Engineering Arena 2022

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STEMGames

Introduction

The ever-growing needs for data storage and processing drive the demand for the creation of data centers – large buildings dedicated to housing a large number of computers whose task is the processing and storage of data. While it may be easy to assume that the creation of the data center is something that will solely be a focus of computer engineers, this could not be further from the truth. Developing the systems that can handle the cooling and power delivery for large data centers is more easily said than done. The ever-growing focus on sustainability is noticeable in the data center construction as well – with the focus being given to the development of energy-efficient cooling and power delivery solutions, combined with automated control systems for lowering the overall ecological impact. In the following three days, your task is to observe and perform calculations, planning, and modeling of the systems involved within a proposed, simplified, data center – which can be seen in the image below.
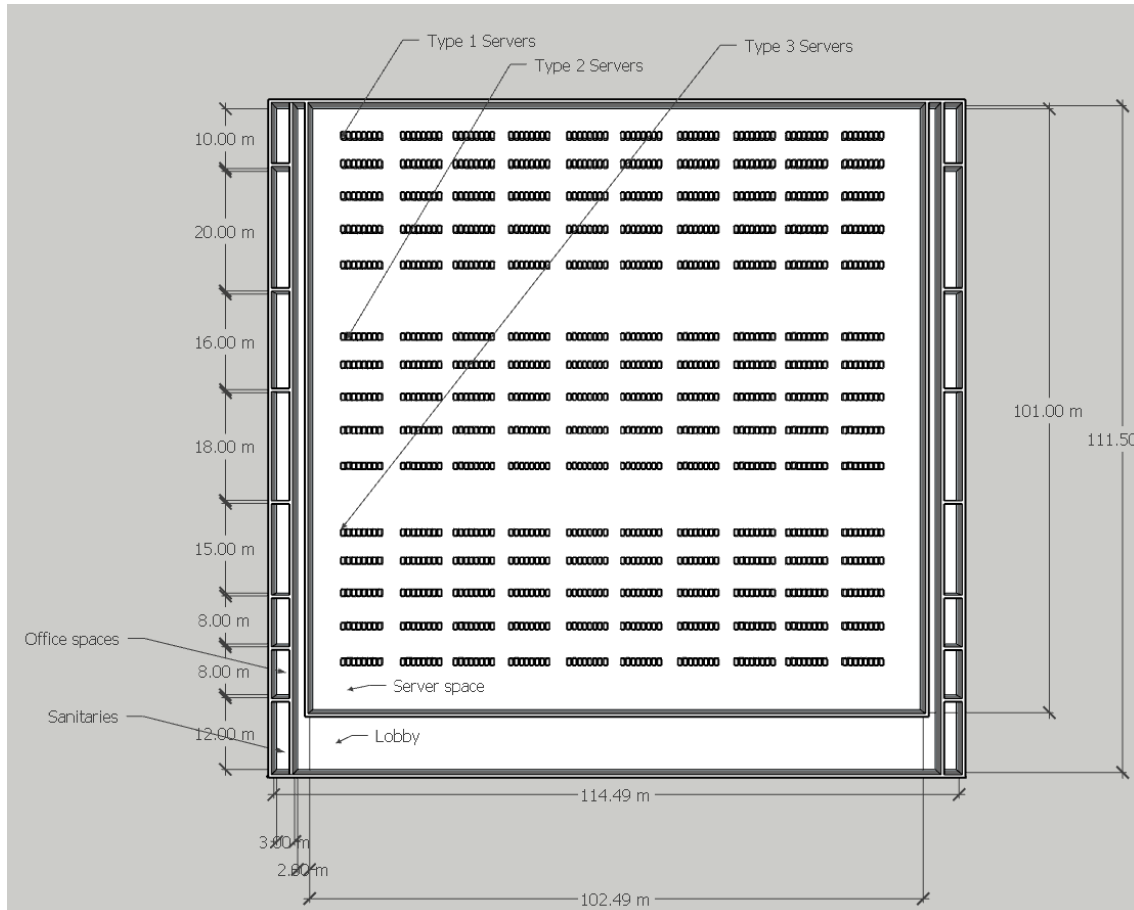
Helpful information

This section includes some useful information and tools you can download to help you with solving the tasks provided to you. Please read it carefully!

- The knowledge mentors will assist you with any clarifications needed regarding the tasks set before you - but they will not assist you in solving them. This means that they will NOT provide you with equations, modeling techniques, prematurely checking your work, or similar.

- Mentors will assist you with the provided tools to the best of their knowledge. Mentors can assist and direct you with the *suggested* software - but keep in mind that they may not be familiar with other software solutions.

- You are free to use any materials (books, lectures, notes) you have access to. You are allowed to use the internet - if you don't know or can't remember how something is calculated - Google is your friend, and Wolfram Alpha is your BFF.

- You are encouraged to use programs to assist you in reaching the solution - Excel, Python, MATLAB, Octave, or other software can help you speed up your work! If you do use software, you will be expected to submit your program files, worksheets, or equivalents.

Materials

All the information you need to solve the tasks are available to you within the tasks themselves. Still, if you would like here are some materials that you can download and use during the competition - and some other useful links.

You can download the data center model here:

(a) SKP file

(b) STL file

You can download the SKP file at: `bit.ly/38jEVOq` and STL at: `bit.ly/3l1UpJs`

SKP file can be opened using Sketchup, free trial of which can be downloaded from:

`www.sketchup.com/try-sketchup`

Wolfram alpha is a free online tool you can use to solve simple equations or lookup certain values. You can access it here:

`www.wolframalpha.com/`

In case you need a Python distribution, we suggest using Anaconda - free to download from here:

`repo.anaconda.com/archive/`
`Anaconda3-2022.05-Windows-x86_64.exe`

In case you need a block diagram maker software, we suggest using the Lucid Chart:

FESTO   VERTIV.   AITAC

www.lucidchart.com/pages/examples/
block-diagram-maker

The Festo catalogue software can be downloaded here. No installation is needed, you can just run it:

https://bit.ly/3N6KH4D

Vertiv catalogue for cooling solutions can be found on the link below, with some additional helpful links to the Vertiv cooling equipment:

https://www.vertiv.com/en-emea/
products-catalog/thermal-management/

www.vertiv.com/en-emea/
products-catalog/thermal-management/
room-cooling/
liebert-pdx-direct-expansion-floor-mount-cooling-un

www.vertiv.com/en-emea/
products-catalog/thermal-management/
room-cooling/
liebert-pcw-chilled-water-room-cooling-unit/

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Some information on data centers

Data centers consist of servers - many, many servers in fact. Servers are in fact just your normal computers - the only difference being the format they are in and that some hardware is specialized for the server use-cases. In addition, most servers have higher performance than your common desktop PC because they are expected to be used by many people at once. The servers are placed in the so-called

"racks" can fit a larger number of servers with additional equipment (network switches, patch panels, UPSs, and others). For simplicity (server rack configurations can be complex) we are assuming each rack houses a single type of the server, with as many servers as can fit in it. If you see the term "U" this refers to a single rack unit, which is a unit of height equal to 44.45 mm. Servers commonly fit into chassis which are 1U, 2U (88.9 mm), or 4U high (177.8 mm)- although other configurations are possible. Racks themselves are commonly 42U high - but other configurations are also possible. Data Centers themselves can have many uses - mass data storage, virtualization, high performance computing... But it is obvious that, due to the increase in the amount of data collected, cloud solution use, and the performance necessary in modern computing they are here to stay.
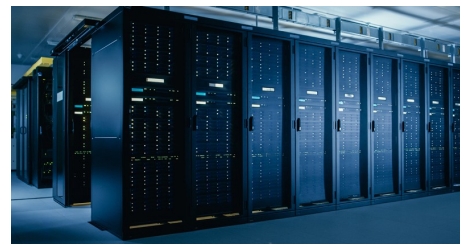
Day 1

Estimating the power consumption of the data center

As you can see on the provided figure the server setup of the given data centre consists of three different server types, split into three groups - each of which has 400 racks. Each server configuration is as follows:

1. **Type 1**: Storage servers (10 servers per rack)

   - 2 x CPU Intel Xeon Gold 6240R
   - 24 x IronWolf Pro 18TB NAS HDD

2. **Type 2**: GPU servers (10 servers per rack)

   - 1 x CPU AMD EPYC™ 7H12
   - 8 x NVIDIA RTX A6000

3. **Type 3**: CPU servers (20 servers per rack)

   - 2 x CPU AMD EPYC™ 7773X

The main power drawing components of each server type are given in the list. Assume that each of the servers draws additional 50 Watts of power, in addition to the listed components. Assume that each rack contains a network switch drawing 80 W of power. The information on the power consumption of the components can be found on the internet. Based on the calculated power consumption, calculate the heat output of the data center servers in BTUs. Assuming no heat escape and the starting room temperature of 20 degrees centigrade, calculate the temperature at which the servers would raise the room if no cooling was provided (the height of the ceilings is 4.5 meters). Use maximum operating power draw or default TDP for the calculation. The thermal conductivity of the brick wall is 0.87 $Wm^{-1}K^{-1}$, while the insulation thermal conductivity is 0.05 $Wm^{-1}K^{-1}$. The wall and insulation thicknesses are 300 mm and 200 mm, respectively. The

convection heat transfer coefficient from the server room to the wall is $8\ Wm^{-2}K^{-1}$, while the corresponding value between the wall and the environment is $25\ Wm^{-2}K^{-1}$. Assume that the roof and wall thermal and geometrical properties are identical.

Power efficiency estimation

Our server power supplies are far from perfect. If we assume that our PSUs in each server type have the curves shown in figure 1, and their maximum rated power is as follows, per server type:

- **Type 1**: 1200 W,

- **Type 2**: 4400 W, and

- **Type 3**: 1000 W,

you can calculate how much additional power is drawn by the power supply units (PSUs), at different server loads.
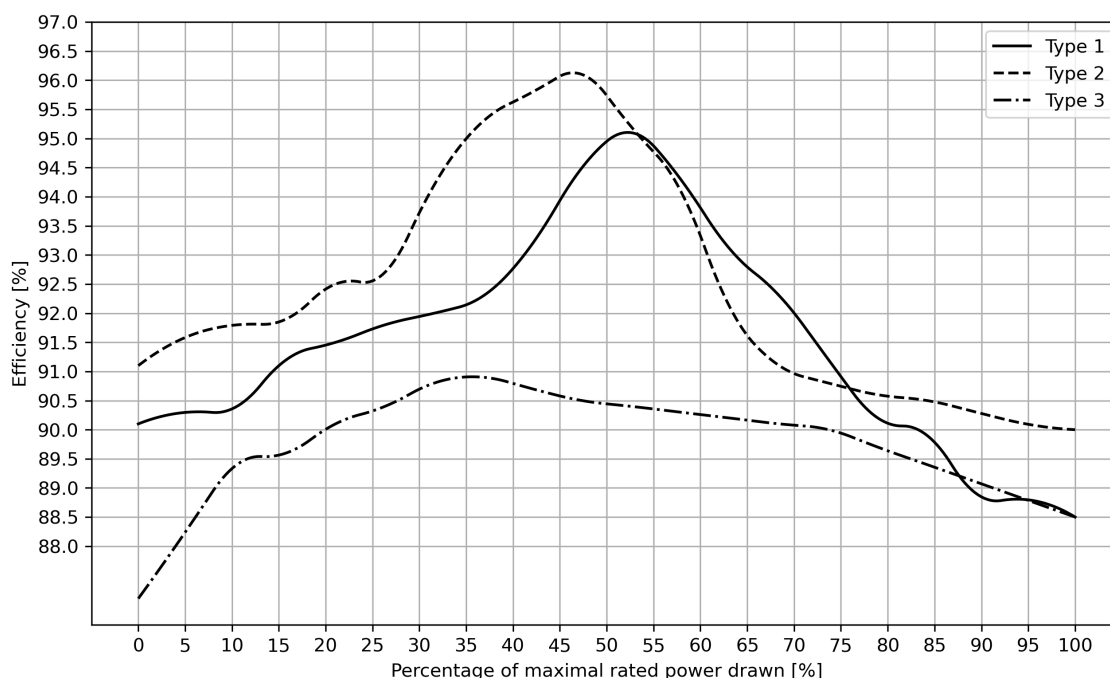
Figure 1: Power efficiency curves of power supply units for each server type

Assuming that the power loads of each server are given in the format as in Table 1., develop a computational model for calculating the

Table 1: Number of servers at different loads, per server type

Load	10%	25%	50%	75%	90%	100%
Server type	**Number of servers per each load level**					
Type 1	2483	1245	243	0	8	21
Type 2	6	23	89	86	59	137
Type 3	256	418	245	1245	1480	356

Note - the power levels given are for the power draw from server components you calculated in the previous task, not the PSU power draw - that needs to be calculated from the values given in this task.

total power consumption of the data center, based on the PSU efficiency curves. You may use whichever software you are familiar with for the development of the model (Python, MATLAB, or Excel are suggested), but the number of servers at each of the loads should be variable. You can also develop a purely mathematical model.

At which power consumption level of the total rated PSU delivery power is the data center most efficient per power level? Assuming that the cost of electricity is 0.14 € for 1 kW/h is calculated and compare the costs at the full power and the (all the servers for each server type at 100%) and idle (all servers for each server type at 10%). Calculate hourly, daily, and weakly costs.

Noise pollution

While many forms of pollution are discussed when the problem of sustainability is raised, one not oft mentioned is noise pollution which can adversely affect people and nature. If the referent noise level in the data center is 60dB, what is the noise level at the following points [1]:

- center of each rack type (marked with purple circle) on figure 2,

- in each of the additional spaces outside the data center (marked with blue cross) on figure 2, and

- outside the building (marked with a green triangle) on figure 2.

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[1] If you are unsure about measurements, all the marks are centered.

Assume that each server rack contains only the following noise making elements:

- Type 1: 4 fans, each producing 22 dB

- Type 2: 4 fans, each producing 25 dB

- Type 3: 6 fans, each producing 44 dB
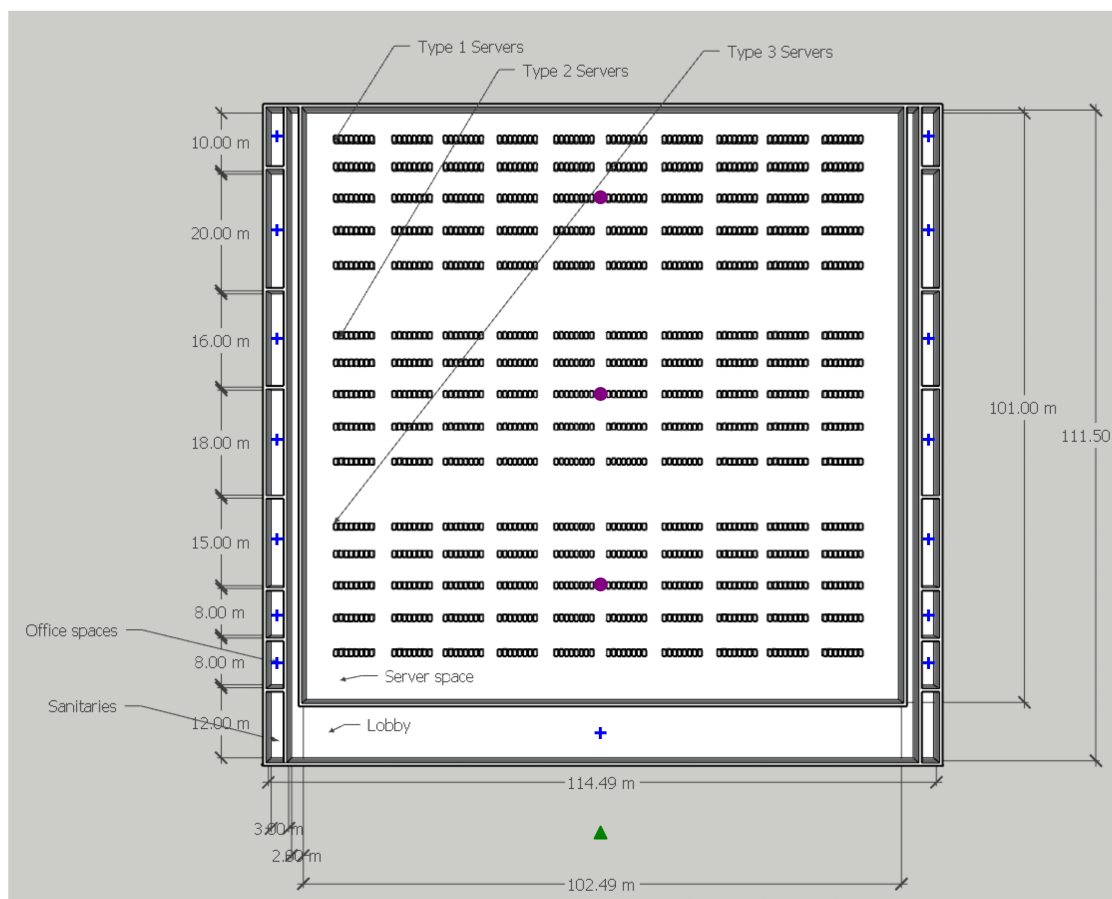
Figure 2: Floor plan with the locations at which you will need to determine the sound levels marked.

Assume that each set of 8 racks is an individual source. Once the red points are calculated, base the blue point calculations on assuming that the red points are the sources of noise. Do the same for the green points - using blue as sources.

The power of the Sun

The sun delivers a staggering amount of energy to Earth every second - but most of this energy goes unused. Could some of it be used in

the data center, combining solar collectors and solar panels?
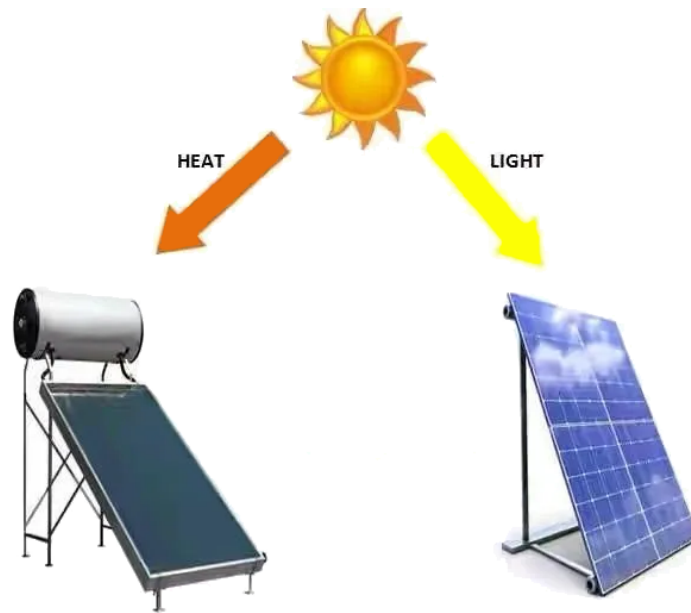
Figure 3: Solar collectors and panels, with the type of energy they convert into heat or electricity.

Assume that 20 liters of hot water are used on average per person in the office daily associated with the data center. If the 45 employees are employed in the office, how many liters are used per average, on a daily basis? If a solar collector can produce an average of 1 liter of hot water per hour, can the total water consumption be covered, if the total area available for the installation of solar collectors is 2000 m^2? If this is not enough, how much space would be needed? If a solar panel can produce an average of 250 Wh of electrical energy per hour, is it more efficient to use electrical power from the panels, to heat the water? How much area is needed to raise the water temperature by Δt of 60 deg C? Is this a better solution space-wise? If the solar panels are used, how much of the data center power consumption can be offset by covering the aforementioned 2000 m^2 with solar panels? What if the entire roof area of the data center was covered with solar panels? If this is not enough space - how much area would be needed? Assume 8 hours of sunlight in a day. Design a system for monitoring the temperature and pressure of the water, using sensors available in the FESTO catalog.

Day 2

Humidity

Humidity control in data centers is required to prevent damaging electrical equipment. For existing data centers the recommended level is a humidity level of 5.5°C dew point to 60% relative humidity and an allowable range of between 20-80% relative humidity seen in Figure 1.
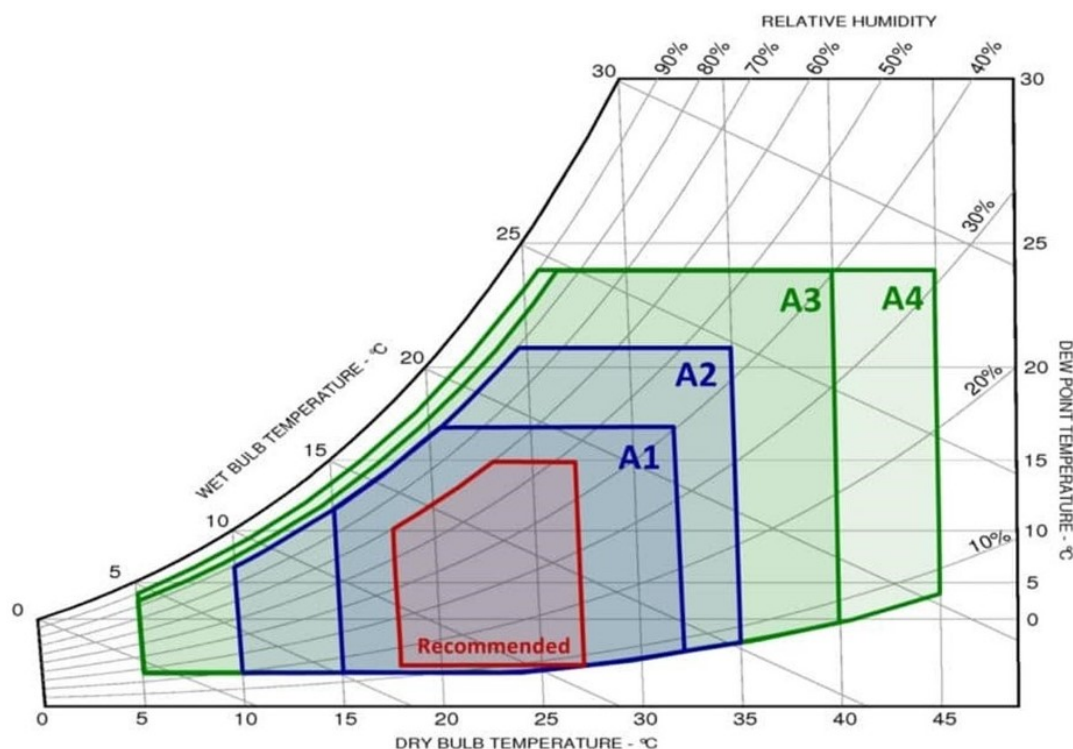
Figure 1: ASHRAE Diagram of humidity levels and recommended level in data centers

Figure 1 [2] shows The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) psychrometric chart showing the IT equipment manufacturer recommended and the allowable ranges: recommended range: temperature-18 C to 27 C, RH-60%; allowable range: A1: 15 C to 32 C, RH-8% to 80%; allowable range: A2: 10 C to 35 C, RH-8% to 80%; allowable range: A3: 5 C to 40 C, RH-8% to 85%; and allowable range: A4: 5 C to 45 C, RH-8% to 90%, where Relative humidity (RH) is defined as the amount of moisture in the air at a given temperature in relation to the maximum amount

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[2]https://www.condairgroup.com/m/0/data-center-humidification-and-cooling-brochure-condair.pdf

of moisture the air could hold at the same temperature, so from this point there are several questions that need answers:

- which zone from A1 to A4 data center should belong to and should be,

- which are normal RH levels and which are the hazardous ones,

- what will happen if RH level is too low,

- what will happen if RH is too high?
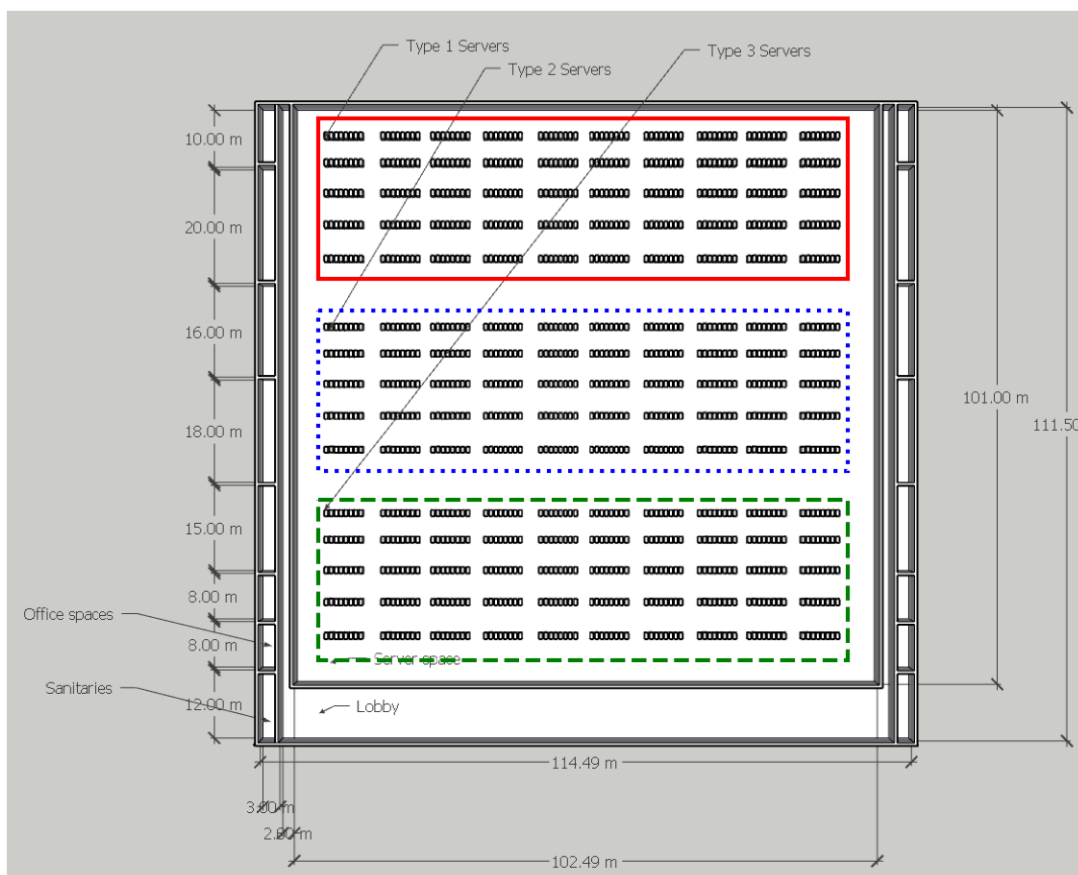
Figure 2: Areas that may need dehumidification.
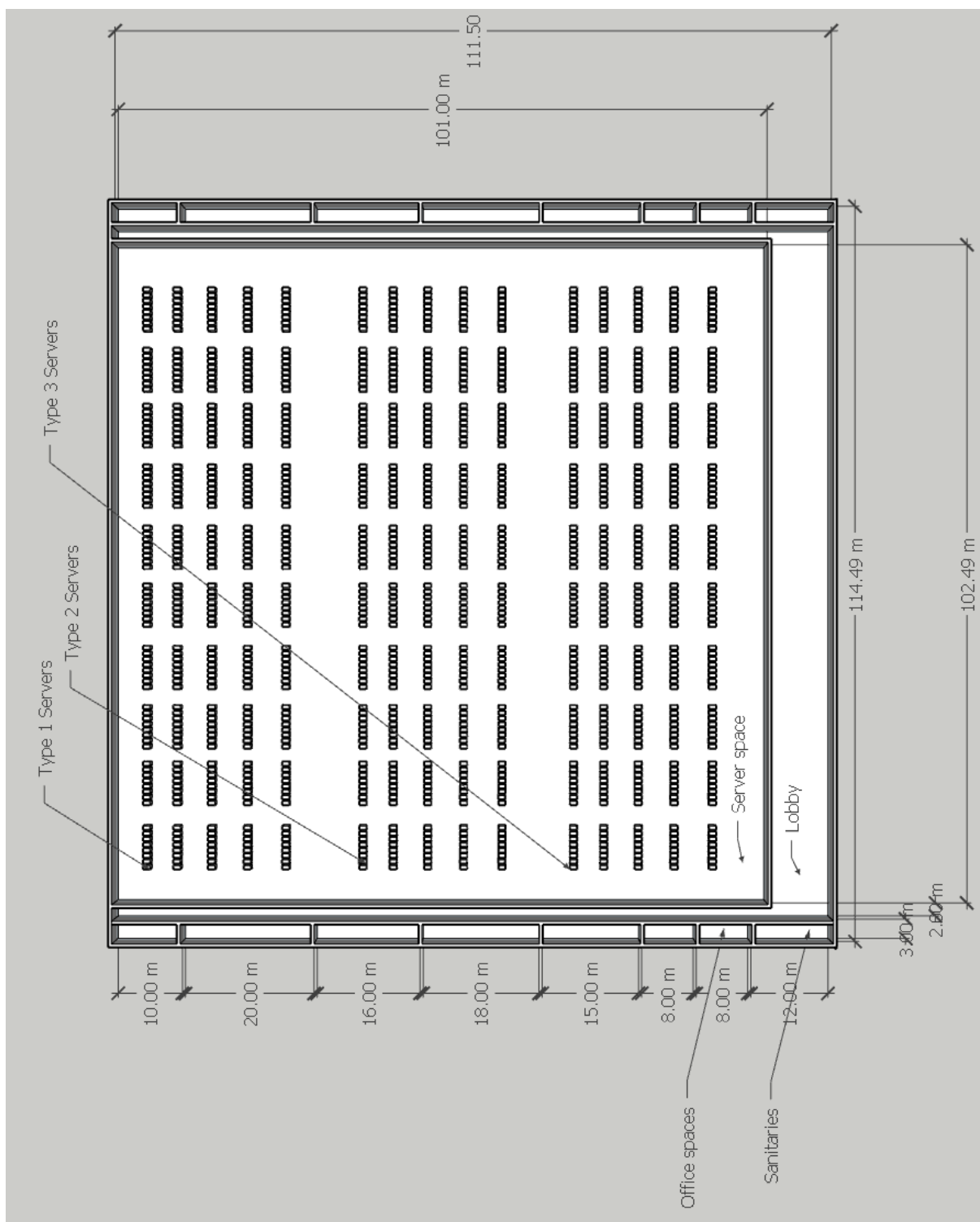
Figure 3: Data center schematic for marking humidifier locations

Outdoor	Outside sensor		Sensor 1		Sensor 2		Sensor 3	
TIME	*T [° C]*	*RH [%]*	*T [° C]*	*RH [%]*	*T [° C]*	*RH [%]*	*T [° C]*	*RH [%]*
1:00	10	60	20	49	20	77	22	48
2:00	10	60	18	45	25	63	22	51
3:00	10	58	18	68	24	68	22	47
4:00	10	60	23	42	25	65	22	34
5:00	9	64	25	44	23	64	22	36
6:00	9	59	21	50	21	66	22	58
7:00	9	56	20	49	21	67	22	30
8:00	10	53	19	69	25	76	22	46
9:00	12	60	23	47	20	80	22	62
10:00	12	50	18	54	25	78	23	33
11:00	12	52	23	65	20	71	23	69
12:00	11	55	25	47	25	67	24	49
13:00	12	55	21	67	20	69	23	37
14:00	11	57	24	61	24	65	23	69
15:00	12	60	25	47	24	74	23	39
16:00	13	55	18	51	22	75	23	30
17:00	12	60	20	40	23	74	23	36
18:00	12	62	20	68	20	73	23	65
19:00	11	63	23	59	21	69	23	49
20:00	11	67	20	66	21	76	22	52
21:00	10	70	21	68	24	73	22	48
22:00	10	71	18	50	24	70	22	63
23:00	10	74	25	52	21	65	22	66
0:00	9	80	22	44	20	76	22	60

Table 1: Temperatures and humidities across the day

If sensor 1 shows data for a section of Type 1 servers in the red rectangle, sensor 2 for Type 2 servers in the blue rectangle (dotted line), and sensor 3 for Type 3 servers in the green rectangle (dashed line) where would you implement and which type of humidifier to put average relative humidity in 50% RH? Temperatures are given in table 1. Sketch position of devices on the scheme of data center below. How much it would cost to build your kind of humidity system? Explain your solution/s briefly.

Emergency control system

Every plant, office building, and even data center has several sensors. The sensors receive the information from the space in which they are located and continue to use that information and react accordingly. However, sometimes the user cannot be constantly in the room and react to unwanted interference. Sometimes unexpected factors can

influence the judgment of the supervisor himself, thus adding to the uncertainty of the system itself. Microcontrollers that do this automatically are relatively robust and will practically always react in the same way regardless of the time of day or night. It is necessary to make a block diagram or ladder logic simulation of the microcontroller of your choice that detects:

- too high of a temperature,

- too high humidity,

- smoke, and

- CO_2 level,

- air quality,

- excessive noise.

Datacenter security is one of the most important things to look out for. Data centers consist of many cost-effective computer components, and in today's modern age of the "Crypto age," there are many curious eyes that would do anything to get their hands on the expensive hardware that data center servers contain. Today's data centers contain a variety of ways to maintain a level of security using microcontrollers. Our data center needs to be secured, secured by designing a security system to detect the presence of a person in the vicinity of the data center, it is important to note that a person only passing is not a threat, but if that person remains there for a period of time, an alarm should be raised.

In addition to the sensors, each of the servers can submit readings on the temperature of its internal components, as well as the current load of the server in percent. As this is a large number of signals (16,000 total servers are present in the proposed data center), how do you propose this system is handled? The emergency control system should also be capable of sending shutdown signals back - how would you handle this?

Depending on the inputs given in Table 2, the notifications should be made accordingly.

In the above table the signals mean the following:

- Raise warning - turn on a blinking visual signal of your choice in the control room.

- Raise alarm - turn on a solid visual signal and a sound alarm in the control room.

- Notify operators - send a mobile notification to the operators.

- Notify emergency services - send the data about the location and emergency type to the appropriate emergency service.

- Manual activation - you must choose which type of activation will this be. Should there be more than one? If yes, include them and explain.

Each of the raised alarms and warnings should be different, so the operators can identify the potential issue directly. In addition to the system architecture design a user interface board for the warnings. How would you make it look to avoid mistakes by operators? Try to make it as readable as possible. How will the sensors be positioned? One the below schematic of he data center mark the positions at which you would place the sensors. Use the following notation:

- $'x'$ - temperature sensor,

- $'+'$ - humidity sensor,

- $'\bigtriangledown'$ - noise sensor,

- $'\bigtriangleup'$ - smoke detector.

- $'\triangleright'$ - air quality sensor,

- $'\triangleleft'$ - CO_2 sensor,

- $'o'$ - presence sensor,

- '$' - light sensor.

Keep the economical element in mind - what is the cost of your system? Keeping the system simpler may lower the costs, and lower the risks of errors (or at least simplify discovering them). If possible use sensors from the FESTO catalog (provided on the link in the Materials section), as well as electromechanical switches from the same source. If the appropriate solution cannot be found there, you can use any online catalog of your choosing. If no appropriate sensor can be found in the provided catalog, feel free to search for it in other sources. You can design the system as a block diagram or a ladder diagram.

Table 2: Conditions for the emergency system

Sensor	Conditions	Action
Temperature	≥ 50 deg C, < 60 deg C	Raise Warning
	≥ 60 deg C, <75 deg C	Raise Alarm
	≥ 75 deg C	Notify emergency services, Turn on evacuation signs, Send shutdown signal to servers, Notify operators
	>50 deg C, but average load lower than 25	Raise Alarm, Notify operators
Humidity	>70%, ≤ 80%	Raise Warning
	>80%, ≤ 80%	Raise alarm, blinking
	>90%	Automatically activate dehumidifier systems, Notify operators
Smoke	Detected	Activate fire suppresants, notify emergency services, turn on evacuation signs, send shutdown signal to servers
Excessive noise	In line with the load	Raise warning.
	Higher than expected due to the load	Raise alarm.
Manual emergency button		Raise alarm, notify emergency services, turn on evacuation signs.
CO$_2$	Normal level	Do nothing.
	Medium level	Raise warning
	High level	Raise alarm
Air Quality	Air quality OK	Do nothing.
	Air quality Low	Activate HVAC
Presence sensor	Person in unauthorized area, working hours — Working hours, Duration <3 minutes	Raise warning
	Person in unauthorized area, working hours — Duration ≥ 3 minutes	Raise alarm, Activate lights
	Person in unauthorized area — Non working hours, Duration <1 minute	Raise alarm, Activate lights, Activate locks
	Person in authorized area, working hours — Working hours, Duration <5 minutes	Raise alarm, Activate lights, Activate locks
	Person in authorized area, working hours — Duration ≥ 3 minutes	Raise alarm, Activate siren for max 3 minutes.
	Person in unauthorised area — Non working hours, Duration <1 minute	Raise alarm, Activate lights, Contact authorities, Notify emergency services, Activate siren, until deactivated
Light sensor	Below threshold	Activate lights
	Above threshold	Activate lights

Note: You must select the activation type for this manual activation. Would you have more than one? If yes, include in the solution and explain.
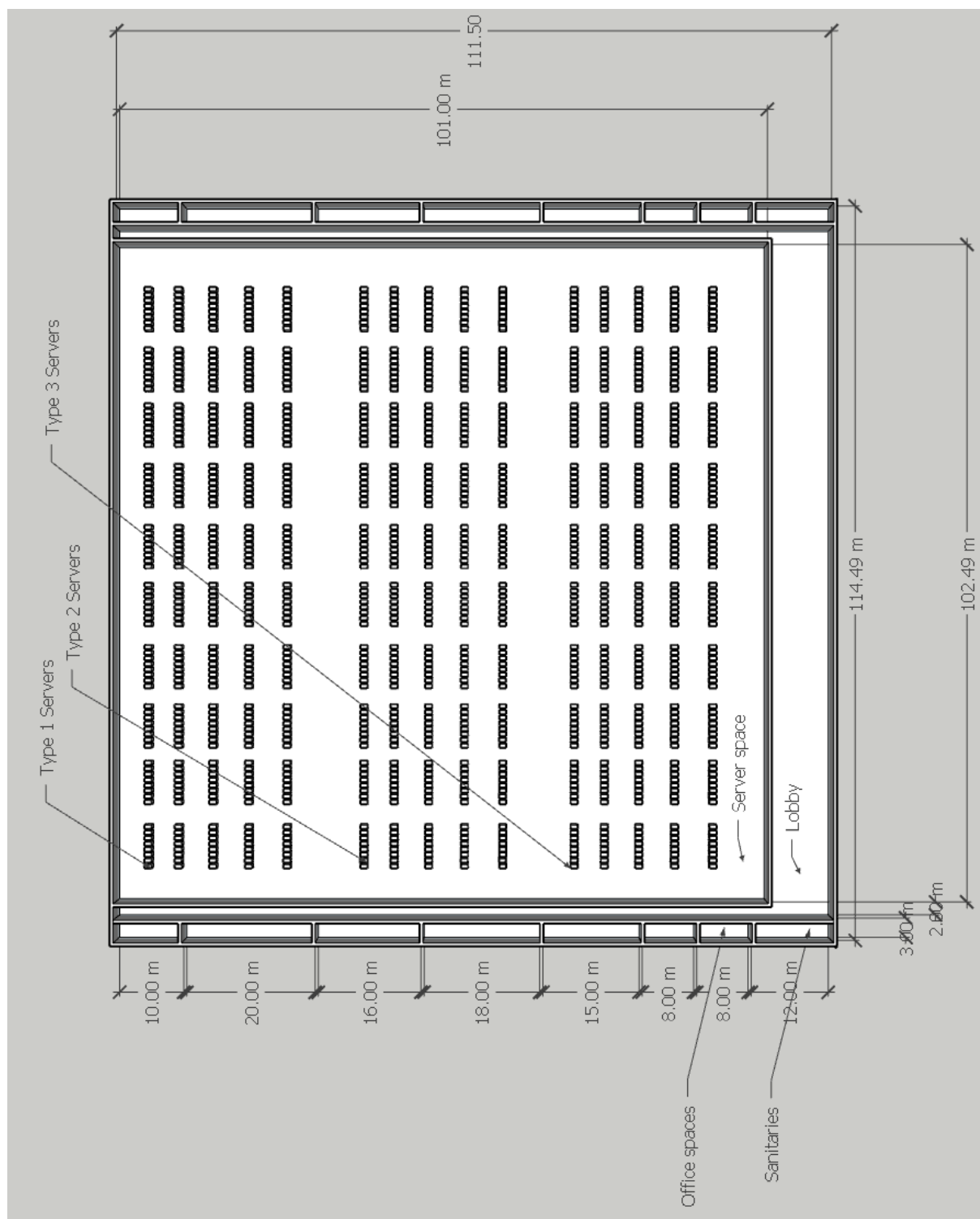
Figure 4: Data center schematic for marking sensor locations

Day 3

Location, location, location

Choosing a location for data centers is one of the most important factors when building the center itself. Many conditions must be met for the center to work effectively. It is necessary to choose a location on the map of Croatia that meets the following conditions:

- uninterrupted operation of the center - what are the potential obstacles to the operation of the center?

- the work of the data center should not interfere with the local population and nature - but it should still be close enough to allow for easy access to workers, deliveries, external experts, and others,

- can the external existing natural, renewable, resources be used to improve the operation of the data center itself?

Explain why the position was selected, and how it meets the above criteria. If you have considered any other factors, do note what they were.

Keep your cool

From the calculations you performed in the preceding days, it should be clear that data centers generate a lot of heat. Your final task is to design a climate control system for the data center building.
Keep in mind - while the server space will need cooling, other spaces may need to be heated in the colder months.

The building itself

While the server-generated heat is far from negligible, there are other heat gains that must be considered. Those can be divided into two main categories – internal (human-induced, lighting, machinery, . . .)

and external (heat gains through the walls via radiation or transmission). The heat flow will also be affected by the external temperature. The building design and material selection will have a significant influence on the heat flow between the building interior and the surrounding environment. Hence, both will affect the temperature inside a server room; the overall heat transfer coefficient was provided for each building segment (see Table 1). To avoid the Solar radiation effects, assume that there are no windows through which the Sun will reach the inside of the building. When attempting to cool down the server room, in addition to heat gains, helpful heat losses must be considered, such as the losses towards the ground. Using the provided building parameters and climate data for the selected localization, find:

- total heat gains and losses,

- total yearly heat energy required for cooling the building,

- the reduction in required energy should the allowed server room temperature would be increased by 3 °C.

Table 1: Building characteristics

| Building segment	Overall heat transfer coefficient, U
Outer wall	0.25 W/(m^2K)
Flat roof	0.20 W/(m^2K)
Floor	0.70 W/(m^2K)

Coolers

Calculate the BTU needs for cooling the server room of the data center and select the appropriate cooling solutions. You are free to set up and cool the environment however you wish. You can select the cooling elements from the Vertiv catalog provided in the materials. Use the below figure to mark the approximate locations of the selected equipment.

Design guidelines

When making cooling, determine the dimensions of the cooling system, define the dimensions and whether it is possible to implement in the current construction of the data center itself. In addition, determine how efficient your cooling system is and how much volume it can cool in a given amount of time. Finally, determine the price of your system. So in short the evaluation comes down to the following:

- the price of the system,

- the volume of the system,

- the speed of cooling the room and

- the possibility of implementation in the current data center and if it is not possible spent investments in building a new part of the building infrastructure to position your cooling system.

So be sure to pay attention to engineering problems. :)
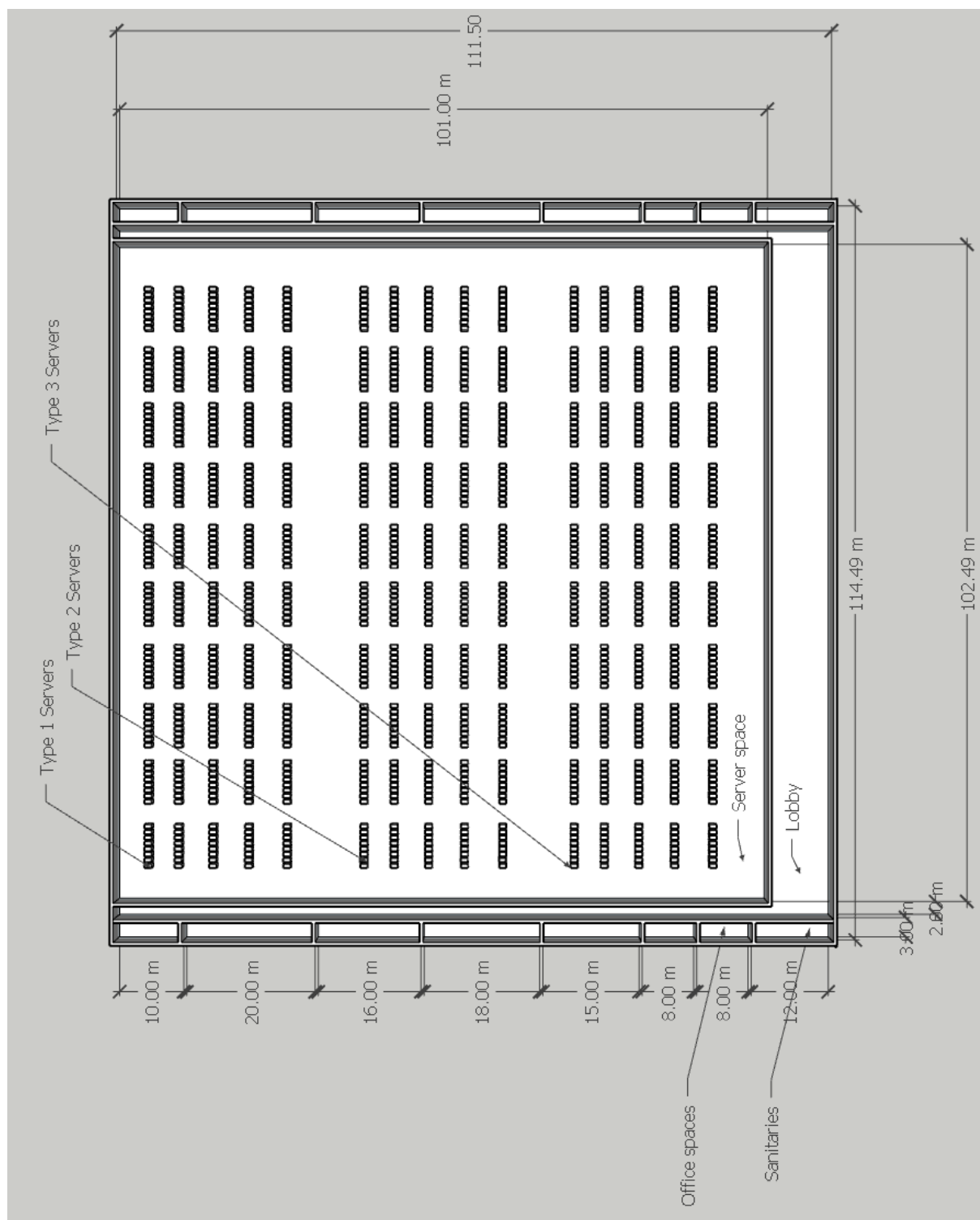
Figure 1: Data center schematic for marking cooling equipment locations.

Integrating sustainability

The sustainability of the system itself is an important thing, but whether it is possible to do so with the help of "green energy", i.e. renewable energy sources. Renewable energy sources are one of the most common questions of world-class giants. Today's humanity is taught to be instantaneous and instant and not very aware of the climate change around us. One of the questions is, is it possible to use renewable energy sources to enable cooling or heating of plants without potential pollution of the environment and ourselves? Can heat exchangers or heat pumps be included? Can you utilize the temperature generated by the data center in some way? If your answer is yes, write down the advantages and disadvantages of this system, what should a designer potentially pay attention to when designing such a system? If you owned a data center, would you use renewable energy sources for potential heating and cooling or would you use conventional ways to maintain room temperature? Explain the answer. As far as sustainability is concerned, could the thermal energy of the data center be "recycled", ie is there a possibility of self-heating the room using the disciplined thermal energy of the server racks themselves? Do you think that electromagnetic radiation or sound (noise) affects the external environment during the operation of the data center itself? If yes address this or reduce potential impacts. When choosing the answer, it is necessary to pay great attention to the economic factor when dimensioning the sustainability of the data center. Will the investment be worthwhile compared to the conventional one after, for example, 20 years of using such a heat regulator? Explain the answers mathematically, the price of 1 kWh is 0.14 euros and it is a reference regardless of the more expensive or cheaper electricity tariff.