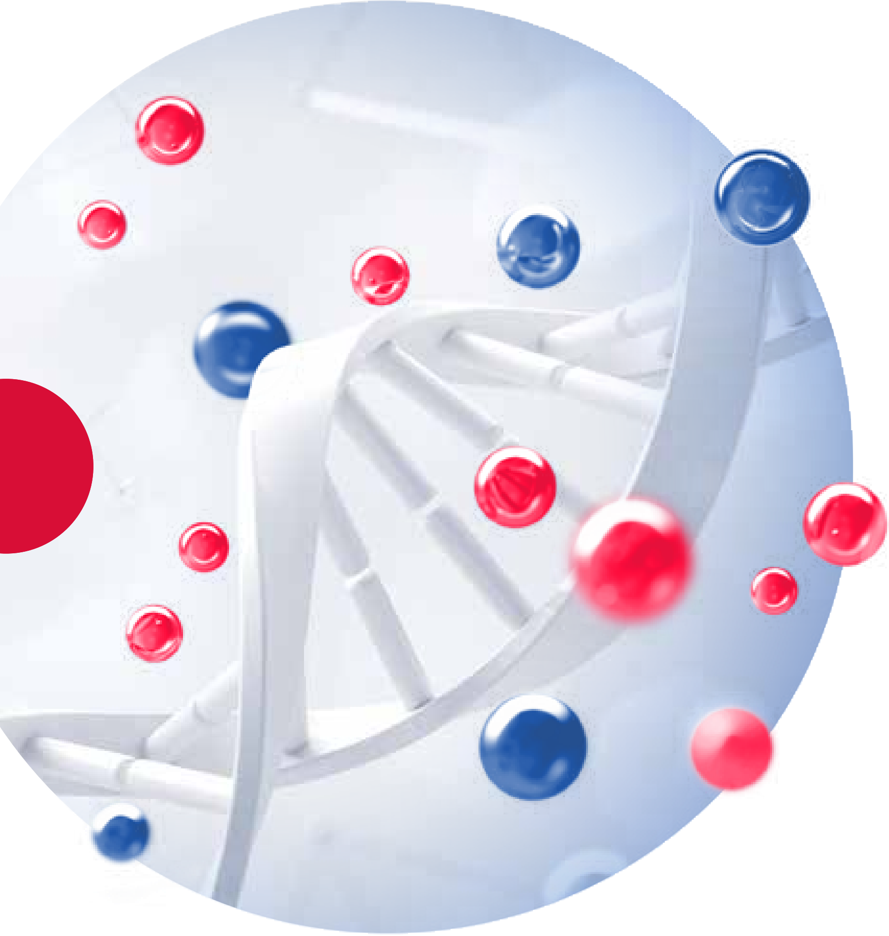
A guide to energy efficiency with the EXP multi-purpose systems



Dedicated seasonal indicators

RHOSS

NIBE GROUP MEMBER

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Working group

Rhoss S.p.A
Politecnico di Torino - TEBE @ IEEM Group

1.
Polyvalent units

Polyvalent units are advanced heat pumps, equipped with total recovery for the production of cold and hot water simultaneously or independently throughout the year.

They were introduced to the market more than 20 years ago and were immediately successful due to their **efficiency**, **versatility** and **flexibility** in all areas of application.

EXP System polyvalent units may find their natural place in **4-pipe systems**, where there is a need for air conditioning and heating throughout the year, rather than in **2-pipe systems**, where there may be a demand to satisfy opposite loads in the summer season and only heating in the winter season.

Design offices are even more interested in energy efficiency issues of the building-plant system: polyvalent units can be the key to achieve the set goals.

Polyvalent units, which have always been part of Rhoss' offer, have followed the technological development of refrigeration units in recent years. From the change of refrigerant gases to the current low GWP with reduced environmental impact, through the technological evolution of components with energy-efficient inverter solutions, to the increase in functional working ranges for the production of increasingly hot water for the most diverse uses.

2.
Simultaneous demand for heating and cooling loads

Limits of the current European legislation

Lack of indicators

The ability to provide heating and cooling loads independently or simultaneously (not just seasonally, like reversible heat pumps) makes the polyvalent unit a promising technological solution, especially in the tertiary and commercial sectors. The use of a polyvalent EXP System unit, alone or in combination with other HVAC systems (e.g. chillers, heat pumps, etc.), can offer significant benefits in terms of reducing electricity consumption with an impact on CO_2 equivalent emissions, operating and overall costs.

However, there is currently a lack of indicators capable of comprehensively assessing the functioning and benefits of polyvalent units.

So far, the performance of polyvalent units has been evaluated in terms of the well-known seasonal SCOP *(Seasonal Coefficient of Performance*) and SEER *(Seasonal Energy Efficiency Ratio*) indices, calculated according to EN 14825. While these indices are particularly useful for expressing the potential of conventional heat pumps, which provide one service at a time (cooling or heating, depending on the season in question), SEER and SCOP are not sufficient for assessing the performance of polyvalent units when they provide a dual service, cooling and heating, at the same time. EN 14825 requires SEER and SCOP to be calculated using linear loads, defining the number of hours of the heating and cooling seasons and the reference temperature range for the calculation, based on different climatic conditions.

Criticalities of the approach

This approach presents critical issues when used to evaluate the performance of a polyvalent unit. It is indeed limiting to consider fixed temperature ranges for the definition of load curves, as well as to define two separate and independent heating and cooling seasons; in fact, **using this method, it is not possible to take into account the possible simultaneous heating and cooling demands, or to consider the number of hours of simoultaneous loads, aspects that represent the main advantages of polyvalent units.**

3.

Annual Performance Indicator

New performance indicator for polyvalent units

The methodology

In order to quantify and enhance the benefits that the use of a polyvalent technology can offer, **the collaboration between Rhoss S.p.A. and the Politecnico di Torino - TEBE @ IEEM Group aimed at developing new indicators capable of taking into account the hours of simultaneous demand for heating and cooling.**

The proposed methodology consists of two phases:

1.

Numerical experimentation

Needed to model the coupling between load profiles and the operating dynamics of polyvalent units;

2.

Definition of indicators

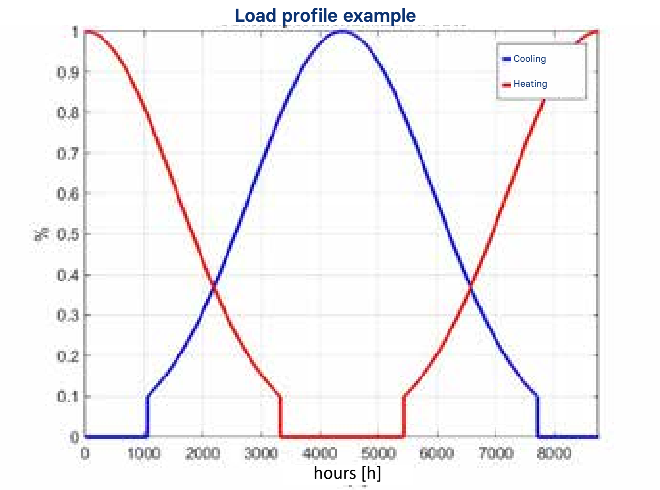
Aimed at defining a set of metrics capable of expressing the performance of polyvalent units, overcoming existing limitations, and focusing on applications in 4-pipe systems.

1.
Numerical modelling

The numerical modelling phase is developed around three methodological steps, making it possible to: create the load profiles, define the operating modes of the units and model the load-unit coupling, considering partial loads and outside air temperature as influencing parameters. This step is preparatory to the subsequent phase of defining performance indicators.

Load profile creation

In order to generalise the methodological framework and move away from specific cases, **the cooling and heating load profiles are distributed over the hours of the year according to theoretical and normalised Gaussian curves**, allowing for the possibility of simultaneous demands and setting a specific percentage of simultaneity (i.e., number of hours in which heating and cooling services are required simultaneously). During non-simultaneous hours, only cooling and heating loads are present, while simultaneous hours are characterised by simultaneous heating and cooling demands.



Definition of operating mode

The technical features of the polyvalent EXP System unit allow it to operate in **three main modes of operation**:

A1 or **cooling only** (the unit works as a conventional chiller);

A3 or **heating only** (the unit works like a conventional heat pump);

A2 or **combined heating and cooling**. In the last mode, the polyvalent unit allows the recovery of condensation heat during the production of chilled water that would otherwise be wasted.

Load-unit coupling

A model was created to characterise the operation of polyvalent units and **five possible coupling modes** were identified:

$\mathbf{A1_{NCont}}$ (cooling only during hours of non-contemporaneity),

$\mathbf{A3_{NCont}}$ (heating only during hours of non-contemporaneity),

A2 (simultaneous heating and cooling demand),

$\mathbf{A2{+}A1_{Cont}}$ (when A2 mode requires integration into A1 mode to meet cooling demand during hours of contemporaneity)

$\mathbf{A2{+}A3_{Cont}}$ (when A2 mode requires A3 mode integration to meet heating demand during hours of contemporaneity)[1].

1. For more details on the numerical model and methodology adopted, please refer to the publications on the subject:

- Abbà, S. Cellura, S.P. Corgnati, S. Morassutti, L. Prendin. Overall energy performance of multi-purpose heat pump systems. REHVA Journal 57, pp. 26-31, 2020.
- Abbà, G. Crespi, S.P. Corgnati, S. Morassutti, L. Prendin. Sperimentazione numerica delle dinamiche di funzionamento di sistemi polivalenti. 37° Convengo Nazionale AiCARR – Obiettivo 2030: Scenari, tecnologie e strategie per la sostenibilità energetica nella climatizzazione, Luglio 2020.
- G. Crespi, I. Abbà, S.P. Corgnati, L. Prendin, M. Babuin. Contemporary and unbalanced loads in buildings: new performance indicators. REHVA Journal 59, pp. 16-20, 2022.
- Abbà, G. Crespi. A Multi-criteria Assessment of HVAC Configurations for Contemporary Heating and Cooling Needs. NMP 2022, LNNS 482, pp. 1711-1720, 2022.
- G. Crespi, I. Abbà, S.P. Corgnati. Innovative metrics to evaluate HVAC systems performances for meeting contemporary loads in buildings. Energy Reports 8, pp. 9221-9233, 2022.

2.
Performance indices

Inspired by the coefficients that currently exist for heat pumps, **five performance indices** were defined to assess performance for each mode of operation:

$SCOPnc_{mode}$

$SCOPc_{mode}$

$SEERnc_{mode}$

$SEERc_{mode}$

$S\text{-}EXP_{mode}$

Each metric is calculated as the ratio between the total energy demands and the respective electrical energy absorbed for a specific mode of operation. Any integration via an electrical back-up system (with efficiency of one) for peak heating demands is included in the calculation of the indicators. Although some metrics ($SCOPnc_{mode}$, $SCOPc_{mode}$, $SEERnc_{mode}$, $SEERc_{mode}$) may be reminiscent of the SCOP and SEER based on standards known in the commercial sphere, it is important to note that there are differences in their definition.

Development of the Annual Performance Indicator (API)

Starting from the developed indicators, the main objective of the study was to define an **aggregate index on an annual basis**, capable of effectively expressing the performance of polyvalent units, and to allow comparison with other systems, including traditional ones.

This results in the Annual Performance Indicator (API), calculated as the sum of the five previously described indices, each weighted by the unit's operating hours in each operating mode. In detail, defining P1, P2, P3, P4 and P5 as the fractions of annual hours in which the polyvalent operates in $A3_{NCont}$, $A1_{NCont}$, A2 , $A3_{Cont}$ e $A1_{Cont,}$ the API is calculated as follows:

$$API = P_1 \times SCOPnc_{mode} + P_2 \times SEERnc_{mode} + P_3 \times S\text{-}EXP_{mode} + P_4 \times SCOPc_{mode} + P_5 \times SEERc_{mode}$$

Definition of performance indicators and weights for each mode of operation

hours of NON contemporaneity	**$A3_{NCont}$**	**$SCOPnc_{mode}$**	Hours of unit operation in $A3_{NCont}$ **(P_1)**
	$A1_{NCont}$	**$SEERnc_{mode}$**	Hours of unit operation in $A1_{NCont}$ **(P_2)**
hours of contemporaneity	**A2**	**$S\text{-}EXP_{mode}$**	Hours of unit operation in A2 **(P_3)**
	$A3_{Cont}$	**$SCOPc_{mode}$**	Hours of unit operation in $A3_{Cont}$ **(P_4)**
	$A1_{Ccont}$	**$SEERc_{mode}$**	Hours of unit operation in $A1_{Cont}$ **(P_5)**

4.

Multi-unit configurations

The answer to the new requirements of covering unbalanced loads

Multi-unit configurations as a response to new requirements to cover unbalanced loads

In modern systems, partly as a result of regulations pushing for efficient building insulation, the cooling and heating loads to be met are increasingly unbalanced.

Furthermore, in 4-pipe systems, **the need for simultaneous cooling and heating has increased over the years**, driving the increasing use of polyvalent units.

These two aspects do not always result in the definition of a single polyvalent unit that fully and comprehensively satisfies all requirements, often leading to over-dimensioning of the system with increased costs, and, in some cases, to a decrease in the high energy efficiency of the unit due to the decrease in simultaneous operation in the production of cold and hot water.

It would be better to be able to choose the polyvalent unit to meet the lowest of the cooling/heating demand and cover the remaining demand with the addition of chillers or heat pumps, making it necessary to be able to run units of different technology and capacity efficiently and reliably to meet unbalanced load demands from the user.

MTM - Multi Technology Manager was then developed, in order to manages the units chosen at the plant design stage to optimise the overall energy efficiency of the system.

5.

How to optimise the energy efficiency of multi-unit configurations

The Multi Technology Manager

Multi Technology Manager

MTM - Multi Technology Manager is a **device for the intelligent management of RHOSS refrigeration units, heat pumps and polyvalent** units (up to a maximum of 10 units), with control of the individual units according to load (cooling and heating) and optimisation of their operation, with the aim of maximising their yield and energy efficiency, working time, and guaranteeing the precision of the temperatures of the hot and cold water produced.

MTM performs the Manager function by directly controlling the operation of the connected units and its components, using the specificities of each technology to maximise the energy efficiency of the **unit group**, minimising its energy consumption.

Application of the MTM

MTM can be applied in installations of:

1.

4 PIPES

A system in which cold water is produced in the main circuit, and hot water in the secondary/recovery circuit, throughout the year;

2.

2 PIPES

A system in which cold water is produced in the summer season and hot water in the winter season, in the main circuit;

3.

2 PIPES + DHW

A system in which cold water is produced in the summer season and hot water in the winter season, in the main circuit; at the same time there may be a demand for hot water for DHW production in the secondary/recovery circuit.

Characteristics of the units used

The units used may be different in terms of:

Type
(chillers, reversible heat pumps, EXP polyvalent equipment, ...)

Technology used
(scroll, semi-hermetic screw, ON-Off and inverter compressors, Turbocor)

Size

MTM manages the sequence/insertion of the units based on the system's load assessment and priority is established according to standard and customisable logics.

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In the case of installations with strong cooling or heating load imbalances

the most efficient solution is the coupling of polyvalent units with chillers or heat pumps.

In this case, the implemented logics **favour the operation of polyvalent units in the combined production mode of cooling and heating, leaving the integration of excess cooling or heating loads to the chiller or heat pump.**

6.
Applications

Is the performance of multi-unit systems better than a single polyvalent heat pump?

The aim of this part of the research is to evaluate the potential of coupling polyvalent units with other HVAC systems by means of efficient management and control systems that can strategically optimise the use of technologies efficiently in the case of unbalanced loads. The analysis presents a comparison of **single-unit** (polyvalent only) and **multi-unit** (polyvalent unit + chiller/heat pump) plant configurations using different load conditions, comparing performance in terms of energy (API) and economic indicators (overall cost and payback time).

Assumptions

1. **Climate**
   Strasbourg ('Average' climate according to EN 14825)
2. **Simultaneous demand for heating and cooling loads**
   52% (average) - 4557 hours per year
3. **Load profiles**
   Gaussian curves as defined in the methodological chapter.
4. **Unbalanced loads**
   one load is double of the other

   • **Imbalance towards cold**
   cooling load is the double of the heating one

   • **Imbalance towards heat**
   heating load is the double of the cooling one
5. **Maximum powers requested**

   High loads: 600 kW
   Average loads: 300 kW
6. **Plant configurations (focus on 4-pipe systems):**

   • **Mono-unit:** a single polyvalent unit

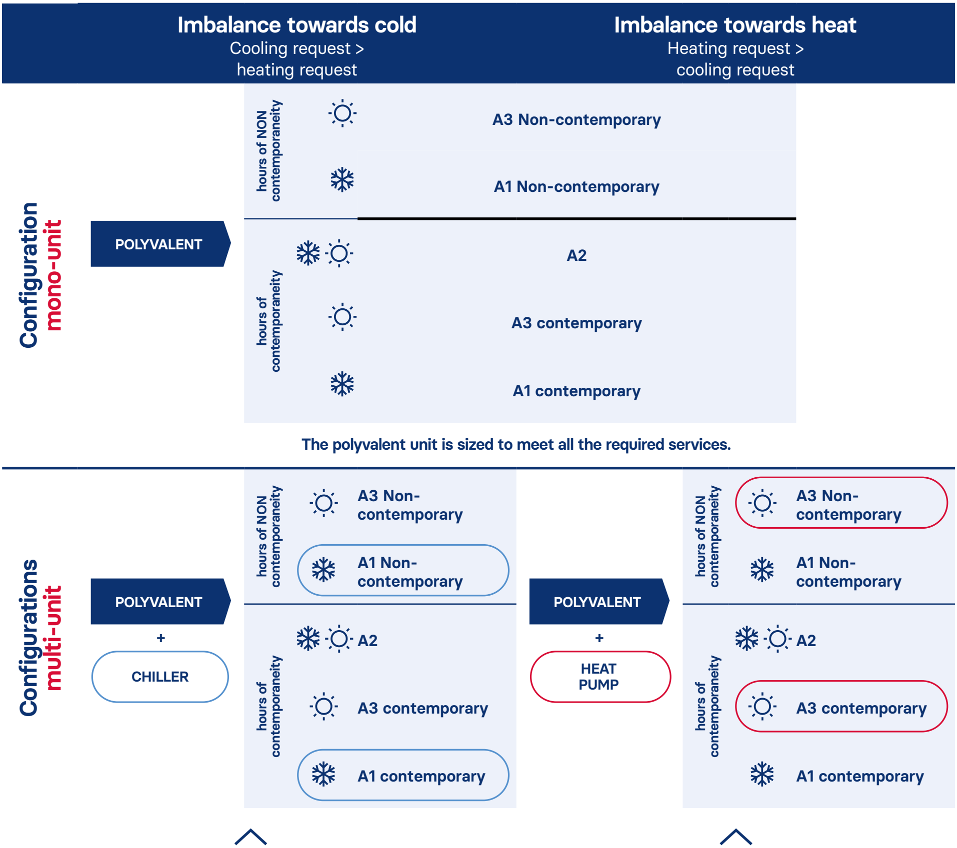
   • **Multi-unit:** polyvalent unit + chiller or polyvalent unit + heat pump, depending on the type of imbalance
7. **Unit type**

   EXP System units with scroll technology and R454B refrigerant gas with low GWP

   Chillers and heat pumps with scroll technology and R32 refrigerant gas with low GWP

		mono-unit	multi-unit
High loads	Imbalance towards cold	**TXAETU 6660** (polyvalent)	TXAETU 4370 (polyvalent) + TCAETI 4280 (chiller)
	Imbalance towards heat	**TXAETU 6660** (polyvalent)	TXAETU 4370 (polyvalent) + THAETI 4350 (heat pump)
Medium loads	Imbalance towards cold	**TXAETU 4330** (polyvalent)	TXAETU 4160 (polyvalent) + TCAETI 2160 (chiller)
	Imbalance towards heat	**TXAETU 4330** (polyvalent)	TXAETU 4160 (polyvalent) + THAETI 4220 (heat pump)

Definition of analysed configurations



The polyvalent unit is not sized to meet all the required loads. The system requires the integration of a chiller to meet peak **cooling request**. The chiller only operates in $A1_{NCont}$ and $A1_{Cont}$ modes

The polyvalent unit is not sized to meet all the required loads. In particular, the system requires the integration of a heat pump to meet peak **heating request**. The heat pump only operates in $A3_{NCont}$ and $A3_{Cont}$ modes

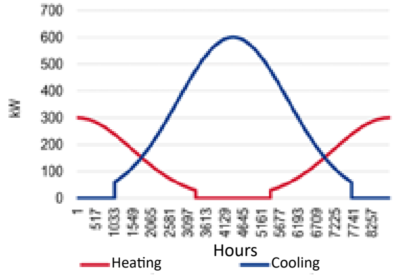
In the case of **multi-unit** configurations, the coupling of the two units can be easily managed via the MTM management system, which allows efficient decision-making on the start-up and operating strategies of the units.

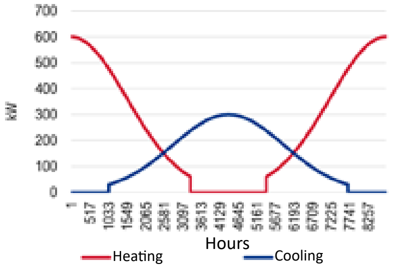
Ideal load profiles (Gaussian curves) were used to consistently compare the various technological alternatives.

Load profiles used

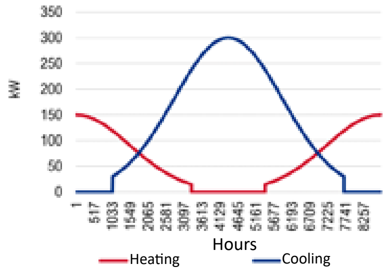
	Imbalance towards cold Cooling request > heating request	Imbalance towards heat Heating request > cooling request

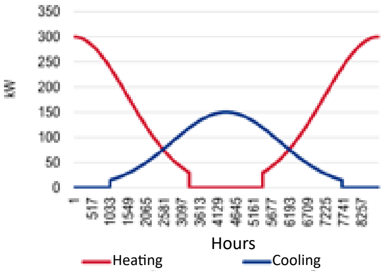
High Loads





Medium loads





The comparison between the proposed configurations is presented from an energy and economic point of view, using the following indicators:

API
for the performance evaluation of plant configurations.

API Delta (ΔAPI)
percentage variation between the API of the multi-unit alternative versus that of the polyvalent single unit.

A positive delta indicates that the multi-unit configuration is more cost-effective in terms of energy than the single-unit polyvalent configuration.

Global Cost Delta (ΔCG)
Global cost represents the cost of a technology over its life cycle and includes not only the investment cost, but also annual discounted operating costs[2]. The ΔCG represents the percentage change in the overall cost of the multi-unit alternative compared to the single-unit polyvalent alternative.

A negative delta indicates a cost-effectiveness of the multi-unit configuration.

Payback time (PBT)
Defined as the ratio between the delta investment cost and the delta energy saving of the two configurations. This indicator can only be calculated for application in which the investment cost of multi-units is higher than that of the single polyvalent unit.

2. In this application, the costs were applied with an interest rate of 4%. The investment and maintenance costs of the machines come from the Rhoss S.p.A. price list, and the cost of the MTM system has only been added in the case of multi-unit configurations. To estimate the cost of energy, reference was made to the energy price (€/kWh) for the first quarters of 2022 provided by ARERA.

Performance, energy and economic indicator results for high loads

High Loads [kW]	API mono-unit	API multi-unit	Δ API	Δ CG	PBT [years]
600 C – 300 H	5,118	5,280	+3.2%	-3.4%	N.A.
300 C – 600 H	4,978	5,078	+2%	-2.7%	3,10

C = Cooling H = Heating N.A. = Not available

Performance, energy and economic indicator results for medium loads

Medium loads [kW]	API mono-unit	API multi-unit	Δ API	Δ CG	PBT [years]
300 C – 150 H	4,581	4,970	+8.5%	-5.8%	N.A.
150 C – 300 H	4,451	4,943	+11.1%	-7.7%	2.61

C = Cooling H = Heating N.A. = Not available

The application of the methodology developed by the Politecnico di Torino in the case of unbalanced loads has demonstrated the convenience of hybrid solutions consisting of polyvalent units and chillers or heat pumps, depending on the load imbalance.

The multi-unit configuration is always better than the single-unit configuration, for both imbalances (heat or cool) and regardless of maximum load conditions. This energy convenience is well illustrated by the annual API indicator, whose delta between configurations is always positive, even exceeding 10%. The value of the indicator is influenced by the load conditions and the characteristics of the units themselves, in terms of efficiencies at partial loads at different ambient air temperatures.

From an economic point of view, in cases with an imbalance towards cold, multi-unit systems, in addition to being more cost-effective from an energy consumption point of view, have lower investment costs than multi-unit configurations: for these cases, therefore, the payback time is not calculated.

On the contrary, in cases with an imbalance towards heat, the multi-unit system has a higher investment cost than the configuration with only the polyvalent unit; only in these cases, therefore, is it possible to calculate the payback time, which is less than three years. Despite the higher initial investment, the power consumption (and consequent energy cost) of the multi-unit system is lower, resulting in greater overall cost-effectiveness.

Does the API succeed in enhancing the theme of simultaneous loads?

Focusing on multi-unit configurations, the convenience of which was previously demonstrated through the proposed application cases, this part of the study aims to verify the API indicator's ability to highlight the effect of simultaneity on unit performance.

Assumptions

1. **Climate**
   Strasbourg ('Average' climate according to EN 14825)

2. **Simultaneous demand for heating and cooling loads**
   23% (low) - 1971 hours per year

   52% (medium) - 4557 hours per year

   76% (high) - 6691 hours per year

3. **Load profiles**
   Gaussian curves as defined in the methodological chapter

4. **Unbalanced loads**
   one load is double of the other

   • **Imbalance towards cold**
   cooling load is the double of the heating one

   • **Imbalance towards heat**
   heating load is the double of the cooling one

5. **Maximum powers requested**

   Medium loads: 300 kW

6. **Plant engineering configurations (focus on 4-pipe systems):**

   • **Multi-unit:** polyvalent + chiller or polyvalent + heat pump, depending on the type of imbalance

7. **Unit type**

   EXP System units with scroll technology and R454B refrigerant gas with low GWP

   Chillers and heat pumps with scroll technology and R32 refrigerant gas with low GWP

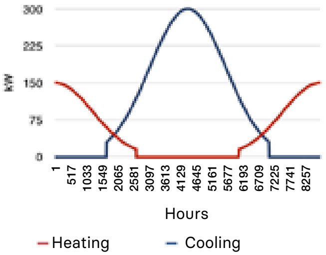
		mono-unit	multi-unit
Medium loads	Imbalance towards cold	**TXAETU 4330** (polyvalent)	TXAETU 4160 (polyvalent) + TCAETI 2160 (chiller)
	Imbalance towards heat	**TXAETU 4330** (polyvalent)	TXAETU 4160 (polyvalent) + THAETI 4220 (heat pump)

Ideal load profiles (Gaussian curves) were used to consistently compare the various technological alternatives.

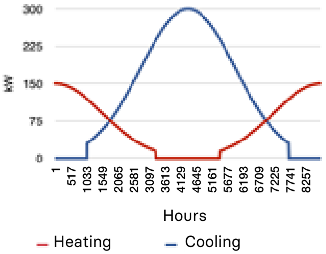
Load profiles as a function of simultaneous service percentage

Imbalance towards cold
Cooling request > heating request

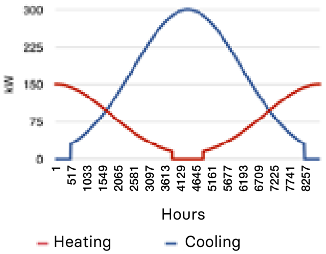
23%
(low contemporaneity)



52%
(medium contemporaneity)



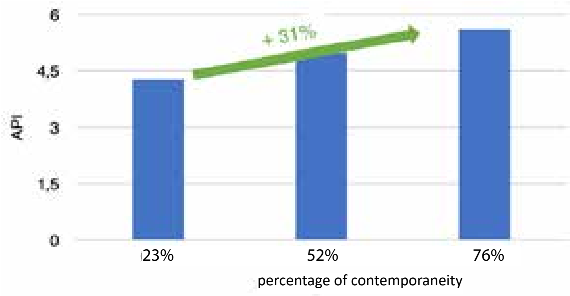
76%
(high contemporaneity)



The application made it possible to verify the effectiveness of API in exploiting the issue of simultaneous heating and cooling mode, which is not properly evaluated by current regulations.

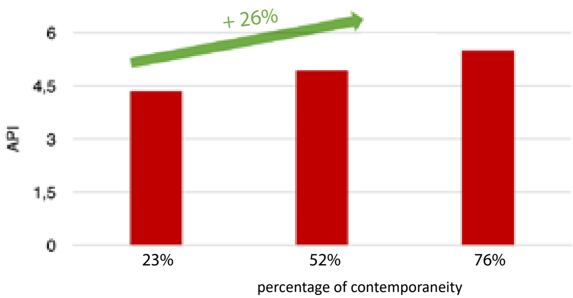
In particular, the indicator increases in absolute value as simultaneous load increases, for all the considered load scenarios. In the cases analysed, for multi-unit systems, the API value increases by about 30% for both unbalances.

Imbalance towards cold



Variation of the API for multi-unit systems when the percentage of contemporaneity changes: unbalance towards cold.

Imbalance towards heat



Variation of API for multi-unit systems when the percentage of contemporaneity changes: unbalance towards heat.

7.
Conclusions

1.
The API index - Annual Performance Indicator - is able to **realistically characterise the operation of a polyvalent unit**, giving evidence of seasonal performance, compared to the limitations of traditional indices.

2.
In the presence of unbalanced loads, adhering to real applications in 4-pipe systems, it is observed that **the multi-unit configuration has a better API index** than the use of a single polyvalent unit sized to the maximum load to be met.

3.
The multi-unit solution is more cost-effective (lower overall cost).

4.
The percentage variation of the API index between the multi-unit configuration and the single-unit solution **is influenced by the combination of load profiles chosen** and the coupling of the units selected to meet the required system loads.

5.
In line with expectations, **in 4-pipe applications** where the use of polyvalent units is now a commonly used solution, **the API index increases as the percentage of simultaneous loads increases**.

New air
for the future.

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