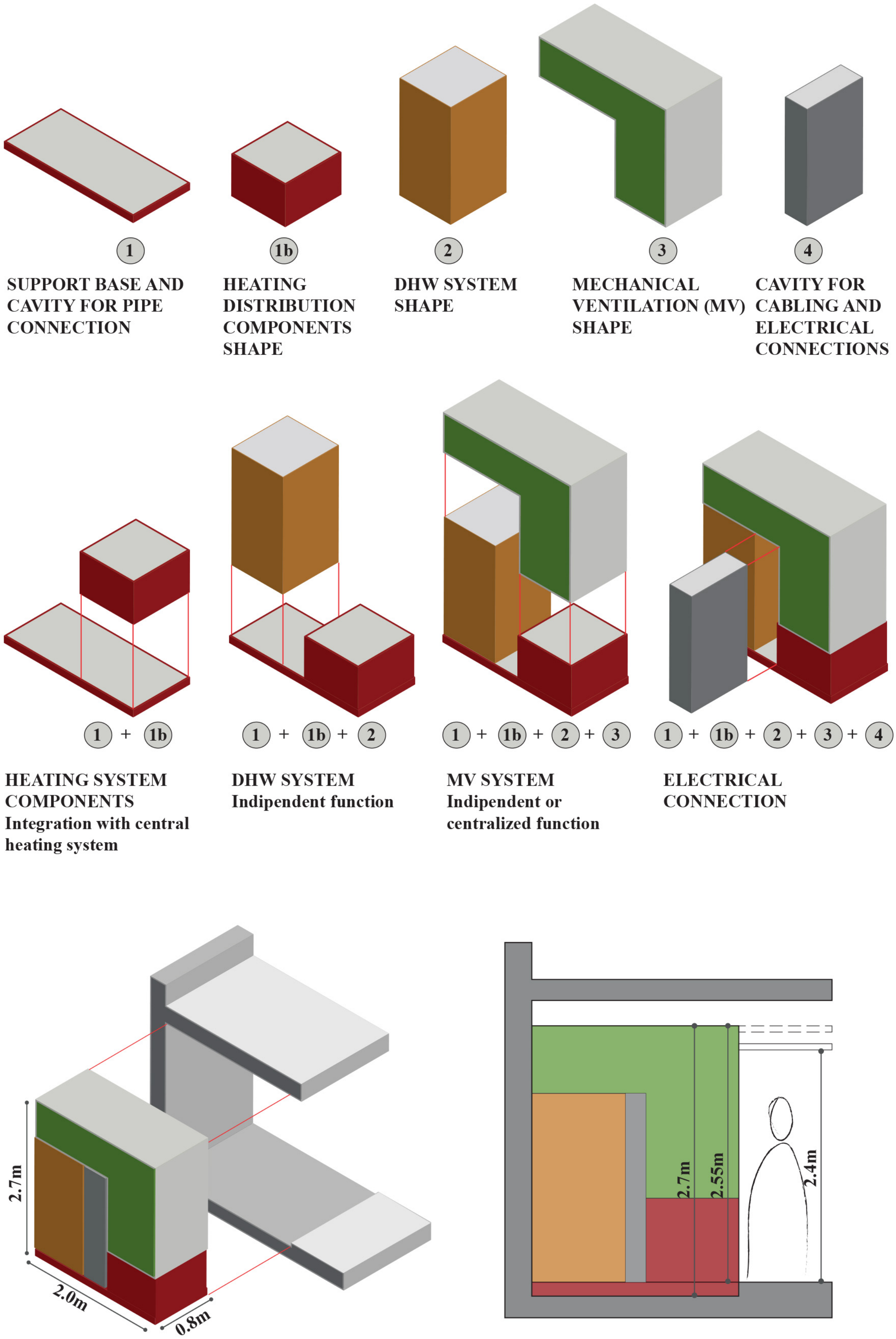

Example of a services cupboard design for the building model "M" Size.
The isometric views show the envelope of the each services and their combination into the cupboard.

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The integrated design of building services by an equipped and eco-efficient module (MOTE²)

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ABSTRACT

The targets set out by European Directives concerning the energy savings in the construction sector refer both to building envelope and to its services. With regard to building services it is mandatory meeting requirements related to heating, cooling, lighting and ventilation.
Building services take up a variable space in the buildings that cannot be considered anymore negligible and they would always be fully integrated into buildings.
Equipped and Eco-efficient Technological Module (MOTE²) is a research project aimed at implementing the integration in a unique services cupboard of some building services: heating and cooling; domestic hot water; mechanical ventilation.
The project was organized according to four main phases. In phase 1 a set of rules was defined matching requirements related to the energy efficiency to environmental building design standards. During the phase 2 six building models were studied in order to size the corresponding building services according to scenario analysis set down for existing buildings. In phase 3 the project was focused on designing the assembly among services. The cupboard design is like a Tetris® game through the planning of the best combination among services shape. Based on the drawings developed a first mock-up was built up and monitored. Finally, in phase 4 the paper deals with the MOTE²'s expected performances.
Outlook and some conclusions point out the future steps of the research activities.

KEYWORDS
technological integration of building services, services cupboard for building

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1. INTRODUCTION

In recent years a consistent legislative framework aimed at significantly improving the energy efficiency of European buildings stock have been laid down, i.e. the Energy Performance of Buildings Directive (Directive 2010/31/EU), the Energy Efficiency Directive (Directive 2012/27/EU) and the Renewable Energy Directive (Directive 2009/28/EU).
Particularly relevant is the EPBD recast stating that new buildings occupied by public authorities and properties have to be Nearly Zero Energy Buildings (NZEBs) by December 31, 2018 and that new buildings have to be NZEBs by December 31, 2020. According to the EPBD a NZEB is a building that has a very high-energy performance with nearly zero or very low amount of energy required to be covered by energy from renewable sources, including renewable energy produced on-site or nearby.
Based on these premises in the last years several European Countries, including Italy, have been adopting several measures and incentives to get energy savings in the construction sector.
The set out targets refer both to building envelope, by means an improvement of building systems performances in term of thermal insulation, control of air leakages and thermal inertia, and to building services, since it is mandatory meeting requirements related to heating, cooling, lighting and ventilation (Perago et. al., 2009).
Nowadays building services take up a variable space in the buildings - according to their uses - that cannot be considered anymore negligible (e.g. hospitals or some factories require sophisticated installations).
Only in recent times it grows the awarness about the impact of servicing systems and subsystems on the building. Until few years ago the design and installation of services was considered relatively unimportant. The buildings were simpler; featured with boilers and air heating, pipeworks, radiators and convectors as well as with a fume cupboard in the kitchens and in the bathrooms. Nothing more than that. A fragmented approach in planning and construction often took place (Harrison et. al., 2000).
Unpleasantlty the lack of a proper integration is frequently noticeable even in newly constructed buildings.
Systems, pipes and ducts are ungracefully leaned on the buildings roof and on the walls (Figure 1).
On the whole a general building design rethinking is required. Architects, civil engineers and other stakeholders involved in the design and construction processes have to be conscious on the relevancy concerning the building services "accommodation" as well as the importance of their support and enclosure.
The paper deals with a reserch project where the building services were sized to providing occupants comfort but – above all - they are designed to be fully integrated into the building.

Figure 1.

Reale Mutua Insurance Headquarter (Turin). Example of lack of integration between building design and its services.

2. THE RESEARCH PROJECT: MOTE[2]

With the knowledge that services would always be integrated into the structures and systems of the buildings - since the earliest stages of the design process - it was defined the main objective of a research project entitled MOTE[2] (Equipped and Eco-efficient Technological Module) to integrating in a unique services cupboard (or small storeroom) the main building environmental services. Particularly the research was focused on the following systems: heating and cooling; Domestic Hot Water (DHW); mechanical ventilation.
In the research project other services, such as: lift installations, usually defined as self-contained elements, and sanitary accommodations, usually defined as utility services, were not included.
As mote in English means a small particle or a very tiny part of a substance, the project laid down to use the smallest volume in the apartments with a cupboard where the environmental services are collected in the closest space possible without scarifying safety, maintenance and repairs.
An interdisciplinary team was involved in the research project: the Department of Architecture and Design, DAD (Politecnico di Torino) and a leading enterprise in prefabricated buildings and preassembled systems (Sarotto Group S.r.l.).
The refurbishment of the existing residential building and new semidetached houses are the main reference markets for the Sarotto Group. According to such assumptions the research was focused mainly on developing a services cupboard fit for housings retrofit, new houses with central heating system and new houses with indipendent heating system for four families[1].
Two Italian climate zones (Figure 2) were considered in the scenario analysis and in the energy assessment: Zone E (degree days average value 2700) and Zone F (degree days average value 3500).

3. METHODOLOGY

The research was organized according to the phases hereafter described:

- phase 1: set out of energy and environmental requirements;
- phase 2: scenario analysis and energy assessment;
- phase 3: design and prototyping;
- phase 4: value proposition definition and performance evaluation.

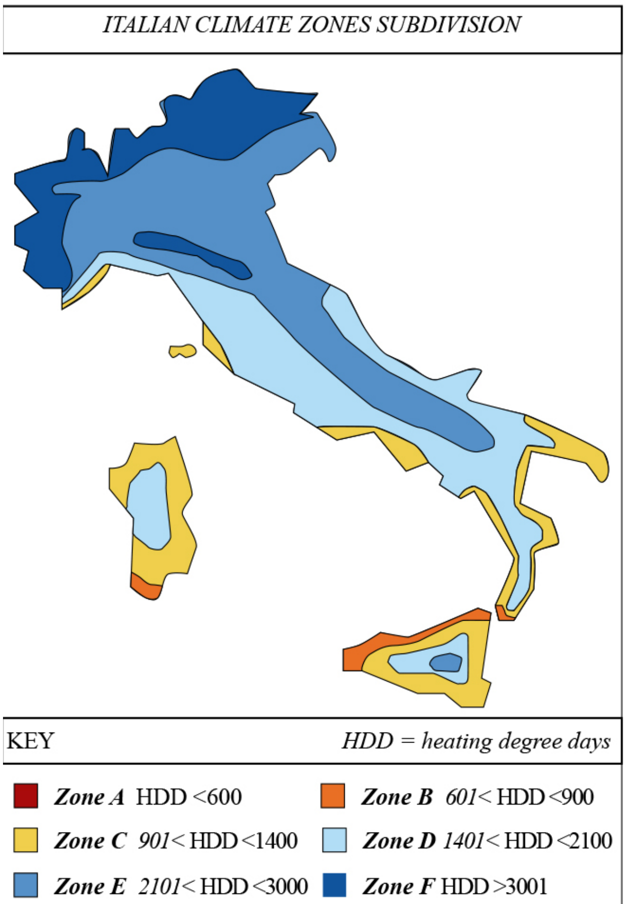


Figure 2.

Italy Climate Zones. Zone E and Zone F were chosen in the building energy analysis.

3.1 SET OUT OF ENERGY AND ENVIRONMENTAL REQUIREMENTS

As mentioned environmental building services normally include installations for meeting indoor comfort requirements with regards to heating, cooling and ventilation.
In phase 1 a set of rules was defined matching mandatory requirements related to the European Directives on energy efficiency to technical standards and specifications governing the environmental building design approach.
Specifically the following environmental standards were analysed and adopted:

- UNI EN 15643-1 and 2: 2010 - Sustainability of construction works;
- UNI 11277:2008 - Sustainability in buildings.

Such standards enable to assess the environmental life cycle of new buildings and the environmental performances of the remaining service life and the end-of-life of existing buildings.
Thus a broader set of requirements was taken into account according to the well-known life cycle design approach.
On the whole four life cycle stages were considered: production stage; construction stage; use and maintenance stages; end-of-life stage.
Seven requirements were associated to production, including mechanical strengths of materials, weight of components and use of green materials. Two requirements were associated to construction, comprising assembling solutions for easy repairs and replacing. Thirteen requirements were associated to use stage, encompassing services maintenance and occupant comfort. Three requirements were finally associated to end-of-life, involving materials and components life-span and recycling.
For each of the twenty-three requirements a related performance assessment (quantitative or qualitative) was provided, according to the standards and technical specifications, or ad-hoc implemented, in coherence with the standards and technical specifications.
As shown in the following paragraphs the requirements set out was meaningful for the service cupboard design, for sizing the services and for the materials selection.

3.2 SCENARIO ANALYSIS AND ENERGY ASSESSMENT

The scenario analysis carried out refers to a set of theoretical building models with same building features, envelope performances and users behaviour.
Three initial building models reference sizes were assumed in the analysis, with the following conditioend (usefull) floor area: Small Size (S= 50 m^2), Medium Size (M=80 m^2) and Large Size (L = 120m^2). Afterwards the reference Sizes were further split in two categories according to the type of heating system. The building models that were studied with a central heating system were classified with the code X.
Thus three building models were classified as: S, M, L (independent heating system) and three building

Building Models	Size		
	S;X_s	M;X_M	L; X_L
Gross Floor area (m^2)	60	95	140
Conditioned floor area (m^2)	50	80	125
Conditioned volume (m^3)	150	240	375
Number of storey above floors (n)	1	1	1
Average floor-to-floor height (m)	3	3	3
Surface area-to-volume ratio (m^{-1})	0.8	0.8	0.8

Table 1.

Theoretical building models features

models were classified as: X_S, X_M, X_L (central heating system). The main reference buildings features are summarised in the table 1.
With regard to the buildings envelope, the models were designed to meet the mandatory energy requirements in force (reference year 2016; UNI TS 11300: 1-2-3-4) for climate zone E and F (Table 2).

Building systems	Zone E	Zone F
Wall systems (with thermal bridge correction)	External insulation layer	External insulation layer
Roof System	Ventilated roof, external insulation layer	Ventilated roof external insulation layer
Windows system	Double glazing with one layer low-E	Double glazing with one layer low-E
Average U-value opaque elements (W/m^{2}K)	Uop=0,25	Uop=0,22
Average U-value galazing elements (W/m^{2}K)	Uw=1,7	Uw=1,5

Table 2.

Building envelope performances

Furthermore in the scenario analysis were defined the number of users and their needs in terms of indoor comfort temperature and water consumed by washing and cooking. See table 3.
In the scenario analysis was not considered the Primary Energy Demand (PED) for heating and cooling. Such assumption is directly correlated to the NZEB approach mentioned in the introduction. The NZEB expects an amount of electricity to feed the building produced on-site or nearby by renewable energy sources. In the building models the direct energy was deduced according to a reference framework: climate data; building features; user needs. But in such models it was not possibile setting down the primary energy conversion factors, since such factors (correlated to the indirect energy value) are strongly dependent on the renewable or fossil sources used; the primary energy it is not an easy predictable based model, its value is influenced by several conditions such as the regional and national electricity energy-mix as well the type of energy sources adopted on site, nearby or far from the building site, e.g. although France and Italy are each other near the electricity is produced with completely different systems. Thus due to the high number of variables to consider for every building Size analysed - were only accounted the direct energy needs.
Finally for the six scenarios no solar or internal gains were taken into account. It was assumed to carrying out an energy analysis through a conservative approach. The heating and cooling loads and the DHW demand were referred to a “design day” when services run at full capacity or fully loaded and the building models are fully occupied by users.
The energy analysis was carried out with regards to the six scenarios developed (Pianese, 2009 and UNI 10339:1995). The following data were performed: thermal energy need for heating and cooling; thermal energy need for DHW; airflow rate (exchange and cooling).

Building models	S,X_S	M,X_M	L,X_L
Nr° of occupants	2-3	3-4	5-6
DHW supply (l/day)	90	120	190
Occupancy schedule	24/24 hours -7/7 days		
Indoor comfort temperature	Tin,$_H$ = 20° C		
	Tin,$_C$= 26° C		

Table 3.

Users and associated needs for the building models

Building Models: M Size; XM Size	Climate Zone	
	E	F
Heating		
Energy need (kWh/m^2)	40	56
Max. thermal load (W/m^2)	28	33
Cooling		
Energy need (kWh/m^2)	16	16
Max. thermal load (W/m^2)	45	35
DHW (Domestic Hot Water)		
Energy need (kWh/y)	1270	
Water need (l/day)	120	
Max. DWH flow rate (l/min)	25	
Max. DWH temp. supply (C°)	45	
Air-Flow rate		
Exchange air-flow rate (m^3/h)	150	
Cooling air.flow rate (m^3/h)	1050	750

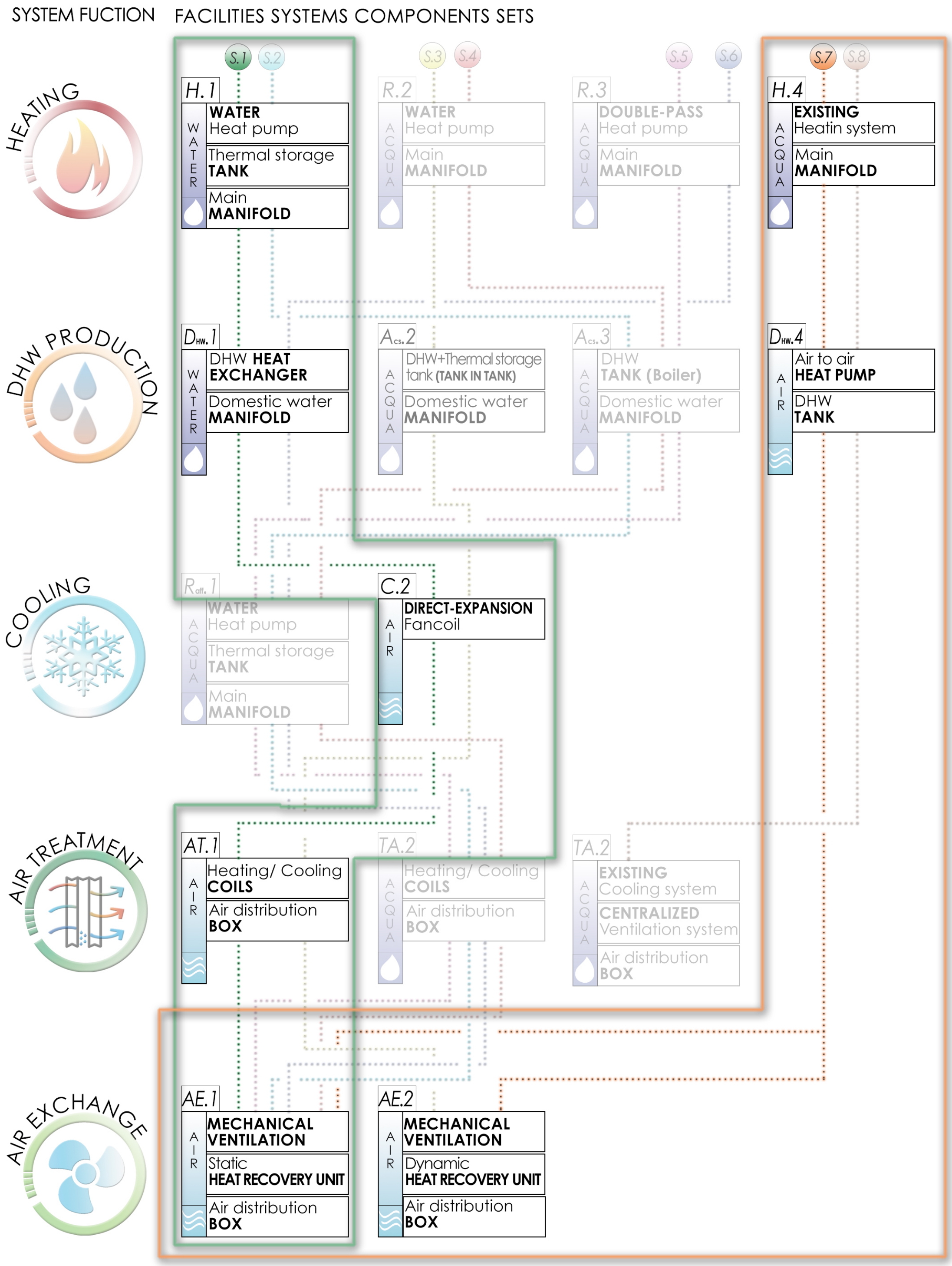
Table 4.

Thermal needs and building services sizing parameters. Summary table.

Figure 3.

The building services options analysed and the possible configurations aimed at providing heating, cooling, Domestic Hot Water and ventilation in the building models.

Table 4 displays the energy analysis results concerning two of the building models analysed: M Size and X_M Size.
For the six scenarios the types of buildings services can vary extremely according to energy demands and to exchange airflow rate calculation.
The research projects outlined eight options that can be assumed as best services nowadays available onto the market for the indoor environmental comfort and the domestic water supply (Figure 3) (ASHRAE 2006; D'Alessandris, 2011; Palmieri, 2011).
With regard to figure 3, on the left side are shown the types building services taken into account in the research project. According to the energy analysis carried out, the code S matched with a number (from 1 to 8) shows the suitable configurations planned to provide heating, cooling, DHW and air changes.
For every building model to deducing the number and the type of services to use it is necessary following the dotted line.
For example the S.1 configuration provides a hydronic heating system feed with electricity (H.1); a DHW heat exchanger connected to the thermal storage (D.1); a fan-coil (C.2 and AT.1); an electric ventilation facility (AE.1). While for cooling, air dehumidification and air exchange services the S.1 configuration provides a system (C.2+AT.1+AE.1) that integrates a two-way flow ventilation system (blowers, heat recovery unit and air plenum) and a cooling treatment on the intake air (direct-expansion coils fuelled by refrigerant gas).
Furthermore for every analysed service are identified the system features (e.g. H.1 is a service comprising a hydronic heating system, a tank for the storage and an intake manifold).
Furthermore the building service systems are classified both according to the function and to the main fluid used (gas, air or water).
Finally the S.7 and S.8 are the configurations fit for buildings with central heating systems.
Among the eight reference configurations a couple were chosen (see figure 3, the highlighted configurations S.1 and S.7). The selection was based on the requirements set out in phase 1 with regards to use stage. The former - S.1 - is suitable for independent heating systems; the latter – S.7 – (as mentioned) is


SYSTEM FUCTION
FACILITIES SYSTEMS COMPONENTS SETS
HEATING
DHW PRODUCTION
COOLING
AIR TREATMENT
AIR EXCHANGE
S.1
S.2
S.3
S.4
S.5
S.6
S.7
S.8
H.1
WATER
WATER Heat pump
Thermal storage TANK
Main MANIFOLD
R.2
ACQUA
WATER Heat pump
Main MANIFOLD
R.3
ACQUA
DOUBLE-PASS Heat pump
Main MANIFOLD
H.4
ACQUA
EXISTING Heatin system
Main MANIFOLD
DHW.1
WATER
DHW HEAT EXCHANGER
Domestic water MANIFOLD
ACS.2
ACQUA
DHW+Thermal storage tank (TANK IN TANK)
Domestic water MANIFOLD
ACS.3
ACQUA
DHW TANK (Boiler)
Domestic water MANIFOLD
DHW.4
AIR
Air to air HEAT PUMP
DHW TANK
Raff.1
ACQUA
WATER Heat pump
Thermal storage TANK
Main MANIFOLD
C.2
AIR
DIRECT-EXPANSION Fancoil
AT.1
AIR
Heating/ Cooling COILS
Air distribution BOX
TA.2
ACQUA
Heating/ Cooling COILS
Air distribution BOX
TA.2
ACQUA
EXISTING Cooling system
CENTRALIZED Ventilation system
Air distribution BOX
AE.1
AIR
MECHANICAL VENTILATION
Static HEAT RECOVERY UNIT
Air distribution BOX
AE.2
AIR
MECHANICAL VENTILATION
Dynamic HEAT RECOVERY UNIT
Air distribution BOX

suitable for central heating systems.
Note that in the S.7 configuration the cooling needs are met by the mechanical ventilation system.

3.3 DESIGN AND PROTOTYPING

Following completion the energy assessment for the six building models and the choice of the building services, the research project was focused on designing the assembly of services themselves.
The services cupboard design was basically carried out through a correlation process among the services that were selected and the requirements set out in phase 1.
As a rule the design was influenced by the following performances: durability of services; easy integration of services into the buildings; flexibility for the services to be used in different housing conditions (Attaianese, 2008).
The sizing of the building services and the study of their life stages were key aspects. Particularly the study was focused on the following characteristics:

- services weight (kg);
- services envelope (m^3);
- set up procedures (e.g. minimum space in cm around the service to permit their installation in safety and properly conditions);
- maintenance frequency (number and time of repairs and replacements);
- disposal procedures and services waste management.

In this phase a set of real building services was selected and compared to thermal and ventilation needs for each model analysed. Based on average values in terms of length, width and height, the building services were shaped and sketched-out as a simplified envelope. Further to each shaped services was associated a colour.
The cover figure - with reference to S.7 configuration - shows the services needed for the M Size building model. A number identifies a service, while a number and a letter refers to a combination of services. In particular in figure 3: 1 and 1b were matched to identifing the heating service; 2 was matched to DHW system; 3 was matched to the combination of mechanical ventilation system and cooling service; 4 was matched to space required for hosting the electrical devices. For the M model the cupboard is 2,00 m length; 0,8 m width and 2,40 m height. As shown in figure 4 the cupboard height (less than 2,70 m) makes available an easy technological integration both in the new buildings and in the existing ones.
On the whole the services cupboard design was like a Tetris® game. The cupboard envelope derives by the best combination among all necessary shapes.
An analysis and a selection of materials and components implemented the services cupboard design. Consistently to the design approach adopted for sizing and shaping the building services, the materials and components were sorted - once again - according to the requirements framework defined in phase 1.
The wood based panels were assumed as suitable solution. Such selection is the outcome of a correlation process among performances related to: mechanical resistance; life span; vibration dampen; noise reduction; embodied energy and embodied carbon used for the panelling manufacturing; production costs; distance of potential suppliers. A solid wood panelling was designed for the service cupboard shell (50 mm thickness) and for the partitioning (40 mm). Particularly the partitioning was helpful to define the cavity for store the electrical devices and the wire connections.
Based on the detailed cupboard drawings a first mock-up – named as the research project: MOTE[2] – was finally built up. To get a quickly technological assessment a couple of workshops were arranged (the number was influenced by research project duration: 18 months). The workshops were aimed at assessing the achievability of the building services design along with the materials selection carried out. During the workshops Sarotto Group laid-down to build the S Size building model with independent heating system. While the mock-up was assembled some little improvements to the previews drawings were necessary. Nevertheless the methodological approach

based on a comprehensive set of requirements to be assessed in the different design and assembling stages has shown its effectiveness and value. On the whole the difference between the design and the mock-up was trivial. In particular the S Size services cupboard dimensions (length, width and height) were comparable to the M cupboard described previously. The mock-up photo is reported in figure 4. On the left – between the shell and the partitioning – were placed the electrical devices. On the top was installed a combined service for mechanical ventilation and cooling. Finally in the central part were positioned the heating service and the DHW system.
The mock-up was 10 cm suspended from the floor in order to facilitate the handling in the construction stage (Figure 5). It was finally planned to monitoring the mock-up in order to check any critical issues that it was not taken into account in the design stage. The monitoring is on going.

3.4 THE PERFORMANCE EVALUATION

The service cupboard – once will be available for the construction market – might be included among the cutting-edge integrated building services.
The last phase of the research was focused to point out the MOTE^2's value proposition. MOTE^2 can be standout

Figure 4.

The MOTE2 mock up.

Figure 5.

The MOTE2 mock up handling after the service cupboard assembling.

among similar services for the reasons listed below:

- The service cupboard is designed bearing in mind the user needs. The cupboard service is not a ready-made solution imposed. Users chose a customised solution in cooperation with architects and technicians.
- The service cupboard is developed to reduce the on-site installation, since it is designed to be assembled off site and it is easy handling in construction yard.
- The service cupboard envelope is sufficiently strength and resistant to be used both as packaging and shell avoiding extra materials need. Thanks to its features it reduces the amount of waste to dispose.
- The service cupboard is designed to allow an easy access among services and their connections. The space enables an easy access for siting, maintenance and repairs.
- The service cupboard panelling is customizable. The wood based panel can be fixed with different cladding textures.
- The service cupboard provides optimal comfort performances at any time. Each of the configuration developed integrating services for controlling: temperature; relative humidity; air changes per hours. Thus for users indoor pollutions risks are almost completely avoided.
- The service cupboard is both an easy assembling and an easy disassembling technology. A single service can be replaced and dismantled without damaging the other services.
- The service cupboard can be relocated and revised several times. Thus it can be reused in the case of refurbishment or if it is moved to other buildings.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

The increasing demands of users for improved comfort standards and the energy requirements expected by regulations in force for all kinds of buildings are leading to a change of habits for architects and technicians. The close cooperation is a behaviour that is getting necessary for the sake of the architecture.
The MOTE^2 research project outcomes prove that an effective integration of building systems and building services is possible. The building 'designed as a whole' in the future probably will be more complicated and sophisticated but still achievable.
Further researches and developments activities on the mock-up require to be undertaken in order to validate the models.
A future research project is under development. Based on the analysis and the monitoring carried out, the achievements will lead to the construction of a prototype. Such prototype will be monitored on a residential building under construction or under refurbishment. The building will have the same features and performances described in paragraph regarding the scenario analysis.
Further comparative studies concerning the materials used for the cupboard shell and partitioning will be drawn up in order to assess other options in addition to those already taken into account.
The monitoring requires to be carried out over a period of 24 months (or more) in order to be able to assess the building thermal performances encompassing a couple of winters and summers. Such periods allows also to test the services durability and plan the their maintenance and replacement.
A proper set of energy and indicators will be also laid down to characterise properly the energy and environmental performances. More climate zones should be considered in the scenario analysis and in the energy assessment.
Finally the project aims to implementing the data available through a Life Cycle Assessment and a Life Cycle Cost, according to NZEB upcoming requirements.

NOTES

1. In compliance with Italian regulations a building with more than four apartments need to be heated with a central heating system.

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