Czech Technical University in Prague

Faculty of Civil Engineering

Department of Building Structures

Numbulwar health centre – development of a sustainable building concept

Master's thesis

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Study program: Buildings and Environment

Field of study: Buildings and Environment

Supervisor: Ing. Jan Růžička, Ph.D.

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Declaration

I hereby declare that this thesis is my own work and that all the sources of information I have used are listed in the references.

Prague, January 6, 2019

……………………………..

Ema Škarecká

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I would like to thank my supervisor, Ing. Jan Růžička, Ph.D., for his guidance throughout the writing process, his time and advice. I would also like to thank my Australian supervisor Dr Steve Burroughs for giving me the inspiration to write this thesis. I would like to thank my family for the support throughout my studies.

Abstrakt

Tato diplomová práce se zabývá návrhem udržitelné kliniky v odlehlé části Austrálie, ve které hrají hlavní roli klimatické podmínky. Stěžejní myšlenkou je implementace přírodního materiálu, konkrétně Compressed Earth Blocks, namísto běžně užívaného materiálu v této oblasti. Součástí práce je provedení environmentální analýzy založené na návrhu nového konstrukčního a materiálového řešení, který bude porovnán se stávající budovou. Aby bylo zjištěno, zda je konstrukce z CEB vhodná do tohoto klimatu, bude provedena energetická analýza, konkrétně letní tepelná stabilita. Rozhodujícím faktorem pro nově navrženou budovu bude roční spotřeba energie spolu s provedenou environmentální analýzou. Pro vybrané konstrukční varianty bude proveden zjednodušený životní cyklus, na jehož základě bude vyhodnoceno použití CEB.

Klíčová slova

Austrálie, klinika, klima, udržitelnost, CEB, letní tepelná stabilita, energetický koncept

Abstract

This diploma thesis deals with the design of a sustainable health centre in the remote part of Australia, where climatic conditions play the main role. Instead of commonly used materials in this area, the idea is the implementation of natural materials in the form of Compressed Earth Blocks. Part of the work is to carry out an environmental analysis based on the design of new structural variants of CEB, which will be compared to the current building. To determine whether the CEB structure is suitable for this climate, an energetic analysis, particularly thermal stability analysis, will be done. Based on the results, the decisive factor will be the annual energy consumption of the clinic together with the undertaken environmental analysis. To evaluate the incorporation of CEB into the structure, a very broad life cycle analysis of the chosen options will be executed.

Keywords

Australia, health centre, climate, sustainability, CEB, thermal stability, energy concept

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1. Aim

The main goal of this thesis is to find an environmental and energy efficient solution for a remote health clinic in Northern Territory, Australia. The idea is the implementation of natural materials instead of commonly used materials in this environment. While typical houses in this climate zone are made of the light steel wall frame, the work focuses on the application of Compressed Earth Blocks. Not only is it a better solution from the environmental point of view, but the social part plays the role as well. The clinic is located in a country of Northern Territory, where aboriginal communities reside. The construction of the clinic could be erected by them while strengthening the community and learning new things among them. By implementing natural material into the structure, production of CO_2 will be reduced, indoor air quality will be improved, the community will be brought together, and financial expenses will be lower. By doing so, the triple bottom line will be incorporated into the whole project. This thesis focuses mainly on the environmental part of the triple bottom line. [1]

Together with finding an environmentally friendly option for the structure, operation of the building will be assessed in order to improve the overall energy consumption and to find an energy efficient solution. The whole design of the clinic will much depend on climatic conditions as this area of Australia has a high demand on effective cooling throughout the year. Part of the energetic analysis is an assessment of the thermal stability of how the building behaves in summer months when a risk of overheating occurs. All structural variants will be compared to the current building to see how various types of wall composition influence the indoor environment. By selecting the best option, a concept of ventilation and cooling will be designed.

In order to find the most suitable construction, a few options of wall composition will be created to determine which one improves the indoor environment of the clinic, has the lowest annual energy consumption and the lowest environmental impact. The chosen options will be assessed in a very broad life cycle analysis.

[1] Triple bottom line - an accounting framework that incorporates three dimensions of performance: social, environmental and financial. The TBL dimensions are also commonly called the three Ps: people, planet and profits [1].

2. Wider context

This diploma thesis deals with a design of the health centre in a village in Northern Territory, Australia. The decisive factor is the local climatic conditions and material composition of the structure, on which operation of the building depends. Sustainability is brought to the project by implementing natural material and finding an energy efficient solution for the building.

The reason I have chosen this topic for my diploma thesis is mainly because I have always been interested in Australia. I wanted to find out more about this country, especially the culture and nature and that is why I have spent one semester on study exchange in Melbourne, Australia. I had the chance to try the educational system, but also meet the culture and experience real Australia through travelling the country. During my studies abroad, study exchange program has incorporated the courses of sustainable constructions which helped me to better understand how important the term sustainability is. By taking these courses, my interest in sustainability has increased and I started to participate in projects with a sustainable background.

The main idea is to design a sustainable building, and therefore the meaning of sustainability must be explained. The most famous definition of sustainability comes from Our Common Future, known as the Brundtland Report: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."* [2].

These days, the problematics of climate change is crucial as the temperature slowly rises and may have fatal consequences for the planet Earth. That is why sustainability became part of our lives, because without any important and coherent steps, the current state of the Earth will only worsen. Building industry accounts for approximately 40% of CO_2 emitted into the atmosphere. To reduce the environmental impact of the construction sector, it is essential to use materials that do not require fossil fuels [3]. And as we spend 80% of our lives in buildings, it is relevant how good the indoor environment is and what impact it has on us.

1.1. Location

Australia is the sixth largest country in the world and the smallest continent with a population of 25 million people [4]. The country is highly urbanised on the eastern coastline, while the central area is sparsely populated. Almost 70 years ago, Australia had a population of around 8 million people and today it has three times more and it is forecasted that the number is going to rise.

The building is situated in a small town called Numbulwar in the Northern Territory of Australia. Despite Northern Territory is the third largest federal division, its population density is low. With approximately 247 000 inhabitants, it is the least populated of all states and territories of Australia. Most of the population is concentrated in the capital city of Northern Territory Darwin and coastal regions. The travelling distance between Numbulwar and Darwin is around 780 kilometres and it takes 15 hours by car. There is one road to Numbulwar, which is only accessible in the dry season with a 4wd car.

Figure 1: *Numbulwar*

The small city of Numbulwar lies at the Top End of Australia, built on the land. The health centre is found at the very north of the village. Part of the plot is reserved for an ancillary housing which was constructed together with the clinic. The building is located at the northern part of the plot with two entrances and carparks [5].

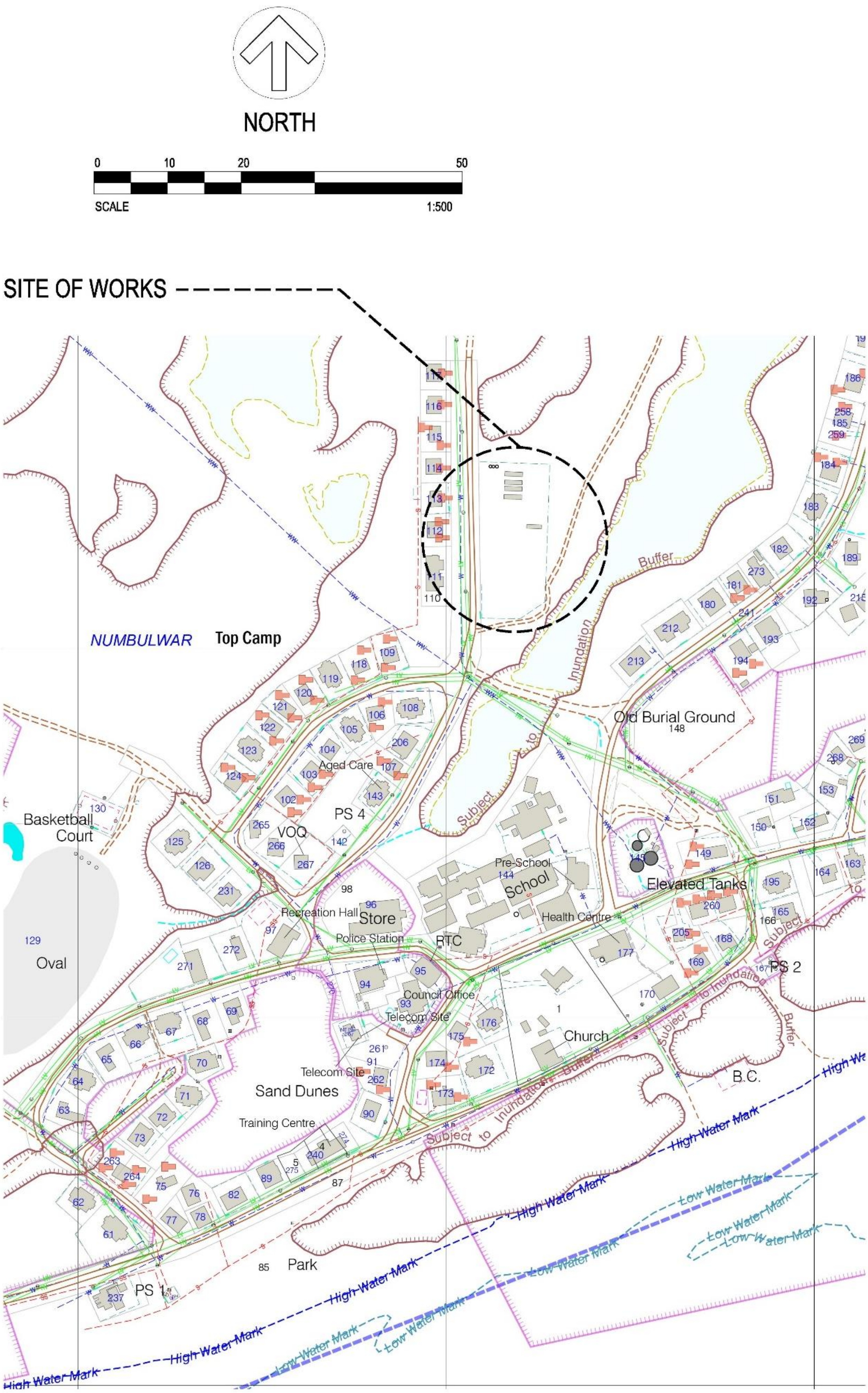


Figure 2: Location of Health Centre in Numbulwar [6]

1.2. Culture – social economic issues

First inhabitants of Australia are indigenous people who came to Australia from Southeast Asia around 70,000 years ago. There are over 250 indigenous languages, however, only 20 of them are spoken nowadays [4]. On the mainland of East Arnhem Land, there is the city of Numbulwar which is primarily an Aboriginal community with a spoken language of their community called Nunggubuyu. Numbulwar was established as a permanent settlement by Aboriginal people and the Church Missionary Society in 1952. Administrative authority was handed over to Aboriginal people from around 1975. Nowadays there are around 700 inhabitants. If visitors want to visit any remote communities such as Numbulwar, they need a permit to enter the country [7].

Together with the Numbulwar Health Centre, there were other Health Centres openings at the Top End communities. Numbulwar Health Centre was funded by the Commonwealth's and Hospitals Fund Regional Priority program – a $50,29 million program to upgrade 11 remote health centres across the Northern Territory [8].

Figure 3: *Typical house in Numbulwar [7]*

1.3. Boundary conditions analysis

Australia is a continent comprising through several climate zones. There are eight climate zones defined by the Building Code of Australia. Design and construction requirements differ in each zone. Northern Territory has two climate zones. Numbulwar is in the very northern part of Australia in Zone 1. This zone has a tropical climate with hot humid summer and warm winter. There are two distinctive seasons, the wet season with humidity of approximately 70% (October to April) and the dry season with an average humidity of 30% (May to September) [9]. In comparison to other climate zones, Zone 1 has the highest consumption of energy in order to achieve thermal comfort in the building. Therefore, the use of passive design when designing a building is important as there might be significant savings on energy consumption.

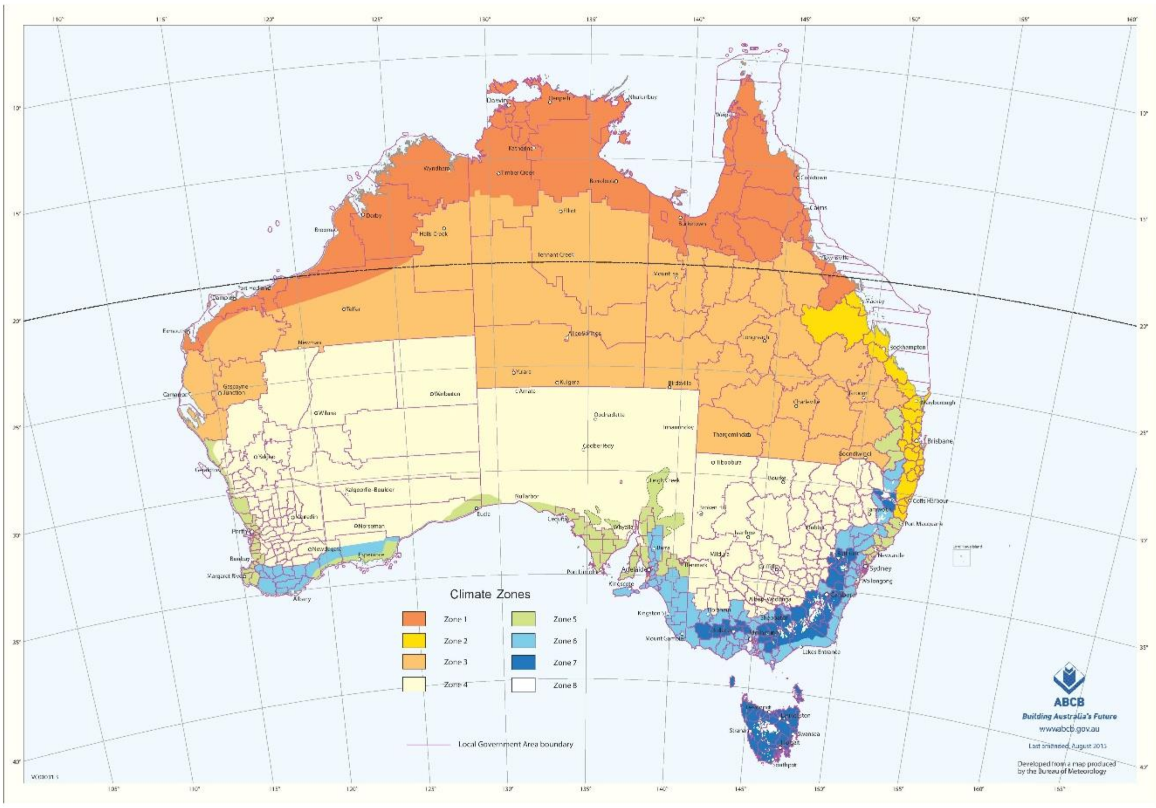


Figure 4: *Climate zones in Australia [10]*

To design an efficient building with sustainable features, it is crucial to know the climate. All climate data can be downloaded from the Bureau of Meteorology (BOM), Government of Australia [11]. There used to be a Bureau station in Numbulwar, however, this station is no longer active since 2015. The nearest place to Numbulwar, where all data is collected is Groote Eylandt Airport and is approximately 85 kilometres away.

Summary statistics for all years Move mouse over highest and lowest daily temperature to view dates.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	33.3	33.0	32.6	32.5	31.0	29.0	28.9	30.1	32.6	34.1	34.5	34.3
Highest monthly mean	35.3	35.3	34.7	34.6	32.3	30.7	30.5	31.3	33.3	35.3	36.5	36.0
Lowest monthly mean	31.7	31.6	31.4	30.3	29.5	26.6	27.3	29.2	31.3	33.1	32.8	33.0
Highest Daily	38.7	38.0	38.6	35.9	34.8	33.0	33.0	33.7	36.4	39.1	39.9	39.1
Lowest Daily	26.8	26.3	26.0	26.1	22.9	21.4	21.8	21.5	26.3	26.3	28.1	27.5

***Figure 5:** Average outdoor temperature in Groote Eylandt Airport (1999-2017) [11]*

As seen in the table (fig. 5), this is a summary of all the years (1999-2017) in Groote Eylandt Airport. Even in winter, monthly mean temperature rises up to 27 degrees. Therefore, heating in this area is not needed.

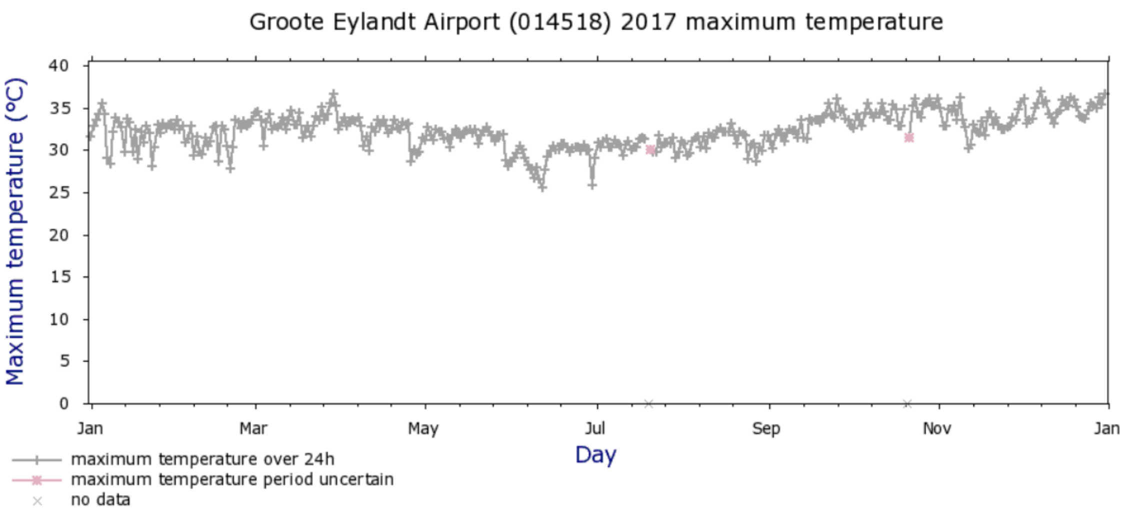


***Figure 6:** Maximum outdoor temperature in 2017 at Groote Eylandt Airport [11]*

While outdoor temperature is measured at Groote Eylandt Airport, observation of solar exposure is measured in Numbulwar. In Alice Springs which is the second biggest city in the territory and is around 1400 km away from Numbulwar, the average solar exposure in winter is 4,7 kWh/m^2, while in Numbulwar it is 5,5 kWh/m^2. Annual mean daily global exposure for 2017 in Numbulwar is 6,3 kWh/m^2. This leads to overheating in summer.

Summary statistics for all years

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	5.9	5.9	5.9	5.8	5.3	5.1	5.4	6.2	6.9	7.4	7.2	6.6
Highest monthly mean	7.3	7.0	7.2	6.4	5.7	5.5	5.8	6.9	7.3	8.0	7.8	7.8
Lowest monthly mean	5.1	5.0	4.8	4.9	4.9	4.2	4.8	5.9	6.2	6.4	5.8	5.7

***Figure 7:** Average solar exposure in Numbulwar (2007-2017) [11]*

Another source of data is the investigation, which Dr Steve has undertaken and which contains over 2.9 million data. This data is compared together with data from DesignBuilder, a software where a model of the clinic is created and assessed from the energetic point of view. DesignBuilder has a dataset from Darwin, which is 783 kilometres away from Numbulwar.

Since the BOM provides temperature, rainfall and solar exposure for Groote Eylandt airport, this data was analysed together with another downloaded dataset. This analysis has shown what is the divergence between all provided data and which data should be used for energetic analysis. Since the data in DesignBuilder is from 2002 and the values show the trend in the long-term, this data cannot be properly assessed together with data from the year 2017. Therefore, the average temperature out of ten years 2008-2017 was added to the analysis to show the difference. The analysis was made for particular months April, August and December, where the biggest divergence between BOM 10 and DesignBuilder is in December. The graphs show daily highest outdoor dry bulb temperature during months of April, August and December.

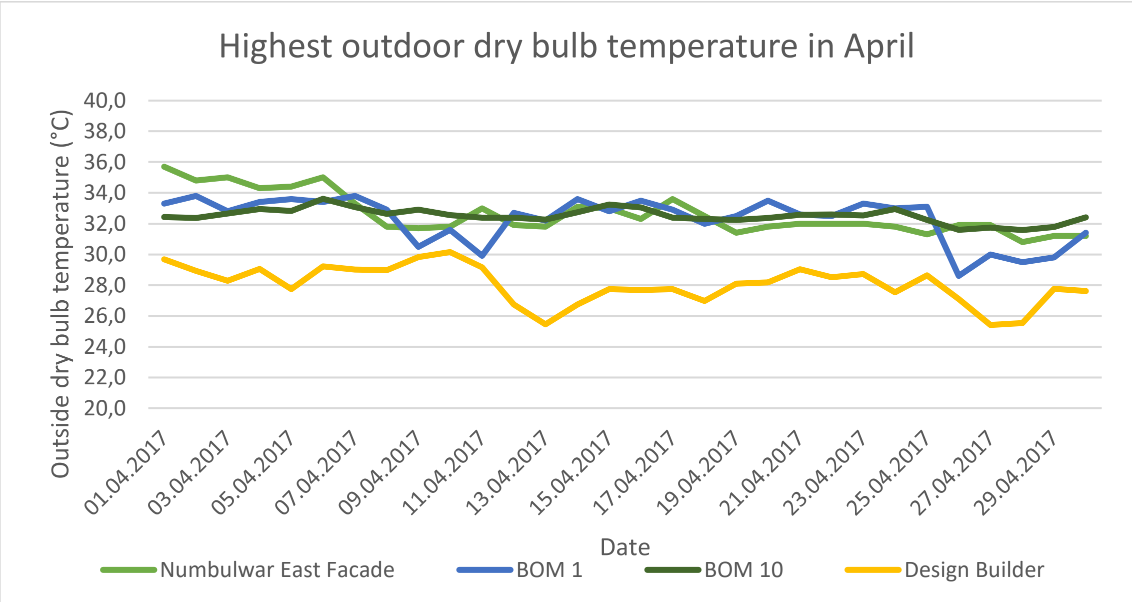


Figure 8: *Comparison of the highest outdoor dry bulb temperature in April*

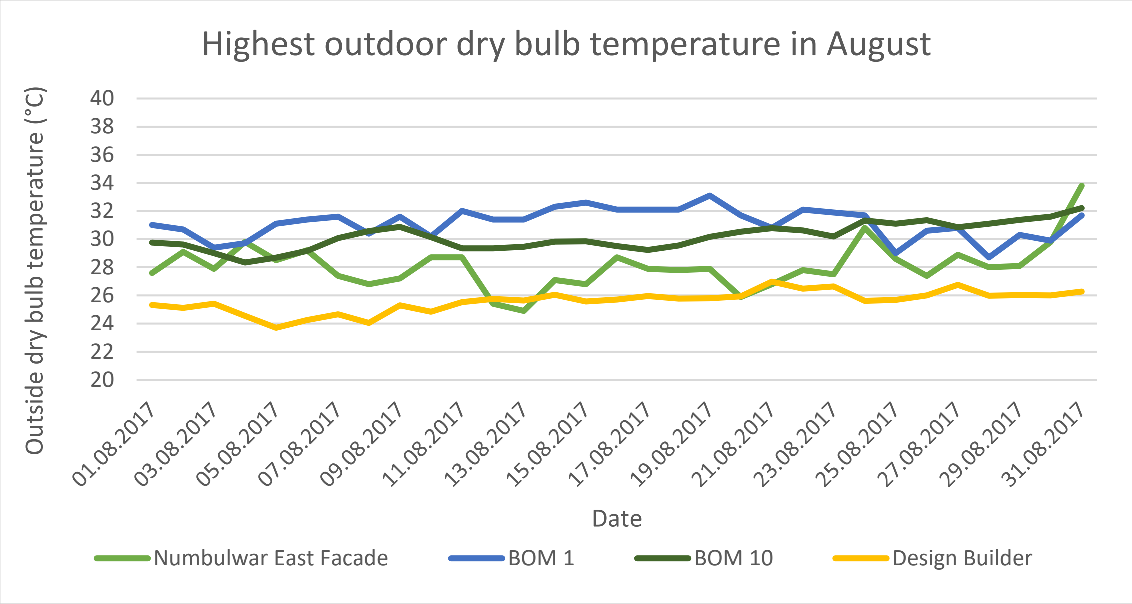


Figure 9: *Comparison of the highest outdoor dry bulb temperature in August*

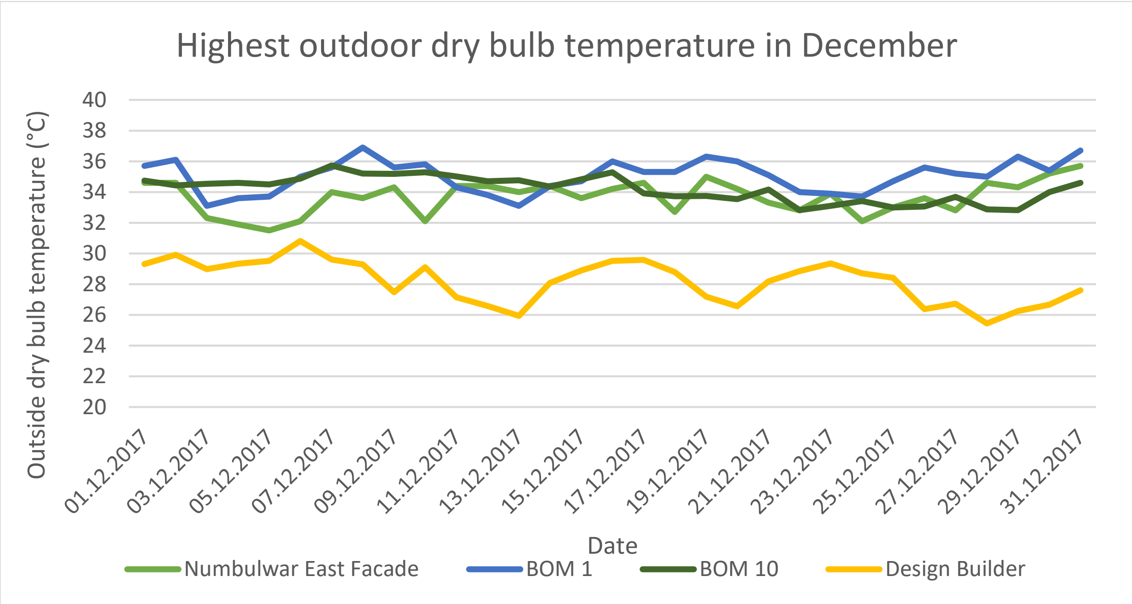


Figure 10: *Comparison of the highest outdoor dry bulb temperature in December*

As seen in the graphs (fig. 9,10 and 11), the divergence is between 4-6 degrees. While in April, data from BOM and Numbulwar reach similar values, outdoor temperature from DesignBuilder is lower, which happens also in December. In August, the temperature of the three sources differs more as its course is around 2 degrees higher or lower. Information about how the data is collected is not known, therefore, the divergence might be caused by various conditions and factors of collecting data in those three places.

The work is based on the possible implementation of CEB into this climate, therefore, it is crucial to know what type of soil there is in Numbulwar. Because of environmental reasons, particularly production of CO_2, the presence of the right type of soil at the site is very important. According to a fact sheet provided by the Department of Land Resource and Management, the soil in Numbulwar is called Tenosols. This type of soil is sandy and include sandplains, granitic soils and the sand dunes of beach ridges and deserts [12]. The best soil composition to create earth blocks is a composition of 80% of sand, 10% of silt and 10% of clay.

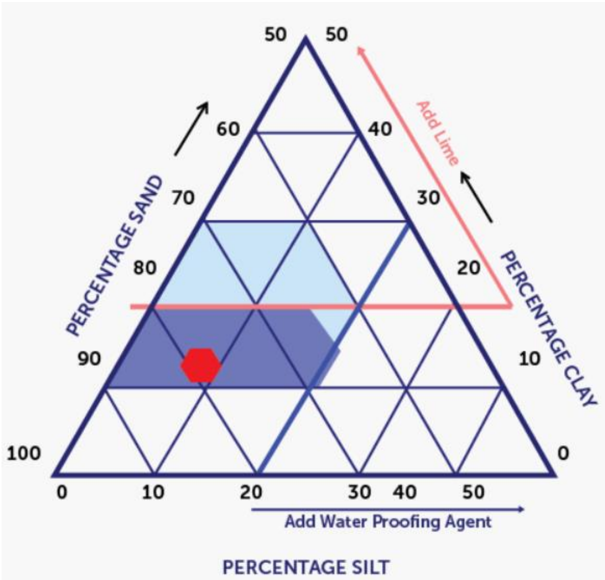


Figure 11: *Soil grading composition limits [13]*

There are several tests which help to determine whether the soil has desired features to be suitable for the construction [13]. Regarding the provided fact sheet, soil in Numbulwar appears to be suitable for creating the Earth Blocks.

1.4. Health Centre Investigation

The health centre has undergone an investigation into the environmental performance of the Numbulwar Health Clinic which involved collecting indoor and outdoor climatic data together with energy consumption and indoor air quality (IAQ). Environmental performance refers to energy use patterns, the thermal performance of the building and indoor air quality. The Health Centre Investigation has been done by Dr Steve, publishing a Report about the Investigation and sharing with me the project documentation of the Health Centre of Numbulwar [5,6].

Data was collected by integrated data loggers, which were placed inside and outside the building on various spots and measured the variables every 10 minutes for 12 months. The investigation started in late March 2017 when the building was not occupied. The clinic started to be occupied and operating in September. The investigation finished at the end of April 2018.

1.4.1. External temperature and humidity

During the investigation, the external temperature was measured outside the northern and eastern façade of the building. The highest external temperature occurs from December to March and April to May, whereas the minimum mean temperature was from June to September.

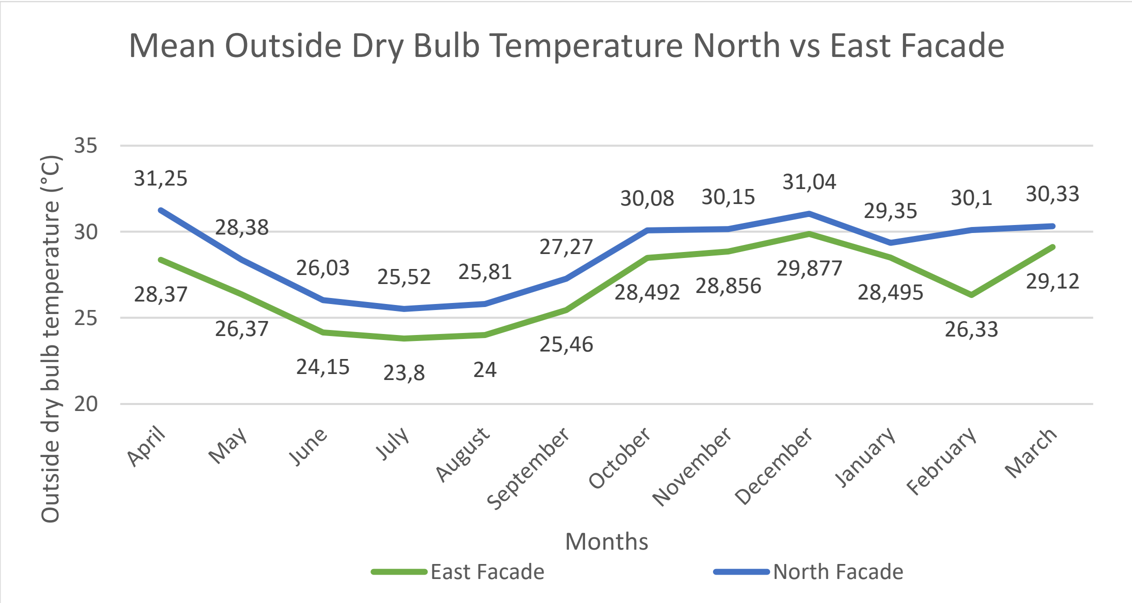


Figure 12: Monthly mean outdoor temperature at the clinic

External humidity was measured at the same spot and varied between 25.9% and 97.5% during the year. The highest humidity was from January to March and the lowest from April to June. Monthly mean humidity ranged from 65% in May to 77,5% in January.

1.4.2. Internal temperature and humidity

The internal temperature has three apparent periods starting in April to March when the clinic was not operational and occupied and the thermostat was set to a higher thermostat-controlled temperature. Another drop happened in October when the thermostat control was changed again. During the operational phase, the internal temperature varied more as the heat gains consisted of solar exposure. The operation of HVAC has to be taken into consideration as seen on the graph, the temperature is around 24 degrees. This temperature has been set to the thermostat. Zone 4 is Female Consult and zone 5 is Male consult.

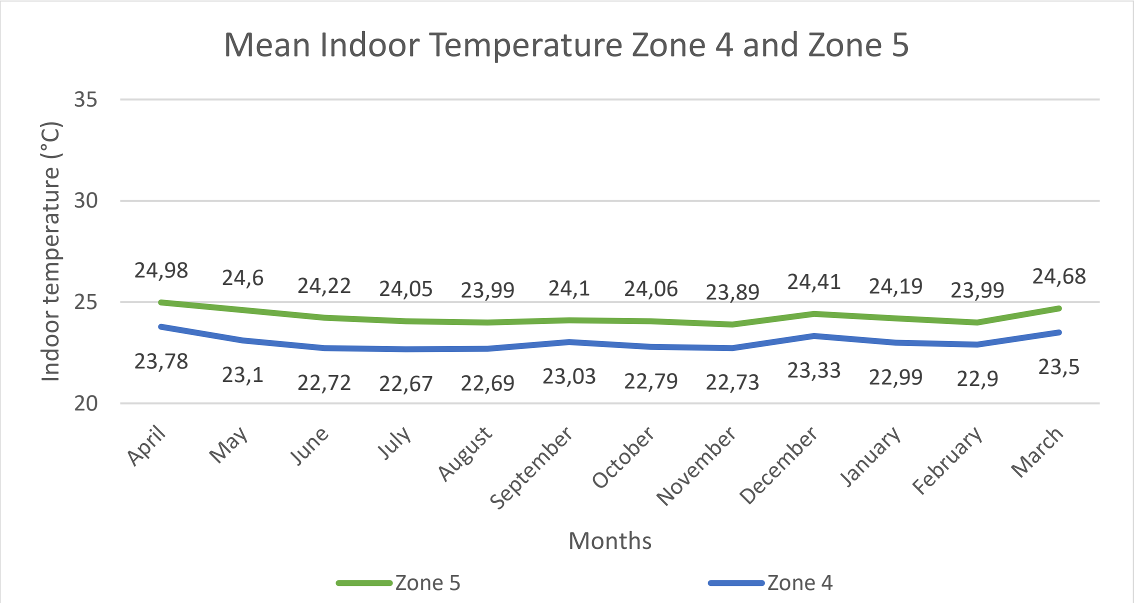


Figure 13: *Mean indoor temperature at the clinic in Zone 4 and 5*

1.4.3. Energy consumption

The building was not occupied when the investigation started, therefore there are two phases in which the energy consumption was analysed. The building was not operational from April to mid-September 2017 when the consumption was around 10-15 kWh per hour, whereas from mid-September to April 2018 it was 25-35 kWh per hour depending on the month. From the graphs, it is seen the clinic operates 12 hours a day with staff being in the building from around 6:00 to 16:00 on weekdays. The HVAC is running for 10 hours during the weekdays and around 5,5 hours during the weekends.

Month	**Energy meter 1 (kWh/month)**	**Energy meter 2 (kWh/month)**	**Energy meters (kWh/month)**
April	2581	5843	8425
May	1937	6613	8550
June	1345	5726	7071
July	1303	5540	6843
August	1440	5514	6954
September	1628	5625	7253
October	2888	5862	8749
November	3177	5842	9019
December	3540	6180	9719
January	3245	6047	9292
February	2888	5532	8420
March	2906	5718	8624
YEAR	28877	70041	**98918**
Energy consumption (kWh/m^2)	42	101	**142**

Table 1: *Energy consumption of current building*

As seen in the table (tab. 1), there are two energy consumption meters, one measuring electrical supply and the other one measuring non-essential supply. According to the report, this division is not meaningful as both supplies contribute to energy on air-conditioning and various other types of electrical devices. However, this two-fold division was essential, so the total energy consumption could be calculated.

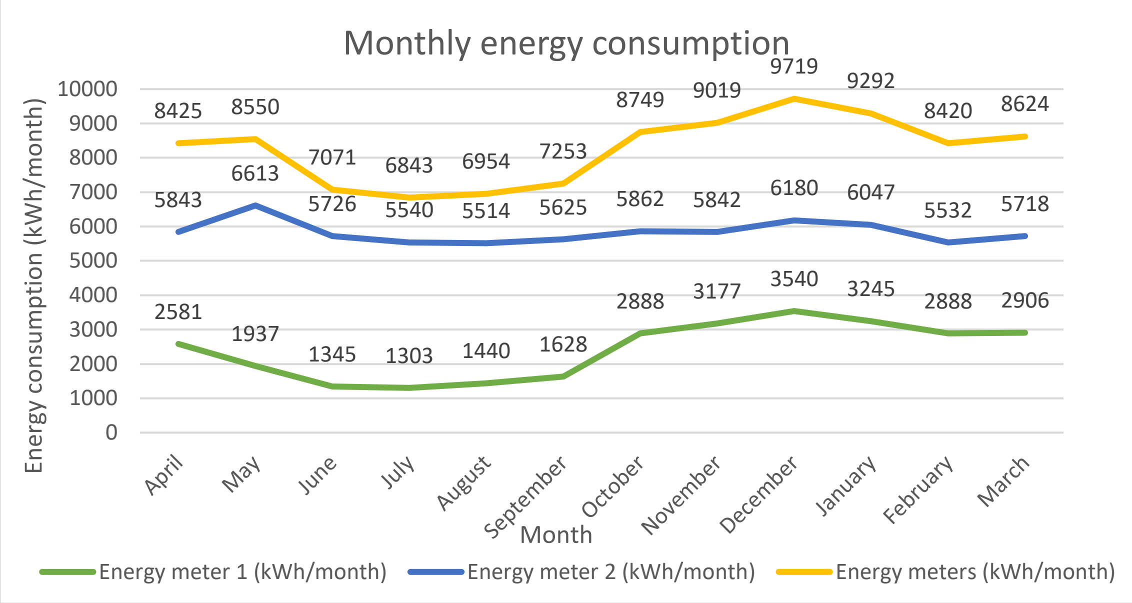


Figure 14: *Monthly energy consumption at the clinic*

As seen on the graph (fig. 15), when the building was open, the initial energy consumption was higher in the first two months. From June to September, energy consumption was lower which was caused by the absence of people, and also the season of the year – winter. Higher consumption was during the months of October to May because of a bigger difference between internal and external temperature. Over the monitoring period, the clinic used approximately 99000 kWh of electricity. During the non-operational phase, the clinic used about 46% of the total energy consumption with the average energy consumption of 7516 kWh, while during the operation the average energy consumption was around 8971 kWh (9% of total energy consumption) a month.

1.5. Technical specification of current building

1.5.1. Construction system

The structural system of Numbulwar health centre is a combined system. The load-bearing structure is made of steel columns and steel beams. Concrete blockwork is used both as a load-bearing structure and bracing structure. Blockwork is reinforced with steel helping the structure to be stiff. The non-load-bearing structure consists of the light steel wall frame. The structure is designed with a module of 4.75 metres, however, the module is not regular as it changes along its length. The rigidness of whole structure is provided by transverse reinforced concrete walls and bracing steel bars jointed to beams.

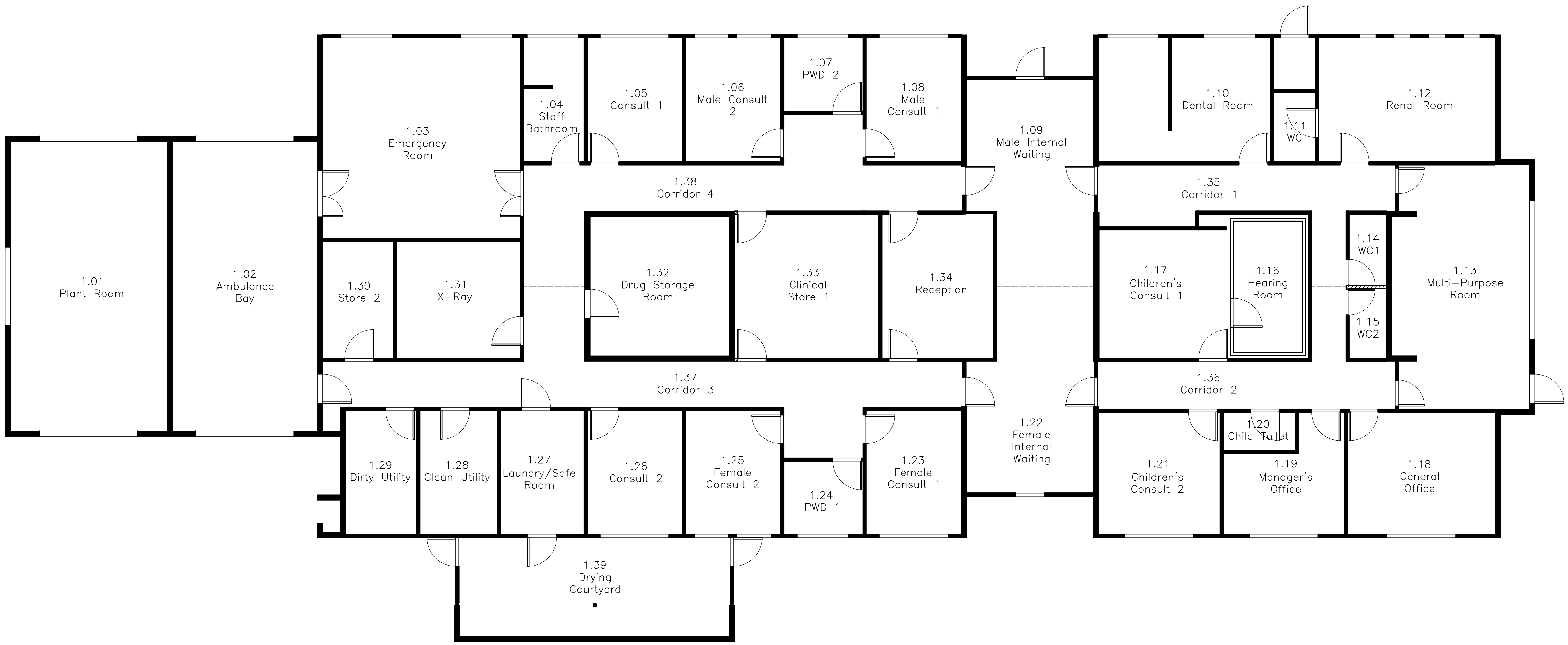
Figure 15: *Northern facade of Numbulwar Health Centre [14]*

1.5.2. Floor plan

The size of the building is approximately 20 x 60 metres with the shape of a regular rectangle. The total area is approximately 1200 square meters. The building has only one floor with a saddle roof and is divided into three parts, the left side is used as a technical room (plant room) and an ambulance bay with an emergency room. The right side of the clinic serves as an area for preventive doctoral inspections. The middle of the building is divided into men and women consulting area.

Figure 16: *Numbulwar Health Clinic: Emergency Room [14]*

FLOOR PLAN SCHEME



Nb.	Room	Area m2	Nb.	Room	Area m2	Nb.	Room	Area m2
1.01	Plant Room	54,15	1.14	WC1	3,14	1.27	Laundry/Safe Room	12,47
1.02	Ambulance Bay	50,15	1.15	WC2	3,14	1.28	Clean Utility	11,61
1.03	Emergency Room	47,57	1.16	Hearing Room	10,92	1.29	Dirty Utility	10,54
1.04	Staff Room	8,93	1.17	Children's Consult	20,27	1.30	Store 2	9,94
1.05	Consult 1	14,19	1.18	General Office	21,67	1.31	X–Ray	17,44
1.06	Male Consult 2	14,19	1.19	Manager's Office	14,14	1.32	Drug Storage Room	23,18
1.07	PWD 2	7,01	1.20	Child Toilet	3,36	1.33	Clinical Store 1	25,00
1.08	Male Consult 1	14,23	1.21	Children's Consult 2	17,85	1.34	Reception	19,35
1.09	Male Internal Waiting	29,0	1.22	Female Internal Waiting	28,92	1.35	Corridor 1	21,85
1.10	Dental Room	25,26	1.23	Female Consult 1	14,23	1.36	Corridor 2	20,1
1.11	WC	3,48	1.24	PWD 1	7,01	1.37	Corridor 3	46,24
1.12	Renal Room	26,27	1.25	Female Consult 2	14,19	1.38	Corridor 4	34,63
1.13	Multi–purpose Room	39,21	1.26	Consult 2	14,19	1.39	Drying Courtyard	32,04
							Total area m2	791,06

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Student	Ema Škarecká	Scale	1:150
Advisors	Ing. Jan Růžička, Ph.D. Dr Steve Burroughs	Format	A3
		Year	2018/19
Drawing	FLOOR PLAN SCHEME	Nb.	1

2. Structural design in variants

2.1. Current Building

The current building has been designed and constructed according to the Building Code of Australia. The structural system is made of steel columns, steel wall frame and concrete blockwork. While blockwork is used mostly as a load-bearing structure, steel wall frame is used as a filling structure between steel columns. Lightweight framed construction is the most common structure system in Australia. The main advantage is being durable, stable and termite-proof. Although steel production requires large amounts of energy, steel is 100% recyclable. These days current framing products often include recycled content (up to 40%) [15]. Light weight framed construction has low thermal mass and is, therefore, unable to store passive heat which will be shown during the energetic analysis.

ZONE 1
Darwin, Katherine

ROOF

Thermal resistance	**Total R-Value 2.7** (down)
Solar absorptance	Any
Ventilation	Nil
Thermal resistancet	**Total R-Value 2.2** (down)
Solar absorptance	Upper surface solar absorptance more than 0.55
Ventilation	Nil
Thermal resistance	**Total R-Value 2.2** (down)
Solar absorptance	Any
Ventilation	Fixed ventilation with aggregate fixed open area at least 1.0% of ceiling area; **OR** Two wind-driven roof ventilators with aggregate opening area at least 0.14 m^2, and fixed ventilation with aggregate fixed open area at least 0.2% of ceiling area; **OR** The roof is tiled without sarking

EXTERNAL WALLS

Thermal resistance	**Total R-Value 1.9**
Surface density	Any
Other construction	Any
Thermal resistance	**Total R-Value 1.4**
Surface density	Any
Other construction	Concrete slab-on-ground
Thermal resistance	**Nil**
Surface density	Any
Other construction	Shaded
Thermal resistance	**Reflective insulation (emittance not more than 0.05) inwards**
Surface density	Any
Other construction	External weatherboard, sheet clad or masonry veneer walls, shaded

CONCRETE SLAB-ON-GROUND

Thermal resistance	**No requirements, except when there is in-slab heating or cooling**

Figure 17: *Required minimum total R-values for roofs, walls and floors [16]*

Energy efficiency of a building can be determined based on how well the thermal envelope performs. In this case, the thermal envelope of the clinic meets the requirements for the R-value. Because the building is divided into two parts with different cooling requirements, only the right part of the building is cooled and thus has a better insulated building skin. The peripheral walls of the cooled area are insulated, whereas plant room and ambulance bay do not require insulation and the walls are made of blockwork.

CURRENT BUILDING			
Wall type 0	Thickness d (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Fibre cement lining	0,009	0,24	0,037
Steel frame with insulation	0,076	0,04	2,111
Vapour barrier	0,002	0,35	0,006
Wall cladding	0,0045	50	0,0001
External surface	n/a	n/a	0,06
Total thermal resistance of Wall R_T (m^2K/W)			**2,334**
Total thermal transmittance U-value (W/m^2K)			0,428

Table 2: *Thermal resistance and transmittance of the wall type 0 in current building*

Wall type 6	Thickness d (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Fibre cement lining	0,009	0,24	0,037
Insulbreak 65	0,0065	n/a	1,600
Air gap	0,02	0,17	0,020
Concrete blockwork	0,19	0,7	0,271
Render blockwork	0,01	0,57	0,017
External surface	n/a	n/a	0,06
Total thermal resistance of Wall R_T (m^2K/W)			**2,126**
Total thermal transmittance U-value (W/m^2K)			0,470

Table 3: *Thermal resistance and transmittance of the wall type 6 in current building*

Wall type 7	Thickness d (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Render blockwork	0,015	0,57	0,026
Concrete blockwork	0,19	0,7	0,271
Render blockwork	0,015	0,57	0,026
External surface	n/a	n/a	0,060
Total thermal resistance of Wall R_T (m^2K/W)			**0,504**
Total thermal transmittance U-value (W/m^2K)			1,984

Table 4: *Thermal resistance and transmittance of the wall type 7 in current building*

Wall type 7 has a low R-value because this wall composition is only in areas with no cooling and there is no requirement for its R-value.

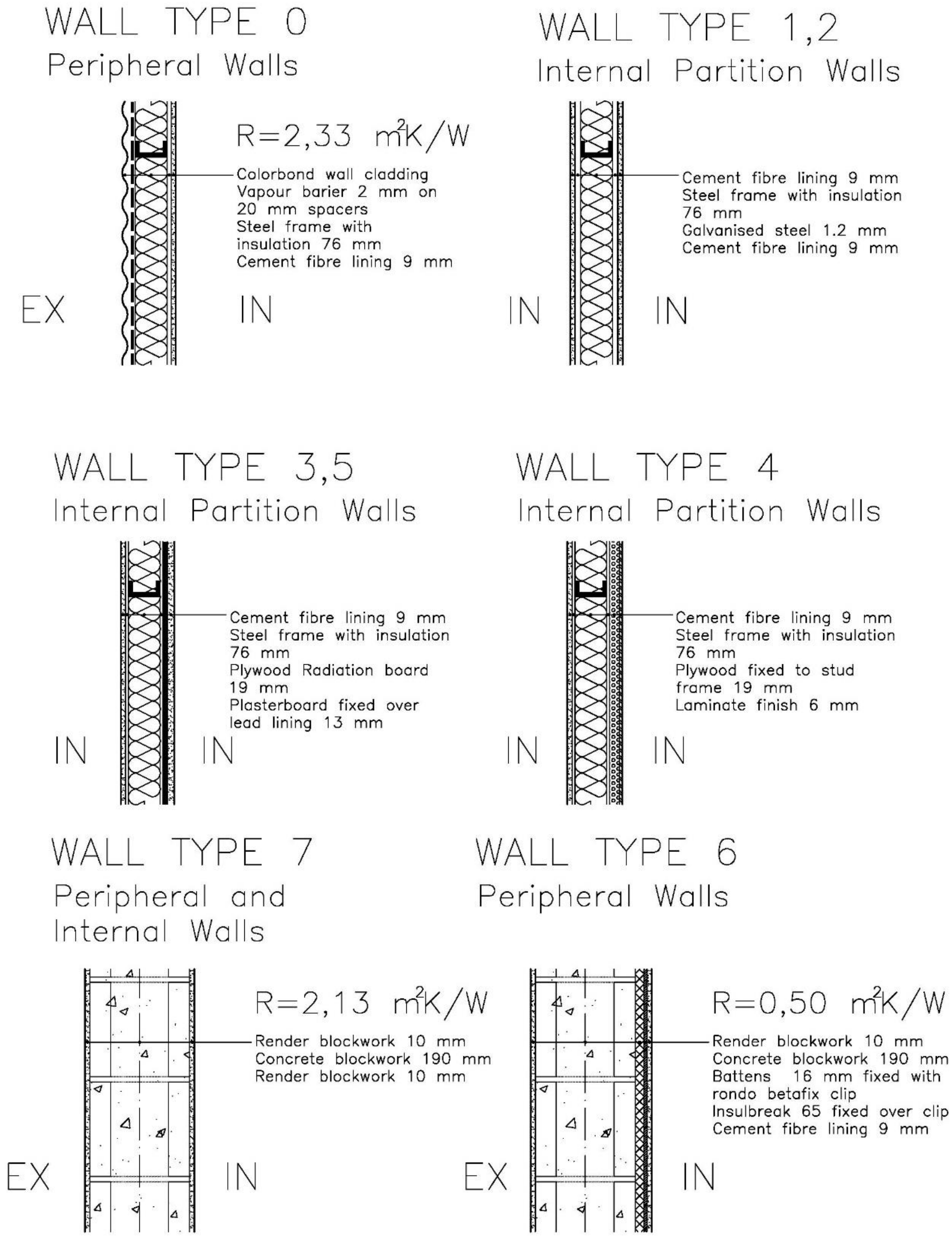
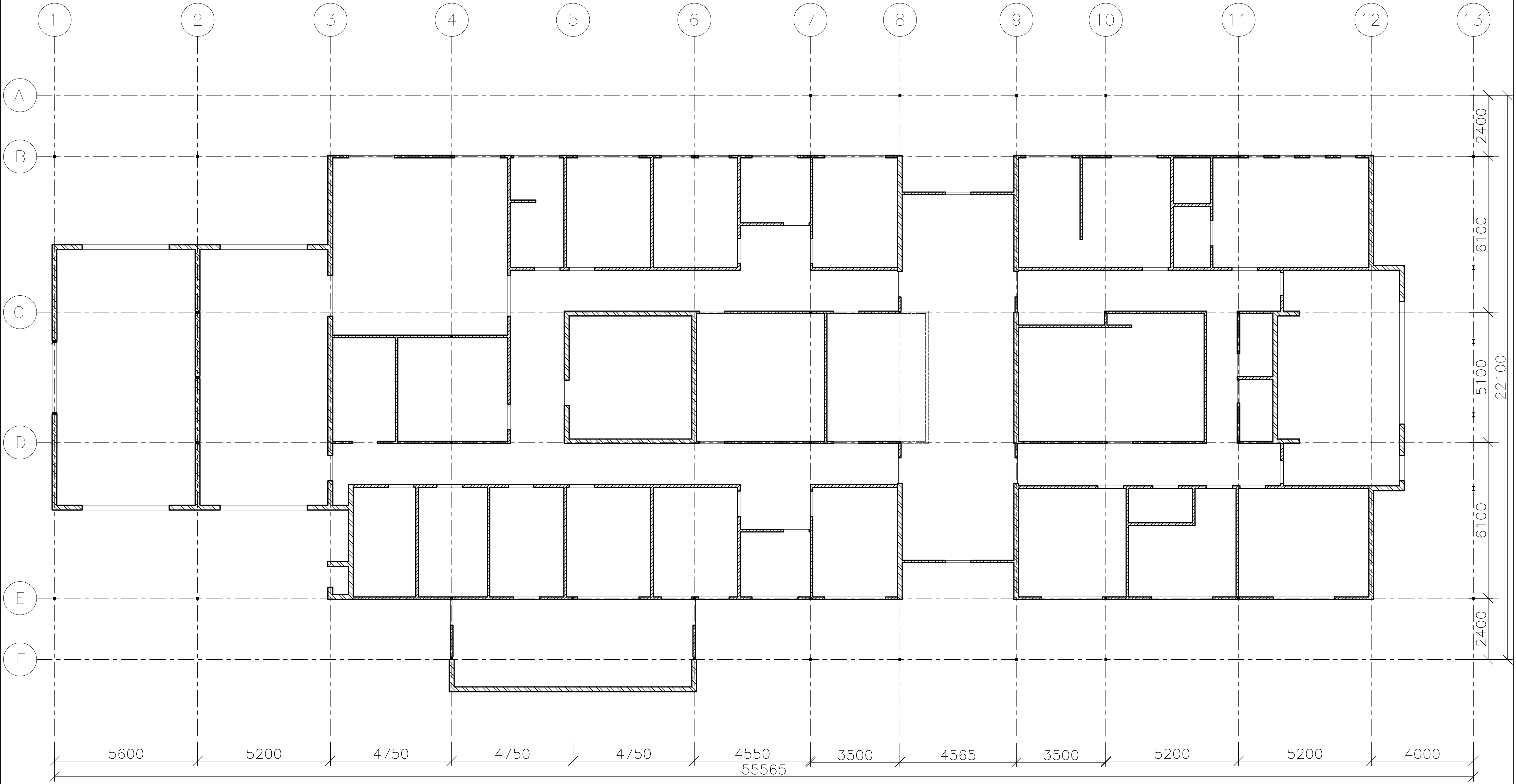


***Figure 18:** Wall compositions of the current building [6]*

Although this structural system is very common in remote areas, a new structural system will be designed to show other effective and more sustainable possibilities.

STRUCTURAL SYSTEM CURRENT BUILDING



BLOCKWORK 190 mm

STEEL WALL FRAME 100 mm

STEEL COLUMNS

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		Year	2018/19
Drawing	CURRENT BUILDING	Nb.	2

2.2. First option

The idea of the first option of the structure is to use different construction material. To see how the building enhances its features in terms of environment and energy, concrete blockwork is replaced by Compressed Earth Blocks (CEB). Earth is the oldest building material, but with time, structures of the earth have lost its importance. To create an earth structure is time and money effective because they eliminate transportation costs, but the social part plays the role as well. Earth blocks are natural and therefore do not emit any toxic gases from glues and preservatives as other materials do. Building a CEB structure increases indoor air quality as the earth blocks can naturally regulate heat and humidity inside the structures. Other advantages of CEB are its sustainability as the material comes from the earth and the structure can be reused anytime. CEB have the lowest embodied energy of any building material and the smallest carbon footprint. As the earth blocks are able to regulate temperature and humidity naturally, less energy is spent to maintain the indoor environment [13].

To carry out the environmental analysis, wall composition of CEB has the same thermal resistance as the concrete blockwork. However, compressed earth block alone has a bit different features than blockwork. Both materials have high thermal mass and that is the reason why blockwork is located on eastern and western façade. In this case, they are not exposed to the sun and they accumulate less heat.

Blockwork is used both as a load-bearing structure carrying the roof structure and bracing structure in the building improving the rigidness. In this option, blockwork is exchanged for CEB walls.

Wall type 6	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Plaster	0,01	0,57	0,017
CEB	0,18	0,62	0,290
Insulation	0,06	0,036	1,666
Render	0,01	0,57	0,017
External surface	n/a	n/a	0,060
Total thermal resistance of Wall R_T (m^2K/W)			**2,172**
Total thermal transmittance U-value (W/m^2K)			0,460

Table 5: *Thermal resistance and transmittance of the wall type 6 in proposed building 1*

Wall type 7	Thickness d (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Plaster	0,01	0,57	0,017
CEB	0,18	0,62	0,290
Render	0,01	0,57	0,017
External surface	n/a	n/a	0,060
Total thermal resistance of Wall R_T (m^2K/W)			**0,505**
Total thermal transmittance U-value (W/m^2K)			1,979

Table 6: *Thermal resistance and transmittance of the wall type 7 in current building*

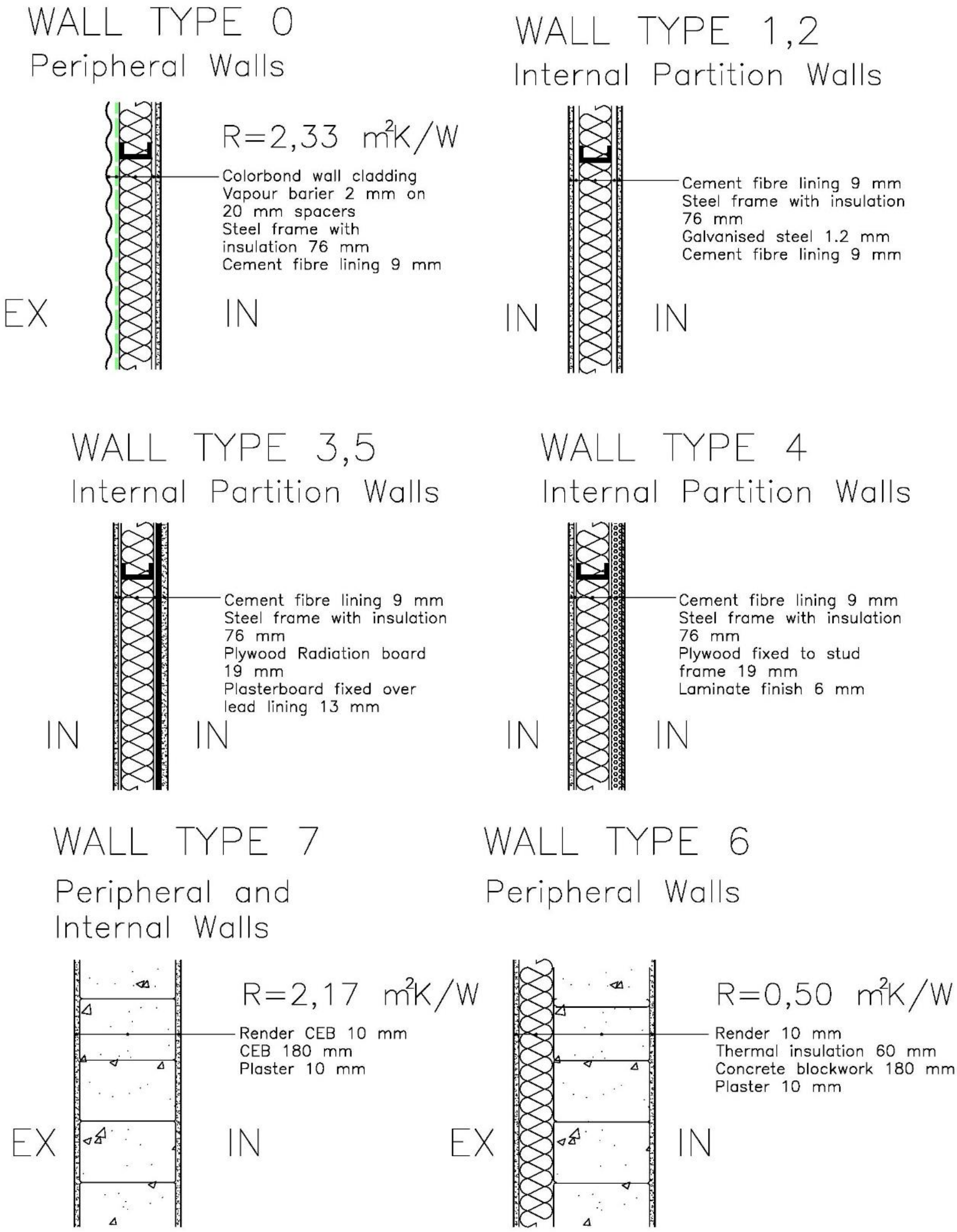
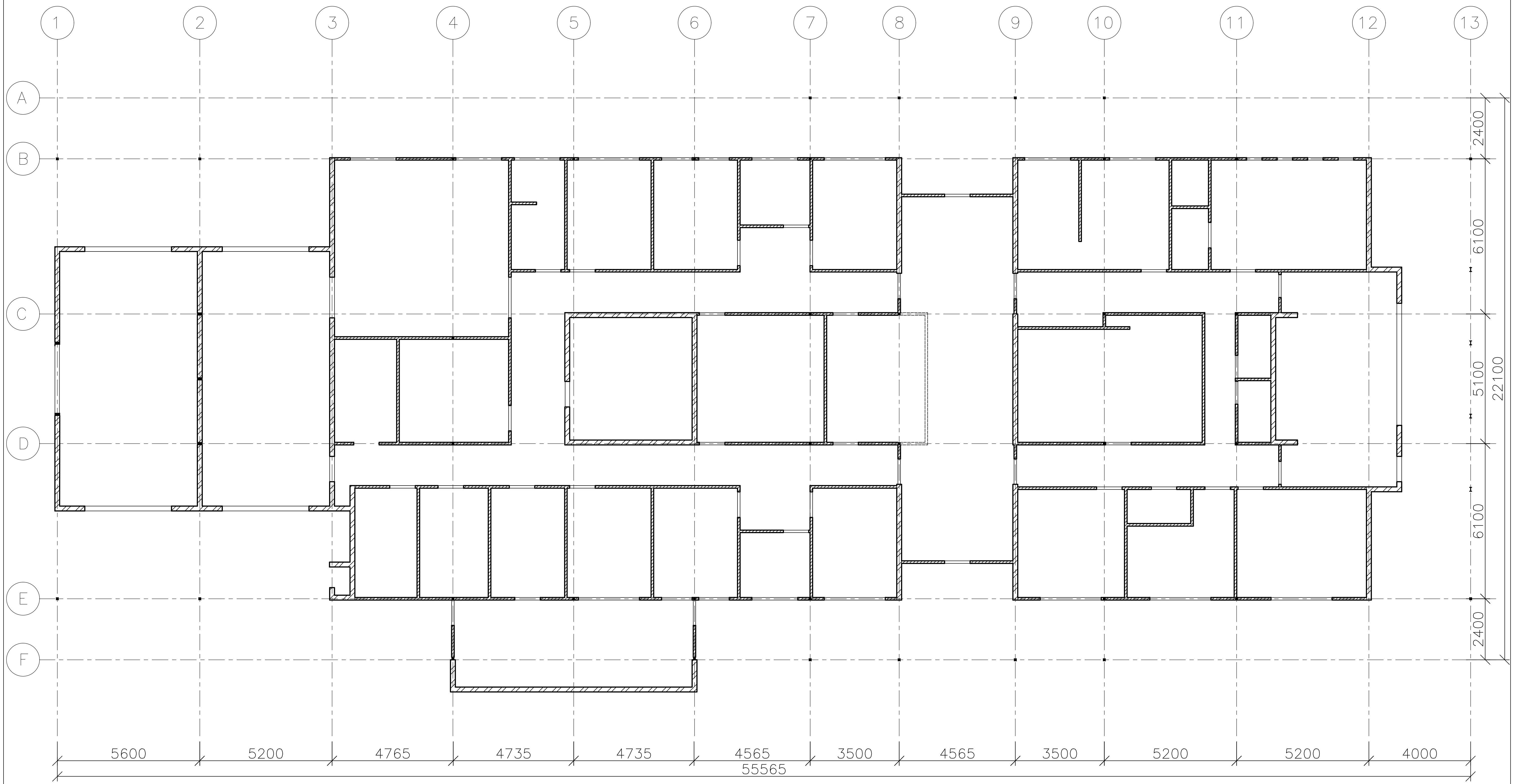


Figure 19: *Wall compositions of Option 1 [6]*

STRUCTURAL SYSTEM FIRST OPTION



CEB 180 mm

STEEL WALL FRAME 100 mm

STEEL COLUMNS

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	Dr Steve Burroughs	Year	2018/19
Drawing	OPTION 1	Nb.	3

2.3. Second option

Another option to be considered is to use earth blocks for both load-bearing and non-load-bearing structure. The structural system stays the same. The non-load-bearing structure is made of CEB with the thickness of 180 mm for the replacement of blockwork and 140 mm thick CEB instead of the steel wall frame. Peripheral blocks are insulated on the outer side to improve thermal resistance. Although this option has the highest weight of building material, it is the most convincing option because of improved thermo-technical features.

Internal walls are made of 140 mm thick earth blocks, reducing the floor area of rooms by approximately 5,5%. Because every room has its purpose and the operation is different, surface finishes have their function (e.g. radiation board in x-ray room), thus they remain the same as in the current building.

SECOND OPTION - CEB WALLS AND COLUMNS			
Wall type 0, 6	Thickness (m)	Thermal Conductivity (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Plaster	0,01	0,57	0,017
CEB	0,18	0,62	0,290
Insulation	0,06	0,036	1,666
Render	0,01	0,57	0,017
External surface	n/a	n/a	0,060
Total thermal resistance of Wall R_T (m^2K/W)			**2,172**
Total thermal transmittance U-value (W/m^2K)			0,460

Table 7: *Thermal resistance and transmittance of the wall type 0 and 6 in proposed building 2*

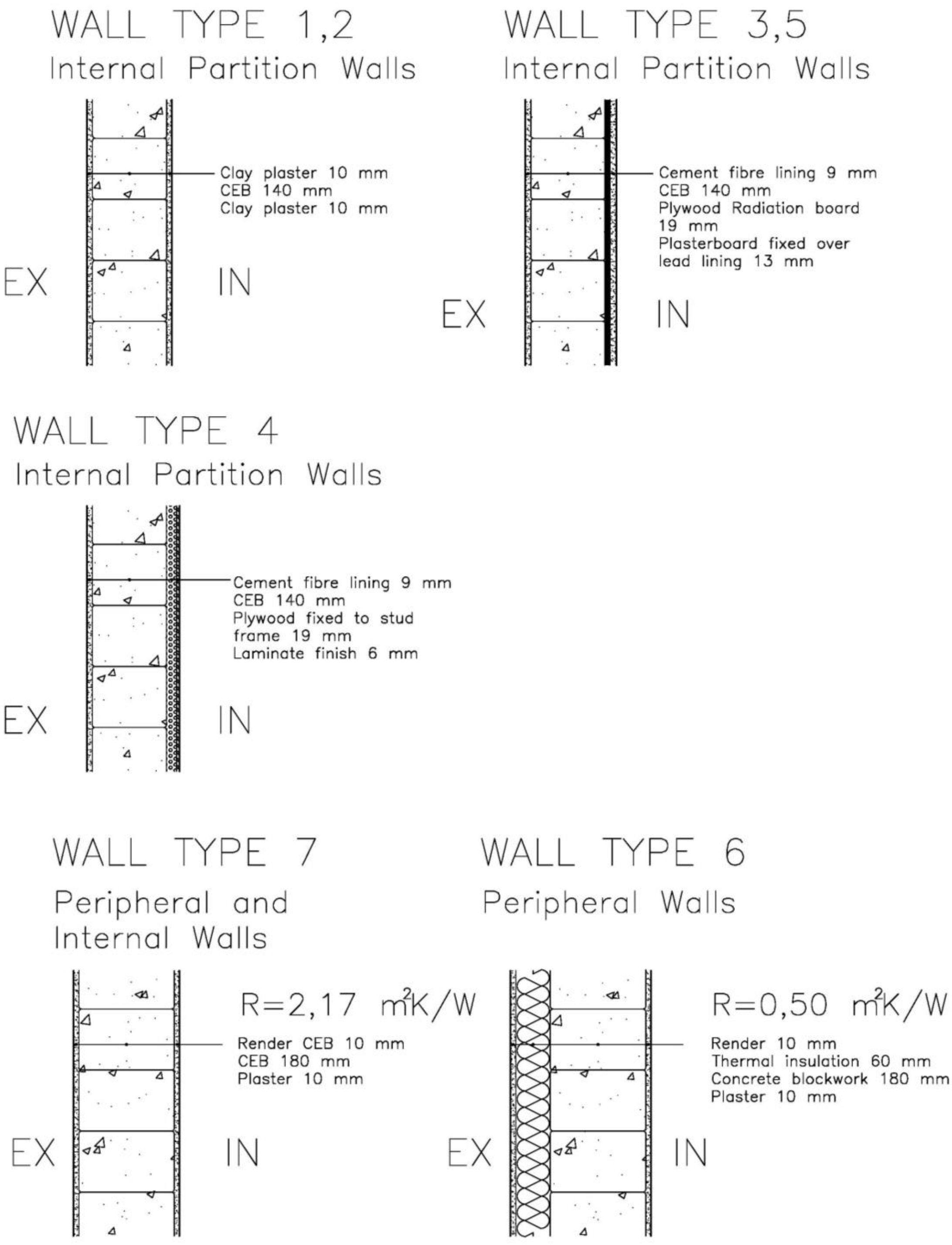
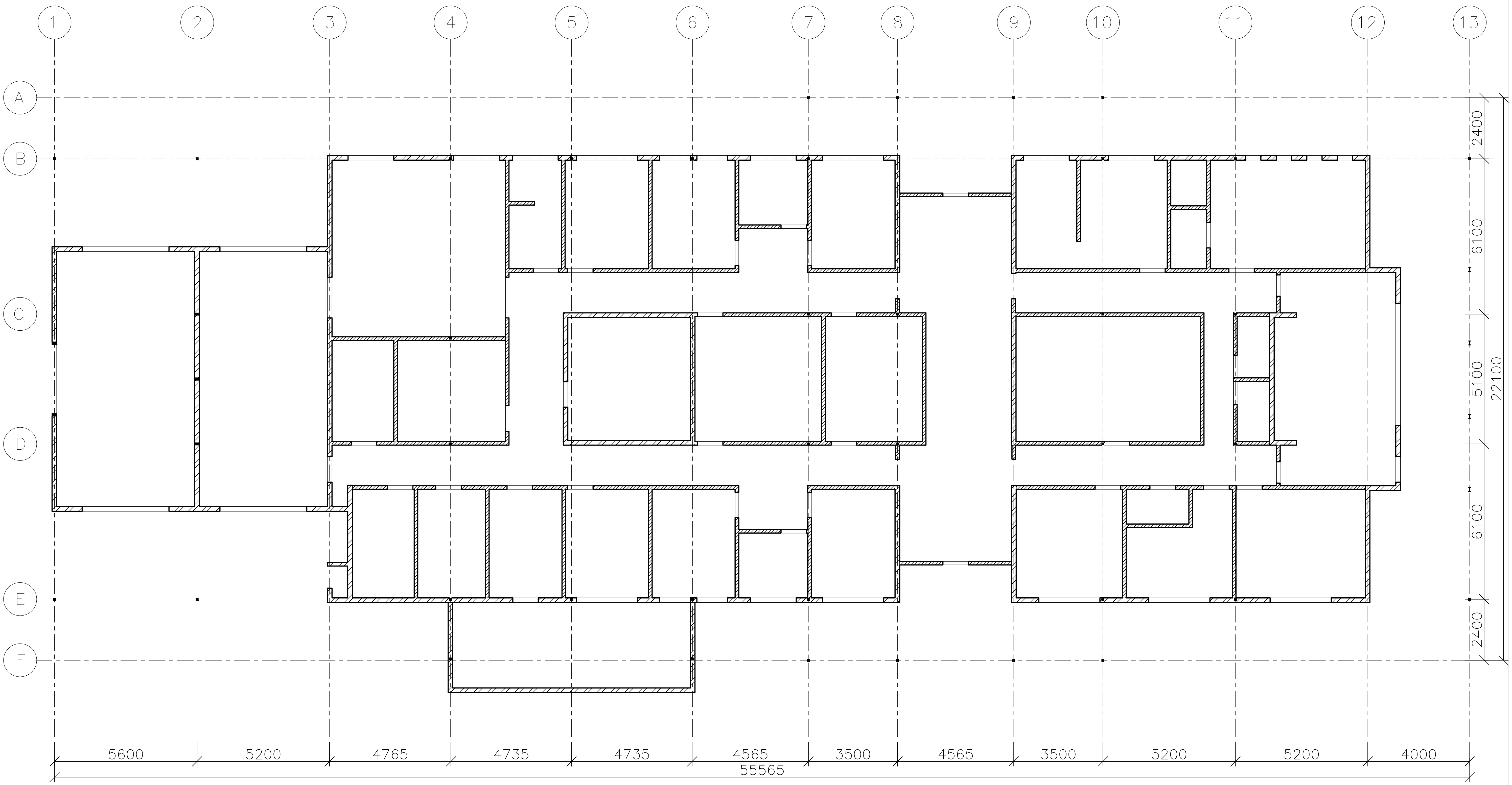


Figure 20: *Wall compositions of Option 2*

STRUCTURAL SYSTEM SECOND OPTION



CEB 180 mm

CEB 140 mm

STEEL COLUMNS

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Drawing	OPTION 2	Nb.	4

2.4. Floor and roof structure

For the environmental analysis, only wall compositions are changed. Foundations and horizontal load-bearing structure remain the same as they are commonly used in these areas and there is no better substitute considered in this work for this structure.

The thermal resistance of the floor is very low which is caused by the lack of thermal insulation. In the Czech Republic, every house has insulation in the floor because of heat loss. However, in Australia, houses in hot humid climate do not need floor insulation as there are any requirements for R-values. Even in winter, the average outdoor temperature is around 28°C and thus the insulation is not needed.

The roof structure is made of steel beams covered by roof cladding. The roof system is called Ashgrid system with a suspended plasterboard ceiling with insulation. The ceiling is attached to the steel rafters. In between the suspended ceiling and load-bearing structure, the area is used for building services such as ventilation and AC installation.

Floor layer	Thickness (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	0,24	0,120
Vinyl floor	0,004	0,2	0,020
Concrete slab	0,12	1,36	0,088
Damp proof membrane	0,0002	0,35	0,001
Sand bed	0,05	0,95	0,053
External surface	n/a	n/a	0,060
Total thermal resistance of Floor R_T (m^2K/W)			**0,341**
Total thermal transmittance U-value (W/m^2K)			2,929

Table 8: *Thermal resistance and transmittance of the floor for all options*

Roof composition	Thickness (m)	Thermal Conductivity λ (W/mK)	Thermal Resistance R (m^2K/W)
Internal surface	n/a	n/a	0,120
Plasterboard	0,01	0,36	0,028
Insulation	0,1	0,04	2,778
External surface	n/a	n/a	0,060
Total thermal resistance of Roof R_T (m^2K/W)			**2,986**
Total thermal transmittance U-value (W/m^2K)			0,335

Table 9: *Thermal resistance and transmittance of the roof for all options*

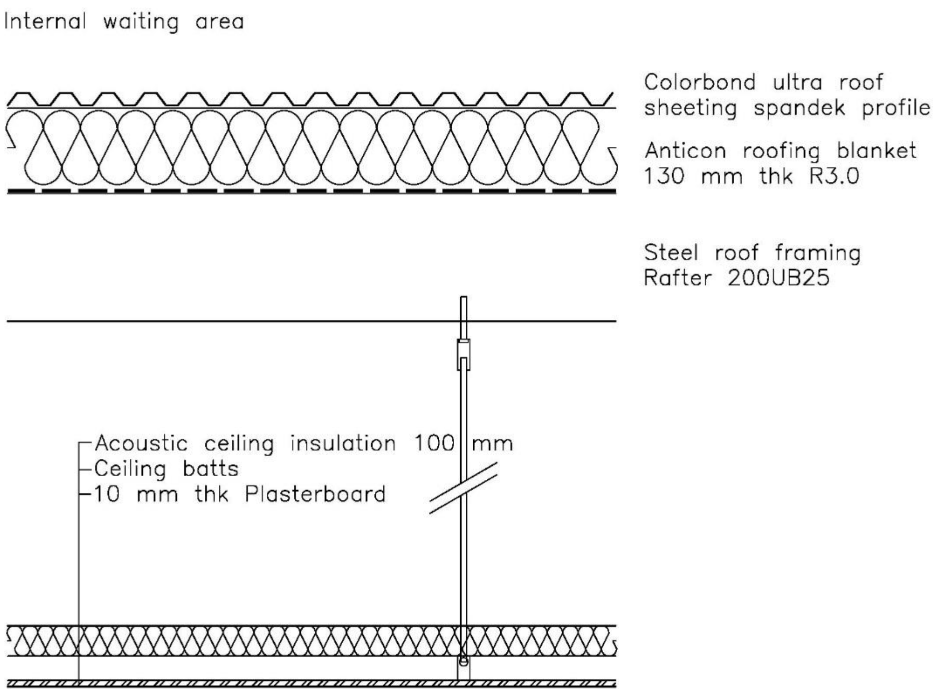


Figure 21: *Roof composition [6]*

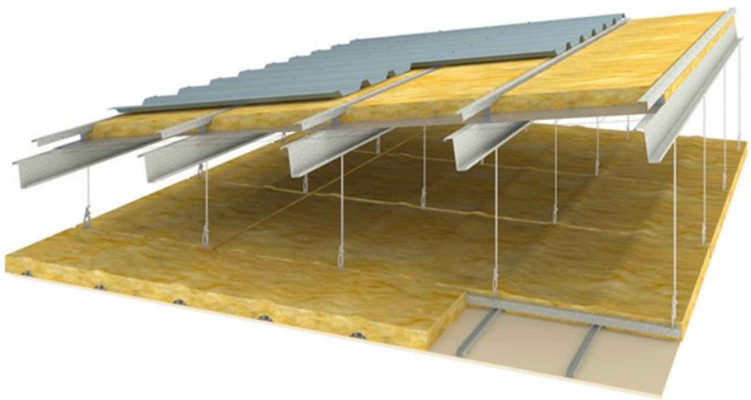


Figure 22: *Illustrative picture of Ashgrid System with plasterboard ceiling and ceiling insulation [17]*

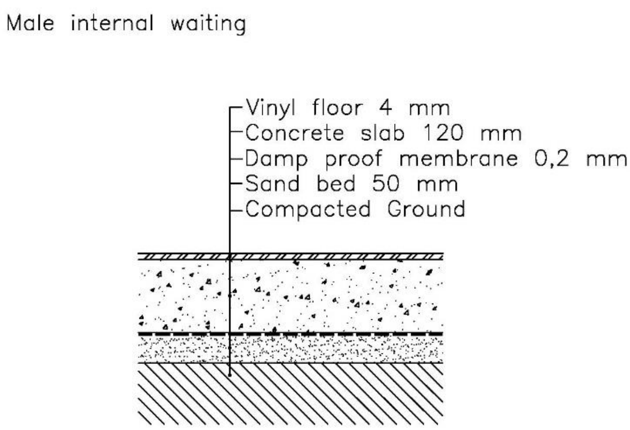


Figure 23: *Floor composition [6]*

3. Environmental analysis of building structures

Human-based activities have a significant impact on the environment which further has irreversible consequences. Therefore, to avoid further deterioration, one must take small steps to improve the current state of the environment. In this case, the improvement is based on the change of building material with a lower environmental impact.

3.1. Environmental parameters of embodied energy

The environmental analysis was aimed at the calculation of embodied energy of the structure including primary energy input (PEI), embodied CO_2 as global warming potential (GWP), and embodied SO_2 as an acidification potential (AP). Embodied energy is the energy consumed by all processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery. It does not include the operation and disposal of the building material [18].

PEI – Primary energy input is the total energy consumption of renewable resources during the whole life cycle of products. This unit is measured in Megajoules (MJ).

GWP – Global warming potential is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It does not include only the emission of CO_2 but also the emission of greenhouse gases such as methane. Their greenhouse effect is converted into the effect of CO_2. Its unit is kilogram equivalent to CO_2 (kg CO_2, ekv.)

AP – Acidification potential indicates embodied emission of SO_2 which is produced during the whole life cycle of a product or its part causing acidification of environment. Same as for the global warming potential, it is not only the emission of SO_2 but also other gases causing acidification on the same effect level as SO_2. Its unit is grams or kilograms equivalent to SO_2 (kg SO_2, ekv.)

Although the building is situated in Australia, provided data from Environmental Product Declaration database in Australia was not complete. The database does not contain all construction materials used in the structure, therefore a Czech database named Envimat was used [19]. By using Czech environmental parameters, the analysis is adjusted to Czech conditions and coefficients. The result of this analysis displays the total environmental impact of the Numbulwar clinic structure.

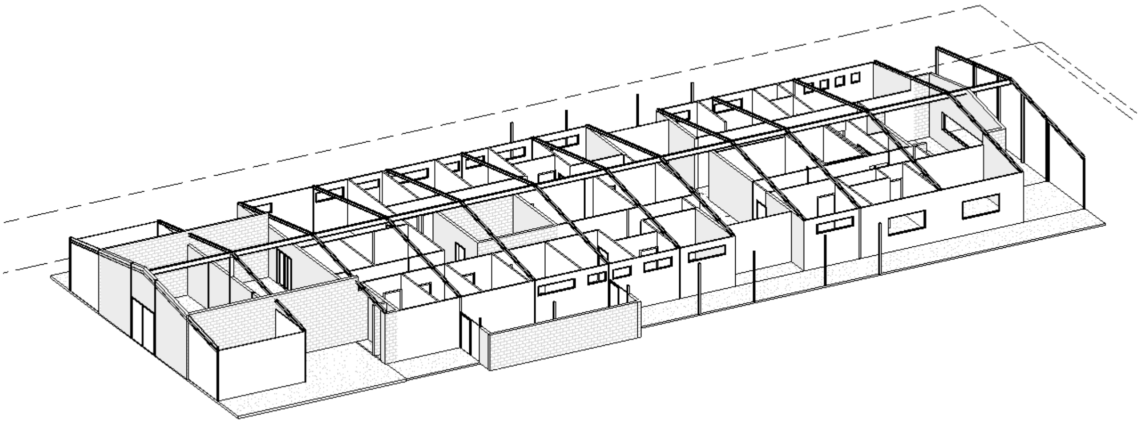


Figure 24: *Model of the clinic in Revit*

To determine how much material has been used for rough construction, a simplified model in Revit was created (fig. 23). With the tool Material take-off, the whole structure was divided into the horizontal and vertical structure and its compositions. Most of the structural elements are composite materials, for example, blockwork walls or concrete slabs which are reinforced. These materials are calculated as a material with the majority of the composite, the reinforcement in the slabs or walls is incorporated in the overall calculations. Reinforcement is used for all options, therefore, the numbers are similar for each option. It does not have an influence on the assessment of the proposed options, as the evaluation comprises of vertical load-bearing and non-load-bearing structure. Used materials were multiplied with their thickness and the area of the wall to get the volume and weight of the material. The calculations were made composition by composition. The total environmental impact depends on the weight of each material.

As the Czech database Envimat does not contain CEB parameters, the environmental parameters were estimated by putting together aggregate with cement and water. Water is a renewable source, so the parameters are made of 85% of aggregate and 10% of cement.

Compressed Earth Blocks	Ratio	PEI	GWP	AP
	-	MJ	kg CO_2	g SO_2
cement	0,1	3,38632	0,76122	1,0855
aggregate	0,85	0,1243	0,0044	0,0254
water	0,05	0	0	0
Total		**0,444**	**0,080**	**0,130**

Table 10: *Environmental parameters of CEB*

3.1.1. Current Building

For every option, foundations have the highest environmental impact. Concrete slab and footings are reinforced with steel. Even though plastic material such as a damp-proof membrane or vinyl floor has the highest environmental impact, these materials are not in such a great amount. When comparing PEI, concrete has the biggest volume of all materials, thus the highest environmental impact. Whereas steel beams have the lowest impact.

CURRENT BUILDING	Primary Energy Input	Global Warming Potential	Acidification Potential
Type of structure	MJ	kg CO_2	kg SO_2
Foundations	795495	44724	106
Vertical Load-Bearing Structure	184185	23271	55
Horizontal Load-Bearing Structure	763971	43438	179
Vertical Non-Load-Bearing Structure	288679	29286	94
Total	**2032330**	**140718**	**434**

Table 11: *Environmental impact of current building*

3.1.2. First Option

Changing blockwork for earth blocks has a positive impact as PEI of vertical load-bearing structure is reduced by 29%. On the other hand, GWP of the same structure is reduced by only 8% Other structures remain the same.

PROPOSED BUILDING 1	Primary Energy Input	Global Warming Potential	Acidification Potential
Type of structure	MJ	kg CO_2	kg SO_2
Foundations	795495	44724	106
Vertical Load-Bearing Structure	130841	21382	50
Horizontal Load-Bearing Structure	763971	43438	179
Vertical Non-Load-Bearing Structure	288678	29285	94
Total	**1978985**	**138829**	**429**

Table 12: *Environmental impact of proposed building 1*

3.1.3. Second Option

Earth blocks have the dominance in this structural system. PEI of the vertical load-bearing structure is reduced by half when compared to the current building. PEI of vertical non-load-bearing structure is diminished by two-thirds.

PROPOSED BUILDING 1	Primary Energy Input	Global Warming Potential	Acidification Potential
Type of structure	MJ	kg CO_2	kg SO_2
Foundations	795495	44724	106
Vertical Load-Bearing Structure	174170	35543	76
Horizontal Load-Bearing Structure	763971	43438	179
Vertical Non-Load-Bearing Structure	100505	12942	27
Total	**1834140**	**136647**	**388**

Table 13: *Environmental impact of proposed building 2*

3.2. Comparison of all options

When comparing all three options, the current building has the highest environmental impact. Because foundations and horizontal load-bearing structure remain the same, the rest of the structure is compared as seen in the graph below (fig. 24). The vertical non-load-bearing structure has the highest improvement as the PEI is reduced by two-thirds. GWP is the highest for the current building, however, the vertical load-bearing structure of option 2 has higher all environmental parameters than the current building. This is caused by adding insulation to earth blocks in order to keep the same thermal resistance. AP of the vertical non-load-bearing structure is lower in the third option (option 2) because of earth blocks. Total reduction of AP of option 2 is about 20% than AP of the current building.

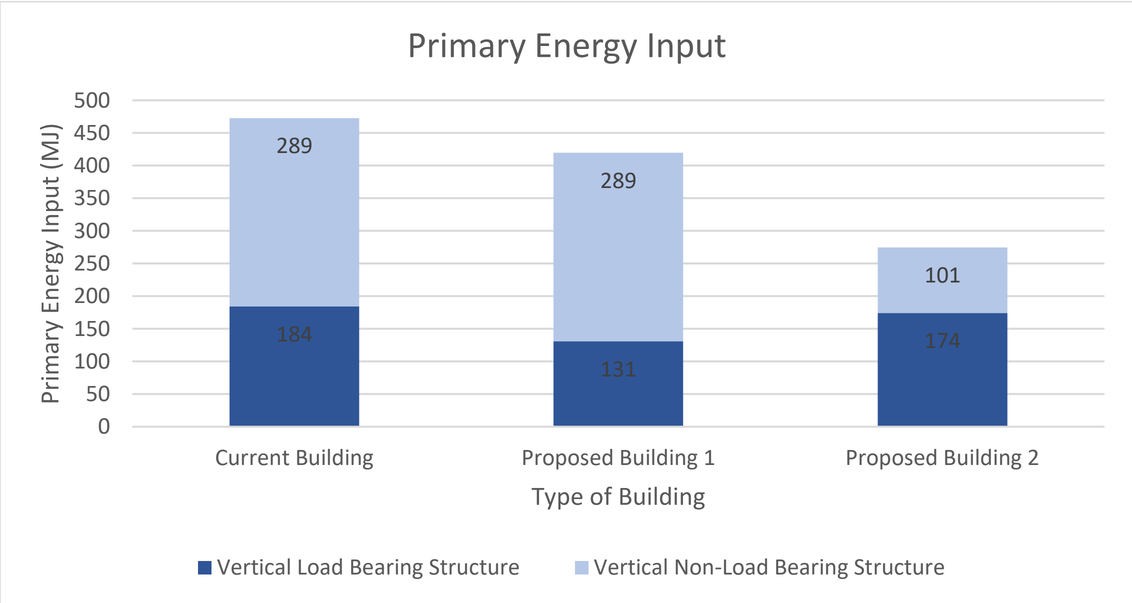


Figure 25: *Primary energy impact of analysed options*

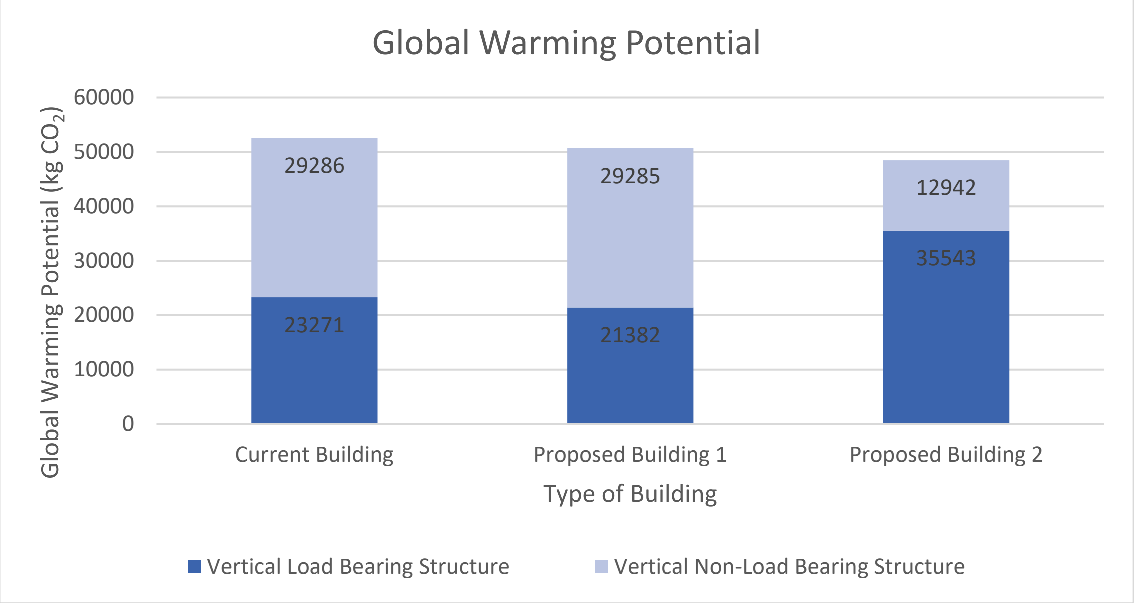


Figure 26: Global Warming Potential of analysed options

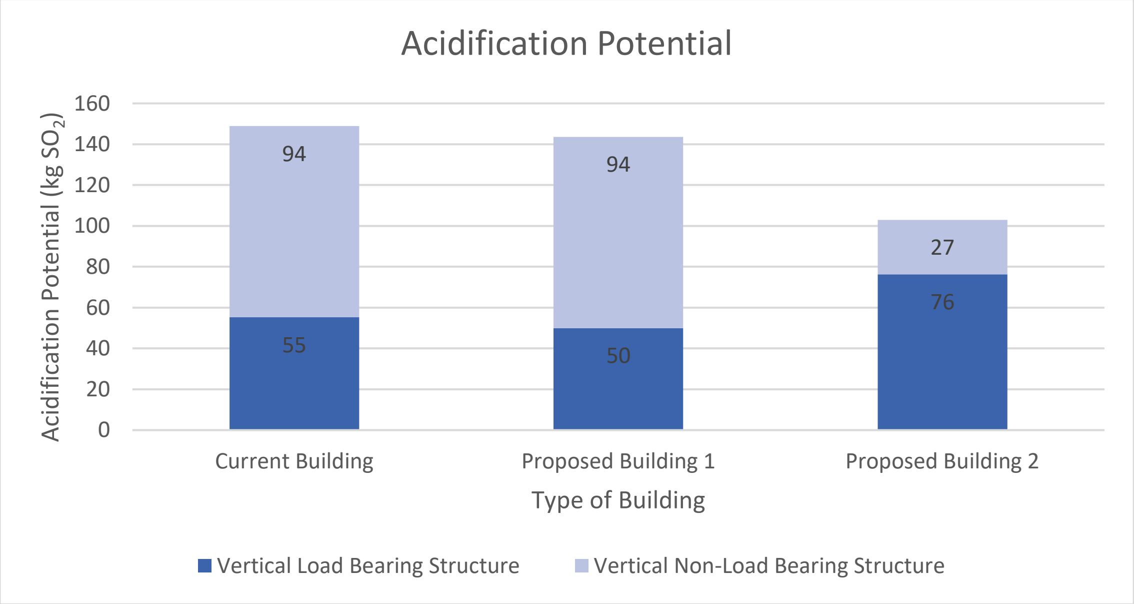


Figure 27: Acidification Potential of analysed options

3.3. Transportation analysis

Together with these environmental parameters, the impact of transporting materials to the site was assessed as well. The transportation analysis is mainly based on assumptions as there is no exact information on how far the construction material is supplied from. The distance of transported material is relevant when it comes to the production of CO_2 as there might be significant savings in case of using the material on the site.

Weight of structures (kg)	Current Building	Proposed Building 1	Proposed Building 2
Foundations	534652	534652	534652
Vertical Load-Bearing Structure	129197	114108	185049
Horizontal Load-Bearing Structure	17636	17636	17636
Vertical Non-Load-Bearing Structure	24238	24238	164924
Total	**705723**	**690634**	**902261**
Concrete on site (-)	417576	417576	417576
Cement to transport (+)	61250	61250	61250
CEB on site (-)	0	97481	301941
Total material weight	**349397**	**236827**	**243995**

Table 14: *Environmental analysis of material transportation*

It is assumed that all the material was transported from Darwin, a capital city of Northern Territory which is around 783 kilometres far from Numbulwar. Maximum road weight in Australia is limited to 42,5 tons. Average Australian truck has a maximum weight of cargo of around 26,27 tons. According to Survey of Motor Vehicle Use in Australia, the average fuel consumption of a truck is 27 l/km [21].

Boundary conditions	
Transportation distance (km)	783
Maximum load on the truck (kg)	42500
Truck fuel consumption (l/km)	40
Specific emission factor of CO_2 for petrol	23,38
Production of CO_2 (g CO_2/km)	935,2

Table 15: *Boundary conditions for transportation analysis*

The Czech environmental database Envimat also provides a calculator for calculating the production of emissions based on fuel consumption. According to the calculations, the average CO_2 emissions of the considered truck with unleaded petrol is 631 g/km. By multiplying the distance with the production of CO_2 per kilometre, the total production of CO_2 is found.

Transportation	Current Building	Proposed Building 1	Proposed Building 2
Transported material weight (kg)	349397	236827	243995
One-way journeys	8,2	5,6	5,7
Total journeys	18	12	12
Total distance	14094	9396	9396
Total production of CO_2 (kg)	13181	8787	8787
Total production of CO_2 (t)	**13,18**	**8,79**	**8,79**

Table 16: *Environmental impact of transportation materials on site*

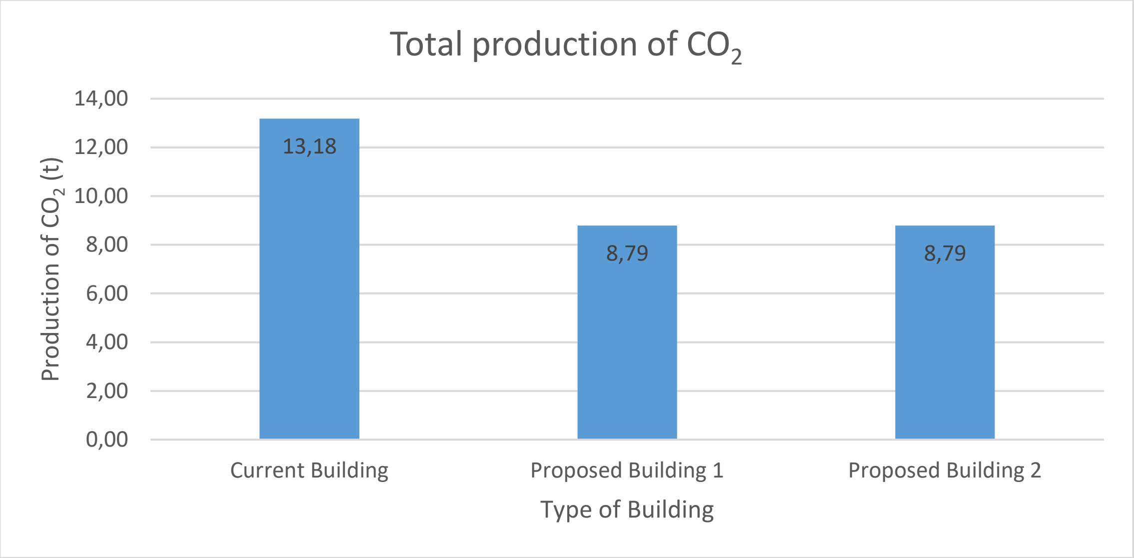


Figure 28: *Total production of CO2 of considered options*

From the results, it is apparent that the least production of CO_2 is the same for both option 1 and option 2. Production of CO_2 of the current building is 4,39 tons higher than for both proposed building 1 and 2 which is caused by transporting more material. Regarding previous results, altogether the most convincing option is option 2 as it has the lowest environmental impact.

4. Building operation analysis – energy consumption

The clinic operates every day a week with a set schedule. According to opening hours, the health centre is open from 9:00 to 16:00 on weekdays and on weekends from 10:00 to 12:00. However, while processing provided data, it was apparent, the clinic runs a few hours before and after opening hours. As seen on the table (fig. 28), on weekdays people start to work around 6:30 till 16:30, 10 hours a day depending on the zone. During weekends the clinic runs from 9:00 to 14:30. On holidays, the building is closed. The clinic serves also as an emergency and in case of an accident the clinic is fully operating. Although the clinic is opened 10 hours a day, part of equipment runs overnight. For example, lighting is switched once people leave from work and so are the computers. Refrigerators and other equipment run 24/7.

General	
Name	**Numbulwar Clinic**
Description	
Source	
Category	Hospitals/Care Homes
Region	General
Schedule type	1-7/12 Schedule
Design Days	
Design day definition method	2-Profiles
Heating design day profile	Off
Cooling design day profile	6:30 to 16:30

Profiles

Mo...	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Jan	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Feb	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Mar	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Apr	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
May	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Jun	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Jul	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Aug	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Sep	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Oct	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Nov	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00
Dec	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	6:30 to 16:30	9:00 to 14:00	9:00 to 14:00

Figure 29: *Schedule of the Numbulwar Clinic in DesignBuilder*

As there is no specific number of people who work at the clinic and the number of patients going on regular examination, occupancy is a rough estimation. It is assumed there are around 20 employees and 10 patients a day. However, the visits may differ. Some days, the clinic is occupied only by clinical staff and some days, there might be over 10 patients. In this case, the assumed number of people is not as decisive as the activity of occupants is more important because of internal heat gains. When people do hard work, the internal gains rise and so the production of CO_2. The activity in the model is stated as standing or walking.

Based on the investigation, there are 7 zones in which climatic data was collected. These zones were assessed by the software called DesignBuilder. This programme provides advanced modelling to develop energy-efficient design of buildings. A model of the clinic was created in the programme with the specification of the structure, activity, lighting and openings, HVAC etc.

Collected data from the clinic was analysed, however, it is not possible to create a model with exact boundary conditions. That is why the model is based on calculations and assumptions of how the clinic operates, but the reality might be different as there are many factors which influence the whole operation of the building. Every zone was assigned by a set of conditions depending on room operation. The whole clinic has around 34 rooms, but the model consists of only 6 zones to simplify the model.

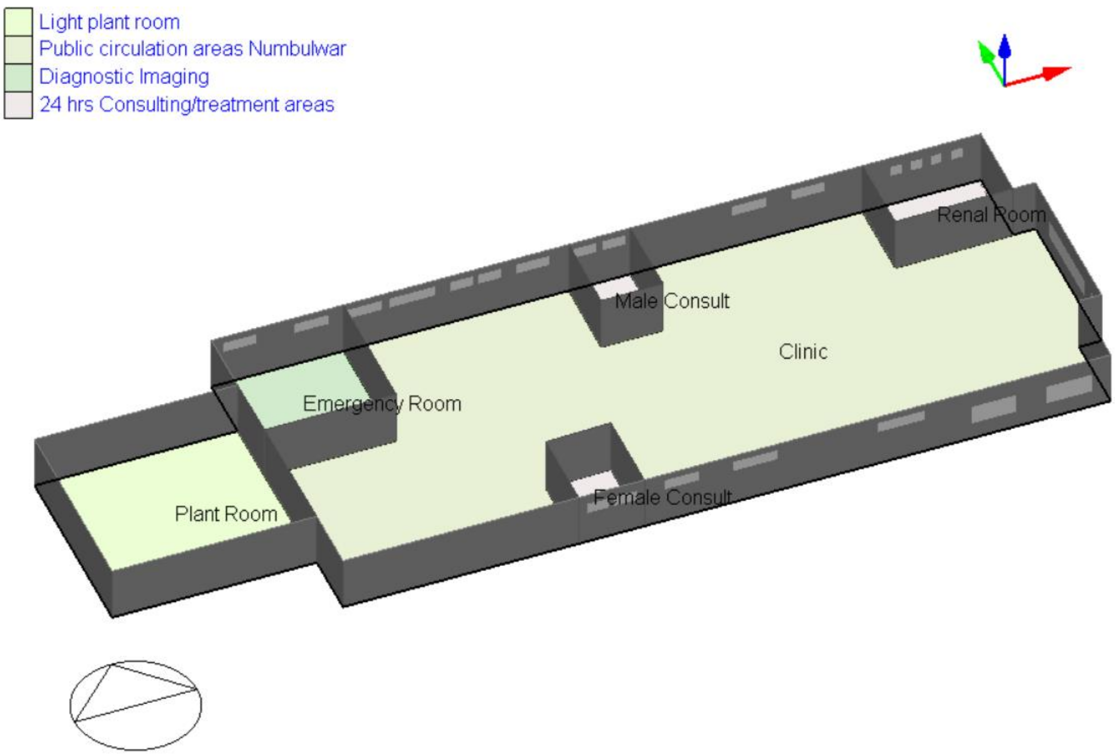


Figure 30: *Model in DesignBuilder with separated zones [DB]*

As seen in the picture above (fig. 29), the model is divided into two bigger zones. The left part of the building serves as an open space with a plant room and an ambulance bay. This area is not cooled but has a natural ventilation system and is rarely occupied. The right, bigger part, is an area with rooms, most of them occupied on daily basis.

The aim of the analysis is to optimize energy consumption based on the building skin and cooling system. The energy consumption of current building has been measured and the results serve as a reference value. The model has been adapted to the investigation, although the conditions differ as there are always some deviations when compared to the operation of the current building.

4.3. Thermal stability

Climate zones with hot summers and hot winters always demand a proper design of cooling in order to achieve thermal comfort in the building. The clinic is situated in the very north of Australia where overheating occurs every day of the year. Even in winter, temperature rises up to 30 degrees. Therefore, it is crucial to minimize internal heat gains by designing effective building skin together with passive cooling as well as undoubtedly necessary auxiliary cooling.

Regarding the investigation from Dr Steve, there are seven zones in which indoor parameters were measured and analysed. Three of the zones are facing the north side with the highest heat gains where a risk of overheating must be assessed. Every room stands for a different ratio of wall composition. However, there are many factors in which they differ and the most influential one is the operation of each room. Another difference of the analysed rooms is the ratio of peripheral and internal walls as well as window floor ratio [22]. All rooms have small windows with high windowsill to minimize direct sunlight. All these factors influence indoor conditions.

The thermal stability analysis is based on the traditional method according to ČSN 730540-4:2005 [23]. The calculations are done for the rooms with the risk of overheating for the hottest day of the year which is 6th December. In the fundamental model, windows are single glazed with the thickness of the glass of 6 mm, all facing north.

Rooms with the risk of overheating	Floor Area	Window area	Window floor ratio
	m^2	m^2	%
Renal Room	27,44	1,44	5,25
Male Consult	14,46	1,44	9,96
Emergency Room	49,54	2,16	4,36

Table 17: *Rooms with the risk of overheating*

There are four options of window shading to determine which one of these is the most suitable one. There might be another relevant type of shading, but that would be for a broader analysis. Windows are 0,6x0,6 metres in size and its shading will help to minimize internal heat gains, however, the significant component of heat gains will be mainly caused by the building envelope. Inner shading is in the form of slats with a medium reflectivity, while the outside shading is slats with higher reflectivity. Windows overhang is 1,5 m long, covering the whole windows.

According to climate data analysis, the highest outdoor temperature is at the end of December and the lowest at the beginning of July. That is why the analysis is focused particularly on these two weeks. To analyse which building structure is the most effective, all three options from environmental analysis were considered as well as other options of CEB. The cooling system was turned off to determine how the building behaves for a selected wall composition.

Option	Peripheral walls	Thermal Resistance R_T (m^2K/W)	Thermal Transmittance U (W/m^2K)	Internal walls
Current Building	Steel wall frame	**2,334**	0,428	Steel wall frame + blockwork
Option 1	Steel wall frame	**2,334**	0,428	Steel wall frame + CEB
Option 2	Single skin CEB with insulation	**2,172**	0,460	CEB
Option 3	Single skin CEB without insulation	**0,505**	1,979	CEB
Option 4	Double skin CEB with insulation and cavity	**2,708**	0,369	CEB
Option 5	Double skin CEB	**0,796**	1,257	CEB

Table 18: *Thermal Resistance of wall compositions*

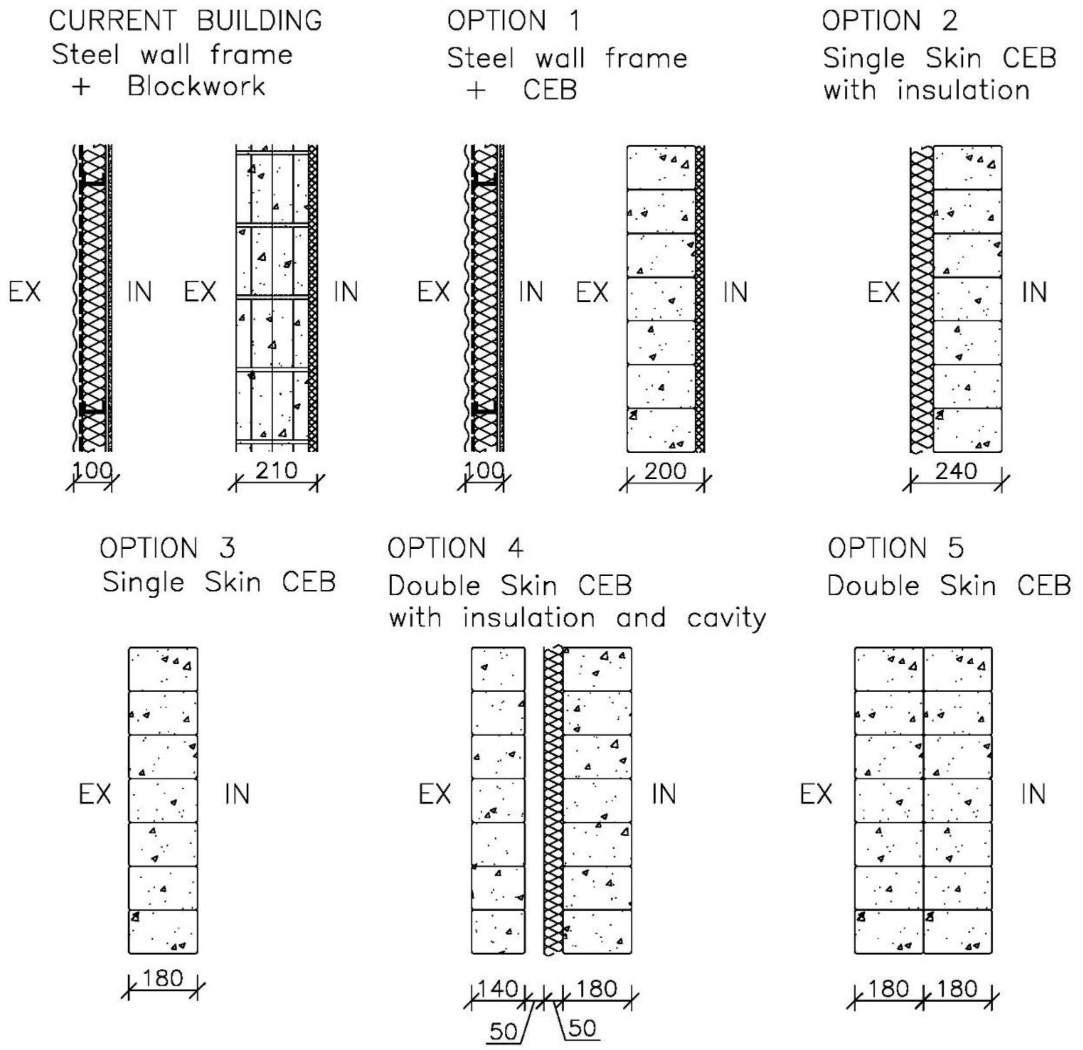


__Figure 31:__ Various options of wall composition of peripheral walls

4.3.1. Renal Room

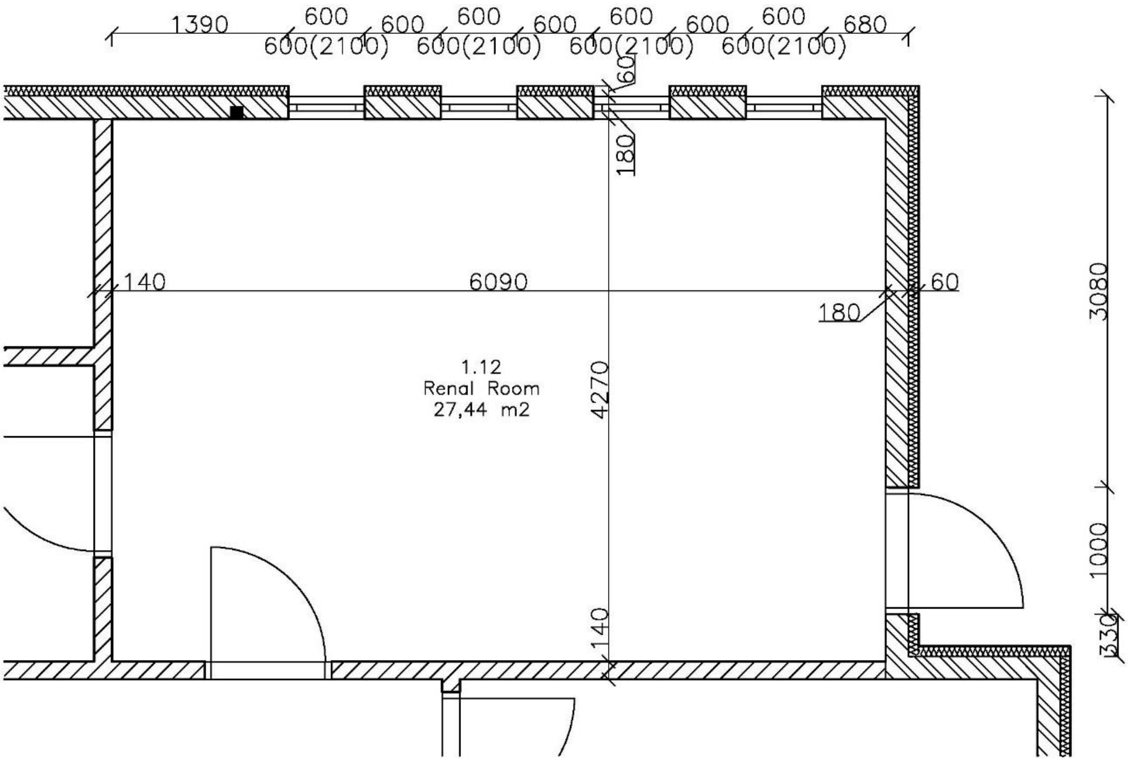


Figure 32: *Renal Room*

Highest temperature difference (°C)	Renal Room			
	no shading	inner shading	outside shading	overhang
Current Building	11,57	9,21	8,92	9,13
Option 1	8,08	7,90	7,63	7,80
Option 2	4,67	4,64	4,53	4,57
Option 3	5,42	5,38	5,27	5,31
Option 4	4,59	4,54	4,36	4,45
Option 5	4,56	4,51	4,33	4,43

Table 19: *Highest temperature difference in Renal room*

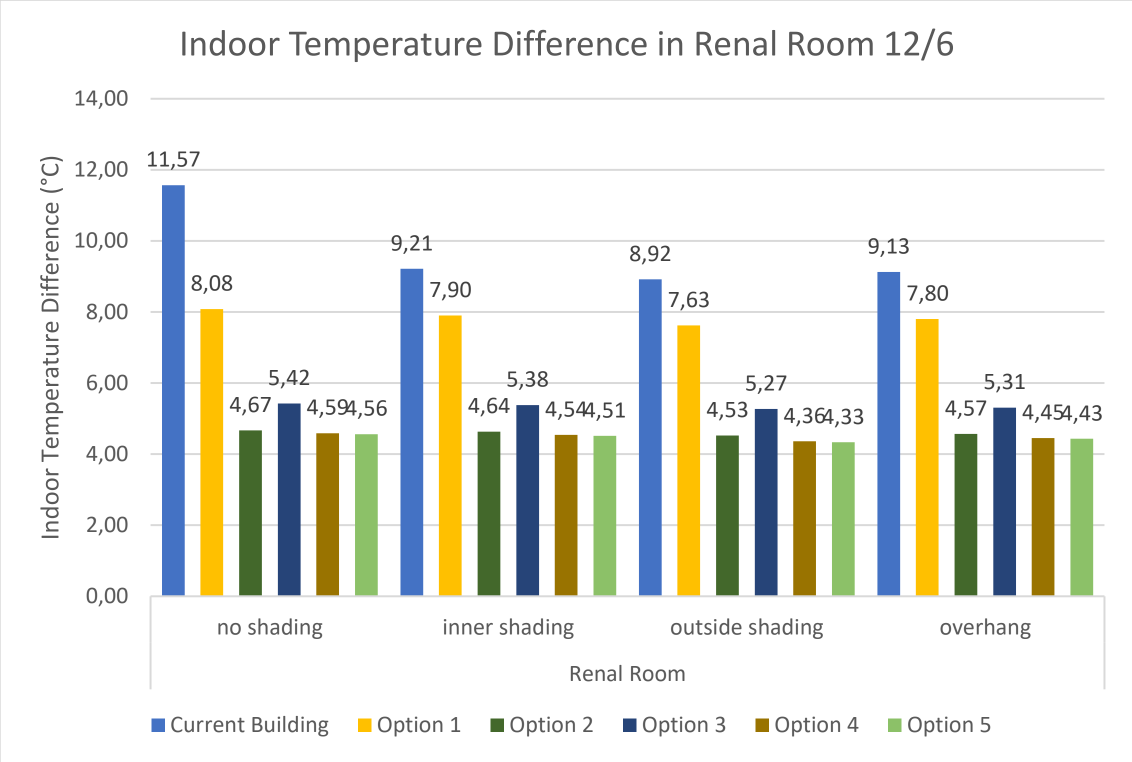


Figure 33: Indoor temperature difference in Renal Room

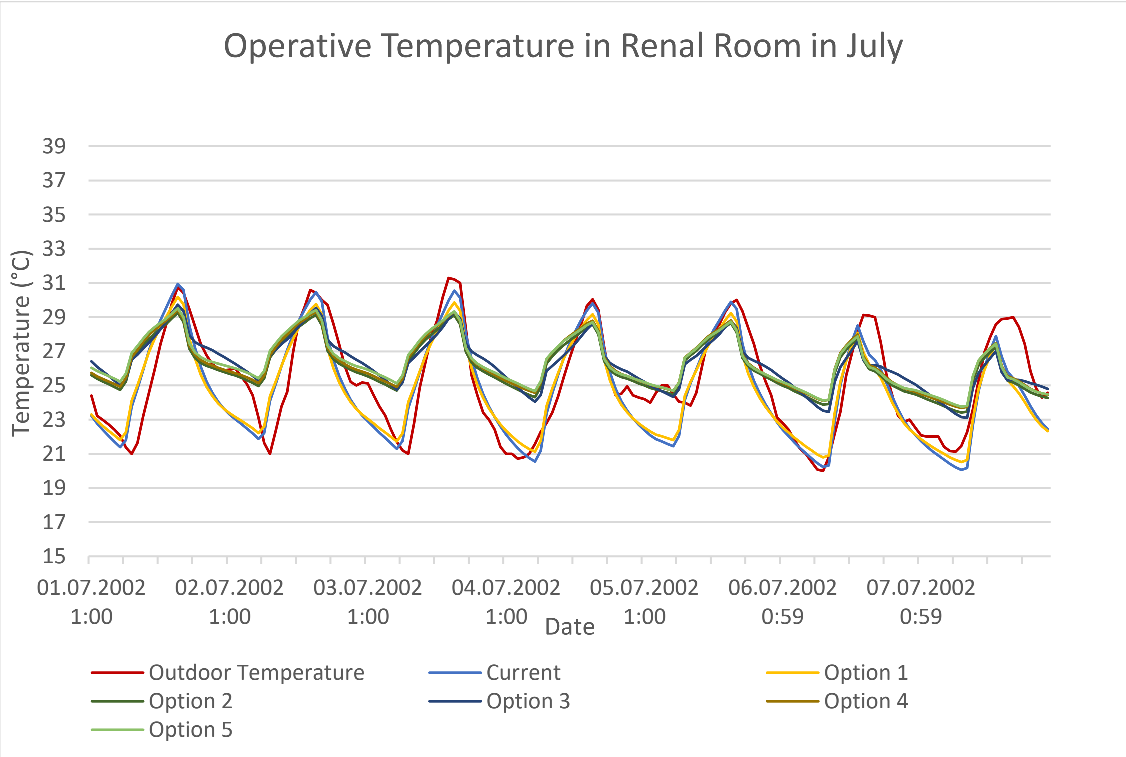


Figure 34: Operative Temperature in Renal Room in July

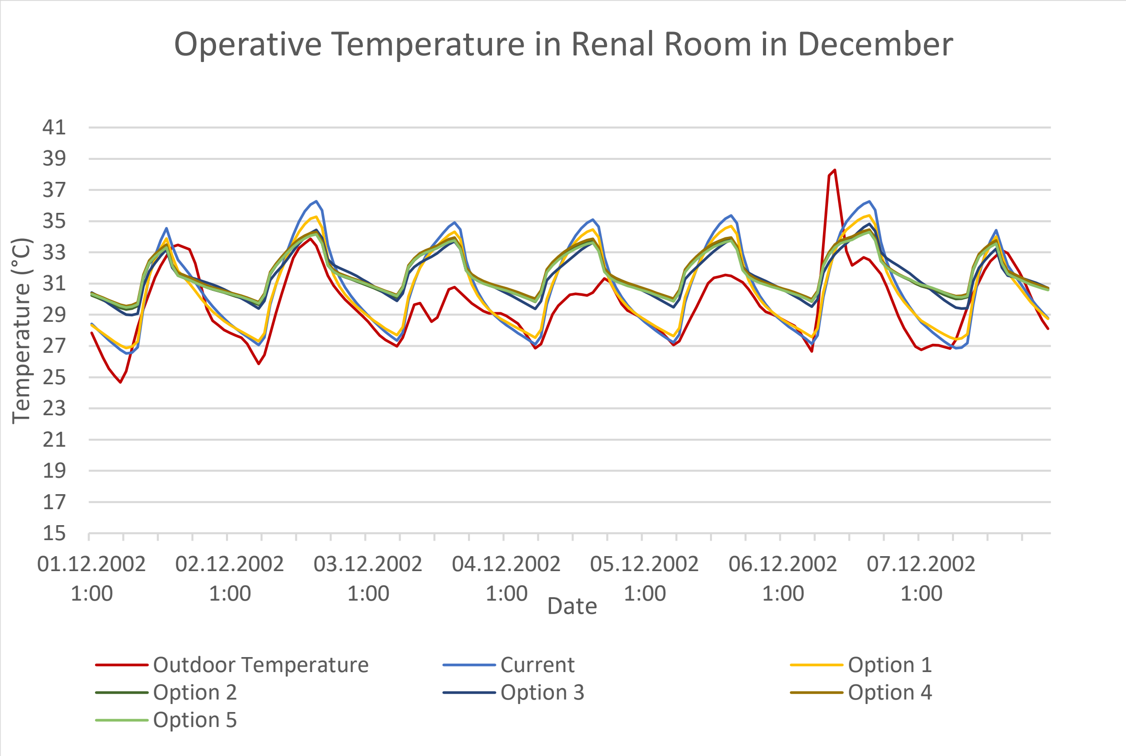


Figure 35: *Operative Temperature in Renal Room in December*

As seen in the graphs (fig. 33 and 34) during winter, the indoor air temperature in the current building and option 1 goes up to 31 degrees around midday, while at night it drops to 22 degrees. For other wall compositions made of CEB, temperature fluctuations are not significant, and its temperature difference is around 4 degrees. In summer, the temperature difference is smaller, for the current building and option 1, it is around 6 degrees and for other wall compositions, the temperature difference is 4 degrees. However, the indoor air temperature in summer is around 4 degrees higher than in winter.

4.3.2. Male Consult 2

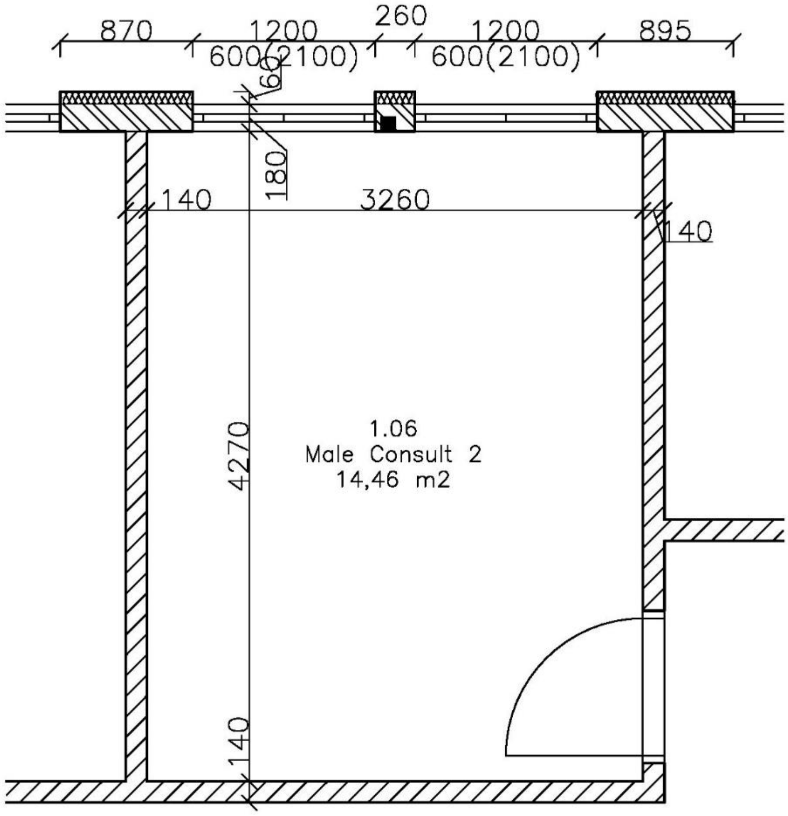


Figure 36: *Male Consult*

Highest temperature difference (°C)	Male Consult			
	no shading	inner shading	outside shading	overhang
Current Building	16,56	15,85	14,98	15,33
Option 1	16,51	15,80	14,93	15,29
Option 2	5,26	5,18	5,00	5,02
Option 3	5,44	5,35	5,17	5,19
Option 4	5,41	5,26	4,95	5,06
Option 5	5,41	5,25	4,94	5,07

Table 20: *Highest temperature difference in Male Consult*

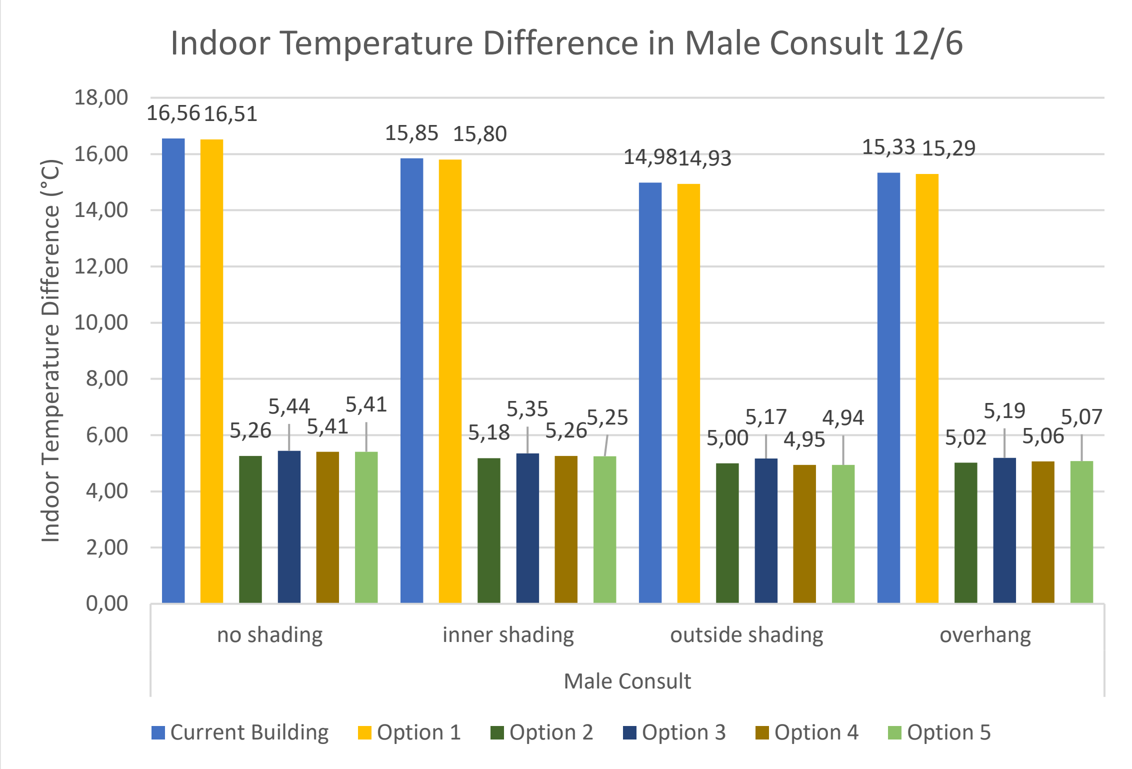


Figure 37: *Indoor temperature difference in Male Consult*

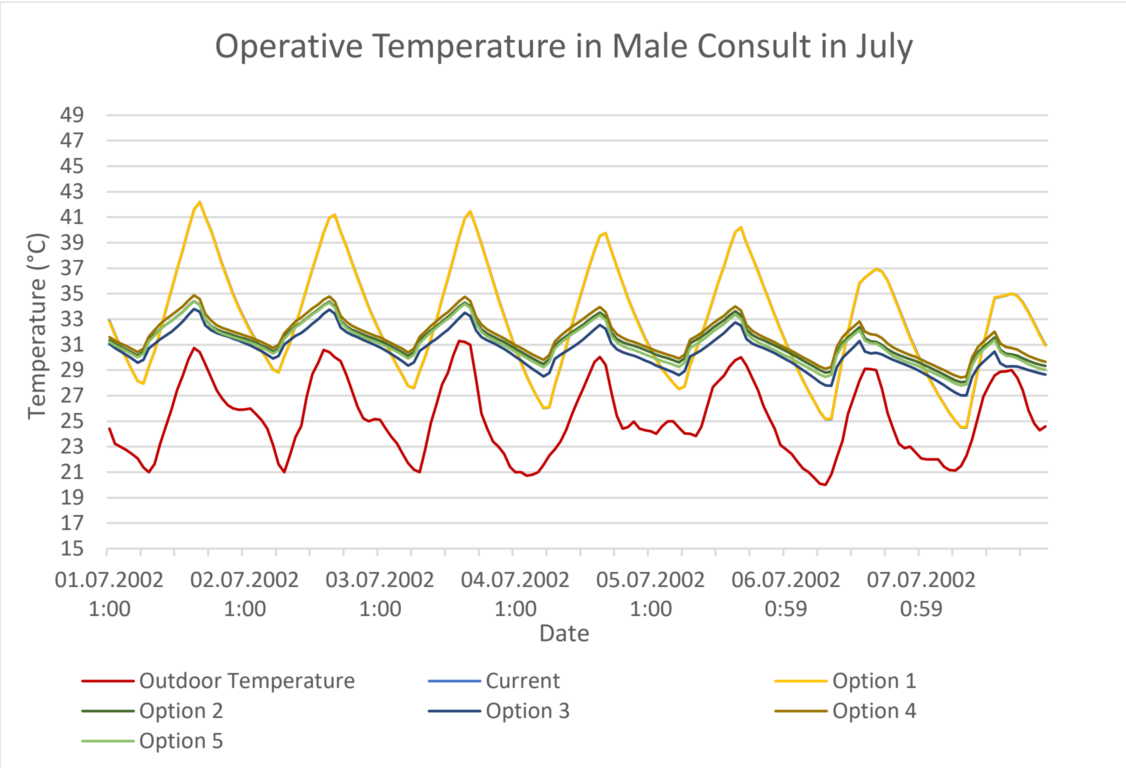


Figure 38: *Operative Temperature in Male Consult in July*

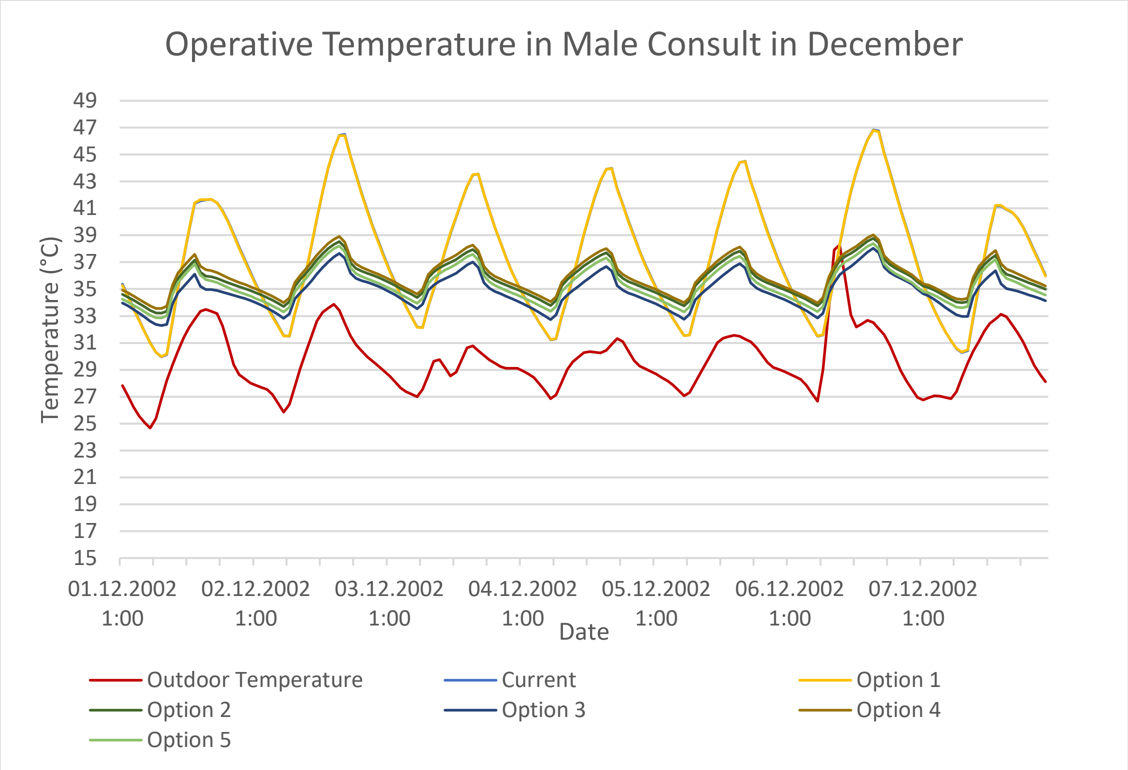


Figure 39: Operative Temperature in Male Consult in December

Male consult has a different operation than the Renal room, therefore, the indoor air temperature is a bit higher. As seen on the graphs, the behaviour of the CEB wall structure is rather stable when compared to the steel wall frame wall compositions. While in July, the temperature difference of the steel wall frame wall composition is around 14 degrees, for the CEB structure it is around 5 degrees. In the summer months, the indoor temperature in the current building and option 1 rises to 47 degrees. The CEB wall compositions have indoor temperature difference lower, approximately 5 degrees.

4.3.3. Emergency Room

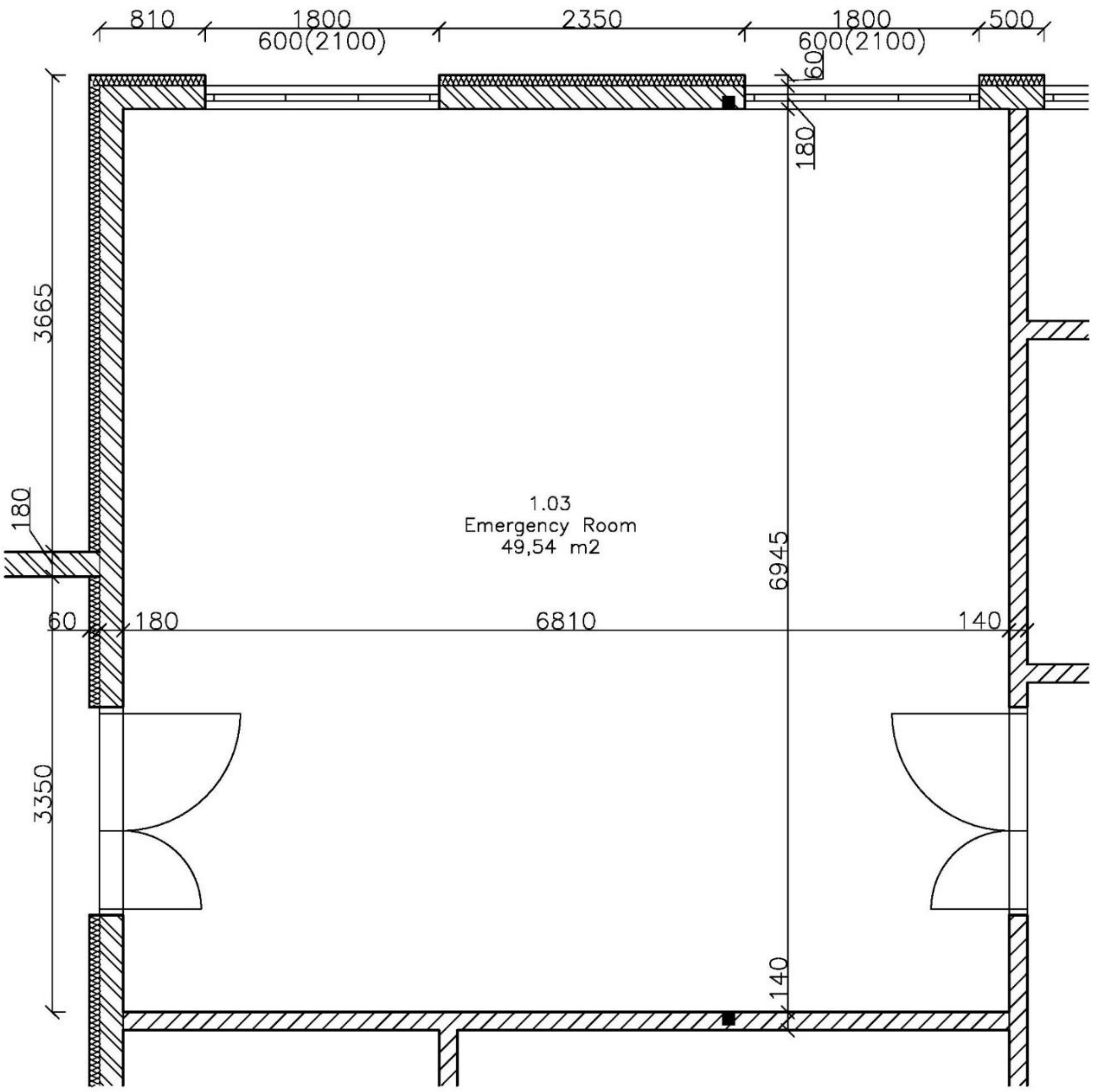


Figure 40: *Emergency Room*

Highest temperature difference (°C)	Emergency Room			
	no shading	inner shading	outside shading	overhang
Current Building	11,57	11,54	11,52	11,52
Option 1	11,40	11,37	11,35	11,35
Option 2	5,39	5,38	5,37	5,37
Option 3	5,43	5,42	5,41	5,42
Option 4	4,81	4,80	4,79	4,79
Option 5	4,84	4,82	4,81	4,82

Table 21: *Highest temperature difference in Emergency Room*

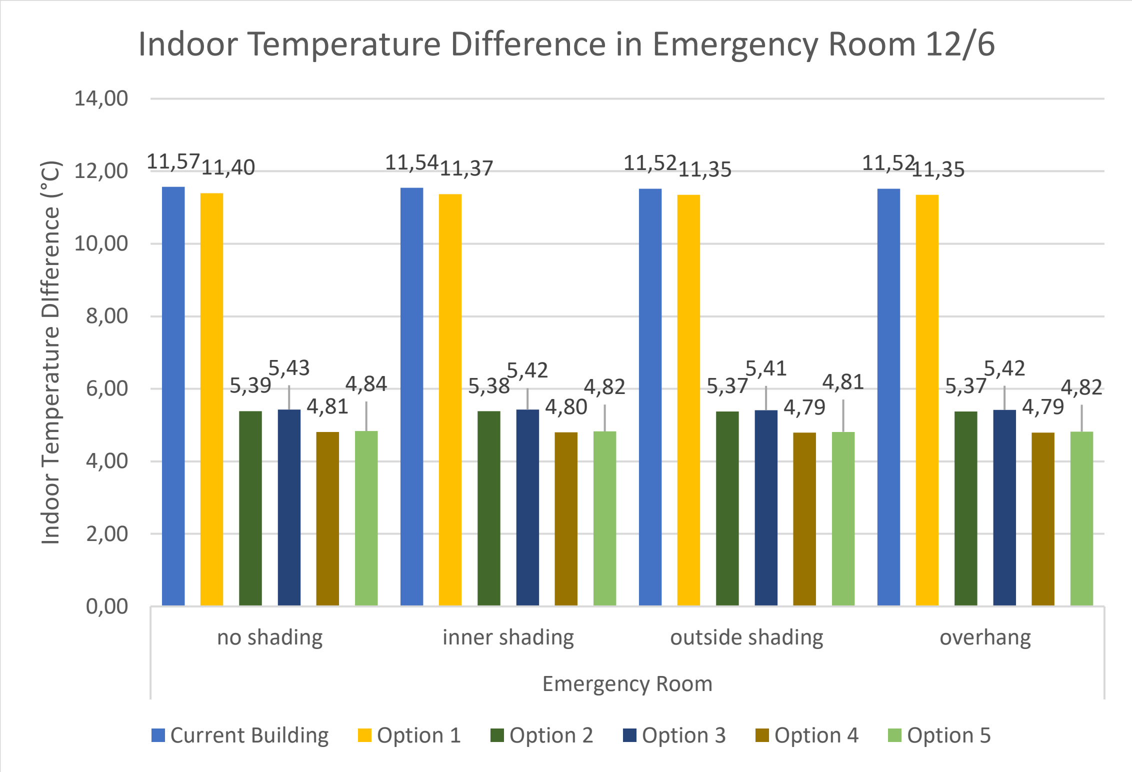


Figure 41: Indoor temperature difference in Emergency Room

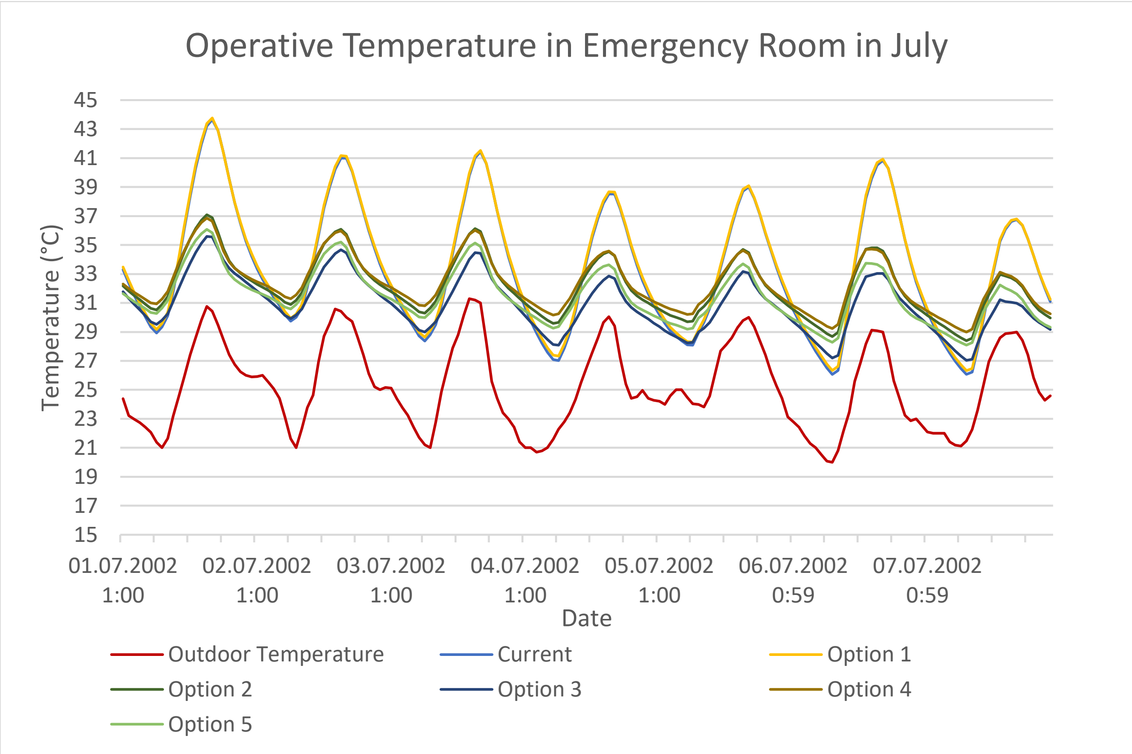


Figure 42: Operative Temperature in Emergency Room in July

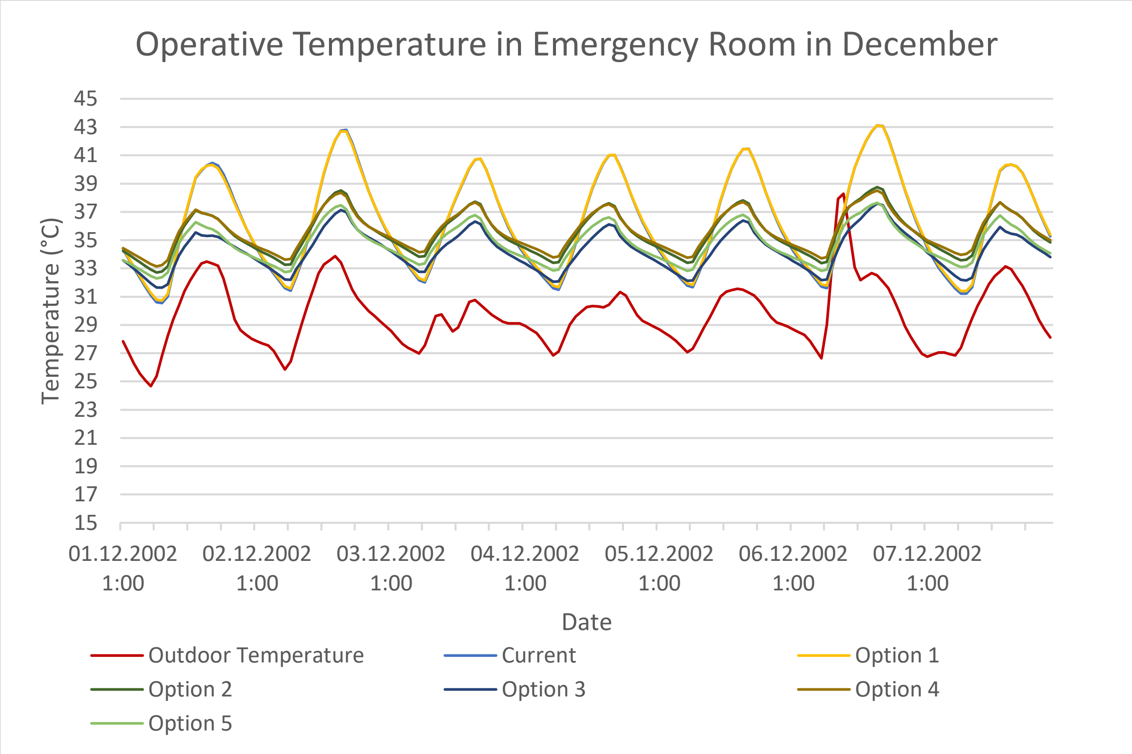


Figure 43: *Operative Temperature in Emergency Room in December*

Various wall compositions in the Emergency room have quite similar behaviour in winter and summer. The indoor air temperature difference is not significant for both seasons. However, in winter the current building and option 1 causes bigger temperature fluctuation than in summer months. While the temperature difference is around 12 degrees, for the CEB structure it is around 6 degrees.

Comparing the indoor temperature differences of the highest and lowest temperature in each room, the highest difference has the steel wall frame wall composition. That is caused by the low heat capacity of the steel. Option 2 has most of the times the lowest temperature difference. As seen in the graphs (fig. 32,36 and 40), the divergence between types of shading is not significant which is caused by the size of windows. Internal heat gains depend more on building skin and its ability to accumulate heat. For the window shading, the best option is the external shading in the form of slats with high reflectivity, although the temperature difference between chosen options is slight. In this case, price of each shading and maybe its environmental impact could be considered. By choosing external shading together with roof overhang, internal heat gains are reduced not only through windows but also through part of the walls. This variant is chosen for the following analysis.

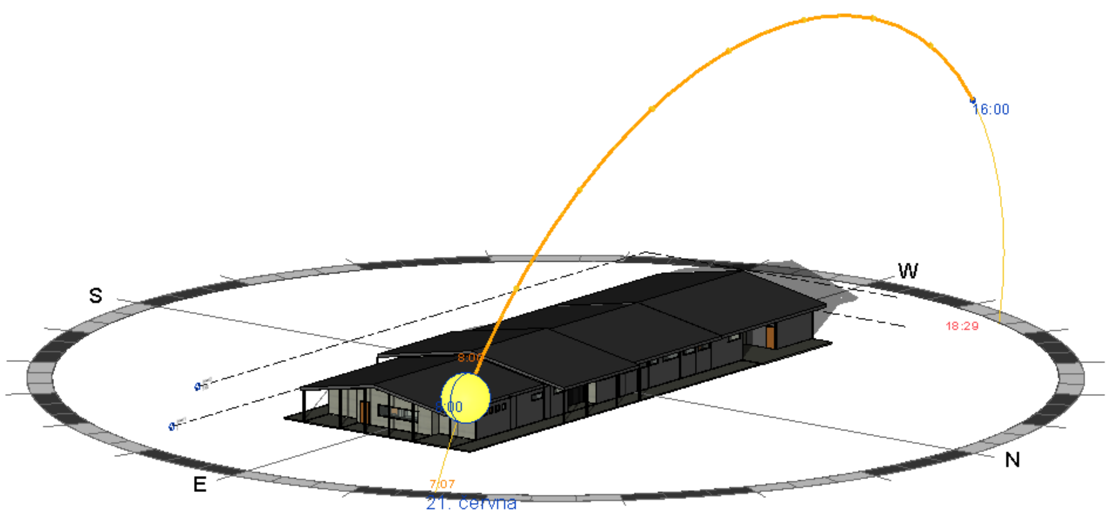


Figure 44: *Solar analysis – northern façade in winter solstice*

To minimize solar gains through windows, all windows are shaded by the roof with an overhang of 1,35 metres on northern and southern façade and 0,8 metres on eastern and western façade. According to a solar analysis done in Revit, the sun is very high throughout the year and so the windows of northern façade do not get any direct sunlight. The main problem is overheating of the roof as it is exposed to the sun all year long.

When it comes to wall compositions, the first two variants (current building and option 1) have the highest temperature difference during winter and summer. Steel has a lower heat capacity than CEB and therefore, the construction does not hold any heat. On the other hand, CEB has higher capacity and store the heat in the construction and then radiates the heat to the indoor environment. Another factor is the finish of the wall composition. In the case of the steel wall frame, there is a steel wall cladding, whereas CEB have a finish in the form of plaster. Various options of CEB were showed to determine which one is the most suitable in terms of thermal-technical features, but also environmental. The temperature difference between CEB options is not significant and it is hard to say which wall composition is the best one based on one-week temperature analysis as this may differ every year depending on climate and other factors. Therefore, the decisive factor will be the annual energy consumption of each option.

4.4. Ventilation

Ventilation at clinics usually requires high ventilation demand because of the high rate of pollutants production. Ventilation is provided both naturally and mechanically. Natural ventilation works particularly in the plant room and ambulance bay, where the building skin is firstly not insulated and secondly consists of a perforated panel which helps the air comes through. Ventilation in the occupied area is mainly mechanical. Natural cross ventilation works through windows on northern and southern façade. However, in climate such as this one, cross natural ventilation is not a good idea as the day temperature is very high and can only work during a night with night breezes.

The ventilation system has two main units, each operating in half of the building. One operates in the northern half of the building where rooms have higher indoor heat gains and the other one operates in southern part with lower heat gains. It is a pressured balanced system, except ventilation of hygienic spaces with under pressured system. There is usually one 4-way diffuser in every room for supply fresh air and the exhaustion of polluted air is at the corridors.

The lowest recommended amount of supplied fresh air is stated at 25 m^3/h for a person according to ČSN EN 15665 [24]. If there are 30 occupants, there will be a supplement of fresh air of 750 m^3/h, which is a minimum value. The ventilation system is designed for more people just in case of an unfavourable situation. According to the scheme of ventilation and cooling drawing, assumed supply air is stated as 75 m^3/h for most of the rooms. It is assumed there are 3 people in each room. However, it will mostly run on lower performance to save energy, and therefore there are 30 occupants set in the model.

4.5. Cooling

A proper design of a cooling system is essential in this climate zone. Concerning the analysis of outdoor temperature throughout the year, cooling is necessary all year long. Cooling is provided both by the ventilation system and indoor units. The outlets (4-way diffusers) bring fresh air to every room with the desired temperature. In some rooms, there are air-conditioning units because of higher cooling demand. These rooms require cooling depending on activities with specified modification of supply air and high demand for clean space.

The current cooling system is a separate system. The level of comfort is subjective, the temperature in the rooms is usually set around 21 to 23 degrees depending on the season and activity. There are two main units located in the plant room. From these two units, one half operates with the southern part of the building and the other half with the northern part of the building. This distribution is because of higher solar gains from northern façade.

As mentioned before, to create an exact model of the clinic and how it operates is not possible without site observation. Therefore, the total energy consumption which was observed by Dr Steve will be as a reference value. The fact, that the clinic started operating in September 2017 and provided data indicates only 6-month operation must be taken into consideration. As seen in table 1 (pg. 21), the average energy consumption of the whole building during operation is approximately 9000 kWh per month. Under the same conditions, the clinic would spend 108000 kWh a year. Since the clinic was opened last year, it is assumed the energy consumption will be a bit higher during the following years.

Simulations in DesignBuilder show the annual operation of each option. The main focus was on cooling as this part of consumption might bring significant energy savings and can determine wall composition with the highest efficiency. Every option of the building has the same template operation, but various wall compositions. The first three options (current building, option 1 and 2) are taken from the environmental analysis and have similar R-value, while the rest three options (option 3,4 and 5) have various R-values. Option 3 and 5 do not even meet the requirements for the minimum recommended R-value for walls. Nevertheless, these options were created to show the difference in energy demand for cooling.

Annual building utility performance	Energy consumption for cooling	Total energy consumption	Energy consumption
	kWh	kWh	kWh/m^2
Current Building	122868	146102	**174,96**
Option 1	122412	145646	**174,42**
Option 2	117752	140986	**168,84**
Option 3	123997	147231	**176,32**
Option 4	122587	146520	**175,46**
Option 5	126292	150225	**179,90**

Table 22: *Annual total energy consumption of various options*

Comparing the annual energy consumption of the current building with actual consumption in the model, the values differ in 19% which is an acceptable deviation. The highest and lowest annual energy consumption is around 6200 kWh for the whole building, which is around 8 kWh per square meter. It is obvious from the results that wall compositions of option 3 and 5 have the highest demand for cooling because of their poor thermo-technical features.

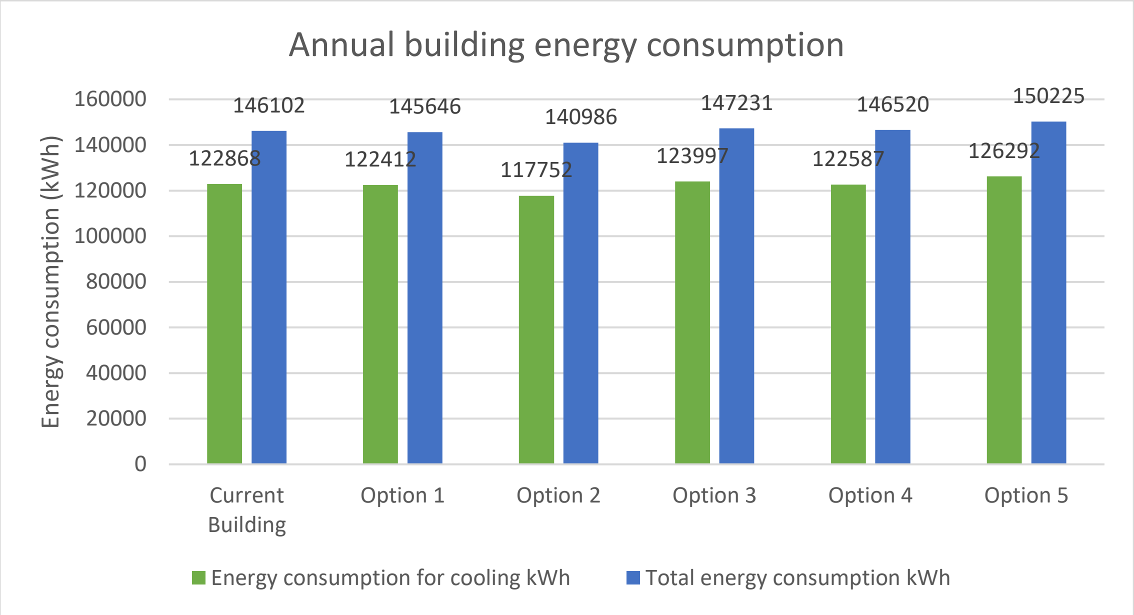
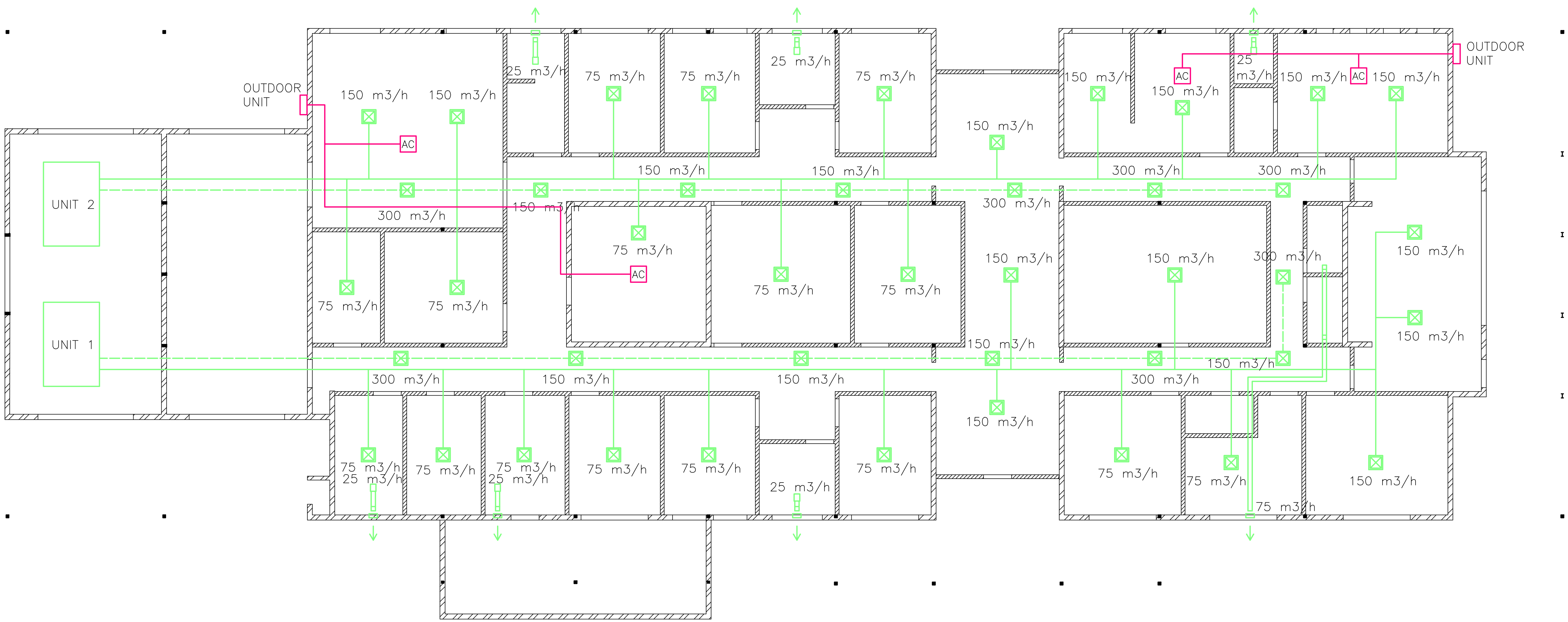


***Table 23:** Annual building energy consumption*

From the graph above it is seen that the biggest energy consumption has option 3, which is caused by the absence of insulation. This option has the lowest R-value, thus the building gets the highest heat gains and the highest demand for cooling. Whereas the lowest energy consumption has option 2 when it comes to total energy consumption for the whole building.

VENTILATION AND COOLING SCHEME



- 4 WAY DIFFUSER
- SUPPLIED FRESH AIR
- EXHAUSTED AIR
- AC UNIT

CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF CIVIL ENGINEERING
DEPARTMENT OF BUILDING STRUCTURES

NUMBULWAR HEALTH CENTRE – DEVELOPMENT OF A SUSTAINABLE BUILDING CONCEPT

Student	Ema Škarecká	Scale	1:150
Advisors	Ing. Jan Růžička, Ph.D.	Format	A3
	Dr Steve Burroughs	Year	2018/19
Drawing	VENTILATION AND COOLING	Nb.	5

4.6. Proposed improvements on energy savings

Although the building was opened last year, yet there is always a possibility of energy savings, even if it is a small amount of energy. Possible improvements would be designed properly with the site observation as the following improvements are based on assumptions. Replacement of building envelope is one step for energy efficiency as the building skin has the biggest influence on the whole indoor environment. From the analysis of energy consumption, option 2 has the lowest consumption and therefore, it is going to be used for a new model of a building with another effective solution. Another savings can be made by replacing single glazed windows which have poor R-value. These windows will be replaced by double glazed windows, improving the R-value by 60%. Windows will be shaded by roof overhang but also by outside shading slats improving the overall features of windows.

Another savings can be reached by proper cooling settings. Cooling system partly works together with ventilation, so it must be on when the clinic operates, while the separate air-conditioning units have quite different settings. Set back temperature will be set higher during the night period from 28°C to 30°C. During the day, the temperature will be set to 24°C instead of 22°C. It is assumed the temperature will differ according to weather conditions, and therefore, the settings will change together with boundary conditions.

Because the daylight factor in the rooms is not satisfactory and the required value is reached by artificial lighting, energy consumption on lighting is high. On the other hand, a solution of small windows with high windowsill is suitable as with large windows, solar gains would be bigger and energy consumption on cooling would be even higher. Using LED lights will improve the overall consumption. Implementing all these improvements into the model, energy consumption on cooling will be reduced by 12,5%.

5. Results analysis

The thermal stability analysis has shown how the building behaves depending on various wall composition. Since the results of CEB wall composition differ in hundredths of °C, the environmental impact and annual energy consumption of each composition will decide. Option 3 and 5 do not meet the requirements on minimal R-value of the wall, therefore these options cannot be considered. The thermal resistance of option 4 is even better than the rest of the options, however, the thickness of the wall is higher than other proposed options. Considering the fact, more material would be needed for this structure and the total floor area would become smaller. According to the analysis of energy consumption, the results move around 120 000 kWh annually, except option 4. Energy consumption of the current building which was measured at the site differs only about 19% from the current building created in DesignBuilder. Since the deviation is within the limits, the created model with set boundary conditions validated the current building.

That is why the most convincing option is option 2, CEB wall with 0,06 m of thermal insulation. Although this option requires insulation to meet the requirements for R-value, from all the options it is the most suitable from the environmental as well as energetic point of view. The chosen construction is competitive to the current construction, the energy savings are not significant, however, the environmental impact of the two compared options is relevant.

Type of structure	Energy consumption		Environmental Analysis			
	Energy consumption	**Price for energy**	**PEI**	**GWP**	**AP**	**CO_2**
	kWh	$AUD	MJ	kg CO_2	kg SO_2	t
Current building	146102	43830,6	1760038	132092	400	13,2
Option 2	140986	42295,8	1561849	128020	354	8,8
Improved Option 2	123439	37031,7	1561849	128020	354	8,8
Difference	**22663**	**6798,9**	**198189**	**4072**	**46**	**4,4**

Table 24: *Comparison of current and proposed building*

The chosen variant has been improved in an energetic way to see possible energy savings. All three options were compared to determine how the improvement helped in terms of sustainability. While the environmental part of option 2 stays the same, the energy consumption differs by 12,5%, saving around $5300 annually. Energy cost is calculated assuming 30cents/kWh with no solar electricity input.

To evaluate whether the chosen variant is actually efficient, a very broad Life Cycle Analysis (LCA) was created comparing the current building with the chosen variant and improved version of the chosen option. The focus was on the amount of energy production from building the construction to 50 years of operation. The calculations of the life cycle are simplified based on the previous analysis as the problematic of LCA is very complex and demand detailed research on elements of the structure and site observation. The PEI factor of both options was considered as an initial input of energy plus annual energy consumption. These calculations are based on the simulations from DesignBuilder and might be different from the actual situation. Another fact to be considered is that throughout the years, a lot of things can change, renovation may happen and so the boundary conditions might differ in a few years. These results only show a prediction of the three options within the following years.

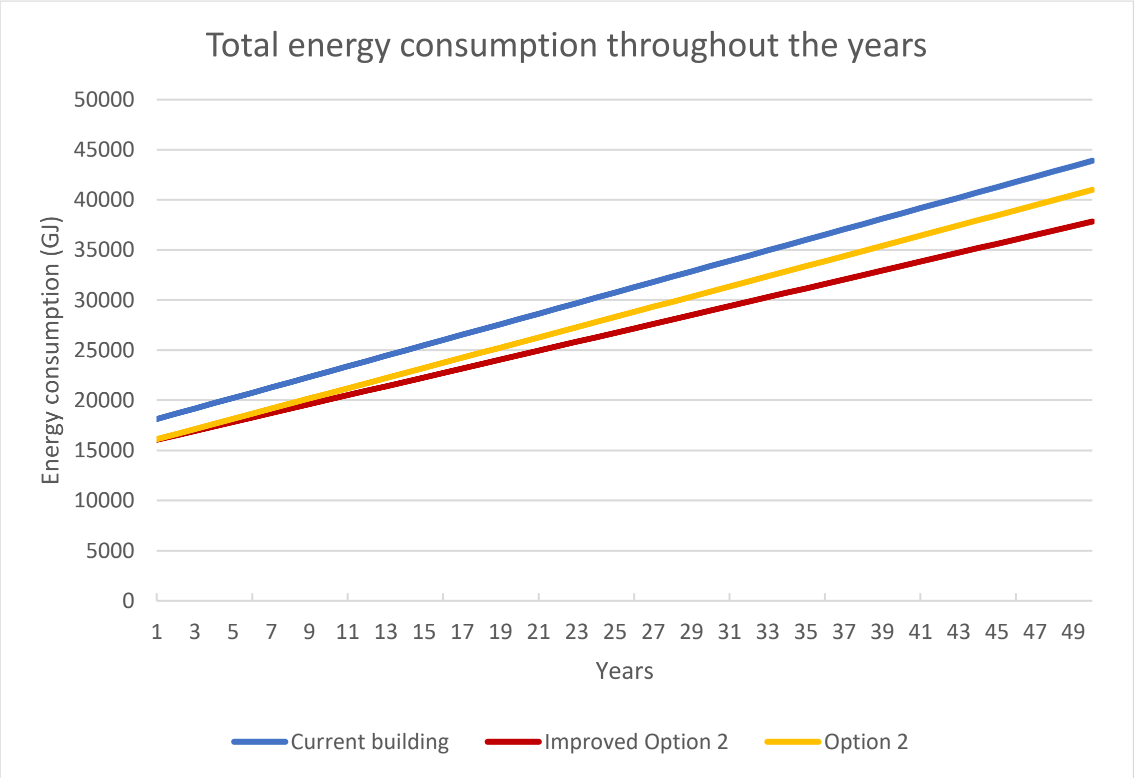


Figure 45: *Total energy consumption throughout the years*

Comparing the analysed options, the initial energy demand is higher for the current building. On the other hand, in 50 years, the current building would consume 14% more energy than the improved version of option 2. Although the improvement of option 2 is not significant, the results show that in 50 years, one can build about 1/3 of a new house.

6. Conclusion

All carried out analysis during the work have shown a positive environmental impact of CEB structure. Although commonly used construction in this area is the light steel wall frame, earth blocks have proved their good thermo-technical features, also considering their positive impact on the indoor environment. By implementing natural material into the structure, production of CO_2 drops significantly, particularly when the whole vertical load-bearing structure is made of CEB.

Regarding the environmental analysis, construction with the majority of CEB has the lowest production of CO_2 of analysed options and it is a convincing solution for the proposed structure. The newly designed structure of CEB has a lower environmental impact than the current building as Primary Energy Impact is minimized by 12%, Global Warming Potential only by 3% and Acidification Potential is reduced by 12%. Although these results might not be compelling, the transportation analysis has shown that by using the material on site, 4,39 tons of CO_2 is saved.

Because of a risk of overheating, thermal stability analysis was done to determine which construction has good thermo-technical features for this climate. North oriented rooms were assessed in the program DesignBuilder, analysing the indoor environment for the hottest week of the year. Four types of window shading were considered to reduce internal heat gains. The best option appears to be outside shading in the form of slats with high reflectivity in the combination with a roof overhang. Another part of the thermal stability analysis was to assess the behaviour of various wall compositions. The current building together with option 1 has a non-load-bearing structure from the steel wall frame. These wall compositions cause the biggest indoor temperature difference. Because steel has a lower heat capacity, the indoor air temperature fluctuates more, with the temperature difference of around 12 degrees. While CEB structure has the ability to accumulate heat, the difference of the indoor temperature for the hottest week is around 4 degrees. Comparing the pros and cons of all options, the decisive factor was the annual energy consumption on cooling. Option 2, CEB with 0,06 metres of insulation has the lowest energy consumption. The energy consumption of option 2 is 6 kWh/m^2 lower than the consumption of the current building. Concerning thermal stability analysis and environmental analysis, option 2 is overall the best option.

Although the building skin has proofed to be energy efficient, another factor affecting energy demand is the operation of the building. The option 2 has been chosen as the most suitable solution and therefore, improvements in energy savings were proposed. By changing cooling settings, replacing single glazed windows for double glazed windows or implementing LED lights into the building, the energy demand becomes lower. However, the overall consumption can be changed by the behaviour of occupants by turning off the devices when they are not used. By incorporating these changes into the model, the annual energy consumption has reduced by 12,5%.

The last analysis was focused on energy consumption of chosen variants within 50 years. Even though the results have not shown a significant improvement, CEB structure is still the best option when it comes to the environmental and energetic features. By improving the option 2, this variant will produce 14% less energy in 50 years than the current building. This amount covers one-third of the initial energy for building a new house. Although the savings are not compelling, the main factor is the good indoor environment and satisfaction of occupants.

7. Reference

[1] SLAPER, Timothy F. HALL, Tanya J. The Triple Bottom Line: What Is It and How Does It Work? In: Indiana Business Review [online]. Indiana Business Research Centre, Indiana University Kelley School of Business. Spring 2011. [vid. 2018-01-06]. Available on: http://www.ibrc.indiana.edu/ibr/2011/spring/article2.html

[2] BRUNDTLAND, GH. Our Common Future: Report of the World Commission on Environment and Development. Oxford University Press, 1987. 383 pages.

[3] Construction and CO2 emissions to the atmosphere. In: Growing Buildings. May 2017. [vid. 2018-01-06]. Available on: https://growingbuildings.com/en/construccion-y-emisiones-co2-a-la-atmosfera/

[4] Australia. In Wikipedia: The Free Encyclopedia [online]. Wikimedia Foundation, 2003. Edited 19 December 2018, at 09:57 (UTC). [vid. 2018-01-06]. Available on: https://en.wikipedia.org/wiki/Australia

[5] BURROUGHS, Dr Steve. Numbulwar Health Clinic – An investigation into the environmental performance of the clinic building based on instrumental monitoring. Research report. Canberra: DSB Foundations, 2018. 38 pages.

[6] Numbulwar Health Centre. Project Documentation. 2015.

[7] KUIPERS, Ludo. South Eastern Arnhem Land – Numbulwar. In: OzOutback [online]. [vid. 2018-01-06]. Available on: https://ozoutback.com.au/Australia/numbulwar/index.html

[8] Top End Communities celebrate Health Centre openings. In: Northern Territory Government [online]. Department of Health, 2018. [vid. 2018-01-06]. Available on: https://health.nt.gov.au/news/top-end-communities-celebrate-health-centre-openings

[9] REARDON, Chris, Paul DOWNTON. Design for climate. In: YourHome, Australia's guide to environmentally sustainable homes [online]. 2013. [vid. 2018-01-06]. Available on: http://www.yourhome.gov.au/passive-design/design-climate

[10] Climate Zone Map: Australia Wide. In: Australian Building Codes Board [online]. Australian Building Codes Board, ©2015 [vid. 2018-01-06]. Available on:

https://www.abcb.gov.au/Resources/Tools-Calculators/Climate-Zone-Map-Australia-Wide

[11] Bureau of Meteorology [online]. Australian Government [vid. 2018-01-06]. Available on: http://www.bom.gov.au/climate/data/

[12] Northern Territory Land Resource Surveys mapping status [online]. Department of Environment and Natural Resources, Northern Territory Government of Australia. [vid. 2018-01-06]. Available on: https://denr.nt.gov.au/land-resource-management/rangelands/information-requests/land-soil-vegetation-information

[13] CEB Soil Science [online]. Dwell Earth. [vid. 2018-01-06]. Available on: https://dwellearth.com/compressed-earth-blocks-soil-science/

[14] Numbulwar Health Centre&Duplex. In:PROBuildNT [online]. 2018 [vid. 2018-01-06]. Available on: https://probuildnt.com.au/achievement/numbulwar-health-centre-duplex/

[15] REARDON, Chris, Tom DAVIS, Paul DOWNTON. Lightweight framing. In: YourHome, Australia's guide to environmentally sustainable homes [online]. 2013. [vid. 2018-01-06]. Available on: http://www.yourhome.gov.au/materials/lightweight-framing

[16] Cement Concrete & Aggregates Australia. ENERGY EFFICIENCY in Building Regulations and the Use of Concrete in Housing [online]. 2011 [vid. 2018-01-06]. Available on: https://www.ccaa.com.au/imis_prod/documents/Library%20Documents/CCAA%20Datasheets/DS2011EnergyEfficiency.pdf

[17] Ashgrid Roof Spacer System. In: Bradford [online]. 2011 [vid. 2018-01-06]. Available on: https://www.bradfordinsulation.com.au/commercial-and-industrial-insulation/roofing/ashgrid-roof-spacer-system/overview#current

[18] KIBERT, Charles J. Sustainable Construction, Green Building Design and Delivery, 3rd edition. John Wiley & Sons, 2013. ISBN 978-0-470-90445-9.

[19] Envimat [online]. Univerzitní centrum energeticky efektivních budov. © Envimat.cz, 2010. [vid. 2018-01-06]. Available on: http://envimat.cz/

[20] RŮŽIČKA, Jan, FIALA, Ctislav, LUPÍŠEK, Antonín, MUKAŘOVSKÝ, Jan, VONKA, Martin. Environmentální hodnocení variant konstrukčního návrhu bytového domu – případová studie, Praha 2007.

[21] Survey of Motor Vehicle Use Data Cubes, Australia [online]. Australian Bureau of Statistics, Commonwealth of Australia, 2017. [vid. 2018-01-06]. Available on: http://www.abs.gov.au/ausstats/abs@.nsf/mf/9208.0/

[22] DEKTRADE. Tepelná stabilita v letním období. In: stavební komunita [online]. Stavebnikomunita.cz, 2015. [vid. 2018-01-06]. Available on: http://stavebnikomunita.cz/profiles/blogs/tepeln-stabilita-v-letn-m-obdob

[23] ČSN 73 0540-4:2005. Tepelná ochrana budov – Část 4: Výpočtové metody. Praha: ÚNMZ, červenec 2005.

[24] ČSN EN 15665. Větrání budov – Stanovení výkonových kritérií pro větrací systémy obytných budov. Praha: ÚNMZ, prosinec 2009.

8. List of used program and software

Microsoft Office Word 2012

Microsoft Office Excel 2012

AutoCad 2017

Revit 2018

DesignBuilder

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11. Attachments

- Environmental analysis – calculations of compositions
- Drawings 2xA3 Floor Plan

  A4 Cross Section

  A3 Complex detail 1

  A3 Complex detail 2

ENVIRONMENTAL ANALYSIS - CURRENT BUILDING													
Vertical Load bearing structure		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Wall type 6	Fibre cement lining	0,0090	175,50	1,58	1200,00	1895,36	5,39	10219,08	0,62	1178,53	1,14	2154,70	0,24
	Insulbreak 65	0,0065	175,50	1,14	42,00	47,91	4,21	201,80	14,90	713,87	30,00	1437,31	0,04
	Concrete blockwork	0,1800	175,50	31,59	1500,00	47383,92	0,76	35903,84	0,12	5746,25	0,24	11529,46	1,20
	Render blockwork	0,0100	175,50	1,75	2000,00	3509,92	1,46	5123,29	0,21	748,21	0,35	1242,76	0,99
Wall type 7	Render blockwork	0,0100	238,55	2,39	2000,00	4771,06	1,46	6964,13	0,21	1017,05	0,35	1689,29	0,99
	Concrete blockwork	0,1800	238,55	42,94	1500,00	64409,31	0,76	48804,35	0,12	7810,92	0,24	15672,07	1,20
	Render blockwork	0,0100	238,55	2,39	2000,00	4771,06	1,46	6964,13	0,21	1017,05	0,35	1689,29	0,99
Vertical Load bearing structure			l	m		m	PEI	PEI	GWP	GWP	AP	AP	λ
			m	kg/m		kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Steel columns	75x6	SC1	74,40	12,00		892,80	29,07	25950,84	2,09	1868,09	8,27	7386,85	50,00
	100x6	SC2	52,70	16,70		880,09	29,07	25581,40	2,09	1841,50	8,27	7281,69	50,00
	100UC23	SC3	12,40	23,00		285,20	29,07	8289,85	2,09	596,75	8,27	2359,69	50,00
	200x100x5.0 RHS	SC4	15,50	22,60		350,30	29,07	10182,10	2,09	732,97	8,27	2898,31	50,00
	Total					**129197**		**184185**		**23271**		**55341**	

Vertical Non Load Bearing Walls		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Wall type 0	Fibre cement lining	0,0090	187,71	1,69	1200,00	2027,28	5,39	10930,36	0,62	1260,56	1,14	2304,67	0,24
	Steel frame	0,0004	187,71	0,08	7850,00	589,41	29,07	17132,34	2,09	1233,29	8,27	4876,68	50,00
	Insulation	0,0760	187,71	14,27	32,00	456,51	4,21	1922,88	14,90	6802,05	30,00	13695,39	0,04
	Vapour barier	0,0002	187,71	0,04	900,00	33,79	78,22	2642,90	2,10	71,04	7,95	268,62	0,35
	Wall cladding	0,0045	187,71	0,84	2700,00	2280,69	27,93	63701,46	1,76	4010,27	8,73	19913,01	50,00
wall type 1 wall type 2	Fibre cement lining	0,0090	553,57	4,98	1200,00	5978,53	5,39	32234,11	0,62	3717,45	1,14	6796,58	0,24
	Steel frame	0,0004	553,57	0,22	7850,00	1738,20	29,07	50524,01	2,09	3637,02	8,27	14381,55	50,00
	Insulation	0,0760	553,57	42,07	32,00	1346,28	20,19	27184,44	1,13	1525,47	8,36	11252,59	0,04
	Fibre cement lining	0,0090	553,57	4,98	1200,00	5978,53	5,39	32234,11	0,62	3717,45	1,14	6796,58	0,24
wall type 3	Plasterboard	0,0130	64,58	0,84	1000,00	839,57	5,74	4822,91	0,35	297,45	1,10	921,51	0,36
	Plywood	0,0120	64,58	0,77	500,00	387,49	26,19	10148,53	1,25	485,10	6,74	2609,95	0,13
	Steel frame	0,0004	64,58	0,03	7850,00	202,79	29,07	5894,38	2,09	424,31	8,27	1677,82	50,00
	Insulation	0,0760	64,58	4,91	32,00	157,06	20,19	3171,47	1,13	177,97	8,36	1312,78	0,04
	Fibre cement lining	0,0090	64,58	0,58	1200,00	697,49	5,39	3760,59	0,62	433,70	1,14	792,92	0,24
wall type 4	Plywood	0,0190	22,72	0,43	500,00	215,88	26,19	5653,91	1,25	270,26	6,74	1454,05	0,13
	Steel frame	0,0004	22,72	0,01	7850,00	71,35	29,07	2074,01	2,09	149,30	8,27	590,36	50,00
	Insulation	0,0760	22,72	1,73	32,00	55,26	20,19	1115,92	1,13	62,62	8,36	461,92	0,04
	Fibre cement lining	0,0090	22,72	0,20	1200,00	245,42	5,39	1323,21	0,62	152,60	1,14	279,00	0,24
wall type 5	Fibre cement lining	0,0120	23,25	0,28	1200,00	334,80	5,39	1805,12	0,62	208,18	1,14	380,61	0,24
	Plywood	0,0190	23,25	0,44	500,00	220,88	26,19	5784,78	1,25	276,51	6,74	1487,70	0,13
	Steel frame	0,0004	23,25	0,01	7850,00	73,01	29,07	2122,02	2,09	152,76	8,27	604,03	50,00
	Insulation	0,0760	23,25	1,77	32,00	56,54	20,19	1141,75	1,13	64,07	8,36	472,61	0,04
	Fibre cement lining	0,0090	23,25	0,21	1200,00	251,10	5,39	1353,84	0,62	156,13	1,14	285,46	0,24
	Total					**24238**		**288679**		**29286**		**93616**	

Foundations		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Concrete slab	Concrete slab	0,100	234,35	23,44	2385,00	55892,95	0,48	27039,84	0,07	3743,07	0,14	7764,31	1,36
	Damp proof membrane	0,0002	234,35	0,05	960,00	45,00	76,40	3437,78	1,95	87,67	6,53	293,73	0,35
	Sand bed	0,050	234,35	11,72	1750,00	20505,80	0,05	1100,21	0,00	49,35	0,02	310,17	0,95
	Vinyl floor	0,010	712,62	7,13	1400,00	9976,64	60,01	598658,14	2,01	20036,08	5,36	53495,73	0,20
	Concrete slab	0,120	712,62	85,51	2385,00	203950,99	0,48	98667,20	0,07	13658,31	0,14	28331,65	1,36
	Damp proof membrane	0,0002	712,62	0,14	960,00	136,82	76,40	10453,61	1,95	266,60	6,53	893,18	0,35
	Sand bed	0,050	712,62	35,63	1750,00	62353,99	0,05	3345,51	0,00	150,05	0,02	943,17	0,95
	Concrete slab	0,150	274,34	41,15	2385,00	98145,14	0,48	47480,56	0,07	6572,64	0,14	13633,73	1,36
	Damp proof membrane	0,0002	274,34	0,05	960,00	52,67	76,40	4024,38	1,95	102,63	6,53	343,85	0,35
	Sand bed	0,050	274,34	13,72	1750,00	24004,75	0,05	1287,94	0,00	57,77	0,02	363,10	0,95
Pad footings	Concrete footing	0,450	8,00	3,60	2385,00	8586,00	0,48	4153,73	0,07	574,99	0,14	1192,72	1,36
	Concrete footing	0,450	47,52	21,38	2385,00	51000,84	0,48	24673,14	0,07	3415,45	0,14	7084,73	1,36
	Total					**534652**		**795495**		**44724**		**106373**	

Horizontal load bearing structure - roof structure			l	m	m	PEI	PEI	GWP	GWP	AP	AP	λ
			m	kg/m	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Steel beams	200UB25	R1	246,40	25,40	6258,56	29,07	181916,31	2,09	13095,41	8,27	51782,07	50,00
	200PFC	R2	20,0	22,90	458,00	29,07	13312,59	2,09	958,32	8,27	3789,40	50,00
	100 x 3.0 SHS	S1, S2	156,96	9,00	1412,64	29,07	41060,92	2,09	2955,81	8,27	11687,90	50,00
	150 x 100 x 5.0 RHS	WH1, DH1	99,37	18,70	1858,22	29,07	54012,48	2,09	3888,14	8,27	15374,53	50,00
	125 x 75 x 4.0 RHS	WH2	22,40	11,60	259,84	29,07	7552,72	2,09	543,69	8,27	2149,86	50,00
	250FPC	FP1	116,40	35,50	4132,20	29,07	120109,83	2,09	8646,22	8,27	34189,00	50,00
	250 x 150 x 5.0 RHS	FP2	40,60	29,90	1213,94	29,07	35285,35	2,09	2540,05	8,27	10043,90	50,00

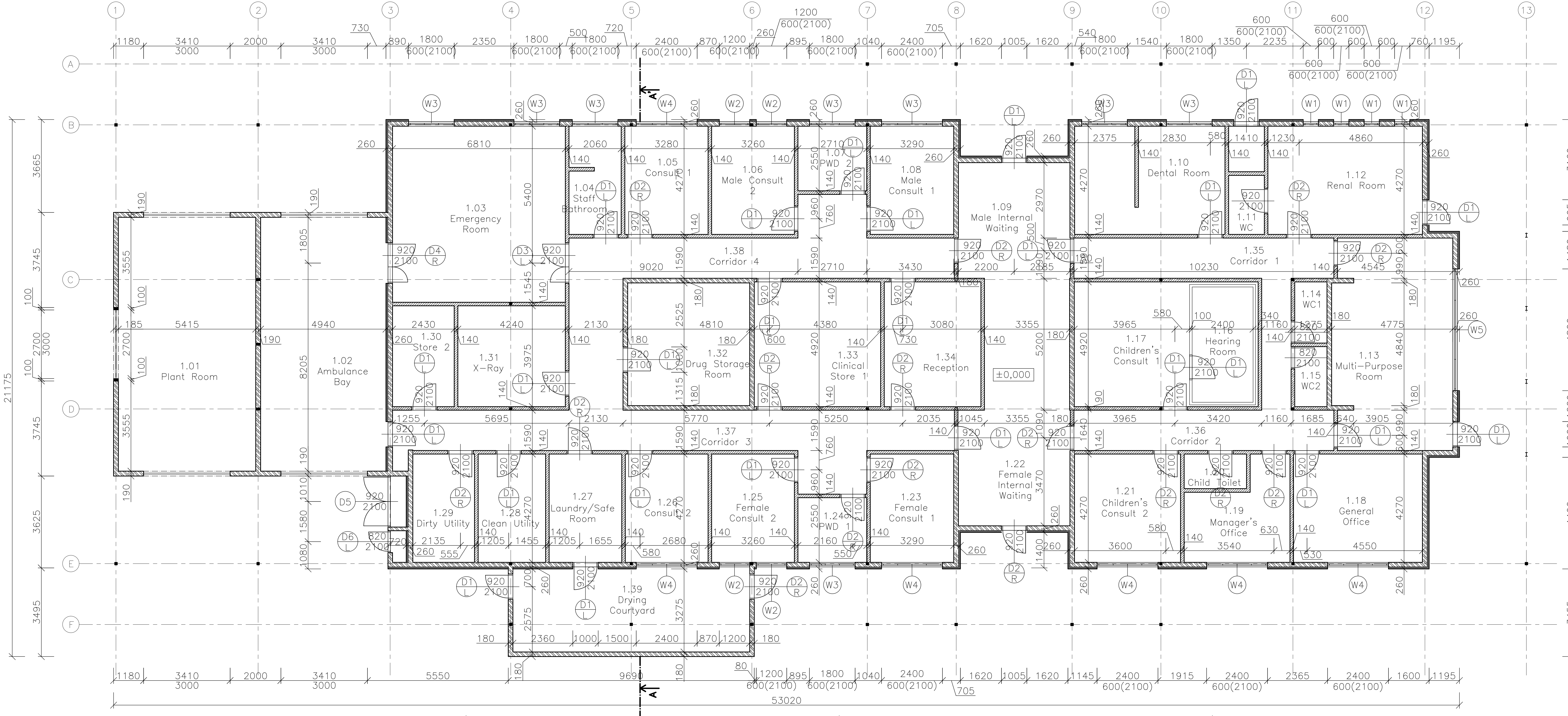
Ceiling structure		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Ceiling	Metal deck	0,00042	694,22	0,29	2700,00	787,25	22,05	17358,13	1,38	1086,56	6,11	4809,20	204,00
	Insulation	0,23	694,22	159,7	40,00	6386,82	45,53	290819	1,50	9553,41	6,97	44500,20	0,04
	Steel frame	0,0004	694,22	0,01	7850,00	43,60	29,07	1267,23	2,09	91,22	8,27	360,71	50,00
	Plasterboard	0,01	694,22	6,94	32,00	222,15	5,74	1276,15	0,35	78,71	1,10	243,83	0,36
	Total					**23033**		**763971**		**43438**		**178931**	

ENVIRONMENTAL ANALYSIS - PROPOSED BUILDING 1													
Vertical Non Load-bearing Filling Walls		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Wall type 6	Fibre cement lining	0,0090	175,50	1,58	1200,00	1895,40	5,39	10219,31	0,62	1178,56	1,14	2154,75	0,24
	CEB	0,1800	175,50	31,59	1500,00	47385,00	0,44	20849,40	0,08	3790,80	0,13	6160,05	0,62
	Insulation	0,0650	175,50	11,41	42,00	479,12	4,21	2018,08	14,90	7138,81	30,00	14373,45	0,04
	Plaster	0,0100	175,50	1,76	1815,00	3185,33	0,48	1535,11	0,02	60,99	0,07	228,03	0,57
Wall type 7	Plaster	0,0100	238,55	2,39	1815,00	4329,68	0,48	2086,61	0,02	82,90	0,07	309,95	0,57
	CEB	0,1400	238,55	33,40	1500,00	50095,50	0,44	22042,02	0,08	4007,64	0,13	6512,42	0,62
	Plaster	0,0100	238,55	2,39	1815,00	4329,68	0,48	2086,61	0,02	82,90	0,07	309,95	0,57
Vertical Load-bearing Structure			l	m		m	PEI	PEI	GWP	GWP	AP	AP	λ
			m	kg/m		kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Steel columns	75x6	SC1	74,40	12,00		892,80	29,07	25950,84	2,09	1868,09	8,27	7386,85	50,00
	100x6	SC2	52,70	16,70		880,09	29,07	25581,40	2,09	1841,50	8,27	7281,69	50,00
	100UC23	SC3	12,40	23,00		285,20	29,07	8289,85	2,09	596,75	8,27	2359,69	50,00
	200x100x5.0 RHS	SC4	15,50	22,60		350,30	29,07	10182,10	2,09	732,97	8,27	2898,31	50,00
	Total					**114108**		**130841**		**21382**		**49975**	

Vertical Non Load-bearing Walls		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Wall type 0	Fibre cement lining	0,0090	187,71	1,69	1200,00	2027,27	5,39	10930,30	0,62	1260,56	1,14	2304,66	0,24
	Steel frame	0,0004	187,71	0,08	7850,00	589,41	29,07	17132,25	2,09	1233,28	8,27	4876,66	50,00
	Insulation	0,0760	187,71	14,27	32,00	456,51	4,21	1922,87	14,90	6802,01	30,00	13695,32	0,04
	Vapour barier	0,0002	187,71	0,04	900,00	33,79	78,22	2642,89	2,10	71,04	7,95	268,62	0,35
	Wall cladding	0,0045	187,71	0,84	2700,00	2280,68	27,93	63701,12	1,76	4010,25	8,73	19912,91	
wall type 1 wall type 2	Fibre cement lining	0,0090	553,57	4,98	1200,00	5978,53	5,39	32234,11	0,62	3717,45	1,14	6796,58	0,24
	Steel frame	0,0004	553,57	0,22	7850,00	1738,20	29,07	50524,01	2,09	3637,02	8,27	14381,55	50,00
	Insulation	0,0760	553,57	42,07	32,00	1346,28	20,19	27184,44	1,13	1525,47	8,36	11252,59	0,04
	Fibre cement lining	0,0090	553,57	4,98	1200,00	5978,53	5,39	32234,11	0,62	3717,45	1,14	6796,58	0,24
wall type 3	plasterboard	0,0130	64,58	0,84	1000,00	839,54	5,74	4822,76	0,35	297,44	1,10	921,48	0,36
	Plywood	0,0120	64,58	0,77	500,00	387,48	26,19	10148,22	1,25	485,09	6,74	2609,87	0,13
	Steel frame	0,0004	64,58	0,03	7850,00	202,78	29,07	5894,20	2,09	424,30	8,27	1677,77	50,00
	Insulation	0,0760	64,58	4,91	32,00	157,06	20,19	3171,37	1,13	177,96	8,36	1312,74	0,04
	Fibre cement lining	0,0090	64,58	0,58	1200,00	697,46	5,39	3760,47	0,62	433,68	1,14	792,90	0,24
wall type 4	Plywood	0,0190	22,72	0,43	500,00	215,88	26,19	5653,91	1,25	270,26	6,74	1454,05	0,13
	Steel frame	0,0004	22,72	0,01	7850,00	71,35	29,07	2074,01	2,09	149,30	8,27	590,36	50,00
	Insulation	0,0760	22,72	1,73	32,00	55,26	20,19	1115,92	1,13	62,62	8,36	461,92	0,04
	Fibre cement lining	0,0090	22,72	0,20	1200,00	245,42	5,39	1323,21	0,62	152,60	1,14	279,00	0,24
wall type 5	Fibre cement lining	0,0120	23,25	0,28	1200,00	334,80	5,39	1805,12	0,62	208,18	1,14	380,61	0,24
	Plywood	0,0190	23,25	0,44	500,00	220,88	26,19	5784,78	1,25	276,51	6,74	1487,70	0,13
	Steel frame	0,0004	23,25	0,01	7850,00	73,01	29,07	2122,02	2,09	152,76	8,27	604,03	50,00
	Insulation	0,0760	23,25	1,77	32,00	56,54	20,19	1141,75	1,13	64,07	8,36	472,61	0,04
	Fibre cement lining	0,0090	23,25	0,21	1200,00	251,10	5,39	1353,84	0,62	156,13	1,14	285,46	0,24
	Total					**24238**		**288678**		**29285**		**93616**	

ENVIRONMENTAL ANALYSIS - PROPOSED BUILDING 2													
Vertical Non Load-bearing Filling Walls		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Wall type 6	Fibre cement lining	0,0090	363,21	3,27	1200,00	3922,67	5,39	21149,61	0,62	2439,11	1,14	4459,41	0,24
	CEB	0,1800	363,21	65,38	1500,00	98066,70	0,44	43149,35	0,08	7845,34	0,13	12748,67	0,62
	Insulation	0,0650	363,21	23,61	42,00	991,56	4,21	4176,56	14,90	14774,29	30,00	29746,90	0,04
	Plaster	0,0100	363,21	3,63	1815,00	6592,26	0,48	3177,02	0,02	126,22	0,07	471,92	0,57
Wall type 7	Plaster	0,0100	238,55	2,39	1815,00	4329,68	0,48	2086,61	0,02	82,90	0,07	309,95	0,57
	CEB	0,1800	238,55	42,94	1500,00	64408,50	0,44	28339,74	0,08	5152,68	0,13	8373,11	0,62
	Plaster	0,0100	238,55	2,39	1815,00	4329,68	0,48	2086,61	0,02	82,90	0,07	309,95	0,57
Vertical Load-bearing Structure			l	m		m	PEI	PEI	GWP	GWP	AP	AP	λ
			m	kg/m		kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
Steel columns	75x6	SC1	74,40	12,00		892,80	29,07	25950,84	2,09	1868,09	8,27	7386,85	50,00
	100x6	SC2	52,70	16,70		880,09	29,07	25581,40	2,09	1841,50	8,27	7281,69	50,00
	100UC23	SC3	12,40	23,00		285,20	29,07	8289,85	2,09	596,75	8,27	2359,69	50,00
	200x100x5.0 RHS	SC4	15,50	22,60		350,30	29,07	10182,10	2,09	732,97	8,27	2898,31	50,00
	Total					**185049**		**174170**		**35543**		**76346**	

Vertical Non Load Bearing Walls		d	A	V	ρ	m	PEI	PEI	GWP	GWP	AP	AP	λ
		m	m^2	m^3	kg/m^3	kg	MJ/kg	MJ	kg CO_2 ekv./kg	kg CO_2	g SO_2 ekv./kg	g SO_2	W/mK
wall type 1 wall type 2	Plaster	0,0100	553,57	5,54	1815,00	10047,26	0,48	4842,09	0,02	192,37	0,07	719,25	0,57
	CEB	0,1400	553,57	77,50	1500,00	116249,28	0,44	51149,68	0,08	9299,94	0,13	15112,41	0,62
	Plaster	0,0100	553,57	5,54	2000,00	11071,36	0,48	5335,63	0,02	211,98	0,07	792,57	0,99
wall type 3	Plasterboard	0,0130	64,58	0,84	1000,00	839,54	5,74	4822,76	0,35	297,44	1,10	921,48	0,36
	Plywood	0,0120	64,58	0,77	500,00	387,48	26,19	10148,22	1,25	485,09	6,74	2609,87	0,13
	CEB	0,1400	64,58	9,04	1500,00	13561,80	0,44	5967,19	0,08	1084,94	0,13	1763,03	0,62
	Plaster	0,0100	64,58	0,65	2000,00	1291,60	1,46	1885,30	0,02	24,73	0,35	457,32	0,57
wall type 4	Plywood	0,0190	22,72	0,43	500,00	215,88	26,19	5653,91	1,25	270,26	6,74	1454,05	0,13
	CEB	0,1400	22,72	3,18	1500,00	4772,04	0,44	2099,70	0,08	381,76	0,13	620,37	0,62
	Plaster	0,0100	22,72	0,23	2000,00	454,48	0,48	219,03	0,02	8,70	0,07	32,53	0,57
wall type 5	Plaster	0,0100	23,25	0,23	2000,00	465,00	0,48	224,10	0,02	8,90	0,07	33,29	0,99
	Plywood	0,0190	23,25	0,44	500,00	220,88	26,19	5784,78	1,25	276,51	6,74	1487,70	0,13
	CEB	0,1400	23,25	3,26	1500,00	4882,50	0,44	2148,30	0,08	390,60	0,13	634,73	0,62
	Plaster	0,0100	23,25	0,23	2000,00	465,00	0,48	224,10	0,02	8,90	0,07	33,29	0,57
	Total					**164924**		**100505**		**12942**		**26672**	



Room Legend

Nb.	Room	Area m2
1.01	Plant Room	54,15
1.02	Ambulance Bay	50,15
1.03	Emergency Room	47,57
1.04	Staff Room	8,93
1.05	Consult 1	14,19
1.06	Male Consult 2	14,19
1.07	PWD 2	7,01
1.08	Male Consult 1	14,23
1.09	Male Internal Waiting	29,0
1.10	Dental Room	25,26
1.11	WC	3,48
1.12	Renal Room	26,27
1.13	Multi–purpose Room	39,21
1.14	WC1	3,14
1.15	WC2	3,14
1.16	Hearing Room	10,92
1.17	Children's Consult	20,27
1.18	General Office	21,67
1.19	Manager's Office	14,14
1.20	Child Toilet	3,36
1.21	Children's Consult 2	17,85
1.22	Female Internal Waiting	28,92
1.23	Female Consult 1	14,23
1.24	PWD 1	7,01
1.25	Female Consult 2	14,19
1.26	Consult 2	14,19
1.27	Laundry/Safe Room	12,47
1.28	Clean Utility	11,61
1.29	Dirty Utility	10,54
1.30	Store 2	9,94
1.31	X–Ray	17,44
1.32	Drug Storage Room	23,18
1.33	Clinical Store 1	25,00
1.34	Reception	19,35
1.35	Corridor 1	21,85
1.36	Corridor 2	20,1
1.37	Corridor 3	46,24
1.38	Corridor 4	34,63
1.39	Drying Courtyard	32,04
	Total area m2	791,06

Material Legend

CEB 180 mm
CEB 140 mm

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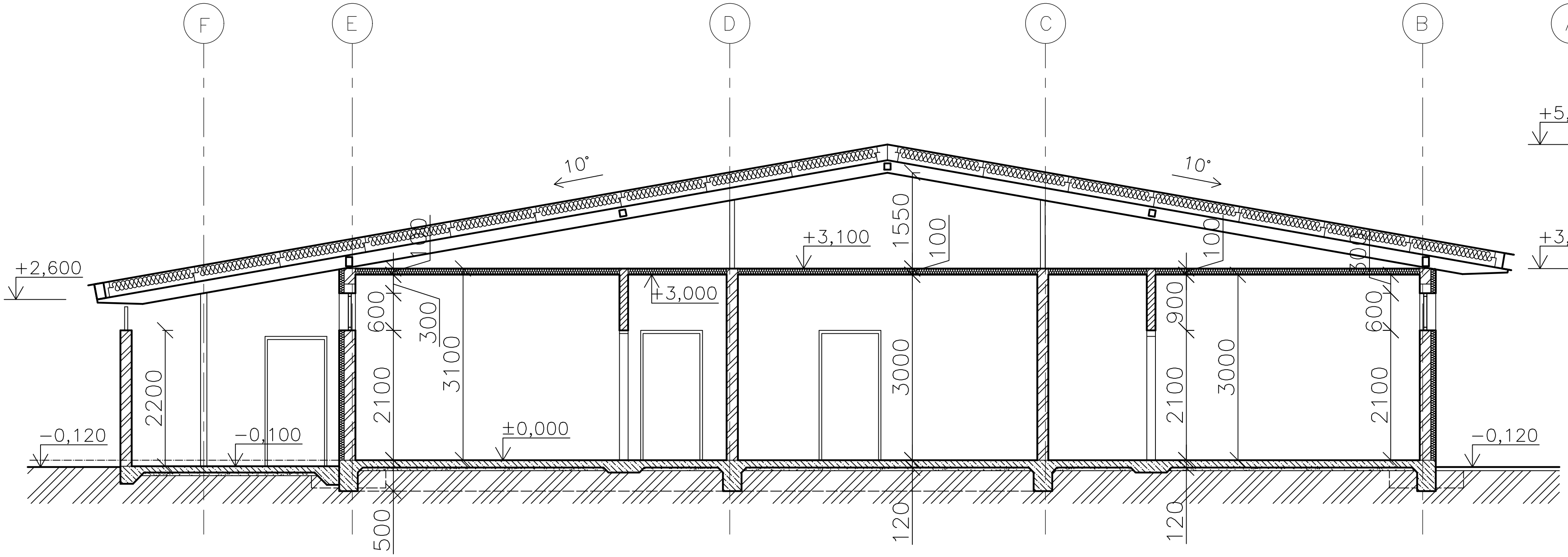
CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF CIVIL ENGINEERING
DEPARTMENT OF BUILDING STRUCTURES

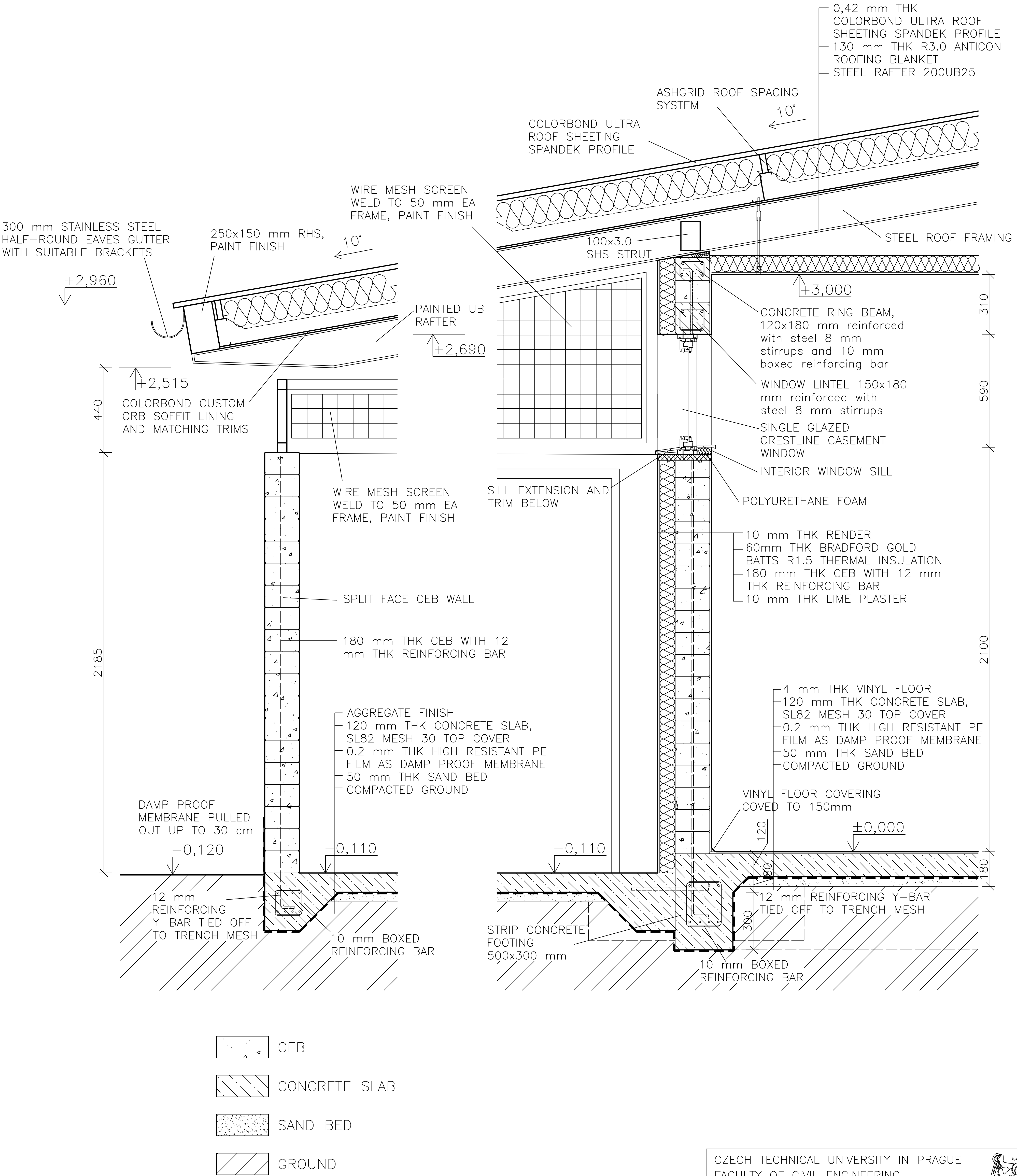
NUMBULWAR HEALTH CENTRE – DEVELOPMENT OF A SUSTAINABLE BUILDING CONCEPT

Student	Ema Škarecká	Scale	1:100
Advisors	Ing. Jan Růžička, Ph.D. Dr Steve Burroughs	Format	2xA3
		Year	2018/19
Drawing	FLOOR PLAN	Nb.	6

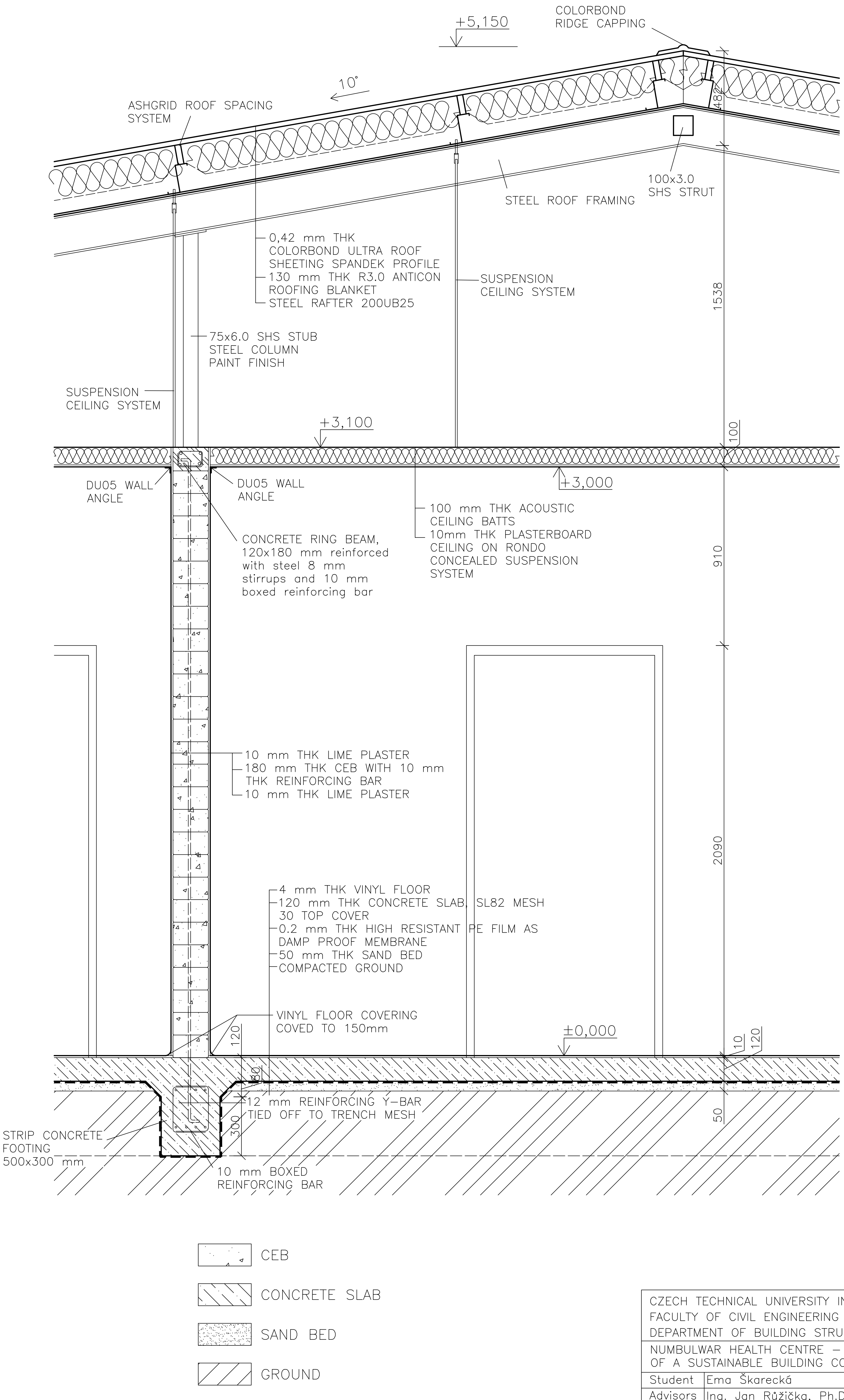


- CEB 180 mm
- CEB 140 mm
- CONCRETE SLAB
- SAND BED
- GROUND

CZECH TECHNICAL UNIVERSITY IN PRAGUE FACULTY OF CIVIL ENGINEERING DEPARTMENT OF BUILDING STRUCTURES			
NUMBULWAR HEALTH CENTRE – DEVELOPMENT OF A SUSTAINABLE BUILDING CONCEPT			
Student	Ema Škarecká	Scale	1:100
Advisors	Ing. Jan Růžička, Ph.D. Dr Steve Burroughs	Format Year	A4 2018/19
Drawing	CROSS SECTION	Nb.	7



CZECH TECHNICAL UNIVERSITY IN PRAGUE FACULTY OF CIVIL ENGINEERING DEPARTMENT OF BUILDING STRUCTURES			
NUMBULWAR HEALTH CENTRE – DEVELOPMENT OF A SUSTAINABLE BUILDING CONCEPT			
Student	Ema Škarecká	Scale	1:20
Advisors	Ing. Jan Růžička, Ph.D. Dr Steve Burroughs	Format	A3
		Year	2018/19
Drawing	COMPLEX DETAIL 1	Nb.	8



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FACULTY OF CIVIL ENGINEERING
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<tr><td>Student</td><td>Ema Škarecká</td><td>Scale</td><td>1:20</td></tr>
<tr><td>Advisors</td><td>Ing. Jan Růžička, Ph.D.</td><td>Format</td><td>A3</td></tr>
<tr><td></td><td>Dr Steve Burroughs</td><td>Year</td><td>2018/19</td></tr>
<tr><td>Drawing</td><td>COMPLEX DETAIL 2</td><td>Nb.</td><td>9</td></tr>
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