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Pre-assessment tool for achieving Net Zero Energy in New Zealand schools

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Internship report

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Preface

First I would like to thank dr.ir. Mehdi Shahbazpour for hosting my internship at the University of Auckland. I would also like to thank Mehdi to make time every week to discuss my progress and thoughts about the project. His feedback during our weekly meetings was very useful and helped me a lot during the project.

The internship itself was a nice and interesting experience for me. I am sure it will help me during the rest of my career and I also developed myself as a person by doing my internship abroad. The subject of the internship was interesting because the energy problem gets more and more attention everyday. I am happy that I was able to contribute in developing a tool that hopefully will contribute to a greener and more energy efficient New Zealand. I hope that the tool will be used widely in New Zealand when it is fully developed and I am very interested to take notice of its further developments in the future.

Summary

The aim for this project was to further develop a pre-assessment tool for achieving Net-Zero energy schools in New Zealand. A school with a Net-Zero energy building has a building that generates as much energy as it uses annually. Given the older education buildings throughout the country together with the growing interest in energy efficient buildings as well as the growing use of energy in buildings illustrate the needs for a pre-assessment tool. The tool aids in making a decision whether it is feasible to build a new Net-Zero energy building or to refurbish an existing building into a Net-Zero energy building and provides the optimal mix of energy saving and energy generating technologies to achieve this. Another purpose for the pre-assessment tool is to raise awareness among students about the energy problem and educate them to create energy efficient behavior.

The methodology used during this project is as follows. First information and data is gathered to verify and validate the estimates already provided by my predecessors, to add new technolgies and regions to the tool and to compile useful tips and a technology inventory. Then the data is analyzed and modified to ensure it is useful for the tool. Meanwhile the framework of the tool is programmed with Visual Basic in Excel to ensure an easy to use tool with a great functionality. The last stage of the project is to enlarge the tool's publicity especially among government institutions to facilitate in all sorts of ways the development of the tool.

As aforementioned the pre-assessment tool is an Excel tool. The framework of the tool follows the aspects of passive design. This means first a reduction in the energy usage by passive methods such as insulation. Per energy category users are able to select this type of technologies in the tool before selecting other methods to reduce the energy usage. Thereafter users can select products per category that nevertheless reduces the used energy but are no part of a passive design such as heat pumps and type of light bulbs. The users can subsequentely select a technology to generate the reduced energy need. The last stage of the tool displays the outputs of the tool such as costs, energy savings, payback period and NPV of the project. The outcomes of the tool allow decision makers to consult about the outcomes with architects and, in the end, to make an educated decision about whether to continue with the project and with which mix of technologies.

Unfortunately the tool could not be tested on accuracy because there is only one existing Net-Zero energy school in New Zealand and a lot of data about this school is missing. Despite being in contact with the Ministry of Education for quite a while to obtain contact information about interested schools also user feedback lacks at the moment. hence the first recommendation would be to get user feedback and make improvements based these experiences. Some other future developments of the tool are making the tool into a website, which could easily be updated when new information becomes available, involving specialized architects in the further development of the tool to ensure it is accurate and users can easily contact these specialists and making the tool open source such that other people can add data and information about other technologies and other countries.

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Chapter 1

Introduction

1.1 Motivation

In New Zealand a lot of school buildings are outdated and have problems with their construction. This means they have high maintanace costs and some need complete replacement. To clearly sketch the problem; sixty-eight percent of school are between 30 and 100 years old, and most are over 50 years old. The problems with the construction of the building does not only affect the buildings itself but also the performances of students in a negative way. Another problem is that there are not enough school buildings or at least not enough in the right places. Estimations are that $1.3 billion is needed for new education buildings because of the growing population of students. The goverment has already stated that these problems must be solved and is spending a lot of money on school properties. [1]

At the same time the energy usage of people all around the world rises dramatically, especially in developing countries, but also in developed countries as New Zealand. When looking at the distribution of this energy usage, one can see that a lot of the energy is consumed by activities in and around buildings. This percentage lies around 40% and hence it highly contributes to the total energy usage. This suggests that a lot of energy can be saved when developing, refurbishing and building energy efficient buildings. [2]

Over the last past years Net-Zero-Energy Buildings (NZEBs) have become more interesting for people because of the risen awareness of global warming and climate change of the earth but also because of the lower costs of such a building. This means that decision makers are more inclined to do something about this problem and increasingly consider to incorporate energy saving technologies in their buildings to retain a positive image as school and to show that their schools keep abreast of the times.

Combining the three reasons mentioned in the previous paragraphs makes it the perfect time to think about oppertunities to reduce energy usage in New Zealand education buildings and to develop a tool that maps the opportunities in this area. The tool focuses primarily on New Zealand schools building although other buildings can benefit as well of the technologies to reduce energy usage. Although the information about these technologies is already available for most of them it is scatterd across the internet and for decision-makers without knowledge about the subject it is hard to determine what is useful and what not.

The tool combines all the available information about the relevant technologies to reduce and generate energy. It also gives an rough estimatation about the costs and savings compared to a baseline. For decision makers the pay back time and NPV of the project are one of the most important parameters to base a decision on. Hence those parameters are among the outputs of the tool. This general character of the tool, it can be used by every school in New Zealand, makes it unique in New Zealand.

1.2 Framework

The pre-assessment tool is developed as an internship assignment at the University of Auckland. It is a continuation of a project started by Kate & Michelle as part of their study programme Mechanical Engineering. First the project started as a refurbishment project for a local school but due to circumstances the project became a general project for schools in New Zealand. New information, technologies and functionalities are added to their version of the tool and the estimates and assumptions in their tool are validated and verified.

1.3 Goals

The first purpose of the pre-assessment tool and thus of the project is to aid decision-makers such as school boards explore the idea of NZEBs and familiarize themselves with the subject. Raising awareness that it is possible to build a NZEB nowadays or perhaps trying to reduce the energy consumption as much as possible and advising which technologies are renewable and should be used in a NZEB are also among the goals of the tool.

Another important goal of the tool is to raise awareness about energy waste inside a building. This is highly influenced by human behavior and some tips to reduce energy usage can be found in the tool. Needless to say educating students is also one of the goals of the tool. When students learn about the technologies used in their schools they become automatically more aware of the concept of energy and why it is important not to waste it.

A third goal of the tool is to familiarize people with all the technologies involved in creating a NZEB. The tool hopes to achieve a better understanding of the energy saving and energy generating technologies such that decision-makers can consult with architects and be able to give a critic review about a proposed design.

The last purpose of the tool is to provide estimated costs about the technologies which enables decision-makers to make informed decisions without spending ample time on research. The tool should only be used as a guide and costs will vary greatly depending on suppliers and specific school properties such as ease of access and complexity of the build. The costs provided are aimed to give decision-makers a rough idea of what to expect when incorporating a particular technology into their schools building. Therefore it is advised to use the tool in a very early stage of the design phase to be able to get a first indication about the possibilities to achieve a NZEB and a rough indication about the costs.

Chapter 2

Methodology

The following approach is used during the internship and explained in this chapter; first data is gathered, then analysed and modified. Meanwhile the tool is developed and brought to the attention of the possible interested government institutions.

2.1 Data gathering

The following methods are used during the project to gather relevant information and data. First a literature review is conducted to gather information about all energy saving and energy generating technologies, information about New Zealand schools and universities and New Zealand climate data. The information is gathered by consulting experts in the field and searching for articles, books and databases on the internet and in the library. It contains, among other things, data about the current energy consumption in education buildings, data about the different climates in New Zealand, legislation of the New Zealand Building code but also useful tips to reduce energy consumption by human behavior. A couple of examples of the used databases are Scopus, CliFo database and Rawlinsons contruction handbooks.

2.2 Data analysis

All the gathered information is scheduled and modified so it can be used in the tool and is relevant. This means that all the gathered data is analysed and therafter it is decided whether to use it in the tool. Some of the information is modified to make it relevant or useful for the tool. Everytime data is modified it is always done in a conservative way to ensure that the tool never overestimates the available energy savings or the price of a technology. An example of the data that is modified to make it useful for the tool is data about energy savings in other countries than New Zealand with a different climate. The differences in climate between the two countries are subsequentely analysed and based thereon the data is made useful for New Zealand education buildings.

2.3 Development tool

Meanwhile the functionality of the tool is improved such that it can be used by people with al sorts of backgrounds involved in decision making about education buildings. Originally it is developed as an Excel tool because most people are familiar with Excel. The programming is done step by step to make it manageable. Per sheet code is added and when the code of a sheet is finished the code of the next sheet is programmed such that the code of a sheet can immediately be tested when finished.

2.4 Publicity tool

To ensure that the tool will be used in the future it is indispensable to enlarge its publicity. Therefore the Ministry of Education is made aware of its existence and the tool is brought to the attention of the Sustainability Office of the Auckland City Coucil. To be in touch with this kind of authorities makes it easier, for example, to arrange meetings with friendly schools boards in the future and set up a test and feedback session. Also funding from these kind of government organizations is welcome. Organizations as Branz or EECA are made aware of the existence of the tool to ask them for extra information, if available, or to check the estimates and prices in the tool. Most of this type of contact is maintained by email. At the last stage the project a demo is given to people of the Sustainability Office to show the opportunities and progress of the tool.

Chapter 3

Pre-assessment Tool

In this chapter the framework and userflow of the tool are briefly explained, then the use of VB is concisely described together with the introduced changes and implemented changes to improve the functionality of the tool. To put this in context first the structure and framework of the tool of my predecessors is explained. An image of (the top of) every sheet of the tool is depicted in appendix A.

3.1 Version predecessors

At the start of my internship a draft version of the tool was already available. My predecessors, Kate & Michelle, developed this first version during their final project in year four of their study Mechanical Engineering. They invented the framework of the tool and provided most of the estimates for the energy saving and energy generating technologies. However the tool was far from finished and needed to be further developed and their estimates verified. Screenshots of their tool can be found in appendix B.

3.2 Framework & Structure

The framework of the tool is very important because it is based on the principles of passive design. The most important aspect of passive design is to reduce the energy consumption as far as possible and then think about ways to generate energy. The best way to reduce energy is with so called passive methods such as insulation and shading instead of choosing more energy efficient heat pumps for example.

Needless to say the tool also works in this way. However before making any calculations for energy saving technologies some parameters of the school must be completed in the tool. All the calculations are based on these completed inputs of users. First the average energy consumption of a typical school that complies to the building code is estimated. It is also possible to provide real energy data though, if applicable, for a more accurate result.

Then by selecting energy saving technologies users are able to reduce the current energy consumption. The users can select whatever technology or combination of technologies they want, but they are restricted to one product per technology. It makes no sense to select multiple products per category since this does not result in extra savings. There are more restrictions for the selection of the technologies though. Some technologies are obligatory such as windows. I.e. some product has to be selected in this category. Other categories are optional, for example sensors, and the last category is neither obligatory nor optional because it depends on the choices made by the user. The latter mentioned category is the other influences category. The tool provides passive energy reducing technologies first, which is an important principle of passive design. In this way the highest achievements can be made by these kind of technologies.

After the user has decided which energy saving technologies to implement they can move on to the energy generating technologies. In this section the user can select technologies that have to met the reduced energy demand. Sometimes some energy generating technologies may not be feasbile, but the tool will let the user know when this is the case. After the user is happy with all the selected technologies the tool presents different outputs such as costs, energy savings, payback period and NPV. All the inputs and outputs are depicted in table 3.2 below:

Inputs	Outputs
Kind of Project	Total cost in $
Historical Data	Savings per year in $
Location	Energy Savings per year in kWh
Type of School	Number of PV solar panels
Area	Size PV solar panels in kW
Number of Pupils	Number of Wind Turbines
Building Layout	Size Wind Turbines in kW
Number of storeys	Payback Period in years
Higher buildings in Surroundings	NPV in $

3.3 Userflow

For a clear overview the userflow through the tool can be seen in figure 3.1.

Figure 3.1: Userflow through the tool

It can be seen in the figure that there are more sheets than mentioned in paragraph 3.2. To provide the user some background information before starting with the tool the intro, instructions and net zero energy are added to the tool. These sheets provide the user with some basic knowledge about the subject and comprehensive instructions how to use the tool. The last two sheets in the process are the tips sheet and the technology inventory sheet. Also these two sheets provide information about the subject, especially tips for human behavior and information about the specific technologies. It is not necessary to know this information beforehand though, and the information can be accessed when it is desired by the user.

3.4 Visual Basic

The first version of the tool was only an Excel version. It was decided that using Visual Basic to update the tool is tidier because users of the tool cannot accidentally delete formulas in cells. The structure of the tool is as follows, when a user fills in information about the school and clicks the next button on a sheet all the relevant information is written to an output row in the School data table on the Data sheet. This table also contains information about energy usage, climate data and so on. This data is matched with the data that corresponds to the school specifics, which are completed by the user and also written to the output row of the table.

Based on these two different types of data on the output row of the School data table all the calculations are subsequentely conducted. However this is not the only data there is available to calculate the outputs of the tool. Together with specific data per technology such as price and energy savings the outputs of the tool are calculated. Also this data can be found on the Data sheet. One result of introducing Visual Basic code is that the tool does not update immediately when a cell is completed but only when the next button on the sheets is clicked.

3.5 Functionality

Besides introducing Visual Basic code in 3.4 to improve the tool also the functionality of the tool required some improvements. Only the major improvements for the functionality are touched on in this section. One of these improvements is the addition of menus on the left side of the sheets. These menus enable to browse faster through the tool to see what is still to come or to visit the instructions sheet within one click. Also clearly visible buttons are added to the pages to make it easier for users to navigate through the tool. The buttons play an important role in the tool because they also take care of updating the tool. The last improvement for the functionality is the style of the tool. It is decided to add more contrast between the background color, the font color and the color of some cells to increase readability. It is easier, after the improvements, to see the purpose of the different cells by adding specific colors for specific types of cells.

3.6 Other changes

Besides the changes mentioned above a couple features have been added to the tool to improve the accuracy of the tool. Some missing energy savings categories are added; airtightness and shading. More products have been added per category to give a clear view of the effects per category for users. Another feature that has been built in the tool to further improve the accuracy is the influence of technologies on other categories. For example the effect of solar panels on the roof has an infuence on the required cooling energy during the summary. This kind of influences represents a minor saving, but can be significant when summed up though. Also, if applicable, the estimates for energy savings are corrected and based on comparing relevant parameters instead of just estimations.

A couple of sheets has been added or made more comprehensive. For example the tips sheet has been added to provide information about funding and a lot of information about the best energy efficient electrical devices. The biggest addition to the tool, however, is the addition of refurbishment. Instead of only new build it is possible to obtain an accurate result for refurbishment as well. Every estimate for energy saving and price is adjusted for refurbishment based on the current situation of the building.

Chapter 4

Data input sheets

In the following chapters; chapter 4, chapter 5, chapter 6 and chapter 7 a justification is given for the estimation of all the parameters in the tool. This parameters cover a broad range of subjects and thus to give a complete overview it was chosen to address them in the same order as the userflow mentioned in section 3.3. Only parameters for which an estimation was computed are explained in the section below. Other parameters such as region are a given fact and are not explained.

4.1 Building estimates

If available, it is possible for users to incoperate actual energy data in the tool. Nevertheless the tool should also be useful when this kind of information is unknown or schools are unwilling to conduct a test to provide this kind of information because of finanical objections. Therefore estimations are conceived for the average energy consumption and average energy end-use of schools and universities in New Zealand.

4.1.1 Energy consumption

The energy consumption of a school is the total amount of energy a school uses annually. I.e it is the sum of the energy used as gas, electricity or other fuels throughout the year. Needless to say this depends on a lot of factors, for instance the type of school, the climate of the region where the school is located and the age of the building. Since this is a rough pre-assessment tool it simply fails to achieve its objectives when taken all the factors into account. Only the major factors should be addressed.

Therefore a couple of major factors have been distinguished for which the annual energy consumption differs. These factors are the type of school, the kind of building project. Also the climate was considered as significant, however, because of the lack of information and the relative minor climate differences in New Zealand the climate as a factor is left out of consideration for energy consumption. If gradually more information becomes available it is recommended to implement this in the tool. The energy consumption is given in kWh/m2 per year to allow for the total building area of a building.

New build

After consulting WSP group my predecessors Kate & Michelle already found an estimate for a tertiary campus in New Zealand. This estimate is in compliance with the Building Code and has no Greenstar energy rating. It is concurred that a new tertiary education building needs about 180 KWh/m2 per year. The estimates for a secondary and primary school are based on global benchmarks of the US DoE and WSP group for new build education buildings. A primary school uses about 125 kWh/m2 per year and a secondary school uses 150 kWh/m2 per year. [3], [4] The differences stem from the needs for the different types of schools. For example a primary schools does not have science rooms, where a secondary school does and a teritary school might additionally has labs.

Refurbishment

Unfortunately EECA, the Energy Efficiency and Conservation Authority of New Zealand [5], only has information available about the total energy end-use of educational institutions in their database of New Zealand instead of information about the energy consumption. [6] To estimate the energy consumption of existing school buildings in New Zealand the database of the US DoE has been used. [7] Their database contains a lot of information about schools in the USA. This data can be split for different regions, types of school and also contains information about the area of the schools. It is important to select the data of the schools that are relevant for New Zealand. This means data of schools in regions with a similar climate as New Zealand. A justification about which climates region are used is given in the subsection 4.2.

The estimates for energy consumption in existing education buildings are also divided in the same three school types. A primary school in New Zealand uses 225 kWh/m2 per year based on schools in the USA. 275 kWh/m2 per year is used as an estimate for secondary schools in New Zealand based on similar schools in the USA. An estimate for a tertiary campus, however, was harder to conceive. The sample size of tertiary education buildings in similar climates in the USA was too low to come up with a reliable estimate about energy consumption. In this case the energy consumption of a new build tertiary educational building is applied with the help of a factor to estimate the energy consumption of an existing tertiary education facility. The factor that has been used is 1.8 since this was also the difference between existing buildings and new build buildings for primary and secondary education buildings. One can conclude that the energy consumption of an existing tertiary building must be 325 kWh/m2 per year.

4.1.2 Energy end-use

The energy end-use means how the energy consumption is divided between different categories. These categories are heating, cooling, ventilation, hot water and lighting. Likewise energy consumption, energy end-use depends on numerous factors with different significance. The factors that are distinguished for energy end-use are the type of school and the climate of the region where the school is located. Of course the total school area has its influences on the energy end-use but it is believed to be very little and hence it is neglected.

New build

As mentioned in paragraph 4.1.1 EECA has a database about energy end-use for buildings in New Zealand including education buildings. [6] It is possible to access the information for 16 different regions. This regions are adopted in the tool. Even so this database is not used for new build education buildings because it was impossible to differentiate between existing and new buildings. Again, the US DoE provides useful information for this subject. The US DoE, in conjunction with three of its national labratories, developed reference buildings for new construction building including education buildings for primary and secondary schools. This buildings can be analysed for all the different climates that are present in the USA. [7]

However not 16 different regions are used, but only 2 climate zones were differentiated, a cold and a warm one. Based on the climates zones for insulation of the Building Code are 1 and 2 the warm climate zone and is 3 the cold climate zone. Unfortunately tertiary education buildings were not available since they do not represent a significant part of the commerical buildings in the USA. The energy end-use of tertiary buildings is estimated based on the energy end-use of existing tertiary education buildings in New Zealand for the two different climate zones and reference buildings of the US DoE most similar to universities. Nevertheless some prudence is advised when using the information for the all new build buildings because it differs a lot from the energy end use of existing buildings. Presumably this is due to the fact of poor insulation in existing education buildings in New Zealand. And again, if new information about energy end-use in new buildings becomes available it should be inplemented in the tool.

Refurbishment

EECA has chosen to merge the data for primary and secondary schools. This distribution is maintained in the tool. Instead of using just two regions to base energy end-use on for new build it was possible to use the earlier mentioned 16 different regions for refurbishment. The data is directly adopted from the energy end-use database of EECA and is not modified.

4.1.3 Wall area

To simplify the use of the tool and minimize the effort for the user the input fields of the tool are limited as much as possible. This means that some parameters must be estimated based on the completed data. One of these parameters is the total wall area and it is computed as follows. First the outside perimeter is determined by using the completed building layout. Since it is a rough pre-assessment tool only six buildings layouts are possible to choose. All these layouts are rectangular shapes because this kind of layout is most common for education buildings. The user must determine which building layout fitst the actual building the best if the actual building layout is aberrant. Together with equation 4.1 the perimeter can be determined:

$$p(x) = 2\sqrt{\frac{A}{x}} + 2\sqrt{xA} \tag{4.1}$$

Where A is the total floor area per storey and x is the ratio between the width and length of the building. The total outside wall area is then the outcome of 4.1 multiplied with the wall height and number of storeys. The wall height is an advanced input and is explained in paragraph 4.1.4.

4.1.4 Advanced inputs

The advanced inputs can be divided into two categories. The first category is the advanced inputs for both new build as well as refurbishment. The second category is the advanced inputs for the refusbishment case only. The advanced inputs that fall within the first category are wall height, window-to-wall-ratio and skylight-to-floor-ratio. The latter category consists of R-values of the roof, walls and underfloor and the already installed options per energy saving technology. The advanced inputs differ from the normal school inputs as average values have been already provided for the user because these values either differ minimally between education buildings mutually or they are seen as hard to determine without any knowledge on the subject.

Both project cases

The average wall height per storey is determined at 3.5m. It is an input value that can be changed by the user if known but it is seen as a good baseline value.

The window-to-wall-ratio is originally set at 0.3. According to [8] this is the average value in the optimal range in terms of energy saving. The value is useful for all climates because it is a baseline value that can be used anywhere around the world. Although designers should strive for this value in existing education buildings it can be hard to change this ratio when renovating a building. It is recommended to change the value, if it is known, to the actual value when renovating.

The last input value in this category is the skylight-to-roof-ratio. The already completed value is also an optimum. [9] describes when using a ratio of between 0.02 and 0.04 a minimum is found in the energy usage in a building. Since the simulated climates in the article do not agree with the climates in New Zealand the value is sligthly modified to 0.03 such that it is an appropriate value for New Zealand buildings.

Refurbishment only

For every technology the most common products in New Zealand education building have been chosen as baseline product and these products do not differ much between buildings. However users can select an already installed product as baseline if it differs from the actual baseline.

The R values on the other hand may differ much because they are dependent on the construction of the building. Unfortunately information about this subject is not available. Some value have been chosen based on American values. It is recommended when this information becomes available for New Zealand it is inplemented in the tool. The R value for the roof is 0.35, the R value for the walls is 0.6 and the R value for the underfloor is 0.75. Although average R values for the different building parts are provided users can always change those values to the actual values.

4.2 Justification of used climates USA

As mentioned above a lot of information about energy use in buildings is not simply available or in limited extent. The US DoE, however, has a lot of information available that is free to access on their website. Since this information cannot be used directly New Zealand the information is modified such that it can be used. This modification includes selecting appropriate climate zones in the USA.

According to Koppen New Zealand has climate zones Cfb and Cfc. Cf is an oceanic or marine climate and features warm summers and cool winters, with a relatively narrow annual temperature range. Cfb is the dry summer variant and Cfc is the subpolar variant. [10] These zones are more or less the same as the climate zones for insulation in the Building Code. Cfb is close to climate zones 1 and 2 and Cfc is close to climate zone 3. The US DoE, however, uses ASHRAE climates zones to distinguish the climate regions in the USA. These climate zones are especially designed for energy efficiency. [11]

Cfb and thus climate zones 1 and 2 can be found in the USA around Seattle. According to the ASHRAE climate zones this coincides with 4C. In the same way Cfc and climate zone 3 are similar to climate zone 5C. Unfortunately this climate zone does not exist in the USA. The two most similar climates are 5A (Chicago) and 5B (Boulder). Although these climates differ in some ways they have the same annual HDDs and CDDs as 5C because there are all in climate zone 5. This means that in terms of energy consumption and energy end-use no big differences are expected and 5A is used as reference climate zone. 5A, humid, is chosen over 5B, dry, because it is closer to 5C, marine, to ensure the most similarities. Summarizing the paragraph gives that 5C is used for zones 1 and 2 and 5A is used for zone 3. The different climates zones of New Zealand can be found in appendix C.

Chapter 5

Data energy saving sheet

All the parameters involving energy saving technologies are discussed in this chapter. There are two groups of parameters in this section. The first group are the parameters used to determine the energy saving per product. Second is the group of parameters used to determine the cost per product. Both will be justified per energy saving technology to provide a clear overview. There is a difference in which parameters are used and how for new build and refurbishment thus they will be discussed seperately. In the appendix D a list of all the used products in the tool are displayed. Together with the important parameters and other additional information about the energy savings and costs. Remarks about every category can be found in appendix E as well as some general remarks and assumptions about this section. These could be remarks about either disregarded products or recommendations about the category.

5.1 Reduce heating

The total energy that goes to heating is determined with the energy end-use of the corresponding school. This is explained in section 4.1.2. Then the total energy that is used to generate heat in the building is divided between five different potential places where heat is lost in a building. The roof, walls and floor will all be discussed in the section 5.1.1. The windows and airtightness have there own sections; respectively 5.1.2 and 5.1.3. The heat loss distribution for new build is as follows: 25% to roof, walls, windows and floor and 0% to airtightness. The reasoning behind this is that in the Building Code the R values for the roof are higher than for the rest of the building. This ensures that although heat rises the heat loss is evenly distributed over the building. One problem is that there is no actual data available. Needless to say when data becomes available this should be implemented in the tool. In contrast to insulated houses the heat loss distribution of uninsulated houses is known.

According to Branz the following heat loss distribution is used in the tool; 33% heat losses through the roof, 22% through the walls, 13% through the floor, 25% through windows and the last 8% due to air leakage. [12]

5.1.1 Insulation

The R value represents how well a product insulates the building envelope. It is a converse linear relation between the R value and how much heat is lost through the building envelope. Also the thickness of the insulation material is an important property espacially for the refusbishment case as the insulation material must be fitted in the wall cavity. The thickness of the material also contributes to the R value. If a product of the same material is twice as thick the corresponding R values is twice as high.

New build

For new build the baseline R value, called minimum standard in the tool, is in compliance with the Building Code of New Zealand. It is assumed that the energy consumption of the school is also in compliance with the Building Code and hence a fair comparison can be made about energy savings wherein the Building Code R value represents a 0% energy saving. The energy saving is calculated with the following formula:

$$\%saving_{overall} = \%saving_{heating} * \%saving_{roof/walls/floor} * (1 - \frac{R_{baseline}}{R_{product}}) \tag{5.1}$$

The total costs for the products are determined with the following formulas:

$$costs_{insulation} = costs_{R/m2} * A * R + costs_{annual} * years \tag{5.2}$$

$$totalcosts_{insulation} = costs_{product} - costs_{baselineproduct} \tag{5.3}$$

In formula 5.2 A is the area that needs to be insulated.

Refurbishment

There are some small differences between the refurbishment and new build, which mainly lie in the calculation for the price. The first difference is that the baseline is not substracted from the costs per product. I.e. one have to pay the full price. Another difference is that the costs for insulating the floor are 25% higher than for new build because the floor needs to be removed first in most cases.

5.1.2 Glazing

Windows are typically one of the worst insulated areas in the building envelope. When installing high performance windows an high energy reduction can be achieved. As for the insulation section the energy savings are based on the R value of the different products. The R values of the different products are based on the R values that Branz calculated and approved to use for various common types of a combination of frames and glazing. [13] There are 6 different products for glazing incorparated in the tool, see appendix D for a list.

New build

As well as for the insulation section the baseline R value for the new build is in compliance with the Building Code and hence the calculations for energy and price are the same as for insulation. The corresponding formulas are 5.1, 5.2 and 5.3. Only the second saving percentages are exchanged for the energy savings percentage per window type.

Refurbishment

Again, one of the differences between refurbishment and new build for glazing is the baseline R value. It is concluded that single glazing is the most common in New Zealand education building and hence the R value for single glazing with a minimum frame is the baseline R value for refurbishment. Another difference is the installation price for glazing in case of refurbishment. Since the old windows need to be removed first the costs for glazing are higher. These removing costs are estimated $100 per square m glass unregarded which type of frame or glazing. [14]

5.1.3 Airtightness

Every building has its leaks whereby air and thus heat can escape the building. It is important to ensure that a building is air tight to prevent heat loss by convection. The parameter involved is the amount of air flow volume in $\frac{m^3}{h}$. A blower test can be conducted to determine this parameter and subsequentely decide whether the air leakage of the building needs to be handled. The lower the air flow from the inside of the building to the outside the less heat is lost. It is not known how to relate the airtightness of a building to energy savings though. Hence the energy savings in this section are based on experiments instead of calculations. Furthermore it is assumed that a new build education building, which complies to the building code, already has a sufficient airtight building envelope and thus only refurbishment is discussed.

Refurbishment

In [15], different measures are taken to reduce the leakage of air in a building step by step. A building without any products to prevent air leakage is used as baseline. This corresponds with the baseline in the tool for refurbishment; an uninsulated building. Only the products with the highest savings in the article are combined and included as an option in the tool. These products are an airtight membrame, connection strips for windows and tape to seal joints for the membrame. This gives the following equation for the energy savings:

$$\%saving_{overall} = \%saving_{heating} * \%saving_{airtightness} * \%saving_{prodcuts} \tag{5.4}$$

Once the energy savings are calculated, the price for the products can be computed:

$$\begin{aligned} costs = costs_{membrame} * A_{membrame} + costs_{connectionstrips} * p_{windows} \\ + costs_{tape} * l_{tape} + costs_{annual} * years \end{aligned} \tag{5.5}$$

In this formula the $A_{membrame}$ is the required area for the airtight membrame and equates the total outside area of the building minus the window area. $p_{windows}$ is the perimeter of the windows and is calculated as follows:

$$p_{windows} = \frac{A_{windows}}{2} * (2 * \sqrt{\frac{2}{3}} + 2 * \sqrt{\frac{3}{2}}) \tag{5.6}$$

The assumptions made for this calculation are that an average window is 2 square meter and that the width is 3 times the height of the window. The last parameter that needs to be explained from equation 5.5 is l_{tape}. It is calculated as follows:

$$l_{tape} = \frac{A_{wall}}{h_{wall} * number_{storeys}} + 4 * h_{wall} * number_{storeys} \tag{5.7}$$

In this formula h_{wall} is the height of the wall and it is multiplied by 4 because there are 4 outside walls in a rectangular building.

5.1.4 Other influences

Skylights have an effect on heating because skylights influence the R value of the roof. The R value of the skylight is used to calculate a new total R value for the roof but only when users select skylights as an option in the tool. The following formula is used:

$$R_{new} = R_{old} * (A_{roof} - A_{skylights}) + R_{skylights} * A_{skylights} \tag{5.8}$$

5.2 Reduce cooling

All the products to reduce cooling affect the direct sunlight that shines on a building. I.e. all these products create a shade for the building. The total energy that goes to cooling is determined via the energy end-use of the corresponding school.

New build

The baseline for this section is that there is no shading present because it is optional to choose shading devices. There is no parameter to indicate how well shaded a building is. Therefore the energy savings are based on articles. In these articles the energy savings of the different products are compared with a building without shading products. [16]–[18] Then the overall savings can be easily calculated:

$$\%saving_{overall} = \%saving_{cooling} * \%saving_{product} * \%rooms_{normal} \tag{5.9}$$

In formula 5.9 the savings for the products are multiplied by the percentage of normal rooms in the building. A room is considered normal when all the energy for cooling is used to cool a room due to the weather outside. A special room is a room which needs cooling regardless of the weather outside, such as certain labratories. The costs for shading per product can subsequentely be calculated with the following formulas:

$$costs_{louvres} = A_{louvres} * costs_{louvres} + costs_{annual} * years \tag{5.10}$$

In this formula the $A_{louvres}$ represents the area that is required for louvres. This is the same as the total window area.

$$costs_{awnings} = number_{awnings} * costs_{awnings} + costs_{annual} * years \tag{5.11}$$

The required number of awnings is computed as follows:

$$number_{awnings} = \frac{number_{windows}}{2} \tag{5.12}$$

The number of windows, already calculated in the airtightness section, is divided by 2 because only the west and north faced windows require awnings.

$$costs_{blinds} = A_{blinds} * costs_{blinds} + costs_{annual} * years \tag{5.13}$$

In this formula the A_{blinds} is the same as the total window area. Since there is no baseline for shading the total costs for shading equals the costs per product. The costs for building overhangs or eaves are considered 0. There is one condition for this assumption. They have to be included early in the design phase. Then no extra costs for design are counted and the extra costs for materials are neglected.

Refurbishment

The differences between refurbishment and new build stem on the fact that there could be a different baseline product for shading. When for refurbishment no shading option is chosen as baseline the energy savings are the same and only the prices differ. A cost factor for removing the old shading option is multiplied with the costs per product. This cost factor is 1.1. When another shading option is chosen as baseline product the calculation for the energy savings are as follows:

$$\%saving_{overall} = \%saving_{cooling} * (1 - \frac{\%saving_{baseline}}{\%saving_{product}}) * \%rooms_{normal} \quad (5.14)$$

There is one exception on this rule though. Building overhangs are never an option to install because that means very high costs or it is even impossible to install them.

5.2.1 Light transibility windows

Light transibility is an influence of the type of windows on the amount of required cooling energy. The calculations for energy savings are the same for new build and refurbishment and, of course, no surcharge is counted for the windows. The calculations for energy savings are based on the ability to prevent heat transfer through the different windows. [13] To calculate the overall energy savings the following formula is used:

$$\%saving_{overall} = (\%saving_{cooling} - \%saving_{shading}) * (1 - \frac{Heat\ stopped_{baseline}}{Heat\ stopped_{product}}) \quad (5.15)$$

The overall savings for shading are substracted because that is the remaining cooling energy left after eventual applying one of the shading products, if applicable.

5.2.2 Other influences

The other influences category consists of four other energy savings technologies that influences the cooling energy. Research shows that a well insulated building also reduces the required amount of cooling energy. [19] This means that only if users select best or average standard insulation the energy savings on cooling energy will apply.

[9] describes the influence of skylights on the cooling energy thoroughly. Since the experiments were conducted in other climates than the New Zealand climate an average is used for energy savings because the climate of New Zealand is somewhere in between the two climates in the experiment.

The one but last other influences concerns solar panels. When installed on the roof of a building solar panels will provide extra shading for the building by blocking direct sun light on the building. This has a favorable effect on the cooling energy. [20]

The last other influence on cooling energy is natural ventilation. Only natural ventilation is added as other influence because mechanical ventilation requires electricity and thus the benefits of energy savings are lost. Natural ventilation provides an air flow through the building which will create a colder feeling for people inside the building. Hence it reduces the need for cooling during the summer. One condition for natural ventilation is the presence of wind on those days. [21]

5.3 Provide heating & cooling

The most important aspect of Net Zero Energy Building is the passive design of the building. Reduce the energy consumption as much as possible with passive strategies. It is impossible to reduce the energy consumption to zero though, and thus providing energy in a efficient way is the next step. The total energy that goes to the provide heating category is the energy that goes to heating minus the saved energy by the applied energy saving technolgies for heating. The energy savings of the products in the provide heating category will only affect that part of the heating energy.

There are 3 different ways incorporated in the tool to provide heating. A gas heater is only added as a baseline option and not renewable, so users cannot select it in the tool. There are two different ways for the three heating options to heat the building, which are underfloor heating and high wall heating. Whereas high wall heating is the more common way these days. Since heating and cooling are a reverse process for heat pumps, they can be used for both processes. The gas heater, however, cannot be used for cooling. In the provide cooling section the gas heater is replace by a standard airconditioner system, which has many similarities with a air source heat pump.

5.3.1 Heating

The best way to compare the different systems for heating is with the COP. The COP or coefficient of performance is the ratio between the amount of output heat and the amount of input energy. However the COP is not directly used in the tool due to the fact that the products have different types of input energy; electricity and gas. Since the percentages of energy savings are applied to calculate how much money is saved also the price difference between gas and electricity must be taken into account. The COP and the price difference combined give the price for 1kWh of useful heat. It is just the price of the input energy divided by the COP.

New build

The baseline for provide heating is the price for 1 kWh of useful heat for the gas heater. Again, it is assumed that the energy consumption per square meter according to the Building Code corresponds to the energy used by the gas heater. Then it is a fair way to calculate the savings for the other options with the follwing formula:

$$\%saving_{overall} = (\%saving_{heating} - \%savings_{reduceheating}) * (1 - \frac{Heat_{baseline}}{Heat_{product}}) \quad (5.16)$$

When the energy savings are determined the price of the products is next to be computed:

$$costs_{heating} = costs_{heating} * A + costs_{annual} * years \quad (5.17)$$

$$totalcosts_{heating} = costs_{product} - costs_{baselineproduct} \quad (5.18)$$

Refurbishment

The only difference between refurbishment and new build lies in the fact that people can choose their current product. Based on that decision it is impossible to select the other way of heating. I.e. if underfloor heating is chosen than it is impossible to select high wall heating as an option because it is rather expensive to change the whole system and hence not advised. Again for the refurbishment schools need to pay the full price for the product. There are no extra costs involved for refurbishment since these are considered minor compared to the total installation costs.

5.3.2 Cooling

As aformentioned the section for cooling and heating is more or less the same qua products. The only difference is that the gas heater is replace with standard air conditioner. This ensures that it is possible to use the COP as the parameter for comparison because all the products have now electricity as input energy. The tool automatically selects the same option for cooling as for heating. There is one exception tough, when the product for cooling cannot provide enough cooling it is possible to add air conditioner as extra cooling option. The energy savings for provide cooling are applied after the passive design options for reduce cooling and the other influences on cooling.

New build

Since cooling has a lot of similarties with heating the formulas are the same. In formula 5.16 the savings for heating are replaced with the savings for cooling and the useful heat is replaced with the COP. Together with the percentage of normals rooms this gives:

$$\%saving_{overall} = (\%saving_{cooling} - \%savings_{reducecooling}) * (1 - \frac{COP_{baseline}}{COP_{product}}) \quad (5.19)$$

Obviously no surcharge is counted for cooling when the same option is selected hence there are no formulas for the costs.

Refurbishment

What applies to new build for cooling also does for refurbishment. The formulas are almost the same as for the heating refurbishment case except there is no surcharge. There are no extra costs involved for refurbishment compared to new build since these are considered minor compared to the total installation costs.

5.4 Ventilation

Ventilation becomes one of the most important aspects of a building when it is very well-insulated and airtight. To ensure a good indoor environment, which highly affects performances of the people inside the building, a good ventilation system is required. There are two ways to provide fresh air for a building; mechanical ventilation and natural ventilation. The total energy that goes to ventilation is based on the energy end-use for ventilation of the corresponding school.

A distinction is made between two different type of rooms; normal rooms and special rooms. Normal rooms do not necessarily need mechanical ventilation whereas special rooms such as canteens and science labs always need mechanical ventilation because natural ventilation is not simply strong enough to comply with the Building Code. [22] Since every school has toilets and also toilets require mechanical ventilation this is already included in the energy savings and prices for normal rooms natural ventilation only.

5.4.1 Normal rooms

The baseline for normal rooms is a mechanical ventilation system. The other options are a mechincal ventilation system with Green Star rating, a system with options for both mechanical and natural ventilation, a system with both options where the mechanical ventilation part has a Green star rating and a natural ventilation only. For the options with both natural ventilation as well as mechanical ventilation users have to fill in another percentage. This is the percentage of the time throughout the year when natural ventilation is possible to properly ventilate the building. The energy savings for natural ventilation only apply for the time of the year when natural ventilation is possible. Since the Building Code only provides a required minimum amount of fresh air per time period for schools and not how this should be achieved this parameter cannot be used to calculate the energy savings. Therefore the energy savings are based on books and consultations with energy and ventilation experts. [4], [23], [24]

New build

The energy savings for natural ventilation and mechanical ventilation are straightforward and can be found in appendix D. Likewise the savings for the other options can be found in this section. However the they still need to be multiplied with the percentages of normal rooms. The energy savings formula for the option with both natural ventilation and mechanical ventilation is:

$$\begin{aligned} \%saving_{overall} = \%saving_{ventilation} * \%rooms_{normal} \\ *(\%time_{naturalventilation} * \%saving_{naturalventilation} \\ +(1 - \%time_{naturalventilation}) * \%saving_{mechanicalventilation}) \end{aligned} \tag{5.20}$$

After the energy savings the costs are next:

$$costs = costs_{product} * A * \%rooms_{normal} + costs_{annual} * years \tag{5.21}$$

$$totalcosts_{ventilation} = costs_{product} - costs_{baselineproduct} \tag{5.22}$$

Refurbishment

Refurbishment for ventilation is somewhat different than refurbishment for other sections. When users select a certain technolgy as baseline it is thereafter impossible to select a technolgy that performs worse than the selected technology due to simplicity. It is very hard to estimate the costs of replacing a ventilation system and it is not always needed to remove the old system hence the costs for the refurbishment case are the same as the costs for the new build case. The formulas 5.20, 5.21 and 5.22 are also used for the refurbishment case. The only difference with formula 5.22

is that the costs for the baseline are not substracted of the costs for the selected product.

5.4.2 Special rooms

The baseline for special rooms is ventilation is mechanical ventilation. Special rooms can be kitchens, science labs or acoustically sensitive rooms. The only other option is mechanical ventilation with Green Star rating because natural ventilation is not suitable for special rooms. The products displayed in the tool represent a 4 star Green Star rating which corresponds to a 25% energy saving compared with products without a Green Star rating. [4] For specials rooms this is the only energy saving that can be achieved. The costs are calculated in the same way as for normal rooms for both new build as well as refurbishment.

5.5 Hot water

Usually the energy that goes to hot water is a small part of the total energy consumption. It can still be useful to try reduce energy here though because hot water systems are not very expensive. Also for hot water the costs of useful heat of a system is the parameter on which the energy savings are based. Solar hot water is the only exception because it is unfair to compare the other systems with the costs of useful heat for solar hot water since the sun provides free and renewable energy. The energy savings for the solar hot water system are estimates from EECA based on the ability of the system over time to provide the required amount of hot water. [25] Sometimes this system fails because of the lack of sun light for example and a back-up system, an electric heater, needs to be used and no energy savings can then be achieved. The baseline option in this category is a gas heater just as for heating. This is only a baseline option and cannot be chosen since it uses a non renewable energy source.

5.5.1 New build

The energy savings for the products, except solar hot water, are calculated with the following formula:

$$\%saving_{overall} = \%saving_{hotwater} * (1 - \frac{Heat_{baseline}}{Heat_{product}}) \tag{5.23}$$

When the energy savings are determined the price of the products is next to be computed:

$$costs_{heating} = costs_{hotwater/L} * number_{pupils} * 5 + costs_{annual} * years \tag{5.24}$$

In formula 5.24 the costs and number of pupils are multiplied by 5 because that is the required amount of hot water per pupil. [26] The total price is as follows:

$$totalcosts_{heating} = costs_{product} - costs_{baselineproduct} \tag{5.25}$$

The costs for the two heat pumps are zero when either one is also chosen for heating the building. Of course this is not completely true because another system of tubes need to be installed. However it was impossible to estimate the extra costs involved in the extra tube system and therefore they are assumed zero. Users must be advised that this is not reality.

5.5.2 Refurbishment

There are no differences between the new build and refurbishment for hot water. The prices for refurbishment are the same as for new build since the costs of replacing a system with another are considered to be minor or it is not necessary to remove the old system.

5.6 Reduce lighting

There are multiple ways to ensure there is enough light in a classroom but first ways to reduce the required energy for lighting are discussed. Among these measures are skylights and sensors. The total energy that goes to lighting is determined with the energy end-use of the corresponding school.

5.6.1 Skylights

Skylights are a good way to harness natural light. Skylights influences also a lot of other energy aspects such as heating and cooling. The influences on those energy aspects are already discussed in the corresponding sections; 5.1.4 and 5.2.2. For New Zealand a 3% skylights-to-floor-ratio was apprehended. /citeGhobad The total energy for reduce lighting is the energy end-use for lighting for the corresponding school.

New build

Skylights are an optional addition for a building and therefore there is no baseline in this section. This gives a very easy formula for the overall energy savings:

$$\%saving_{overall} = \%saving_{lighting} * \%saving_{skylights} \tag{5.26}$$

When the energy savings are determined the price of the products is next to be computed.

$$costs_{skylights} = costs_{m^2} * A_{skylights} + costs_{annual} * years \tag{5.27}$$

Refurbishment

The formulas for the costs and energy savings are the same for refurbishment as for new build. If one of the skylights is chosen as baseline no more extra energy savings can be achieved. The extra costs to install skylights on an existing roof are \$129 per square meter. [14]

5.6.2 Sensors

The second measure to reduce lighting energy is the use of sensors. These sensors are occupancy/vacancy sensor to determine whether a room is occupied and a daylight sensor with dimming control to control the amount of lumen output of the artificial lights based on the amount of daylight. The total available energy is the energy end-use for lighting minus the eventual overall energy savings of skylights. Skylights are chosen first because they are part of passive design on contrast to sensors. The different energy savings for sensors can be found in appendix D.

New build

Also for sensors there is no baseline. This means that the formulas are very simular as seen above for skylights:

$$\%saving_{overall} = (\%saving_{lighting} - \%saving_{overallskylights}) * \%saving_{sensors} \tag{5.28}$$

When the energy savings are determined the price of the products is next to be computed.

$$costs_{sensors} = costs_{m^2} * A + costs_{annual} * years \tag{5.29}$$

Refurbishment

The only difference between the refurbishment case and the new build case is the extra cost factor to install sensors in an existing building. This extra cost factor is 1.1 for the costs per square meter. When as baseline one of the sensors option is chosen the recalculated available energy savings are:

$$\%saving_{overall} = (\%saving_{lighting} - \%saving_{overallskylights}) * (1 - \frac{\%saving_{baseline}}{\%saving_{product}}) \tag{5.30}$$

5.7 Provide lighting

When daylight is not enough to provide the required amount of light in a building artificial lighting comes in. There are 4 different ways of artifical lighting included in the tool. The total available energy savings for provide lighting are the energy end-use for lighting minus the eventual overall energy savings of the skylights section and minus the eventual overall savings of the sensors section. The parameter to determine how energy efficient a light is, is the luminous efficiency (LE). It equals the lumens of the lights divided by the watts that the light requires for this output. The energy savings are directly linked to this parameter.

5.7.1 New build

The baseline for lighting is incandescent. In New Zealand this is still the most common way of lighting nowadays. This gives the following formulas for the overall energy savings:

$$\%saving_{overall} = (\%saving_{lighting} - \%saving_{overallskylights} - \%saving_{overallsensors}) * (1 - \frac{LE_{baseline}}{LE_{product}}) \tag{5.31}$$

There is a distinction between two different types of rooms for lighting which affects the formula for the costs. Some rooms such as music rooms, gyms, textile craft rooms and labratories require a higher amount of lumens per square meter than a normal classroom. [27] The total required number of lights for the building is:

$$number_{lights} = \frac{\frac{\%rooms_{normal} * \frac{lumens_{normalrooms}}{m^2} * A}{LE_{product}} + \frac{\%rooms_{special} * \frac{lumens_{specialrooms}}{m^2} * A}{LE_{product}}}{lumen_{product}} \tag{5.32}$$

The total costs for the products iare determined with the following formulas.

$$costs_{lights} = costs_{lights/pc} * number_{lights} + costs_{annual} * years \tag{5.33}$$

$$totalcosts_{lights} = costs_{product} - costs_{baselineproduct} \tag{5.34}$$

5.7.2 Refurbishment

The difference for refurbishment and new build is that for refurbishment users need to pay the full price for lights and some extra costs for removing the old option. This removal cost factor is 1.1 applied to the costs for lights per piece.

5.8 Connectivity

This section aims to estimate the costs to connect every energy saving technology, if applicable. This ensures that there is one system which contains all the data of different sensors and subsequentely act on the input signals. For example close windows opened for natural ventilation when the temperature drops below a certain lower bound and then automatically turn on the central heating system.

A monitor & control system is a very important feature to keep track of energy consumption throughout a year. Overall it is a system that helps you to achieve all the energy savings. Extra energy savings, however, cannot be achieved by installing this system. The energy savings for monitor & control are already incorporated in the energy savings in the previous energy savings technologies.

5.8.1 New build

Naturally there is no baseline for this section. This gives the following formula to calculate the costs:

$$costs_{connectivity} = costs_{m^2} * A + costs_{annual} * years \tag{5.35}$$

5.8.2 Refurbishment

The only difference between the two different project cases is the costs to install the system. The costs for installing a monitor & control system in an existing building are 10% higher than for a new building.

Chapter 6

Data energy generating sheet

In this chapter all the different energy generating technologies will be presented. Two technolgies can actually be chosen in the tool; wind turbines and solar panels. These technologies will be addressed first. Two different groups of parameters are involved with these technologies. The cost parameters and the energy parameters. Both will be justified per category as in the chapter 5 for energy saving technologies. For the last two technolgies, biomass and hydro, only a short introduction is given. These technologies are less suitable for the average school. Remarks about every category can be found in appendix F as well as some general remarks and assumptions about this section. These could be remarks about disregarded products or recommendations about the category.

6.1 Wind turbines

Since the focus of the wind turbines industry is either around large commerical wind farms or small wind turbines for dwellings medium wind turbines for school projects are a long way off the current market. Nevertheless wind turbines are being seen as the ideal energy generating technology for a showcase purpose. This means raise awareness by students for the current energy problem. Nowadays for a feasbile wind turbine the average wind speed must be higher than 7m/s, which is only the case in the Wellington region, Stewart Island and Northland. To produce some energy, however, an average wind speed of 2.5 m/s is sufficient. For the regions with an average wind speed between 2.5 and 7 m/s the wind turbine is seen as a good showcase energy generating technology. The prices for the different wind turbines are determined after consulting with Technico Site Services, a company which specializes in wind turbines. [28]

6.1.1 Calculations

The calculation for wind turbines consists of three different parts. First the energy requirement per month for the wind turbines needs to be calculated. Then based on the average windspeed of a region, the number of required wind turbines can be computed and the total cost can subsequentely be calculated.

The total energy required per month is simply the average monthly energy usage after applying all the chosen energy saving technologies converted to kW multiplied with a desired percentage for wind turbines. It is possible for users to adjust this percentage to their preferences. However it is advised to use as many solar panels as possible especially with an average wind speed below 7 m/s. Based on the ratio between the average wind speed to the rated speed of the wind turbine the actual output power is determined. The rated speed is the average wind speed at which the wind turbine is able to produce the displayed output power. Although it is not completely true, it is assumed that this relation is linear due to simplicity:

$$power_{actual} = \frac{windspeed_{average}}{ratedspeed} * power_{ratedspeed} \tag{6.1}$$

The number of wind turbines is then simply the energy requirement for wind turbines divided by the actual power of the different wind turbines. An adverse property of wind turbines is that the performance over time degrades. The average degrade factor for wind turbines is considered 1.6% per year. [29] This means that every year the actual power output is 1.6% less. To ensure that schools produce enough energy on-site the required number of wind turbines over 10 years is calculated. This means that from the start on the wind turbines harness more energy than needed but when looking at a time period of 20 years more or less the total requirement of energy is generated by the wind turbines.

$$number_{windturbines} = \frac{\%energy_{windturbines} * energy_{required} * (1 + n^{10}_{windturbines})}{power_{actual}} \tag{6.2}$$

In formula 6.2 n is the degrade factor. The total costs for wind turbines consist of an installation cost and the cost per turbine:

$$cost_{total} = number_{windturbines} * (cost_{installation} + cost_{windturbine}) \tag{6.3}$$

6.2 Solar panels

Solar panels are considered as the best option to harness renewable energy nowadays. Since the market is constantly developing the prices have dropped considerabe over the last past years making it a very interesting and inexpensive oppertunity for schools. There are different types of panels available but the monocrystalline are considered the best cost effective option. The calculations in the tool for solar panels are based on an average price and power output based on two monocrystalline solar panels. These two panels are from different manufacturers and are widely used in New Zealand for school projects. The estimated prices for solar panels are determined after consulting with Solar City, a company that specializes in solar panels systems for New Zealand education buildings. [30]

6.2.1 Calculations

It is impossible for users to select a type of solar panels since an average is calculated for solar panels. The outcome for solar panels should be treated as an average for area, number of panels and price. The calculations for solar panels consist of the same three parts as for wind turbines. First the total size for solar panels needs to be determined, then the number of solar panels and total costs can be calculated. The total size in kW is simply the total energy requirement minus the power output of the wind turbines. Also the solar panels have a degrade factor. The degrade factor for this type of solar panels is 0.8

$$totalarea_{solarpanels} = \frac{\%energy_{solarpanels} * energy_{required} * (1 + degradefactor^{10}_{solarpanels})}{\%_{efficiency} * radiation} \tag{6.4}$$

$$number_{solarpanels} = \frac{totalarea_{solarpanels}}{area_{panels}} \tag{6.5}$$

The formula for the total cost is somewhat different then for wind turbines. It is based on the size of the solar panels:

$$cost_{total} = \begin{cases} \$2.2 * W & \text{if total system size} < 30kW \\ \$2 * W & \text{if } 30kW \leq \text{total system size} < 100kW \\ \$1.8 * W & \text{if } 100kW \leq \text{total system size} \end{cases} \tag{6.6}$$

Chapter 7

Data output sheet

The output sheet is arguably the most important sheet for decision makers. It displays financial and energy parameters and aids the users in determining the feasibility of their project. It is up to the user of the tool to decide whether the project is achieveable. The tool only gives certain estimated outcomes but no further advise regarding the continuation of the project. After using the tool the users can confer about the outcomes and the selected energy technologies with an architect to discuss the follow-up of the project. Again, it should be noted that the outcomes of the tool are averages and hence might differ from the actual costs, energy savings and so on. The outcomes can be used as a rough estimate and guideline for further developing the project during the design phase.

7.1 Output parameters

There are three different types of output parameters; financial parameters, energy savings parameters and energy generating parameters. The selected energy saving technologies are omitted on this sheet due to clarity. The output parameters are discussed in the same sequence as they are presented in the tool.

7.1.1 Total costs

The total costs of the project cannot be lacking on this sheet since every decision for a school boards is based on money. The total costs are simply the initial investments required to install both the selected energy saving technologies as well as the selected energy generating technologies.

7.1.2 Savings per year

The total savings per year in terms of money only include the savings achieved by saving electricity. Other eventual savings such as lower maintenance costs are excluded because they were only calculated for the heating and cooling category. The savings per year are based on the price for 1 kWh electricity in the year 2015. Assuming that the price continue to rise, which is the trend, the savings in the future can become even higher. [31] It should be noted that inflation is not taken into consideration in the tool.

7.1.3 Energy savings per year

Instead of presenting the energy savings per month the energy savings per year are more interesting to decision makers to be able to plan for the long-term. The energy savings are in kWh to give decision makers an actual idea what is possible.

7.1.4 Energy outcomes

The energy outcomes include the size of solar panels and wind turbines as well as the number of solar panels and wind turbines. Although these paramters were already presented on the previous sheet, they are displayed again to give a clear overview. As aformentioned the selected energy saving technologies are missing on this sheet. There are simply too many technologies to display and the sheet would become unclear.

7.1.5 Payback period

As the total costs display just an amount of money, the payback period also provides a financial analysis of the project. This tells more about the project than just the total costs and based on these parameters an educated and informed choice can be made whether the project is viable. The payback period is one of the simplest financial analysis there is available and provides therefore only a rough indication:

$$P = \frac{C}{S} \tag{7.1}$$

In this equation C are the costs and S are the savings per year. Since the payback period is a very simple analysis it has its flaws. The weakness of the payback period is that it does not consider the time value of money. A dollar today is worth more than a dollar tomorrow or in a year.

7.1.6 NPV

The NPV of the project, however, does consider the time value of money because it incoporates interest in its calculation. The time value of money is very important for decision makers since it tells something about the present value of the project. If this value is positive or minimal zero it could be a viable project for schools since they do not need to make profit and only want to cover their expenses. The formula for the NPV is:

$$NPV = \sum_{t=0}^{n} \left(\frac{S_t}{(1+d)^t}\right) - I \tag{7.2}$$

In the formula d is the discount rate of the project, S the savings per year and I the investment at the start of the project. The chosen discount rate is based on recommendation from the government for buildings with a single use. It is 7%. [32].

In the tool is opted for a time period of 20 years because this is the lifespan of most of the energy technologies. After 20 years some products need to be replaced and this means new installation costs. It hugly affects the calculation for the NPV value and makes it more complex since future investments in renewing products also should be considered and so on. A second reason to choose for a 20 year period is the nature of the tool. It provides a rough estimation for the project and has to keep its simplicity. Users must keep this in mind when evaluating the outcomes of the tool because the NPV would almost always be negative for this period of time. Another time period can be the expected building life, which can easily be 50 years or more. Obviously the NPV could be calculated per different energy category as well to see where the most interesting options lie and to see which category causes the losses.

Another way to determine the feasibility of the project is to compare the NPV of the project with other NPV values of NZEB prjects. It is best to consider the NPV value of NZEB per square meter of the building to be able to make a fair comparison to other buildings of different sizes. Also the total costs per square meter of the project may be compared to the NPV per square meter to see how viable the project is.

Chapter 8

Other sheets

Besides the sheets with the input and output of the tool a couple other sheets are important as well. These sheets aim to raise awareness about the energy problem or display important information about the tool.

8.1 Tips

The tips sheet is divided in four sections. The first section explains the different energy ratings for equipment within a building as well as the building itself. Also how to improve human behavior and how to manage the energy usage are dealt with on this sheet. The last two sections address where and how it is possible to apply for funding and that it is possible to sell the abundance of energy, if applicable.

It is important to mention why the savings for electrical devices are mentioned on the tips sheet and are not included in the calculations of the tool. It is chosen to exclude the savings for electrical devices in the tool because of two reasons. The first reason is that it is impossible to calculate the exact energy savings because the used electrical devices differ too much per school. Simply use an average would not result in a realistic representation of the available energy savings. The second reason is the price for new devices. There are simply too many different devices to give an estimation about the average price for new electrical devices.

8.2 Technology inventory

The technology inventory is one of the most important sheets of the tool. It aims to improve the knowledge of people about the energy saving and energy generating technologies in the tool. For every technology information is presented to aid users in making a decision between several products within a technology but also general information about the technology is presented.

8.3 Data

The last sheet in the tool to mention is the data sheet. It is an important sheet for the tool itself but of less importantance for users. However when users are interested to see how the outputs are calculated they are free to visit the data sheet.

Chapter 9

Reflective

This chapter includes some experiences during my work as intern but also some comments about the work I have done.

Due to the nature of the tool as a pre-assessment tool it was very hard to gather usable knowledge from professionals. Kate & Michelle already mentioned this during our meetings but most people contacted from different companies did not respond at all or were unwilling or unable to give information. This was caused by two reasons. The first and most important reason is money. It was impossible for them and their companies to earn any money with it and hence they were not interested. The second reason was that the aim of the tool was to present a big picture and rough estimates. People in companies, however, were used to calculate and estimate specific cases. Only people from non-profit organizations such as Branz were very interested in the tool especially because of its nature.

During the last part of the my internship it was the intention to get user feedback from boards of schools who are actually interested in developing a NZEB. The interested schools were contacted by the Ministry of Education. Due to the bureaucracy on the Minsitry of Education it was impossible to get some real user feedback of interested schools. In the last part of the internship a last try to get in contact with some schools failed because non of the contacted school gave a response or were interested.

Despite the problems to get in touch with schools a demo was given to people from the sustainability office of the Auckland City Council to show a first impression of the tool. They were interested in the further development of the tool into an online tool and also had some great ideas about the tool. It was a useful experience for me to give a demo and get some feedback about the tool and useful information about schools.

Chapter 10

Conclusions and recommendations

10.1 Conclusions

It can be concluded that there are a lot of different energy saving technologies available and that selecting the optimal solution is highly dependent on the location and situation of a school. This tool aims to provide some guidance for decision makers to select a combination of technologies to achieve a NZEB or perhaps something close. It was developed with the needs of decision makers without any engineering knowlegde in mind. This is the reason that there are only simple inputs and outputs and extra sheets to enhance their knowledge about energy saving and energy generating technologies as well as tips to reduce energy usage in buildings by changing human behavior.

It is hard to draw other conclusions about the tool because of the following three reasons. The first reason is that the tool is not completely developed yet and therefore never used. Hence there are not results available to show accuracy or users who can say if the tool was useful for them. The second reason is that it was impossible to visit school to get user feedback about just the functionality of the tool and draw some conclusions from the feedback. The last reason is that it is hard to test the tool on existing NZEBs in New Zealand for accuracy because there is currently only one school in New Zealand which has a NZEB. A lot of parameters about this school are unknown, which makes it hard to give a proper overview.

10.2 Future developments

Beside the recommendations about the content of the tool, which can be found in the chapters per category. There are some other, more general plans for the tool in the future. Therefore in this section some future developments instead of general recommendations are elucidated.

Even tough a lot of people have experience with Excel it would be convenient when the tool becomes available online. The tool can easily be evolved in an online tool. The different sheets can be pages of a website. Users can save their progress online and it is easier to keep track of the actual users and their result, if they are willing to accept that their results are saved. The results of the tool can then be compared to the actual results.

It is possible to publish the tool online as an open source project. People from all over the world can add climate data of their countries to create a tool that can be used throughout the world. It is also possible to use different estimates for energy savings and costs per country, if they are known, to increase the accuracy. A second advantage is that the estimates in the tool can be verified and validated by other people in this field to further improve the accuracy.

Involving architects in the development of the tool could be beneficial, especially when they have experience in designing a NZEB. They can check the tool and give feedback about it. In return they can advertise in the tool. This is beneficial for users of the tool as well because they can get in touch with the right people.

The functionality of the tool can be further improved with user feedback. Although it was impossible at the last stage of the internship to visit some schools it is still advised to get feedback. Users can give tips about, for example, inputs they do not know or are to hard to measure or outputs that they think are lacking. Also some feedback about the functionality of the tool would be welcome. Questions as; is it easy to use, is it easy to browse through the tool and so on.

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Appendix A

Pictures of the tool

In appendix A the sheets of the tool are depicted to give an idea about the appearance and structure of the tool. The sheets are depicted in the order of the userflow.

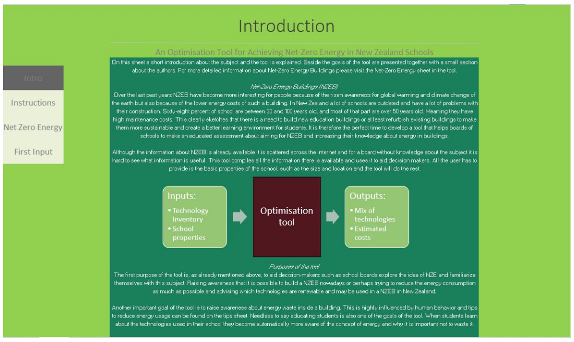

Figure A.1: Intro sheet

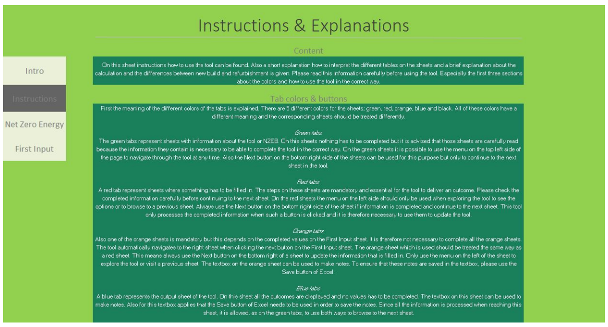

Figure A.2: Instructions sheet

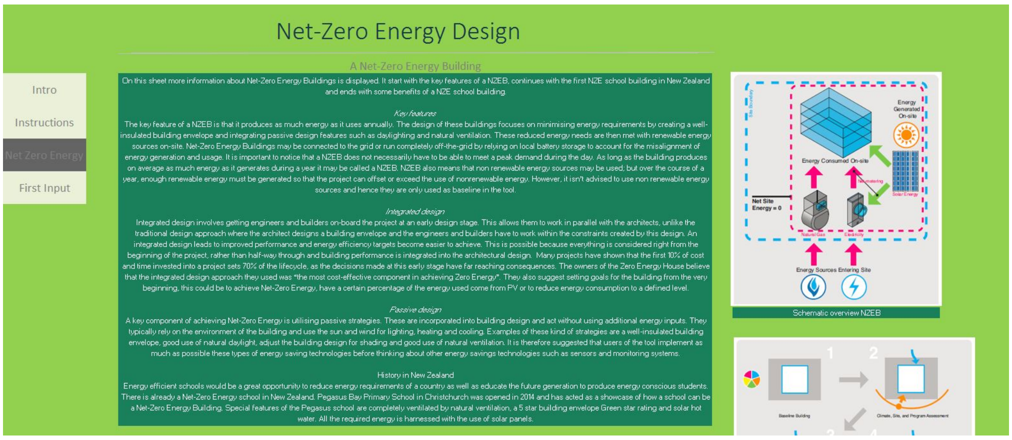

Figure A.3: Net-Zero Energy sheet

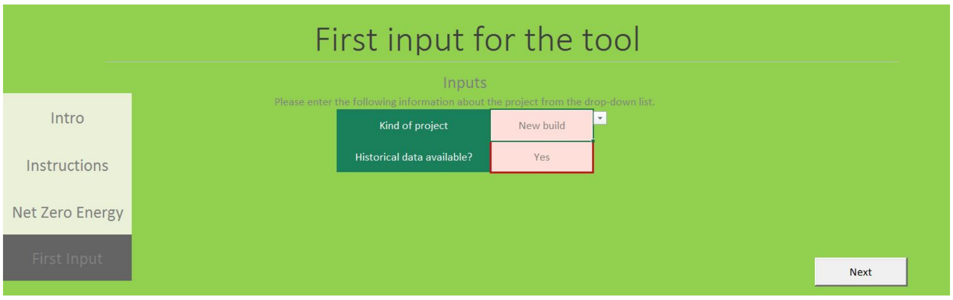

Figure A.4: First Input sheet

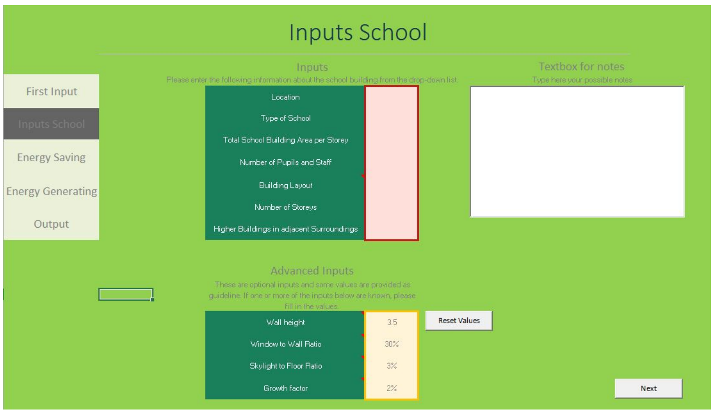

Figure A.5: New build no data sheet

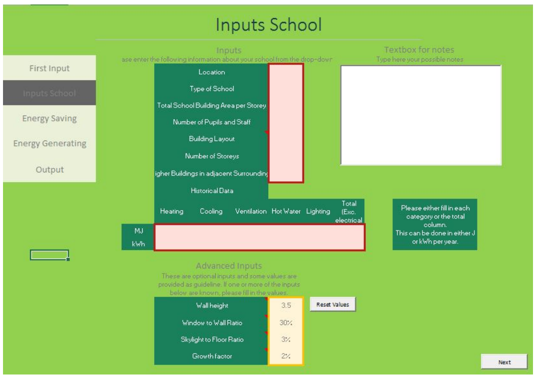

Figure A.6: New build data sheet

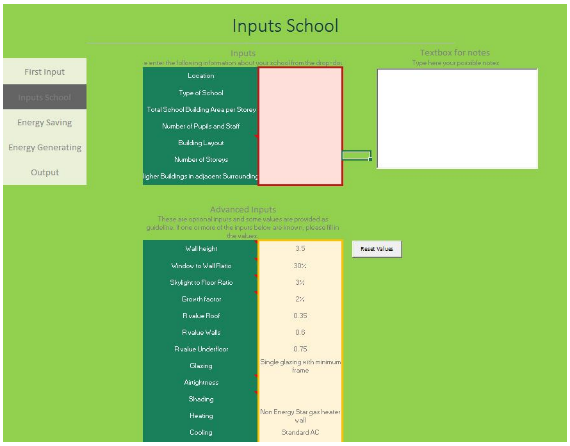

Figure A.7: Refurbishment no data sheet

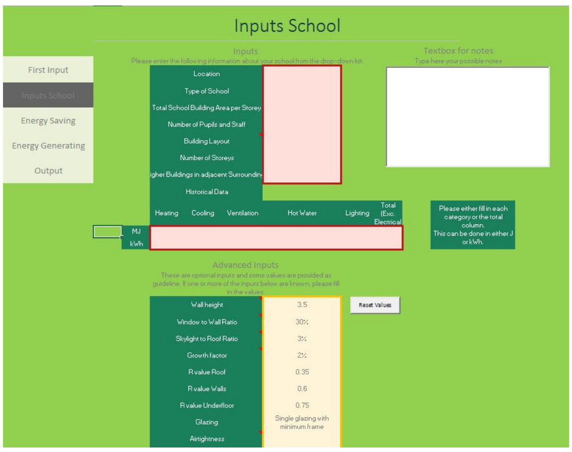

Figure A.8: Refurbishment data sheet

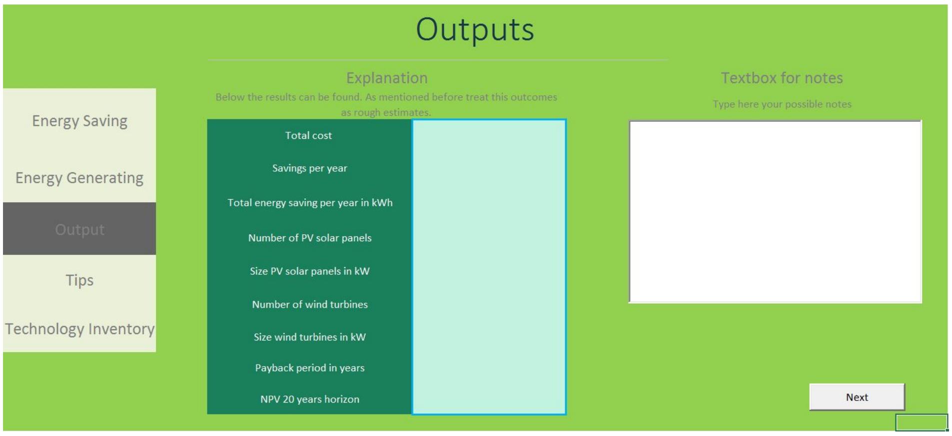

Figure A.9: Output sheet

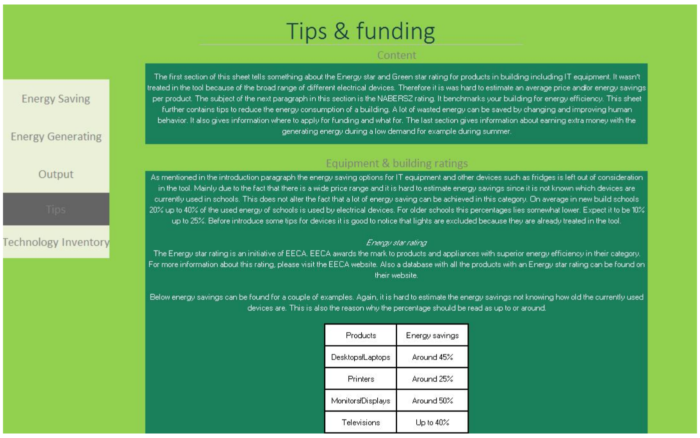

Figure A.10: Tips sheet

Figure A.11: Technology inventory sheet

Appendix B

Pictures of the first version of the tool

In appendix B the sheets of the last version of the tool of my predecessors are depicted to give an idea about the appearance and structure of the tool. The sheets are depicted in the order of the userflow.

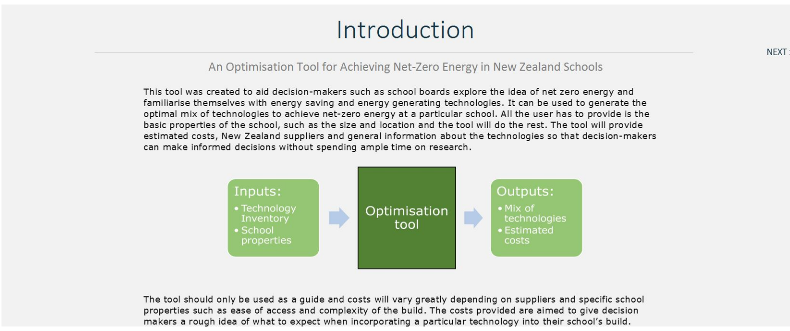

Figure B.1: Intro sheet

Figure B.2: Net-Zero Energy sheet

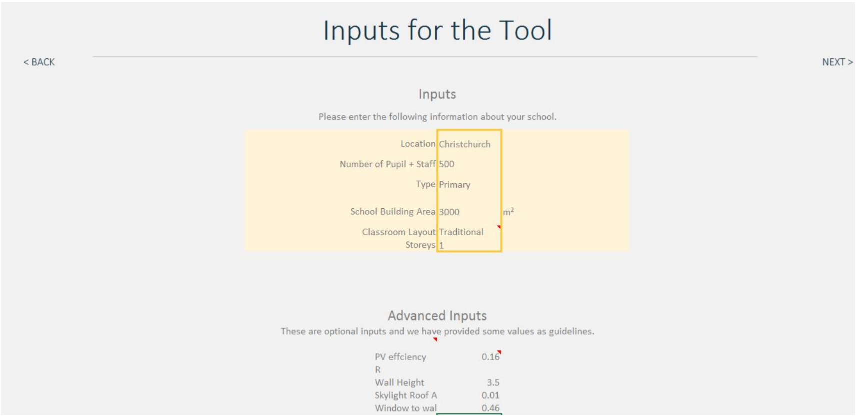

Figure B.3: IInput sheet

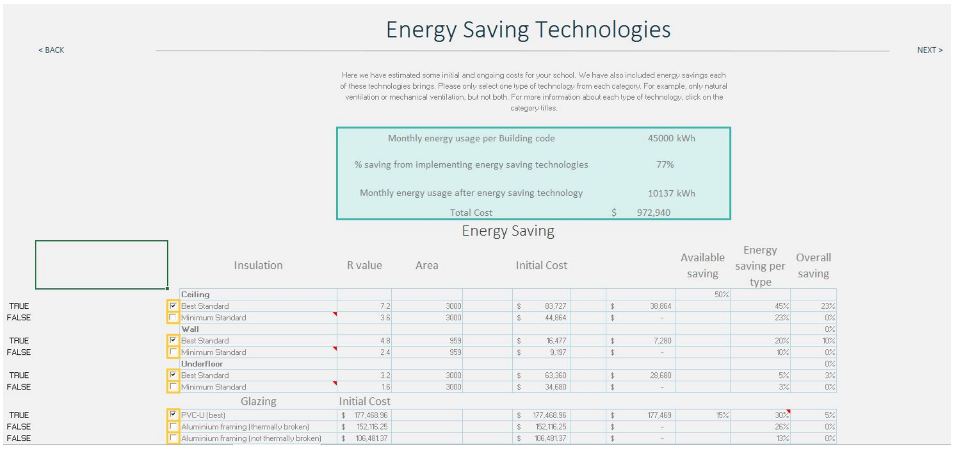

Figure B.4: Energy saving sheet

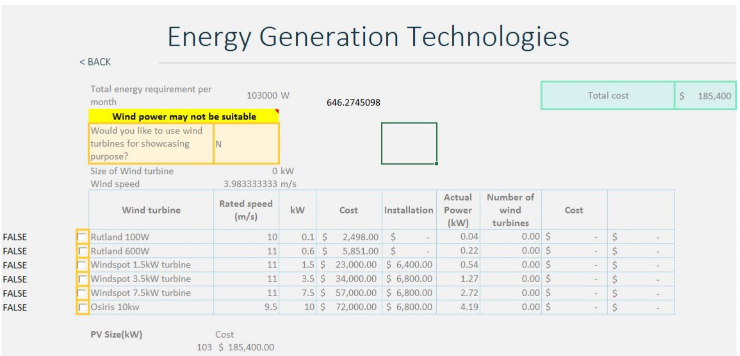

Figure B.5: Energy generating sheet

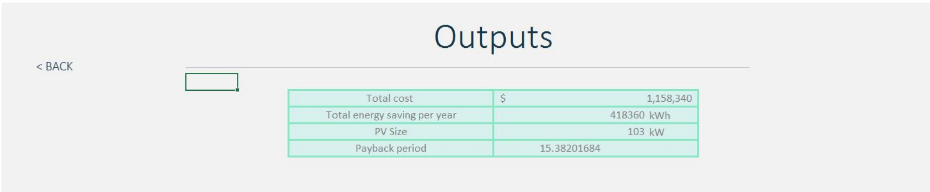

Figure B.6: Output sheet

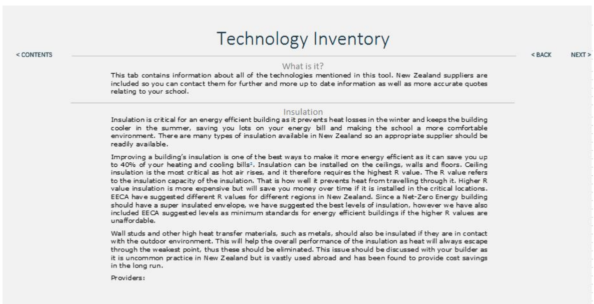

Figure B.7: ITechnology inventory sheet

Appendix C

Pictures of climate zones

In this appendix maps of the different climate zones for New Zealand are depicted below:

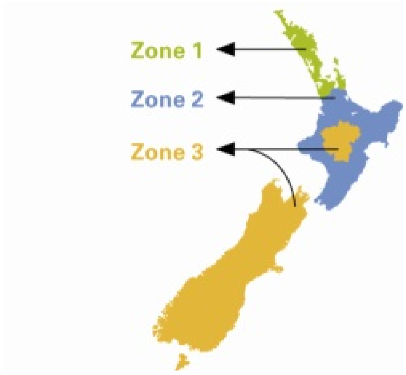

Figure C.1: Three different insulation zones New Zealand

Figure C.2: Two different climate zones New Zealand

Appendix D

Products in tool

In this appendix a list with products per category is presented.

D.1 Reduce heating

The products for roof insulation are:

	R value	
Product	Insulation zone 1 & 2	Insulation zone 3
Best Standard	9.6	10.8
Average Standard	6.4	7.2
Medium Standard	4.8	5.4
Minimum Standard	3.2	3.6

The price per R per square meter is \$5.7 for every insulation zone and is an average based on different products. [33] The products for wall insulation are:

	R value	
Product	Insulation zone 1 & 2	Insulation zone 3
Best Standard	6.6	7.2
Average Standard	4.4	4.8
Medium Standard	3.3	3.6
Minimum Standard	2.2	2.4

The price per R per square meter is \$8.7 for every insulation zone and is an average based on different products. [33] The products for floor insulation are:

Product	R value Insulation zone 1 & 2	Insulation zone 3
Best Standard	4.8	4.8
Average Standard	3.2	3.2
Medium Standard	2.4	2.4
Minimum Standard	1.6	1.6

The price per R per square meter is $16.1 for every insulation zone and is an average based on different products. [33] The minimum standard for new build for insulation complies to the Building Code. [34] The minimum standard for refurbishment can differ because users can change the provided values in advanced inputs. The prices for refurbishment are the same except for the floor. The price for the floor is $20.1 per R per square meter or 25% extra. The surcharge is counted because the floor of the building needs to be removed for installation.

The products for glazing are:

Product	R value	Percentage heat stopped	Price per m2
Clear/Low e glass Argon filled with best frame	0.53	30%	$735
Clear/Low e glass Air filled with best frame	0.48	55%	$691
Double glazing Air filled with best frame	0.36	26%	$578
Double glazing Air filled with medium frame	0.31	26%	$543
Double glazing Air filled with minimum frame	0.26	26%	$509

Also the minimum frame for new build for glazing complies to the Building Code. [34]. The R values and values for heat stopped for the different glazing products can be accessed on the website of Branz. /citeBranzvalues The prices are, again, from Rawlinsons. [33] The prices for refurbishment are $100 per square meter higher than for the new build case. This is based on the price difference between replacing a window and a new window in SPON'S Architects and Builders Price Book. [14]

The products for airtightness are:

Product	Price
Membrame	$8.7 per m2
Connection strips	$7.5 per m
Tape for sealing overlaps	$2.1 per m

A combination of the three products gives an energy saving of 15%. This is a modified percentage of the savings found in [15]. The prices are from Pro Clima. [35]

D.2 Reduce cooling

The products for shading are:

Product	Price	Energy Savings
Exterior louvres	$602 per m2	50%
Retractable awnings	$452 per pc	40%
Building overhangs	$-	30%
Interior blinds	$73 per m2	20%

The prices are from Rawlinsons. [33] The energy savings are modified values from the following articles; for louvres [18] , for awnings [**?**], for overhangs [16] and for blinds [**?**]. The prices are the same for both new build as well as refurbishment.

D.3 Provide Heating

Product	COP	Price useful heat	Initial costs per m2	Annual costs per m2
Geothermal HP Underfloor	5	$5.8	$262	$4.3
Geothermal HP Wall	5	$5.8	$291	$5
Air HP Underfloor	3.5	$8.3	$167	$3.7
Air HP Wall	3.5	$8.3	$196	$4.4
Gas boiler Underfloor	0.85	$21	$111	$5.8
Gas boiler Wall	0.85	$21	$127	$6.8

Above the products for provide heating are displayed. The prices are based on the Pegasus School case, which was designed by Jasmax [36]. The calculations for the costs were executed by the WSP group. [4] The prices are the same for both new build as well as refurbishment.

D.4 Provide Cooling

This section is more or less the same as section D.3. The only difference is the addition Standard AC wall for cooling. The prices for this cooling unit is $50 per square meter without any annual costs because they were impossible to estimate. This price is based on estimations of an estimator who works at Aquaheat [24].

D.5 Ventilation

The products for ventilation are:

Product	Price per m2	Savings natural ventilation	Savings mechanical ventilation
NR natural ventilation	$275	90%	-
NR both with Greenstar	$600	90%	25%
NR both without Greenstar	$525	90%	0%
NR mechanical ventilation with Greenstar	$500	-	25%
NR mechanical ventilation without Greenstar	$425	-	0%
SR with Greenstar	$700	-	25%
SR without Greenstar	$625	-	0%

In the table D.5 NR is short for normal rooms and SR is short for special room. The prices are based on correspondence with an estimator from Aquaheat and are the same for refurbishment. The energy savings for natural ventilation are modified energy savings from [23]. The savings for the Greenstar rating products are based on correspondence with WSP group. [4]

D.6 Hot Water

In paragraph D.3 is already dealt with some products for hot water. No surcharge is counted when these products are also used for heating. Only the new products are depicted in the table below:

Product	COP	Price useful heat	Initial costs per L	Energy Savings
Solar hot water	-	-	$5.7	50%
Electric heater	1	$28	$7.4	-33%
Gas heater	0.85	$21	$10.5	0%

The savings for solar hot water are based on numbers provided by EECA on their website. [25]. The prices are from Rawlinsons. [33] The prices are the same for the refurbishment case.

D.7 Reduce Lighting

First the different products for skylights are dealt with in this paragraph:

Product	R value	Initial costs per m2	Energy Savings
Fixed skylights	0.53	$1434	50%
Manually opened skylights	0.53	$1548	50%
Automatic opened skylights	0.5	$2241	50%

The prices are based on Rawlinsons. [33] The energy savings of the skylights are based on this article; [9]. The price for refurbishment is $129 higher per installed skylight and is independent of the chosen product. [33]

The following category of products in reduce lighting are the sensors:

Product	Initial costs per m2	Energy Savings
Occupancy sensor	$1.64	40%
Daylight sensor	$1.94	40%
Products above + scheduling & control	$5.19	70%

The prices for the sensors are from Amazon. [37]. The costs for installation are calculated with a factor, which is 10% of the cost per square meter. The prices for refurbishment are calculated by multiplying the costs for new build with a refurbishment factor of 1.1. The savings are based on the following article; [38].

D.8 Provide Lighting

The products for lighting are:

Product	Luminous efficiency	Lifespan in hr	Price per m2
LED	90	15000	$12.66
CFL T2	60	6000	$4.51
Halogen	23	2000	$3.63
Incandescent	15	1000	$0.50

The prices are based on websites as [39]. The installation cost factor is 1.05 and the refurbishment cost factor is 1.1.

D.9 Monitor & Control

What is described as Monitor & Control are basically a lot of different products which are concerned with monitoring or controlling the energy usage in a building. The prices are from EvidentConnect [40] and based on a correspondence with one of their employees. The refurbishment factor is, again, 1.1. There are no extra savings that can be achieved in this category.

D.10 Other influences

In this paragraph all the other influences together with the energy savings are displayed in the table below:

Technology	Influence on	Energy Savings	Source
Insulation	Cooling	10%	[19]
Skylights	Cooling	8%	[9]
Solar panels	Cooling	15%	[20]
Natural ventilation	Cooling	25%	[21]

In the tool also the influence of lights on heating and cooling energy is added as an influence. Unfortunately it was impossible to accuractely estimate the influence of the lights on heating and cooling. Therefore these influences are disregarded.

Appendix E

Remarks energy savings categories

Some remarks per energy saving or energy generating category can be found in this appendix. They deal with aspects that are disregarded in the tool and an explanation is given why they are disregarded or tell something about the reasoning of the calculations.

E.1 Insulation

The products in the tool used to insulate a building are just the most common way of insulation namely glass wool. Of course there are more techniques to insulate a building.

In the tool only interior insulation is an option. Obviously also exterior insulation, such as cladding and vegetation, can be installed to ensure better insulation of the building envelope. It is recommended that these options will be added in the tool in a later stadium. A very promising new technique, VIP, vacuum insulated panels, was during this research not available in New Zealand but should be added as well when it becomes available.

Important to mention is the use of the R value instead of the LTTR value in the tool. The LTTR value is the R value of the product in the long-term. This could be the R value in 5 years but also 10 years depending on the kind of tests that are conducted. Since not a lot of research is conducted in this area and some manufactures state in their warranty that the thermal performance may be expected to remain the same for 50 years it is chosen to use the R value in the tool.

E.2 Glazing

Also for glazing there are some things left out of consideration in the calculations but they are nevertheless worth mentioning. It should be noted that because of simplicity only six different options are included in the tool. However there are a lot more possibilities possible. In fact every combination between a type of frame and a type of glazing is possible.

Secondary glazing is not discussed in the tool but is an option to enhance the insulation of windows. Instead of removing the window and replace it with a double glazed window a second glass is installed to achieve the same effect as double glazing. However the performances are considered inferior compared to real double glazing and hence it is disregarded in the tool.

The third aspect which is disregarded in the tool is the leaking of gas. This only concerns the Argon filled windows. On average 0.6% of the Argon leaks to the outside per year and is replaced with air. Therefore it is assumed that the thermal performance of the windows declines over time. This is not backed by scientific research so it it still unknown how exactly it influences the performance and hence it is not taken into account in the tool.

Besides Argon also Krypton and Xenon can be used as a gas to improve the thermal performance of glass. Krypton en Xenon are even a better insulators than Argon but come at a much higher price. Argon is the best cost-effective improvement and thus included in the tool.

The latest possibility for glazing is triple glazed windows. These windows enhance the thermal performance of windows even further than double glazing but they are not available in New Zealand nowadays.

E.3 Airtightness

The products that were disregarded in the tool are sealing boxes for light switches and sealing grommets for cables and pipes.

E.4 Other influences heating

The differences in heat gain by the amount of people in a building due to the growth are neglected. It was impossible to estimate the influence on the overall energy savings of this type of heat gain. The contribution to the overall savings are also considered minor.

There are two other energy savings technologies that influence the amount of energy required for heating. The type of lights that is present in a building and the eventual present skylights. Unfortunately the outcomes by different studies for the influence of the type of lights were not unambigous so it was decided to neglect this factor in the tool. It is recommended to implement this factor in the future though, when better studies are conducted because this factor can have a hugh influence on the heating energy.

E.5 Shading

One of the products that is not displayed in the tool is the option to create shade with vegetation. A couple of trees are suited to create the same effect as with building overhangs or eaves. This means in the summer the sun light is blocked by the trees to avoid extra cooling energy and during the winter sun light is allowed to shine on the building to reduce heating energy. An extra benefit of vegetation is that it absorbs carbon dioxide from the air and therefore reduces greenhouse gasses. Although this sounds as a promising product it is excluded from the tool because there might not always be space around a school building to plant enough trees and it is not part of the building itself. The latter aspect provides budgetting problems because it is unsure whether to include the costs for vegetation as extra costs towards an Net Zero Energy Building or as just costs for gardening.

Exterior louvres have an extra benefit. Exterior louvres are also capable of improving the light distribution of a room. This means that less artifical light is required for a sufficient amount of light in a room.

E.6 Other influences cooling

Again, also for other influences to reduce cooling energy the difference in heat gains by people is neglected for the same reasons as for heating. Heat gain of people affects the cooling energy in the summer as it does for heating energy in the winter.

The lights in a building also have an effect on the cooling energy. It is precisely the opposite effect on heating energy but unfortunately also for cooling energy the outcomes of experiments are ambigous so it was decided to neglect this factor in the tool.

E.7 Provide heating

It is important to mention that underfloor heating is the preferred way of heating a building. Underfloor heating provides a more consistent and even heat flow in a building, ensuring a better indoor environment which leads in its place to better performances of students. [2]

A couple of products are excluded from the tool but nevertheless worth mentioning. Electric heater can also be used to provide heat for a building. However they are only suited for small spaces and not for central heating and have a smaller COP than the heat pumps. A wood burner or biomass burner are options as well. The reasons to exclude them from the tool are respectively due to safety concerns and the lack of 'free' fuel for the latter option.

A gas heater is the baseline product for heating in the tool. However during a meeting with Andrew and Adam from the sustainability office of the Auckland Council came forward that coal burners are still widely used in New Zealand schools. Unfortunately time did not permits it to include this as a second baseline option in the tool. A last remark about this section is that it lacks a oppertunity for heat recovery which is discussed in more detail in section E.8.

E.8 Ventilation

In the tool the calculation for energy savings with a system capable of both natural and mechanical ventilation assumes that when natural ventilation is not possible the mechanical ventilation system takes over. However this is not always necessary if people are willing to accept the fact that natural ventilation does not always provides enough fresh air. When this is the case users should select the natural ventilation option. This is only possible when the cause of lack of enough ventilation is because it is a hot windless summer day. In other cases such as air pollution in the direct surroundings or high noises it is simply not possible to have natural ventilation and accept the circumstances. Then a mechanical ventilation system with filters is necessary. Users should carefully look into what applies to their building and surroundings and may consult an expert about their situation.

Ventilation together with hot water are the sections in which worse performing options are not displayed in the tool. Of course it is possible to display this options yet but due to very slow response of the Ministry of Education it was impossible to get user feedback on this aspect of the tool. In the future when it becomes clear which option users prefer this can be straigthen for the whole tool such that uniformity and more simplicity is achieved.

An option to further reduce the required energy is mechanical ventilation with heat recovery. Some of the heat waste is recovered to be used again to heat a building. It is excluded in the tool because it is hard to determine in which category this energy savings ought to be. Nevertheless users should choose a system when it is beneficial in terms of saving money.

Last but not least a remark about natural ventilation. Users are warned to only select natural ventilation when also very good insulation is installed and when it is combined with shading options. Due to the fact that natural ventilation needs openings in the building envelope the performance of reduce heating and cooling energy is highly influenced in a negative way by natural ventilation.

E.9 Hot water

A couple of important caveats regarding the energy savings and costs need to be addressed in this section. The first one is the difference in energy savings for solar hot water. It is assumed that the achievable energy savings are the same everywhere in New Zealand. However it is highly dependent on the climate. A very sunny climate is able to achieve higher energy savings than a cold climate. Therefore is should be noted that the energy savings can differ across different location in New Zealand even tough the climates in New Zealand does not differ very much.

The second remark that influences the costs is the assumption regarding the storage of hot water. All the storage of hot water takes place in the heaters. It is also possible to buy a storage tank to store extra hot water. This would be cheaper since the storage capacity of the heaters is limited and therefore you have to buy a heater just for storage in some cases. For the tool, however, it is impossible to determine the optimal sizes and amount of heaters in combination with storage tanks that would be required per different school and therefore it is left out of consideration.

Another important remark which needs to be touched on is the distance of the heating system and the point of use of hot water. Of course it is possible to insulate the hot water tubes but it is better to ensure this distance is minimized.

E.10 Skylights

It should be noted that the current energy savings are based on the optimal value for the skylight-area-to-floor-area-ratio in terms of overall energy savings. It is possible for users to change this ratio. They should keep in mind that this change also has consequences for the energy savings but this is not incorporated in the tool.

One of the products that is not included in the tool are so called sun tunnels. These are skylights especially designed for hard to reach areas. For the tool it was assumed that few school buildings have such troubles for rooms who require a lot of light. However if this is nonetheless the case it is possible to install a sun tunnel on the roof.

E.11 Sensors

More different combinations of sensors with different control programmes are possible but left out for simplicity. Itl is chosen to implement the most simple options; the two different sensors and the most comprehensive option and best energy saving option; the combination of both sensors with different control programmes.

E.12 Lighting

Extra annual costs are incorporated when a school needs to buy new lights. The lifespan of the different options for lighting is calculated based on the assumption that they are turned on 4 hours per day.

E.13 General remarks

An assumption that is made for all the energy saving categories is proper installation and maintanance throughout the period that the technology is used. In this way all the displayed lifespans are achieveable. The lifespans displayed in the tool are all minimum lifespans. For some products the actual lifespan may be longer. 20 years is still displayed as lifespan because it is used as time period in the NPV calculation.

A decline factor is added to the tool for energy savings technologies, however, it is not used for most categories. Some products simply do not have a declination in performance over time but for other products it is unsure whether they have the same performances over time, for example heat pumps. When more information becomes available the corresponding decline factors can be adjusted.

It was hard to estimate the extra costs for the refurbishment case. I.e. how much does it cost to remove the old product for a building. It is chosen to set the factor for refurbishment cost for all the unknown costs on 1.1. When testing shows that it is an unaccurate number it can easily be changed in the tool. The same holds for installation costs when they are not incorporated in the price already.

Appendix F

Remarks energy generating categories

This is the same appendix as Appendix E is for the energy saving categories.

F.1 Wind turbines

The relation between the rated speed and the average wind speed to compute the acutal power output is not linear. All manufacturers provide graphs on their website to exactly determine the output per wind speed. If a more accurate output power is required, this graph is the way to determine it. The graph is based on different tests with the windturbines in a wind tunnel.

When schools are interested in installing a wind turbine for showcasing purpose it is advised to install as less wind turbines as possible. This is due to the fact that solar panels are simply more efficient to harness renewable energy. Just select the smallest wind turbine and order one of that type.

F.2 Biomass

Biomass is one of the energy generating technologies which is only briefly described in the tool. It could be a feasible way to produce renewable energy but only for a couple of schools. Since a biomass boiler does not have a good showcasing purpose it is left out of consideration. Tips to make a biomass boiler feasible for a school and some estimates about the price can be found on the Energy Generating sheet.

F.3 Hydro

Hydro energy is even less likely to produce enough energy for the average school but since it is one of the most common ways to generate renewable energy in New Zealand it is nevertheless mentioned. The conditions for hydro energy can be found on the Energy Generating sheet.