An iOS application for the pre-design of geothermal ground loops

Andrew Sheehan
The University of Melbourne, Melbourne, Australia
asheehan@dekastudio.com

Liangliang (Leon) Zhang
The University of Melbourne, Melbourne, Australia
liangliangz@student.unimelb.edu.au

***Abstract**: Geothermal heating and cooling has the potential to help create a sustainable and environmentally friendly built environment. This investigation confirmed that there is a need for a (commercially) user-friendly approach to support the pre-design process to increase the success rate of installing optimal ground source heat pump systems (GSHP). The GSHP systems present both environmental and economical benefits when installed successfully, though the current success rate is poor as a result of the complexity and costs associated with available design software. These issues are highlighted when contractors are required to quickly budget and cost a system but are restricted by the cumbersome tools available. A mobile application was proposed as a potential solution to these issues and Apple's iOS platform was identified as the most appropriate platform use due to its wide market penetration, accessibility and development in technology. This paper details how a mobile application is built and how a geothermal application was created as a tool to support engineers in the pre-design process of GSHP systems.*

1 Introduction

This paper is founded on the intention to create something new and focuses on the design process of closed-loop ground source heat pump (GSHP) systems, their ground heat exchangers (GHEs) and how the development of a mobile application could support the speed and accuracy to which the systems are designed.

GSHPs are geothermal systems used to provide heating and cooling to both domestic and commercial buildings, and can also provide heating for hot water. In a closed-loop GSHP system, GHEs are pipes buried in precisely designed and drilled boreholes for vertical systems and either boreholes or trenches for horizontal systems. If well designed, a GSHP system offers significant long-term financial and environmental benefits as a source of clean energy which utilises the relatively constant temperature of the earth to act as a heat source and sink.

There are two main circuits in GSHP systems, the primary circuit (GHEs) and the secondary circuit (indoor heat exchange), connected by a ground source heat pump. The GHE is intimately embedded into a designed depth underground to either absorb or reject heat from or to the ground. Connected to the primary circuit by GSHP, the secondary circuit represents the heat exchange process within the space that requires to be heated or cooled.

There are three main configuration designs for closed-loop GHE systems, those which are vertically-bored (Figure 1), horizontally bored (Figure 2) and horizontally trenched (Figure 3). These systems utilise the relatively constant temperature of the earth at depth (Figure 4) to supply heating and cooling to buildings more efficiently than air source heat pumps, which exchange heat with the air instead of with the ground.

The first decision when designing a closed-loop GHE according to IGSHPA (2010) is the configuration of the system based on a site survey. Horizontally trenched systems tend to have a lower associated cost because they do not require borehole drilling which can be significantly expensive and are therefore preferable. However, horizontal systems are not always feasible for all buildings as they require more land than vertical systems and a soil depth of at least 1.5 metres before bedrock is encountered, otherwise the ground temperature will not be consistent enough to make the system viable (Ground Source Heat Pump Association, 2007).

Even though horizontally trenched systems are typically a cheaper method to achieve the desired heating and cooling, IGSHPA (2010) highlights the importance of completing a site visit before making a decision. This is because any retrofit designs to existing structures can incur significant costs in damages both during installation and afterwards when fixing the landscape. Therefore, even if a site has the space required as well as a sufficient soil depth to accommodate a horizontally trenched system, it is not always the most cost effective or efficient system setup and as a result all configurations need to be considered.

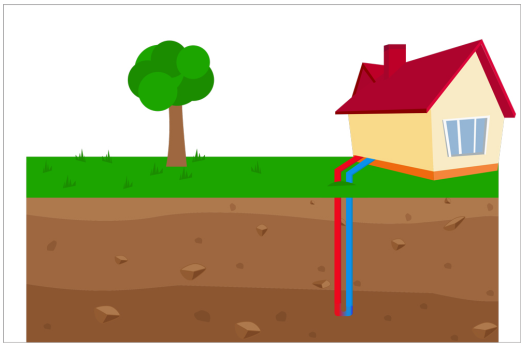

Figure 1: Vertical-Bored GSHP

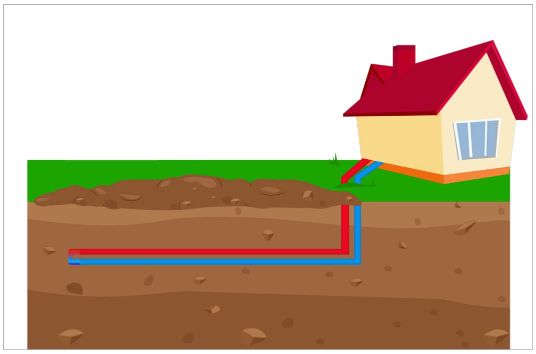

Figure 2: Horizontal-Trenched GSHP

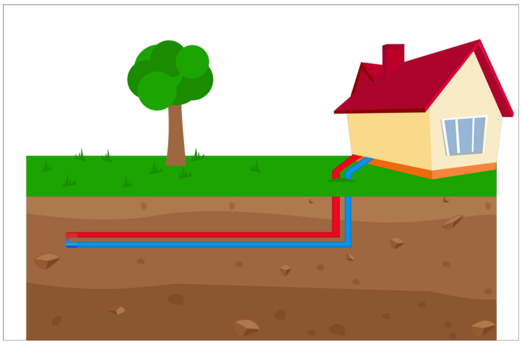

Figure 3: Horizontal-Bored GSHP

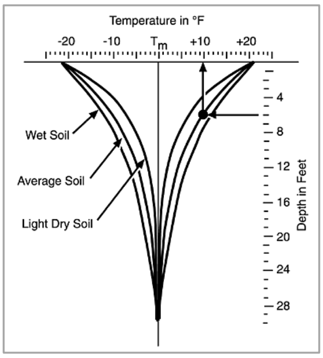

Figure 4: Amplitude of seasonal soil temperature (Source: Canadian GeoExchange™ Coalition 2010 ©)

Geothermal Energy typically refers to heat that is derived from the earth, utilised through GHEs. There are two forms of geothermal energy according to Narsilio et al. (2014), that which is indirect and that which is direct. The indirect form involves drilling boreholes kilometres into the ground surface where the water temperature is high enough to use steam turbines to generate electricity, however, this type of geothermal energy is not considered in this paper. This paper will focus on the direct form of geothermal energy that only exchanges heat from the ground within several tens of metres depth by GSHP. Within this depth range, the ground temperature can be relatively constant (Figure 4) and very similar to the mean atmospheric temperature. As a result, in certain environments the ground temperature can be warmer than the outside air temperature during winter and cooler during summer.

GHEs and GSHP systems are complex to design because they take into account a significant amount of variables, each of which requires detailed information and testing, including for example, the ground thermal conductivity for a particular location (Mikhaylova, Johnston, & Narsilio, 2016). The level of complexity that GHEs present has resulted in numerous modelling and design methods that can calculate the length of pipe required for a particular GSHP system in a certain environment. The length of pipe will determine the amount of energy the system is able to provide and as a result, this length will dictate which configuration is most viable. This paper focuses on the two most common design methods that can determine this length, which many systems are based on, the American Society of Heating and Refrigerating and Air-Conditioning Engineers (ASHRAE) method, and the International Ground Source Heat Pump Association (IGSHPA) method.

Commercial contractors who design GSHP systems currently have access to software such as EED, GLD and GLHEpro which typically incorporate the ASHRAE and(or) IGSHPA method(s) to help with their design calculations. However, these tools themselves are complex in their use and present significant expense and training issues to contractors who use them. As a result, domestic designers are reverting to hand-based calculation methods (Curtis, Pine, & Wickins, 2013) which is time consuming and limits the accuracy to which systems are designed as a result of human error.

Since the release of Apple's iPhone in 2007, the literature research in this paper shows the significant development in Smartphone technology and the roles that mobile applications are playing in our day to day lives. Prior to this advancement in mobile sophistication, organisations that required technology for employees or their consumers, would design computer software because at the time, mobile applications were mostly only email orientated (Charland & Leroux, 2011), utilised on devices such as the BlackBerry.

Today, a mobile application exists for almost anything (Scott, 2015) and as a result commercial industries are adopting the technology and utilising it as mobile software. In December 2015, the America College of Emergency Physicians (ACEP) released a mobile application that guides users through the process of antidotes in toxicology. Doctors and medical students now use this application to not only clarify which antidotes to use for certain situations, but also for guidance on the initial dose, frequency and follow up procedures.

Currently there are no mobile applications for geothermal systems and therefore this paper highlights how a geothermal mobile application presents a viable solution to the current state issues contractors are confronted with when facing clients who demand quick 'back of the envelop' estimations. The development process of building a mobile application as a tool for engineers to utilise during the pre-design phase of geothermal systems is detailed.

2 Literature Review

2.1 Pre-design methods

2.1.1 The IGSHPA Method (IGSHPA, 2010)

IGSHPA present calculation methods for the length of pipe required for vertically bored, horizontally bored and horizontally trenched GHE systems, along with variations of each method for heating and cooling. For bored systems, it is assumed that the ground, from which heat is exchanged, has a constant temperature all the time. This assumption works well when the amount of energy gained from and released to the ground is equivalent. However, if this assumption becomes false at a point in time, an unbalanced ground load correction factor needs to be verified to adjust the borehole length. Similarly, in horizontally trenched systems, multipliers for pipe and trench spacing are applied to adjust the variables due to physical features of the design. Although these correction factors can improve the accuracy of the design, it results in further complication in the pre-design phase and therefore will not be considered in this paper.

The final design pipe length for all of IGSHPAs configurations are taken as the greater length determined by the respective heating and cooling equations for the setup.

The calculation for the pipe length required in IGSHPAs vertical borehole systems for heating and cooling are represented by Equations 4 and 5 respectively.

$$L_{H.T} = \frac{HC_D\left(\frac{COP_D-1}{COP_d}\right)\times(R_b+R_G\times F_H)}{T_G-\left(\frac{EWT_{min}+LWT_{min}}{2}\right)} \quad (4)$$

$$L_{C.T} = \frac{TC_D\left(\frac{EER_D+3.412}{EER_d}\right)\times(R_b+R_G\times F_C)}{\left(\frac{EWT_{max}+LWT_{max}}{2}\right)-T_G} \quad (5)$$

The calculation for the pipe length required in IGSHPAs horizontally-bored systems heating and cooling are represented by Equations 6 and 7 respectively.

$$L_{H.T} = \frac{HC_D\left(\frac{COP_D-1}{COP_d}\right)\times(R_b+R_G\times F_H)}{T_{S.L}-\left(\frac{EWT_{min}+LWT_{min}}{2}\right)} \quad (6)$$

$$L_{C.T} = \frac{TC_D\left(\frac{EER_D+3.412}{EER_d}\right)\times(R_b+R_G\times F_C)}{\left(\frac{EWT_{max}+LWT_{max}}{2}\right)-T_{S.H}} \quad (7)$$

The calculation for the pipe length required in IGSHPAs horizontally-trenched systems heating and cooling are represented by Equations 8 and 9 respectively.

$$L_{H.T} = \frac{HC_D\left(\frac{COP_D-1}{COP_d}\right)\times(R_P+R_S\times P_M\times S_M\times F_H)}{T_{S.L}-\left(\frac{EWT_{min}+LWT_{min}}{2}\right)} \quad (8)$$

$$L_{C.T} = \frac{TC_D\left(\frac{EER_D+3.412}{EER_d}\right)\times(R_P+R_S\times P_M\times S_M\times F_H)}{\left(\frac{EWT_{max}+LWT_{max}}{2}\right)-T_{S.H}} \quad (9)$$

Where:

$L_{H.T}$	Pipe length required during heating conditions (ft.)
$L_{C.T}$	Pipe length required during heating conditions (ft.)
HC_D	Heat pump total cooling capacity at design cooling conditions (Btu/hr)
TC_D	Heat pump heating capacity at design heating conditions (Btu/hr)
T_G	Deep earth temperature (F)
COP_D	Coefficient of performance (design)
EER_d	Energy efficiency ratio at design cooling condition
R_b	Borehole thermal resistance (hr ft. F/Btu)
R_G	Ground thermal resistance (hr ft. F/Btu)
F_H	Run fraction in cooling mode during cooling design month (hours)
EWT_{min}	Minimum entering water temperature at heating design conditions (F)
LWT_{min}	Minimum leaving water temperature at heating design conditions (F)
EWT_{max}	Maximum entering water temperature at cooling design conditions (F)
LWT_{max}	Maximum leaving water temperature at cooling design conditions (F)
$T_{S.L}$	Design soil temperature for heating at average horizontally-bored pipe depth (F)
$T_{S.H}$	Design soil temperature for cooling at average horizontally-bored pipe depth (F)
S_M	Trench spacing multiplier, can be found in (IGSHPA, 2010) from Table 5.17-5.29
P_M	Pipe diameter multiplier, can be found in (IGSHPA, 2010) in Table 5.30;

2.1.2 The ASHRAE method

The method presented by ASHRAE is a single equation that accounts for both heating and cooling modes and can be used for vertical borehole systems. This method utilises a temperature penalty (T_p) that factors in the long-term borehole heating exchange effect and also includes three representative building heat loads along with their respective thermal resistances. By factoring in a temperature penalty, the strength of this method is its simplicity as it can be easily performed in comparison to other methods (Rolando, 2015). However, the simplicity of this method has led to a number of people refining the method in an attempt to remove its uncertainty, including by Philippe et al. (2010) who recasts the method.

The recast ASHRAE method below (Equation 1) proposed by Philippe et al. (2010) "was derived from the assumption that heat transfer in the ground occurs only by conduction and that moisture evaporation or underground water movement are not significant".

$$L = \frac{q_h R_b + q_y R_{10y} + q_m R_{1m} + q_h R_{6h}}{T_m - (T_g + T_p)} \qquad (1)$$

Where:

L	Length of pipe required (m)
q_y	The yearly average ground load (kW)
q_h	The peak hourly ground load (kW)
q_m	The average monthly ground load (kW)
R_b	Effective thermal resistance of the borehole (m K/W)
R_{10y}	Effective thermal resistance of the ground to 10-year ground load (m K/W)
R_{1m}	Effective thermal resistance of the ground to 1-month ground load (m K/W)
R_{6h}	Effective thermal resistance of the ground to 6-hour ground load (m K/W)
T_m	Mean GHE fluid temperature (°C)
T_g	Undisturbed ground temperature (°C)
T_p	Temperature penalty (°C)

The ASHRAE method also incorporates a Fourier number based graph to calculate the G-function, however this paper uses a simplified table presented in Phillipe et al. (2010) where:

$$R = \frac{1}{k} f(\alpha, r_{bore}) \qquad (4)$$

$$f = a_0 + a_1 + a_2 r_{bore}^2 + a_3 \alpha + a_4 \alpha^1 + a_5 \ln(\alpha) + a_6 \ln(\alpha)^2 + a_7 r_{bore} \alpha + a_8 r_{bore} \ln(\alpha) + a_9\, \alpha \ln(\alpha) \qquad (3)$$

and a_{0-9} are the correlation coefficients for f at 10 years, 1 month and 6 hours.

Detailed calculations for all variables can be found in Narsillo, Johnston & Mihaylova (2016) and the simplified G-function table within Philippe et al. (2010). This refined method still contains levels of uncertainty as found in Mikhaylova et al. (2010), where a case study indicated that the level on uncertainty even in this method was still high enough that it requires further refining. This suggests that the even though the ASHRAE method is one of the most commonly applied methods when designing GSHP systems, it is both an approximation and complex.

2.2 Mobile Applications

2.2.1 Software commercially available

Earth Energy Designer (EED), Ground Loop Design (GLD and Ground Loop Heat Exchanger Design (GLHEpro) are the three main software applications that are used commercially to design GSHP systems. However, these tools are rarely used by domestic contractors due to their complexity and costs associated with training and operating (Curtis, Pine, & Wickins, 2013) and as a result, domestic designers are reverting to hand-based calculation methods which is limiting accuracy and introducing a larger element of human error.

2.2.2 Developing a geothermal mobile application

Since the release of the first iPhone in 2007, smartphone technology has advanced to a point where it has become essential in people's lives. Today, phones are more user friendly and for most cases equally powerful than/to computers, which has changed the way people use them. Due to this significant development in technology, a vast variety of mobile applications have been designed for vendors such as Apple, Google and Microsoft with statistics showing that it is now vital for organisations to integrate mobile technology in their strategic planning (Hoehle & Venkatesh, 2015). This has resulted in consumers not only using their phones as tools to communicate but also as a practical tool that facilitates their daily lives.

The outputs of a geothermal mobile application would not only need to give the user a specific result and unit, but also information about the variable itself and how it was calculated. The user could then utilise this information and compare it to their typical methods of calculation to understand and interpret any variances.

2.2.3 Selecting Apple's iOS

Research shows that since the release of Apple's first iPhone, the number of mobile applications available to download on from Apple's App Store has rapidly increased to a point where as of June 2015, there were over 1.5 million unique mobile applications available to download (Figure 3). Hoehle & Venkatesh (2015) indicate that Apple's iTunes store is now the most accepted mobile application store with statistics showing that as of 2013, consumers had downloaded more than 50 billion applications.

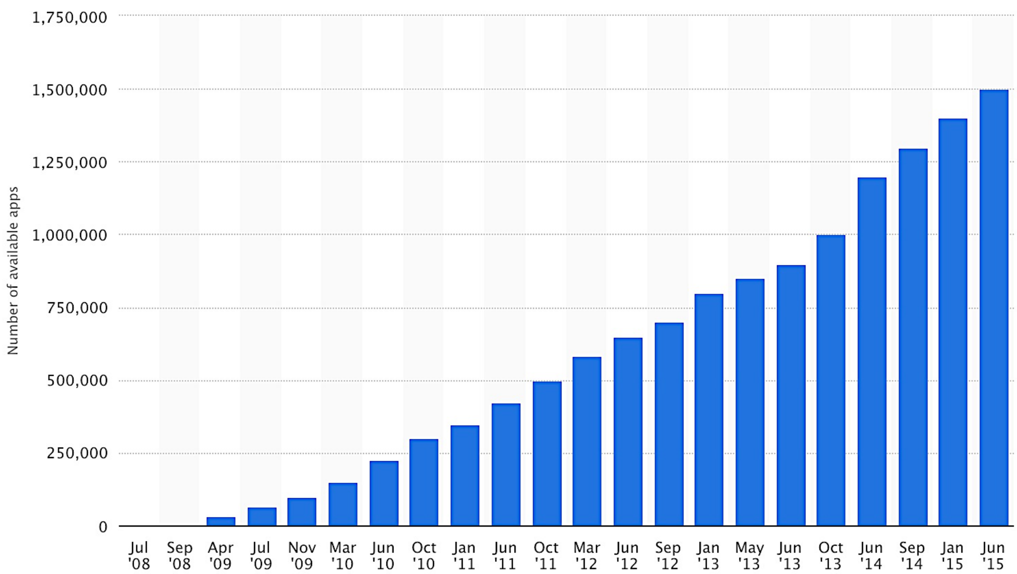

Figure 5 The number of applications available on Apple's App Store (Statistica)

2.2.4 The structure of an iOS app

Stanford University's 'Developing Apps for iOS' CS193P course (Stanford University, 2014-2015), describes the structure of an iOS application as being governed by a method referred to as Model-View-Controller (MVC). As depicted in Figure 4, the Model, View and Controller are three distinct elements that communicate with one another to create a mobile application. CS193P uses an analogy of a basic calculator application to explain MVC which is what will be used below.

The Model consists of all functionality required for an application to do what it is supposed to do. In this case, some fundamental functionality of a calculator is the ability to add, subtract, multiply and divide, and therefore this functionality is created in the Model.

The View is the user interface (UI), which is simply everything that the end user will interact with. In this instance, some elements of the View would include basic numbers, operators and an area to display the results.

The Controller is what communicates actions made by the user within the View to the Model and also returning resultant information the other way. In the case of a calculator, the Controller interprets the numbers and operators the user has entered and sends it to the Model to calculate, before the Model returns the result to the Controller to display in the View.

One of the most fundamental rules in best practice coding is that the View and Model should never directly talk to each other.

2.2.5 Developing an iOS mobile application and coding

Xcode is Apple's integrated development environment (IDE) which is used to build applications for all of Apple's products. This IDE is what enables an iOS developer to create the Views, Controllers and Models required, along with providing the functionality to test, optimise and submit application to the App Store. However, before creating a mobile application a developer must first learn how to communicate in a language that Xcode understands.

The Swift Language is the newest coding language which was released by Apple in late 2014 and intended to be the new developing language for iOS which would replace Objective-C as the developer's language of choice (Wells, 2015). The Swift language is the least restrictive coding language currently in existence as Apple has been able to include all of the most functional coding elements from the most prominent coding languages including Java, Objective-C, Python and many others (Hoffman, 2015).

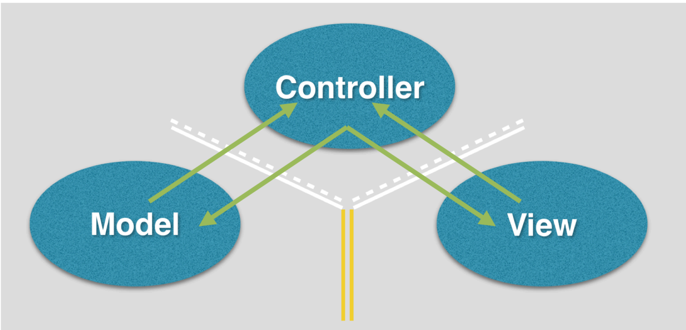

Figure 6 The structure of an iOS application

2.3 Conclusion of Literature Review

The literature review indicates that geothermal heating and cooling design is an environmentally friendly, viable option to heat and cool buildings, though its complex nature and variation in design has hindered its success. One of the significant issues this literature identified was the complexity and costs associated with the currently available pre-design software was resulting in domestic designer reverting to hand calculation methods.

Mobile applications have been found to be a modern platform capable of simplifying previously complex software. It is therefore the intention of this research project to create and test a mobile application on the iOS platform as a supporting pre-design tool particularly for the domestic contractor. This application must be sophisticated and accurate, but at the same time economically viable for the domestic contractor and simple enough to enhance the time a spent during the pre-design phase of a geothermal system.

3 Methodology

The primary goal of this investigation was to create an accessible mobile application that could be utilised as a pre-design tool for GSHP systems. The literature review of geothermal systems and in particular the IGSHPA and ASHRAE methods was the foundation on which our research project progressed.

3.1 Designing GSHP software

Three fundamental elements were considered and analysed during the design phase of GSHP software which included the calculation methods applied, the assumptions they make and the user experience (UI). The authors of this paper elected to apply both the ASHRAE and IGSHPA methods to this software as options for the user to select from.

It was fundamental to ensure that the user understands the difference between the two methods of calculation and in particular which configurations they are used for and the assumptions that they make. As shown in Figure 7, the first screen that the user is presented with is a selection between the two design methods. This screen has an information symbol in the top-right corner (located as directed in Apple's iOS Developer Guidelines), that when tapped, expands and provides the user with information about each method and where they can go to find out more information if required. The content that appears within these sections are condensed from the literature review within this paper.

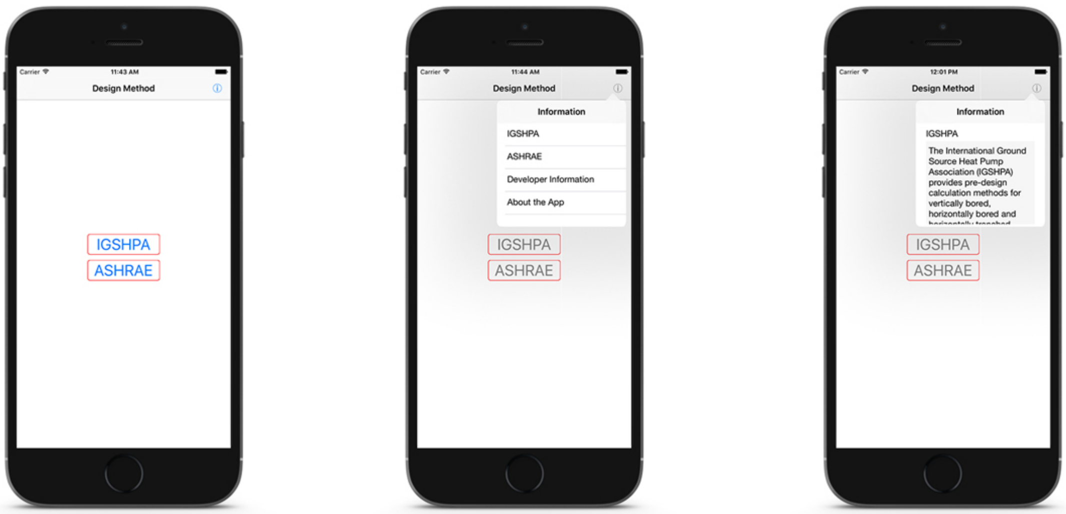

Figure 7: Display of user information about Design Methods in iOS application

Current software commercially available for the pre-design of geothermal systems include modelling GSHP systems functionality as a core feature. The modelling is an in-depth analysis of the system which can help the contractor design to a greater accuracy, however, the research highlighted that the complexity of modelling within software was a large contributor to why users required extensive training to understand how to operate and interpret the results. This mobile application is intended to be a time-saving tool to the domestic contractor and therefore will not incorporate modelling functionality. The mobile application will instead provide the user with numerical values for all secondary parameters that are calculated from the primary inputs provided by the user to calculate the length of pipe needed for the system.

To ensure that the user understands what all the variables represent, each parameter is accompanied with its own information icon. This icon identifies what the variable represents, the units that it is measured in and recommended typical values for Melbourne.

3.2 Distinguishing between primary and secondary variables

Primary variables were defined as input parameters that the user needs to enter and secondary variables were defined as parameters that the App would calculate and provide as an output on the results page. The most fundamental aspect that dictated whether a variable was considered primary or not was whether it was reasonable to expect the user to either know or be able to find the value of that variable. Table 1 provides a list of all the parameters that were considered as primary variables in both the ASHRAE and IGSHPA methods.

ASHRAE Primary Parameters			
Cp	the ground heat exchanger (GHE) fluid (water) thermal heat capacity (J/(kg K))	k_{pipe}	the U loop pipe thermal conductivity measured in (W/(m K))
m_{fls}	the fluid mass flow rate per kilowatt of peak hourly ground load (kg/(s kW))	k_{grout}	the grout's thermal conductivity measured in (W/(m K))
T_{inHP}	the heat pump entering water temperature (°C)	L_u	the centre-to-centre distance between pipes of U loop (m)
A	the borefield geometrical aspect ratio	$r_{p,in}$	the U loop inner radius (m)
B	the distance between boreholes (m)	$r_{p,ext}$	the U loop outer radius (m)
H	the borehole depth (m)	T_g	the undisturbed ground temperature (°C)
N_B	the number of borehole GHEs	q_y	the yearly average ground load (kW)
a	the ground thermal diffusivity (m2/d)	q_h	the peak hourly ground load for heating (kW)
r_{bore}	the borehole radius (m)	q_{mc}	the monthly ground load for cooling (kW)
k	the ground thermal conductivity (W/(m K))	h_{conv}	the internal convection coefficient (W/(m2 K))
IGSHPA Primary Parameters			
k_g	the ground thermal conductivity (Btu/hr ft F)	T_M	the mean earth temperature in the top 10 feet of earth (F)
D_{GD}	the diameter of ground surrounding borehole affected heat transfer (ft)	A_s	the earth surface temperature annual swing above and below Tm (F)
D_B	the diameter of borehole (ft)	T_0	the number of days after January 1 to reach minimum earth surface temperature (days)
D_{PI}	the inside pipe diameter (inches)	k_p	the thermal conductivity of pipe (Btu /hr ft F)
D_{PD}	the pipe outer diameter (inches)	α	the soil thermal diffusivity (ft^2/day)
k_{Grout}	the grout thermal conductivity (Btu/hr ft F)	T_{CD}	the heat pump heating capacity at design heating conditions (Btu/hr)
RT_{JUL}	the actual equipment run time in cooling mode in July (hours)	H_{CD}	the heat pump heating capacity at design heating conditions (Btu/hr)
RT_{JAN}	the actual equipment run time in heating mode in January (hours)	COP	COP is the coefficient of performance
h_{B-JUL}	the total bin hours in July (744 hours)	EWT_{min}	the minimum entering water temperature at heating design conditions (F)
h_{B-JAN}	the total bin hours in January (744 hours)	EWT_{max}	the maximum entering water temperature at cooling design conditions (F)
$T_{(d,t)}$	the earth temperature at depth (d, ft) after (t, days) days from January 1st (F)	LWT_{min}	the minimum leaving water temperature at heating design conditions (F)
EER_d	the energy efficient ratio at design cooling condition	LWT_{max}	the maximum leaving water temperature at cooling design conditions (F)

Table 1: Primary variables in both ASHRAE and IGSHPA methods

3.3 Creating the iOS Application

3.3.1 The Build Process

This project was completed over a 12-week period where the authors spent the first six week researching literature on geothermal systems and learning how to read and write basic Swift code within Xcode. These skills were self-taught using a combination of Apple's iOS Developer Guidelines and Stanford University's CS193P online course, as these skills were not taught within the core subjects of the Masters of Engineering degree at the University of Melbourne.

The second half of the project was spent building, designing and testing the application to ensure that it produced accurate results relative to published examples. Every week throughout the project, meetings were held with supervisors to plan and review progress.

3.3.2 Creating the Foundations

The first task to build the application was to create the Models in Xcode that would perform the calculations of each equation presented by IGSHPA and ASHRAE. As a result, the application has 6 Models that contain the unique equations required to calculate the secondary and tertiary variables specific to each method, utilising the primary variables entered by the user. Once the Models had been completed, Views were created to allow the user to select which method they would like to use before entering the primary variables specific to their setup to return a set of results. To do this, a total of 18 unique Views were created to guide the user through this process. Finally, the last foundation that needed to be created was the Controllers which were required to facilitate communication between the Views and the Models. A total of 18 Controllers (1 per View) were created to do this.

3.3.3 Responsive & User Friendly Designs

A fundamental element when designing the Views was to implement a responsive design, meaning that on any Apple device (iPhone, iPad, etc.), orientated in landscape or portrait, the application would automatically adjust itself to the screen dimensions and still be useable. To do this, every element within each View has a relationship with the elements surrounding it and also with the edge of the screen. As shown in Figure 9, on all devices the elements of the application are legible and useable, this application is therefore considered responsive.

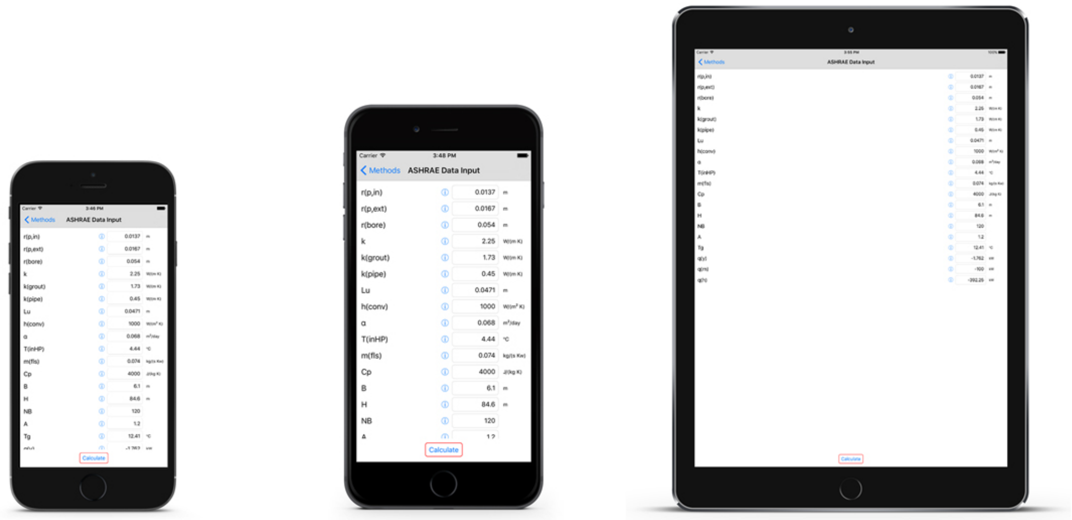

Figure 8: Responsive Design. View of ASHRAE Data Input Screen on the iPhone 6, the iPhone 6 Plus and the iPad

Responsive design is considered a very significant element that contributes to the ability of a user to easily navigate the application. To further ensure that the application is easy to use, Apple's iOS Developer Guidelines were utilised to make sure that all elements (buttons, logo's, tabs, etc.) were located in the correct places. This process was essential as Apple's guidelines emphasised the importance of locating common functionality in places that users expect to find them.

3.3.4 Design & Branding

All of the code, graphics and content that appears within the mobile application is original work by the authors. The University of Melbourne's logo was also incorporated into the logo for the application (Figure 9) to represent the university's contribution to the application. These designs are to be submitted to the University of Melbourne's marketing department for approval prior to the application becoming publically available.

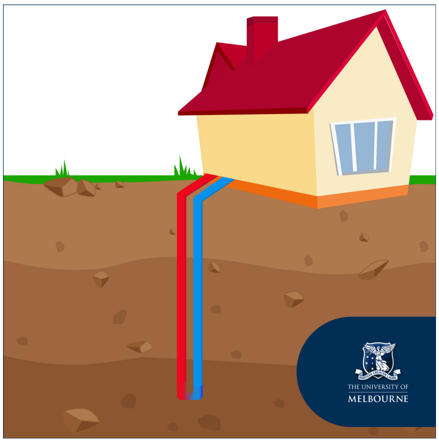

Figure 9: Logo for Geothermal iOS application

The logo was designed to complement the title of the application which has been labelled 'Geothermal'. It was a consensus between the authors of this paper and their supervisors that the name Geothermal, along with a logo depicting a GSHP system, was the best combination to allow users to find the app and easily understand its purpose.

3.3.5 Functionality

The functionality that was deemed necessary for the first iteration of this application needed to ensure that the user was able to select the method they required, enter primary variables that are specific to their scenario and heat pump, and receive a set of results with an accurate approximation of pipe length required. This was all implemented into the application via the Models, Controllers and Views detailed previously and further functionality was also added.

Within this application, every variable that the user enters has a unique information icon that the user can select to find out what the variable represents. The user can also email a CSV file of the results to themselves or to other people who may require that set of results. The file within this email will also be date and time stamped so that it is known when these results were computed for future records.

3.4 Addressing Legal Implications

Creating a mobile application as an engineering tool that doesn't currently exist is the second project of its kind in a series of software applications that are intended to be developed. As a result, during the development of the first application a disclaimer was created by the legal team of the University of Melbourne, explaining the nature of the App and removing responsibility from the University and development team. This disclaimer has been utilised when the user opens the application for the first time they must accept the Terms and Conditions to use the application (Figure 10). This application is intended to be used as a supporting tool in the design process of GSHP systems. It is not intended to be used as a replacement tool to current software and processes used.

4 Results

4.1.1 Output Testing

To test the accuracy of the application, each method (IGHSPAs Vertically Bored (VB), Horizontally Bored (HB) and Horizontally Trenched (HT), and ASHRAE) was tested for two cases. One case which gave a pipe length for a cooling result (CR) and the other case giving a pipe length for a heating result (HR).

Each example case was from a published source that provided all required inputs as well as results to ensure accuracy. Table 2 shows the results of each case example, the results of the application for the same set of inputs, and the average difference between the results for each method.

	IGSHPA VB	IGSHPA HB	IGSHPA HT	ASHRAE
Example HR (m)	360	520	2555	151
Application HR (m)	359.04	518.87	2557.04	150
Example CR (m)	319	362	1041	10150.3
Application CR (m)	318.3	361.33	1039.34	10150
Average Difference (m)	**0.92**	**0.90**	**1.85**	**0.65**

Table 2: Testing results

All the results were very positive for the accuracy of the application, particularly the cooling results for the ASHRAE method which had a difference of only 0.3m. The IGSHPA results typically had a larger variation than the ASHRAE results which could a result of the unit transformations applied. The IGSHPA hand book provides its variable in Imperial units and so the user can input SI units, the application therefore converts the input SI units to Imperial units, performs the methods calculations and finally again converts the Imperial unit results back to SI units for the output. Figure 10 shows the statistical accuracy of the application for each design method in relation to the published examples used to compare.

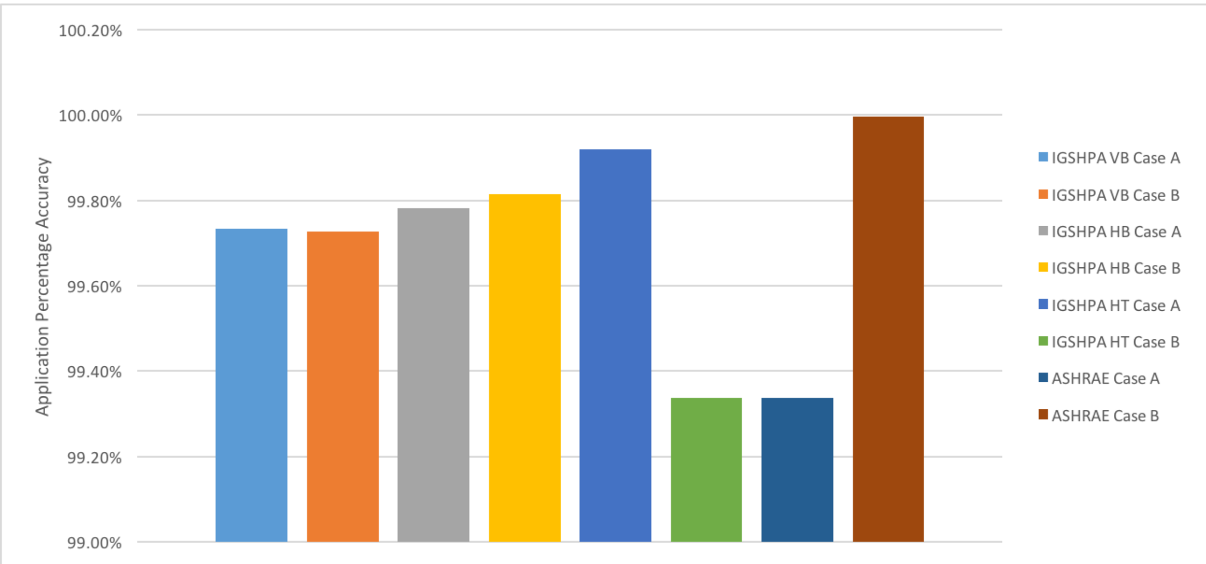

Figure 10: Test result of the Application's outputs for each Case

4.1.2 Useability & Functionality Testing

To test the useability and functionality of the application, a focus group was used to trial the application and provide feedback. The focus group consisted of researchers within the geotechnical group of infrastructure engineering at the University of Melbourne. This demographic was selected as an appropriate group that reflected the potential users of the application who have a moderate understanding of geothermal systems.

The feedback from the focus group confirmed that the fundamental functionality of the application was a success. All members were satisfied with the ability to input unique variables or use the values that are recommended. They were also satisfied with the outputs that the application calculated and how they would be useful during the pre-design phase of a geothermal system.

Extra functionality that was mentioned by members of the focus group included the the user experience when entering variables. It was suggested that variables that have defined upper and lower limits could have sliders rather than editable boxes to adjust the value of the variable, in turn increasing the users experience.

The useability of the application was also deemed satisfactory, however, there were a number of alterations recommended to make the application even better. These recommendations were mostly orientated around the aesthetics of the application and attracting not just commercial users but also potential consumers to use the application. These recommendations included incorporating more graphs and images that further depict what both the inputs and outputs represent.

The final piece of feedback received was that the input variables for each method should be categorised into collections of parameters that are relative to certain aspects of the design. As shown in Figure 11, this piece of feedback was implemented in time for the first iteration of the application, however the rest of the feedback is intended to be addressed and implemented in the next iteration.

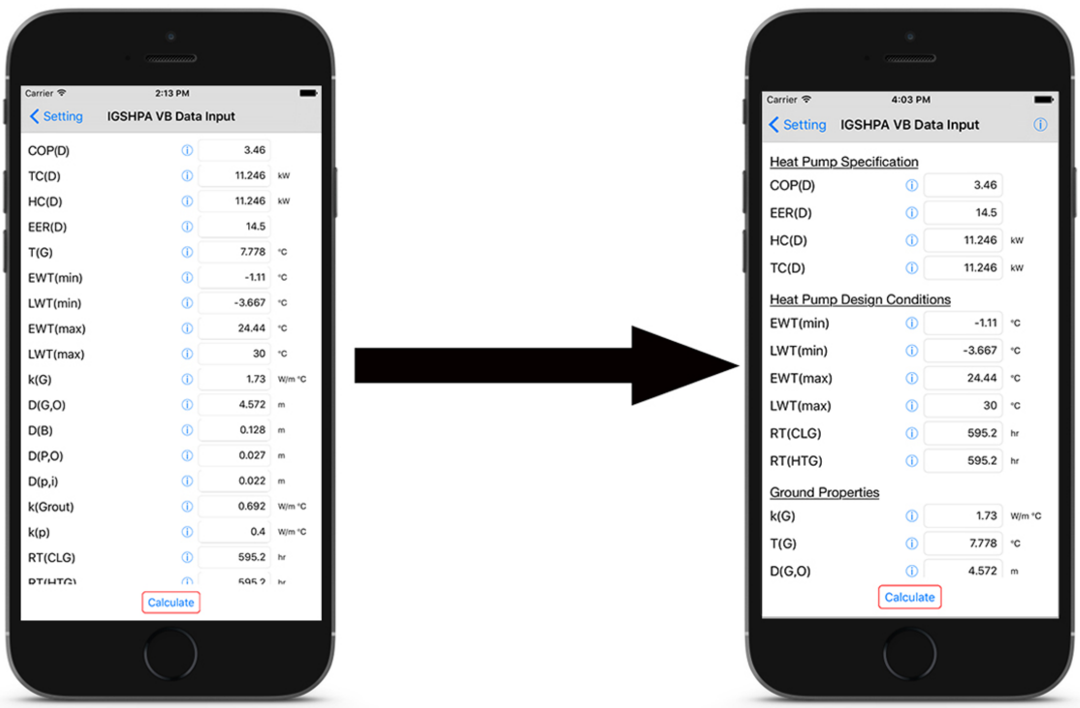

Figure 11: Changes made to input layout as a result of focus group feedback

4.1.3 Time Saving

One of the essential design components of this application was to ensure that it saved time during the pre-design phase, particularly for domestic contractors performing the calculation by hand.

To test this, a Masters of Engineering student familiar with geothermal systems was given all of the input data required to design a geothermal system, along with all of the calculations required to compute the pipe length required.

The student was told to perform the calculation 4 times, keeping record of all variables, their units and ultimately the pipe length required. For each iteration, the student was timed as to how long it took them to complete the task and told whether the system was designed correctly or not, though they were not told what the error was if there was one. This was done to attempt to replicate a real-life scenario where the designer would only know that the system was poorly designed once it had already been installed. Therefore, for each new iteration, all the student knew was that they had made a mistake in the previous calculation.

Once the student had completed the 4 iterations, they were then asked to then repeat the process again for the same scenario, but this time using the application to compute results. Again in this scenario, errors were recorded and the student was told whether there was an error in their results or not though not specifically what the error was.

An error throughout the calculation was deemed any variable that was calculated incorrectly. Whether the calculation was deemed successful or not, was whether the max pipe length was the correct value. An example where the student made an error, though calculated the correct pipe length was in Attempt 3 (Figure 12). The student made a calculation error on the pipe length required for cooling, though calculated the heating pipe length correctly which was the larger measurement.

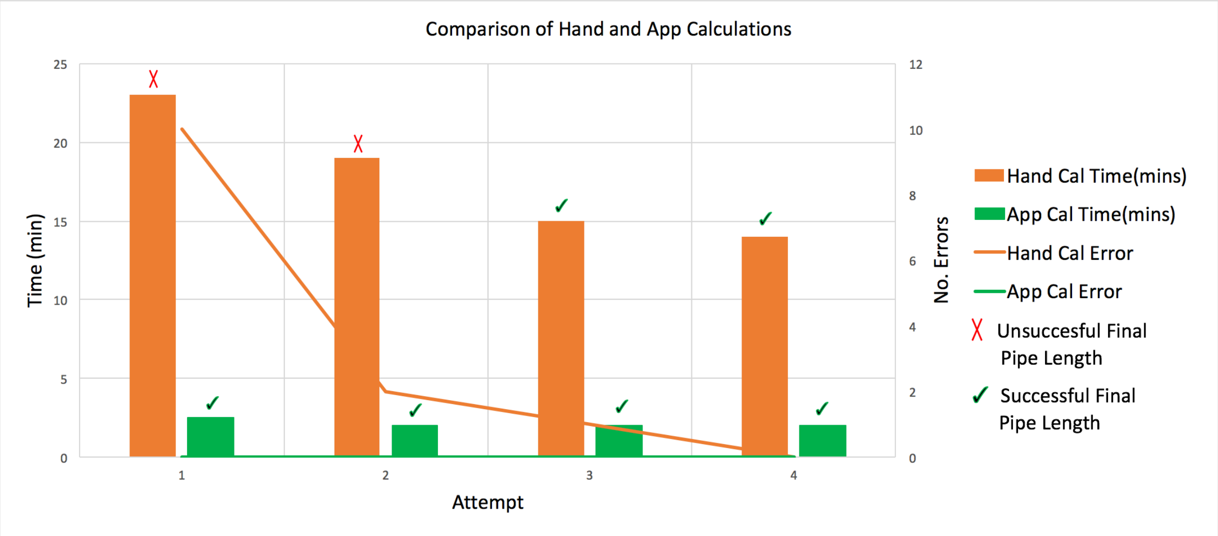

Figure 12: Calculation Test Results

Figure 12 shows the results of the test where with repetition of the same process with the same variables, the students hand calculations became progressively quicker. However, the using the application to calculate the required pipe length proved to be substantially quicker while producing no errors.

4.1.4 Public availability & Cost

The development cost of the application itself was a total of $0 plus the authors time. In order to make the application publically available on Apples App store, there is a $99 USD developer fee per year.

Currently the application is in the process of being made publically available to download from Apple's App Store. However, before it is made available, both Apple and the University of Melbourne are required to approve its use. There is an extensive bureaucratic process which needs to be followed in order to launch this application through the University of Melbourne which is underway.

Currently the proposal is to offer the application to consumers for $2 for the first 12 months to encourage people to trial the application before adjusting the cost in the future. Within the University of Melbourne's Research Innovation Commercialisation (RIC) department, the UoMC Pty Ltd (University of Melbourne Commercial) are going to be consulted to approve and further develop the commercialisation strategy.

4.1.5 Future intentions

Due to time restrictions, there was functionality that had to be omitted from the first iteration of this application, though it is intended to be included in the future. For example, all units within the IGSHPA methods were initially presented in Imperial units and have all been converted to SI units within the App. In the future it is planned that in the user will be able to select what units they wish to enter and receive variables in to cater for a global market. Along with the ability to select units of measurement, the application currently offers recommendations for Melbourne and typical Heat Pump variables. In the future the user will be able to select from a number of common Heat Pumps which in turn will enter their relevant values automatically and the same would apply for different locations around the world.

5 Conclusion

This project was founded on the desire to create something new that could be used as a practical tool in the engineering industry. Geothermal systems were identified as an area on which to focus and the literature reviewed in this paper identified that the current complexity of available design software was resulting in domestic contractors reverting to hand calculations for the pre-design process. This was a significant issue because when facing clients who demand quick 'back of the envelop' estimations, hand calculations are time consuming and allow for a large element of human error.

By incorporating Apple's Developer Guidelines, the authors were able to create a tool that previously did not exist which is capable of addressing the issues of time and accuracy that hand calculations present. The feedback received from the testing of this tool supported the theory that a simplified piece of mobile software has the capability to compute complex equations in a way that is both user-friendly and informative during the pre-design process for geothermal systems.

The result of this study should provide a basis for not only engineers but also professionals in other industries as well, to view mobile technology as a tool that can save time and increase accuracy when calculating complex problems.

6 Bibliography

Apple. (2016, 4). *App Distribution Guide*. Retrieved 4 18, 2016, from https://developer.apple.com/library/ios/documentation/IDEs/Conceptual/AppDistributionGuide/SubmittingYourApp/SubmittingYourApp.html#//apple_ref/doc/uid/TP40012582-CH9-SW1

Bernier, M. A. *Closed-Loop Ground-Coupled Heat Pump Systems.* 2006: ASHRAE Journal.

Charland, A., & Leroux, B. (2011). *Mobile Application Development: Web vs. Native.* New York: Communications of the ACM.

Curtis, R., Pine, T., & Wickins, C. (2013). *Development of new ground loop sizing tools for domestic GSHP installations in the UK.* Cornwell: GeoScience Ltd, Falmouth Business Park.

Ground Source Heat Pump Association. (2007). *Design and installation of closed-loop systems.* London: Ground Source Heat Pump Association.

Hoehle, H., & Venkatesh, V. (2015). *Mobile Application Usability: Conceptualization and Instrument Development.* Arkansas: MIS Quarterly.

Hoffman, J. (2015). *Mastering Swift 2.* Birmingham: Packt Publishing.

IGSHPA. (2010). *Design and Installation of Residential Ground Source Heat Pump Systems.* Canadian GeoExchange Coalition.

International Ground Source Heat Pump Association (IGSHPA). *Ground Source Heat Pump Residential and Light Commercial.* Oklahoma University. 2011: Oklahoma State University.

Lund, J., Sanner, B., Rybach, L., Curtis, R., & Hellstrom, G. (2004). *Geothermal (Ground-Source) Heat Pumps A World Overview.* USA, USA: Geo-Heat Center, Oregon Institute of Technology.

Mikhaylova, O., Johnston, I. W., & Narsilio, G. A. (2016). *Uncertainties in the design of ground heat exchangers.* Melbourne: ICE Publishing.

Narsilio, G. A., Johnston, I. W., & Mikhaylova, O. (2016). *Uncertainties in the design of ground heat exchangers.* Melbourne: ICE.

Narsilio, G., Johnston, I., Bidarmaghz, A., Mikhaylova, O., Kivi, A., & Aditya, R. (2014, August 27-29). Geothermal Energy: Introducing an Emerging Technology. *International Conference on Advances in Civil Engineering for Sustainable Development* , 142-154.

Philippe, M., Bernier, M., & Marchio, D. (2010). *Vertical Geothermal Borefields.* America: ASHRAE Journal.

Rolando, D. (2015). *Improved Ashrae method for BHE field design at 10 tear horizon* (Vol. 116). Genova, Italy: Cross Mark.

Sailer, E., Taborda, D. M., & Keirstead, J. (2015). *Assessment of Design Procedures for Vertical Borehole Heat Exchangers.* Stanford, California: Stanford University.

Scott, D. M. (2015). *The New Rules For Marketing & PR.* New Jersey: John Wiley & Sons, Inc. Hoboken.

Stanford University. (2014-2015). *CS 193P iPhone Application Development*. Retrieved 4 20, 2016, from Stanford University: http://web.stanford.edu/class/cs193p/cgi-bin/drupal/

Statistica. (n.d.). *Number of available apps in the Apple App Store from July 2008 to June 2015*. Retrieved April 14, 2016, from Statistica: http://www.statista.com/

Wells, G. (2015). *The Future of iOS Development: Evaluating the Swift Programming Language.* Claremont: Claremont Mckenna College.