DEVELOPMENT OF A DISTANCE LEARNING PLATFORM BASED ON A NETWORK OF CONNECTED LABS TO STUDY THE ENERGY PERFORMANCE OF BUILDINGS SYSTEMS

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Abstract

The energy performance of building systems for heating, cooling, lighting and ventilation is a driving factor to reduce global CO2 emissions and mitigate climate change. Five Universities located in Belgium, France, Germany and Luxembourg have joined to connect their thermal laboratories to provide complementary research and teaching capabilities to contribute to more sustainability in the building sector.

Within the project RCC|KN, Network of Climatic Chambers ("Réseau de Chambres Climatiques | Klimalabor Netzwerk") which started in 2018, the laboratories and their equipment were connected through a remote connection on a digital platform [1]. The platform delivers real time data (temperature, pressure, humidity, flow rates, controls from the equipment, thermal comfort values) from the laboratories and it offers the opportunity to perform remote experiments between the connected labs. Furthermore, the platform can be connected to a simulation tool (TRNSYS) to extend the applicability of the experiments via emulation [2].

This paper aims to present the next step of the RCC/KN project which is the development of a multi-stakeholder distance learning platform for university students and practitioners. It will be based on the RCC/KN platform and allows the remote testing and distance learning in the field of thermal systems and building environment. In addition to the complementarity of sensors and equipment in the different labs, the Covid pandemic further increases the need for such a joint effort to offer cross-institutional collaboration in a digital format.

The platform will encourage the interaction of students as they can decide over possible solutions, for example in terms of choosing the right system to maintain thermal comfort, they can experience the inertia of different heat emission systems and the actual energy demand needed to achieve the required conditions. It will enhance the students' ability to set up an experiment with the given systems, monitoring the output during the experiment, working with the gathered data and analysing the results. Through the digital lab experiments they will improve their understanding of how to operate buildings in an energy efficient way and hence, later on in their career, they are able to contribute to a reduction of greenhouse gas emissions in the building sector.

Keywords: Virtual distance learning platform, distance teaching, building energy performance, thermal systems, connected laboratories, remote experiments.

1 INTRODUCTION

Distance Learning and respectively distance education is getting a key instrument for universities and education centres due to the pandemic of Covid. Although there was a visible increase for available online courses over the past decades, the first year of the pandemic lead to a broad turnaround. E-learning was not anymore an optional decision, but a requirement for almost a year. This change caused particularly problems for research fields which require laboratory experiments.

Especially the field of civil engineering or the field of the built environment, requires sophisticated machinery and equipment. In the field of energy performance, experiments and respectively validation are crucial elements. For this, laboratory tests are as important as the in-situ analysis and optimization.

Climatic chamber tests, energy systems and also studies for thermal and visual comfort are executed. As in the most research areas, these different in-depth research fields have their own equipment and special knowledge in some branches, as for example building simulation, thermal and visual comfort, electrical energy storage.

This paper presents a concept to conduct laboratory experiments across universities and, if necessary, also within online courses. This approach is based on a research experiment in which the equipment of five universities was linked. The universities are located in the area of the Greater Region (GR) of Belgium, France, Luxembourg and Germany and the project was funded through an INTERREG VA project [3].

The here presented approach addresses professors and lecturers in the fields of Building Science, Civil and Mechanical Engineering. The paper shows a concept of two test courses of a series of online courses. The main topic, which is covered by the two test online courses is the energy demand of buildings. The energy performance of buildings is a driving factor to further reduce the CO_2 emissions and the energy demand of buildings to achieve the goal of a highly energy efficient and decarbonised building stock by the year of 2050. Thermal sensation, thermal comfort, the influence of solar load and the right operation of heating and cooling systems are key factors of the building energy performance.

The courses are designed to improve the understanding of students regarding the operation of heating and cooling systems and further topics in the realm of energy performance of buildings. It covers the energy demand by considering various heating and cooling systems, but also the building occupants' need for comfortable conditions. It shows the performance of different heating and cooling systems via online monitoring and remote control. The courses will help students to create an understanding of the optimization of various systems.

Furthermore, it is well known, that the learning success of the students depends heavily on their interaction, which is considered for the concept of the course. This paper shows a new approach for distance learning in the field of energy management and energy performance of buildings which will involve the students' interactions in terms of real-live implementation.

The paper has been divided into two main parts. The first part deals with the introduction of the RCC/KN project and the data exchange which is the base for the evolution of this online course series. The second part addresses the tests series of the two already developed online lecture units of the planned course series. After the main part the student's feedback, the analysis of the test courses and an outlook part will follow.

2 RCC/KN PROJECT AND ONLINE COURSES

2.1 RCC/KN ("Réseau de Chambres Climatiques | Klimalabor Netzwerk")

The project RCC/KN ("Réseau de Chambres Climatiques | Klimalabor Netzwerk") shows a connection of four laboratories of the "Greater Region" (GR) (Figure 1). The "Greater Region" is the cross-border region extending over Wallonia in Belgium, Grand-Est region in France, Rhineland-Palatinate and Saarland in Germany and Luxembourg. The project was funded in the framework of the European program Interreg V-A Greater Region with the specific goal of the program, to strengthen the cross-border cooperation in the field of research. The following universities are connected within the project RCC/KN: BEMS research team (Building Energy Monitoring and Simulation) of University of Liege (ULiège) in Belgium, Living Lab Smart Office Space of the Technical University of Kaiserslautern - Department of built environment in Germany, ENERBAT platform of LERMAB - Faculty of sciences and technologies, University of Lorraine in France, Electrical Batteries test laboratory of HTW Saar (University of Applied Sciences) in Germany.

Figure 1. Universities of the "Greater Region"

Each of the laboratories has one special research topic and according to this specialized equipment in the research field of the energy performance of buildings. The specialized research topics are also shown in the Table 1. Most of the equipment can be only operated on site (e.g heating/cooling systems) and with special knowledge. The goal of the research project RCC/KN was to link the equipment of the different labs "virtually". This offers new opportunities for experimentations in the area of the greater region [1]. So far, no further comparable cooperation is known in the field of building energy performance in the GR.

Table 1. Specialties and equipment of the different teams

Research Team	**Specialities / Equipment / Systems**
BEMS (University of Liège)	Climatic chamber, weather station, thermal solar panels, photovoltaic, heat pump, cooled ceiling, air handling unit, etc.
Built environment (TU Kaiserslautern)	Visual and thermal comfort, PMV sensor stations, decentralized heating and cooling systems, electrochromic glazing, operable venetian blind systems, etc.
HTW Saar Battery Laboratory (University of Applied Science)	Test bench for electric batteries, grid connection and grid integration, etc.
ENERBAT (University of Lorraine)	Adsorption chiller, climatic cells with cold ceilings/heating floors, photovoltaic, geothermal heatpump, CHP, etc.
RUES (University of Luxembourg)	Reversible heat pump, 3 storage tanks, a thermal collector emulator, ice storage and 2 convectors, battery storage system, PV emulator

The focus of the BEMS research team from the University of Liège is the study of the building energy performance with a "system" approach by mobilizing the resources and monitoring and digital simulation. They offer a climatic chamber, to replicate special environmental conditions testing different heating and cooling systems in large scale tests [4–6].

The team of the built environment of the University of Kaiserslautern offers the Living Lab Smart Office space which is a collaborative project of the University of Kaiserslautern and the German Research Center for Artificial Intelligence (DFKI). Here, innovations in the field of personalized environment and ambient intelligence, thermal and visual comfort are developed and tested under real office conditions [7–10].

The ENERBAT platform of LERMAB is developed from the faculty of sciences and technologies of the University of Lorraine. The aim of ENERBAT is to study the optimal coupling of energy equipment to the building envelope. It is a platform which is able to simultaneously produce heat, cold and electricity, which makes it a tri-generation platform [11, 12].

The HTW Saar Battery Laboratory of the University of Applied Science is connected to the project with the test bench for electric batteries. The laboratory is part of the institute for electrical energy systems (PowerEngS) of HTW Saar. The research focus of the team is the grid connection and grid integration of storage facilities for electrical energy. The lab offers different inverters and energy storage systems and high-quality measuring equipment for the evaluation of the voltage quality. One key competence of the battery laboratory is the possibility of investigate new battery or storage technologies [13].

For further steps of the project the Department of Engineering of the University of Luxembourg is joining with its facilities. This laboratory was built to study the energy systems of buildings and to optimize their energy efficiency [14]. This optimization focuses on both thermal (heat pump, ice storage, thermal solar collectors) and electrical aspects (photovoltaic emulator, battery storage system), using a so-called MPC (Model Predictive Control) controller.

The aim of the RCC/KN project was to connect these laboratories in different levels. Not only exchanging experiences and researchers, but also the aim to implement a remote connection between the labs. With this remote connection between the labs, the equipment can be shared via an emulation technique due a messaging platform and a real time data exchange between the labs on a platform which is called RCC/KN [1].

2.2 RCC/KN data exchange

Behind the RCC|KN project is the idea to share equipment between the four laboratories involved in the consortium and to be able to conduct remote and joint experiments. Indeed, the equipment used in a thermal laboratory is not only expensive, but also difficult to lend or to move. In this context, the implementation of a technical solution enables researchers and lecturers to carry out experiments while avoiding important investments. RCC|KN has responded to this challenge by setting up a communication platform between the different sites making it possible to perform remote experiments and to work with several laboratories together in real time. Beyond the communication aspect, RCC|KN implements the emulation technique allowing the realization of those joint experiments between laboratories. This method consists in reproducing the behavior of one specific (distant) equipment by another type of (local) equipment.

As illustrated in Figure 2, the RCC|KN communication platform is above all a message exchange solution allowing to send data from one point to another through the network. Data gathered by the hundreds of sensors from a specific laboratory can be sent to one or more other connected laboratories. The data is obviously collected for afterwards analysis of an experiment but are also used to remotely control the equipment (e.g., remotely set a set point temperature). For this purpose, data messages are sent in (almost) real time with a data acquisition time of about 10 s.

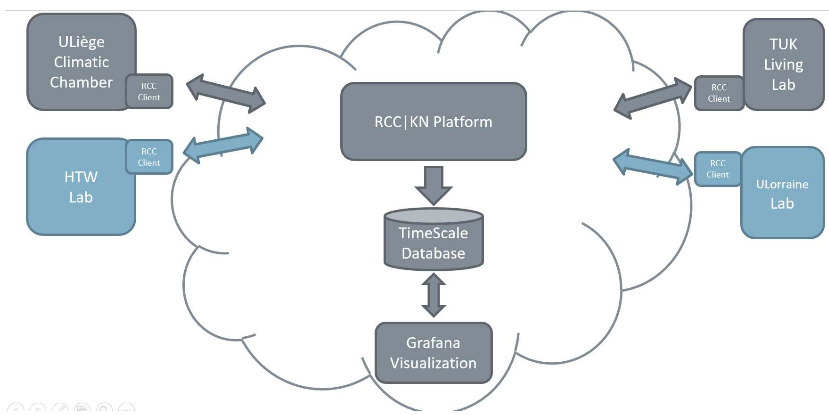

Figure 2. Data exchange on RCC/KN

Data analytics and visualization on the RCC|KN platform are important concerns and are facilitated by the implementation of different open-source tools. At first, a time series-oriented database (i.e., TimescaleDB) stores all the large volumes of data transiting over the platform. Raw data is collected for fine-grained analysis and monitoring. The latter is also automatically aggregated over different time steps (5 minutes, 1 hour, 1 day). CSV formatted files can easily be extracted to work with standard analysis tools. Then a near real time visualization tool (i.e., Grafana) is used to present data with a convenient dashboarding solution (see Figure 3).

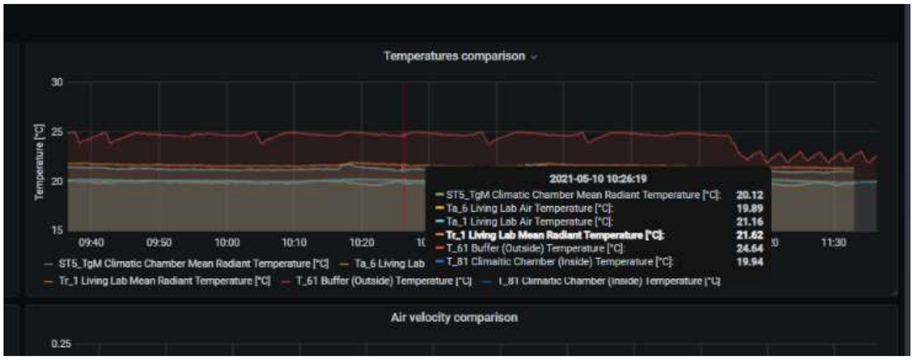

Figure 3. Example of Grafana dashboard visualizing real time data

If the first goal of RCC|KN is to interconnect laboratories to be able to share equipment and conduct joint experiments, the architecture has always been designed to remain open to other uses. As an example, the use of the platform in the industrial world as an equipment test bed has always be in mind. The capability to interconnect simulation software (e.g., TRNSYS) or data analysis tools are also a track in progress. More recently, in the context of the pandemic, a promising option is to use this platform as a remote educational support that offers the possibility of real time demonstrations. As a proof of concept two distance learning lecture units (2 x 180 min) have been developed, held and evaluated.

2.3 Proof of concept through two experimental lectures

The two experimental lectures that have been developed and tested were based on a hybrid presence/remote concept. For the tests, three to five students (both, graduate and undergraduate students) from the participating universities were together in one room and participated collectively in the online event. Some students participated through remote connection. As a great advantage of the course concept, the hybrid approach allows students to take part from home in case of emergencies, such as a Covid-quarantines, when students might not be able to attend courses for several weeks. The overall course concept allows for different options: as a pure online course, a pure presence event or in a mixed mode concept.

The course was taught by two professors and three research assistants of two universities (ULiege and TU Kaiserslautern). Two test courses were run in May 2021 while this paper has been completed. The first online course covered the topics: energy calculation of cooled ceilings, subjective evaluation and calculation of thermal comfort related metrics. The second online course focuses on energy performance of air-based cooling systems and the impact of solar load and different shading systems.

An important point for the concept of the course was the students' interaction between their peers as well as between them and the lecturers to deepen their knowledge and understanding. During the class they got the opportunity to make their own decisions, they had to discuss their decision several times and defend their choice. During the course they checked a couple of times, if this decision was right.

The participants got access to the data-visualization platform (Grafana) to check and extract the measured data of the lab, in which the physical experiment is running. The equations needed are introduced to the participants during the lecture and the students calculated the energy performance based on these data.

2.3.1 Concept of the online courses 1 and 2

The following graph shows the timeline and the progress of the online courses. It consists of student's interactions in terms of surveys, discussion boards or calculations with real time data (big red and light green circles) and in between the teaching parts (small blue circles). The big blue circles (introduction with an icebreaker session and the conclusion) are collaborative parts at the beginning and at the end.

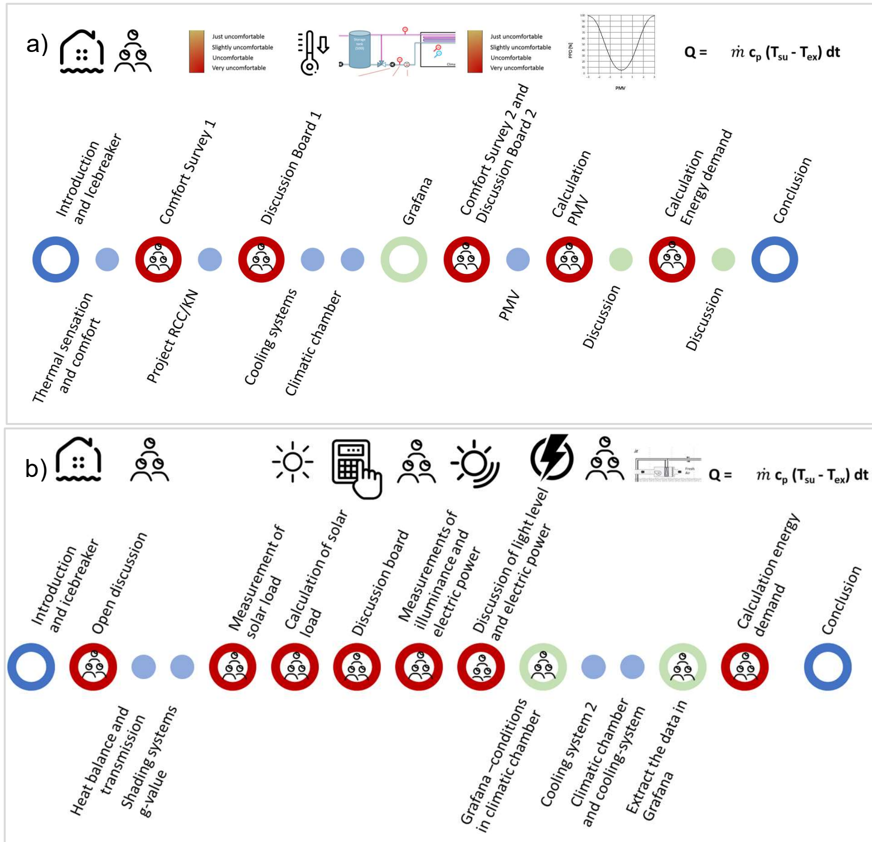

Figure 4. Procedure of the online course 1 (a) and online course 2 (b) and possible interactions of the students (red, light green), collaborative parts (big blue) and newly introduced topics (small blue)

Preparation beforehand

At the beginning of the course 1, the Living Lab Smart Office Space (University of Kaiserslautern) was overheated (up to 25°C) to produce slightly uncomfortable conditions. The climatic chamber of Arlon emulated the conditions of the Living Lab and reproduced the same temperatures.

Introduction and icebreaker session

After a short introduction and overview of the topics, the courses started with an icebreaker session, where the different participants of the five universities got mixed and introduced themselves in smaller groups. This should also encourage the exchange within the students as they have various backgrounds from different research areas (facility management, machine engineering etc.). To encourage discussions, they should think about simple issues, which were relevant for the particular courses and presented this afterwards, e.g., the advantages and disadvantages of various cooling systems or the pros and cons of large windows.

Students' interaction

In Fig. 4 the parts with students' interactions are marked with big red circles. As an example, for the first online course (Fig. 4a) the students' interactions were distributed over two thermal comfort surveys, two discussion boards afterwards, a calculation for the thermal comfort value PMV and the energy calculation.

After a short introduction into thermal comfort, all participants were asked to participate in the online comfort survey (Figure 5).

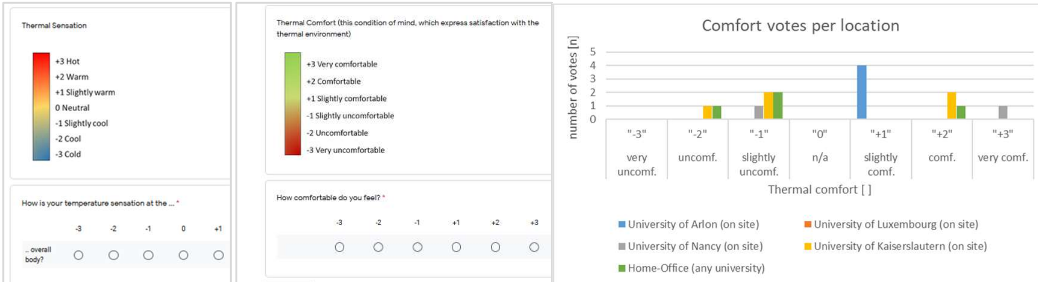

Figure 5. Online survey for the participants for thermal sensation and comfort and thermal comfort votes

Immediately, after the survey the results were visible in graphs, which showed the distribution of thermal sensation and comfort votes. The students recognized immediately that the thermal sensation is perceived individually in terms of thermal comfort. This leads to another interaction, in form of an open discussion with all participants. They should think about which environmental and personal conditions influence thermal sensation and comfort. For the students it was interesting to compare their own subjective evaluation with the real-live data.

Another interaction was the calculation of the thermal comfort value “PMV”. For this the students extract the data from the data-visualization platform Grafana and fill in a prepared excel sheet. The got the opportunity to change some values and check the influence on the estimated comfort value PMV (PMV: predicted mean vote, a broadly used thermal comfort metric) by changing the environmental parameters like room temperature, air velocity etc. or the personal parameters like the clothing factor and the activity level.

A further interaction for both test courses was the energy calculation of the used system. Here the students extracted again the real-live data from the data-visualization platform Grafana and use the given equation. The first minutes were used for the calculation in their international mixed groups, before the solution was elaborated together with the whole course.

For the second test course (Fig. 4b), the interaction appeared in the form of the operation of various shading systems. Especially the students in Kaiserslautern could change the state of the systems and could test different systems, e.g different combinations of the EC-glazing with tinted, low-tinted or clear state. They explained this to their peers, which could follow the real-time explanations and also through the live-video.

The students measured the illuminance for different states of the shading systems (EC-glazing and venetian blinds). To understand the influences of solar load and respectively artificial light on the energy demand, they conducted further measurements after changing the state of the shading system and adjusting the artificial light to their needs. Their peers could follow the actions via live-camera recording and they participated through direct discussion amongst the students. After that the students were again mixed in international groups to calculate the solar load in the room and to discuss this afterwards with all participants.

<u>Topics of the lectures (small blue dots)</u>

For the first online course the topics were thermal sensation and comfort, evaluation of the latter and the PMV-metric, the project RCC/KN, possible cooling systems with the advantages and disadvantages, the used climatic chamber, the cooling systems, and the data-visualization platform Grafana (Fig. 3).

The second test course covered the topics of the solar load, calculation of the latter, possible shading systems, energy demand of artificial lighting, cooling systems and the calculation of the energy demand.

<u>Discussion boards 1 and 2 (big red circle)</u>

In both courses several discussion boards were planned. Sometimes as open discussion with all course participants and they got also the possibility for a discussion with 5 to 7 students in a break out room. Due this concept, the students thought about the topics and brought their own approaches to solve the problem.

3 ANALYSIS

3.1 Students’ feedback

As the presented course was a test course the feedback of the participants was highly appreciated and useful for the next planning steps. The participants liked the structure of the course and they highlighted the influence of the online surveys and calculations for their understanding and for their attention which they spend to the specific topics. They mentioned also a great chance for the structure of the course in terms of getting an overview of different cross-topics.

The real-live experiment with regularly checking the room temperatures and the emulation process of the climatic chamber and the living lab smart office space helped them to understand the procedure of the cooling process, regarding the used energy and the influence on thermal comfort. They like this format, as they can experience it by their own. They could check according to the used system, how the energy demand and the thermal comfort changed.

During the test run of the first course, interesting discussions took place, which were not planned and which led to a time delay of the course. For the planning process of further courses enough time for open spontaneously occurring discussions should get considered, as this encourages the students’ cooperation and understanding of the topic. The verbal feedback showed that this format was successful for the participants. For the final course it should get well considered the knowledge of the students of the different fields. This could be challenging or a chance to get an overview of cross-topics.

To further encourage the exchange between the students from all universities, students work in the “mixed groups” in preparation for the courses or afterwards could be also an option. All over, the verbal feedback showed that the participants liked this new course structure.

3.2 SWOT Analysis

Based on the students’ feedback and the authors’ personal analysis a SWOT-Analysis was performed. Not only the strengths and opportunities, but also weakness and threats were discovered.

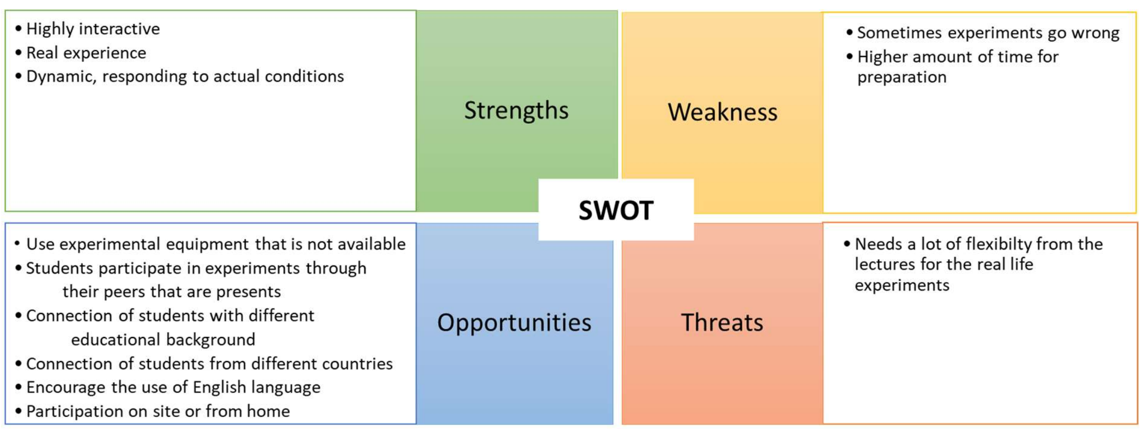

Figure 6. SWOT Analysis of the two test courses

The courses were perceived as very dynamic as experiments responded to actual conditions like the weather conditions or the state of the shading system. But this leads also to weakness and threats of this course structures. As it is highly depending on the weather and outside conditions, the lectures need a lot of flexibility to respond to these real-time experiments. Also, experiments can go wrong due to malfunctioning of equipment and the lectures need to be able to handle this: They need to discover on time what was going wrong and explain this to the students. For these lectures five different researchers prepared various parts and presented these. This structure of a course needs a higher amount of time for the preparation, compared to classic lectures. On the other hand, the concept of changing the speakers several times lead to a higher attention of the participants.

Despite the weaknesses and threats, the strengths and opportunities of this course structure predominate. Especially that each university can introduce the equipment which is not available at the home university is a great opportunity. The students can participate in experiments through their peers (students of collaborating universities) which are present on site. Also, the connection of the students with different educational background, research fields, and countries is a significant characteristic of this planned course series. Especially the ice-breaker sessions and the mixed-group work encourage the students to use their English skills which will strengthen their communication skills. If, during the next months and years, further quarantines and restrictions of presence at the institutions occur, this course system will offer great possibilities, as it still allows the students to participate in lab experiments from home. The strengths of the planned online series are the highly interactive format and the possibility of experiments for which the equipment is not available at their own university.

4 PLANNED LECTURE SERIES

During the writing process of this paper, two test courses were conducted and two of five labs were involved in the emulation process. For further courses the battery test laboratory of HTW Saar, the ENERBAT of University of Nancy and the Research Unit in Engineering Science of the University of Luxembourg should get involved. Here further approaches like the consideration of storage capacity (Battery test laboratory of HTW Saar) and the production of heat, cold and electricity of the tri-generation platform (ENERBAT), or the optimization of energy systems through advanced controllers (RUES) are possible. Further work should focus on considering the other available heating and cooling systems in Arlon, Nancy and Luxembourg and to implement these specific topics in various courses.

Additional envisaged topics for courses are visual comfort, the influence and the correct calculation of solar loads, internal loads, etc. It is planned to develop a course series with 20 lecture units, which will be held as blocks, with two lectures each 90 minutes. The complete series will be offered as an optional course for 6 CP, which includes the pre- and post-preparation for the class. The students will get corresponding course material beforehand and afterwards.

5 OUTLOOK

The participating universities that are developing this new concept of experimental distance learning are looking for further exchange and cooperation with interested partners from European (and internationals) institutions. Knowledge transfer and the exchange of digital educational materials would be appreciated. The new lecture series to be developed in the future will be accessible for participants from the five universities in the cooperation project, but if there is enough interest and demand it could be extended to students from other institutions as well.

Furthermore, universities and individuals are highly encouraged to express their interest in active participation in the development of the described lecture series through adding their own experimental set-ups. As this concept requires a high amount of time and dedication, the collaborating partners will be looking for funding opportunities to support the joint effort.

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