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Article

The importance of education and motivation in the training of HVAC&R professionals in Europe: Lessons from the Portuguese case

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Abstract: The Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC&R) industry is pivotal to Europe's goals for energy efficiency, sustainability, and technological advancement. As demand for skilled HVAC&R professionals rises, the effectiveness of educational programs in this field has become a focal point. This article explores the Portuguese case to analyze how pedagogical strategies and student motivation contribute to the quality of HVAC&R training across Europe. The study highlights innovative teaching methodologies such as active and competency-based learning, as well as the use of laboratory training and digital simulations to provide hands-on experience. Additionally, it emphasizes Bloom's Taxonomy as a framework for curriculum development, ensuring that students advance from foundational knowledge to complex problem-solving abilities. Motivation is also identified as a critical factor for student engagement and long-term career commitment. The article concludes that a balanced integration of theoretical knowledge, practical skills, and motivational support is essential for producing highly qualified HVAC&R professionals. This approach not only meets current industry needs but also aligns with Europe's broader environmental and technological objectives, offering valuable insights for educators, policymakers, and industry stakeholders.

Keywords: pedagogy; HVAC&R; education; professional training; Portugal

1. Introduction

The Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC&R) industry is a cornerstone of modern infrastructure, with an increasing role in Europe's push toward energy efficiency, sustainability, and innovation, integrated in the overall sector of engineering (Love and Hughes, 2022; Rüütmann, 2019; Tymkiv and Tymkiv, 2023). As demand grows for skilled professionals capable of designing, installing, and maintaining complex HVAC&R systems, the effectiveness of vocational and technical training programs has come under scrutiny (Berman et al, 2020, Hartoyo, 2023; Khalil et al., 2024). In this context, two critical factors stand out as determinants of training success: the pedagogical strategies used in the classroom and the motivational levels of students (Fu et al., 2022; Kersten, S., 2018). Pedagogy in HVAC&R training involves more than the transmission of technical knowledge; it requires dynamic approaches that prepare students for practical, problem-solving roles in the workforce (Rillero, 2024; Shaqour and Hagishima, 2022). Effective pedagogical methods, such as active and experiential learning, can enhance students' understanding of both theoretical concepts and hands-on applications, aligning education with industry demands (Kersten, 2018; Straková and Hrmo, 2024). However, even the best-designed curriculum may fail if students lack the motivation to engage deeply with the material. Motivation, therefore, becomes a vital component in students' educational journeys, shaping not only their learning experience but also their long-term career satisfaction and commitment to the field. In Europe, where workforce demands in HVAC&R continue to evolve, understanding how pedagogy and motivation interact within educational settings can provide valuable insights for educators, policymakers, and industry stakeholders (Asiksoy, 2023). This article examines current practices in HVAC&R training programs across Europe, focusing on how innovative pedagogical methods and strategies for fostering motivation can enhance the quality of training. By exploring these dimensions, the article seeks to underscore the importance of aligning educational practices with both student needs and industry expectations to produce highly qualified, motivated HVAC&R professionals. The HVAC&R industry is crucial in supporting modern infrastructure, particularly in Europe, where there is a strong push for energy efficiency, sustainability, and technological innovation, this effort has been made in various aspects as theoretical studies (Garcia and Rosa, 2019), real case applications (Garcia and Semedo, 2024) and computational simulations (Alvarenga et al., 2012). As this sector evolves, so too must the educational approaches that train future HVAC&R professionals. In recent years, pedagogical advances have increasingly emphasized active, experiential, and collaborative learning over traditional, lecture-based approaches (Sierla, 2022). In engineering education—and HVAC&R training specifically—these modern pedagogical strategies are reshaping how technical knowledge and practical skills are conveyed, directly impacting student engagement, skill acquisition, and readiness for the workforce. Contemporary pedagogical developments, such as active learning, problem-based learning (PBL), competency-based education (CBE) and design of experiences (Costa and Garcia, 2015), prioritize student-centered approaches that encourage critical thinking, adaptability, and hands-on experience. In HVAC&R, these methods are particularly relevant, given the sector's focus on real-world problem-solving and the need for precise technical skills (Khalil et al., 2024). Active learning, for example, encourages students to interact directly with materials and equipment, which is vital in developing the manual skills and troubleshooting abilities essential to HVAC&R roles. PBL, on the other hand, immerses students in realistic engineering scenarios, prompting them to collaborate, analyse, and solve complex HVAC&R issues in ways that mimic industry challenges. This not only builds their technical competency but also strengthens teamwork and communication skills—qualities increasingly valued in engineering professions. In parallel, digital learning tools and simulations have become integral to HVAC&R education. These technologies allow students to model and experiment with HVAC&R systems in a virtual environment, offering opportunities to explore advanced concepts and troubleshoot issues without the constraints of physical equipment. Additionally, competency-based education, which allows students to progress as they demonstrate mastery of specific skills, has gained traction in technical fields like HVAC&R, where proficiency and precision are crucial. This approach ensures that students leave their programs with the hands-on experience and specialized knowledge that the industry demands. As HVAC&R systems grow more complex and sustainable engineering solutions become imperative, adopting these pedagogical innovations enables training programs to align more closely with industry needs. By fostering not only technical acumen but also the motivation and adaptability required in modern engineering, these advancements support the development of HVAC&R professionals who are equipped to meet Europe's future energy and environmental goals (Piselli et al., 2024). Through this examination of pedagogical evolution, this article underscores the importance of combining theoretical rigor with practical, student-centered learning in preparing the next generation of HVAC&R specialists.

2. Objective

The purpose of the present article is to provide a comprehensive approach to the development of training programmes and pedagogical practices aimed at professionals who will work in the installation, operation or maintenance of HVAC&R systems, based on the Portuguese case. Emphasis is placed on the structure of training programmes, their content, teaching tools (including support materials), theoretical and practical exposure in training environments, and monitoring in laboratories and direct action situations. The main aim of this article is to ensure that future professionals in the sector, during their training phase, acquire crucial competences both in functional operability and in the interaction between different duties within the sector. Said competences are viewed from various perspectives, including those of contractors, building owners and inspection agents. In addition, this article seeks to promote the effective dissemination of theoretical and practical knowledge in various types of training, ranging from technical-vocational courses to higher levels, such as bachelor's and master's degrees, with a focus on technologies or engineering. Finally, the article also addresses the importance of choosing the right methods, content and equipment so that the training objectives are fully achieved, guaranteeing the training of competent professionals who are prepared for the challenges of the HVAC&R field.

3. The relevance of education in HVAC&R training and teaching

Education plays a crucial role in engineering and is equally indispensable in the fields of energy, air conditioning, as well as refrigeration. It lays the foundations for understanding, applying and operating systems and equipment safely and efficiently (Fathi et al., 2021). Adequate training enables professionals to design and execute installations that are efficient, rational, safe and environmentally sustainable.

Effective teaching enables future professionals to understand the scientific principles essential to air conditioning and refrigeration, such as heat transfer, fluid mechanics, thermodynamics, psychrometrics, the refrigeration cycle and the properties of refrigerants. In addition, students learn about the central components of the systems, such as compressors, condensers, evaporators and control devices. Education should also emphasise the importance of energy efficiency and sustainability. With proper training, professionals are able to design, install and maintain optimised systems to reduce energy consumption, minimising environmental impact and operating costs.

It is paramount that professionals are made aware of the environmental impact, safety and sustainability of air conditioning and refrigeration systems. Pedagogical training promotes the search for sustainable solutions, such as the use of refrigerants with a low environmental impact, heat recovery systems and design strategies that favour energy efficiency.

In addition, the education applied to air conditioning and refrigeration encourages the adoption of good maintenance and operating practices, ensuring proper performance and extending the useful life of the systems. Professionals learn how to carry out regular inspections, cleaning and adjustments to equipment, as well as how to identify and resolve operational problems. This not only improves the efficiency of the systems, but also reduces the risk of failures and the need for premature equipment replacements (Amelito and Sungahid, 2024).

4. Research methods

4.1. Training components

This study adopts a qualitative research design to explore the effectiveness of educational strategies and student motivation in HVAC&R training in Portugal. It is both descriptive and exploratory, aiming to identify best practices, challenges, and opportunities within the Portuguese context while drawing broader implications for Europe.

4.2. Data collection

The research incorporates both primary and secondary data sources. For primary data, information was gathered through interviews and surveys conducted with instructors, students, and industry professionals from various educational institutions offering HVAC&R training in Portugal. These institutions include polytechnic institutes such as ISEL, IPBeja, and IPS, as well as the HVAC&R Professional Association (APIRAC). The study involved a total of 42 participants, consisting of 5 instructors, 32 students, and 5 industry professionals. Participants were selected based on their active involvement in HVAC&R training programs and their willingness to provide detailed insights into educational practices and challenges. Secondary data was collected through a comprehensive review of existing literature, government reports, and industry publications to contextualize the findings within the broader European educational landscape. Key sources included academic journals, reports from Portuguese educational authorities, and European Commission guidelines on vocational training.

4.3. Criteria for information inclusion

The inclusion criteria for the collected information were based on its relevance to HVAC&R education in Portugal, practical applications of pedagogical methods such as competency-based learning, laboratory training, and digital simulations, insights into student motivation and its impact on learning outcomes, and alignment with national and European goals for energy efficiency and sustainability.

4.4. Focus on educational centers

This study draws on data from educational centers across Portugal to provide a broad and representative analysis of HVAC&R training. The selected institutions include polytechnic institutes such as ISEL, IPBeja, and IPS, which emphasize hands-on, practical education and applied research while also providing advanced theoretical knowledge and research opportunities in areas like energy systems and sustainability. The inclusion of diverse educational institutions ensures that the study captures a wide range of pedagogical practices, student experiences, and institutional challenges. Each institution was selected based on its established reputation in HVAC&R training and its alignment with national education standards.

4.5. Portuguese legislative framework

The study also considers the Portuguese legislative framework governing vocational and technical education, particularly in the HVAC&R sector. Key regulatory documents and policies reviewed include Decree-Law No. 396/2007 of 31st December, as amended by Decree-Law No. 14/2017 of 26th January, which outlines the structure and requirements for vocational education and training (VET) in Portugal. The National Qualifications Framework (NQF) was also reviewed, as it defines the competencies and learning outcomes required for HVAC&R professionals at various qualification levels (ANQ, 2024). Additionally, the study considers the Energy Performance of Buildings Directive (EPBD) and other relevant EU regulations, which influence HVAC&R curriculum development by emphasizing energy efficiency and sustainability.

5. Methodology

5.1. Training components

All HVAC&R training should be based on a well-rounded education that ensures both technical competence and adaptability in an industry that is continually evolving. This can be achieved through three essential components (Salas et al. 2012):

I. Socio-cultural training

II. Scientific training

III. Technical Training

Each of these training components plays a crucial role in the development of technicians, enabling them to tackle complex problems ethically, based on sound scientific principles and with the technical skills needed to turn theory into practical solutions. This balance is paramount to the success and relevance of any training programme. **Table 1** summarises said aspects.

Table 1. Characterisation of the training components.

	What is it?	Importance
Socio-cultural training	It encompasses a broad education in areas such as the humanities, social sciences and communication, focusing on the development of competences in communication, ethics, citizenship and understanding of social, cultural and ethical issues.	Essential for technicians, as it enables them to become complete professionals, able to communicate effectively with colleagues, customers, as well as the general public. It also provides a crucial ethical basis for all decisions, ensuring that solutions are socially responsible and culturally sensitive.

Table 1. (*Continued*).

	What is it?	**Importance**
Scientific Training	It consists of the scientific principles and theories that underpin knowledge, covering subjects such as maths, physics, chemistry and other areas of science. It is essential for understanding the principles behind systems, processes and equipment.	It is the foundation for work in the field of HVAC&R. Technicians must apply these principles to design, analyse and solve complex problems. It also makes it possible to innovate and adapt to technological changes.
Technical Training	It focuses on specific skills and knowledge, covering design, analysis, problem-solving, the use of engineering tools and techniques, as well as mastery of relevant software and hardware.	Essential for the practical application of scientific and socio-cultural knowledge. It enables professionals to design, build, maintain and improve complex systems and infrastructures, as well as keeping up with technological progress and adapting to new solutions and methodologies.

Source: Author.

5.2. Basis of training

Depending on the level of training, any course should be based on Bloom's Taxonomy educational classification system (Armstrong, 2010), which categorises different levels of cognitive skills and educational objectives. This taxonomy is a valuable tool because it provides a clear framework for developing learning objectives, designing teaching activities and creating assessments that cover all levels of cognitive abilities.

Bloom's Taxonomy is generally presented as a hierarchy of six levels, arranged from the simplest to the most complex:

(1) Knowledge (Remembering): At this level, students are asked to remember facts, terms, concepts and information. This involves retrieving data without the need to fully understand it.

(2) Comprehension (Understanding): At this level, students demonstrate understanding of the content by explaining, summarising, interpreting and translating information using their own words.

(3) Application: Students are encouraged to use the knowledge and skills they have acquired to solve problems, apply concepts in practical contexts and carry out specific tasks.

(4) Analysis: Students analyse information, breaking it down into smaller pieces, identifying patterns, relationships and connections, and making judgements based on evidence.

(5) Synthesis (Evaluate): At this level, students are encouraged to develop something innovative, integrate information from different sources, formulate hypotheses, create plans and design solutions.

(6) Evaluation (Create): The highest level of Bloom's Taxonomy covers students' ability to evaluate, criticise, justify and formulate arguments based on defined criteria. It also involves the ability to create something completely new from the knowledge acquired.

5.3. Learning objectives

Learning objectives at all stages of training should be described using action verbs, which indicate the skills that the student should acquire and be able to apply at a given level and type of training. These objectives should be:

a. Clear and specific;

b. Measurable;
c. Achievable within the allotted time;
d. Realists.

5.4. Training levels

In Portugal, the educational certification system is structured on the basis of the National Qualifications Framework (NQF). The NQF aims to standardise and categorise the various levels of qualification and certification in the country. As described in section 4.5 the Portuguese National Qualifications System (NQS) as the objective of raising the qualification levels of the active population, through school and professional progression, as well as to structure an initial and continuous educational and training offer, for young people and adults, adjusted to the needs of companies and the labour market (ANQ, 2024). The main levels of educational certification in Portugal, according to the NQF, are:

Certificate of Basic Education Qualifications (9th year): This certificate proves the completion of basic education, which corresponds to the end of the 9th year of schooling.

Diploma of Secondary Education—This diploma is issued on completion of secondary education, which covers the 10th to 12th school years.

Professional Certification: In addition to formal education, there are a variety of professional certifications that can be obtained through technical training and vocational education programmes. These include certifications related to specific skills and professional qualifications in areas such as technology, health, cookery and much more. There are various vocational training programmes and certificates, which can be obtained through short courses and programmes in specific areas.

Higher Education Diploma: This diploma is awarded after completing a degree programme at a higher education institution, such as a university or polytechnic. The diploma can be a bachelor’s degree, a licentiate degree, a master’s degree or a PhD.

The levels of qualifications directly related to AVC&R training are secondary school certification, vocational training certification, licentiate degree, master’s degree and PhD, following the structure of Bloom’s Taxonomy, starting at the lowest levels of knowledge and understanding and continuing to the highest levels of application, analysis, synthesis, evaluation and creation. In said structure, each level represents an increasing degree of complexity and cognitive ability and, in this way, we can structure the competences for the different levels of training. **Table 2** shows the different levels of training and their respective competences.

Table 2. Training levels and competences.

Level of training	Competences
Secondary Education (Knowledge Level)	Understand the basic principles of thermodynamics
	Understand the basic principles of heat transfer
	Understand the basic principles of fluid mechanics
	Recognise the main HVAC&R systems

Table 2. (*Continued*).

Level of training	**Competences**
Professional Training (Level of Understanding and Application)	Apply practical skills to install, drive, maintain and repair systems
	Understand the principles of equipment design, sizing and selection
	Know safety regulations and standards
Licentiate Degree (Summary and Evaluation Level)	Synthesising and integrating knowledge in mechanical engineering with a specialisation in HVAC&R
	Lead complex systems projects
	Evaluate and develop innovative solutions to HVAC&R challenges
	Carry out research and advanced case studies
Master's Degree (Creation and Evaluation Level)	Develop advanced models, simulations and optimisations of systems, installations and equipment
	Critically evaluate the state of the art in energy efficiency, control and sustainable solutions
	Carry out original research and make significant contributions to the field
	Lead research and innovation projects
PhD (Creation and Evaluation Level)	Develop creative and original solutions
	Demonstrate in-depth knowledge in specialised areas of HVAC&R
	Lead cutting-edge research projects and contributing to scientific progress in the field
	Potential to lead the development of new theories and practices in HVAC&R

Source: Author.

5.5. European Credit Transfer and Accumulation System (ECTS)

ECTS, or European Credit Transfer and Accumulation System, is a system developed by the European Union to facilitate the recognition and comparison of study programmes and qualifications in higher education institutions across Europe. The ECTS system is widely used in higher education institutions in European countries and is part of the Bologna Process, which aims to create a European Higher Education Area (European Commission, 2024).

ECTS are a unit of measurement that quantifies the academic work required to complete a programme of study. They are used to facilitate student mobility between higher education institutions and European countries, allowing students to accumulate credits in a consistent and comprehensible way in different locations.

The main idea behind the ECTS system is that a full academic year of full-time study is equivalent to 60 credits (ECTS). However, the exact workload for each course or subject can vary. An ECTS credit represents, on average, around 25 to 30 h of student work, including lectures, independent study, exams and other academic work.

The main benefits of this system are:

Mobility: ECTS credits facilitate the transfer of students between institutions and European countries, allowing them to continue their studies without wasting time or repeating courses.

Transparency: The system makes it easier for students to understand the workload of a study programme and helps employers better understand candidates' qualifications.

Comparability: ECTS credits make study programmes and qualifications more comparable between different European countries, which is useful for recognition purposes.

Flexibility: Students can choose elective subjects and create their own study programmes according to their interests, as long as they meet the minimum credit requirements to obtain a diploma.

The ECTS system plays a crucial role in promoting mobility, transparency, as well as comparability in higher education in Europe, making it easier for both students and institutions to understand and recognise the academic work done. Therefore, any higher education course in the field of HVAC&R will have to build its structure according to this system. Training programmes at other levels should also make an effort to follow this system.

5.6. Pedagogical tools

In an HVAC&R course, there are several pedagogical tools that should be considered in the structure of the training, with the aim of improving students' understanding of the various topics and deepening their knowledge. Some of the main teaching tools include:

Lectures: Designed to provide fundamental theoretical knowledge of HVAC&R principles;

Practical Demonstrations: Practical demonstrations and problem-solving make it possible to exemplify and illustrate theoretical concepts and real operations;

Laboratory tests: Offering practical experiences in laboratories so that students can learn how to operate and troubleshoot HVAC&R equipment;

Work in workshops—Allows you to develop and apply tasks in HVAC&R installations;

Simulations supported by computer programmes (Software): Using simulation software makes it possible to simulate HVAC&R systems and analyse their performance in different scenarios;

Case Studies: Analysing real cases of HVAC&R systems makes it possible to highlight challenges, solutions and best practices;

Applied projects and practical work: Assigning students practical projects allows them to design HVAC&R systems, calculate thermal loads, select equipment, etc.;

Study visits: Taking students on visits to HVAC&R installations enhances their understanding of how these systems actually work;

E-Learning tools: Use online learning platforms, discussion forums and multimedia resources to support both distance learning and research;

Group work: Promoting collaboration between students in group projects, encouraging the joint resolution of complex problems;

Assessments and tests: Carry out regular assessments to measure students' progress and their understanding of the topics covered;

Diversification of teaching resources: Provide reading materials, textbooks and multimedia resources for students to delve deeper into key concepts;

Practical activities in the classroom: Carry out practical activities in the classroom, such as system sizing calculations, to encourage the immediate application of knowledge.

These teaching tools can be adapted according to the level of the course, the resources available and the needs of the students.

5.7. Training environments

The importance of suitable training environments in HVAC&R training is paramount for successfully achieving the training objectives. Training environments suited to the type of training allow for the development of adequate practical experience, safety and competence in activities, correct application of theoretical knowledge, adequate training with real equipment, development of essential technical skills, preparation for the labour market, collaboration and teamwork, adequate and safe access to resources and tools and the development of innovative solutions. **Table 3** summarises the main objectives and impacts of correctly implementing suitable training environments.

Table 3. Objectives and impacts of training environments.

Objective	Impact
Practical Experience	To provide students with the opportunity to gain practical experience with real or simulated HVAC&R systems, which is essential for them to understand the installation, operation, maintenance and troubleshooting of these systems.
Safety and Competence	To provide students with the opportunity to gain practical experience with real or simulated HVAC&R systems, which is essential for them to understand the installation, operation, maintenance and troubleshooting of these systems.
Application of theoretical knowledge	Allow students to apply the theoretical knowledge acquired in class. This helps to solidify their understanding and make learning more objective.
Proper Training with Real Equipment	Provide the opportunity to work with real equipment and systems, which prepares them to deal with real situations in the future.
Development of Technical Skills	Enable students to develop key technical skills such as installation, maintenance, repair and troubleshooting of HVAC&R systems.
Preparation for the labour market	To introduce students with the working environment in HVAC&R, enabling them to prepare to enter the job market after completing their studies.
Collaboration and Teamwork	Promoting collaboration between students, allowing them to work as a team on projects.
Adequate and secure access to resources and tools	Providing access to specialised equipment, tools and software that are important or unavailable outside the training environment.
Developing Innovative Solutions	These enable students to develop innovative solutions to specific industry challenges.

Source: Author.

In this way, suitable training environments are essential for complete and effective training in HVAC&R, preparing students with the knowledge and skills needed to succeed in the industry and meeting its needs. In a training programme, it is essential to consider a variety of training environments in order to offer complete and practical training. The main training environments and their characterisation are shown in **Table 4**.

Table 4. Training environments and their characterisation.

Training environment	**Characterisation**
Traditional classrooms	Spaces equipped with real equipment where students can carry out experiments, tests and learn practical skills
Technical Laboratories	Spaces equipped with teaching equipment where students can carry out experiments, tests and learn practical skills. This equipment should replicate real equipment as closely as possible.
Practical Training Rooms	Places where students can work with real or simulated systems to gain experience and practice.
Internships or work placements in a business environment	Places for students to apply their knowledge in real work situations, under supervision.
Field Facilities	Technical visits to HVAC&R installations, such as buildings, factories or industrial plants, to learn about the actual operation of systems and equipment.
Virtual Classrooms	Online environments that support distance learning, where students can access course materials, attend classes and interact with trainers and colleagues.
Software Simulators	Virtual training environments that allow students to simulate the operation and control of HVAC&R systems.
Maintenance workshops and training rooms	Spaces equipped with tools and equipment to teach maintenance and repair skills in HVAC&R systems (if applicable).
Project development environments	Spaces where students can develop specific projects, such as system sizing, equipment selection and problem solving.
R&D centres	Facilities or institutions where students and teachers can carry out advanced research, projects and experiments in HVAC&R or related technologies.
Collaborative Work Environments	Spaces where students can work in groups on team projects, promoting collaboration and problem-solving together.
Online Learning Resources (synchronous and asynchronous)	Access to a variety of learning resources, including manuals, videos, tutorials, as well as discussion forums.

Source: Author.

By considering and combining these training environments, HVAC&R training programmes can provide a complete education, covering both theoretical principles and the necessary practical skills.

5.8. Laboratory training

Laboratory training plays a crucial role as it provides a controlled environment in which students can apply theoretical concepts, carry out practical experiments, observe physical phenomena (such as condensation and evaporation), test equipment and components, develop specific technical skills in safe and controlled environments, supported by the teacher. Laboratory training is a valuable extension of theoretical knowledge, providing a space for practical experimentation and active learning. To summarise these scenarios, students can:

Practising Procedures: Opportunity to practise specific procedures relating to the installation, maintenance and repair of systems, ensuring that they can carry out these tasks accurately whenever necessary;

Testing equipment: Laboratories should be equipped with simulators and teaching materials that allow equipment to be tested in a controlled and safe environment;

Troubleshooting: The laboratories offer a safe space to learn how to diagnose and solve technical problems, preparing students to identify and correct faults and malfunctions;

Testing parameters and variables: Students can carry out experiments, adjusting settings and parameters with the aim of optimising equipment performance, saving energy and reducing operating costs;

Learning to use tools and instrumentation: Students can familiarise themselves with tools, measuring devices and instrumentation, acquiring practical handling skills;

Developing maintenance skills: The laboratories make it possible to carry out preventive and corrective maintenance tasks, such as cleaning components and replacing parts;

Gaining Confidence and Safety: By practising in a controlled environment, students gain confidence in their abilities, which is essential to ensure that they can handle challenging real-world situations safely and effectively.

In the laboratories, some of the tests and trials that can be carried out by the students, among others, requiring suitable teaching equipment, are:

- Testing heat exchangers;
- Test of a cooling tower;
- Testing an air treatment unit;
- Testing a dehumidifier;
- Fan testing;
- Testing centrifugal pumps;
- Calculation of pressure drop in pipes and ducts;
- Refrigerated compression cycle test;
- Absorption cycle test;
- Testing the operation of cold rooms;
- Testing the operation of refrigerated displays;
- Testing of refrigeration compressors;
- Vacuum and load testing in refrigeration;

5.9. Direct action training

The final stage of any course should include on-site training. Direct action training is crucial to enable students to apply the theoretical knowledge acquired in practical situations in real installations and with the respective equipment. **Tables 5** and **6** show the main knowledge to be acquired in a direct action context, with the main HVAC (**Table 5**) and refrigeration (**Table 6**) equipment.

Table 5. Knowledge to be acquired with the main HVAC equipment.

Equipment	**Knowledge**
UTA	Know the sections of an UTA such as air filters, fans, batteries and control. Know the equipment's management and control mechanisms.
Chillers Centralised air conditioning Rooftops Individual air conditioning units Air conditioning terminal units	Learn about unit components such as compressors, evaporators, condensers and expansion valves. Know how to load and unload refrigerants. Know the equipment's management and control mechanisms.

Table 5. (*Continued*).

Equipment	Knowledge
Boilers	Know the main components of a boiler, including burners, combustion chamber, heat exchanger, control system and heat distribution system.
Fans	Know the main components of a fan, such as the impeller, motor, casing and inlet, outlet and control sections.
Pumps	Know the main components of a pump, such as the motor, blades, casing, inlet, outlet and control nozzle.
Grilles and diffusers	Know how air moves at the outlet of the grille or diffuser. Know how to balance air flows at the outlet and how to measure air velocity.
Fan coils	Know the main components of a fan coil such as the fan, heat exchangers (batteries), filter, control unit, valves and a housing.
Cooling towers	Know the main components of a cooling tower, such as the sprinkler nozzle, fan, filler, droplet eliminator and water basin. Know the necessary and appropriate water treatment. Identify ways of controlling legionella.
Pipework	Identify the duct layout and good installation practices. Identify the location of manholes.
Pipework	Identify the layout of pipework and good installation practices. Identify the direction of fluid circulation. Identify the function of valves, filters and associated accessories.
Heat exchangers	Understand the function of heat exchangers in the installation.
Air filters	Understand the function of air filters in the installation. Know the type and class of filters.

Source: Author.

Table 6. Knowledge to be acquired with the main refrigeration equipment.

Equipment	Knowledge
Compressors	Know the main components of a compressor and identify how they work properly.
Evaporators	Know how the evaporator works and identify the condition of the tubes and fins.
Expansion devices	Know the type of expansion device and its components, namely (if applicable) the bulb, filter and orifice.
Capacitors	Know how the evaporator works and identify the condition of the tubes and fins.
Liquid deposits	Identify the liquid level in the tank. Identify the function of the tank in the installation.
Filters	Identify the type of filter. Know how to replace the filter or filter load.
Cold storage centres	Know all the components of a centrifuge, namely compressors, separators, tanks, filters, pressure switches and recuperators.
Cooling towers	Know the main components of a cooling tower, such as the sprinkler nozzle, fan, filler, droplet eliminator and water basin. Know the necessary and appropriate water treatment. Identify ways of controlling legionella.
Liquid separators	Learn how the liquid separator works. Identify how liquid separation works at the compressor inlet.
Oil separator	Know how the separator works. Identify the operation of the oil return to the compressor.

Source: Author.

6. Training example

As a follow-up to this article, **Table 7** shows a summarised example of a possible structure for degree-level training in the field of HVAC&R.

Table 7. Example of HVAC&R training structure.

AREA OF EXPERTISE	THEORETICAL/PRACTICAL TRAINING	WORKSHOPS/LABORATORIES
Thermodynamics	• Physical quantities and units • Thermodynamic properties • Changes of state • Laws of thermodynamics • Mass and energy balances • Refrigeration cycles • Psychrometry and humid air processes	• Visualisation of phase change phenomena • Refrigeration cycle test • Thermometry tests • Basic thermometry tests
Fluid Mechanics	• Fluid flow • Concept and ways of measuring pressure • Calculation of load losses • Fans and pumps • Flow in pipelines • Turbomachinery characteristic curves • Sizing hydraulic installations	• Flow visualisation • Load loss tests on pipes and fittings • Fluid viscosity tests • Pump and fan tests
Heat transmission elements	• Understanding the phenomena of conduction, convection and radiation • Calculation of thermal transmission coefficients • Thermal insulation • Vapour barrier • Heat exchangers • Heat production	• Visualisation of heat transfer phenomena • Heat exchanger tests • Conduction, convection and radiation tests
Electricity and Electronics	• Electricity basics • Direct current and alternating current • Electromagnetism • Electrical machines • Electrical circuits • Sizing switchboards • Representation of electrical diagrams applied to HVAC&R	• Visualisation of switchboard operation • Interpretation of electrical diagrams applied to equipment • Electrical machine tests
Instrumentation, Control and Technical Management	• Introduction to electronics • Control basics • Elementary electronic circuits • Characteristic electronic blocks • Instrumentation basics • Control systems • Refrigeration control systems • Centralised monitoring and control • GTC systems applied to HVAC&R	• Experimenting with elementary electronic blocks • Construction of elementary electronic circuits • Implementing a control system for a simple system • Representation of control principle diagrams
Technical Drawing	• Manual drawing • Quotation elements • Notion of scale • Orthogonal projections • Cuts and sections • AutoCAD • Design of cold and air conditioning installations • Standardisation and symbols for refrigeration and air conditioning	• Drawing simple parts by hand • Quotation of mechanical parts • Design of HVAC installations • Design of refrigeration installations • Design of principle schemes • Drawing electrical diagrams • Computer-aided design (AutoCAD, Solidworks, CATIA, Revit, etc.)

Table 7. (*Continued*).

AREA OF EXPERTISE	THEORETICAL/PRACTICAL TRAINING	WORKSHOPS/LABORATORIES
IT	● Introduction to Computer Science ● Word processing (Word and others) ● Spreadsheets (Excel and others) ● Databases ● Project organisation and management ● Programming skills ● Application and development of algorithms	● Preparation of reports in digital format (word, etc.) ● Preparation of specifications in digital format (word, etc.) ● Preparation of quotes in digital format (EXCELL, etc.) ● Development of small programmes to calculate load losses ● Database creation and management
General Design Elements	● Interior and exterior design conditions ● Calculating HVAC thermal loads ● Calculating thermal loads in refrigeration ● Regulations ● Energy certification ● Sizing cooling systems ● Sizing HVAC Systems ● Cold chain sizing	● Verification of energy certification regulations in real cases ● Calculation of thermal loads using computerised tools (HAP, DOE, Energy plus, TRANSYS, Fluent, etc.) ● Dimensioning and layout of pipe and duct networks using design software ● Measurement and budgeting for HVAC&R projects
Refrigeration installations and equipment	● Refrigerants ● Main refrigeration equipment (compressors, evaporators, condensers) ● Secondary refrigeration equipment (separators, tanks, sight glasses, filters, etc.) ● Control equipment ● Automatic feeding equipment (expansion valves, capillary tubes, etc.) ● Regulation and safety devices (thermostats, pressure switches, hygrostats, etc.) ● Cold rooms ● Cold stores ● Refrigerated displays ● Cooling tunnels ● Ice factories ● Refrigerated transport ● Special refrigeration installations ● Energy efficiency in refrigeration plants ● Environmental impact and sustainability in refrigeration	● Assembly and disassembly of compressors, condensers and evaporators. ● Assembly and disassembly of expansion valves and capillary tubes ● Construction of refrigerated pipework ● Insulation of pipes and fittings ● Vacuuming of installations ● Gas charges to installations ● Testing cold rooms ● Industrial Refrigeration Panel Test ● Fault simulation and repair ● Handling and processing copper pipework ● Notions of soldering copper pipework ● Selection of refrigeration equipment through manufacturers' catalogues and software
Air conditioning installations and equipment	● Main air conditioning equipment (chillers, boilers, UTA's, cooling towers, condensing units, etc.) ● Secondary air-conditioning equipment (fan coils, underfloor heating, pumps, valves, etc.) ● Control equipment (thermostats, hygrostats, pressure switches, dampers, etc.) ● Direct expansion systems ● Air systems ● Water systems ● Mixed systems ● Pipework and fittings ● Balancing HVAC installations ● Duct sizing ● Pipe sizing ● Environmental impact and sustainability of HVAC	● Ventilation unit test ● Testing air conditioning units ● Dehumidifier test ● Air Treatment Unit Test ● Heating installation test ● Solar energy teaching installation test ● Pipe insulation ● Measurement of flow rates in pipes and ducts ● Selection of HVAC equipment through manufacturers' catalogues and software

Table 7. (*Continued*).

AREA OF EXPERTISE	THEORETICAL/PRACTICAL TRAINING	WORKSHOPS/LABORATORIES
Maintenance elements	• Introduction to maintenance • Preventive and corrective maintenance • General maintenance plans • Maintenance and start-up of HVAC equipment • Maintenance and start-up of refrigeration equipment • Rules and regulations	• Simulating chiller maintenance operations • Simulation of maintenance operations in UTA's • Simulating fan coil maintenance operations • Simulating maintenance operations in cold rooms • Simulating compressor maintenance operations
Final Project	• Dimensioning and implementing an HVAC or refrigeration installation, using the knowledge acquired during training	

Source: Author.

7. Discussion

Potential challenges in adopting proposed educational methods

While the integration of modern educational methods such as active learning, problem-based learning, competency-based education, and hands-on laboratory experiences offers numerous benefits, there are several challenges that may arise in their implementation, particularly within the context of HVAC&R training. To address the potential challenges in adopting the proposed educational methods, it is important to consider factors such as resource limitations, resistance to change in curricula, and institutional or policy barriers.

One primary challenge is the availability of resources. The implementation of methods like active learning, problem-based learning, and competency-based education often requires modern technology, digital simulations, and updated equipment for hands-on training. In regions with limited funding or access to these resources, educational institutions may face difficulty in adopting these methods. Additionally, instructors may need training to effectively use new technologies and teaching approaches. To overcome these challenges, institutions can seek external funding from industry partnerships or government programs focused on vocational training. The use of low-cost or open-source digital tools can help reduce expenses, while professional development programs can ensure that instructors are adequately prepared to implement these methods.

Another challenge is resistance to change in curricula. Many educational institutions have established, traditional curricula that may not easily accommodate new teaching approaches. Faculty members, administrators, and other stakeholders may be reluctant to adopt unfamiliar methods, fearing disruption or additional workload. Overcoming this resistance requires clear communication about the benefits of the new methods and their alignment with industry needs. Involving key stakeholders in the decision-making process and gradually introducing new techniques through pilot programs or blended learning models can help ease the transition and reduce resistance.

Additionally, national or regional policies governing vocational education and training may impose constraints on curriculum design, limiting flexibility in adopting innovative pedagogical approaches. These policies may prioritize traditional methods and make it difficult to adapt to new educational trends. Engaging with policymakers and advocating for more flexible curriculum standards can help address these barriers. Collaborations between educational institutions and industry leaders can demonstrate the importance of aligning curricula with industry needs and technological advancements.

By acknowledging these potential challenges and offering strategies for overcoming them, institutions can better prepare for the successful implementation of modern teaching methodologies in HVAC&R training, ensuring that the benefits of these approaches are realized.

8. Conclusions

The training of HVAC&R professionals in Europe, especially as illustrated by the Portuguese case, underscores the essential role of structured, multi-faceted education in meeting industry demands for skilled, adaptable workers. Effective HVAC&R education must integrate robust scientific and technical knowledge with practical skills and awareness of sustainability and energy efficiency, equipping professionals to manage complex, real-world challenges in the field.

Key findings from this study indicate that successful training programs employ innovative pedagogical methods, including active learning, competency-based education, and hands-on laboratory experiences, to foster critical thinking, technical proficiency, and motivation among students. Bloom's Taxonomy emerges as a valuable framework for structuring HVAC&R curricula, ensuring that students progress from foundational knowledge to advanced problem-solving abilities aligned with industry requirements.

Furthermore, motivation is a pivotal factor, as it directly influences students' engagement and long-term commitment to the HVAC&R field. Training environments that include real-world equipment, interactive simulations, and problem-based learning projects are instrumental in preparing students for the complex, dynamic demands of the HVAC&R industry.

This study highlights the importance of creating educational pathways that allow students to attain recognized certifications across vocational and higher education levels, facilitated by the European Credit Transfer and Accumulation System (ECTS). Such a system not only supports mobility but also ensures comparability of skills and qualifications across European borders.

In conclusion, the integration of targeted, practical training elements with a strong emphasis on motivation and pedagogical innovation can significantly enhance HVAC&R training programs. Aligning educational practices with the specific demands of the HVAC&R industry is crucial to developing competent, motivated professionals capable of driving Europe's goals for energy efficiency and sustainability in modern infrastructure.

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