A structured approach to online education of future HVAC and energy professionals

Laure Itard[a], *Philomena* Bluyssen[a] ,*Paula* van den Brom[a]

[a] Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, the Netherlands, L.C.M.Itard@tudelft.nl; P.M.Bluyssen@tudelft.nl; P.I.vandenBrom@tudelft,nl

Abstract. The HVAC sector is essential to realize the energy transition and is facing numerous challenges like educating enough HVAC engineers to carry out the task and being able to integrate knowledge from the construction, energy, IT and health sectors and to cope with rapid technological changes. The availability of structured and easy-to-follow courses on HVAC and energy systems for buildings at higher education level could help to motivate (future) engineers to contribute to the HVAC sector, and to understand how challenging and high-tech it is. Such a course program would ideally also bring a basic understanding of the field to architects and building engineers, in such a way that a better common ground is created for collaboration and integrated design. It would also be useful to Machine Learning and Artificial Intelligence experts joining the HVAC sector. Last but not least, it could help bridging the gap between engineering and policy making, by here too, offering common views on primary energy, resource depletion and CO2 emissions relating to HVAC systems. The paper describes the structure and content of such an on-line course program. It was developed based on years of teaching experience with international master students of Mechanical Engineering, Civil Engineering, Architecture, Technical Management and Policy, Electrical Engineering and with professionals from housing associations, ministries and municipalities. The choices for the program structure, based on systems engineering, are underpinned and explained, as well as the choices for specific contents. Additionally, experience with the development of self-assessment tools for students, and self-paced courses is shared, as well as the feed-back from students. A first version of the course program was tested on the edX platform with more than 5000 students participating in each module and is publicly available.

Keywords. On-line education; HVAC; Building services; Professional program; MOOC.
DOI: https://doi.org/10.34641/clima.2022.401

1. Introduction

The Heating, Ventilation and Air Conditioning (HVAC) sector is essential to realize the energy transition and is facing numerous challenges like educating enough HVAC engineers to carry out the task and being able to integrate knowledge from the construction, energy, IT and health sectors and to cope with rapid technological changes. However, the building services sector is facing huge challenges. These challenges have been identified in studies in the Netherlands [1], or in the European BuildUpSkills project [2]. Dealing with these challenges have become even more important because they are decisive in realizing the targets of the energy transition. In detail the challenges relevant to this study include the following:

1.Need for a fast-growing professional workforce: There are too few people working in the sector to realize the transition. According to TechniekNL [1] , there is a shortage of 3000 workers per year in the Dutch sector. This has two implications related to education considering a) the continuous professional development of the current workforce as also b) the education of new employees, mainly having no background in building or energy engineering services.

2. Rapid change of technologies as also related competences: The sector is facing rapid changes in energy techniques (e.g. all electric instead of gas-driven; low temperature heating networks, integration of heating and electrical networks, NZEB buildings); engineering methods (e.g. digitization, circularity, design for maintenance); types of contracts (e.g. performance contracts including maintenance; lease); and processes (e.g. industrialization, prefab, turnkey). These changes are driven by societal needs while only a few innovators and early adaptors develop and start mastering these issues, leaving the question open how to accelerate fostering the maturity of the early majority.

3. Uptake of basic and integrated knowledge:

the main questions here are how to increase and improve the uptake of knowledge inside the company (from senior to junior and vice-versa; cross-specialism (e.g. from electrical to mechanical. From design departments to maintenance department)) balancing between innovation, risk management, lack of time and workforce

The availability of structured and easy-to-follow courses on HVAC and energy systems for buildings at higher education level could help to motivate (future) engineers to contribute to the HVAC sector, and to understand how challenging and high-tech it is. Such a course program would ideally also bring a basic understanding of the field to architects and building engineers, in such a way that a better common ground is created for collaboration and integrated design. It would also be useful to Machine Learning and AI experts joining the HVAC sector. Last but not least, it could help bridging the gap between engineering and policy making, by here too, offering common views on primary energy, resource depletion and CO2 emissions relating to HVAC systems.

This paper describes the contents of an online program of four courses, and the choices that were made in terms of structure and premise (section 2) and learning objectives and contents of each of the four courses (section 3-6), In section 7 we finally reflect briefly on the experience with the first run.

2. Structure of the course

2.1 Target Groups

Three target groups were defined, based on the challenges described in Section 1:

1. Starting professionals with a technical background like mechanical engineering, architecture industrial design or electrical engineering who want or need to get acquainted with indoor climate systems, including sustainable energy systems.

2. Traditional HVAC engineers used to piping and sizing calculations of conventional systems who want to broaden their view towards sustainable and renewable systems.

3. Technology-minded policy makers who want to be introduced to the basics of energy usage in buildings.

To match the target groups it was decided that the level of Maths and Physics should be kept limited to high school level in natural/economics sciences.

2.2 Overall structure of the course program

An analysis of the knowledge needed to understand and make basic designs of sustainable, renewable-based and low carbon-emission indoor climates and energy systems was conducted, based on multiple discussions and collaborations between the university and companies working in the field of indoor climate, energy and HVAC design. To the authors' opinion, the premise can be categorized as follows:

1. Because of the importance of energy use in new regulations, conventional maximum load calculation is not sufficient anymore and should be complemented by energy usage estimation on yearly basis. So, a part of the course program should address this.

2. If in the past it was sufficient to know how to size a boiler, multiple options for sustainable energy conversion are present nowadays, and often need to be combined. So a part of the course should address these possibilities and make sure learners do not focus on the one specific solution they know, but are aware of all others and can make an informed choice, accounting for primary energy use and CO2-emissions.

3. In comparison to industrial applications of energy, applications in buildings strongly relate to indoor health and comfort, which is a point acknowledged very well by professionals, but completely overlooked by engineers/students from other disciplines, although the COVID-19 pandemic may have change this a bit. So health and comfort should certainly have a place in the curriculum.

4. Modern HVAC design should include and integrate the three perspectives above. With regards to the target group, the focus should not be on detailed engineering but rather on the principles leading to efficient design of HVAC systems.

The proposed course structure is therefore as described in **Fig.1**. The courses Energy demand, Energy Supply Systems and Health & Comfort can be followed independently and in a random order. However, the dotted lines in the graphic indicate that some basic principles like conservation of energy and the related energy balances are explained in Energy Demand, but not in Energy Supply Systems. The course Health & Comfort makes use of a few concepts explained in the precedent courses (like insulation or emissions by burning fuels) and introduces some HVAC systems already. So, depending on the level of the learner, it can be better to follow them in the order.

The fourth course integrates the 3 domains and build up on them, introducing specific HVAC-related knowledge.

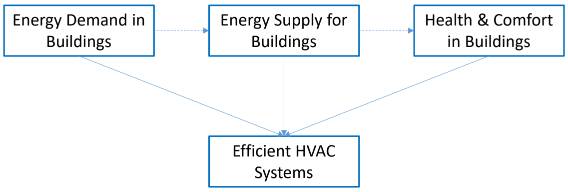

Fig. 1 – Structure of the course program Buildings as Sustainable Energy Systems

In sections 3 to 6 each of these courses is explained in terms of leaning objectives, learning contents and activities.

2.2 Cognitive Levels & Constructive Alignment

The effectiveness of teaching is known (e.g. [3]) to depend strongly on the appropriate correspondence between learning activities and the desired cognitive level, which is called constructive alignment. As for the cognitive levels, we used the ones from the widely applied Bloom's taxonomy [4], as represented in **Fig. 2**.

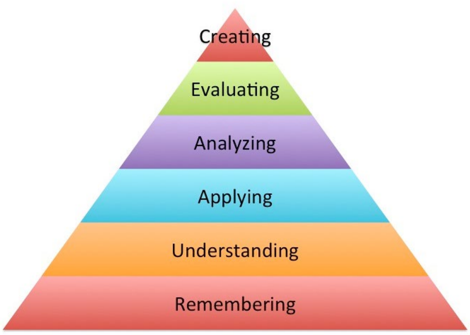

Fig. 2 – Cognitive levels in Bloom's taxonomy [5]

The course is an organized mix of the 5 highest level. Lectures and simple quizzes provide understanding and direct application of the knowledge. More elaborated quizzes vary in level from 'applying' to 'evaluating'. Finally a 'creating' level was introduced in the course 'Energy Demand' in which the students have to create an own design, reviewed by their peers.

Specific for online courses Salmon introduced an additional 5 stage scale [6] stating that knowledge construction by a learner is only one of the phases of learning. In addition to this 4th stage, much attention must be put to: motivating students through efficient access, welcoming and encouraging (stage 1); Online socialization (stage 2); Information exchange like facilitating tasks and supporting the use of learning materials (stage 3); and finally facilitating further development (e.g. links to external sites, stage 5).

In the development of the program stages 1 and 2 are offered by discussion groups moderated from Edx and TU Delft and by putting much attention to the introductions of each week, explanations and activation of the learners by asking about their expectations or sharing their experience in their own countries. In this paper we address only stages 2 and 3, which relate to the contents. In the first version of the course stage 5 was somehow neglected due to time constraints.

Each course consists of 4 to 5 weeks of lessons, organized thematically. Each week consists of 6 to 8 lectures of 10-15 minutes, coupled to many exercises in the form of quizzes to help the learners to understand and apply their knowledge. Much attention was put to make the course suitable for all types of climates over the world and to build understanding of the specific challenges in warm, cold, moderate, dry or humid climates. The course can be used for both new buildings and renovation projects. Learners are expected to study 6-7 hours a week.

3. Energy Demand in Buildings

The main objective of this course is to discover how building design and occupancy determine the energy demand in buildings and to learn how to (re)design buildings with a low energy demand. This course relates therefore to building design. It is based on the extension of the approach proposed in [7].

3.1 Learning Objectives and Subjects

As building design strongly influences the quantity of heating, cooling and electricity needed during building operation, a correct thermal design is essential to achieve low energy and low carbon buildings, with good indoor air quality.

The first objective of the course is to enable learners to understand the basic principles of the energy chain: demand, supply and distribution; and how they relate to design principles for sustainable and energy-efficient buildings. This is handled in week 1, in which the following subjects are addressed:

1. The importance of energy use in Buildings (e.g. climate, resources, comfort), relation with EPBD and with other sectors
2. The energy chain: from demand to supply
3. Design strategies (e.g 3- steps strategy; Reduce; Renewable; Efficiency)
4. Energy Efficient Building concepts (e.g. passive, (N)ZEB)
5. The basics of indoor comfort

The second objective is to discover what type of heat losses and gains take place in buildings and to learn how to estimate these heat flows using simple meteorological data and building materials properties. This way, steady-state heat transfer by transmission, ventilation, solar radiation or caused by internal sources are estimated.
This is combined with the third learning objective which is to learn to make estimates of space heating

and cooling loads on an hourly basis by using simple static energy balances. Week 2 therefore includes the following:

1. Principle and components of the energy balance in buildings
2. Heat transfer by transmission
3. Heat transfer by ventilation and infiltration
4. Solar gains
5. Internal Heat gains
6. Guided example heating & cooling loads

The fourth objective is to discover and apply diverse methods how to extend load estimates to yearly energy demand, which is essential to make sure that a building is energy efficient and to estimate energy savings and energy costs. The following subjects are handled in week 3:

1. The difference between energy use and loads (kWh and kW)
2. Nominal loads and size of heating and cooling equipment
3. Annual energy demand for space heating and cooling (full load hours, degree days and hourly simulations over a year)
4. Annual energy demand and loads for hot tap water
5. Annual energy demand for electricity (appliances and lighting)
6. Introduction to hourly based steady-state annual energy simulation with Excel

The fifth and final objective is to learn how to optimize building's thermal design and to determine (for instance) the optimal window size or the optimum insulation thickness, and more generally to understand and be able to make simple calculations on thermal interactions between building components and to make informed decisions on how to increase the energy efficiency of new and existing buildings. The setup of this week is different as the students have to actively use the excel simulation sheet to come to insights and answers. They had to do this using both a climate year in a moderate climate (de Bilt in the Netherlands) and in a hot climate (Mumbai, India). Sample answers were given after each exercise for both climates. The case study was a large office building, the geometry and thermal characteristics of which were given.

1. Determine cooling, heating & electricity demands and loads
2. Effect of varying occupancy and various ventilation systems (including passive cooling)
3. Effect of diverse levels of facade/roof/floor insulation
4. Effect of type, size, orientation of windows and solar blinds
5. Combine all knowledge to design a low energy building in NL and Mumbai.

Finally a final video recaps what students have learned and put much attention to the *limitations* of the approach (e.g. steady state modelling, neglecting thermal bridges) and what they still could learn in other courses.

3.2 Example of Self-Assessment after a Lecture

As the course is self-paced, and therefore teachers are not available to correct exercises, self-assessment is essential. If self-assessment using quizzes may seem too simple or boring, they also can be made exciting if they are correctly designed, accounting on beforehand for most types of misunderstandings learners can come through. They should include guidance about these faults.

In the following example, a picture of a mineral wool package (**Fig. 3)** is shown to the students and they have to choose the right answer from 5 possibilities. They cannot find the right answer without making the complete calculation, so they are forced to exercise. Alternatively, they can try all answers and learn from the feedback and hints included after choosing any of the answers.

Fig. 3 – Picture of a mineral wool packaging for a quiz

Question: 'You see on the picture a label of mineral wool (λ=0.035W/mK; thickness=120 mm, αi=7.5 W/m^{2}K, αo=25 W/m^{2}K), What is the Rc value [m^{2}K/W] of this mineral wool?

Possible answers: a) 0.29; b) 3.43; c) 3.60; d) 0.28; e) 3429

If learners choose for b (which is the right answer), they are congratulated and also see the right calculation procedure. If they choose a wrong answer, they get a hint, e.g. if they have answered a) or d): ' you are probably confused between U and Rc (U=1/Rc)'; Or, if they have answered c): 'You have added to the resistance the αi and αo heat transfer coefficients, but that is not the definition of Rc'.; Or, if they answered e): ' you have forgotten to convert the mm into meters'.

4. Energy Supply Systems

The main objective of this second course is to discover how to convert natural resources into heat, cold and electricity, what the capabilities of renewable systems are, how to simply match energy supply with buildings' energy demand (the preceding course), and what that means for energy efficiency and carbon emissions. The working principles of the diverse systems are explained without going too much into the details of all components, with as less as possible formula's, except when it comes to efficiencies and CO2-emissions. Here too, the course is(partly based on the approach proposed in [7].

3.1 Learning Objectives and Subjects

The first step is to consider how to convert natural resources into the energy needed by buildings: what are the options to create heat, cold and electricity? Students will also learn about efficiency and use this concept to estimate building's primary energy use and carbon emissions. This methods are widely used in many national and international policies and building regulations, and are essential to counteract climate change.

The second objective of the course is to understand the performances of *single heating systems* like electrical heating, gas, or renewables like biomass, solar boilers and geothermal heat, followed by *single cooling systems* like evaporative cooling and environmental cold. For each of these systems, working principles, efficiencies , primary energy and resources used are studied as well as CO2-emissions. An additional lecture on heat exchangers was added, as many students appeared not to be familiar with it. Although gas is a fossil fuel, it has been included in the course as a reference, and because many countries consider gas as a transition fuel.

A third objective is to understand systems that *concurrently produce heat and cold* (heat pumps & chillers; Aquifer Thermal Storage systems). These three objectives are divided over the two first weeks of the course. Electrical and fuel burning boilers are handled in the first week, as easy-to-understand illustration of efficiency and carbon emissions.

Week 1:

1. Recap on energy demand (energy vs power, principle of energy balance)
2. Overview of supply systems for heating (resistance, fuel burning, heat pumps, waste heat, geothermal, solar), cooling (chillers, evaporative, geothermal cold) and electricity
3. Efficiency of systems and Primary Energy
4. CO2 and CO2-eq emissions, calculation principles
5. Electrical Resistance Heating and grid efficiency
6. Fuel burning in boilers
7. Guided boiler example with annual primary energy, resources used, CO2-emissions, investments costs and energy costs

Week 2

1. Heat Exchangers
2. Heat pumps and chillers: working principle
3. (Seasonal) Efficiency of heat pumps ((S)COP)
4. Geothermal Systems
5. Chillers and their efficiency ((S)EER)
6. Evaporative cooling and Environmental cold
7. Guided example on a reversible heat pump (same setup as in week 1)

The objective of the third week is to understand *electricity generation* methods using turbines (fuel-burning and nuclear based, wind, hydro), photovoltaics and hydrogen fuel cells. It is often left out from courses on buildings' energy use. It is however essential to fully understand primary energy use and CO2-emissions of buildings, and their relation to the electrical grid. This week is also meant to learn how *cogeneration of heat and power* works and relates to smart heating and cooling grids, and why this is important for the rational use of energy resources.

1. Combustion based electricity generation (generator with (combined) gas turbine, steam turbine (including nuclear))
2. Waste heat, cogeneration and rational use of energy
3. Electricity from geothermal heat, hydropower and wind
4. Hydrogen Technology and smart grids

Finally, the last two objectives of the course, handled in week 4, are to understand *solar systems*, and to apply the knowledge gained during the course to *design efficient building concepts* in order to match buildings' energy demand while keeping costs acceptable, using a minimum of natural resources and producing a minimum of carbon emissions. Week 4 is shorter than others to allow time for the final assessment for certified learners.

1. Solar heat
2. Solar electric (photovoltaic)
3. Guided example NZEB and energy positive buildings.

5. Health & Comfort in Buildings

The main objectives of this course are to raise awareness about the determinants and importance of a healthy indoor environment and to enable the learners to apply the basics of thermal comfort and indoor health theories when designing buildings and their energy systems. People spend more than 80% of their time in buildings. Therefore a good thermal comfort and quality of the indoor environment are essential for their wellbeing, health and productivity. Part of the course is based on [8, 9,10].

Prior to the first week, learners were invited-if they wanted to, to fill in an anonymous survey about their health and comfort at home. This survey is described in [11] and is repeatedly used to collect new data. Next to activate the students, it is also useful for research purposes.

The objective of week 1 is to understand what is Indoor Environmental Quality (IEQ), what are its parameters and how it impacts health. After IEQ has been defined, two aspects of it, lighting and acoustical qualities are handled briefly. In Bloom's taxonomy we are working here at the level of remembering and understanding. As the focus of the course program is on thermal energy systems we have chosen to address these 2 aspects only lightly in order to put the focus on indoor air quality and thermal comfort, who are both affected greatly by thermal systems (including ventilation).

1. Why is environmental quality important (links with diseases and disorders)?
2. What is environmental quality (lighting, acoustical, thermal and air qualities)?
3. Lighting Quality: relation with health
4. Lighting quality: parameters of light indoors
5. Acoustical quality: relation with health
6. Acoustical quality: parameters of sound indoors

The second week of the course is devoted to thermal comfort with the objectives to familiarize the learners with the two main theories currently in use and to apply them to assess simple building designs.

1. Thermal quality and homeostatis (link with energy balance of human body and the 6 thermal comfort parameters, consequently handled in the following lectures)
2. Metabolism and Clothing
3. Air Temperature and Velocity; comfort diagrams
4. Relative Air Humidity, simple definition and comfort diagrams
5. Mean Radiant Temperature, definition, relation with insulation and comfort diagrams
6. Fanger's Comfort Model (PMV and PPD)
7. Local Discomfort
8. Adaptive Comfort Model

The third week is entirely devoted to indoor air quality (IAQ), with the objective of the learners becoming aware of all parameters of IAQ and being aware of efficient control strategies in the design of ventilation systems. A special lecture was devoted to the COVID pandemic and aerosols.

1. Reception of air and Health Effects
2. Parameters of Indoor Air (particles; gaseous pollutant and humidity)
3. Pollutants and Sources: Particles (sizes; biological and chemical; health effects)
4. Pollutants and Sources: Gaseous pollutants (inorganic; VOCs; health effects)
5. SARS Cov-2 (particle; droplets and aerosols)
6. Control strategies (low emitting materials; filtering of air and cleaning of ventilation systems; appropriate ventilation strategies)

To close this third week, the general results of the home survey like held in week 1 are discussed.

The objective of the last week of the course is that the students learn to apply their knowledge on the design of healthy buildings and to assess and analyse practices in building design and HVAC systems. All concepts learned before are translated to engineering aspects. In this sense week 4 is also an introduction to HVAC systems. The subjects handled are the following:

1. What is a healthy building? (summary or preceding weeks, with much attention to control possibilities, which are worked out in next lectures)
2. Introduction to healthy HVAC systems (basic description of air handling units, needs for filtering, clean components and piping and avoid recirculation)
3. Clean components for ventilation systems (characteristics of filters, humidifiers, heat exchangers and location air supply)
4. Healthy air supply (clean ducts, noise prevention, draught in supply grilles)
5. Façade & Ventilation: design of ventilation openings, acoustical and thermal insulation of openings, façade heat recovery, outdoor air quality, double skin facades.
6. Window design: thermal and lighting qualities and control in cold and warm climates, outside view
7. Energy efficient artificial lighting control (needed light levels, electricity use of diverse types of lighting, configurations and zoning)
8. Room heaters and coolers: energy efficiency and comfort (air-based & water based heaters and coolers, their temperatures and relation to mean radiant temperature, noise and draught and to energy use)

6. Efficient HVAC systems

All three previous courses are integrated into this last one, with as main learning objective to apply the knowledge in HVAC design practices at the level of basic and preliminary designs. In the design of the course we aimed at linking with more conventional HVAC design courses –generally focused on air handling units (AHU) and to complete the understanding of learners with essential subjects that were not covered before, like dealing with humidification and de-humidification. The course is based for a part on [10], [12], [13].

The first week of the course is therefore a recap of all three previous courses, presenting the essentials of energy demand, energy supply and health & comfort, to which an additional lecture on the basics of heat exchangers was added.

The second week handles humid air, humidification and dehumidification processes and processes in air handling units. The students should be able to describe related processes and to make simple calculations of energy use and humidity contents. They learn to do so using either Mollier diagrams, psychrometrics charts or equations, to fit with habits in their own country. Learners can test their knowledge about equations if they want, but the attention is put to the use of diagrams and charts, as it fits better with the lower mathematical background of many students. Week 2 is organized as follows:

1. Introduction to properties of humid air
2. Psychrometric charts and humidity
3. Dew point: condensation, cooling & de-humidification processes
4. Enthalpy of humid air; Heating and cooling processes
5. Wet bulb temperature and humidification processes
6. Handling of humid air: summary of the possible processes.

The third week has been designed to familiarize the students with the diverse types of air, heat and cold distribution systems in buildings. We know from previous courses that knowledge is very local and it may be difficult for students to realize that there are diverse options. For instance learners from hot climates are not aware of water-based heat distribution systems, while learners from cold climates may not realize the problems water-based cold distribution systems would cause. In each presentation calculation examples are given and systems are visualized. The contents of week 3 are:

1. Overview of possibilities to transport hygienic air, heat and cold and their possible interactions; Advantages and disadvantages; Duct sizes)
2. Air handling units: the theoretical processes described in week 1 are applied in AHUs
3. Transport of air in ducts (location of supply, velocity & noise, sizing and efficient routing of ducts)
4. Pressure drop in ducts en fan energy
5. Transport of heat by water systems: hydronic heating (location of generation system; design of hydronic networks; sizing of convective/radiant emitters)
6. High and low temperature heating (advantages and disadvantages in relation to comfort, energy use and use of renewable sources)
7. Hydronic cooling (location of generation system; design of hydronic networks; options and sizing of emitters, low and high temperature cooling; dew point control)

In week 4, the students are familiarized with the basic principles of sizing and controlling simple systems. In view of the target audience, we've deliberately avoided to go into the details of control engineering (which is still handled in the last lecture), but rather focus on designs enabling control.

1. Enabling control (sizing, zoning, readjusting, combining, buffering)
2. Design for control: zoned HVAC systems (zoning of distribution ducts for flexibility in use and maximum efficiency; Introduction to Process and instrumentation diagrams (P&IDs)
3. Readjustments systems at room level (mixed air/water systems; central and decentral control; graphical review of possible configurations, for instance like in shown in **fig. 4**)
4. Load duration curves and generator combinations; relation to investment costs and energy use
5. Buffers for peak shaving, renewable energy and match between supply and demand; Design of buffers
6. HVAC operation control: basics of control (sensors, actuators, controllers) and application to temperature, pressure, flow rate and humidity control, using P&IDs.

The last week of the course handles design and control of integrated systems for Net Zero Energy Buildings. It starts with a lecture about the design process itself, before digging into the aspects of technical design. This includes 2 subjects on specific designs for moderate and cold climates, 2 subjects specific to hot climates, and stresses finally the importance of aquifer thermal storage systems (ATES).

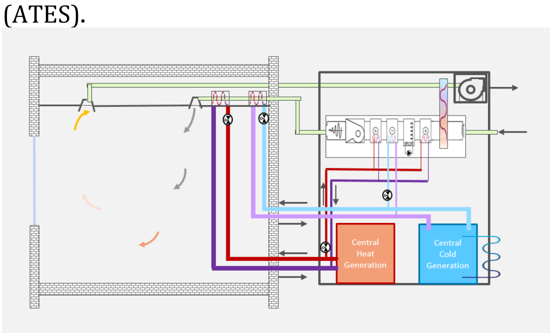

Fig. 4 - A configuration for central & decentral control

1. Design process for efficient HVAC systems (aims, collaboration with other experts,

process from program of requirement to maintenance, commissioning)
2. Efficient control of conditioned air from AHUS (CAV & VAV; energy efficient set point temperature control; flow patterns in rooms)
3. Efficient buildings and HVAC systems for moderate and cold climates (reduced heating demand; high quality ventilation, emitters, generators; solar electricity; NZEB)
4. Heat sources for heat pumps (ground, solar, (ventilation) air, working modes and control, collective systems)
5. Efficient buildings and HVAC systems for hot climates (reduced cooling demand, ventilation strategies, generators; solar electricity; NZEB)
6. Heat sinks for chillers and environmental cold (air, water, ground, collective systems; absorption systems)
7. ATES systems for heating and cooling (working modes explained in words and P&IDs)

7. Reflections

The first run of the complete program took place between September 2020 and November 2021. The four courses were offered in the same order as described in the paper. More than 5000 learners subscribed to each of them and 8-10% of them were following it on an active way, which is quite standard on the edX platform. Course 4 (Efficient HVAC systems)ended in the shortlist of 100 most popular online courses 2021 (out of 2900) [14], indicating a wide and worldwide interest for sustainable HVAC systems.

Although the detailed analysis of the students reviews still has to be done, it can be noted that the courses were highly rated with grades between 8 and 9, except for course 2, what was rated a little bit lower. About half of the students were junior HVAC professionals, many of them from India and US. It is not completely clear yet in how far policy makers have followed and/or appreciated the course.

In general the technical/theoretical level of course 1 (Energy demand) was found to be right, while the level of course 2 (Energy supply) was too high (mainly because of mismatch with background on heat transfer and heat exchangers). Course 2 was also less well-balanced between the levels of explanations on diverse technologies (e.g. too less solar in comparison to heat pumps). The last of week of course 1 (the only one at 'create' level, see **Fig. 1**) was appreciated a lot. Leaners found it 'fun'.

The first lecture in course 4 (design process and stakeholders) was highly appreciated and students asked for similar lectures in the other courses, as this helps to place the activities of the course in their context. Finally it was noted that there is very little literature or handbooks addressing the subject of design for control (e.g. zoning, readjustment, multiple generators) on a structured way. This is also true for reading and understanding P&IDs.

8. Acknowledgements

We thank Delft Extension School, and in particular Bertien Broekhans, Eloïse Ruby and Rins Lindeman for their support and help with financing, organizing and moderating the program. The development of this professional course program was partly founded by Climate-Kic City Retrofit Ecosystem Build Benelux and Delft University of technology.

9. References

[1] Interview Terpstra D., Techniek NL https://www.nu.nl/ondernemen/4476618/installatiebranche-tekort-15000-vakmensen-komende-vier-jaar.html
[2] https://buildupskills.eu/,access23-01-2022
[3] Duffy, T. M., Jonassen, D. H. (2013). Constructivism and the technology of instruction: A conversation. Routledge
[4] Bloom, B. S. (1956). Taxonomy of educational objectives. Vol. 1: Cognitive domain. New York: McKay, 20-24.
[5] Hernandez, A, access 21-01-2022, https://www.flickr.com/photos/21847073@N05/5857112597,\, License CCBY-SA2.0
[6] Salmon, G (2002) E-tivities. London. Kogan Page Ltd..
[7] van Bueren E., van Bohemen H., Itard L., Visscher H. (2012) Sustainable urban environments, Chapt. 5, Springer.
[8] Bluyssen, P.M. (2015) All you need to know about indoor air, Delft Academic Press, NL.
[9] Bluyssen, P.M. (2019) All you need to know about air conditioning, Delft Academic Press
[10] van Paassen A.H.C. (2004), 'Fundamentals: Thermo-dynamic aspects of humid air and comfort', course WB4426 (ME45111) Indoor Climate Control Fundamentals, TU Delft.
[11] Bluyssen, P.M., Zhang, D., Ortiz-Sanchez, M. (2021) Self-reported rhinitis and headaches of students from universities in Taiwan, Chile, Suriname, China and the Netherlands, and its association with their home environment, *Intelligent Buildings International*: 1964424. https://doi.org/10.1080/17508975.2021.1964424.
[12] ASHRAE handbook Fundamentals
[13] ISSO-TVVL Handboek Installatietechniek (2002), the Netherlands
[14] https://www.freecodecamp.org/news/most-popular-free-online-courses/, access 23-1-2022