

Real-world experiments over the Internet: the solar energy e-learning laboratory experience

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Abstract—This paper presents the experience from the operation of the solar energy e-learning laboratory in Cyprus, (<http://e-lab.hti.ac.cy>), and demonstrates the benefits of remote engineering in the field of solar energy. The aim of the solar energy e-learning laboratory (Solar e-lab) is to use the Internet as a tool to make the laboratory facilities accessible to engineering students and technicians located outside the e-lab premises. In this way, the solar energy e-learning lab, its equipment and experimental facilities are available and shared by many people, thus reducing costs and widening educational experiences.

Index Terms— Collector efficiency, e-learning, real world experiments, remote laboratories, solar energy.

I. INTRODUCTION

Engineering work is undergoing significant structural changes worldwide. As online education becomes an everyday part of engineering education, online methods in engineering education will increase the breadth and scale of engineering education, thus extending the reach of institutions and the delivery of education to broader audiences [1]. Various studies give evidence for the increasing for telematic-based work environment important in the context of geographically distributed commissioning, installation, maintenance and repair of plant and machinery. Remote engineering, remote maintenance, teleservice or e-maintenance are all catchwords for these novel engineering and management concepts whereby construction and maintenance of plants and machinery are monitored and managed over the Internet [2, 3].

Remote engineering is becoming an important element in engineering education. The role that distance learning now undertakes within the teaching and learning environments has gained widespread acceptance over the last number of years. Subsequently, there is a growing need for new educational concepts, learning media and tools to accommodate for these new advancements in technology. The development of internet based remote engineering experimentation laboratories can significantly enhance the students' learning experience. A recent assessment study [4] comparing versions of remote labs versus hands-on labs in a junior-level mechanical engineering course on machine dynamics and mechanisms, the results suggest that students learned lab content information equally well from both types of laboratories, and that they have a realistic understanding and appreciation of the practical advantages of remote laboratories.

The solar energy e-learning laboratory (solar e-lab) developed within the MARVEL project of the Leonardo

da Vinci programme focuses on experiential based learning arrangements allowing remote and distributed working with laboratories, workshops and real working-places to train students in remote engineering [5]. This paper presents the experience from the operation of the solar e-lab, and demonstrates the benefits of remote engineering in the field of solar energy.

II. THE SOLAR E-LAB SETUP AND ARCHITECTURE

The solar energy e-learning laboratory comprises a pilot solar energy conversion plant which consists of two flat-plate solar collectors having a surface area of 3 m² located on the roof of the laboratory, an insulated thermal storage tank located in the solar energy laboratory and other auxiliary equipment and accessories. It is also equipped with all necessary instrumentation, control and communication devices which are needed for remote access, control, and data collection and processing. The schematic diagram of the system is illustrated in fig. 1.

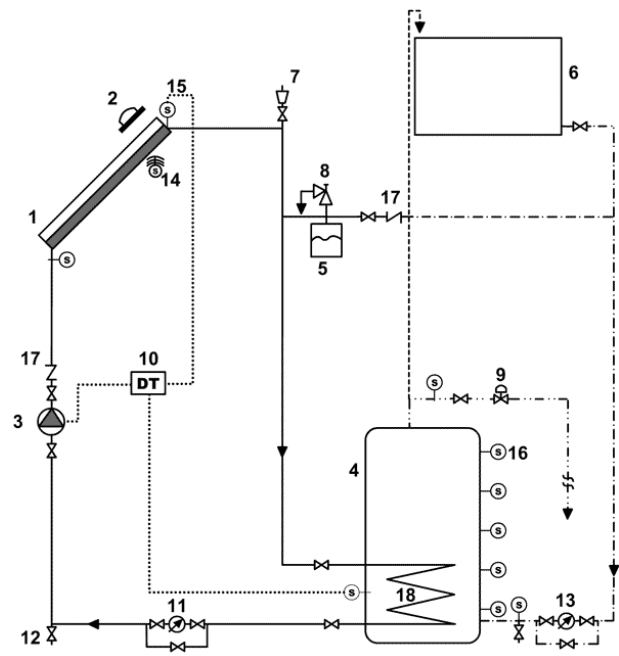


Figure 1. System schematic diagram of the experimental setup: (1) solar collector; (2) pyranometer; (3) pump; (4) storage tank; (5) expansion tank; (6) feed water; (7) and (17) check valves; (8) pressure relief valve; (9) motorised valve; (10) differential temperature controller; (11) and (13) water flow meters; (12) drain valve; (14) ambient air temperature sensor; (15) and (16) temperature sensors; (18) heat exchanger.

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A major goal of the solar e-lab is the usage of real worlds in virtual learning environments in order to support work-process-oriented and distributed cooperative learning with real-life systems. Its aim is to use the Internet as a tool to make the laboratory facilities accessible to engineering students (especially handicapped) and technicians located outside the laboratory, including overseas. In this way, the solar energy e-learning lab and its equipment and experimental facility will be available and be shared by many people, thus reducing costs.

The installed hard- and software includes features for controlling external devices, responding to events, processing data, creating report files, and exchanging information with other applications. All relevant weather data as well as operational and output data of the system are registered during an experimental session and can be stored on the users' PC for various calculations and/or documentation.

The system architecture used in the solar energy e-learning lab is illustrated in fig. 2. The user can access the solar e-lab through a PC which acts as a web server. This server hosts the e-learning platform with all necessary extensions for PHP support as well as the database necessary for this platform. It also communicates with the machine hosting the application software (TestPoint) [6]. Whenever a user wishes to get into the system, the communication will be done through this server. That is, the user sends his/her request to the system, the web server communicates with the TestPoint web server and it collects the data and transfers them to the user.

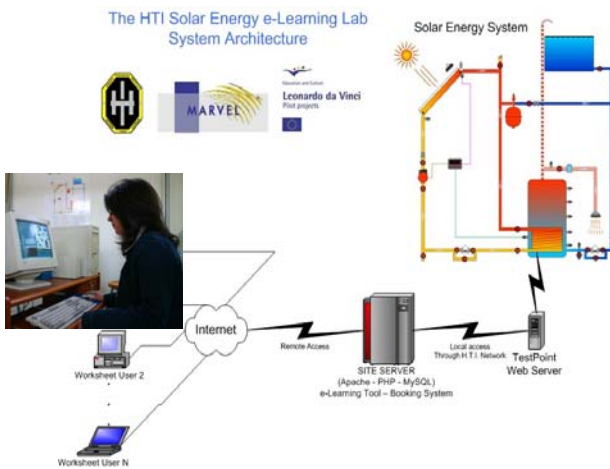


Figure 2. The solar e-lab system architecture

The actual running of the set-up is done via the TestPoint, which is an interface tool capable of acquiring data through various sensors, storing the data in a form that the user likes, and processing and handling the data in a meaningful manner. This particular software consists of two parts, the programming and the runtime parts. The programming is needed only to the system designer, while the runtime is necessary to run the particular experiment and is available to the interested user free of charge. Any collected data can be stored in popular programme formats (Word, Excel, etc.) allowing the user to print his own report formats and hand in a report of his choice. This tool is located on a dedicated server allowing faster data handling.

A user may visit the laboratory website anytime from anyplace in the world. The only requirements are a computer connected to the internet and any of the standard web browsers. By typing the address of the solar energy e-learning laboratory (<http://e-lab.hti.ac.cy>), the user can visit the initial page of the website. It is possible for visitors with little interest in solar energy to read and study on the subject with no requirements or registration or testing. So, not all of the pages require login. As a matter of fact, one can see most of the pages without the need of creating an account. Login, and thus creating an account, is only needed when the user decides to take the so called "pre-lab test" and conduct an online live experiment through the internet. All activities in the web site are presented in fig. 3. These include the e-learning environment (presentation of the system, familiarisation tests, terminology of solar energy, notes on solar energy, etc.), the booking system, and the online live experiment part where the user logs in to perform an online real time experiment.

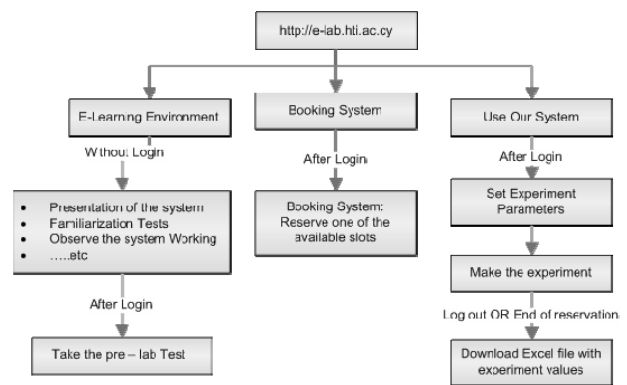


Figure 3. Activities in the solar e-lab

A booking tool is available to control the access time to the system (see fig. 4). In order to be able to make a booking, to have access to the system for conducting an experiment, a remote student has to attempt the pre-lab test and get a passing grade. If he/she fails to score the passing mark, he/she can try again, unlimited times. The user can make use of the notes available as well as the "Glossary of Terminology" available in the website.

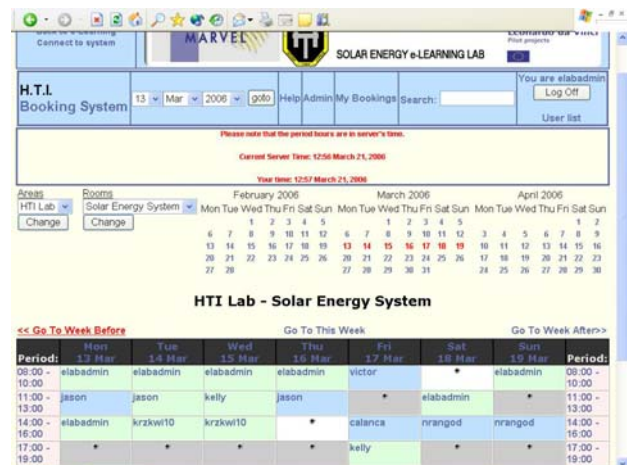


Figure 4. The booking system

In case the system is busy, because another user is online performing an experiment, the user is entitled and he/she can get into the e-lab as an observer, without any booking, without needing to conduct the pre-lab test. The system will open a new window and the remote user will be able to have a view of the system in operation and get the readings but he/she will not be allowed to intervene into the operation and control of the system. The “observer user” can, however, record the readings and use them for calculations if he/she wishes so.

The selected e-learning platform at the web server is Moodle. In this particular case, Moodle is used for the first time ever as a demonstration, a quiz and an experimental tool all tight up together. The Moodle capabilities were enhanced so that the running of the actual experimental set-up is only allowed after the successful completion of the preliminary exercises.

III. THE ONLINE LAB EXPERIMENTS

A number of laboratory experiments and learning tasks were developed including familiarisation exercises as well as system performance investigations and e-maintenance tasks. All exercises and learning tasks are supported by web-based learning materials in the form of “virtual books” [7]. The user is advised to start by downloading the “User Guide” which is available in three languages. English, German and Greek. There is also an “Illustrated User Guide” which guides the user, step by step, through screenshots and illustrations.

The design of the learning scenarios comprises of a series of exercises of different degree of difficulty and complexity [8]. For each exercise, the student undergoes an online assessment and is allowed to proceed to a real experiment only if he/she is successful to the pre-lab test. It also comprises an indexed glossary which includes a good number of terms and definitions related to the solar energy laboratory. The introductory exercises start with the familiarization of the student with the solar plant.

During these introductory exercises the student becomes familiar with the solar energy e-learning lab and make him/her conversant with the components of the pilot solar energy conversion plant. Upon completion of these exercises the student should be able to name each component in the plant and identify the various components needed to construct a solar plant.

As a last step into the real world of experimentation the student may get access to the system and perform system control and data gathering. During this part of the work the student will get acquainted with the remote control of the system and exercise in taking the readings of the various measuring devices, such as temperatures, flow rates and solar radiation. The student will take sets of readings for various conditions and different scenarios. One of the scenarios will be to elaborate on the stratification of temperatures in the vertical type storage tank and get a first-hand experience of the variation of temperatures across the tank at different operational conditions, explain the stratification effect and comment on the results.

Another experiment is to investigate the instantaneous efficiency of the collector or determine the rate of thermal energy removed from the storage tank to the consumption. For this purpose, the student can record a number of readings (incident solar radiation, water flow rates, temperatures, etc.) and using certain thermodynamic

equations [9] he/she will determine the performance characteristics of the collector and compare them with those given by the manufacturer. The test can be conducted at various conditions and with different scenarios such as for example: with or without consumption of service hot water, at different temperature differentials, etc. Should the student have more time available, he/she could use the data recorded in the Excel file (see fig. 5) downloaded at the logout or any time during the experiment, to plot graphs for the system thermal behaviour.

In case the system is busy, because a user is online performing an experiment, another user may get into the e-lab as an observer, without any booking and without needing to conduct the pre-lab test. The system will open a new window and he/she will be able to have a view of the system in operation and get the readings but he/she will not be allowed to intervene into the operation of system or to control the system. He/she can, however, record the readings and use them for calculations if he/she wishes so. There is no limitation to the number of “passive” participants.

	Collector Temperatures (°C)		Water Temperatures (°C)		Storage Tank Temperatures (°C)			Ambient Temp (°C)	Solar Radiation (W/m²)	Collector Flow Rate (l/s)
	Outlet	Inlet	Hot Water out	Fresh water in	Bottom	Midpoint	Top			
4	60.7	58.5	40.8	20.6	37.9	52.8	56.8	13.3	1122.0	0.11
5	60.7	58.5	40.2	20.0	34.9	51.7	47.1	14.5	1119.6	0.11
6	61.3	58.5	40.8	20.6	35.5	52.8	47.1	13.3	1122.0	0.11
7	60.7	58.5	41.9	20.6	37.9	53.4	56.8	13.3	1129.2	0.12
8	61.3	58.5	39.6	19.4	33.8	51.1	46.8	13.3	1134.0	0.11
9	61.3	58.5	40.8	20.0	36.1	52.8	56.7	13.9	1134.0	0.11
10	61.3	58.5	41.4	20.6	37.3	53.4	51.7	13.9	1134.0	0.11
11	61.3	58.5	41.4	20.0	35.5	52.8	47.7	14.5	1119.6	0.11
12	61.3	58.5	41.9	20.6	38.4	53.4	52.3	13.9	1134.0	0.11
13	61.8	59.0	40.8	20.6	36.1	53.4	56.2	13.9	1143.8	0.11
14	61.8	59.0	41.9	20.6	37.9	53.4	48.3	13.9	1153.2	0.11
15	61.8	59.0	40.8	19.4	34.9	52.8	54.5	14.5	1153.2	0.11
16	61.3	59.0	41.4	20.6	39.0	54.0	55.1	13.9	1159.0	0.11
17	61.8	59.6	41.4	19.4	34.9	52.8	47.7	14.5	1153.2	0.11
18	61.8	59.0	40.8	20.0	36.1	52.3	56.2	13.9	1155.6	0.11
19	61.8	59.0	40.8	20.6	35.5	52.8	56.2	13.9	1155.6	0.11
20	62.4	59.0	40.8	20.0	36.7	53.4	57.3	13.9	1162.8	0.11
21	62.4	59.6	41.4	20.6	37.3	53.4	46.8	13.9	1165.2	0.11
22	62.4	59.6	40.8	19.4	34.3	52.8	52.8	13.9	1170.0	0.11

Figure 5. The downloadable EXCEL file with previously recorded data

IV. EXPERIENCE FROM THE SOLAR E-LAB OPERATION

The solar e-lab has been accessed by users from over 400 locations from 75 countries spread all over the world and continents [10]. Furthermore, a number of colleges and Universities are using the solar e-lab as part of their training programme. Fig. 6 shows a group of students in Delmenhorst College, Germany, performing an online experiment at the solar e-lab through the Internet. Most of them logged in as “guests” and surfed through the various parts of the solar e-lab site and its courses. Other users registered and went through the various steps ending with the remote access to the online live experiments; some of them communicated their experiences to the e-lab administrator with comments and suggestions for improvements that have been seriously considered.

Several course trials were conducted at the Higher Technical Institute to test the system operation and reliability and check for the consistency and reliability of the data acquisition and transfer as well as the validity and reliability of the Temperature differential controller settings. During these tests a number of problems were

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traced and appropriate corrective measures were taken to end up with the final system.



Figure 6. Students at Delmenhorst College, Germany, performing an online experiment at the solar e-lab in Nicosia, through the Internet.

The aspect of remote experimentation through the Internet was tried and validated from a number of academic institutions from Thessalonica (Greece) in November 2004, from Delmenhorst (Germany) several times in the period of March-April 2005, from Brussels in April 2005 and from Stockholm (Sweden) in 2006 and 2007. The validation tests included navigation through the e-learning part but emphasis was given on the reliability of the booking system and the live connection and remote experimentation aspect. Furthermore, there is a continuous feedback from the e-lab users through the “Online evaluation” which is seriously taken into consideration for improvements.

One of the main concerns was whether the data was transferred to the user in the appropriate format and in the correct way and also whether the differential temperature controller was controlling the pump according to the settings. Following a good number of validation tests it was verified that the system works successfully. Nevertheless, there were a number of problems faced during the 4 years of operation, most of which had to do with usual problems met in traditional physical experiments and to a lesser extent to internet and communication issues.

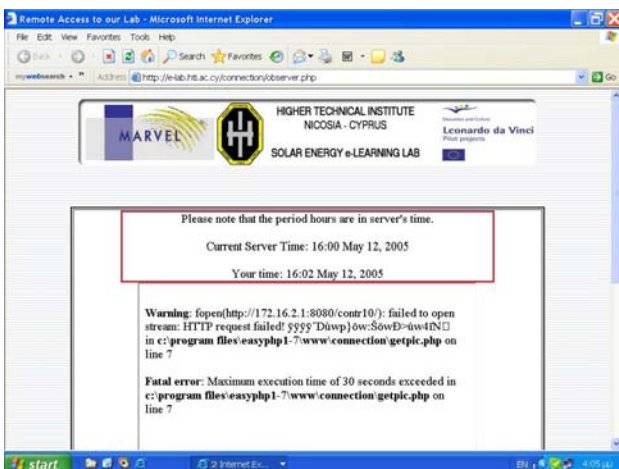


Figure 7. Error message showing a failure in the system.

One of the most frequent problems for example, was with the operation of a motorized valve controlling the flow of water discharge from the storage tank, which was stuck. In such cases, an error message is produced by the system, appearing on the user's screen, as shown in fig. 7. The user communicates that to the e-lab administrator either by e-mail or by phone, and the necessary corrective measures are taken.

Fig. 8 shows a screenshot of the diagrammatic layout of the system and the real readings during a live experiment conducted by students in the Royal Institute of Technology in Stockholm. On purpose, the screen refreshes every 5 minutes in order to allow the student enough time to see the readings and discuss them with his/her classmates or the teacher. The student can see for example the temperature stratification in the storage tank (in fig. 8 the temperature at the bottom level of the storage tank is 23.0°C, at mid-point it is mid-point 50.6°C, and at the top of the tank it is top 51.7°C), the solar radiation intensity, the water temperatures at the inlet and the outlet of the solar collector, etc. It is to be noted that all the data are recorded into an Excel file and can be downloaded at the end of the live experiment (see fig. 5).

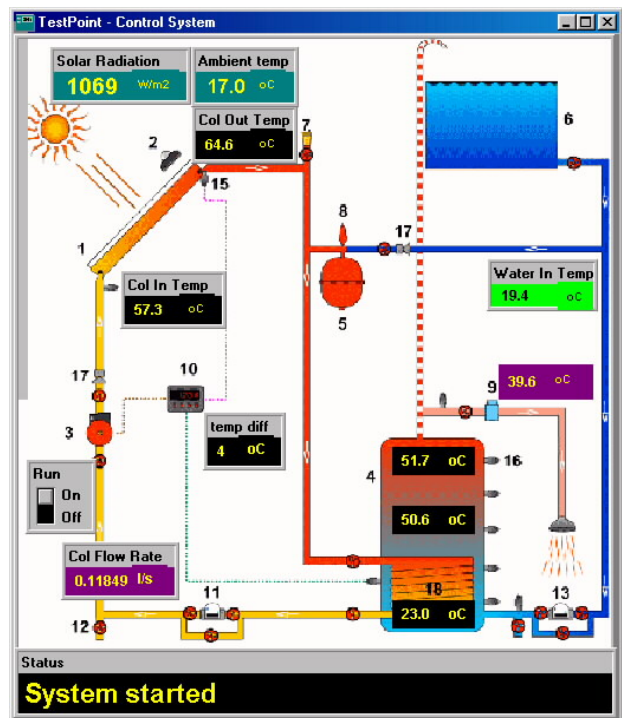


Figure 8. Live online experiment – System real-time readings: solar radiation 1069 W/m²; ambient air temperature 17.0°C; water flow rate through the collector 0.11849 l/s; collector inlet and outlet temperatures 57.3 and 64.6°C respectively; temperatures in the storage tank: bottom 23.0°C, mid-point 50.6°C, top 51.7°C; temperature differential controller setting 4°C.

As mentioned above, in addition to the on-screen diagram showing the instantaneous readings during the live online experiment, all measurements are recorded and saved in a tabular form that can be downloaded in an EXCEL format. Using these data, the student can calculate the instantaneous efficiency of the solar collector and also plot the collector performance graph showing the variation of the collector efficiency with $\Delta T/I$, where ΔT is the temperature difference between the solar collector

inlet and the ambient air temperature and “I” is the intensity of incident solar radiation.

Following is an example from a real time online experiment conducted by a group of students in the Royal Institute of Technology in Stockholm. The test was carried out during a period where the weather in Stockholm was cloudy while in Nicosia there was plenty of sunshine. Following a booking, the students in the in Stockholm logged on the system and conducted the experiment for the 2 hour session. At the end of the lab session, the students downloaded the Excel file with all measurements recorded (see fig. 5). Using the downloaded data and the Excel facilities, they plotted the graph illustrated in fig. 9 which shows the variation of the instantaneous efficiency of the solar collector with $\Delta T/I$. Using the Excel capabilities, they also found the efficiency equation, as shown on the graph of fig. 9.

The plotted graph and the efficiency equation were then compared with the theoretical ones, which are available on the website. Every step of the procedure for the experiment is explained in the relevant experiment sheet available in the solar e-lab website.

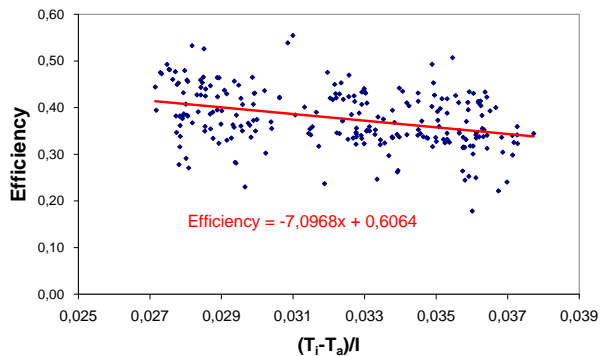


Figure 9. Investigation of the collector efficiency from data collected during an online real time experiment at the solar e-lab, through the internet.

CONCLUSIONS

The solar energy e-learning laboratory goes beyond traditional remote engineering laboratories by providing distributed work places for complex remote learning tasks. An important innovation within the solar e-lab is that concepts and examples for real working and learning are developed and accessed virtually through remote processes. Accordingly it goes beyond ‘traditional’ remote laboratories, because it provides distributed work places for remote engineering in technical training.

The four years of operation of the solar e-lab demonstrated how the Internet can be used as a tool to make the laboratory facilities accessible to engineering

students and technicians located anywhere in the world. In this way, the solar e-lab and its experimental facilities are made available free of charge and are shared by many people and Institutions, thus reducing costs and widening educational experiences.

REFERENCES

- [1] Bourne J., Harris D., and Mayadas F., “Online Engineering Education: Learning anywhere, Anytime”, *Journal of Engineering Education*, pp. 131-146, Vol. 94, No. 1; January 2005.
- [2] Lee, J., Qiu, H., Ni, J., Djurdjanovi, D., “Infotronics Technologies and Predictive Tools for Next-Generation Maintenance Systems”, 11th IFAC Symposium on Information Control Problems in Manufacturing. Salvador, Brasil April 5-7th, 2004
- [3] Graupner, Tom-David; Westkämper, Engelbert, “E-maintenance web-based services for production systems”, in Qu, Liangsheng (Ed.) et al.: *Proceedings of International Conference on Intelligent Maintenance Systems*. October 30 - November 1, 2003, Xi’an, China. Changsha, China: National University of Defence Technology Press, 2003, pp. 637-645.
- [4] J. V. Nickerson, J. E. Corter, S. K. Esche, C. Chassapis. A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers & Education*, Vol. 49 , 3, pp. 708-725, November 2007.
- [5] Müller, D., Ferreira, J. M., "MARVEL: A mixed-reality learning environment for vocational training in mechatronics," *Proceedings of the Technology Enhanced Learning International Conference, (TEL'03)*, Milan, Italy, November 2003.
- [6] TestPoint-Keithley Solutions for Data acquisition. http://www.testpoint.com/gen_tp.html.
- [7] The solar energy e-learning laboratory, <http://e-lab.hti.ac.cy/mod/resource/view.php?id=34>
- [8] I. Michaelides, P. Eleftheriou, and D. Müller. A remotely accessible solar energy laboratory - A distributed learning experience. *Proceedings 1st International Conference on Remote Engineering and Virtual Instrumentation (REV2004)*, Villach, Austria, 28-29 September 2004, ISBN 3-89958-090-7, (2004).
- [9] Duffie J. A. and Beckman W. A.: *Solar Engineering of Thermal Processes*. John Wiley, New York, 1991, pp. 301-307.
- [10] The solar energy e-learning laboratory, <http://e-lab.hti.ac.cy/mod/resource/view.php?id=55>.

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