



Development of a Heat Transfer Analysis Software by Using Microsoft Excel

Soo Jun Chun¹, Mohd Azwir Azlan^{1*}, Mohammad Kamil Abdullah¹

¹Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author Designation

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Abstract: Heat Transfer is the study of three different modes which are conduction, convection, and radiation. However, in order to analyze the problem, it usually requires a lot of times going through lots of tables and figures to locate the data and determine the suitable formulas. Therefore, this project aims to develop a software that can analyze heat transfer problems which can help students, lectures or researchers to solve the problems in the simplest way possible. All the results should be able to obtained instantaneously after entering all the required inputs and can be dynamically updated by its own if certain input changes. The software was built by using Microsoft Excel with VBA coding and macros, while the formulas and equations used were mainly referred from the Cengel Heat Transfer textbook, 5th Ed. The developed software was able to solve most of the problems that are available in heat transfer with an accuracy up to 95%. Overall, the development process had been considered as successful and the main objective has been achieved.

Keywords: Heat Transfer, Microsoft Excel, VBA Programming, Thermal Resistance Concept, Finned Surfaces, External Forced Convection, Internal Forced Convection, Natural Convection, Combined Forced and Natural Convection, Heat Exchangers.

1. Introduction

Heat transfer is a compulsory third year course under the field of Mechanical Engineering Program which builds from the concept of Thermodynamics and Fluid Mechanics. It enables students to analyze some real-world problems such as conduction, which happens internally inside a solid body or between two solid surfaces which are interconnected, convection, which take place in between a solid surface and the surrounding liquid or gas that is in motion with a finite value of fluid movement, and radiation, which can be occur when there is an emitter or also known as heat source. Some of these involve a serious mathematical work and a very strong foundation in Mechanical Engineering disciplines to be able to understand and analyze them correctly.

*Corresponding author: azwir@uthm.edu.my

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Heat transfer problems usually begins with the searching of all the required parameters such as density, thermal conductivity, dynamic viscosity and so on, followed by filtering through giant lists of tables and formulas based on the type of analysis in order to determine the most suitable one to use in the calculation. This process will normally take up a huge amount of time, where it could be spent on some better places such as researching additional problems. Furthermore, if certain cases that deals with value assumptions in the beginning, user will need to go through a number of iterations to get appropriate value and complete the analysis. Hence, this heat transfer analysis software is developed to solve all these problems. The user will no need to spent their time to define all the formulas, rather they just select the type of analysis they wanted and enter initial values such as surface temperature, ambient temperature, and fluid velocity, and let the program do the rest of the jobs automatically.

The first scope of this project is targeted in the field of heat convection which covers both force (external and internal) and natural convection, as well as both forced and natural convection combines together. The second scope is in the field of heat conduction which covers thermal resistance concept and finned surfaces. The third scope is in the field of heat exchangers which includes both log-mean temperature and effectiveness NTU method solving. It is able to obtain certain parameters which are crucial in heat transfer system analysis such as heat transfer coefficient, temperature variation, heat rate, drag force, pressure loss and efficiency. It focuses in the heat transfer analysis process between two solid surfaces or a solid surface and a fluid medium. It has certain limitations including the fluid needs to be incompressible (Density is constant throughout), the heat transfer process must be steady, and the system is only available for one way problem solving.

The program that successfully developed throughout this project will be able to analyse heat transfer problems and display relevant answers which are needed for engineer to study the heat transfer system in order to determine the performance and characteristics of it. The user-friendly interface in the software will be able to speed up all the cumbersome processes which required before this, and get to the results much faster. It can also help examiners during the marking process of papers since it can get a much accurate results in a much faster time.

2. Review of Literatures

The literature review is a very important part in this project. All the formulas and equations need to be studied carefully and understand deeply in order to properly develop this software with minimal error. The information gathered at this stage are to be use as a guideline so that any advantages or disadvantages can be discovered in order to help and develop a good heat transfer analysis software.

2.1 Book review

The selected book to do the revision was the Heat and Mass Transfer 5th Edition by Yunus A. Cengel. and Afshin J. Ghajar, and it is only narrowed down to the seven sub-chapters which related to the analysis involved in this development.

For thermal resistance concept, the study was based on the calculation of individual resistance, total resistance, and total heat rate that happens in plane wall, cylindrical wall and spherical wall. For finned surfaces, the study was based on the fin efficiency, fin heat rate, and fin effectiveness, for a total of eight different types of fin cross sectional area which are available in the textbook. For external forced convection, the study was based on the calculation of Reynolds number, Nusselt number, heat transfer coefficient, heat rate, and drag force for both flat plate and blunt body. For internal forced convection, the study was based on three different types of duct's cross-sectional areas, with two different analyses, which are the constant surface temperature and constant surface heat flux. The effect of entrance length also has been emphasized especially for laminar flow. Other than that, the calculation of head loss, pressure drop and pumping power required have also been researched. For natural convection, the study

was based on seven possible cases that might occur with the determination of Nusselt number, heat transfer coefficient and total heat rate. For combined forced and natural convection, the different types of flow direction and how it will affect the overall approach to perform the analysis, as well as the determination of the domination of each type of flow has been heavily emphasized. For heat exchangers, both log-mean temperature difference (LMTD) and Effectiveness-NTU approach has been studied with all eight types of heat exchangers that available in the textbook [1].

2.2 Software review

The purpose of a software review is to study the general workflow of the analysis process. It is vital to assure the program developed later on has a proper workflow that can be easily understand by users. There are two software which had been selected to do the review. The first one was SimScale, it is a full online simulation software that is able to achieve quite a number of possibilities, including the simulation of CFD, FEA, and thermal [2]. The second one was the heat transfer spread calculation which developed by John R Andrew on 12 June 2011. It covers all three types of heat transfers which are conduction, convection and radiation. Users can input their desired data and Excel will perform the calculations [3]. The comparison of both software has been visualized in Table 1 below:

Table 1: Comparison of the existing software

Aspects	Software	
	SimScale:	Heat Transfer Spreadsheet Calculations:
Ease of access	Has a website, easy to find	Hidden in the web, hard to find
Usage experience	Very user-friendly interface, easy to use	Densely packed number, need time to understand
Calculations of important parameters	Requires to manually input	Can calculate by only input the raw parameters
Diversification	Can simulate a large variety of heat transfer system based on a 3D-model, but lack of the calculations of important parameters	Can calculate a lot of important parameters in heat transfer, but lack of the option to select different types of configurations

3. Methods of approach

In every project, methodology is a must have in order to implement all the studies involved. The detail process to design and develop the software is presented by the means of flow charts and rules of implementation.

3.1 Project Implementation

In Bachelor Degree Project (BDP) 1, the background study about the whole project and literature review about books and software are to be made. This might seem like a tedious process but it is very important in order to ensure the developed software from this project meets the user requirements, follow standards and has high accuracy. The study on books and software also enables the deeper exploration about the knowledge of heat transfer and to observe what other software are capable to achieve.

In BDP 2, the software development and testing are to be made. The process in development can be referred to the completed flowcharts in BDP 1 to make sure it follows the correct flows. After the software is finished, several testings need to be performed such as using the software to solve some example problems and make sure the outcome is correct. The interface of the software also needs to be easy understandable by users before it is put into services. Figure 1 shows the project implementation flowchart.

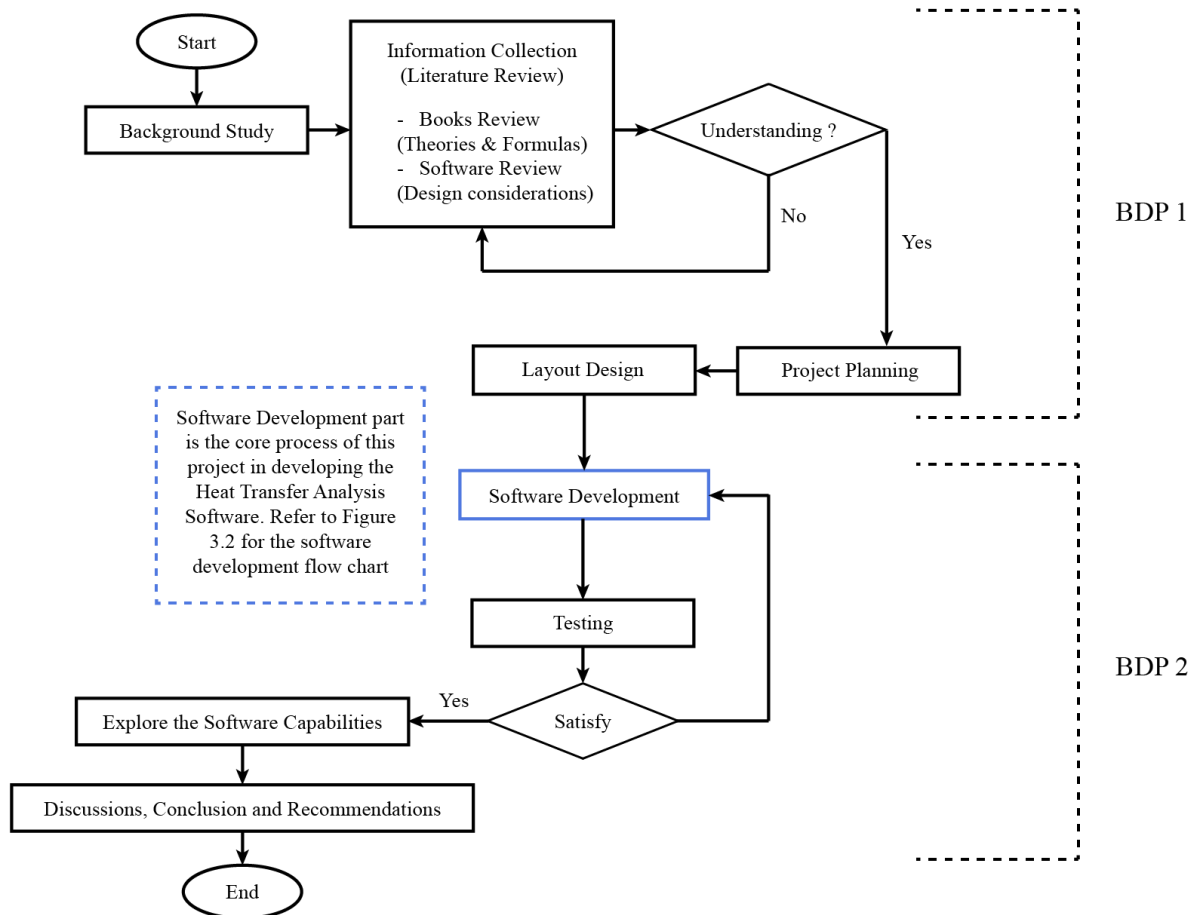


Figure 1: Project implementation flowchart

3.2 Project Methodology

There are several main processes that need to be done in this project. For this, the waterfall method has been chosen to be the guideline in designing the software. It is separated into four different phases starting with the user requirements and ends with testing.

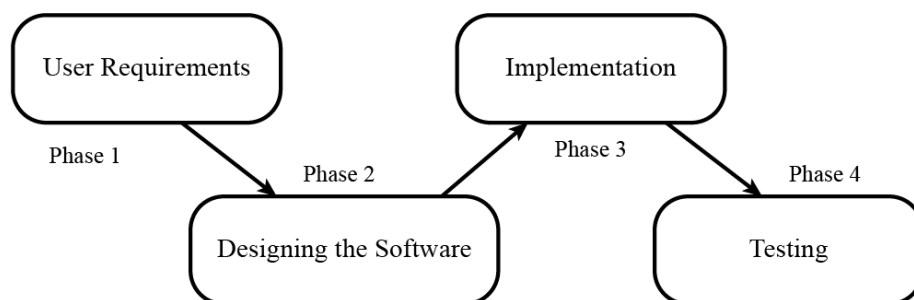


Figure 2: Waterfall Methodology

In the requirement analysis, it was found that the users are required to go through a lot of formulas, tables and charts and filter out only the necessary ones for the analysis in heat transfer. This process can take up a lot of time and the formulas sometimes can be very complicated, which might potentially lead to miscalculation. Hence, the objective of this project was to build an automated analysis software so that user do not need to go through those formulas and can obtain a more accurate result.

The next stage is the development of the software. To ensure the implementation of the project smoother later on, the design methodology must be clear and straight to the point. The most suitable approach is to build a flow chart for each analysis. It has been divided into 7 sub-categories, which are thermal resistance concept, finned surfaces, external forced convection, internal forced convection, natural convection, combined forced and natural convection and heat exchangers.

In the third stage, all the ideas and flowcharts created beforehand are ready to be applied together and become a workable software. To make it operatable by users, a user interface, or UI is needed for the input of important parameters from users in order to start analyzing. In Microsoft Excel, there is an interactive tool exists which can be used to build interface such as a dropdown menu, checker box, command button, etc.

The last stage of this project is testing. The results obtained from the software is to be analyze to make sure that they are all accurate and follows the right standards. Some corrections or improvements to the designing process also being considered here. A good example for this is by referring to the Cengel Heat Transfer Textbook. If the calculations performed by the software is acceptable and meet all the requirements, then the development will be considered as successful. If it is not, some further modifications need to be made until the software achieved the targeted results.

4. Software development and testing

The developed software needs to be deeply focused in terms of its functionalities and capabilities. This is very important since heat transfer is an extensive subject that consists of a lot of different cases and different scenarios in each chapter. Each of them needs to use an appropriate type of analysis in order to solve it correctly. Hence, the software needs to cover as many different cases that might encounter in each chapter, in order to maximize its capabilities.

4.1 Opening interface

The opening interface is the first thing the user will see when opening the software. It should consist some master buttons to let user navigating around the software, as well as entering the license code to active the software. Figure 3 shows the basic layout of the software's opening interface.

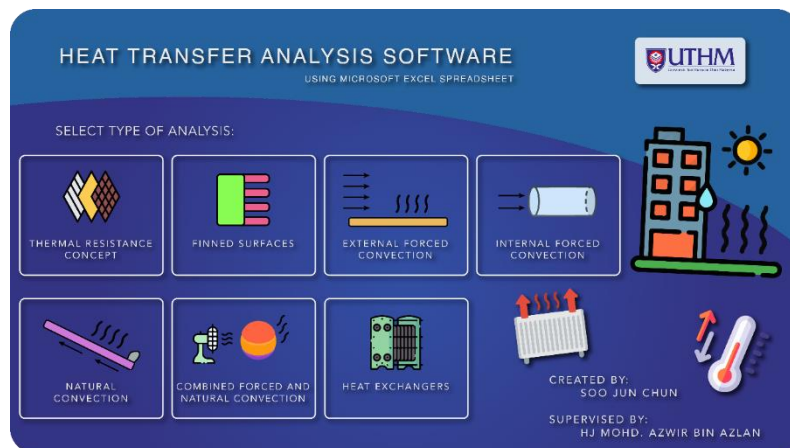


Figure 3: Opening Interface of the software

4.2 Database

The database can be considered as the heart of the whole software. It consists of a huge set of numbers and data which had been collected from tables or transferred from graphs in the Cengel Heat Transfer textbook and Cengel Heat Transfer Tables. Except for thermal resistance concept, all other modules need to call out data from there in order to perform the calculation. To make it work, a series of formulas and equations were developed by using the “MATCH” and “INDEX” functions in Excel to automatically identify where the data should be taken based on the input value from each module, and perform interpolation if the input value is not exactly the same as listed in the database. Figure 4 shows one small portion of the database created.

T(°C)	ρ	c_p	k	α	μ	ν	Pr
-150	2.8660	983	0.01171	4.16E-06	8.64E-06	3.01E-06	0.7246
-100	2.0380	966	0.01582	8.04E-06	1.19E-06	5.84E-06	0.7263
-50	1.5820	999	0.01979	1.25E-05	1.47E-05	9.32E-06	0.7440
-40	1.5140	1002	0.02057	1.36E-05	1.53E-05	1.01E-05	0.7436
-30	1.4510	1004	0.02134	1.47E-05	1.58E-05	1.09E-05	0.7425
-20	1.3940	1005	0.02211	1.58E-05	1.63E-05	1.17E-05	0.7408
-10	1.3410	1006	0.02288	1.70E-05	1.68E-05	1.25E-05	0.7387
0	1.2920	1006	0.02364	1.82E-05	1.73E-05	1.34E-05	0.7362
5	1.2690	1006	0.02401	1.88E-05	1.75E-05	1.38E-05	0.7350
10	1.2460	1006	0.02439	1.94E-05	1.78E-05	1.43E-05	0.7336

Figure 4: A portion of the database

4.3 General features

The general features are the ones which can be found almost in every module of the software. Their main functions were to let the user select different options in order to match the case studies that they are intended with. Some general features that included in this software are the option button and checkboxes. They have been created inside Excel using the ActiveX controls and used the VBA code to program what they should do to the active sheet if triggered. They are extremely important since user can select different types of fin cross sectional area, different shape of duct, different types of geometry conditions, different types of heat exchangers, different types of fluid involved, different types of mathematical analysis, different types of equations and many more. All of the option buttons combined can form a very large number of possible combinations and outcome, making sure that they must be one which fulfills the demands of the user. Figure 5 shows some examples of the option button created inside the software.

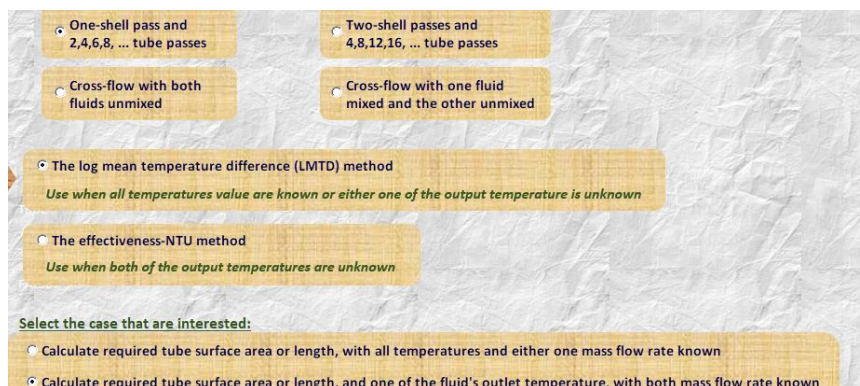


Figure 5: Some examples of the option buttons created

The second general features were the clear inputs and reset controls. It consists of two separate buttons, one is to clear all input data entered by the user, and another one is to reset all options and

checkboxes that has been selected. The code needs to be written inside a module and then assign a macro to a shape in Excel. They are important because they can clear all the unnecessary inputs and blanked out all options to prevent any display error when user starts a new analysis. Figure 6 shows the example buttons of these features.



Figure 6: The clear inputs and reset controls buttons

The last general feature was the display of error messages, which also available in all modules. Their functions were to tell the users whether they had entered an invalid input or selected an invalid option. The messages displayed will be always different by depending on each module and where does it show in the calculation stage. Figure 7 shows some examples of the error messages displayed inside the software.

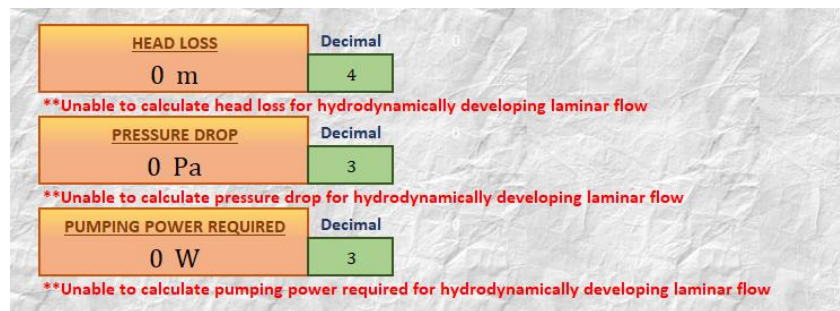


Figure 7: Some examples of error messages displayed in the software

4.4 Detail features

All the seven sub-chapters had been developed in detail based on their unique functionality and different usages. They also have different capabilities in terms of analyzing the problems and how many kinds of output they are able to produce.

In thermal resistance concept module, user can analyze the multilayered-wall and get the answers of resistance value, heat rate and temperature distribution. It has a total of 5 different capabilities. In finned surface module, user can analyze eight different types of fins and calculate various parameters such as the efficiency, heat rate, and fin effectiveness. It has a total of 5 different capabilities. In external forced convection module, user can analyze the convection which happens externally either on a flat plate or blunt body. By entering the required input parameters, the software will calculate and display the Nusselt number, heat transfer coefficient, heat rate, and many more. It has a total of 7 different capabilities. In internal forced convection module, user can analyze the convection which happens internally in a pipe or duct. There are two types of analysis which can be chosen which is the constant surface temperature and constant surface heat flux. The program is able to calculate the Nusselt number, heat transfer coefficient, heat rate, as well as the pumping power required, and many more. It has a total of 11 capabilities. In natural convection module, user can analyze convections which happens naturally without the presence of fluid movement and calculate the Nusselt number, heat transfer coefficient, as well as the heat rate. It has a total of 5 different capabilities. In combined forced and natural convection, the external forced convection and natural convection has been combined to form an even complex type

of analysis. User is able to select the similar types of conditions that are available in the natural convection as well as determine the flow direction of external forced convection and defining the fluid's velocity. The program will determine which type of convection dominates or if they both dominate against each other, as well as obtain parameters such as the overall Nusselt number, heat transfer coefficient, heat rate and many more. It has a total of 11 different capabilities. In heat exchangers module, user can analyze different types of heat exchangers and obtain various parameters such as the required surface area and tube length, or the output temperature. There are also two types of analysis available which is the log-mean temperature difference (LMTD) method and the effectiveness-NTU method. It has a total of 9 different capabilities.

In short, each of the module has their own functions and the user should select the suitable one for their analysis. Some of the more complex module would be the internal forced convection, combined forced and natural convection, and heat exchangers, since they have the greatest number of capabilities and took the longest time to develop.

4.5 Additional features

The additional features are the ones which can be considered as add-ons to the software to make it look more professional, easier to navigate, and also tighten the security issues.

The first one and perhaps the one which took the longest time to design and develop is the security feature. The software is protected by a license code which consists of 20 random characters. In order to activate the software and use it for a certain period of time, the user will be forced to enter the code which provide by the administrator, otherwise the software will do nothing in the calculation and display all answers in zero instead. An administrator file has also been created in order to generate the code with the specified number of activation days to be given to the users. The license code has been generated 100% in Excel by using different formulas and equations which all refers to the date number returned by the algorithms in Excel. Hence, the generated code will always be changed when the date has updated, and the user needs to enter the code into the software before midnight after they obtained from the administrator before it is expired. Due to all these complex systems, the license code is practically impossible to crack in under 24 hours, and the system is also sensitive to date changes, where if the user attempt to revert the computer's date to a previous one in order to increase the activation days, the software will detect this unusual act and lock all the controls automatically. Figure 8 shows the example of the license code generated on 13/01/2022 with 30 activation days.

Today's date	13/1/2022
Activation days	30
Generate license code	
Generated code	M8F53MDU2CYC4ZDKJW93
Expiry date	12/2/2022

Figure 8: License code generated on 13/01/2022 with 30 activation days

Some other additional features would be the link sheets functions and copy and paste protected. The link sheets functions will allow the user to click on a button and navigate around the sheets from the home page and back to the home page itself. It was achieved by using the macro which created using VBA coding in Excel. The coding will also check whether the workbook should be locked if there

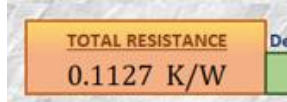

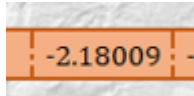
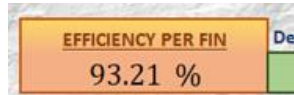
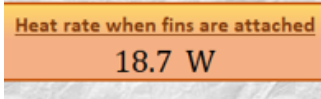
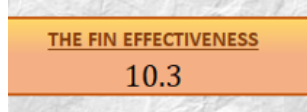
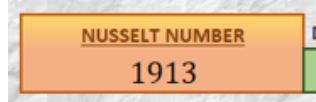
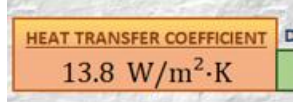

is an issue in the security. The copy and paste protected will locked the copy and paste functions in the entire workbook so that user cannot copy and paste data from any outsources.

One more additional feature is the automatic publishing tool. This is the one which added during the last stage of development. After the button has been clicked, all the input options, data, as well as the results will be compiled and automatically published as a single PDF file and save to the user's desktop. This is to enhance the user experience even more since there is no more need to manually save the sheets in PDF format by the user.

4.6 Software testing

After the development process has finished, the software was tested in order to measures its accuracy and reliability. The testing process was conducted by taking several examples with solutions from the Cengel Heat Transfer textbook, as well as some examples taken from the internet and past year exam questions. Table 2 shows some of the testing results only from the manual and software calculations and compared side to side.

Table 2: Part of the software testing with results only

Types of analysis	Manual calculations	Software calculations
Thermal Resistance Concept	$R_{\text{total}} = R_{\text{conv},1} + R_{\text{glass}} + R_{\text{conv},2}$	
	$\frac{20 - (-10)]^{\circ}\text{C}}{0.4332^{\circ}\text{C/W}} = 69.2 \text{ W}$	
	$= 20^{\circ}\text{C} - (266 \text{ W})(0.0833^{\circ}\text{C/W})$ $= -2.2^{\circ}\text{C}$	
Finned Surfaces	$= \frac{\tanh h(15.5716)(0.0506)}{(15.5716)(0.0306)}$ $= 0.9322 \text{ (a) } 93.22\%$	
	$2.03 = 18.7 \text{ W}$	
	$\frac{(50 \text{ W/m}^2\cdot\text{K})}{(15.5716)(0.0306)}$ $= 10.3$	
External Forced Convection	$2962^{1/3} = 1913$	
	$35) = 13.8 \text{ W/m}^2\cdot\text{K}$	
	$-10)^{\circ}\text{C} = 1093 \text{ W}$	

Internal Forced Convection	$3.7) = 16.3 \text{ W/m}^2 \cdot \text{K}$	HEAT TRANSFER COEFFICIENT 18.0402 $\text{W/m}^2 \cdot \text{K}$
	$\frac{74}{.74} = -19.87^\circ\text{C}$	LOG MEAN TEMPERATURE -19.86 $^\circ\text{C}$ <small>**Removal of heat</small>
	$\frac{N}{n^2} = 73.46 \text{ kW/m}^2$	SURFACE HEAT FLUX 73332 W/m^2
	$2^\circ\text{C}) = -1313 \text{ W}$	HEAT RATE -1315 W <small>**The sign indicates heat gain or heat loss</small>
Natural Convection	$l = 17.39$	NUSSELT NUMBER 17.39
	$7) = 2.971 \text{ W/m}^2 \cdot \text{K}$	HEAT TRANSFER COEFFICIENT 2.972 $\text{W/m}^2 \cdot \text{K}$
	$0)^\circ\text{C} = 138.7 \text{ W}$	HEAT RATE 138.7 W <small>**The sign indicates heat gain or heat loss</small>
Combined Forced and Natural Convection	$4975)^{0.5}(0.7282)^{1/3} = 42.14$	Nusselt number 42.14
	$(42.14^3 - 36.46^3)^{1/3} = 29.8$	Overall Nusselt number 31.9
	$h = 1980 \text{ W/m}^2 \cdot \text{K}$	Heat transfer coefficient 1910 $\text{W/m}^2 \cdot \text{K}$
	$= 249.9 \text{ kW}$	Heat rate 283550 W <small>**The sign indicates heat gain or heat loss</small>
Heat Exchangers	$n) = 109 \text{ m}$	REQUIRED TUBE LENGTH 108 m
	$\left\{ F = 0.91 \right.$	0.9067
	$7^\circ\text{C}) = 1805 \text{ W}$	HEAT RATE 1799 W
	$\text{K} = 66.8^\circ\text{C}$	Exit temperature of cold fluid 66 $^\circ\text{C}$

By observing to Table 2, the results which obtained by the software has a very minimal amount of error in comparison with the manual calculations. Hence, the accuracy of the software can be considered very high. Most of the deviations between the software and manual calculations were mainly caused by the difference in formulas used or the different coefficients assumed in the equations. The calculations made by human also has round-off mistakes which can considered as the additional reason on the difference of results shown. Overall, the accuracy of the software has been observed up to 95% or even higher.

5. Conclusion

Upon the completion of the development and testing of the software, it performed exactly as intended during the planning stage. The software is able to analyze the selected seven subtopics in heat transfer, and calculate the required parameters precisely by interpreting the inputs given. Therefore, the main objective of this project was considered achieved.

The function of this software is to help the users, no matter students or lecturers, or even researchers, in analyzing various heat transfer problem and most importantly, save them a lot of time since all of the tables and formulas do not need to go through again in order to get the calculation data and suitable equations. The development of the software by using Microsoft Excel Spreadsheet has been unexpectedly going well, and its capabilities have been underestimated during the initial planning stage. This is because it contains a lot of powerful formulas and tools to make the complex analysis process become possible. Especially when incorporating with the VBA coding, the potential of the software has been brought to a whole new level since it can include a lot of different options and checkboxes, to make the possible outcome of the analysis become very subjectable and dependent. This is very useful in the field of heat transfer since there are usually a lot of different cases and scenarios which might be included in the same sub-chapter, and all of them require different approaches to solve. By using the VBA coding, it can tell Excel which information that need to be shown and which formulas should be selected to performed the calculations, and dynamically update the appearance of the entire sheet by depending on the input values and options given by the user.

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