How can district cooling become an efficient and sustainable solution for listed buildings using the example of Viennese state schools?

Under which conditions can district cooling be implemented using the example of our school

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Abstract

District cooling – A sustainable and innovative solution for Viennese schools

Rising temperatures that are caused by climate change pose an increasing problem in everyday school life. Concentrating in overheated classrooms is a difficulty and the necessity to regulate the temperature in a sustainable way is undeniable.

District cooling is a possible solution that is already installed in public buildings such as hospitals, train stations and recently the University of Vienna. For that purpose, cold water directly from the Danube or water cooled down with sustainable energy is used. Therefore, it is a suitable alternative to air-conditioning systems, especially for listed buildings of historic interest, such as the school building investigated in this paper.

This study examines the implementation of district cooling, its energy consumption, price efficiency and the carbon footprint. Interviews with local experts, school principals and officials involved in the implementation of district cooling inform the research project.

Our goal is to investigate the advantages and feasibility of district cooling, using the example of our school. Ideally, this paper provides first steps to establish district cooling at our school and serves as an example for other schools in Vienna.

Keywords

District Cooling, effect of rising temperatures, cooling systems

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1. Technical Implementation of District Cooling

1.1 Introduction

The most common way to cool buildings seems to be air conditioning. Yet, this system is problematic, especially in times of global warming. It consumes high amounts of energy and releases tons of carbon dioxide [1]. For that reason, a more sustainable manner to regulate the temperature in buildings is needed. District cooling poses an innovative alternative to conventional cooling systems.

To give an idea of district cooling, it can be said that the costumer imports the coldness from a local provider. A central cooling unit enables a more planned procedure, with a sustainable use of energy and very low exhaust emissions compared to for example air conditioners. The system utilizes water as a coolant with operating modes including water from local water bodies and their low temperature [2].

1.2 Cooling Methods

There are different ways to provide cold water necessary for the process. One approach involves chilling engines powered by electrical energy or heat. A different approach uses natural resources, such as running waters or ground water. Which source is used for district cooling depends on the respective local circumstances. [3]

1.2.1 Technical provision

There are two common procedures to lower the temperature from a coolant, which function in a slightly different way, compression and absorption. The main difference is that one chiller is powered by electrical energy, while the other one uses heat, often waste heat which stems from waste incineration plants [4].

1.2.1.1 Absorption

Both procedures make use of aggregate state changes. Liquid water needs energy in order to evaporate. This energy is taken from the coolant and so its temperature decreases.

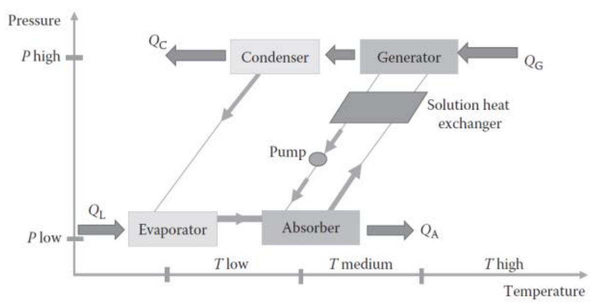

Figure 1: Absorbtion chiller [9]

Absorption chillers [Figure 1] need two liquids apart from the coolant. On the one hand, there is water, which evaporates, and on the other hand, there is a solvent. The water evaporates because of the low pressure in the engine and as a result withdraws heat from the coolant. After that, the solvent absorbs the water and the now mixed liquids are pumped into another tank. This tank, the generator, is heated up or the pressure is increased so that the water can evaporate again and after condensing in a divided part of the tank (Condenser) the water and the solvent are separated. The liquids run back in the original tank and the whole process restarts. As can be seen, the main driving force is the heat, which is needed to divide the liquids. Therefore, this engine is mainly used when there is enough heat, for example in form of waste heat. [5]
In Vienna, a waste incineration plant that takes advantage of the produced waste heat exists in Spittelau [6].

1.2.1.2 Compression

On the other hand, compression chillers are the most popular type of refrigerator for district cooling. [7]
The procedure is similar to the operating mode of a refrigerator. This engine works using a refrigerant, mostly with a low boiling point, so it works more efficiently.
The liquid evaporates in the evaporator/expansion device withdrawing energy from the coolant [see Figure 2]. Then its pressure increases and in the condenser the gas cools down until it becomes liquid again. After this the compressor decreases the pressure and the procedure starts again. The main driving force is electrical energy in order to regulate the pressure. [8] [see Figure 2]

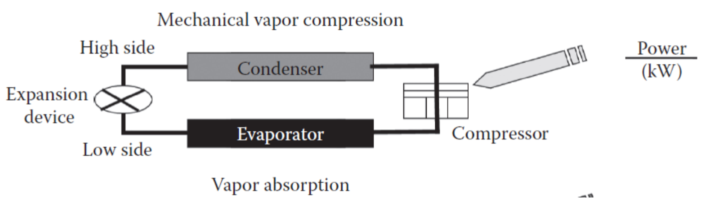

Figure 2: Compression chiller [10]

1.2.1.3 Heat exchangers

Both systems need heat exchangers, a way to release the remaining heat that had been withdrawn from the coolant. A centralized cooling plant where all the cooling engines are positioned allows more sustainable ways to release the heat, than a conventional dry cooler.

Dry coolers simply emit heat in the ambient air lowering temperatures in enclosed spaces. In cities, they can be seen on roofs or outside windows in form of big boxes with ventilators. Their life span is about 15 years, if properly maintained. Another way to emit heat is the use of water heat exchangers. Implementing running water, lake water or ocean water to release heat uses less space and the machines have a longer life span than dry coolers. This type of cooling is managed with cooling towers (evaporative cooling). Compared to the conventional dry cooler, water heat exchangers are more efficient due to lower condensing temperatures [11].

1.2.2 Natural provision

There are also ways to provide coldness for district cooling without using chilling engines. Taking advantage of the low temperatures of ground water or running waters, it is feasible to cool buildings only with natural resources.

Running waters, nevertheless, are mostly used for cooling plants, because in summer these water bodies are not cold enough to solely operate a district cooling system. However, in cold seasons they can provide the necessary heat.

Ground water is a more suitable resource because of its steady temperatures (around 10 °C). Hence, it is slightly warmer than the coolant (water) of the engines, it is often used for cooling surfaces or computer centres, which is realised by pumping up the ground water, piping it through the building withdrawing heat from the rooms and then leading it back into the ground [12].

1.3 Operating Methods

Apart from different cooling methods, there are still two different approaches to manage district cooling. First, the costumer has the option to install a cooling system as above-mentioned, but with all components in their own building. For example, the costumer could position a chilling engine in the basement, which provides the entire building with coldness. The only elements coming from outside would be energy or heat to power the machine. Installing chilling engines at the costumer's building implies that the costumers themselves have to maintain the system. Compared to other ways to manage district cooling, for example through public institutions, local chilling machines are less ecological, less economical and less efficient. Of course, the costumer could also obtain the coldness from local natural resources, using their cold water by pumping it up, piping it through the building withdrawing heat from the rooms and then leading it back. [13]

The second, more common operating mode is to import the coldness from engines, as described above, which are positioned in chilling centres. Costumers then only have a transmission station in the basement. Nearly all responsibilities are then up to the provider and the system becomes more efficient and sustainable than local chilling engines at the costumers. The cold water is delivered to the building through pipes, is then fed into local cooling systems such as ceiling cooling, and afterwards, runs back to the cooling centre where the now warmer water is cooled down again with the local engines and the procedure starts again. [2]

1.4 Efficiency of cooling devices

The efficiency of chillers within cooling plants is an important aspect of a cooling system. The easiest approach when comparing the efficiency of chillers is to compare their Coefficient of performance (COP). The COP can be determined by dividing the cooling power output by the power input that the system uses. The higher the number, the more efficient is the system. For example: An air conditioning device that can be installed at home may be able to reach a cooling power of 2500 Watts with an input power of 550 Watts. Using the equation, the following result is accomplished:

$$\frac{2500}{550} = 4{,}55$$

The COP of the device is 4.55, making it a very efficient retrofit option on the market. [13,14]

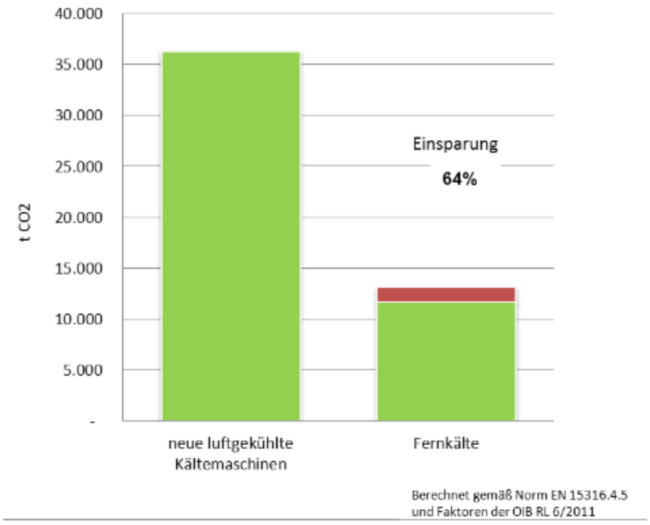

Figure 1

1.5 District Cooling

As stated above there are two different types of chillers used for district cooling. The COP of absorption chillers is only about 0.7. As already explained, it is only economic and ecological to incorporate absorption chillers when implementing the use of waste heat as a power source. In the case of Spittelau [1]there exists a district heating facility as well as a district cooling facility. Hence the integration of waste heat from the district heating plant is ensured.

According to Wien Energie, the city's energy provider electrical compression chillers have a COP of 6.4 while dry cooled compression chillers have a COP of 2.4. When considering that water pumps within the system need to be powered the COP is reduced to 5.4. Additionally, power network losses of about 8 % need to be taken into account. The COP of the facility can be calculated as follows:

$$5{,}4 * (1 - 0{,}08) = 4{,}968$$

The COP of the facility in Spittelau therefore is about 5. [16]

1.6 Environmental Aspects

One goal of utilizing district cooling is to minimize negative effects on the environment. There are different ways to evaluate the environmental impact of different energy cycles. One is to compare the CO_2 emission rate over a year. Another way is to compare different systems based on their primary energy factors after the „Energy Saving Regulation“[2] (EnEV) standard. The primary energy factor (PEF) is a number that is used to compare the effectiveness and the environmental impact of different energy systems. A lower number means better efficiency and less CO_2 emissions of the energy source. For regular cooling methods,

[1] Spittelau is a waste incineration plant that takes advantage of the waste heat and produces District cooling and heating

[2] „Energieeinsparverordnung“

the PEF is 1.3. The district cooling network of the Viennese energy provider Wien Energie has a PEF of 0.5.

In terms of CO_2 emissions, this means a decrease by 64 % to 74 % in comparison to an integrated cooling system that are rated with a PEF of 1.3 (numbers based on external calculations, following EnEV standards) as seen in figure 1. The numbers can vary depending on the integrated cooling system that DC is compared to. [16, 17]

2. Field reports

2.1 Worldwide installations

Werner [21] explains in his overview on district cooling and its implementation worldwide that as early as in the 1890s, attempts were made in New York and other US cities to cool buildings using so-called *pipeline cooling systems*. This method used decentralized evaporators and central condensers, which could then transfer the coldness to the buildings. This was the predecessor of district cooling, which has been becoming an increasingly popular choice for cooling since then. In the 1960s, district cooling systems followed, first in Hartford (USA), Hamburg (GER) and the district of La Defense outside of Paris (FRA). The author furthermore lists cities where large district cooling systems are in operation such as Berlin, Chicago, Dubai, Helsinki, Paris, Singapore, Tokyo and Toronto among others. The number of district cooling systems in the world is not reported, but in Europe there are between 100 and 150 systems in use.

2.2 Implementation in Vienna

As the cooling of buildings with compression chillers is very energy-intensive, district cooling becomes more important in Vienna. District cooling networks are in use at different locations, especially in large buildings such as shopping centers. As reported by the local energy provider *Wien Energie* (2020) the following locations in Vienna are already equipped with district cooling.

SMC East

The Social Medical Centre East has been equipped with district cooling since 2010. Cooling is provided by a decentralized district cooling center of *Wien Energie*. [6]

Geriatric Centre Donaustadt

In the 22nd district in the northwest of Vienna a nursing home, which is located next to the SMC East, is under renovation and a district cooling system is going to be installed. At present, a cooling pipeline is constructed on site, which will be connected to the existing pipeline of the SMC East. [6]

Vienna Central Station

The Vienna Central Station is already supplied with district cooling and an extension is planned. The project consists of three parts: refrigeration machines as a refrigeration center underneath the tracks of the main station, cooling towers for re-cooling in a nearby park and a district cooling network that transports the coldness in pipes to the buildings.

So far, around 400,000 m^2 in the area of the Vienna Central Station can be supplied with a cooling capacity of 20 MW. A further expansion to 25 MW is planned. With this cooling capacity, about 500,000 m^2 could then be cooled. [6]

Hospital Rudolfstiftung

The hospital, which is connected to the Juchgasse project, has been cooled with district cooling since 2012. Since 2018, a total output of 7.6 MW has been available. At this location, special attention is paid to the reliability of the system, as there is a high demand to provide process cooling[3] for the medical-technical facilities. Cooling is decentralized, and absorption chillers, electric chillers and heat pumps are used. [6]

Juchgasse

In the course of the construction of the project Juchgasse 22 in the 3rd district in Vienna, a refrigeration plant was also installed in the building. The cooling plant was built by the Viennese Hospital Association, as there is a hospital directly next to the building, which is also supplied with district cooling. Since 2014, the control center has been operated by Wien Energie. Approximately six months each year the buildings can be cooled with free of charge cooling at this location. This means that no chillers have to be operated, as cooling is provided by the cool outside air. The refrigeration system consists of four compression refrigeration machines (high temperature cooling for technical equipment), one compression refrigeration machine (low temperature cooling for air conditioning) and a connection line to the main building of the Rudolfstiftung hospital. [6]

Major shopping Center

Underneath the large shopping Center in the 3rd district there are large amounts of groundwater, which form a lake. In summer, the heat energy is conducted by refrigeration machines into the groundwater. This groundwater then stores the heat. In winter this groundwater then can heat the center. The base load of the cooling demand is covered by a cooling capacity of 1.7 MW. A refrigeration compression machine with a capacity of 1 MW provides for peak load coverage. The re-cooling is carried out by two open cooling towers, each with a re-cooling capacity of 2.6 MW, which is sufficient. [6]

Renngasse

In the Inner City of Vienna several centrally located buildings in the city center are supplied with coolness by the Renngasse refrigeration project. The installed cooling capacity is 6 MW. The implementation of this project was a special challenge as one of the buildings is a listed building. This means that less of the old building may be converted and that there are more legal restrictions. Therefore, particular attention had to be paid to installing a modern and environmentally friendly refrigeration plant. [6]

[3] Process cooling uses mechanical refrigeration to remove heat from a process.

Schottenring

In 2013 the district cooling plant Schottenring officially went into operation and has a total capacity of 15 MW. The cooling plant is located in a shaft structure, which is underground in the 1st district and borders on an underground car park. In this plant district cooling is produced in three processes: Generation of coldness from the waste heat of the thermal waste treatment Spittelau, generation of cold with electrical energy in compressors, generation of cold by free cooling (Danube Canal water as cooling). As cooling towers in buildings, which might be listed, are to be avoided in the city center, part of the Schottenring refrigeration plant is a withdrawal structure on the Danube Canal. The water from the Danube Canal is used for very efficient re-cooling via refrigeration machines. In this project several buildings along the Ring street, a circular street which leads around Vienna's city center, can be cooled. Among them a hotel, a bank as well as the Austrian National Bank, a new location of the University of Vienna are cooled by district cooling. A district cooling connection is also planned for the University of the Vienna's Law School and the main building of the University.

The cooling network will be extended to a length of 3.3 km and is connected to 26 objects[4]. At full capacity several tens of thousands of people can be supplied with environmentally friendly building climate control. About 50 people were involved in this project and about 15 million Euros were invested in the district cooling network Schottenring.

Schwarzenbergplatz

Since 2007, district cooling has been in use at this location in the center of the Inner City[5] area. An absorption machine and an electric chiller have a combined cooling capacity of 1.2 MW.

Spittelau

The district cooling plant at the Spittelau site went online in 2009. Currently it is Vienna's largest district cooling producer with a capacity of 17 MW. The following buildings are supplied with district cooling from this location the General Hospital of the City of Vienna, the Skyline real estate project on the Döblinger Gürtel, the institute building of the University of Natural Resources and Applied Life Sciences, the Ö3 building in the Muthgasse (headquarters of an Austrian radio channel) and the new building project Space2move (office and commercial space)

Town-Town

The Town-Town project is an office building complex in Vienna's 3rd district. Since 2006, the building has had its own refrigeration plant to ensure cool temperatures during the summer. In the first stage of expansion, 5.3 MW of cooling capacity and 1 MW of free cooling were provided.

Shopping City South

The shopping center, Shopping City South, which is located on the southern outskirts of Vienna, has a total area of about 270,000 m² refrigeration supply for this shopping center is provided by several refrigeration plants for the different locations: the main building, a multiplex cinema and a motor center. An expansion to a cooling capacity of 18 MW is currently underway. [6]

Stubenring (under construction)

The district cooling plant Stubenring, which is part of the Ringstraße, is to be built directly underneath the historic building referred to as Alte Post. In the future, offices, hotels, apartments and shops will be cooled by water of the Danube Canal, the arm of the Danube, which is closest to the city center. With a capacity of 15 MW, a total of 300,000 m² will be cooled.

The construction project consists of the following three steps.

The first phase: January to June 2020, crossing Franz-Josefs-Kai and intake. Then the second phase: April to August 2020, relocation of the Dominican bastion. Lastly the third phase: until April 2021, completion of the district cooling plant. [6]

3. The effect of rising temperatures on schools especially in Vienna

As a side effect of global warming and rising temperatures, the temperature is also increasing in buildings. This is normally not a major issue as it is relatively easy to install an air conditioning system or integrating one when planning a building.
Such constructional measures cannot easily be taken within the educational sector, especially regarding schools and kindergartens. By reason of a legal issue, like the obstacle of listed buildings[6], which are common in Vienna notably in the inner districts and an agreement between the ministry of education and the BIG[7] as well as a deficit of the budget the BIG is not allowed and not able to install air conditioning system at public schools and public kindergartens. The temperatures have especially risen in the classrooms above the first floor and it gets warmer with each story. Thus, students and teachers alike cannot be as productive as normally. It is proven that the learning capability declines in a sub-optimal learning environment. A study by Goodman, Hurwitz, Park and Smith concluded that the efficiency of students declines ex 75 °F or 23.8 °C and that the temperatures are problematic ex 85 to 90 °F or 29.5 to 32.2 °C. From 90 °F the achievements are reduced by a sixth of a years' worth learning and the numbers increase with the temperature [23]. As a result of the high temperatures students and teachers experience symptoms such as headache, tiredness, absent-mindedness and focus disorder. This leads to a poor teaching and learning environment [24].

[4] As of 2018
[5] 1st district of Vienna
[6] Listed building (US: landmarked building): a building of great historical or artistic value that has official protection to prevent it from being changed or destroyed [Cambridge Dictionary]
[7] Bundesimmobiliengesellschaft (BIG) is a governmental company in Austria that manages Austrian publicly owned real estates. Among other things they are the owners of all real estates of public schools, kindergartens and universities.

3.1 Measures already taken against the temperature rise

In the course of inquiries regarding measures that have already been taken against the rising temperatures in classrooms, these steps that are already implemented or in the course of being implemented were determined. This information was acquired in the course of interviews with our headmaster, employees of the BIG as well as the district leader of the fourth district[8].

UV Protective Foil

UV protective foil is a thin material consisting of Polyethylene terephthalate (PET) that is applied either on the inner or on the outer surface of a window. The application either takes place during the manufacturing of the windows or afterwards, when it is already installed.

Using the protection foil comes with benefits. The foil is around 70 µm[9] thick and has a light transmission of around 70 %. Thereby the rays that directly shine on the surface of the window are reduced by 86 %, which also reduces the temperature of the room between 5 to 10 °C[10].

Despite that, there is also a downside to the application of the foil. Although the foil allows for a rather high light transmissions a window with foil, still appears very dark compared to normal windows. Especially in late autumn through spring it is noticeable and therefore considerably darker. Consequently, the room would need more artificial light which will increase the energy and light usage of the school. Additionally, the foil cannot be taken off in winter when it is unnecessary to keep the room cool. Therefore, it will not be as warm in the building and increased heating will also be needed.

Blinds or Curtains

Blinds or curtains help reduce noise, light shining into the room and the temperature. But in comparison to other means to keep the temperature down, they reduce it only minimally that it is not noticeable.

Additionally, only blinds or curtains that are a light color prevent the heat from entering. Blinds can help to reduce the insolation up to 75 % while curtains, which are of light color, just up to 25 %.

3.2Measures that will be taken against the temperature rise

As the already taken measures have not been enough and the temperatures in the classrooms are still too high, we asked which additional measures will be taken to prevent an unbearable classroom environment. When the temperature rises also the humidity and the air quality in a room with up to 25 students are affected. This is because the rise of humidity is directly proportional to the rise of the room temperature. A suitable humidity for humans is above 15 to 20 %rf[11] and when the water content is not above 12 g/kg[12]. Is the water content higher than these 12 g/kg we consider the air humid or sweltering. The perfect room air should be oxygen-rich, odorless and have low-emissions and the CO_2 concentration should not exceed the Pettenkofer-value 13. From 0.1 to 0.15 % of CO_2 the air is already considered bad air but still tolerable for humans. From 2 % of CO_2 concentrations are briefly tolerable and from 3 to 4 % of CO_2 humans have increasing breathing difficulties. As these values should not be exceeded and then cause bad air, which leads to a poor room environment, further measures must be taken. Studies that have already been conducted show that even with extensive airing, a value of 1400 ppm CO_2, which is according to the UBA14 and the EN 13 77915 a bad air quality, is achieved even before the middle of the first period [25].

A measure that is currently in discussion is the plan is to plant trees beside and in front of the school, to reduce the solar radiation and keep the increase of temperature down. Yet, there are special criteria that must be fulfilled, as a three-meter distance to the facade and the absence of water or gas pipes beneath the tree within proximity. Apart from reviewing these aspects, the location close to the main road, the "Wiedner Gürtel", must also be reviewed. Trees planted must not interfere with or pose a threat to the traffic.

4. Case study of our school

Through a case study of our school we aim to illustrate how district cooling could be implemented at public schools that are or are not listed buildings. By means of this case study we want to lay out how other schools' cases could be approached.

4.2 Rising temperatures affecting classrooms

Especially the classrooms above the first floor and on the southside.

The Wiedner Gymnasium is aligned in a rectangle with the south side bordering on one of the main roads, the Gürtel, of Vienna. This road is the one of the most heavily used roads in Austria, and it circles the districts three to nine of Vienna. As a result, the windows of the classrooms located at the south side, cannot be as easily opened as others. The reason for that is noise pollution, which would be too high and as a result disrupt the lessons. The noise pollution is at his highest between 10 a.m. to 2 p.m with a range of 75 to 90db due to a

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[8] Fourth district of Vienna is Wieden where our school is located

[9] 0.070 mm

[10] 41-50 °F

[11] percent relative humidity

[12] The humidity level: it shows the mass of water that is per kg of dry air

[13] Pettenkofer-Value is a CO_2 concentration of 0.1 % of the room air. CO_2 can also be measured in ppm (parts per million) 2000 ppm are sanitarily unacceptable.

[14] UBA: Federal Environment Agency of Germany

[15] EN 13 779 (norm for mechanical cooling and climatization of non-residential buildings, that are meant for the residence of humans) is a European norm that is now replaced by the EN 16 798-3 (energetic evaluation of buildings - ventilation of buildings - Part 3: Ventilation of non-residential buildings)

distance of only 5.20 m to the Gürtel. Thus, students and teachers in the classrooms located on this side of the building not only have to deal with the noise, but also with the extensive heat coming from the sun and the exhaust gases from the motorway. This makes it impossible for the rooms to be aired properly during the school day. The only room in the whole school that is being cooled and aired is the chemistry lab, which is also situated on the south side on the third floor, where it is compulsory, as working with chemicals requires an efficient air exchange.

4.3 Technical background for the implementation of a district cooling system at our school

We consider the rapidly developing technology of district cooling a possible solution to cool our school. This method is already used by office buildings and governmental and public buildings, like universities, hospitals and the central railway station of Vienna. The main station is conveniently located around 800 m away from the Wiedner Gymnasium.

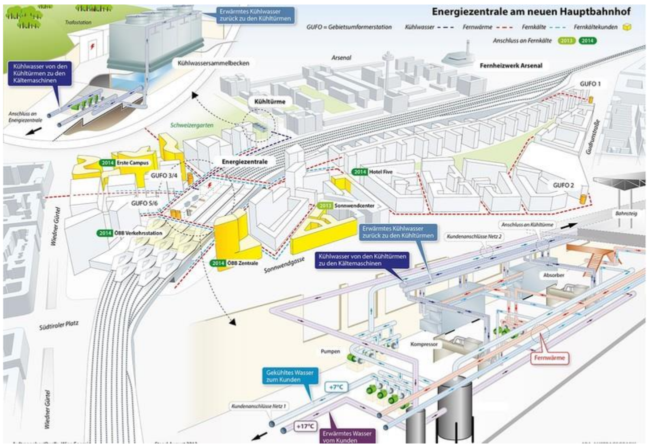

Figure 2 shows the District Cooling Station of the Central Railway Station of Vienna, and its Consumers. [6]

Figure 3 shows the approximately distance between our school, the Wiedner Gymnasium, and the Central Railway Station. As one can see they are both located at the main Road the “Wiedner Gürtel”. [47]

The proximity of the central railway station would allow to construct an extension of its cooling system which could then be used by the school building.

But as the school is located beside the main road and as tramway tracks run underneath that road, the installation of a district cooling system is not as easy as it might seem.

First of all, there are pipes, such as gas, water and the district heating pipes that need to be considered. The option of using the district heating pipes as the district cooling pipe as well is out of question, as the pipes are first of all not built for this. Therefore, they are not properly isolated for these temperatures and subsequently the water would condense on the outer surface of the pipeline. This would lead to mold formation and destroy radiators in the process, too. Secondly, the costs for a pipe from the railway station to our school would be on average 1500 to 2000 € per meter. For some sections the total cost would be even higher. That is because in addition to costs for the conversion work, traffic on the main road as well as tramway traffic would be needed to be closed down for some time.
Also that would not be the only price that would be needed to be paid, as the cost is divided into three parts:

First the building cost, that is a one-time payment and varies from the distance to the center.

Second the performance price that is a basis cost so that the service is provided.

Thirdly the contract cost that is calculated through the contract and the amount the customer uses. The amount is determined through the counter that is installed at the customer.

4.5 Outcome of the Case Study

In conclusion, district cooling would be a sustainable and efficient solution to cool schools, similar to how other buildings are already cooled. However, it would be very cost-intensive, and it would entail an extremely complex re-construction. Considering these aspects, the installation of district cooling would not be efficient for schools anymore. In other words, the project fails because of a lack in financial means and untenable logistical inconveniences. In addition, as the BIG also told us, that it cannot be that one school in Austria, or even Vienna, has it and no other. This would lead to questions arising, why this school got it and when the other schools are going to get it. That is because Austrian public schools are treated equal in all matters and therefore it would be a matter of discrimination against the other schools in Vienne or even in Austria, regarding schools in a rural area.

5. Alternative solutions to stem the temperature increase

In the course of this inquiry it was deducted that district cooling in Viennese schools cannot be implemented due to factors such as budget deficit. Therefore, this chapter is dedicated to alternative cooling systems which might be applied to schools and other institutional buildings.

5.1 Passive cooling systems

Primarily, it is regarded that passive cooling systems only use minimal needed amount of energy which corresponds to the aimed efficiency of budget distribution in the educational sector as well as to the concerns on climate protection. Passive cooling is a term constituted by various non-mechanical means of cooling interior spaces.

Generally, the following two methods of passive cooling could be differentiated: preventative design, modulation and heat dissipation.

Preventative techniques shield the structure against heat gains and incorporate design approaches that take various components of the microclimate on site into account such as solar radiation and wind. Shaping the structure in a concealed way to limit the radiation that can enter it or zoning the interior spaces in a distinct way to reduce overheating are instances for such approaches. It is considered to be a rule of thumb of preventative passive cooling to avoid disjointing the entity of the interior space of the building into small rooms if possible since fractional zoning hinders air conduction causing additional heat. Horizontally flat architectural designs enable the structures to be cross-ventilated naturally, whereas multi-level compounds can take advantage of natural temperature stratification.

Modulation and heat dissipation strategies allow a structure to store heat in heat sinks and discharge it into the surroundings. For instance, the thermal mass of a building can absorb and store heat during daytime hours and release it into the night sky afterwards.

Stack ventilation is a design strategy, which could be classified as a modulation technique, taking advantage of the buoyancy of warm air, which filters out through ceiling openings, enabling cooler air to enter near the bottom.

Night ventilation is a further heat dissipation technique, with the structure itself acting as a heat sink. In this case, the structure is being isolated during daytime to prevent heat gain, then opened at night while the air temperature is lower, flushing out warmth through convection. Night cooling can be executed either by opening windows at night to let the natural airflow cool the space, or by mechanically forcing the air out through ventilation ducts at night, or a combination of the two.

5.2 Hybrid cooling systems

Hybrid cooling techniques combine dry and evaporative cooling to provide heat rejection and reduce water and energy consumption. The implementation of these still requires the construction of cooling towers, yet, in contrast to conventional cooling systems, it heavily relies on the natural architectural properties of the compound and makes it possible for the excessive energy to be stored.

5.3 Conventional air conditioning powered by green energy

In the particular case of Austria, renewable energy makes up a significant percentage of the overall intern electric power generation and this percentage is increases progressively with every year. In fact, it is aimed by the European Union that by 2020, the proportion of green power in Austria reaches 34 %. Conventional air conditioning techniques require a lot of resources but the environmental damage of such could be diminished with the use of green energy. [48] [49]

6. Conclusion

During the Course of this paper we examined if it is possible to implement district cooling at Viennese schools using the example of our school, the “Wiedner Gymnasium”. Our examination has shown that it would not be possible to implement district cooling at our school because of the high cost, regarding the pipe construction and the maintenance. Also, the equality regarding Viennese Schools poses a difficulty that cannot be easily overcome. Thus, district cooling is not a sustainable solution to cool our school during the hot months.

References

[1] Schlossberg, Tatiana. 2016. "How Bad Is Your Air-Conditioner for the Planet?" The New York Times, August 9, 2016, sec. Science. https://www.nytimes.com/2016/08/10/science/air-conditioner-global-warming.html.

[2] Olama, Alaa A. 2017. District Cooling: Theory and Practice. http://www.crcnetbase.com/isbn/9781498705516, p. 1-2.

[3] Patrick-Anastasios, Krystallas. 2017. "Technical, organizational and economic analysis of district cooling on the project 'district cooling Munich.'" Technische Universität München. http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20180508-1363296-1-6, p.40-56

[4] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ed. 2013. District Cooling Guide. Atlanta, GA: ASHRAE, 3.4-3.12

[5] Olama, Alaa A. 2017. District Cooling: Theory and Practice. http://www.crcnetbase.com/isbn/9781498705516, p. 41-47

[6] https://www.wienenergie.at

[7] Olama, Alaa A. 2017. District Cooling: Theory and Practice. http://www.crcnetbase.com/isbn/9781498705516, p.39

[8] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ed. 2013. District Cooling Guide. Atlanta, GA: ASHRAE, 3.4-3.8

[9] Olama, Alaa A. 2017. District Cooling: Theory and Practice. http://www.crcnetbase.com/isbn/9781498705516, p.42

[10] Olama, Alaa A. 2017. District Cooling: Theory and Practice. http://www.crcnetbase.com/isbn/9781498705516, p.39

[11] American Society of Heating, Refrigerating and Air-Conditioning Engineers, ed. 2013. District Cooling Guide. Atlanta, GA: ASHRAE, 3.3-3.4

[12] Patrick-Anastasios, Krystallas. 2017. "Technical, organizational and economic analysis of district cooling on the project 'district cooling Munich.'" Technische Universität München. http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20180508-1363296-1-6, p.40

[13] Patrick-Anastasios, Krystallas. 2017. "Technical, organizational and economic analysis of district cooling on the project 'district cooling Munich. ` Technische Universität München. http://nbn-resolviEnvironmentsolver.pl?urn:nbn:de:bvb:91-diss-20180508-1363296-1-6, p.30-35

[14] Wenjie, Shengwei, und Fu, „District cooling systems and individual cooling systems: Comparative analysis and impacts of key factors, Science and Technology for the Built Environment"; „Klimaanlage: Kosten, Stromverbrauch und praktische Tipps ".

[15] Wenjie, Shengwei, und Fu, „District cooling systems and individual cooling systems: Comparative analysis and impacts of key factors, Science and Technology for the Built Environment ".

[16] Wenjie, Shengwei, und Fu; Wallisch, Fernkälte als Energieeffizienzmaßnahme.

[17] Hölzl, Burkhard. Wien Energie, 11. März 2020.

[18] stromliste.at. „Klimaanlage: Kosten, Stromverbrauch und praktische Tipps". Unternehmen, 23. Mai 2019. https://stromliste.at/nuetzliche-infos/klimaanlage.

[19] Wallisch, Alexander, 2012 „„Fernkälte als Energieeffizienzmaßnahme", https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2012/files/lf/LF_Wallisch.pdf.

[20] Wenjie, Gang, Wang Shengwei, und Xiao Fu. 2017. „District cooling systems and individual cooling systems: Comparative analysis and impacts of key factors, Science and Technology for the Built Environment". https://doi.org/10.1080/23744731.2016.1214474.

[21] Werner, Sven. 2017. International review of district heating and cooling. https://www.researchgate.net/publication/316040285_International_review_of_district_heating_and_cooling, 27.03.2020.

[22] https://www.wienenergie.at/eportal3/ep/channelView.do/pageTypeId/67823/channelId/-47780

[23] Goodman, Joshua and Hurwitz, Michael and Park, Jisung and Smith, Jonathan, Heat and Learning (May 2018). NBER Working Paper No. w24639. Available at SSRN: https://ssrn.com/abstract=3185940

[24] Peter, Gruber, Exhausto GmbH: "Das Innenklima ist in der Schule genauso wichtig wie die Unterrichtsmethoden", unter: https://www.exhausto.de/projektering/Learning%20-%20Skoleventilation/Indeklima/klima-in-klassen (visited 04.02.2020).

[25] Neumann, Buxtrup: Beurteilung der CO2 Konzentration in Klassenräumen in Gefahrstoffe Reinhaltung der Luft, Nr. 6, Juni 2014

[26] Oreskes, Naomi. 2004. The Scientific Cinsensus on Climate Change. Sciencemag: https://science.sciencemag.org/content/306/5702/1686 (27.03.2020)

[27] Cook, Oreskes, Doran, Anderegg, Verheggen, Maibach, Carlton, Lewandowsky, Skuce, Green. 2016. Consensus on consensus: a synthesis of consensus estimates on human-caused global warming. IOPScience: https://iopscience.iop.org/article/10.1088/1748-9326/11/4/048002 (27.03.2020)

[28] http://climate.rutgers.edu/stateclim_v1/robinson

[29] https://www.livescience.com/37057-global-warming-effects.html

[30] https://www.livescience.com/53510-zika-virus.html

[31] https://www.sonnenschutzfolien-fenster.de/uv-folie.html

[32] https://www.erstenachhilfe.de/blog/besseres-lernen-das-ist-die-optimale-temperatur-zum-lernen

[33] https://www.merkur.de/welt/hitzefrei-in-buero-und-schule-ab-welcher-temperatur-darf-man-gehen-zr-12709412.html

[34] https://www.sciencedirect.com/science/article/abs/pii/S0260691702001855

[35] https://luskin.ucla.edu/hot-weather-lowers-students-ability-to-learn-new-study-finds

[36] https://soldera.de/magazin/optimales-raumklima-positiver-einfluss-von-sonnenschutzfolien-auf-die-raumtemperatur
[37] https://www.championac.com/blog/how-room-temperature-affects-your-brain-while-studying/
[38] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3185940#
[39] https://pdfs.semanticscholar.org/5c71/5078518d3d1188a9250df9eddc40bb5caa37.pdf#page=1&zoom=auto,-13,798
[40] https://scholar.harvard.edu/files/jisungpark/files/paper_nyc_aer_new_ucsb.pdf#page=1&zoom=auto,-13,792
[41] https://www.spiegel.de/lebenundlernen/schule/zu-viel-co2-dicke-luft-in-deutschen-klassenzimmern-a-724364.html
[42] http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf
[43] https://climate.nasa.gov/scientific-consensus/
[44] https://www.livescience.com/37057-global-warming-effects.html
[45] Goodman, Joshua and Hurwitz, Michael and Park, Jisung and Smith, Jonathan, Heat and Learning (May 2018). NBER Working Paper No. w24639. Available at SSRN: https://ssrn.com/abstract=3185940
[46] https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/ecoheatcool_more_district_cooling_in_europe.pdf
[47] https://maps.google.at
[48] https://buildabroad.org/2016/11/05/passive-cooling/
[49] https://books.google.at/bokks?id=yLkODAAAQBAJprintsec=frontcover#v=onepage&q&f=false