = 0$.

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The yearly space heating load equals:

$$SHLYR = \sum_{j=1}^{12} SHLM(J)$$

Similarly the domestic water load is calculated as SWLM for each month and DWLYR for yearly total.

$$DWLM(J) = \# \text{ days in month } j * XLIST(11) * Cp * (XLIST(12) - XLIST(13))$$

where XLIST(11) is hot water usage,

XLIST(12) is water set temperature

and XLIST(13) is water main temperature.

In other words the monthly domestic water load equals the number of days in the month multiplied by the amount of water used multiplied by the number of BTU's necessary to raise the temperature of water 1° multiplied by the number of degrees that the temperature of water must be raised.

The yearly domestic water load equals:

$$DWLRY = \sum_{j=1}^{12} DWLM(J).$$

Degree-Days

The FCHART thermal analysis also determines degree-days and ambient temperature. Monthly long-term degree-days and ambient temperature are a function of the information contained in the data blocks, DDATA and TADATA. The yearly long-term average degree-day is calculated as follows:

$$DWLYR = \sum_{j=1}^{12} DD(J).$$

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III. DESCRIPTION OF ECONOMIC ANALYSIS

FCHART ECONOMIC ANALYSIS (ECON)

The FCHART economic analysis is generated by the ECON subroutine of the FCHART model. This routine performs the life-cost analysis of the thermal system. The ECON subroutine calculates the present worth of yearly total costs for solar and conventional systems.

The following computations are also computed within the economic analysis of FCHART. These computations are:

- Yearly mortgage payment
- Yearly interest paid
- Income tax saved
- Auxilliary fuel expense
- Miscellaneous expenses
- Yearly total solar costs
- Yearly total non-solar costs
- Initial cost of the solar system

In each case values are computed for several areas until the optimized area is determined. The optimized area is the area of the collector such that the present worth of yearly total costs with a solar system is minimum.

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The following is the economic theory for the present worth analysis:

- Yearly cost with solar equals:
Mortgage payment + Backup system fuel cost + miscellaneous cost + property tax increase - "solar" income tax credit
- Yearly cost without solar equals:
Conventional system fuel cost - "non-solar" income tax credit

where for a non-income producing building:

- "Solar" income tax credit equals:
Tax rate * (interest paid + property tax paid)
- "Non-solar" income tax credit equals: 0

and for commercial buildings:

- "Solar" income tax credit equals:
Tax rate * (interest paid + property tax paid + miscellaneous expense + backup system fuel cost + depreciation)
- "Non-solar" income tax credit equals:
Tax rate * (conventional system fuel costs).

Present worth for yearly total costs with a solar system equals:

$$\text{Downpayment} + \sum_{I=1}^{\text{Length of Analysis}} (\text{yearly cost with solar}) / (1 + \text{discount rate})^I$$

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and, present worth for yearly total costs without solar equals:

$$\sum_{I=1}^{\text{Length of analysis}} (\text{yearly cost without solar}) / (1 + \text{Discount rate})^I$$

The equations and algorithms which comprise the life cost analysis are now described.

Parameters Passed to ECON from CALC

The following parameters are passed from the CALC subroutine to the ECON subroutine:

IOPMUM = $\begin{cases} 0 & \text{- not optimized} \\ 1 & \text{- optimized} \end{cases}$

XLIST = user supplied parameters

ORGINV = original investment = Area + cost/ft² of collector + fixed cost

TOTLYR = total yearly load for space and water heating

FYR = fraction of total heating load due to solar

PWSOL = present worth of yearly total costs with solar

PWCON = present worth of yearly total costs without solar

IERR = error code

IU = units

ECON Computed Values

The following values are computed by the ECON subroutine:

LENGTH = period of economic analysis = XLIST(18)

AINTRT = annual interest rate = XLIST(22)/100

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N = term of mortgage = XLIST(23)

DISCRT = annual discount rate = XLIST(24)/100

DOWNPT = downpayment = ORGINV * XLIST(21)/100

ICMR = XLIST(34) = $\begin{cases} 1 & \text{- if income producing building} \\ 2 & \text{- if residence} \end{cases}$

EFFTXR = effective federal income tax rate = XLIST(32)/100

PRPTXR = property tax rate = XLIST(33)/100

XMISCI = miscellaneous expenses of system in first year = XLIST(25)

GINFLA = Annual increase in miscellaneous expenses = XLIST(26)/100

CFINIT = Initial cost of auxilliary fuel = XLIST(27)

IOPTCF = XLIST(28) = $\begin{cases} 1 & \text{- linear rise in Conventional Fuel cost} \\ 2 & \text{- yearly rise} \\ 3 & \text{- sequence} \end{cases}$

SLOPE = XLIST(29) if IOPTCF = 1

FINFLA = XLIST(30)/100 = rate of Cf rise if IOPTCF = 2

IOPTDP = XLIST(35) = $\begin{cases} 1 & \text{- straight line depreciation} \\ 2 & \text{- decreasing balance} \\ 3 & \text{- sum of years digits} \\ 4 & \text{- none} \end{cases}$

POFSL = XLIST(36)/100 = % of straight line depreciation if IOPTDP = 1

LIFE = XLIST(37) = useful life

SALVAL = XLIST(38) = salvage value

IOTYPE = XLIST(31) = $\begin{cases} 1 & \text{- printout by year} \\ 2 & \text{- cummulative} \end{cases}$

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Yearly Cost of Auxilliary Fuel Computation

The computations of the yearly cost of auxilliary fuel are as follows:

If IOPTCF = 1 (linear rise)

$$\Rightarrow CF(I) = CFINIT + SLOPE * (I-1); I = 2, 3, \dots, \text{length}$$

If IOPTCF = 2 (yearly rise)

$$\Rightarrow CF(I) = CFINIT * (1 + FINFLA)^{I-1}; \\ I = 2, 3, \dots, \text{length}$$

If IOPTCF = 3 (sequence)

$$\Rightarrow CF(I) = SEQ(I) \quad \forall I$$

Yearly Depreciation

The following are computations of yearly depreciation:

If ICOMR = 1 (income producing building)

then

If IOPTDP = 1 (straight line depreciation)

$$\Rightarrow DEPYR(I) = (ORGINV - SALVAL) / LIFE \\ \text{for all } I=1, \dots, \min(LIFE, LENGTH).$$

If IOPTDP = 2 (decreasing balance)

$$\Rightarrow DEPYR(I) = \frac{ORGINV_I - POFSL}{LIFE}$$

for all $I \geq ORGINV \geq SAVVAL$ and $I \leq LIFE$

and $ORGINV_I = ORGINV_{I-1} * (1 - POFSL/LIFE) \quad \forall I \geq LIFE$

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If IOPTDP = 3 (sum of year digit)

$$\Rightarrow \text{DEPYR}(I) = \frac{(\text{LIFE} - I + 1)}{(\text{LIFE} * \text{LIFE} + \text{LIFE})/2} * (\text{ORGINV-SALVAL})$$

$\forall I \leq \text{LIFE}$

If IOPTDP = 4 (none)

$$\Rightarrow \text{DEPYR}(I) = 0; \forall I$$

If ICOMR = 2 (residence building)

$$\text{then } \text{DEPYR}(I) = 0; \forall I.$$

Yearly Mortgage Payment

The following presents the computation of the yearly mortgage payment:

$$\text{FACTOR} = (1 + \text{AINTRT})^N; N = \text{term of mortgage}$$

$$\text{PAYMT} = (\text{ORGINV-DOWNPT}) * \text{AINTRT} * \frac{\text{FACTOR}}{(\text{FACTOR} - 1)}.$$

Note that $\frac{\text{AINTRT} * \text{FACTOR}}{(\text{FACTOR} - 1)}$ is the capital recovery factor.

$$\text{APAYMT}(I) = \begin{cases} \text{PAYMT} & \text{for } I < N \\ 0 & \text{for } I > N \end{cases}$$

or

$$\text{APAYMT}(I) = \text{annual mortgage payment.}$$

Other Present Worth Computations

The following computations are necessary to compute present worth,

where $I = 1$ through length:

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$PRINC_1$ = initial principle = $ORGINV - DOWNPT$

$$PRINC_{I+1} = \begin{cases} PRINC - APAYMT(I) - XINTPD(I); & 1 < I \leq N \\ 0; & j > N \end{cases}$$

$XINTPD(I)$ = interest paid = $\begin{cases} PRINC * AINTRT & \text{if } XINTPD < APAYMT \\ APAYMT & \text{if } XINTPD > APAYMT \end{cases}$

$TAXLOS(I)$ = property tax increase = $PRPTXR * ORGINV$

$XMISC(I)$ = Miscellaneous yearly costs = $XMISC1 * (1 + GINFLA)^{I-1}$

$FRACSL$ = fraction of total heating load due to solar = FYR

$FUELCT$ = backup system fuel costs

or

$FUELCT = (1 - FRACSL) * TOTLYR * CF(I).$

If $ICOMR = 1$ (income producing building) then

$CONCST(I) = \text{yearly coventional system cost} = TOTLYR * CF(I) * (1 - EFFT XR)$

and $TAXSAV(I) = \text{"solar" income tax credit for commercial building} = EFFT XR * (FUELCT + XMISC(I) + XINTPD(I) + DEPYR(I) + TAXLOS(I))$

If $ICOMR = 2$ (Residence building) then

$CONCST(I) = \text{yearly conventional system cost} = TOTLYR * CF(I)$

and $TAXSAV(I) = \text{"solar" income tax credit for residence building} = EFFT XR * (XINTPD(I) + TAXLOS(I))$

$SOLCST(I) = \text{yearly solar system cost} =$

$FUELCT + APAYMT(I) + XMISC(I) + TAXLOS(I) - TAXSAV(I)$

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SOLSAV(I) = savings of solar to non-solar = CONCST(I) - SOLCST(I)

Present Worth Calculation

The following presents the present worth calculation:

PWSOL = present worth of yearly total costs with solar =

$$\text{DOWNPT} + \sum_{I=1}^{\text{length}} \text{SOLCST}(I) / (1 + \text{DISCRT})^I$$

PWCON = present worth of yearly total costs without solar =

$$\sum_{I=1}^{\text{length}} \text{CONCST}(I) / (1 + \text{DISCRT})^I.$$