University of Jordan
Faculty Graduate Studies

OPTIMIZATION STUDY OF DESIGN REQUIREMENTS OF CENTRAL HEATING RADIATORS FOR JORDANIAN INDUSTRY

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UNDER THE SUPERVISION OF

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TO
MY MOTHER ;
BROTHERS AND SISTERS ;
FRIENDS ;
FOR THEIR ENCOURAGEMENT DURING MY WORK

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NOMENCLATURE

Ac	Cross section area of fin (m^2) ;
As	Surface area (m^2);
c	Constant for natural convection ;
C,C1	Constants for cost ;
g	Acceleration due to gravity (m^2/s) ;
h	Heat transfer coefficient (w/m^2°C)
k	Thermal conductivity (w/m °C) ;
L	Face length of element (m);
m	Mass (Kg);
n	Number of subintervals;
Nu	Nusselt number ;
P	Fin perimeter (m) ;
Pr	Prandtl number ;
q	heat flux (w/m^2)
Q	Heat transfer rate (w) ;
Ra	Rayleigh number ;
Re	Reynold number ;
Xc	Cavity opening in x-direction (m);
XR	Width of radiator (m) ;

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Q	Heat transfer rate (w) ;
Ra	Rayleigh number ;
Re	Reynold number ;
Xc	Cavity opening in x-direction (m);
XR	Width of radiator (m) ;

fa	Fin actual ;
fi	Fin ideal ;
r	Radiation ;
s	Surface ;
t	Total ;

Abbreviation

CEF	Carbon Equivalent Factor ;
C.H.	Central Heating ;
C.I	Cast Iron ;
C.H.R	Central Heating Radiator ;
C.I.R	Cast Iron Radiator ;
HED	Heat Exchanger Design ;
RSS	Royal Scientific Society ;

fa	Fin actual ;
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Abbreviation

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ABSTRACT

OPTIMIZATION STUDY OF DESIGN REQUIREMENT OF CENTRAL HEATING RADIATORS FOR JORDANIAN INDUSTRY

PREPARED BY : Haroon Faraj Al-Hamdan
SUPERVISOR : Prof. Mohammad Al- Sa'ad
Dr. Sabah Al- Bermani

The objective of this research is to study the optimum design of cast iron radiators (C.I.R) for the Jordanian industry. A computer program was used to simulate the heat transfer equations to calculate the minimum mass required to produce a certain quantity of heat effect.

The results showed that the minimum geometrical conditions for cast iron radiator are to be 2.85cm for the cavity opening and 12.5cm for radiator width for a height ranging from 60cm to 55 cm and for temperature difference 10°C and 20°C, respectively.

A comparison study is made between the optimum radiators suggested in this study and the radiators available in the local market. The results showed that the materials needed by the present study is 9% to 15% less than the materials required by radiators in the local market.

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Radiators are the most important components in a central heating system . They constitutes the visible architectural feature of the system , and they make the bulk of it . Therefore , a careful study and design of radiators will raise the efficiency of the whole heating system .

A great variety of radiators are available that differ in size , shape and cost but offer the same heat effect . Frequently, the shape and size is optimized by minimizing the mass of material used to manufacture a radiator for a prescribed heat effect . If the radiator is manufactured from a uniform material , the problem is reduced to a minimum surface area required .

Theoretically , radiators can be modelled as a plate - fin configuration separating two fluids . Therefore , using numerical heat transfer to simulate variations affecting the optimization process is a solution for the minimum surface area with the highest heat effect that can be attained .

The shape and size of radiators are controlled by many factors . The most important ones are :

- Cost and conditions of production : To design any radiator , it is necessary to have a shape which is easy to produce and manufacture at a reasonable cost .
- Overall appearance : Because radiators are the visible part of a heating system they have to be architecturally acceptable .

- Material used : It is quite important to have a material which is available and easy to handle . It should also be rigid enough to withstand a long life .

The present study focuses attention on radiators produced from gray cast iron , because of their long service life . All the previously mentioned factors affecting the optimization process are taken into consideration in order to reach a satisfactory product.

1.2 Objective of research

The increased use of central heating (C.I.) systems in Jordan , and the availability of raw material are important reasons to carry this study . Because there are no factories producing cast iron radiators (C.I.R) in Jordan great quantities are imported from other countries . Present objective is to compare the economical aspects of cast iron radiators (C.I.R) imported from foreign countries with those expected to be produced in Jordan .

The present study is concerned with applying numerical analysis techniques to obtain the optimum geometry for C.I.R to obtain the maximum amount of heat effect with a minimum surface area and can be manufactured locally .

1.3 Layout of the thesis

This study is divided into six chapters . The first chapter is an introduction . The second chapter summarizes some of the previous scientific researches in this field . The third chapter presents the theoretical background , followed by a discussion of local production possibilities in chapter four . Results of the study are presented in chapter five . Finally chapter six presents the conclusions reached by the present work and recommendation for further investigations and possibilities local production of the C.I.R.

CHAPTER TWO
LITERATURE SURVEY

Researchers in industrially advanced countries made several researches to increase the quality of the radiators as a kind of heat exchanger . These studies and research work have dealt with both theoretical and experimental aspects , they focused on several parameters related to increased performance of heat exchangers.

Extended surfaces are used in applications to improve heat transfer . When analyzing fins, it is usually assumed that heat transfer coefficient is specified in advance . Assuming this, the temperature distribution of a fin with a known geometry is easily obtained analytically or numerically.

In actual practice the heat transfer coefficient is not specified in advanced ,especially when natural convection is considered , the heat transfer coefficient is greatly affected by the surface temperature distribution of the fin. Thus there exists a highly coupled interaction between convection in a fluid and conduction in the fin . Heat transfer of a fin is only obtained accurately by solving simultaneously convection and conduction heat transfer equations.Only a few articles on fin heat transfer have taken the coupling between convection and conduction into consideration [1 , 2].

While Karvinen [3] studied the natural and forced convection heat transfer form a straight fin of variable cross section , coupling between surface temperature and convection heat transfer has been treated approximately in the case of forced and natural convection . Finally , general efficiency charts of straight fins with different kinds of cross section

In the thermal analysis of vertical fins , it is usually assumed that the fin is isothermal . This may be a reasonable assumption for short fins with high thermal conductance .

However long fins with low conductance would not be isothermal and for the estimation of heat transfer from such fins , the conjugate problem of conduction within the fin and natural convection in ambient fluid should be considered . A numerical solution of this problem for a short plate fin in a fluid with Prandtl Number (Pr = 0.72) was obtained by Sparrow and Acharya [4] . Kuehn et al. [5] presented a solution for the conjugate free convection heat transfer from a vertical fin of infinite length and obtained results for a uniform conductivity plate fin as a function of the fluid Prandtl number , while Hismaskera [6] presented a solution for the heat transfer rates from vertical fin with variable conductivity and thickness . The solution for the special case of fin with constant thickness and conductivity has been compared with that of Kuehn et al . [5] . An experiment was carried out by Aihara and Maruyama [7] on free convective and radiative heat transfer from dense pin-fin arrays with a vertical isothermal base plate.

Fins are of great practical importance in compact heat exchangers, finned tubes , etc . For a given fin mass , the fin can dissipate various quantities of heat, depending on its shape and geometry. Optimizing the fin to find the shape that would dissipate the maximum heat for a given mass, is an important feature in fin design .

Ullmann and H. Kalaman [8] used a set of idealizing assumptions necessary for the optimizing the fins, and the following are the most

1- The temperature profile is constant.

2- The fin material is homogenous which means that the thermal conductivity and the density are constant (their dependence on temperature is negligible).

3- The heat transfer coefficient between the fin surface and environment is constant.

4- The thickness is small compared to its length, therefore the temperature gradients are only in one direction.

5- The temperatures of the fin base and the surrounding environment are constant.

6- The heat transferred through the edge of the fin is neglected compared to the heat removed from the entire surface of the fin.

Based on the above assumptions Ullmann and Kalaman [8] determined by solving numerically the differential equations the optimum dimensions of four different shapes of annular fins (rectangular, triangular, hyperbolic and parabolic) .Also, Mikk [9] found the optimum fin thickness variation along the fin.

Heat exchanger design (HED) is a composite discipline, combining knowledge and expertise from several fields : heat transfer, mathematical methodology in current use is the well known Case Study Method . The conventional means of solving a HED problem is the Fortran program . A new approach to problem formulation and solution was suggested by Henry and Willmott [10] , although the technique described can be applied to all of heat exchangers .

According to the importance of this subject an extensive review of numerous experimental , analytical and numerical investigation on heat exchangers was studied by many researchers . Himanshu and Webb [11] presented analytical models to predict the heat transfer coefficient and friction factor of the offset strip - fin heat exchangers . Equations were developed for the Nusselt number and friction factor by writing energy and momentum balances on a unit cell of the offset-strip-fin geometry .

A numerical method to determine the effectiveness of the cross flow heat exchanger, accounting for the effect of the two-dimensional longitudinal heat conduction through the exchanger wall structure in the directions of fluid flow was presented by Chiou [12] . The exchanger effectiveness and its deterioration due to the conduction effect have been calculated for various designs and operating conditions of the exchanger . The results indicate that the thermal performance deterioration of the exchanger may be significant for some typical applications .

London and Seban [13] presented a general method for heat exchanger design in addition to the common method of the long-mean-rate equation . Also they presented the exchanger effectiveness concept and a generalized method of calculating the counter flow and parallel - flow heat

CHAPTER THREE

DESIGN OPTIMIZATION OF CAST IRON RADIATORS

3.1 Introduction

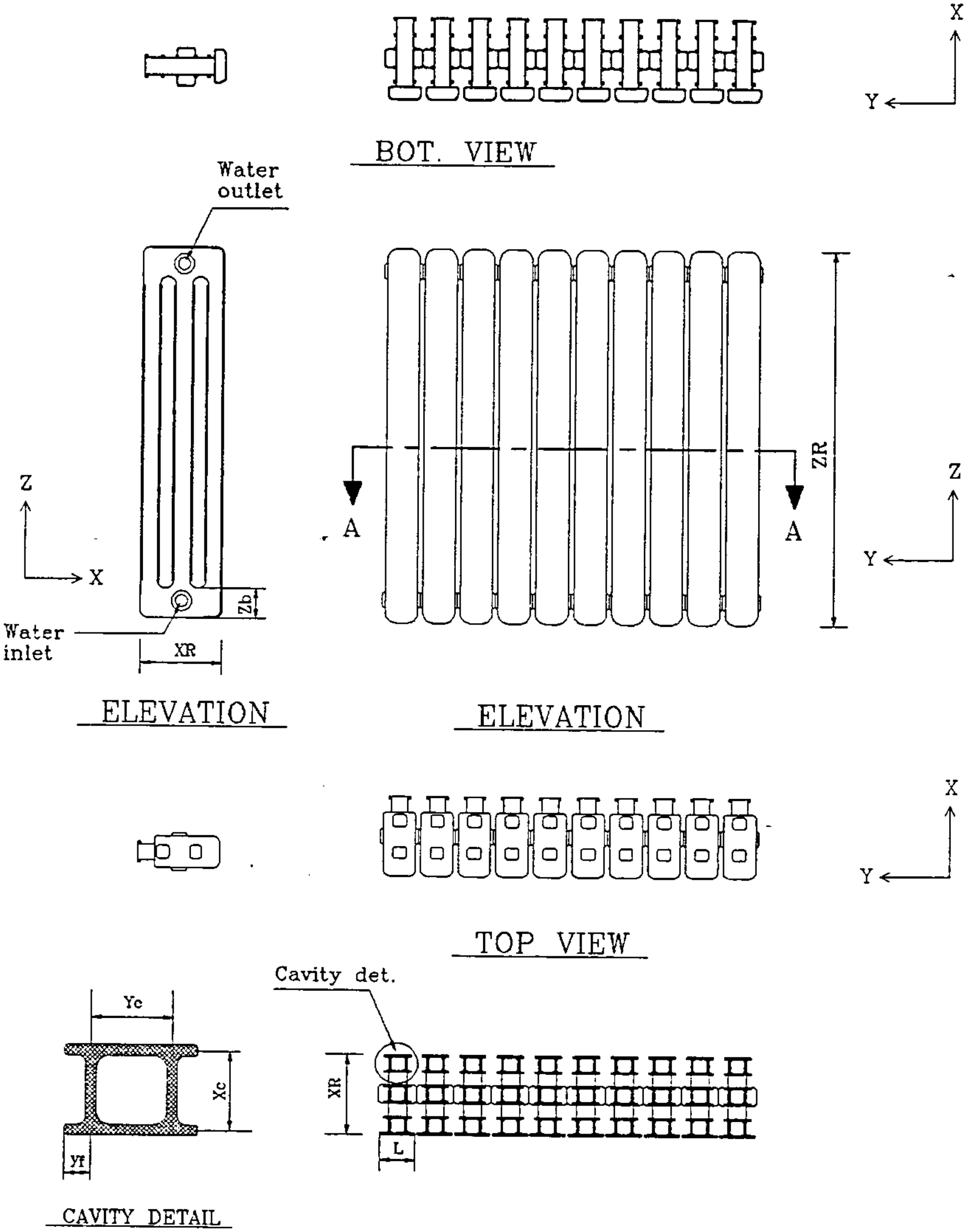
The designer should be interested in choosing the best shape of radiator in regard to economical and manufacturing considerations but, after the shape has been chosen the designer should aspire to the optimized dimension.

The optimized dimensions of a radiator can be found in either one of two ways; the maximum amount of heat dissipation for a given quantity of mass, or the minimum mass for dissipating a given quantity of heat, In this research the second way has been used.

The goal of the present study is to obtain the optimum shape of radiator that gives the highest heat effect with a minimum cost . The shape presented in Figure (3.1) is suggested after studying the radiator geometries available in local market and taking into account the following factors :

1- Radiators are usually placed under windows so their height (ZR) is limited to the clear distance between finish floor level and windows which is about 1 m.

2- The width of radiator (XR) is chosen such that furniture can be placed in front of it . This limits the width to about (10 -15) cm .



Fig(3.1) Geometrical dimensions for the suggested cast iron radiator

3- The number of cavities and its dimensions (Yc , Xc) are limited by the width of radiator and the space to allow air flow .

4- The length of the fin is selected to be 1.0cm according to the manufacturing consideration except the length of fins on the front side (L) are selected to be longer to give the radiator a better look .

5- The dimension of the collectors plate (*Zb*) is limited by the size of fittings to about 7.5cm .

The surface area of radiator transfer heat to the surrounding by natural convection (Q*c*) and radiation (Q*r*) simultaneously ,so the total rate of heat transfer from the radiator is the sum of the heat transfer due to these two modes.

3.2 Natural convection

Two different groups of the suggested equations for heat transfer by natural convection from a vertical surfaces are available . The first one uses the connection between the heat flux and surface temperature. Karvinen [3] , has used the analogy between a condensate film and the inner part of a laminar boundary layer to relate heat flux and surface temperature for Pr for air > 0.6 [3] .

$$q_c = c k_f \left[\frac{g \beta}{\nu^2} P_r \right]^{1/4} \Delta T^{5/3} \left[\int_0^z \Delta T^{5/3} dz \right]^{-1/4} \qquad (3.1)$$

The constant c is given by[3] .

$$c = \frac{0.503}{\left[1 + (0.492/P_T)^{9/10} \right]^{4/9}} \qquad (3.2)$$

Where :

q_c : Heat flux by convection (w/m^2)

z : Vertical distance (m)

kf : Thermal conductivity of fluid (w/m°C)

g : acceleration due to gravity (m^2/s)

β : Volumetric thermal expansion coefficient(K^{-1})

ν : Kinematic viscosity (m^2/s)

Pr : Prandtal number

ΔT : Temperature difference between surface temperature and fluid

The second group of equations are based on the principle of finding the heat transfer coefficient , in which the heat coefficient is a defined quantity

used for convenience to simplify calculation of the surface temperature when the heat flux is known , or vice visa . The definition is

$$hc = \frac{q_c}{(Ts - T_a)} \qquad (3.3)$$

where hc is the heat transfer coefficient in (w/m^2 °C) , q_c is convective heat flux in (w/m^2) ,Ts is the element surface temperature , and Ta is the ambient temperature .

3.2.1 *Natural convection heat transfer from a vertical plate*

Free - convection flow which is caused by temperature difference in a gas or liquid , also builds boundary layers on the surfaces of solid bodies ,the integrated boundary - layer equations for momentum and heat flow can be used to calculate the heat transfer in free convection.The equation by

$$Nu = 0.27\ Ra^{1/4} \quad for\ 10^{5} \leqslant Ra \leqslant 10^{10} \qquad (3.6)$$

and that for upper surface of heated plate

$$and\ Nu = 0.54\ Ra^{1/4} \quad for\ 10^{4} \leqslant Ra \leqslant 10^{7} \qquad (3.7)$$

$$Nu = 0.15\ Ra^{1/3} \quad for\ 10^{7} \leqslant Ra \leqslant 10^{11} \qquad (3.8)$$

Ra is Rayleigh number defined as relative magnitude of the buoyancy and viscus forces in the fluid .

$$Ra = \frac{g\beta(T_s - T_a)L^3}{\nu\alpha} \qquad (3.9)$$

$$L = \frac{As}{p} \qquad (3.10)$$

where :

α : Thermal diffusivity (m^2/s)

As and p are the plate surface area and perimeter ,respectively

The Nu is Nusselt number , which is equal to the dimensionless temperature gradient at the surface , and it provides a measure of the convective heat transfer occurring at the surface.It is expressed as [17]:

$$hc = \frac{Nu\ k_f}{L} \qquad (3.11)$$

Equation 3.9 is used to determine Ra .Once that is found the Nu is determined according to equations 3.6-3.8 .Equation 3.10 determines L .Then hc is found using equation 3.11 for which q_c is given by equation 3.3.

3.3 Heat transfer by radiation

The objective of the radiation analysis was to determine the radiation transfer rate Q_r at location x along the mid-line where the temperature measurement are made.

The net rate of radiation heat exchange between the surface and its surroundings, expressed as [18].

$$Q_r = \varepsilon \sigma As\,(Ts^4 - Ta^4) \qquad (3.12)$$

In this expression, As is the surface area and ε is its emissivity,while σ is Stefan-Blotzman constant ($\sigma = 5.67 \times 10^{-8}$ w/m^2.K^4).

There are many applications for which it is convenient to express the net radiation heat exchange in the following form.

$$Q_r = h_r As\,(Ts - Ta) \qquad (3.13)$$

where, the radiation heat transfer coefficient hr, is

$$h_r = \varepsilon \sigma\,(Ts + Ta)(Ts^2 + Ta^2) \qquad (3.14)$$

3.4 Heat Transfer by Fins:

Heat transfer of a fin is only obtained accurately by solving simultaneously convection and conduction equations. An analysis of the convention heat transfer of a vertical fin with a variable thickness is made by Kårvinen [3].

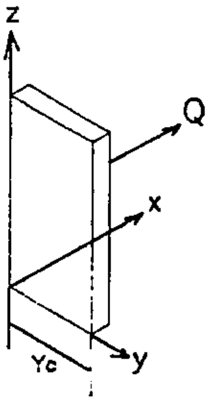


Figure (3.2) Schematic diagram of vertical plate

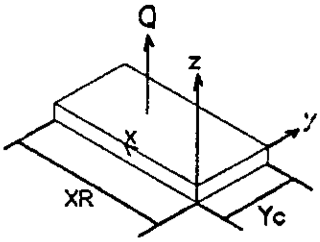


Figure (3.3) Schematic diagram of a horizontal plate

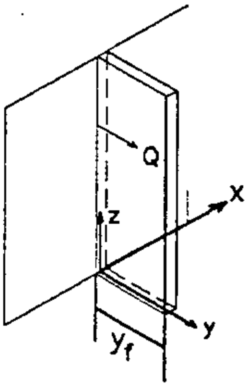


Figure (3.4) Schematic diagram of a straight fin

$$m = \sqrt{\frac{hcp}{kAc}} \qquad (3.17)$$

3.5 *Total heat transfer*

In our application the surface within the surroundings simultaneously transfer heat by convection and radiation . So the total rate of heat transfer from the radiator suggested in fig(3.1) is the sum of heat transfer rate by these two modes from vertical , horizontal and extended surfaces (fins).

$$Q_t = Q_c + Q_r + Q_{fa} \qquad (3.18)$$

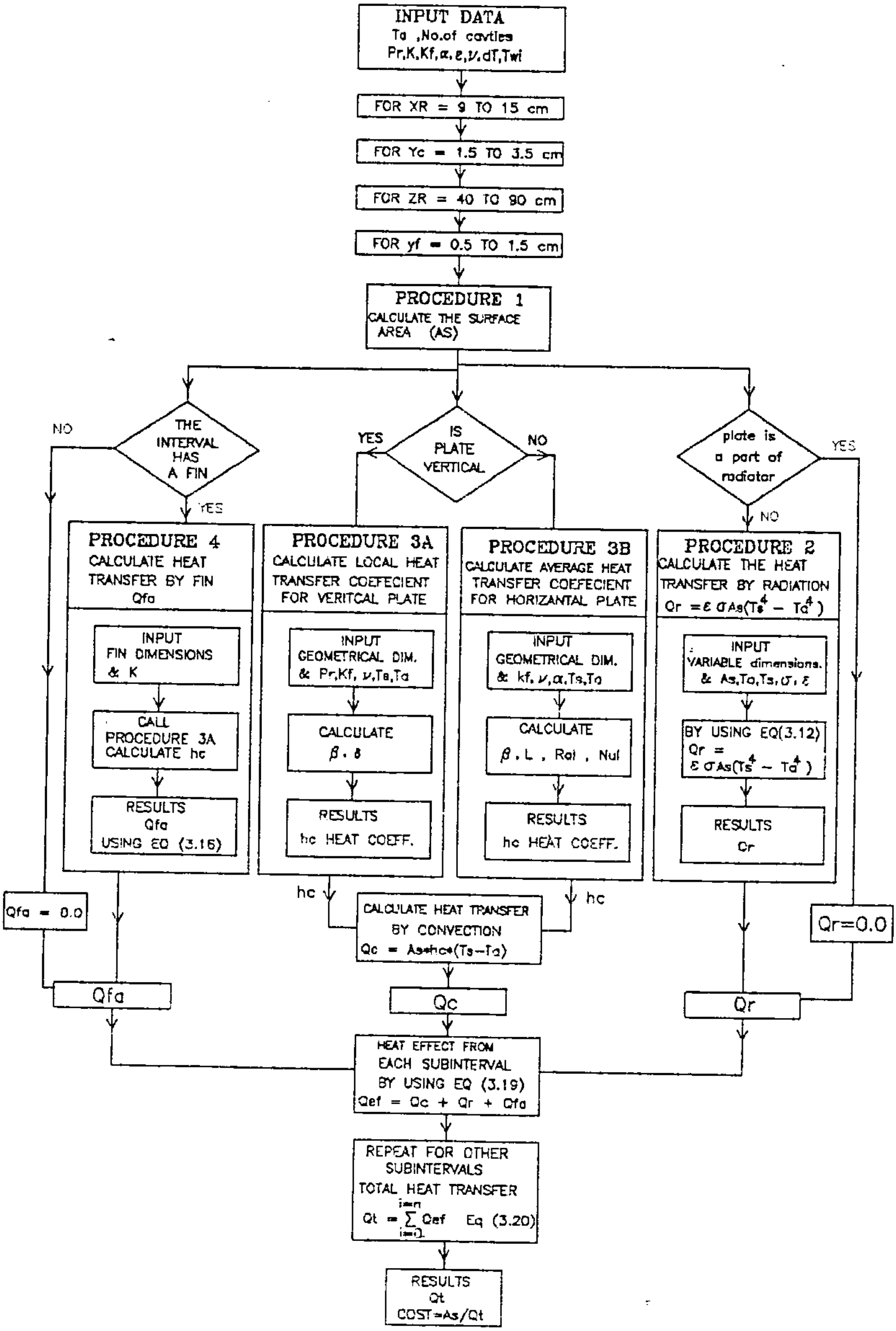
When the heating element is considered as part of the radiator , then Qr from side surfaces area are neglected , the same procedure is followed as before but without considering the Qr from that surfaces .

3.6 Procedure of optimization

To calculate the total heat transfer rate Q_t from one element of radiator , a computer program (see appendix A) is written to simulate the equations (the flow chart is shown in fig (3.5) . The computer program also include the case when the heating element is considered as part of the radiator

The procedure followed summarized as :

1- The heating element is divided into three segments as shown in fig (3.6) ,segment 1 and 3 are considered as four vertical plates and two horizontal plates ,while segment 2 is considered as four vertical plates with fin .



Fig(3.5) Flow chart for a turbo pascal program to calculate heat transfer from C.I.R

2- Each segment is divided into a large number of subintervals in Z-direction

3- The difference in temperature between inlet and outlet water ΔT = 10 °C,20°C) is divided linearly over all subintervals .

4- For each of these subintervals the local heat transfer coefficient is calculated from equation 3.4 and 3.11 for vertical and horizontal plates respectively in order to calculate Qc by using equation 3.3 .

5- The heat transfer by radiation Qr is found using equation 3.12

6- The heat transfer by extended surfaces (fins) Q_{fa} is calculated using equation 3.16

7- The effect of heat transfer from the subinterval is given by summing up all above transfer modes according to the following equation

$$Q_{ef} = Q_c + Q_r + Q_{fa} \qquad (3.19)$$

8- The total heat transfer from the element is calculated as follows

$$Q_t = \sum_{i=0}^{i=n} Q_{ef} \qquad (3.20)$$

where n is the number of subintervals

9- The cost is represented as the surface area required to produce one unit of heat effect according to this relation :

$$Cost(JDs/w) = C1\ m\ /\ Q_t \qquad (3.21)$$

$$Cost(JDs/w) = C2\ As\ /\ Q_t \qquad (3.22)$$

Where :

m : mass

C and C are constants for cost

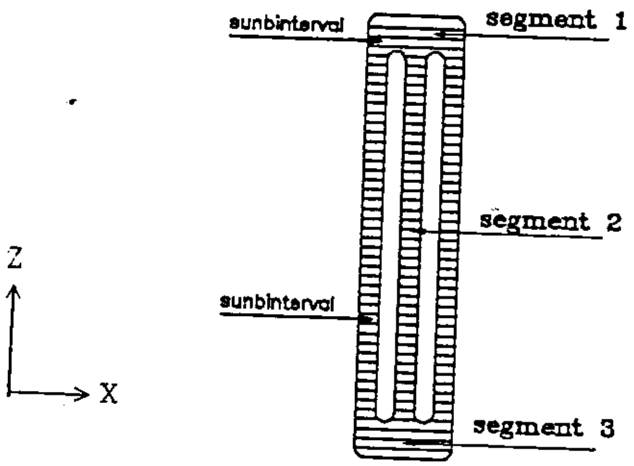


Fig (3.6) Side view for element of radiator

CHAPTER FOUR
LOCAL MANUFACTURING OF CENTRAL HEATING RADIATORS

4.1 Introduction

The objective of this chapter is to give an idea about the local market demand for cast iron radiators and the possibility of manufacturing these radiators in Jordan . By presenting some statistical data about the quantities imported from other countries , the investment in this field is encouraged . .

4.2 Background about casting .

The foundry industry is considered an essential component to the overall industrial development of most countries due to its close relation to most metal working or metal processing activities .Casting plays an essential part of most engineering products required by industrial , agricultural and consumer goods manufacturing .

The casting industry in Jordan is comprised of 37 registered small - and - medium size foundries and an estimated 20 to 25 unregistered micro foundries . Castings are produced to cover the demands of different sectors ; mining , transport , machine tools , construction and various others.
The following data will give the reader an idea about the present state of local market about casting [19,20] :-

1- In 1988 , the Jordanian foundries produced a total of 30,000 ton of cast products , in the same year Jordan imported 40,000 ton of high quality casting to complement local production .

2- The annual consumption of green sand was approximately 150,000 ton in 1988 . The cost of local green sand is half of that imported.

3- In 1988 Jordan imported a total worth of 1.5 millon dollars of sand moulding , while Jordan is a desert country with 70 % of its total area covered with sand .

4.3 Market survey on cast iron radiators.

There is a high demand of C.I.R. which are preferable more than other types due to the following reasons :-

1- C.I.R have high resistance to corrosion .

2- Various types are available in a wide range of sizes that meet all demands.

3- They fit many type dwelling , industrial , hotel , medical , school and other social standard.

4- They have a long lasting .

C.I.R's are not manufactured in Jordan ,So investors should be encouraged to enter this field .All local companies manufacture C.H.R. from sheet metal except one of them manufactures radiators from copper piping and aluminum fins . Nearly all the dealers in Jordan offer C.I.R. imported from Turkey , France and some from Italy.

The following summary lists the availability and price of radiators in the local market:-

1- There are three types of C.I.R. in local market grouped according to their height, the thermal meter (400Kcal/h) capacity , mass and price as indicated in Table 4.1.

Table (4.1) C.I.R available in local market.

C.I.R Height cm	Mass kg/element	Heat rate W/element	Price JD /element	
			Imported France	Imported Turkey
48	4.8	80	9.75	/
68	5.8	116	8.25	5.4
78	7.8	135	8.5	/

[21]

2- Local sheet metal radiators are priced from 12.5 - 13 JD / Thermal meter

3- Local copper pipe and aluminum fins radiators are priced at 28 JD/Thermal meter .

4- Imported C.I (Turkish) radiators 25 JD / Thermal meter , while imported from France are more expensive .

The price of sheet metal is approximately half of the C.I.R.,but the service life for sheet metal radiators is lower because of the following :-

1- The thickness of sheet metal is low
2- The resistance of sheet metal radiator to external effects is low
3- It has a poor corrosion
4- The improper seam welding process affecting the quality of the product

4.4 *Statistical data*

The annual quantities of imported C.I. material for manufacturing boilers, radiators , air heaters and hot air distributors needed for central heating are as shown in Table (4.2) :-

Table (4.2)

Quantity of imported C.I from different countries for C.H applications

Year	Mass Ton	Value Thousand JD	Price JD / kg
1988	3314	1948	0.59
1989	4756	3100	0.65
1990	3425	2776	0.81
1992	5942	4624	0.78
1993	6652	5325	0.80

[21]

Most of these were imported from Turkey and France . Table 4.3 and 4.4 present the quantities imported from each country [21].

Table (4.3)

Cast iron imported from Turkey for C.H applications .

Year	Mass Ton	Value Thousand JD	% Imported from Turkey	Cost JD / Kg
1988	392	91.2	12 %	0.23
1989	1023	368.0	22 %	0.36
1990	2076	940	61 %	0.45
1992	4040	/	68 %	/
1993	4590	/	69 %	/

[21]

Table (4.4)

Cast iron imported from France for C.H applications .

Year	Mass Ton	Value Thousand JD	% Imported from France	Cost JD / Kg
1988	286	876	39 %	0.68
1989	1106	990	23 %	0.9
1990	601	660	18 %	1.1
1992	1140	/	19.2 %	/
1993	930	/	14 %	/

[21]

* A bout 60% of the quantities indicated in tables 4.3 and 4.4 are imported as C.I.R .

In 1991 a total of 2605 ton of C.I.R were imported according to the department of statics.These are distributed as follows:-[22]

- 1651 Ton from Turkey
- 618 Ton from France
- 94 Ton from Italy
- 241 Ton from other sources

From table 4.2 the average cost of 1 Kg is 0.80 JD for the last three years.

4.5 Radiator material composition

The C.I.R available in the local market is tested at Royal Scientific Society (RSS). The results obtained for such tests reveal that its microstructure is as shown in Table (4.5) below

Table (4.5)

Percentages of elements in the C.I.R

Element	Si	Mn	P	C
%	2.3	0.65	0.348	3.349

Data of Table 4.5 can be used to study the effect of metal composition on the casting process of C.I.R. the influence of metal composition is related to the carbon , silicon and phosphorus contents . For a given pouring - temperature , the fluidity is generally determined by the carbon equivalent factor (CEF) . Any increase of one or more of these elements will improve fluidity of iron at a given temperature until the CEF value exceeds about 4.6% according to the relation.

The usual meaning of the term fluidity as applied to molten cast iron , is the ability of the iron to fill a mould completely and to produce every detail of the mould cavity . That is, avoiding misrun casting .
The CEF for the local market C.I.R as tested by RSS is equal to 4.3 %

4.6 Economic consideration

The following is a comparison of the economical aspects of C.I.R manufactured in Jordan as compared with those imported from foreign countries .

Actual data were collected from many sources (as mentioned previously) and from local market .

The items listed below were considered for the economic evaluation of producing 1000 ton / year of C.I.R which is about 50% of full market size.

A - Investment costs : Includes the costs of :

1- Jolt squeeze stripper moulding machine

2- Fixed type aluminum sand (moulding) box size : 18 x 33 x 5/4 inches

3- Induction furnace with 750 watt and capacity of 1000 kg. .

4- Unit for sand preparation about (500 ton - 2000 ton) per year .

5- Analytical and Metallically laboratory

B - Operation cost : Includes the yearly cost of :

1- The raw materials .
2- The maintenance .
3- Employees and staff .
4- Energetics

The following assumptions are made .

1- The annual operation costs are considered as the probable average values

2- The life time assumed for different system components are based on information given by manufacturers or on local dealer practical experience and it is about 20 years for building and machines .

3- Since the C.I.R. are new so the maintenance and repair needs , and respectively costs are rough estimates only , and about 2% from the initial cost of the machines for each year .

4- The raw material are collected for local supplies.

Table 4.6 lists the cost of equipments and labor needed to produce 1000 ton/year of C.I.R

Table (4.6) : The economic evaluation for the factory to produce 1000 ton / year of C.I.R

Item	Quantity	Unit Price JD	Total price
Jolt squeeze stripper moulding machine	4	7,100	28,400
Fixed type aluminum sand (moulding) boxes	150	415	62,500
Core making machine	1	75,000	75,000
Buildings	hanger 2500 m^2	50	125,000
Induction furnace with 1000 Kg capacity	1	150,000	150,000
Laboratory for chemical analysis Composition and physical tests	1	100,000	100,000
Raw material	1000 Ton	80	50,000
Green sand	5000 Ton	10	50,000
Core sand	200 m^3	30	6000
Employees	50	8660	103200
Maintenance	/	yearly	3500

From table (4.6) the cost of manufacturing cast iron radiators in Jordan is about half of that imported from the foreign countries as shown below

CHAPTER FIVE
RESULTS AND DISCUSSION

There are considerable difficulties encountered in this study . The main difficulty is in collecting the data . The background in this field is very slight ,since no factories exist that produce cast iron radiators (C.I.R) in Jordan .

Another difficulty is the manufacturing proccess,where the experience in the casting related to radiators is very limited , so, the possibility of producing the suggested optimized shape of radiator in this study is very difficult .This prevents comparison study between the theoretical and experimental works .

The results of the present study are divided into two groups . In Figures (5.1-5.8) the water temperature difference between the inlet and outlet of radiator is 10 °C , while in figures (5.9 - 5.16) is 20 ° C. These two temperature differences are selected since they are the most common in the local market .

A simulation computer program as shown in Appendix A is utilized to obtain the present results.

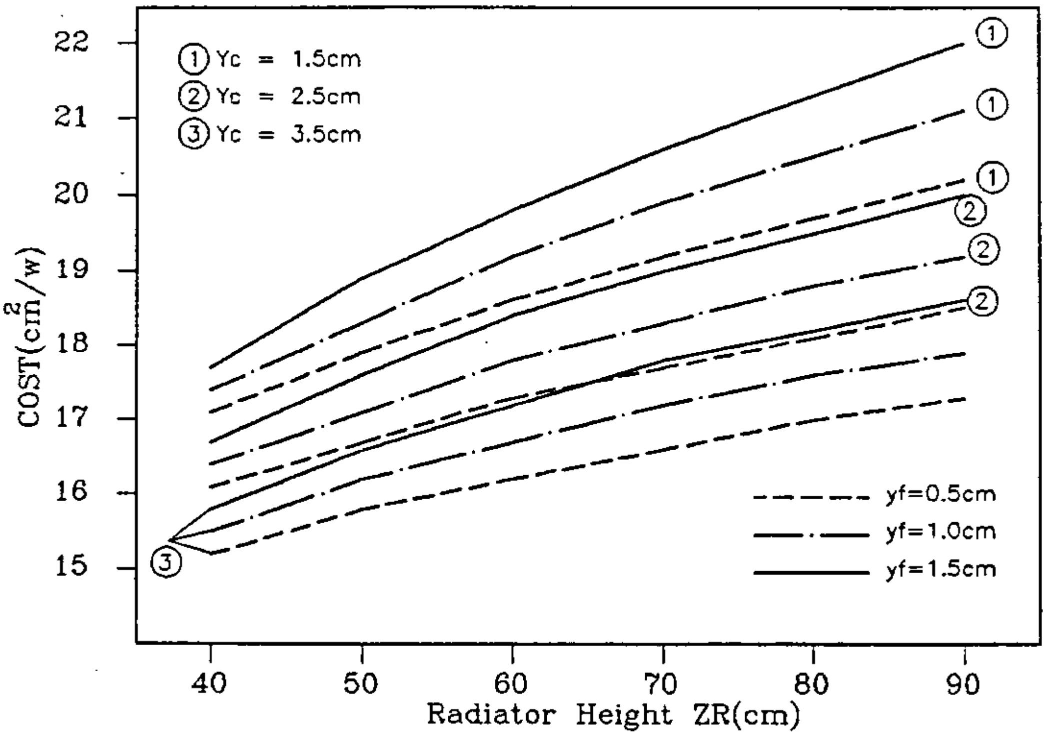
Figures (5.1) and (5.2) show the variation of the cost and heat effect , respectively , with height of radiator at the same geometrical parameters and the same temperature difference .

Figure (5.1) indicates that the cost increases with decreasing the cavity opening in y-direction (Yc) in addition to the increase of radiator height (ZR) , while Figure (5.2) shows that the heat effect increases with increasing the height and the cavity opening .

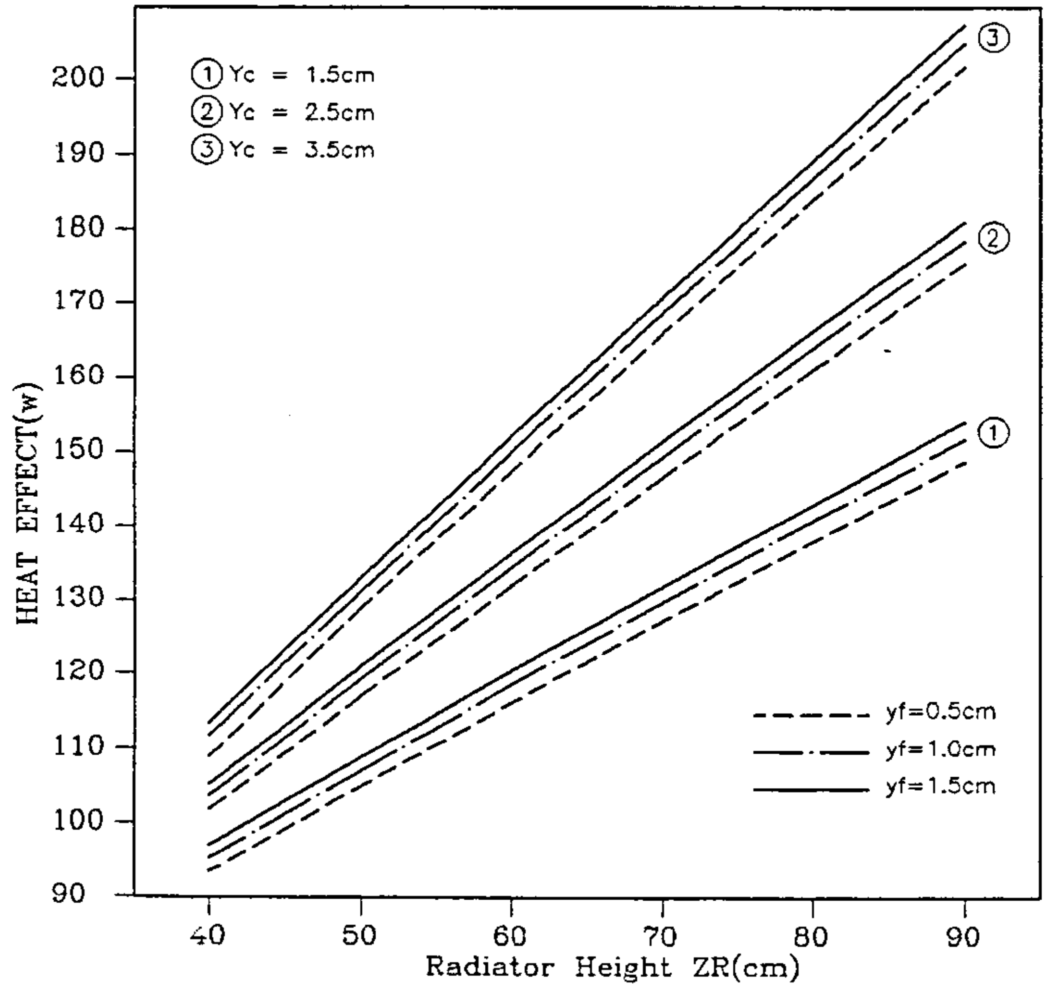
The increase in the height of radiator leads to an increase in both cost and heat due to the increase in surface area . On the other hand , the increase of the height (ZR) leads to a decrease in the local heat transfer coefficient , also , the average plate temperature for each vertical subinterval is decreased . This means that less quantity of heat is emitted to the surroundings , which consequently leads to a higher cost . Conversely, the increase of the cavity opening will achieve an increase in the average plate temperature for each subinterval . Also , it will increase the average heat transfer coefficient .

Figures (5.3-5.8) show the same previously mentioned trends , but at different radiator widths (XR) where (XR) varies from 11cm to 15cm . It is evident that the increase in the radiator width will give the same effect as that of the increase in the cavity opening , due to the same previously mentioned reasons .

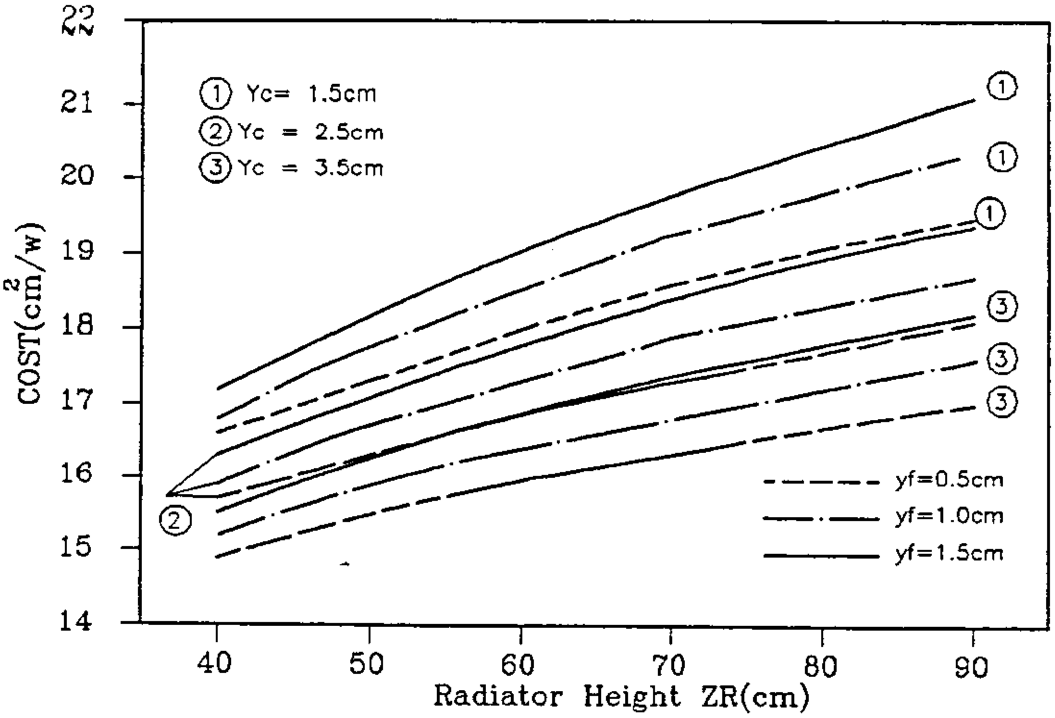
Figures (5.9 - 5.16) are taken at a temperature difference of 20 °C . It is obvious that at higher temperature difference the heat is decreased due to the decrease in the average plate temperature for each subinterval .On the other hand , the cost is increased , which means that the overall performance of radiator is better in the case of low temperature differences than that in the higher temperature differences . By inspection of figures (5.1-5.16) ,it is found that better conditions are attained at 10°C difference than it is in the 20°C difference .



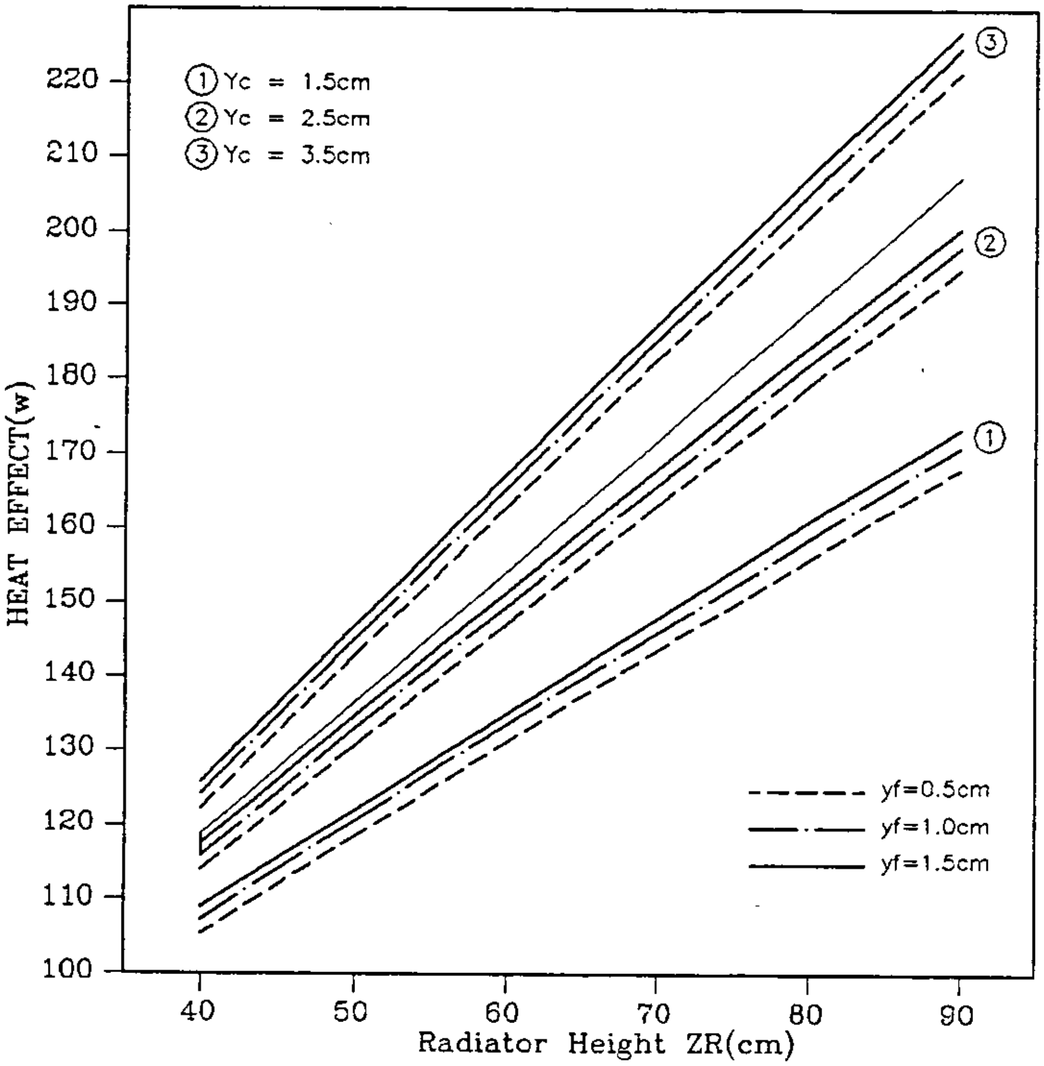
Fig(5.1) Cost versus radiator height
Input/Output temp. (90/80)°C
XR = 9.0 cm .



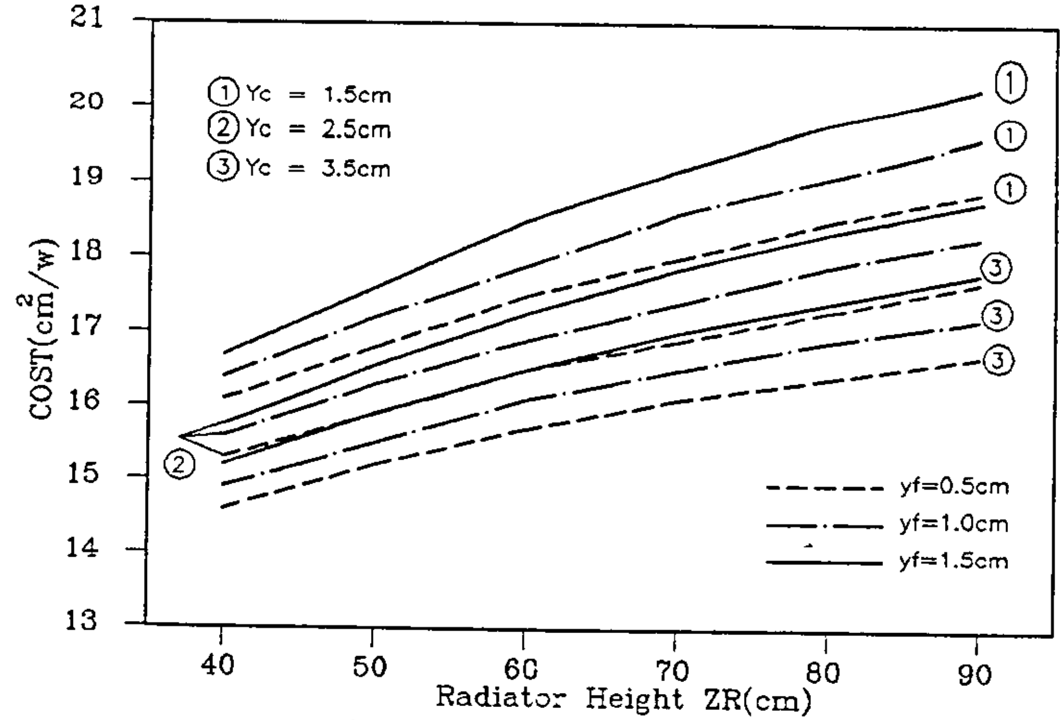
Fig(5.2) Heat effect versus radiator height
Input/Output temp. (90/80)°C
XR = 9.0 cm .



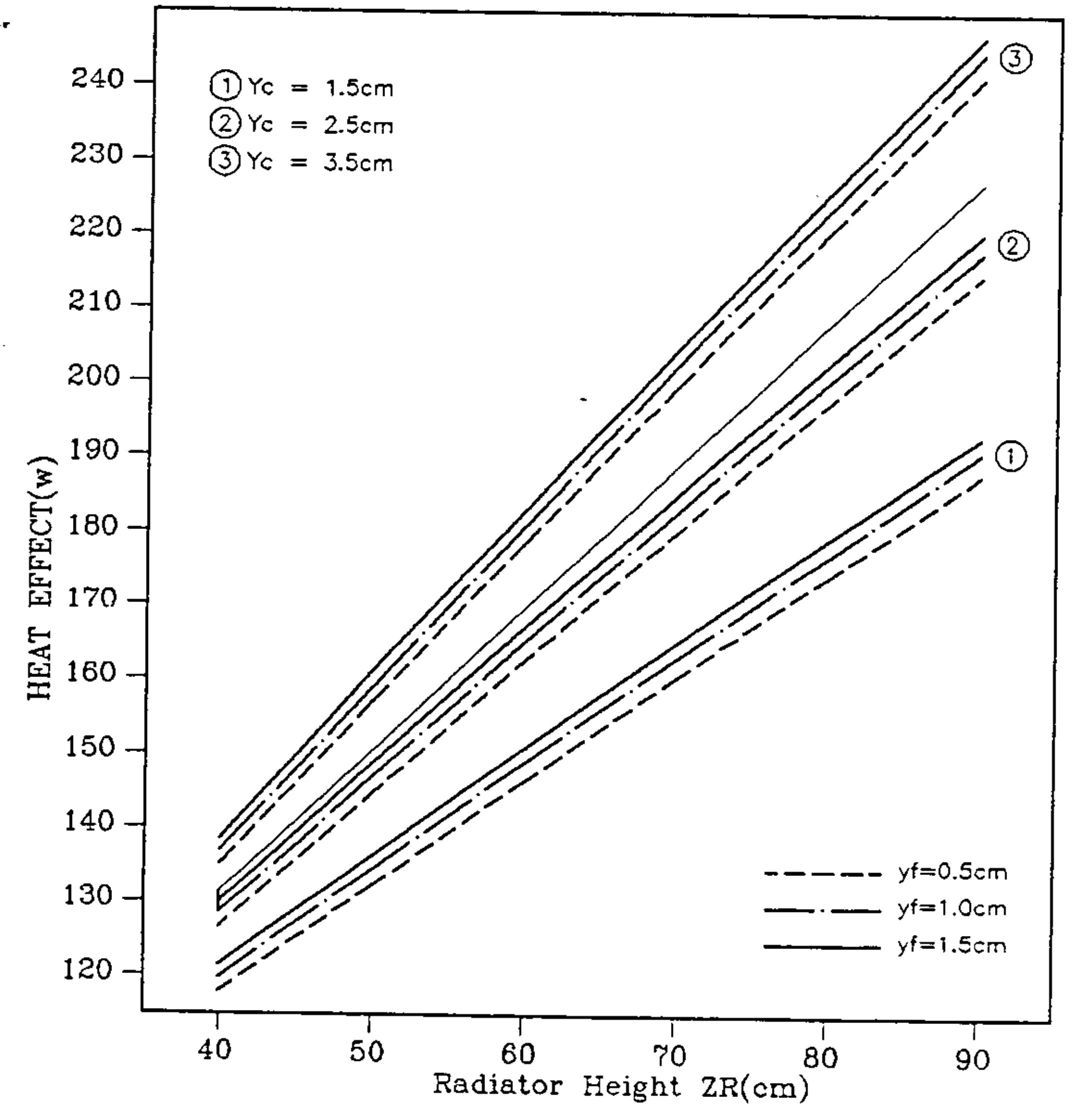
Fig(5.3) Cost versus radiator height
Input/Output temp. (90/80)°C
XR=11cm .



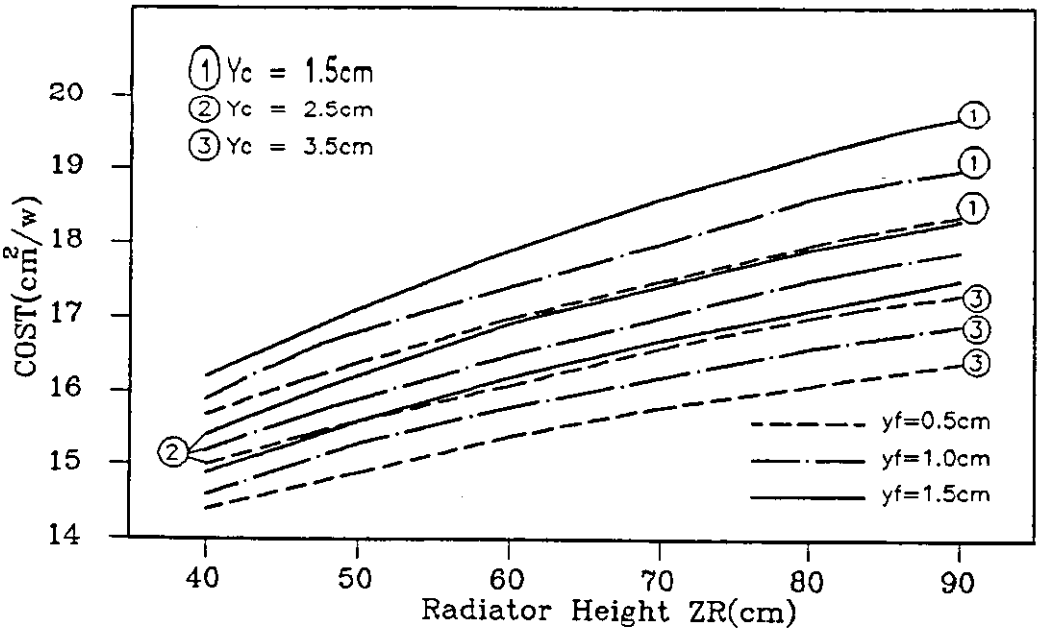
Fig(5.4) Heat effect versus radiator height
Input/Output temp. (90/80)°C
XR=11cm .



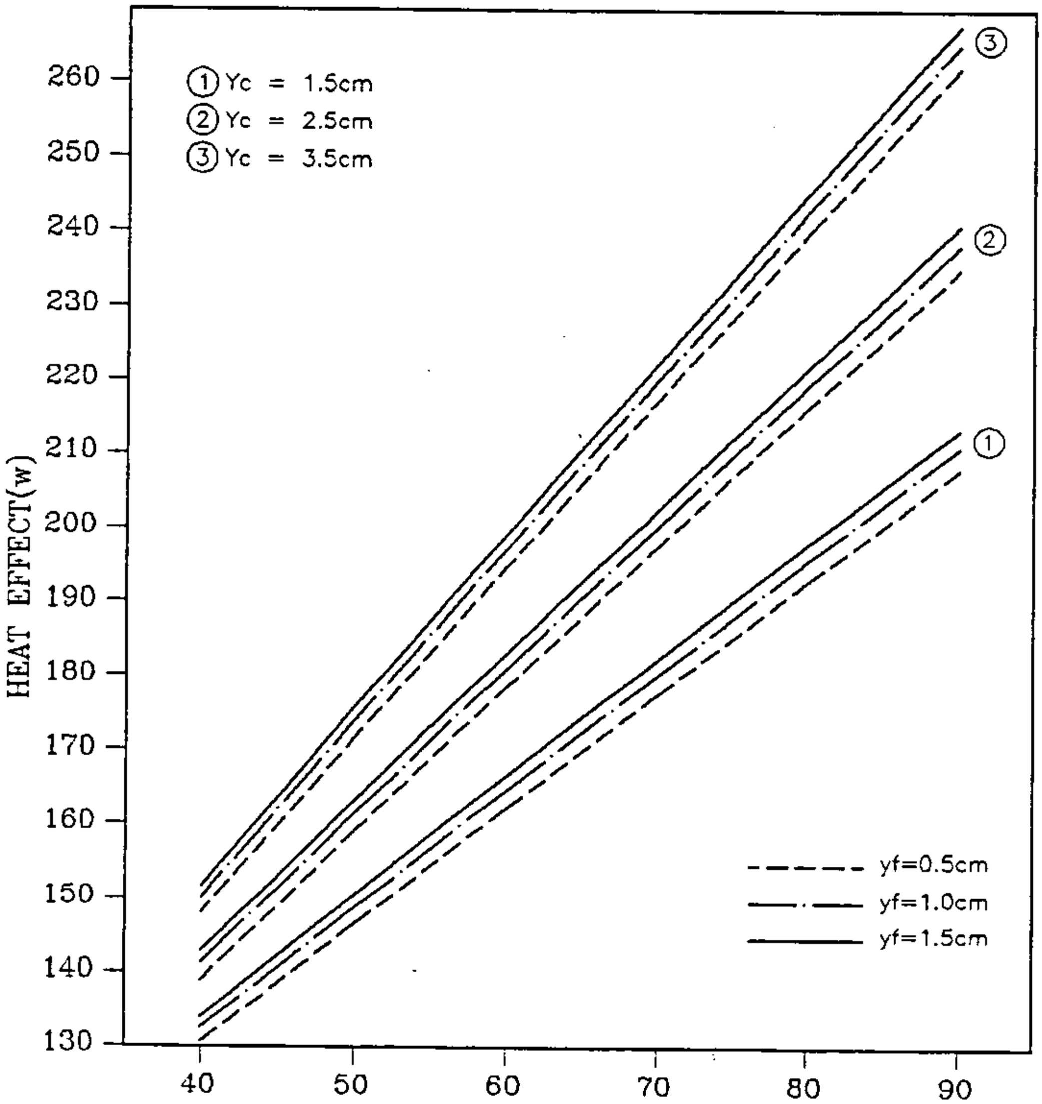
Fig(5.5) Cost versus radiator height
Input/Output temp. (90/80)°C
XR=13cm .



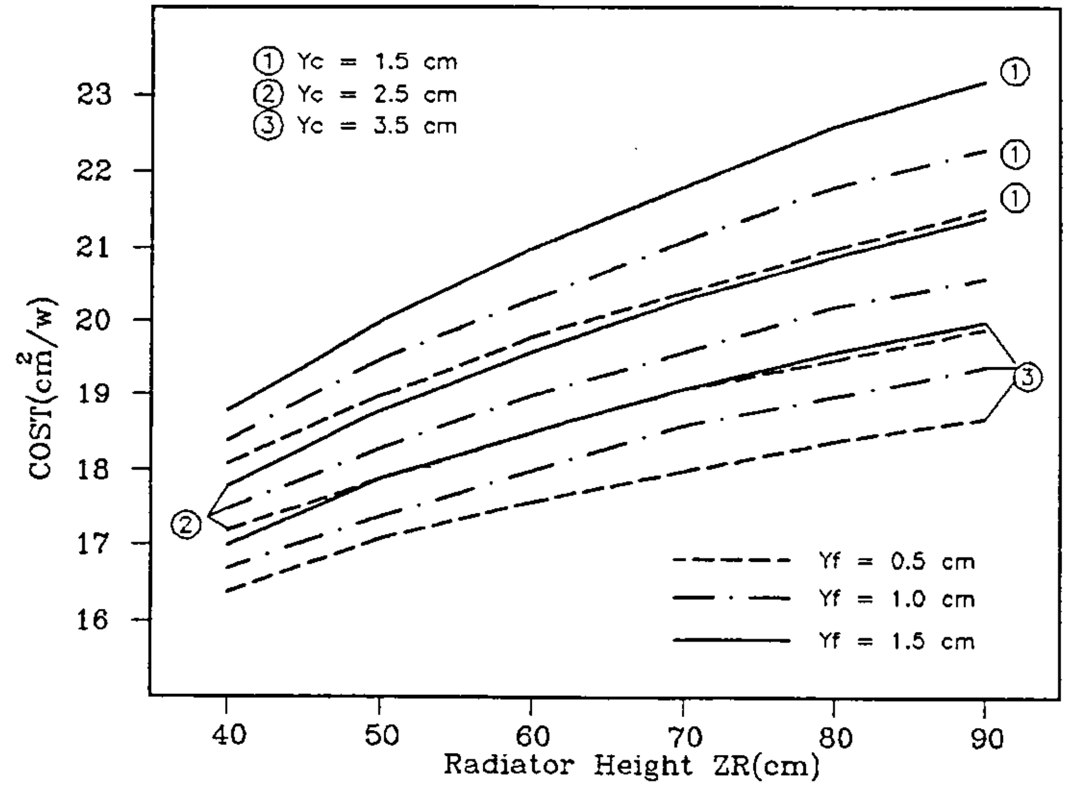
Fig(5.6) Heat effect versus hadiator height
Input/Output temp. (90/80)°C
XR=13cm .



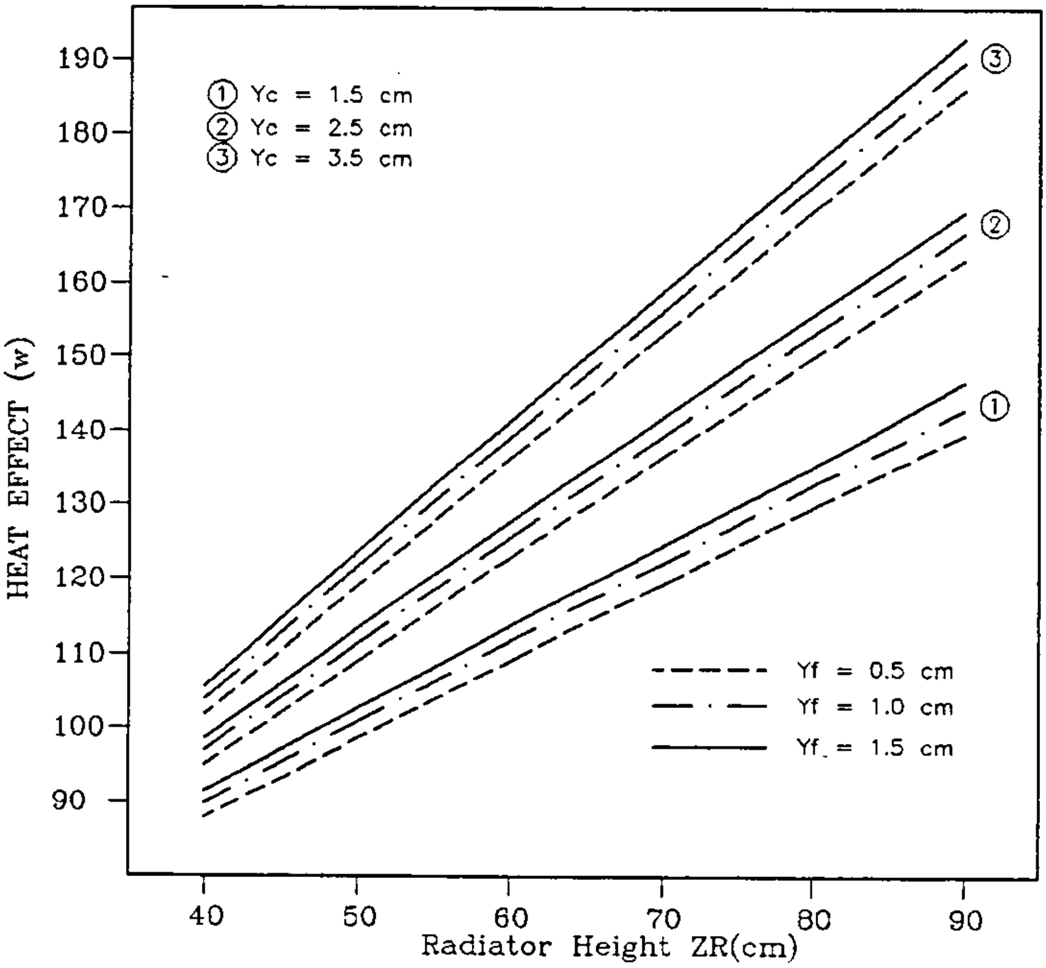
Fig(5.7) Cost versus radiator height
Input/Output temp. (90/80)°C
XR=15cm .



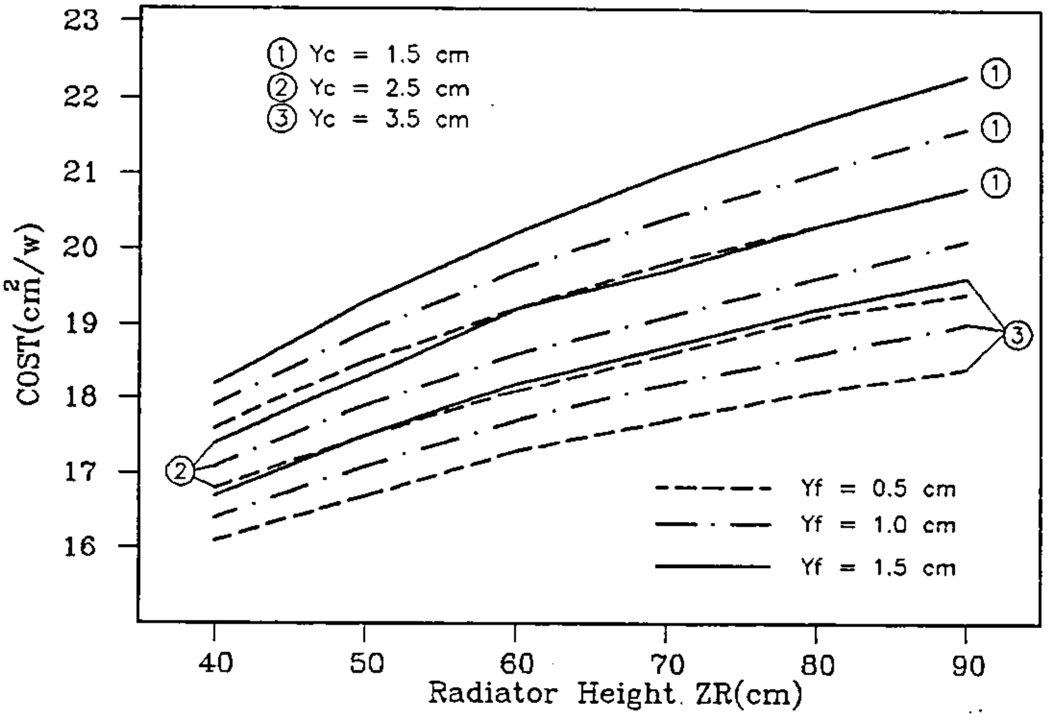
Fig(5.8) Heat effect versus radiator height
Input/Output temp. (90/80)°C
XR=15cm .



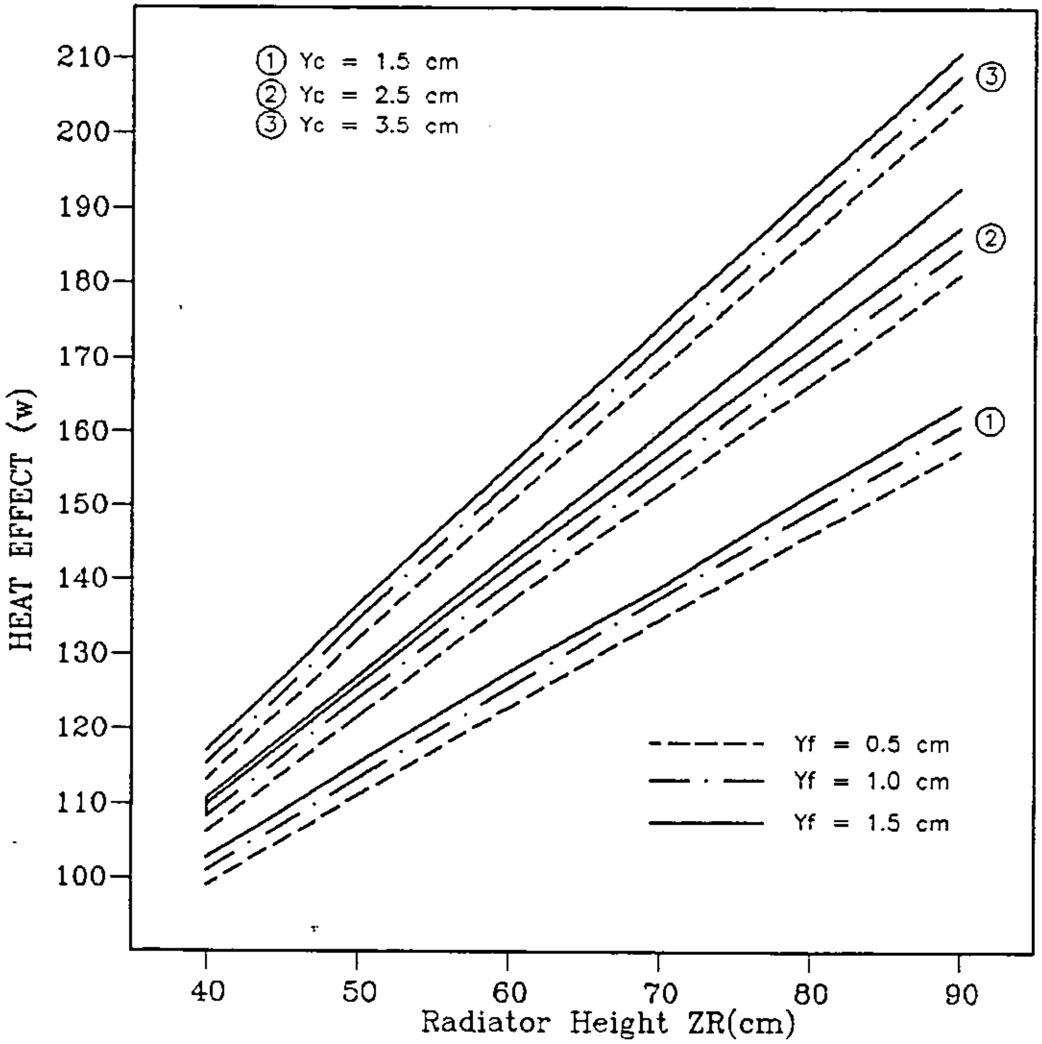
Fig(5.9) Cost versus radiator height
Input/Output temp. (90/70) °C
XR=9.0cm .



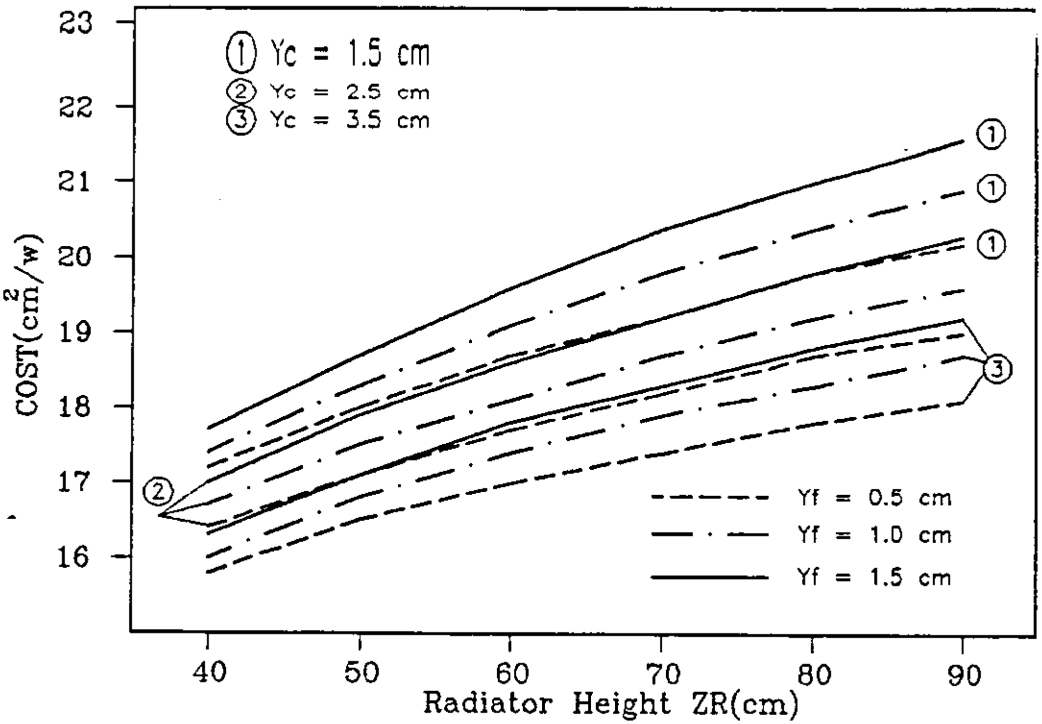
Fig(5.10) Heat effect versus radiator height
Input/Output temp. (90/70) °C
XR=9.0cm .



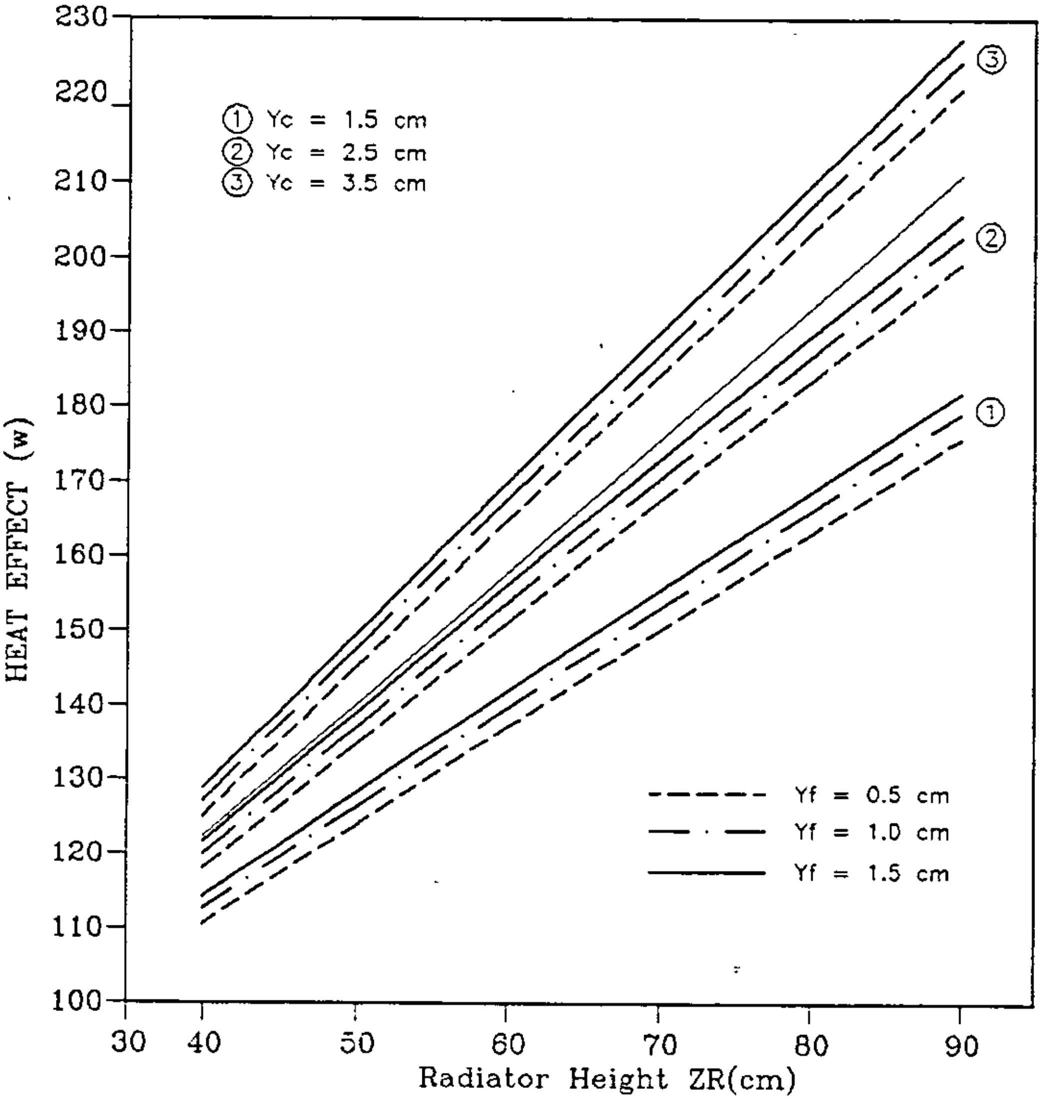
Fig(5.11) Cost versus radiator height
Input/Output temp. (90/70) °C
XR=11cm .



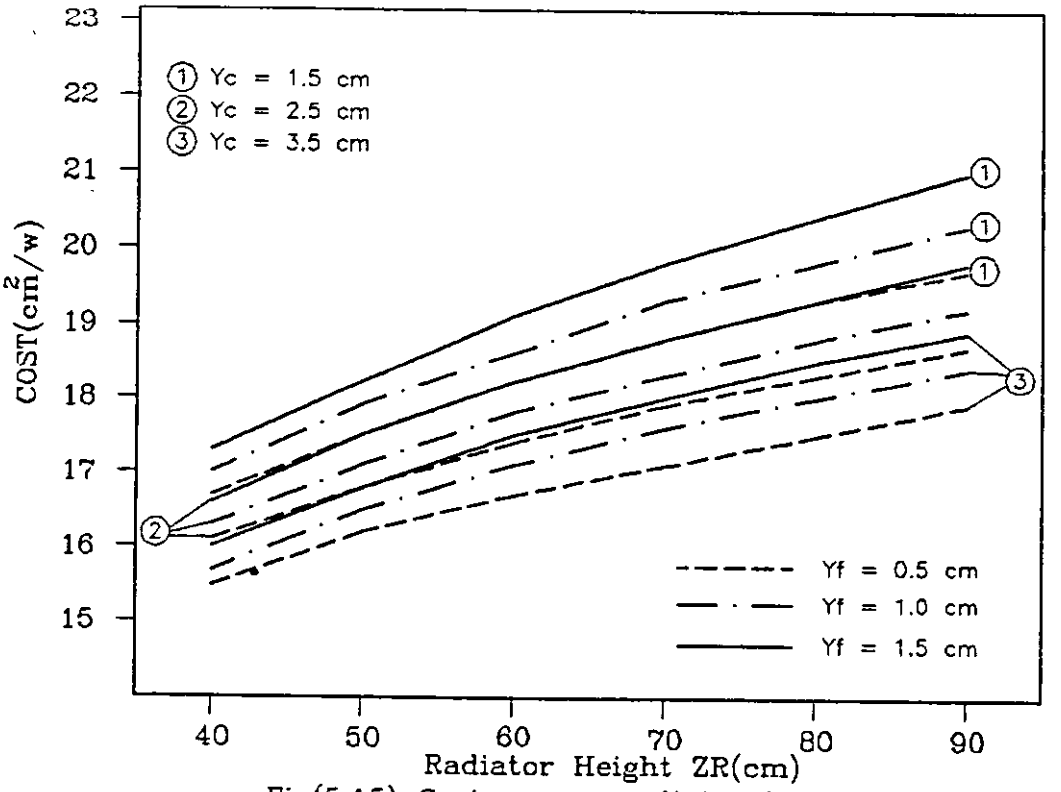
Fig(5.12) Heat effect versus radiator height
Input/Output temp. (90/70) °C
XR=11cm .



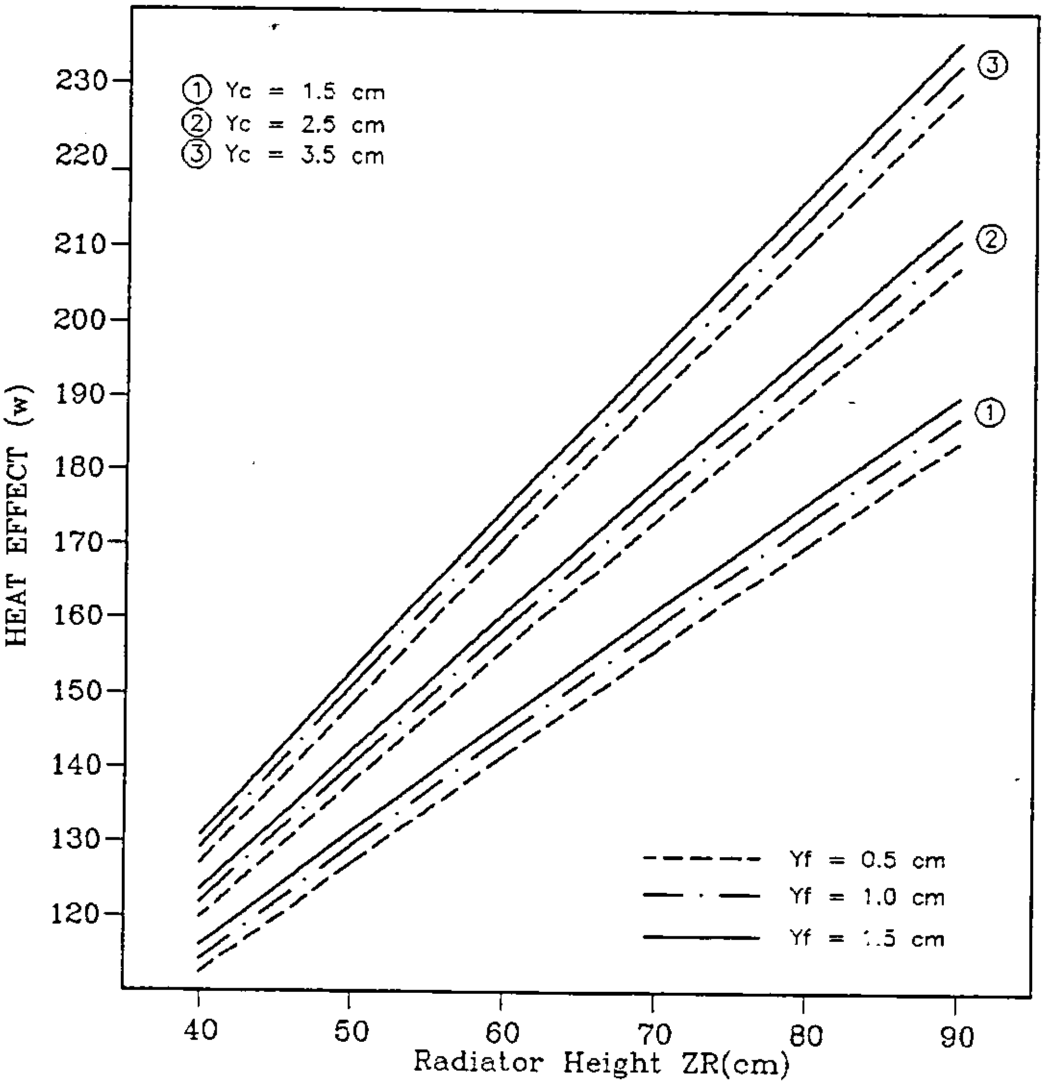
Fig(5.13) Cost versus radiator height
Input/Output temp. (90/70) °C
XR=13cm .



Fig(5.14) Heat effect versus radiator height
Input/Output temp. (90/70) °C
XR=13cm .



Fig(5.15) Cost versus radiator height
Input/Output temp. (90/70) °C
XR=15cm .



Fig(5.16) Heat effect versus radiator height
Input/Output temp. (90/70) °C
XR=15cm .

Primarily, it is essential to find the optimum value for the cavity opening (Yc) at 10°C temperature difference. Accordingly, the following procedure is followed.

1- A plot of the variation of the heat effect and cost against the cavity opening is made, for a certain radiator width (XR).

2- The intersection of the two curves represents the minimum point after which the cost decrease and the heat increase.

3- Step1 and 2 is repeated for different values of radiator width (XR) to find the other minimum points ,the maximum value of these point is the point required.

As an example, the radiator width of 9.0 cm is selected. The variation of the heat effect and cost is plotted versus the cavity opening (Yc)as show in Figure (5.17) .The intersection point represent the minimum value for the cavity opening (Yc) for the geometry consider in figure (5.17)

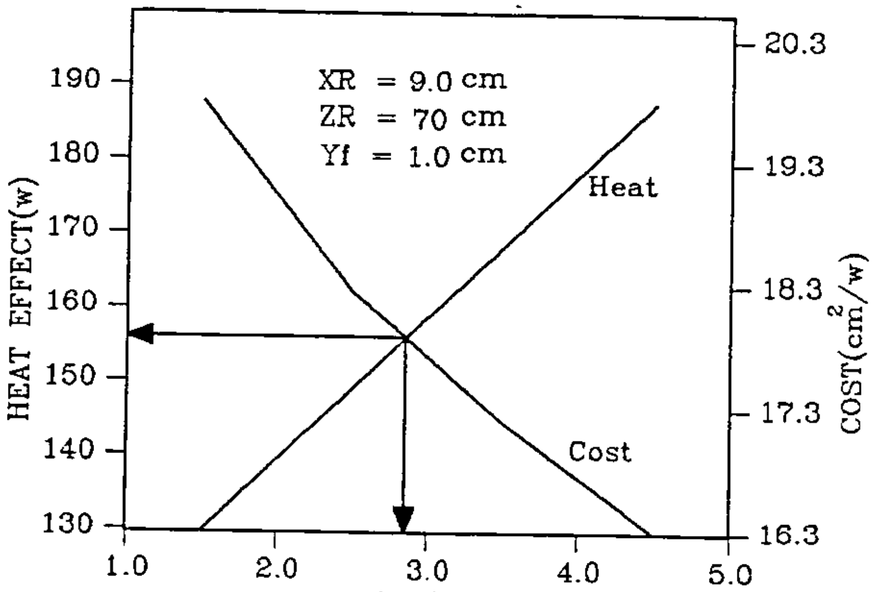


Fig (5.17) Heat effect and cost versus the cavity opening.

The similar graphs to that of figure (5.17) are plotted for various radiator heights (ZR=50,60,..,90 cm) and the intersection point for each graph is obtained at the same radiator width (XR=11 , 13 , 15 cm). The maximum value for the minimum cavity opening (Yc) is found to be 2.85 cm . The minimum cavity opening is the point below which the heat effect is decreases and the cost is increases simultaneously.

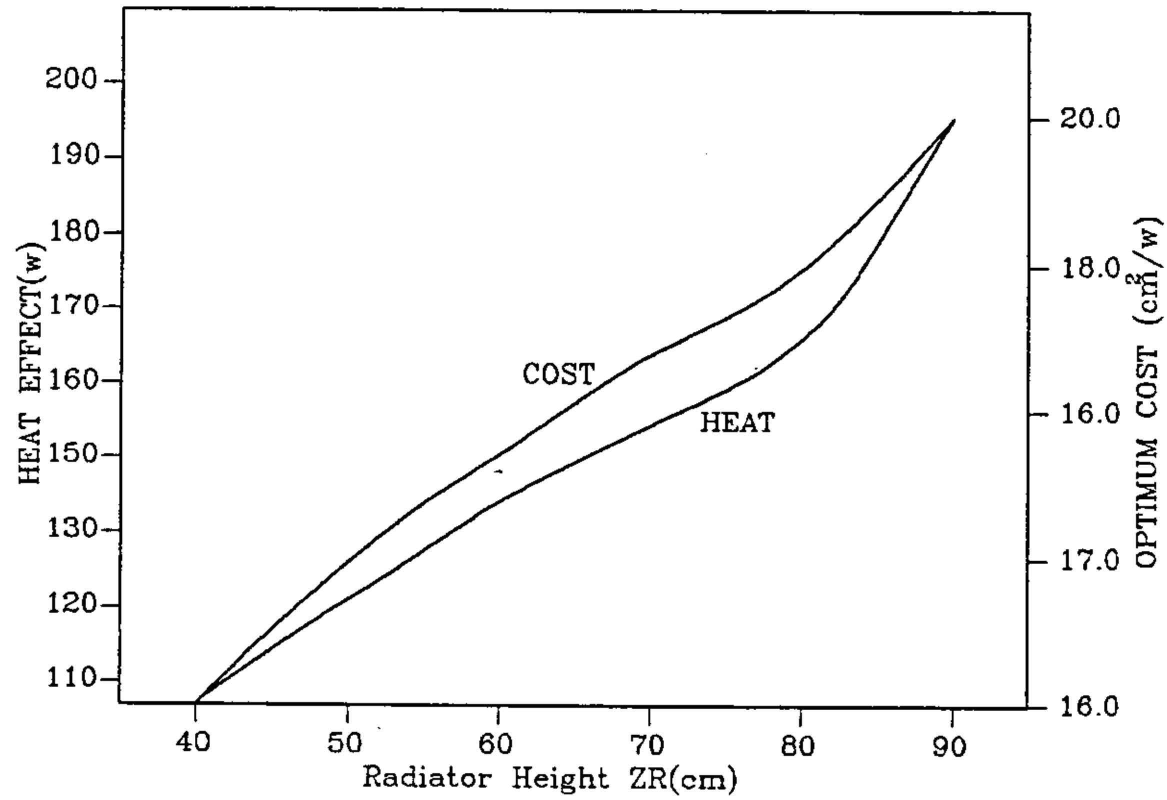
Figures (5.18 - 5.21) show the variation of heat effect and cost with height of radiator (ZR) at various radiators widths (XR) .The figures were plotted at minimum cavity opening (Yc =2.85cm) and at 10°C temperature difference.

To find the minimum value of the radiator width (XR) after the determination of the minimum value of the cavity opening (Yc) , the procedure is summarized as follows :

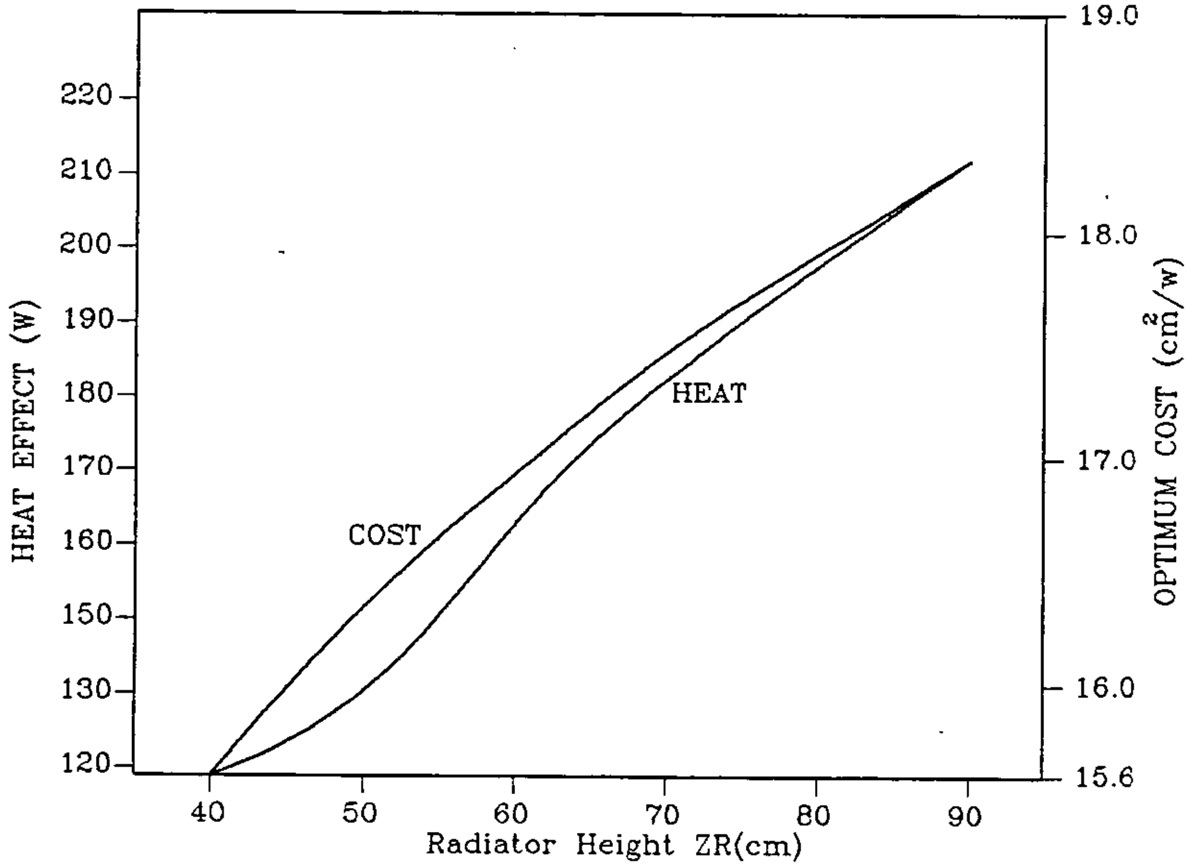
1- A couple of figures similar to that of figure (5.17) is plotted to present the variations of cost and heat effect with radiator width (XR) , at certain value of radiator height (ZR) and (Yc=2.85 cm) , as an example see Figure (5.22) .

2- Step1 is repeated for other radiator heights (ZR = 40, 50, . . . , 90). and figures similar to that of figure(5.22) are obtained.

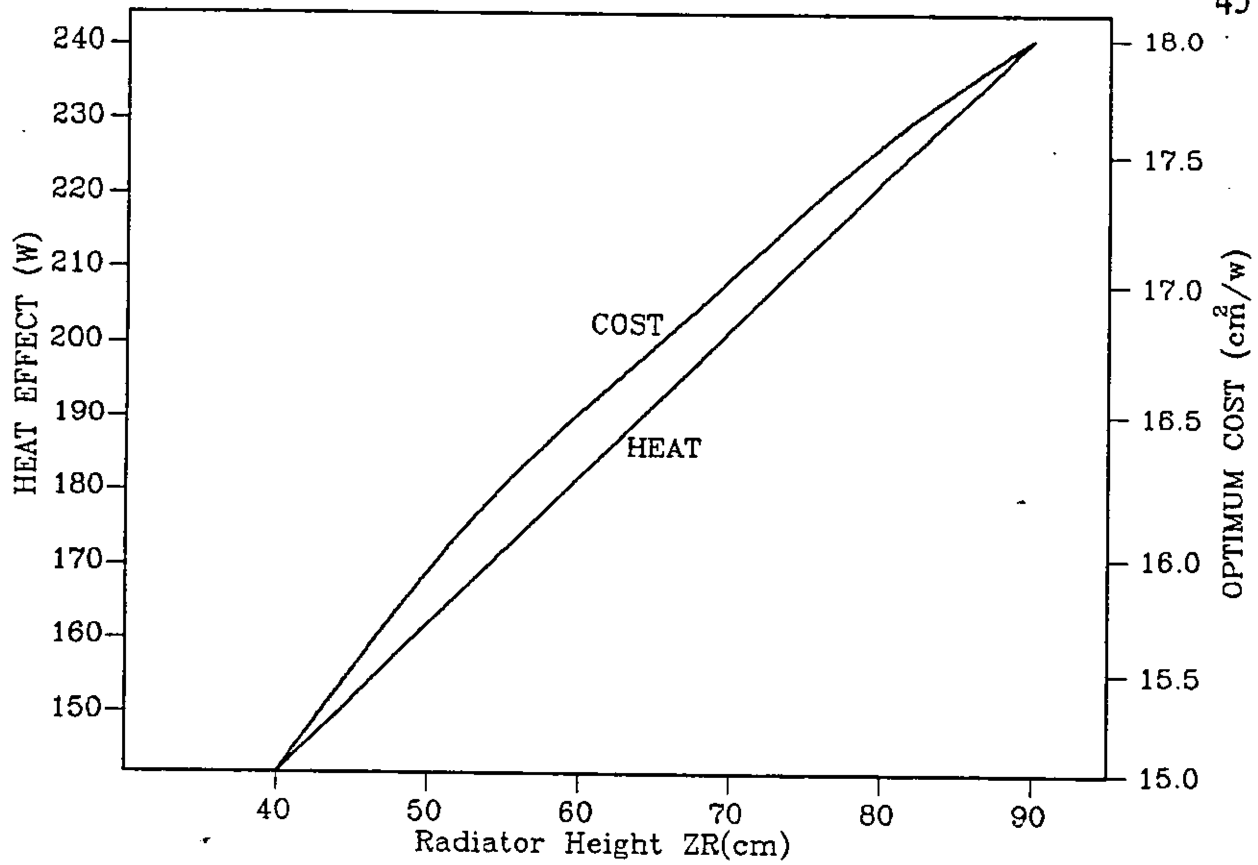
3- The intersection between cost and heat effect for each figure was taken to be the minimum value for radiator widths (XR), after which heat effect and cost are improved .



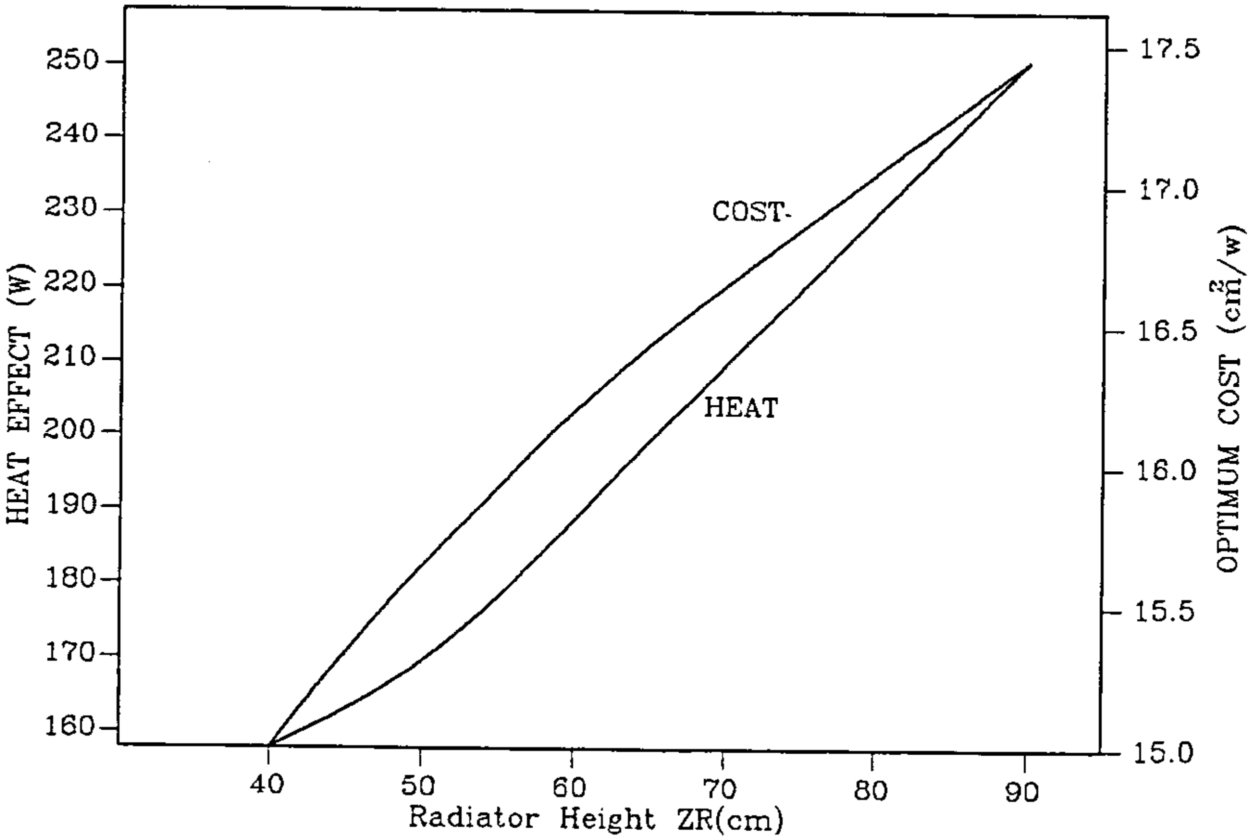
Fig(5.18) Optimum graph of three cavities C.I.R
Input/Output tempt. (90/80) °C
XR=9.0cm ,Yf=1.0cm ,Yc=2.85cm .



Fig(5.19) Optimum graph of three cavities C.I.R
Input/Output temp. (90/80) °C
XR=11cm ,Yf=1.0cm ,Yc=2.85cm .



Fig(5.20) Optimum graph of three cavities C.I.R
Input/Output temp. (90/80) °C
XB=13cm ,Yf=1.0cm ,Yc=2.85cm.



Fig(5.21) Optimum graph of three cavities C.I.R
Input/Output temp. (90/80) °C
XR=15cm ,Yf=1.0cm ,Yc=2.85cm .

4- The maximum value of these minimum points represent the minimum value for radiator width (XR). The maximum value is obtained for temperature difference of 20°C in a similar fashion as for a temperature difference of 10°C.

So following the above procedure, the minimum value for radiator width (XR) is found to be 12.5cm, and the minimum value for the cavity opening in x-direction (Xc) is 2.5 cm.

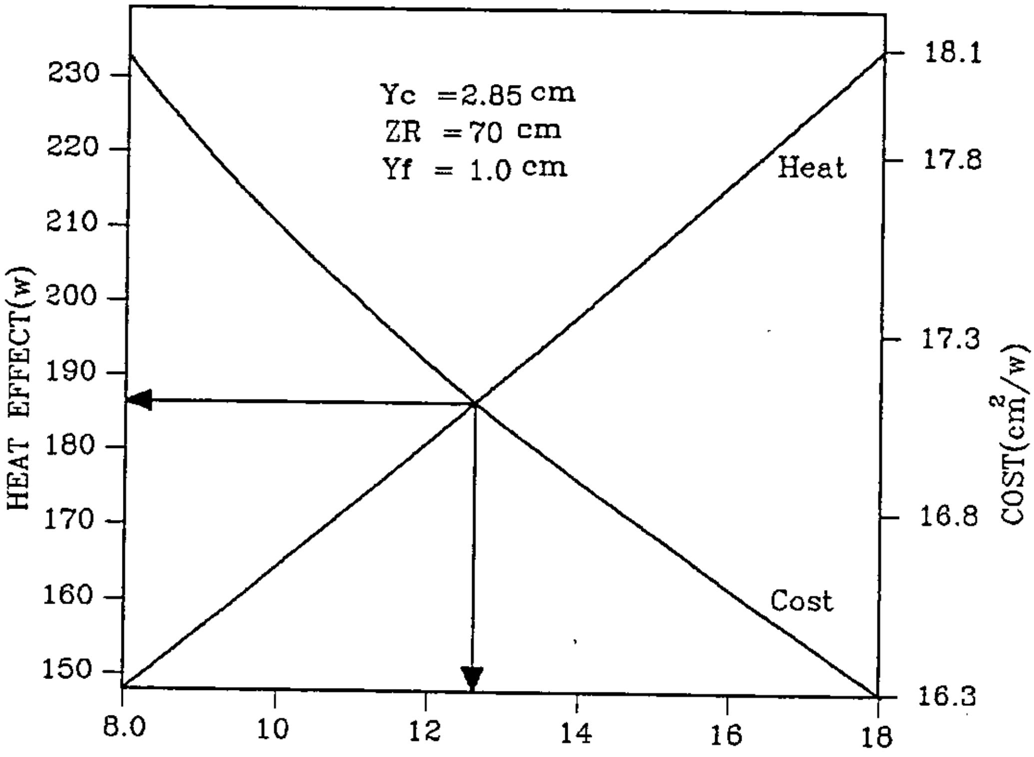
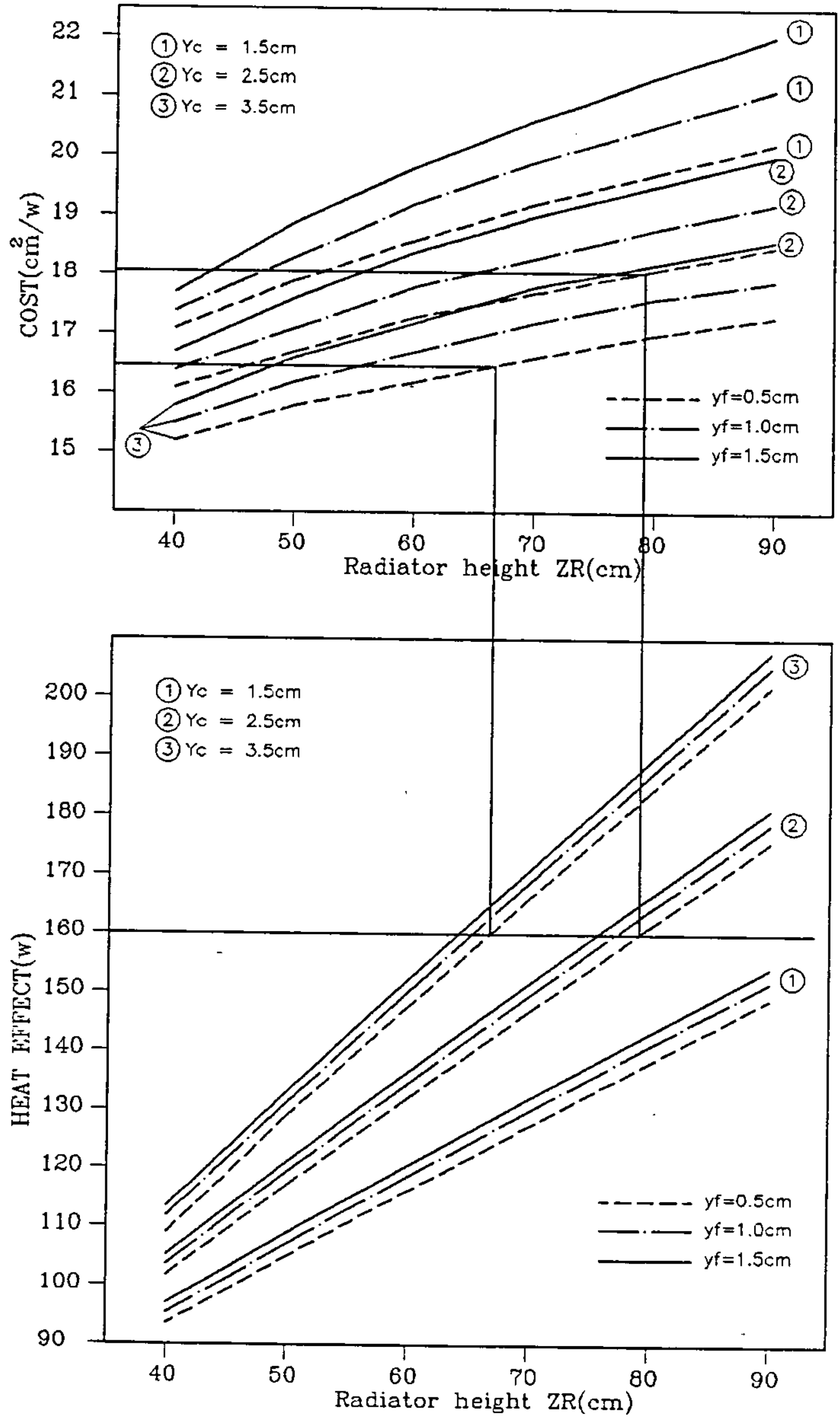


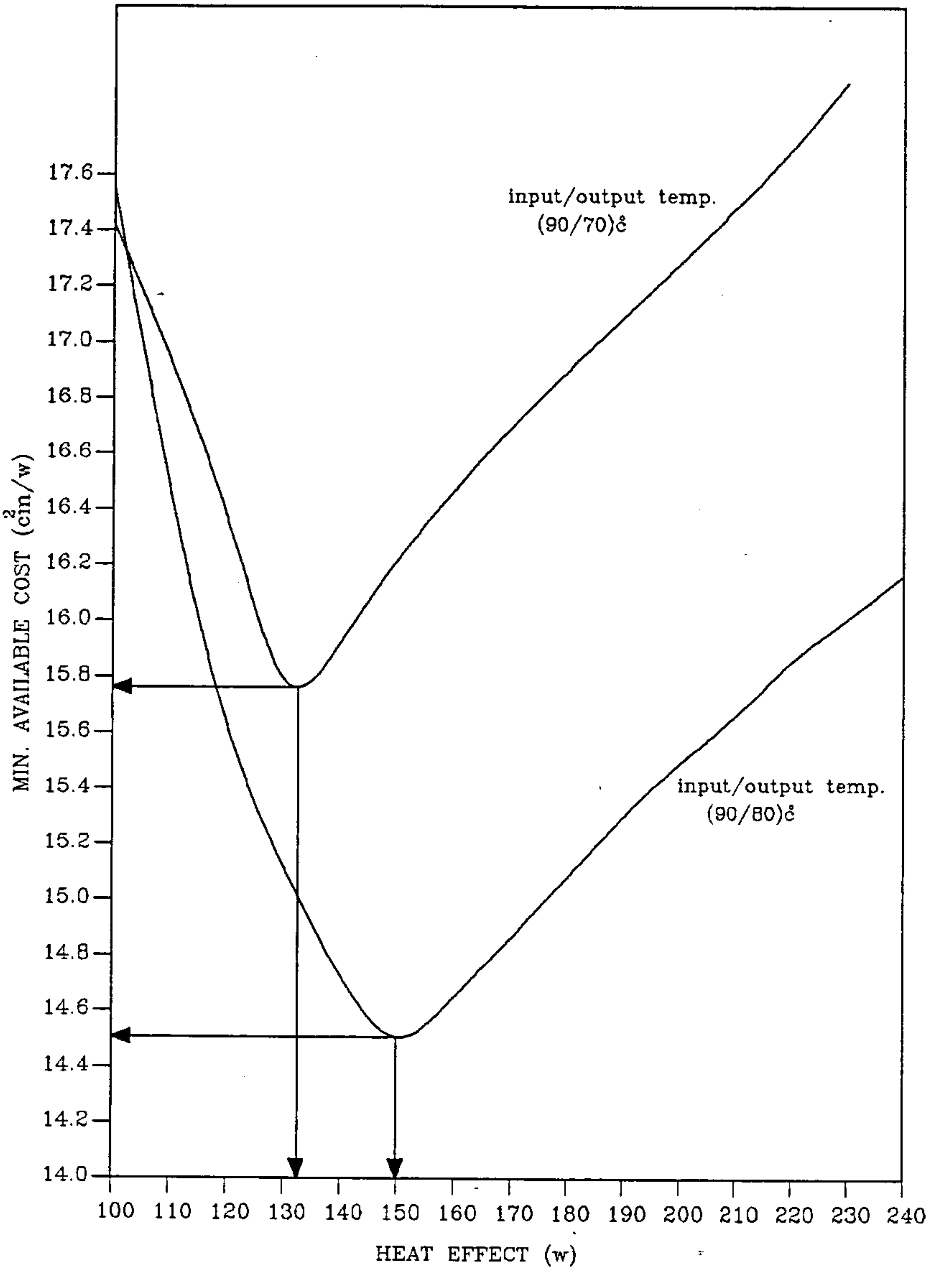
Fig (5.22) Heat effect and cost versus the radiator width

To find the minimum available cost for a specified quantity of heat effect and a temperature difference (90/80°C) the following procedure is followed :-

1- For specified values of radiator width (XR), radiator height (ZR) and for a specified value of heat effect, a line is drawn horizontally for this value of heat effect in the heat effect versus (ZR) graphs, (as an example see fig(5.23)).



Fig(5.23) Example to find the minimum cost for agiven quantity of heat effect.

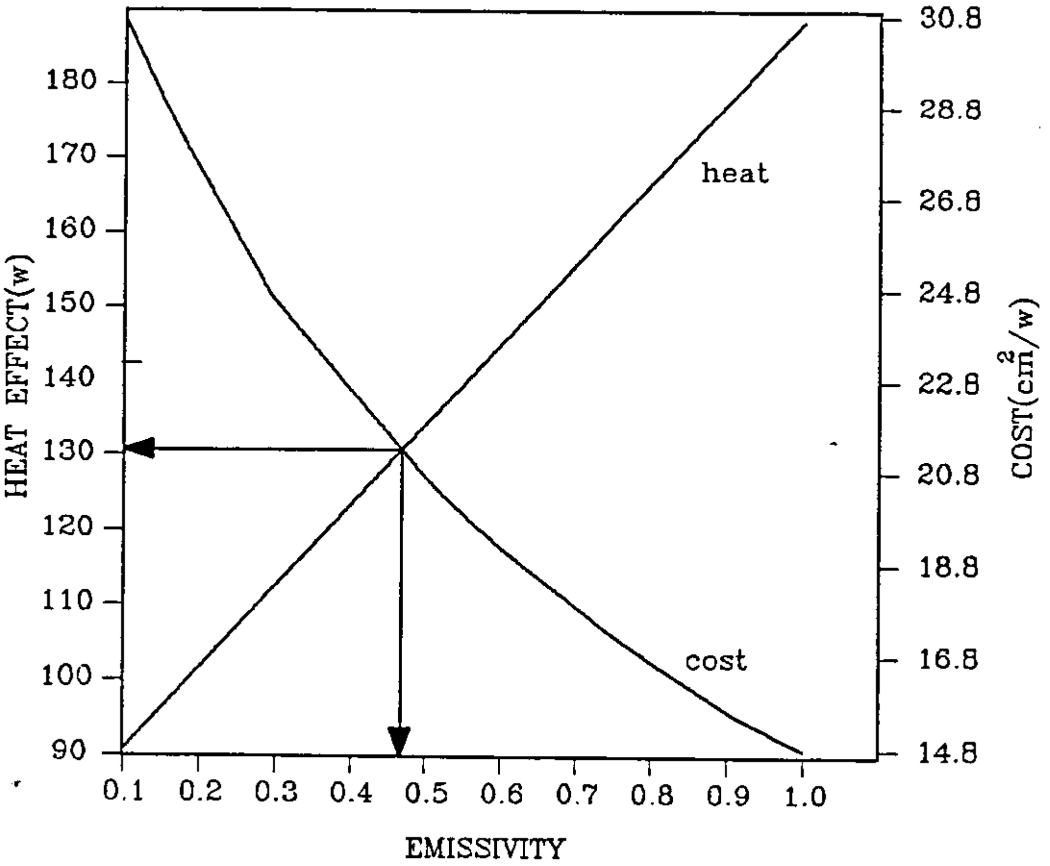


Fig(5.24) Minimum available cost for different heat effect condition is 46.6 and 51.7cm for temperature difference 20°C and 10°C respectively .These heights are the ideal optimum heights .Allowing for the facts that manufactured radiators are not ideal these heights must increased by a safety factor (say 1.15) giving the optimum heights 55 , 60 cm respectively.

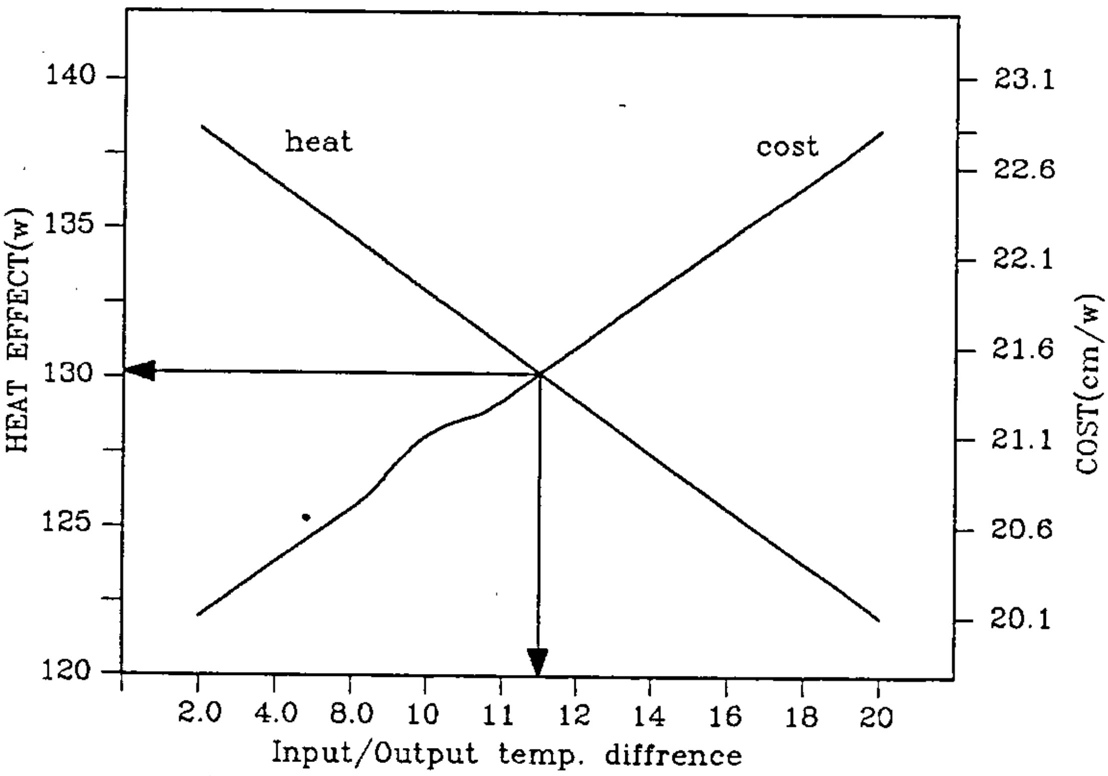
To present the effect of each parameter (such as emissivity ε, temperature difference ΔT and ambient temperature Ta) on heat effect and cost .Figures(5.25-5.27) are plotted at the minimum geometrical conditions that are found to be 2.85cm for cavity opening ,12.5cm for radiator width and 60 cm for radiator height at 10°C temperature difference.

In the radiation mode heat transfer, the surface properties play an important role in determining the overall radiator efficiency . The emissivity of the surface should be maximum in order to give a better performance . Figure (5.25) shows the variation of the cost and heat effect against emissivity . It is evident that the cost decreases with increasing emissivity , while the heat effect increases with the emissivity, but, the minimum value as shown in the figure (5.25) is 0.47.
Appendix (A) shows the results obtained at different values of emissivity (0.5,0.6,0.7 and 0.8) for different geometrical conditions .

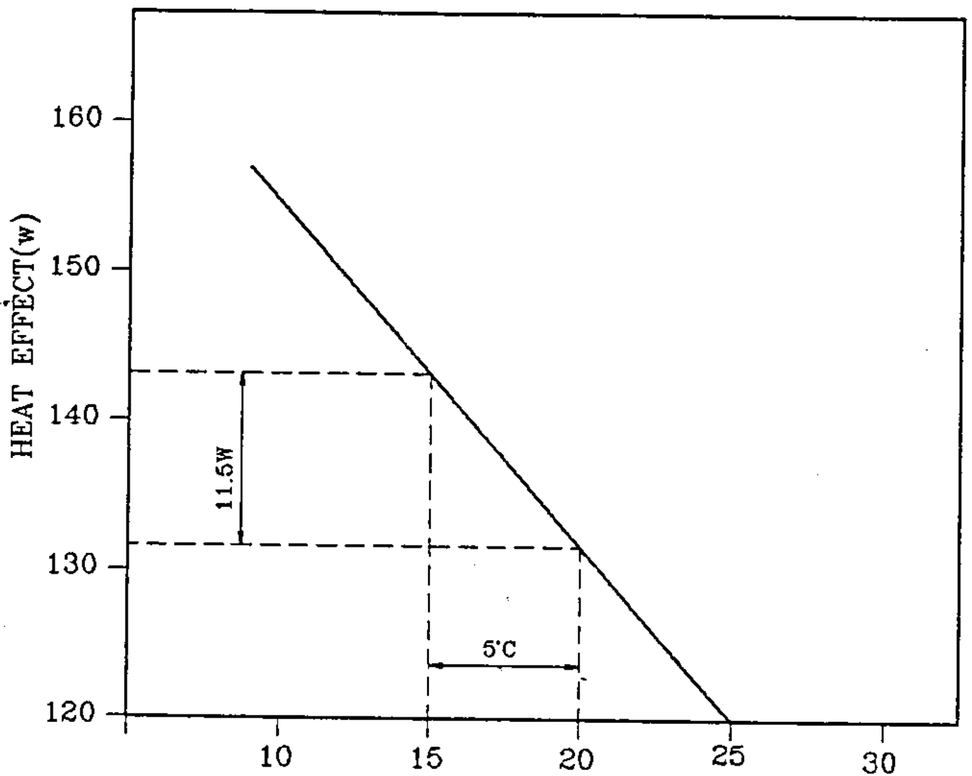
Figure (5.26) shows the variation of the cost and heat effect with temperature difference . As shown in this figure the heat effect decreases with the increase of temperature difference , while the cost decreases , so the intersection represents the maximum value which must not exceed 11.5, ° C.



Fig(5.26) Heat effect and cost versus emissivity
Input/Output tempt. (90/80)°C
XR=12.5cm Yc=2.85cm ZR=60cm



Fig(5.26) Heat effect and cost versus tempt. difference. emissivity=0.47,yf=1.0cm
XB=12.5cm Yc=2.85cm ZR=60cm



Fig(5.27) Heat effect versus ambient temp.
Input/Output tempt. (90/80)'C ,ZR=60cm
XR =12.5 cm , Yc=2.85 cm , yf =1.0 cm
emissivity = 0.47 .

]Figure (5.27) shows the variation of the heat effect against the ambient temperature surrounding the radiator . It is obvious that there is a slight change of the heat effect due to the variation of the ambient temperature (It is 2.3 w each 1°C) .

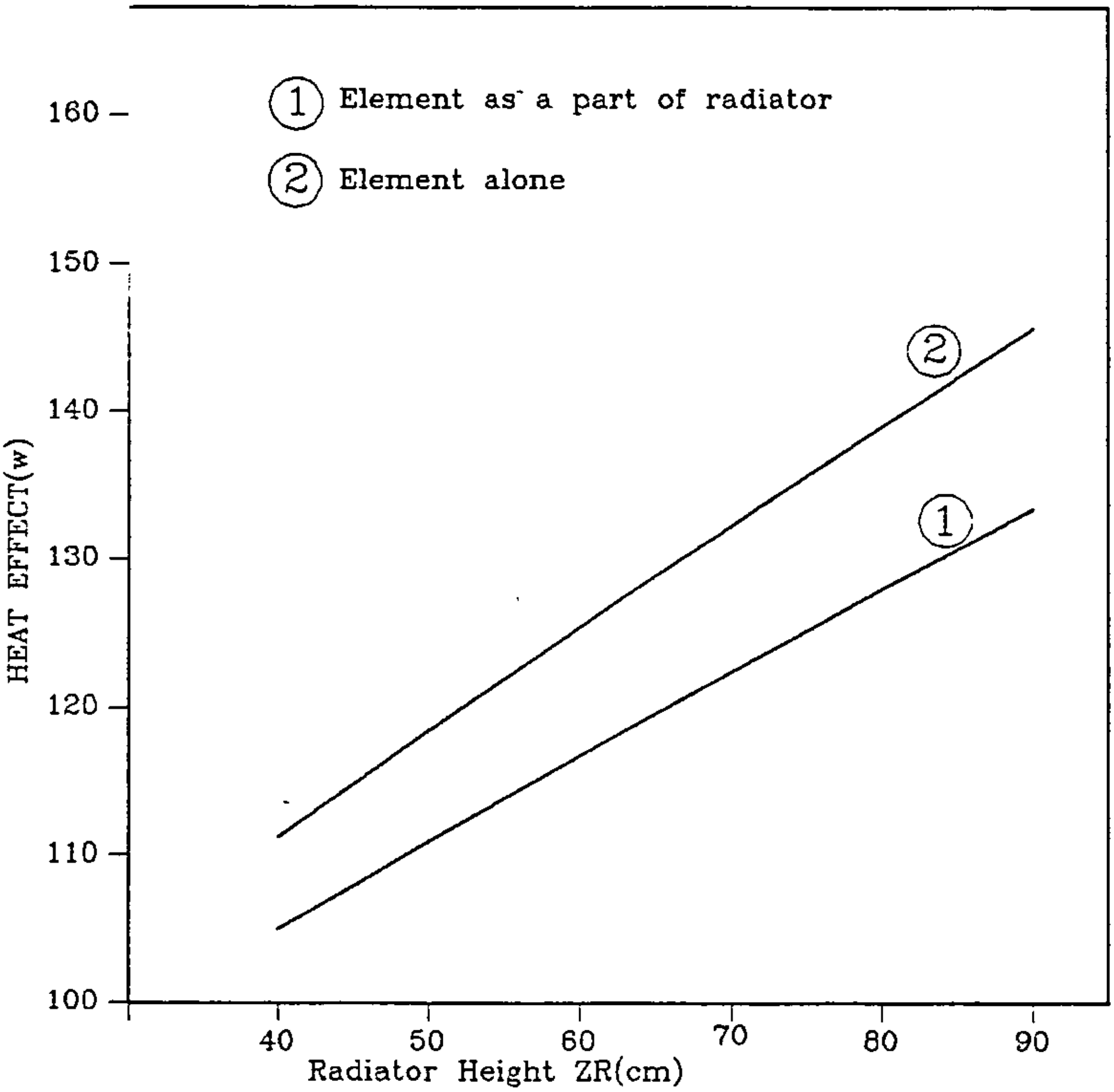
To summarize the optimum conditions for cast iron radiator (C.I.R.) table (5.1) shows the obtained results for minimum cost and maximum heat.

Table (5.1) Worst conditions of ~~optimum~~ values for parameters of C.I.R. at water input 90°C

parameter	value
XR(radiator width)	12.5
ZR (radiator height)	60 cm
Yc(cavity opening in y- direction)	2.85 cm
Xc (cavity opening in x-direction)	2.5 cm
ΔT (temperature difference)	11.5 °C
ε(emissivity)	0.47

A comparison is made between the present obtained results and the radiators specifications available in the local market . Table (5.2) summarizes this comparison .

When the heating element is considered as part of the radiator the results is obtained for the geometrical values of Table 5.1 from figure(5.28) similar to figure (5.2) but with neglecting Qr from the sided surface area. From Figure (5.28) the decrease in Qt can be estimated to be 13 %



Fig(5.28) Heat effect versus radiator height
Input/Output tempt. (90/80)°C .
XR =12.5 cm , Yc=2.85 cm , yf =1.0 cm
emissivity = 0.47 .

Table (5.2) Comparison between radiators available in local market and present study .

Heat effect w/section	Radiator surface area (m^2)					
	MEDITERAN	CHAPPEE (France)	OD OKSAN (Turkish)	Average	present Study	% Ratio of (Study/avg.)
100	0.19	0.214	0.233	0.212	0.200	94
110	0.202	0.236	0.256	0.231	0.214	92.6
120	0.228	0.257	0.280	0.255	0.225	88
130	0.247	0.279	0.303	0.276	0.235	85
140	0.266	0.300	0.326	0.297	0.256	86
150	0.285	0.322	0.350	0.319	0.279	87
160	0.304	0.343	0.372	0.339	0.300	89
170	0.326	0.365	0.396	0.362	0.320	90
180	0.345	0.386	0.419	0.383	0.349	91

From Table (5.2) and for a specified heat effect the surface area required by the radiators suggested in this study is 9 % to 15 % smaller than the surface area required by radiators available in the local market .

For more information about local market Tables (B.1,2,3) show the specifications of the cast iron radiators available in the local market ,as taken from the suppliers catalogs.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6 - 1 Conclusions

Several points have emerged from the present investigation which can be summarized as follows :-

1 - The optimum value of the cavity opening in y-direction (Yc) is 2.85cm . If this value is exceeded the cost decrease while the heat effect increase .

2 - The optimum value of opening cavity in x-direction (Xc) is 2.5 cm , while radiator width (XR) is 12.5cm .

3 - The optimum dimension for radiator height (ZR) is in the range of 60 cm for temperature difference 10°C and 55 cm for 20°C .

4 - There are no limitations for fins length except the problems related to manufacturing process .

5 - The external surface emissivity should be greater than 0.47 by selecting proper paint , that can resist elevated temperature .

6 - The performance of radiators designed at lower temperature difference are better than those designed on higher . This temperature difference should better be less than 11.5 °C .

7- 1°C variations in the ambient temperature can produce a 2.3w per element change in heat effect .

8 - Upon Comparing the heat effect of radiators suggested in this study and the radiators available in the local market the surface area required by first one is 9% to 15% smaller than the surface area required by the second one.

9- The cost of manufacturing cast iron radiators in Jordan is about half of that imported from a foreign countries . Besides that , there are other important aspects which this investigation did not deal with such as the effect of savings on foreign currency .

6 - 2 Recommendations

Despite achieving all the objectives of this study,still there are points that necessitate further investigation ,such as :

1- Investigation could be conducted to study the effect of forced convection on heat effect of the radiators .

2- It is recommend to study the effect of radiator performance on other components of central heating system , such as the pumps and boilers capacity .

3- It is recommended to study the problems associated with moulding , since this is very important in the local market .

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Appendix A

Computer program with some results

In the present program ,Turbo Pascal language is used to calculate the heat transfer from cast iron radiator (C.I.R) , in order to obtain the optimum geometrical conditions .The flow chart of this program is shown in figure (3.2) .While the layout of the program is shown thereafter .

A TURBO PASCAL PROGRAM TO OPTIMIZE CAST IRON RADIATOR FOR LOCAL MARKET

```
program CIR;
uses Crt,printer;
const
  dT     = 10;{diff. between input and output water}
  Twi    = 363.0;         { Water input temperature }
  Ta     = 293.0;     { Temperature of the ambeint }
  cavity = 3;  {No. of the cavities for each element}
  ep     = 0.80;              {emmisivity of Radiator}
  sg     = 5.65e-8;       {Stefan - Blotzman constant}
  v      = 1.77e-5;           { Kinematic viscostiy }
  alfa   = 2.55e-5;             { Thermal diffusivity }
  Pr     = 0.70;                  { Prandtl number }
  k      = 0.02795;             {Thermal conductivity}
  t      = 0.0025;      {thickness of plate expected}
  tf     = 0.0025;        {thickness of fin expected}
  d      = 0.025; {Diam. of the input-output water}
  ZB     = 0.075;              {Height of the collector}

var
 ZR,XR,Yc,Xc,Ze,yf,yfinface,zfinface,spc,spQ :real;
 Sp,Tdrop,Tp:real;
 Abf,Abs,Abt,Abb,Aef,Aes,Atf,Ats,Att,Atb      :  real;
 Aesc,ASTB,ASTE,A,Asfcir,Afin,Absc,Absur  : real;
 Aesur,Ve,Vbb,Vbt,Astotal,Vtotal,Qbf,Qbs       : real;
 Qbt,Qbb,Qef,Qes,Qtf,Qts,Qtt,Qtb,Qtot1        :  real;
 Qfcirb,Qfcirt,Qfine,Qfintot,costQ,Qtotc       : real;
 Qtot,Qcond,Qfinface                           : real;
 mfr,Vinb,Vine,Afinface                         : real;
 cost,cost1,R,U,CP,KK,xx                      : real;
 costf,coste,costb,costt                     : real;
i,j,ii,jj,L1,L2,L3,L4,L5,X,CONT                 : byte;

function sinh(x:real):real;
begin
 sinh:=(exp(x)-exp(-x))/2.0;
end;
```

```
function cosh(x:real):real;
begin
  cosh:=(exp(x)+exp(-x))/2.0;
end;
procedure Calchv(z:real;var h:real);
var
  Gr,gpr,Nu:double;
  Beta,delta:double;

The local heat - transfer coefficient for free convection for vertical plate
       Reference:-
                  Heat and Mass Transfer
                  by E. R. G. ECKERT
 begin
  beta:= 2/(Tp+Ta);
  Gr :=9.801*beta*(TP-Ta)*z*z*z/(v*v);
  delta:=z*3.93*(1/sqrt(pr))*sqrt(sqrt(0.952+pr))/(sqrt(sqrt(Gr)));
  h:=2*k/delta;
end;

procedure Calchh(L,w:real;var h:real);
var
  Gr,gpr,Nu:double;
  Beta,delta,Ral,Nul:double;

The local heat - transfer coefficient for free convection for Horizantal plate
                  Fundamentals Of
                  Heat and Mass Transfer
                  by Frank P. Incropera
   begin
  beta:= 2/(Tp+Ta);
  L:= Yc*XR/(2(XR+Yc));
  Ral:=9.8*beta*(Tp-Ta)*x*x*x/(v*alfa);
  if  AST = 0.0 then
  Nul := 0.27*sqrt(sqrt(Ral)) else
  Nul:=0.54*sqrt(sqrt(Ral));
  h:=(k/L))*Nul;
end;
```

```
procedure CalcArea(Xb,Y,Zb,Xe,Ze:real
                  ;var Abf,Abs,Abt,Abb,Aef,Aes,Aesc,Absc
                  ,Absur,Aesur,Ve,Vbb,Vtotal:real);
begin
  Abf := Xb*Zb-(3.14*D*D/4.0)+(0.065-Y)*3.14*0.05; {In X-direction}
  Abs := Zb*Y;
  Abb := Xb*Y;
  Aes := Y*Ze;
  Aef := Xe*Ze-2*(tf*ze);
  Aesc :=Xe*Y;
  Absc := Xb*Y;
  Abt := Abb-3*Aesc;
  Absur :=2*Abf+2*Abs+Abb+Abt;
  Aesur :=3*(2*Aes+2*Aef);
  Ve :=3*(Xe*Y*Ze);
  Vbb :=Xb*Y*Zb;
  Vtotal :=Ve+2*Vbb;{volum of the cavities (i.e water content)}
end;

function CalcQ(As,AST,Aso,Zo,Zl:real):real;
var
  sum,ZZZ,A10,QQ,t1,t2: double;
  h: real;
begin
  sum:= 0.0;
  A10:=As/10;
  for i:=1 to 10 do
  begin
    ZZZ:=Zo+Zl*i/10;{TO find Heat-Transfer coefficient}
     Tp:=Twi-Tdrop*(Aso+AST*i/10);{Heat transfer by conduction for the
plate}
    CalcHv(ZZZ,h);
    if Zo = 0.0 then
    begin
    Calchh(zzz,Yc,h);{for horizontal plates note: zzz = x direction}
    end;
    t1:=Tp*Tp*Tp*Tp;
    t2:=Ta*Ta*Ta*Ta;
```

```
  writeln(The results of heat effect and cost for different Radiator
geometry);
  writeln(input/output water (90/80));
  writeln(emissivity = 0.8 );


writeln ('
```

Yf			0.5(cm)		1.0(cm)		1.5(cm)	
XR cm	Yc cm	ZR cm	Qtot (w)	Cost cm^2/w	Qtot (w)	Cost cm^2/w	Qtot (w)	Cost cm^2/w

```
                                                              ');
for L3:= 0 to 3 do
  begin
   XR:= 0.09+0.02*L3;   {Width of radiator 0.10 to 0.16}
   write( ,100*XR:4:1, );
   for L4:=0 to 2 do
   begin
    Xc:=XR/(2*cavity-1);
    Yc:=0.015+0.01*L4;
    yfinface:=0.06-Yc;
    if  L4 = 0 then
     write(100*Yc:4:1, ) else
     write(      ,100*Yc:4:1, );
     for L5:=1 to 6 do
     begin
      ZR:=0.3+0.10*L5; {depth of the fin}
      ZE:=ZR-0.15;
      zfinface:=ZR+1.3*XR;
      if L5 = 1 then
      write(100*ZR:4:1, ) else
      write(          ,100*ZR:4:1, );
      for L1 := 1 to 3 do
      begin
       Yf:= 0.005*L1;{ Depth of element and base 0.02 to 0.05}
       R:=(ZR+2*ZB)/kk;
       U:=1/R;
```

```
    CalcArea(XR,Yc,Zb,Xc,Ze,Abf,Abs,Abt,Abb,Aef,Aes,Aesc,Absc
            ,Absur,Aesur,Ve,Vbb,Vtotal);
    Atf:=Abf;
    Ats:=Abs;
    Att:=Abb;
    Atb:=Abt;
    Vbt:=Vbb;
    Afin:=Ze*yf;
    Afinface:=2*zfinface*Yfinface;
    Astotal:=2*Absur+Aesur+(2*cavity-1)*Afin+Afinface;
    Tdrop:=dT/Astotal;
    ASTB:=2*Abf+2*Abs+Abt+Abb;
    ASTE:=3*2*(Aes+Aef);
    Qbf:=CalcQ(Abf,ASTB,0.0,0.00001,Zb);
    Qbs:=CalcQ(Abs,ASTB,0.0,0.000001,Zb);
    Qbt:=CalcQ(Abt,0.0,ASTB,0.0,XR);
    Qbb:=CalcQ(Abb,0.0,0.0,0.0,XR);
    Qef:=CalcQ(Aef,ASTE,Absur,Zb,Ze);
    Qes:=CalcQ(Aes,ASTE,Absur,Zb,Ze);
    Qtt:=CalcQ(Att,0.0,Astotal-Att,0.0,XR);
    Qtb:=CalcQ(Atb,0.0,Absur+Aesur,0.0,XR);
    Qtf:=CalcQ(Atf,ASTB,Absur+Aesur,Zb+Ze,Zb);
    Qts:=CalcQ(Ats,ASTB,Absur+Aesur,Zb+Ze,Zb);
    Qfine:=CalcQf(ASTE,Absur,Zb,Zb+Ze,yf);
    Qfinface:=calcQf(ASTE+2*Absur,0,0,Zfinface,yfinface);
    Qfintot:=(2*cavity-1)*Qfine+Qfinface;
    A:=2*(XR+Yc)*t; {Heat conduction form through the}
    Qcond:=U*A*dT;      {  cast iron }
    Qtot:=Qbf*2+Qbs*2+Qbt+Qbb+3*(Qef*2+Qes*2)
        +Qtf*2+Qtb+Qts*2+Qtt+Qfintot+2*(Qfcirb+Qfcirt)+Qcond;
   cost:=10000*Astotal/Qtot;
   mfr:=Qtot/(cp*dT);
   Vinb:=mfr/(1000*Absc);
   Vine:=mfr/(1000*3*Aesc);
   write(  ,Qtot:5:1,   ,cost:5:1,   );
  end;
  writeln;
end;
```

Table (A.1)
The results of heat effect and cost for different geometry . Input/Output water (90/80)°C emissivity = 0.500

Yf			0.5(cm)		1.0 (cm)		1.5 (cm)	
XR cm	Yc cm	ZR cm	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt
11.0	1.5	50.0	96.5	21.3	98.7	21.7	100.3	22.2
		60.0	106.2	22.2	108.5	22.8	110.4	23.4
		70.0	115.6	23.1	118.2	23.7	120.2	24.5
		80.0	124.9	23.8	127.6	24.6	129.8	25.4
	2.5	50.0	105.7	20.2	107.9	20.6	109.6	21.1
		60.0	118.2	21.0	120.6	21.5	122.4	22.1
		70.0	130.4	21.7	133.0	22.3	135.0	23.0
		80.0	142.4	22.3	145.1	23.0	147.4	23.7
	3.5	50.0	114.8	19.3	116.9	19.7	118.6	20.1
		60.0	130.0	20.0	132.4	20.5	134.3	21.0
		70.0	145.0	20.6	147.6	21.2	149.7	21.8
		80.0	159.6	21.1	162.4	21.8	164.7	22.5
13.0	1.5	50.0	108.0	20.6	110.2	21.0	111.8	21.5
		60.0	118.8	21.6	121.1	22.1	123.0	22.6
		70.0	129.3	22.4	131.9	23.0	133.9	23.6
		80.0	139.7	23.1	142.4	23.8	144.6	24.5
	2.5	50.0	117.3	19.7	119.5	20.1	121.2	20.5
		60.0	130.9	20.5	133.3	21.0	135.2	21.5
		70.0	144.2	21.2	146.8	21.7	148.8	22.3
		80.0	157.3	21.8	160.0	22.4	162.2	23.1
	3.5	50.0	126.5	18.9	128.6	19.3	130.4	19.7
		60.0	142.8	19.6	145.2	20.1	147.2	20.6
		70.0	158.9	20.2	161.5	20.7	163.6	21.3
		80.0	174.6	20.7	177.4	21.3	179.7	22.0
15.0	1.5	50.0	119.9	20.1	122.0	20.4	123.7	20.9
		60.0	131.8	20.9	134.1	21.4	136.0	22.0
		70.0	143.4	21.7	146.0	22.3	148.0	22.9
		80.0	154.8	22.4	157.6	23.1	159.8	23.8
	2.5	50.0	129.3	19.2	131.4	19.6	133.2	20.0
		60.0	144.0	20.0	146.4	20.5	148.3	20.9
		70.0	158.4	20.7	160.9	21.2	163.0	21.8
		80.0	172.5	21.3	175.3	21.9	177.5	22.5
	3.5	50.0	138.6	18.5	140.7	18.9	142.5	19.2
		60.0	156.0	19.2	158.4	19.7	160.4	20.1
		70.0	173.1	19.8	175.8	20.3	177.9	20.9
		80.0	189.9	20.4	192.8	20.9	195.0	21.5

Table (A.2)

The results of heat effect and cost for different geometry . Input/Output water (90/80)°C emissivity = 0.600

Yf			0.5(cm)		1.0 (cm)		1.5 (cm)	
XR cm	Yc cm	ZR cm	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt
11.0	1.5	50.0	103.8	19.8	106.0	20.2	107.7	20.7
		60.0	114.5	20.6	116.9	21.2	118.7	21.8
		70.0	125.0	21.3	127.5	22.0	129.6	22.7
		80.0	135.3	22.0	138.0	22.7	140.2	23.5
	2.5	50.0	114.1	18.7	116.2	19.1	118.0	19.6
		60.0	127.9	19.4	130.2	19.9	132.2	20.5
		70.0	141.4	20.0	144.0	20.6	146.1	21.2
		80.0	154.7	20.5	157.5	21.2	159.7	21.9
	3.5	50.0	124.1	17.8	126.3	18.2	128.1	18.6
		60.0	141.0	18.4	143.4	18.9	145.4	19.4
		70.0	157.6	19.0	160.2	19.5	162.4	20.1
		80.0	173.9	19.4	176.7	20.0	179.0	20.7
13.0	1.5	50.0	116.1	19.2	118.3	19.6	120.0	20.0
		60.0	128.0	20.0	130.4	20.5	132.3	21.1
		70.0	139.7	20.7	142.3	21.3	144.3	21.9
		80.0	151.2	21.3	154.0	22.0	156.2	22.7
	2.5	50.0	126.5	18.3	128.7	18.6	130.4	19.1
		60.0	141.5	18.9	143.9	19.4	145.8	19.9
		70.0	156.2	19.5	158.9	20.1	161.0	20.7
		80.0	170.7	20.0	173.6	20.7	175.8	21.3
	3.5	50.0	136.7	17.5	138.9	17.8	140.6	18.2
		60.0	154.8	18.1	157.2	18.5	159.2	19.0
		70.0	172.6	18.6	175.2	19.1	177.4	19.7
		80.0	190.0	19.1	192.9	19.6	195.2	20.2
15.0	1.5	50.0	128.8	18.7	130.9	19.0	132.7	19.5
		60.0	141.9	19.4	144.3	19.9	146.2	20.4
		70.0	154.8	20.1	157.4	20.7	159.5	21.3
		80.0	167.5	20.7	170.3	21.3	172.5	22.0
	2.5	50.0	139.3	17.8	141.4	18.2	143.2	18.6
		60.0	155.5	18.5	157.9	19.0	159.9	19.4
		70.0	171.5	19.1	174.1	19.6	176.2	20.2
		80.0	187.2	19.6	190.0	20.2	192.3	20.8
	3.5	50.0	149.6	17.2	151.8	17.5	153.6	17.8
		60.0	168.9	17.8	171.4	18.2	173.4	18.6
		70.0	187.9	18.3	190.6	18.7	192.7	19.3
		80.0	206.6	18.7	209.5	19.3	211.8	19.8

Table (A.4)

The results of heat effect and cost for different geometry . Input/Output water (90/80)°C emissivity = 0.800

Yf			0.5(cm)		1.0 (cm)		1.5 (cm)	
XR cm	Yc cm	ZR cm	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt	Qtot (w)	surface area per watt
11.0	1.5	50.0	118.5	17.3	120.7	17.7	122.4	18.2
		60.0	131.2	18.0	133.6	18.5	135.5	19.1
		70.0	143.7	18.6	146.3	19.2	148.4	19.8
		80.0	156.0	19.1	158.8	19.8	161.1	20.5
	2.5	50.0	130.7	16.3	133.0	16.7	134.7	17.1
		60.0	147.2	16.9	149.6	17.3	151.6	17.8
		70.0	163.3	17.3	166.0	17.9	168.2	18.4
		80.0	179.3	17.7	182.2	18.3	184.5	19.0
	3.5	50.0	142.9	15.5	145.1	15.9	146.9	16.3
		60.0	163.0	16.0	165.5	16.4	167.5	16.9
		70.0	182.8	16.3	185.5	16.8	187.7	17.4
		80.0	202.3	16.7	205.3	17.2	207.7	17.8
13.0	1.5	50.0	132.3	16.8	134.5	17.2	136.3	17.6
		60.0	146.5	17.5	149.0	17.9	150.9	18.5
		70.0	160.5	18.0	163.1	18.6	165.2	19.2
		80.0	174.3	18.5	177.1	19.1	179.4	19.8
	2.5	50.0	144.8	15.9	147.0	16.3	148.8	16.7
		60.0	162.7	16.5	165.2	16.9	167.2	17.4
		70.0	180.3	16.9	183.0	17.4	185.2	18.0
		80.0	197.7	17.3	200.6	17.9	203.0	18.5
	3.5	50.0	157.1	15.2	159.4	15.5	161.2	15.9
		60.0	178.7	15.7	181.2	16.1	183.2	16.5
		70.0	199.9	16.1	202.7	16.5	204.9	17.0
		80.0	220.9	16.4	223.9	16.9	226.3	17.4
15.0	1.5	50.0	146.6	16.4	148.8	16.8	150.5	17.1
		60.0	162.2	17.0	164.7	17.4	166.6	17.9
		70.0	177.7	17.5	180.3	18.0	182.4	18.6
		80.0	192.9	18.0	195.7	18.6	198.0	19.2
	2.5	50.0	159.2	15.6	161.5	15.9	163.2	16.3
		60.0	178.6	16.1	181.1	16.5	183.1	17.0
		70.0	197.7	16.6	200.4	17.0	202.6	17.5
		80.0	216.5	17.0	219.4	17.5	221.8	18.0
	3.5	50.0	171.7	14.9	174.0	15.3	175.8	15.6
		60.0	194.8	15.4	197.3	15.8	199.3	16.2
		70.0	217.5	15.8	220.2	16.2	222.5	16.7
		80.0	239.9	16.1	242.8	16.6	245.3	17.1

Appendix B

Some of cast iron radiators available in the local market

Table (B.1)

Heat emission at different room temperature for CHAPPEE cast iron radiators (C.I.R) .

	Height net	Depth	Certified NF Thermal output per section* at Δ t 60° C			Thermal heating surface	Thermal output / thermal m²	Approx. shipping weight per section
	mm	mm	NF Kcal/h	Watt	Btu/h	m²	Kcal/h	kg
S2	480	65	59,3	69,0	235,5	0,148	400,7	3,21
	630		77,8	90,4	308,5	0,194	401	4,06
	780		94,8	110,2	376,1	0,237	400	5,08
	900		109,8	127,6	435,5	0,274	400,7	5,77
S3	480	102	84,6	98,4	335,8	0,211	400,9	4,50
	630		107,4	124,9	426,2	0,268	400,7	5,55
	680		114,6	133,3	454,9	0,286	400,7	6,08
	780		128,9	149,9	511,6	0,322	400,3	6,77
	900		148,9	173,2	591,1	0,372	400,3	8,08
S4	480	142	102,9	119,7	408,5	0,257	400,4	5,44
	630		134,4	156,3	533,4	0,336	400	7,05
	680		142,0	165,1	563,4	0,355	400	7,70
	780		159,8	185,8	634,1	0,399	400,5	8,56
	900		184,1	214,1	730,7	0,460	400,2	10,00
S6	285	223	85,0	98,8	337,2	0,212	400,9	5,32

Table (B.2)
Heat emission at different room temperature for ODOKSAN cast iron radiators (C.I.R) .

No's of Elements	ROOM TEMPERATURES °C									TOTAL LENGTH m	HEATING SURFACE m²	WATER CONTENT Lt.
	5°C	10°C	12°C	15°C	18°C	20°C	22°C	24°C	26°C			
1	135	126	122	115	108	103	98	93	89	0,06	0,24	0,80
2	270	252	244	230	216	206	196	186	178	0,12	0,48	1.60
3	405	378	366	345	324	309	294	279	267	0,18	0,72	2,40
4	540	504	488	460	432	412	392	372	356	0,24	0,96	3.20
5	675	630	610	575	540	515	490	465	445	0.30	1,20	4,00
6	810	756	732	690	648	618	588	558	534	0,36	1,44	4,80
7	945	882	854	805	756	721	686	651	623	0,42	1,68	5.60
8	1080	1008	976	920	864	824	784	744	712	0.48	1,92	6,40
9	1215	1134	1098	1035	972	927	882	837	801	0.54	2,16	7,20
10	1350	1260	1220	1150	1080	1030	980	930	890	0,60	2,40	8.00
11	1485	1386	1342	1265	1188	1133	1078	1023	979	0,66	2,64	8,80
12	1620	1512	1464	1380	1296	1236	1176	1116	1068	0,72	2,88	9,60
13	1755	1638	1586	1495	1404	1339	1274	1209	1157	0,78	3,12	10,40
14	1890	1764	1708	1610	1512	1442	1372	1302	1246	0,86	3,36	11,20
15	2025	1890	1830	1725	1620	1545	1470	1395	1335	0,90	3,60	12.00
16	2160	2016	1952	1840	1728	1648	1568	1488	1424	0,96	3,84	12,80
17	2285	2142	2074	1955	1836	1751	1666	1581	1513	1,02	4,08	13,60
18	2430	2268	2196	2070	1944	1854	1764	1674	1602	1,08	4,32	14,40
19	2565	2394	2318	2185	2052	1957	1862	1767	1691	1,14	4,56	15,20
20	2700	2520	2440	2300	2160	2060	1960	1860	1780	1,20	4,80	16,00
21	2835	2646	2562	2415	2268	2163	2058	1953	1869	1,26	5,04	16,80
22	2970	2772	2684	2530	2376	2266	2156	2046	1958	1,32	5,28	17,60
23	3105	2898	2806	2645	2484	2369	2254	2139	2047	1,38	5,52	18.40
24	3240	3024	2928	2760	2592	2472	2352	2232	2136	1,44	5,76	19,20
25	3375	3150	3050	2875	2700	2575	2450	2325	2225	1,50	6,00	20,00
26	3510	3276	3172	2990	2808	2678	2548	2418	2314	1,56	6,24	20,80
27	3645	3402	3294	3105	2916	2781	2646	2511	2403	1,62	6,48	21,60
28	3780	3528	3416	3220	3024	2884	2744	2604	2492	1,68	6,72	22,40
29	3915	3654	3538	3335	3132	2987	2842	2697	2581	1,74	6.96	23,20
30	4050	3780	3660	3450	3240	3090	2940	2790	2670	1,80	7,20	24,00

Table (B.3)
Heat emission at different room temperature for MEDITERAN cast iron radiators (C.I.R) .

No of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit.)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,18	0,525	4,445	115,8	104,7	98,0	94,0	90,4	85,7
2	120	0,36	1,050	8,890	231,6	209,4	196,0	188,0	180,8	171,4
3	180	0,54	1,575	13,335	347,4	314,1	294,0	282,0	271,2	257,1
4	240	0,72	2,100	17,780	463,2	418,8	392,0	376,0	361,6	342,8
5	300	0,90	2,625	22,225	579,0	523,5	490,0	470,0	452,0	428,5
6	360	1,08	3,150	26,670	694,8	628,2	588,0	564,0	542,4	514,2
7	420	1,26	3,675	31,115	810,6	732,9	686,0	658,0	632,8	599,9
8	480	1,44	4,200	35,560	926,4	837,6	784,0	752,0	723,2	685,6
9	540	1,62	4,725	40,005	1042,2	942,3	882,0	846,0	813,6	771,3
10	600	1,80	5,250	44,450	1158,0	1047,0	980,0	940,0	904,0	857,0
11	660	1,98	5,775	48,895	1273,8	1151,7	1078,0	1034,0	994,4	942,7
12	720	2,16	6,300	53,340	1389,6	1256,4	1176,0	1128,0	1084,8	1028,4
13	780	2,34	6,825	57,785	1505,4	1361,1	1274,0	1222,0	1175,2	1114,1
14	840	2,52	7,350	62,230	1621,2	1465,8	1372,0	1316,0	1265,6	1199,8
15	900	2,70	7,875	66,675	1737,0	1570,5	1470,0	1410,0	1356,0	1285,5
16	960	2,88	8,400	71,120	1852,8	1675,2	1568,0	1504,0	1446,4	1371,2
17	1020	3,06	8,925	75,565	1968,6	1779,9	1666,0	1598,0	1536,8	1456,9
18	1080	3,24	9,450	80,010	2084,4	1884,6	1764,6	1692,0	1627,2	1542,6
19	1140	3,42	9,975	84,455	2200,2	1989,3	1862,0	1786,0	1717,6	1628,3
20	1200	3,60	10,500	88,900	2316,0	2094,0	1960,0	1880,0	1808,0	1714,0
21	1260	3,78	11,025	93,345	2431,8	2198,7	2058,0	1974,0	1898,4	1799,7
22	1320	3,96	11,550	97,790	2547,6	2303,4	2156,0	2068,0	1988,8	1885,4
23	1380	4,14	12,075	102,235	2663,4	2408,1	2254,0	2162,0	2079,2	1971,1
24	1440	4,32	12,600	106,680	2779,2	2512,8	2352,0	2256,0	2169,6	2056,8
25	1500	4,50	13,125	111,125	2895,0	2617,5	2450,0	2350,0	2260,0	2142,5

No. of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit.)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,24	0,695	5,26	154,7	139,5	130,6	126,0	120,6	114,3
2	120	0,48	1,390	10,52	309,4	279,0	261,2	252,0	241,2	228,6
3	180	0,72	2,085	15,78	464,1	418,5	391,8	378,0	361,8	342,9
4	240	0,96	2,780	21,04	618,8	558,0	522,4	504,0	482,4	457,2
5	300	1,20	3,475	26,30	773,5	697,5	653,0	630,0	603,0	571,5
6	360	1,44	4,170	31,56	928,2	837,0	783,6	756,0	723,6	685,8
7	420	1,68	4,865	36,82	1082,5	976,5	914,2	882,0	844,2	800,1
8	480	1,92	5,560	42,08	1237,6	1116,0	1044,8	1008,0	964,8	914,4
9	540	2,16	6,255	47,34	1392,3	1255,5	1175,4	1134,0	1085,4	1028,7
10	600	2,40	6,950	52,60	1547,0	1395,0	1306,0	1260,0	1206,0	1143,0
11	660	2,64	7,645	57,86	1701,7	1534,5	1436,6	1386,0	1326,6	1257,3
12	720	2,88	8,340	63,12	1856,4	1674,0	1567,2	1512,0	1447,2	1371,6
13	780	3,12	9,035	68,38	2011,1	1813,5	1697,8	1638,0	1567,8	1485,9
14	840	3,36	9,730	73,64	2165,8	1953,0	1828,4	1764,0	1688,4	1600,2
15	900	3,60	10,425	78,90	2320,5	2092,5	1959,0	1890,0	1809,0	1714,5
16	960	3,84	11,120	84,16	1475,2	2232,0	2089,6	2016,0	1929,6	1828,8
17	1020	4,08	11,815	89,42	2629,9	2371,5	2220,2	2142,0	2050,2	1943,1
18	1080	4,32	12,510	94,68	2784,6	2511,0	2350,8	2268,0	2170,8	2057,4
19	1140	4,56	13,205	99,94	2939,3	2650,5	2481,4	2394,0	3291,4	2171,9
20	1200	4,80	13,900	105,20	3094,0	2790,0	2612,0	2520,0	2412,0	2286,0
21	1260	5,04	14,595	110,46	3248,7	2929,5	2742,6	2646,0	2532,6	2400,3
22	1320	5,28	15,290	115,72	3403,4	3069,0	2873,2	2772,0	2653,2	2514,6
23	1380	5,52	15,985	120,98	3558,1	3208,5	3003,8	2898,0	2773,8	2628,9
24	1440	5,76	16,680	126,24	3712,8	3348,0	3134,4	3024,0	2894,4	2743,2
25	1500	6,00	17,375	131,50	3867,5	3487,5	3265,0	3150,0	3015,0	2857,5

No of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,27	0,79	6,04	174,5	157,5	150,7	142,0	136,2	129,1
2	120	0,54	1,58	12,08	349,0	315,0	301,4	284,0	272,4 7	258,2
3	180	0,81	2,37	18,12	523,5	472,5	452,1	426,0	9 408,6 5	387,3
4	240	1,08	3,16	24,16	698,0	630,0	602,8	568,0	544,8	516,4
5	300	1,35	3,95	30,20	872,5	787,5	753,5	710,0	681,0	645,5
6	360	1,62	4,74	36,24	1047,0	945,0	904,2	852,0	817,2	774,6
7	420	1,89	5,53	42,28	1221,5	1102,5	1054,5	994,0	953,4 3	903,7
8	480	2,16	6,32	48,32	1396,0	1260,0	1205,6	1136,0	1089,6	1032,8
9	540	2,43	7,11	54,36	1570,5	1417,5	1356,3	1278,0	1225,8	1161,5
10	600	2,70	7,90	60,40	1745,0	1575,0	1507,0	1420,0	1362,0	1291,0
11	660	2,97	8,69	66,44	1919,5	1732,5	1657,7	1562,0	1498,2	1420,1
12	720	3,24	9,48	72,48	2094,0	1890,0	1808,4	1704,0	1634,4	1549,2
13	780	3,51	10,27	78,52	2268,5	2047,5	1959,1	1846,0	1770,6	1678,3
14	840	3,78	11,06	84,56	2443,0	2205,0	2109,8	1988,0	1906,8 1	1807,4
15	900	4,05	11,85	90,60	2617,5	2362,5	2260,5	2130,0	2043,0 2	1936,5
16	960	4,32	12,64	96,64	2792,0	2520,0	2411,2	2272,0	2179,2	2065,6
17	1020	4,59	13,43	102,68	2966,5	2677,5	2561,5	2414,0	2315,4	2194,7
18	1080	4,86	14,22	108,72	3141,0	2835,0	2712,6	2556,0	2451,6 6	2323,8
19	1140	5,13	15,01	114,76	3315,5	2992,5	2863,3	2698,0	2587,6	2452,5
20	1200	5,40	15,80	120,80	3490,0	3150,0	3014,0	2840,0	2724,0	2582,0
21	1260	5,67	16,59	126,84	3664,5	3307,5	3164,7	2982,0	2860,2	2711,1
22	1320	5,94	17,38	132,88	3835,0	3465,0	3315,4	3124,0	2996,4	2840,2
23	1380	6,21	18,17	138,92	4013,5	3622,5	3466,1	3266,0	3132,6	2969,3
24	1440	6,48	18,96	144,96	4186,0	3780,0	3616,8	3408,0	3268,8	3098,4

No. of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,31	0,88	6,525	200,3	180,7	169,3	163,0	156,3	148,2
2	120	0,62	1,78	13,050	400,6	361,4	338,6	326,0	312,6	296,4
3	180	0,93	2,67	19,575	600,9	542,1	507,9	489,0	468,9	444,6
4	240	1,24	3,56	26,100	801,2	722,8	677,2	652,0	625,2	592,8
5	300	1,55	4,45	32,625	1001,5	903,5	846,5	815,0	781,5	741,0
6	360	1,86	5,34	39,150	1201,8	1084,2	1015,8	978,0	937,8	889,2
7	420	2,17	6,23	45,675	1402,1	1264,9	1185,1	1141,0	1094,1	1037,4
8	480	2,48	7,12	52 200	1602,4	1445,6	1354,4	1304,0	1250,4	1185,6
9	540	2,79	8,01	58,725	1802,7	1626,3	1523,7	1467,0	1406,7	1333,8
10	600	3,10	8,90	65,250	2003,0	1807,0	1693,0	1630,0	1563,0	1482,0
11	660	3,41	9,79	71,775	2203,3	1987,7	1862,3	1793,0	1719,3	1630,2
12	720	3,72	10,68	78,300	2403,6	2168,4	2031,6	1956,0	1875,6	1778,4
13	780	4,03	11,57	84,825	2603,9	2349,1	2200,9	2119,0	2031,9	1926,6
14	840	4,34	12,46	91,350	2804,2	2529,8	2370,2	2282,0	2188,2	2074,8
15	900	4,65	13,35	97,875	3004,5	2710,5	2539,5	2445,0	2344,5	2223,0
16	960	4,96	14,24	104,400	3204,8	2891,2	2708,8	2608,0	2500,8	2371,2
17	1020	5,27	15,13	110,925	3405,1	3071,9	2878,1	1771,0	2657,1	2519,4
18	1080	5,58	16,02	117,450	3605,4	3252,6	1047,4	2934,0	2813,4	2667,6
19	1140	5,89	16,91	123,975	3805,7	3433,3	3216,7	3097,0	2969,7	2815,8
20	1200	6,20	17,80	130,500	4006,0	3614,0	3386,0	3260,0	3126,0	2964,0
21	1260	6,51	18,69	137,025	4206,3	3794,7	3555,3	3423,0	3282,3	3112,2
22	1320	6,82	19,58	143,550	4406,6	3975,4	3724,6	3586,0	3438,6	3260,4
23	1380	7,13	20,47	150,075	4606,9	4156,1	3893,9	3749,0	3594,9	3408,6
24	1440	7,44	21,36	156,600	4807,2	4336,8	4063,2	3912,0	3751,2	3556,8
25	1500	7,75	22,25	163,125	5007,5	4517,5	4232,5	4075,0	3907,5	3705,0

No of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit.)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,33	0,99	7,495	211,7	191,0	179,0	172,0	165,0	156,6
2	120	0,66	1,98	14,990	423,4	382,0	358,0	344,0	330,0	313,2
3	180	0,99	2,97	22,485	635,1	573,0	537,0	516,0	495,0	469,8
4	240	1,32	3,96	29,980	846,8	764,0	716,0	688,0	660,0	626,4
5	300	1,65	4,95	37,475	1058,5	955,0	895,0	860,0	825,0	783,0
6	360	1,98	5,94	44,970	1270,2	1146,0	1074,0	1032,0	990,0	939,6
7	420	2,31	6,93	52,465	1481,9	1337,0	1253,0	1204,0	1155,0	1096,2
8	480	2,64	7,92	59,960	1693,6	1528,0	1432,0	1376,0	1320,0	1252,8
9	540	2,97	8,91	67,455	1905,3	1719,0	1611,0	1548,0	1485,0	1409,4
10	600	3,30	9,90	74,950	2117,0	1910,0	1790,0	1720,0	1650,0	1566,0
11	660	3,63	10,89	82,445	2328,7	2101,0	1969,0	1892,0	1815,0	1722,6
12	720	3,96	11,88	89,940	2540,4	2292,0	2148,0	2064,0	1980,0	1879,2
13	780	4,29	12,87	97,435	2752,1	2483,0	2327,0	2236,0	2145,0	2035,8
14	840	4,62	13,86	104,930	2963,8	2674,0	2506,0	2408,0	2310,0	2192,4
15	900	4,95	14,85	112,425	3175,5	2865,0	2685,0	2580,0	2475,0	2349,0
16	960	5,28	15,84	119,920	3387,2	3056,0	2864,0	2752,0	2640,0	2505,6
17	1020	5,61	16,83	127,415	3598,9	3247,0	3043,0	2924,0	2805,0	2662,2
18	1080	5,94	17,82	134,910	1810,6	3438,0	3222,0	3096,0	2970,0	2818,8
19	1140	6,27	18,81	142,405	4022,3	3629,0	3401,0	3268,0	3135,0	1975,4
20	1200	6,60	19,80	149,900	4234,0	3820,0	3580,0	3440,0	3300,0	3132,0
21	1260	6,93	20,79	157,395	4445,7	4011,0	3759,0	3612,0	3465,0	3288,6
22	1320	7,26	21,78	164,890	4657,4	4202,0	3938,0	3784,0	3630,0	3445,2
23	1380	7,59	22,77	172,385	4869,1	4393,0	4117,0	3956,0	3795,0	3601,8
24	1440	7,92	23,76	179,880	5080,8	4584,0	4296,0	4128,0	3960,0	3758,4
25	1500	8,25	24,75	187,375	5292,5	4775,0	4475,0	4300,0	4125,0	3915,0

No of seg-ments	Length (mm)	Heating-area (m²)	Water content (lit.)	Weight (kg)	Heat effect (W/segment) for hot water heating (90/70°C) at ambient temperature (°C)					
					10	15	18	20	22	24
1	60	0,48	1,200	9,60	309,0	278,8	661,2	251,0	241,0	228,5
2	120	0,96	2,310	19,20	618,0	557,6	1322,4	502,0	482,0	457,0
3	180	1,44	3,465	28,80	927,0	836,4	1983,6	753,0	723,0	685,0
4	240	1,92	4,620	38,40	1236,0	1115,2	2644,8	1004,0	964,0	914,0
5	300	2,40	5,775	48,00	1545,0	1394,0	3306,0	1255,0	1205,0	1142,5
6	360	2,88	6,930	57,60	1354,0	1672,8	3967,2	1506,0	1446,0	1371,0
7	420	3,36	8,085	67,20	2163,0	1951,6	4628,4	1757,0	1687,0	1599,5
8	480	3,84	9,240	76,80	2472,0	2230,4	5289,6	2008,0	1928,0	1828,0
9	540	4,32	10,395	86,40	2781,0	2509,2	5950,8	2259,0	2169,0	2056,5
10	600	4,80	11,550	96,00	3090,0	2788,0	6612,0	2510,0	2410,0	2285,0
11	660	5,28	12,705	105,60	3399,0	3066,8	7273,2	2761,0	2651,0	2513,5
12	720	5,76	13,860	115,20	3708,0	3345,6	7934,4	3012,0	2892,0	2742,0
13	780	6,24	15,015	124,80	4017,0	3624,4	8595,6	3263,0	3133,0	2970,5
14	840	6,72	16,170	134,40	4326,0	3903,2	9256,8	3514,0	3374,0	3199,0
15	900	7,20	17,325	144,00	4635,0	4182,0	9918,0	3765,0	3615,0	3427,5
16	960	7,68	18,480	153,60	4944,0	4460,8	10579,2	4016,0	3856,0	3656,0
17	1020	8,16	19,635	163,20	5253,0	4739,6	11240,4	4267,0	4097,0	3884,5
18	1080	8,64	20,790	172,80	5562,0	5018,4	11901,6	4518,0	4338,0	4113,0
19	1140	9,12	21,945	182,40	5871,0	5297,2	12562,8	4769,0	4579,0	4341,5
20	1200	9,60	23,100	192,00	6180,0	5576,0	13224,0	5020,0	4820,0	4570,0
21	1260	10,08	24,255	201,60	6489,0	5854,8	13885,2	5271,0	5061,0	4798,5
22	1320	10,56	25,410	211,20	6798,0	6133,6	14546,4	5522,0	5302,0	5027,0
23	1380	11,04	26,565	220,80	7107,0	6412,4	15207,6	5773,0	5543,0	5255,5
24	1440	11,52	27,720	230,40	7416,0	6691,2	15868,8	6024,0	5784,0	5484,0
25	1500	12,00	28,875	240,00	7725,0	6970,0	16530,0	6275,0	6025,0	5712,5