Comfort and Energy Assessment of the First Italian Nearly Zero Energy Building in a University Campus

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ABSTRACT: The aim of the work proposed in this paper is to test and evaluate the dry stratified construction technology for building envelope in warm climate (such as in Milan, Italy), showing the actual comfort and energy assessment of the first Italian Nearly Zero Energy Building in a University campus. Analyses are conducted on the VELUXlab building, recently opened within the Politecnico di Milano (Italy). VELUXlab is an experimental laboratory coming from a deep energetic and technological retrofit done on the VELUX Atika model home. During the construction phase an innovative wireless sensors network has been installed, including 14 surface temperature sensors on the building envelope. Here is proposed a comparative analysis between the actual data recorded and the theoretical data analysed through dynamic energy simulations. Further analyses are conducted in order to compare VELUXlab data with the data of average existing Italian buildings, and with the theoretical data referring to the minimum requirements suggested by Italian regulations for new buildings.
Keywords: NZEB, thermal comfort analysis, dynamic thermal modelling

INTRODUCTION

VELUXlab is the first Italian NZEB in a University campus. It is placed in Bovisa Campus of Politecnico di Milano and it is a prototype and a case study for the future buildings. The recent European Directive 2010/31/EU states that, by the end of the 2020, all the new buildings shall be “nearly zero energy”. Actually there are no clear suggestions about these new type of constructions [1, 2], and a real example of their peculiarities and features could be a concrete way to make architects aware about the needs of a sustainable design and to provide a sample to follow. In 2011 Velux, the worldwide leader in roof windows, in collaboration with Politecnico di Milano and the design firm Atelier2, converted the demo-house Atika into an experimental laboratory with very low energy request and very high energy efficiency. Thanks to dynamic simulations it was possible to calibrate the intervention in order to minimize the energy needs of the lab, keeping as much as possible the old materials. New technological layers were added in order to optimize the building for the warm climate of Milan. The building envelope was designed as a multi-layer dry construction, based on the duo structure/envelope, and the adopted technology was studied and defined in order to represent a feasible possible solution for zero-energy buildings in Mediterranean region [3, 4]. Furthermore, during the construction phase, an innovative wireless sensors network was installed.

In this paper first results about VELUXlab behaviour are proposed, concerning both energy consumption and indoor environmental quality. A comparison between the data recorded by the sensors during the first year and the theoretical data obtained from the dynamic simulations is addressed in order to understand how much a NZEB behaviour is affected by external and unpredictable interferences. Studies show that, for other NZEBs, during their real life, due to the assumptions and simplifications of the virtual model, the energy consumed is more than the predicted one [5, 6, 7]. In this paper analyses are conducted on VELUXlab in order to quantify and evaluate the real performances of the building. This is the first step to define a nearly zero energy building optimized for Mediterranean climate through the evaluation and comprehension of its real operative performances.

BUILDING STOCK ANALYSIS

In order to comprehend which is the level of improvement introduced with the project, a comparison between VELUXlab and the existing building stock is proposed. The comparative analysis refers to CENED certificated buildings in Lombardia (a region in the north of Italy), where VELUXlab is placed, to figure out strengths and weak points of the intervention.

The European Directive 2002/91/CE was emanated with a double purpose: a reduction of the energy consumption with limited emissions of GHG and the respect of the responsibilities taken with the Kyoto Protocol, reducing at the same time the dependency of the EU from the external fossil fuel sources.

The Directive leaves the responsibility to create the certification system to a National or Regional level, because it must include, besides the building features, the peculiarities of the climate context. In Italy this Directive was transferred with the D.lgs 19/08/05 n192 and integrated with the consecutive decrees, the D.P.R 02/04/09 n59 and the D.M 26/06/09, which clarify the general criteria and the calculation methodology as national guidelines and allows each single region to refine the calculation and certification methodology. In Lombardia the decree of the general director n5796, 11/06/2009 introduces the CENED certification system. This protocol defines and classifies the buildings performance. Since in Milan there are almost the 40% of the buildings already certified in Lombardia (Fig. 1), a wide database to compare VELUXlab is available, thus making the analysis more feasible and relevant.

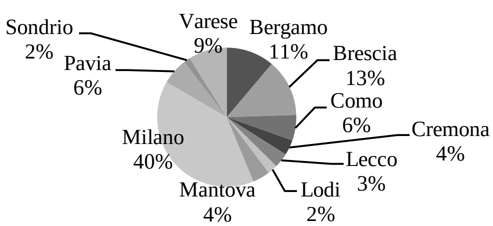

Figure 1: Percentage of certified buildings for each province related to the total number of certifications (data source: CENED, Italy, Updated May 2013).

The certification system defines 8 energy classes (from A+, low energy consumption, to G, high energy consumption) to classify the buildings by their energy performances. It contemplates all the consumptions for heating, hot water production, indoor ventilation and lighting needs (lighting only for commercial buildings). Energy classes are certainly easy tools for a quick check of buildings performances, however the best classes don't always correspond to an environmental conscious design. The design process should be measured and calibrated on the specific needs of every case, balancing the consumption, the requests and the context.

More than half of the certified residential buildings are G classified and more than 34% of certified offices buildings are in the same category (Table 1); this is the lowest category possible and it means that, referring to the Italian E climate zone, the building primary energy need is more than 175 kWh/m^{2}a for residential buildings and more than 65 kWh/m^{3}a for non-residential buildings. Less than 3% of the certified office buildings are included in a B or a superior class (Table 1). VELUXlab, with its primary energy need of 3.82 kWh/m^{3}a, is certificated as A class, thus representing a best practice of designing in this sector; compared to the building stock it is one of the few examples of very low energy office buildings (only 0,56% of the certified office buildings are in A class).

Table 1: Percentage of buildings in each energy class divided for destinations for Lombardia region (northern Italy), I-bars, restaurants and dancing rooms; II-cinema and theatres; III-colleges and convents; IV-hotel and pensions; V-factories and handcraft activities; VII-scholastic activities; VIII-health activities; IX-offices; X-residences; XI-museums and religions activities; XII-sport activities.
(data source: CENED, Italy, Updated April 2013)

	Classes for destinations [%]							
	A+	A	B	C	D	E	F	G
I	0.02	0.20	0.94	3.90	4.51	4.10	5.27	81.06
II	0.00	0.31	3.42	9.63	9.32	6.21	10.87	60.25
III	0.00	1.50	3.00	12.00	16.50	14.50	12.50	40.00
IV	0.66	3.30	12.06	10.98	11.97	11.07	12.55	37.41
V	0.04	0.28	1.59	5.94	8.48	9.74	13.49	60.43
VI	0.05	0.18	1.17	9.24	17.96	14.95	15.36	41.09
VII	0.33	1.37	2.80	10.16	11.85	10.48	11.39	51.63
VIII	0.71	2.48	9.20	23.89	20.00	14.34	10.62	18.76
IX	**0.12**	**0.56**	**2.33**	**10.14**	**19.29**	**16.93**	**15.90**	**34.73**
X	0.12	0.75	5.53	7.40	9.62	11.73	13.18	51.67
XI	0.00	1.00	4.33	12.33	10.67	6.33	7.33	58.00
XII	0.00	0.37	1.92	10.82	9.35	6.87	7.33	63.34

Even compared to the thermal transmittance values of the existing building stock for offices building in Milan (Table 2), VELUXlab represent an interesting and unique example of high energy efficient building. In Table 2 are illustrated in detail the U values that have been also used for the following dynamic energy analyses (see Dynamic Energy Analyses and Monitored Data paragraph for further details). The average values have been estimated weighting the U values on the corresponding energy loosing surfaces.

Table 2: U values (W/m^{2}K) for OF-offices in Milan; VL-VELUXlab; LM-law minimum. These values are the basis for the energetic models.

		U shell [W/m^{2}K]	**U window** [W/m^{2}K]	**U basement** [W/m^{2}K]	**U roof** [W/m^{2}K]
OF	Ave	1,21	3,78	1,21	1,07
	Max	3,59	5,98	2	2,2
	Min	0,11	0,86	0,1	0,1
LM		0,27	1,8	0,3	0,24
VL		0,124	1	0,214	0,133

The U values limits here proposed (Table 2) refer to the most severe and recent Italian regulations on energy retrofit for existing building, having in this way a high quality reference for the comparisons. VELUXlab can be considered as a high quality and low energy building related to the existing building stock (Table 1 and 2). In the following paragraphs VELUXlab energetic and comfort related aspects are analysed in detail.

DYNAMIC ENERGY ANALYSES AND MONITORED DATA

In the previous paragraph VELUXlab building has been compared to the existing building stock in Milan area. In this paragraph preliminary energy and internal comfort assessments are conducted.

Thanks to the innovative wireless sensors network installed within the building during the construction phase and thanks to the weather data collected from the weather station installed on the neighbour building, it was possible to simulate and test VELUXlab real performances. VELUXlab read data are compared to the results of the simulation obtained both for VELUXlab "As Built" model and VELUXlab "Common Practice" ad "U limit" models. While the "As Built" model replicate the real VELUXlab both for the construction technologies and the HVAC system, the VELUXlab "Common Practice" model uses the most diffuse (in Italian building stock) massive construction technology with average U values (Table 2); the VELUXlab "U Limit" uses a common massive technology (bricks wall and concrete slab) with U values taken from law restrictions (Table 2). The dynamic energy analyses are conducted with TRNSYS [7] software using as weather data file an had-hoc file created with the weather station data, in this way the real data can be much more compared to the simulation results.

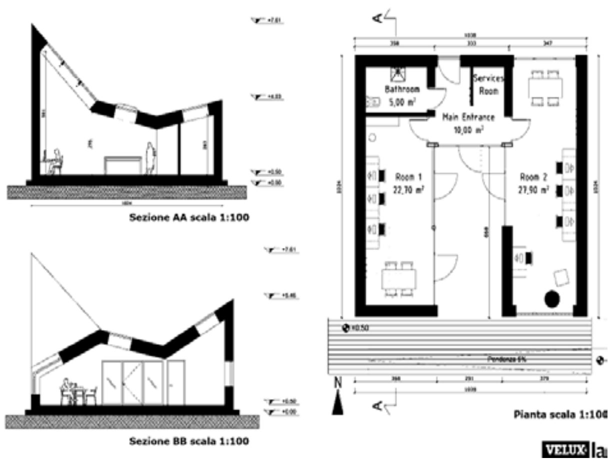

Figure 2:Plan and sections of VELUXlab building (out of scale)

HEATING ENERGY DEMAND ANALYSIS

In order to understand how much the envelope can influence the thermal performance of a building and to evaluate the benefits of the dry-construction technology in warm climate analyses on the heating energy demand in different conditions are addressed. The comparison is made for different energy models, where the envelope is changed. The geometric model used for the simulations refers to VELUXlab building [3,4] and the analyses are made only on the west room (Figure 2), where the wireless sensors network is installed. This choice was led by the intention to compare these results to the monitored data, as soon as an adequate number of values will be collected.

The analyses show the dynamic sensible energy flow through the envelope per square meter of internal floor area, from October 15th to April 15th (Heating days for Italian E Heating Zone) (Fig. 3). They are based on the hourly average energy flow values calculated with TRNSYS software for each model. The building stock database supplies the U values for the comparative case studies:

- As built: the envelope is based on the real construction;
- Common practice: the envelope is based on the common construction practise in Lombardia region, Italy (average values in Building Stock paragraph);
- U Limit: the envelope elements have the U values as by Italian energy regulations (see Building Stock paragraph for further details).

In these models an ideal HVAC system is simulated.

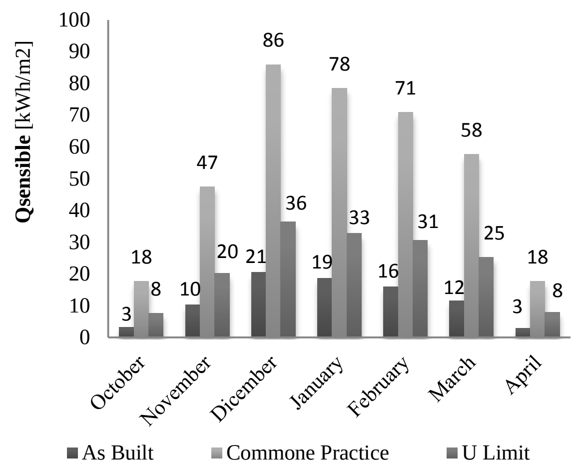

Figure 3: Representation of the energy demand for different envelope technology

VELUXlab (as built) has the best energy performance compared to the other solutions: the envelope's high thermal resistance reduces the energy demand by 50% compared to the limit fixed by standards. Common practise's consumption are very high and far of the limit range.

LOCAL THERMAL COMFORT ANALYSIS

Local thermal comfort analysis is addressed to determine indoor comfort level referring to European Standard EN ISO 7730 by evaluation of daily mean operative temperature. The analysis refers to the heating period, starting from 15th October to 15th April, and is based on ambient and surrounding surfaces temperature data. A comparison between the recorded actual data and the theoretical data is proposed, in order to see how indoor comfort varies depending on the envelope technology and on the simulation limits. Theoretical data has been analysed trough dynamic simulations in three different situations:

- As built: based on the real construction
- Common practice: based on the average identified in the building stock analysis
- U limit: based on the values identified in the Italian standard (Building Stock Analysis paragraph)

During the monitoring campaign, gaps and detection errors were recorded, due to occasional malfunctions of the ad-hoc wireless sensors network [3,4]; for this reasons some of the data collected were excluded.

Operative temperatures have been evaluated referring to European Standard EN ISO 7726 in two different points of the room (Figure 4):

- Point 1: 1m from the west opaque wall, corresponding to workstation
- Point 2: 1 m from the east window

Both of them have been located at 1m above the floor (corresponding to a standing person centre height) and in the middle of the longitudinal length.

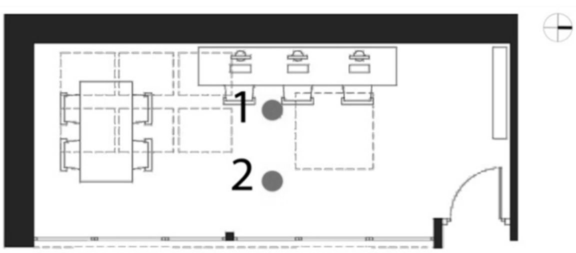

Figure 4: Location of points 1 and 2 for the operative temperatures evaluation in the room.

The daily mean of internal operative temperature is compared to the three comfort classes suggested in standard EN ISO 7730 referring to a "single office" use. Since the room has been habited throughout winter and the users preferred to set up the thermostat room temperature at 20°C, even if the standard suggests an inside air temperature of 22°C for offices space, in this analyses a 20°C set point has been considered.

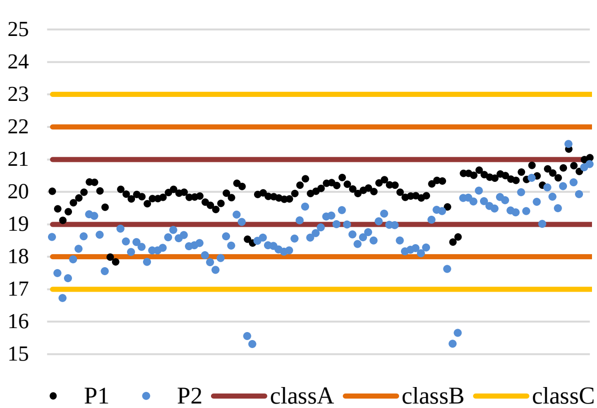

Figure 5: VELUXlab thermal comfort analysis: daily operative room temperature at Point 1 and Point 2

The analysis on local thermal comfort based on recorded actual data shows a prevalent concentration (94%) of the daily operative temperatures in Point 1 within the range corresponding to class A, equivalent to a percentage of satisfied people higher than 95% (Figure 5) . These results confirm the expected thermal performances of the envelope which was designed according to the criteria of high thermal resistivity. A considerable difference has been recorded for Position 2, where only the 37,5% of daily operative temperatures are included in class A and some of the values are even out of class C.

Indeed, surface temperatures recorded on the windows are usually about 2°C less than the others on the opaque enclosures. Therefore, the analysis highlights the importance of the radiant exchange between a person and the surrounding surfaces on the real perceived temperature and, accordingly, on the comfort level. Despite the excellent achievements in windows thermal performances, it is evident that glass surfaces are still a very critical element in buildings envelope, especially in high insulated buildings (where the surface temperature of the opaque component is uniform and closer to air temperature).

The same analysis has been addressed with theoretical data. Although daily operative temperatures at Point 1 are always higher than those at point 2, the differences between these two points are not as relevant as for actual operative temperatures.

This is probably due mainly to software limits in simulating windows thermal behaviour and this is also evident comparing Point 2 real and "As Built" results. In Table 3 results of "As Built" simulation seem to be better in Position 2: temperatures on Point 1 are sometimes higher than 21°C so they overcome comfort class A (Figure 5).

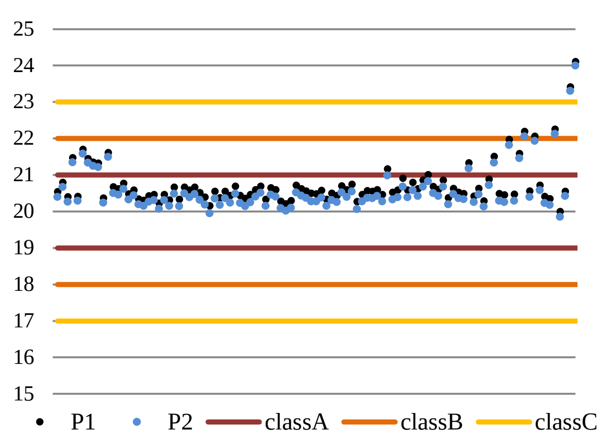

Figure 6: "As built" thermal comfort analysis: daily operative room temperature at Point 1 and Point 2

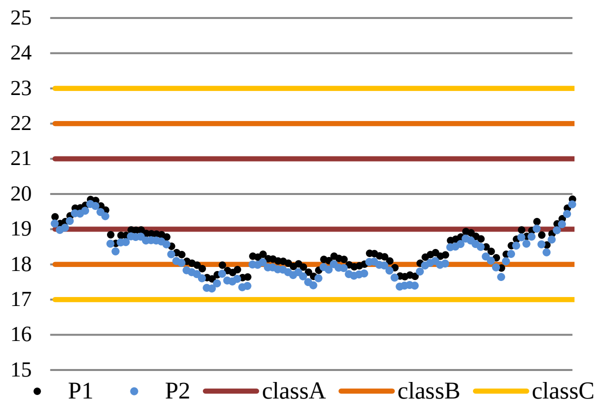

Figure 7: "Common practice" comfort analysis: daily operative room temperature at Point 1 and Point 2

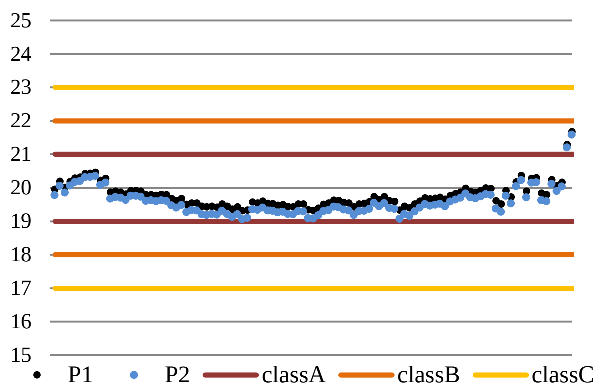

Figure 8: "U limit" thermal comfort analysis daily operative room temperature at Point 1 and Point 2

Table 3: Frequency of values included in the three classes

VELUXlab – actual data			
class	range	% freq P1	% freq P2
A	19-21	94,23%	37,50%
B	18-22	98,08%	84,62%
C	17-23	100,00%	93,27%
As built model			
class	range	% freq P1	% freq P2
A	19-21	94,23%	95,19%
B	18-22	97,12%	97,12%
C	17-23	98,08%	99,04%
Common practice model			
class	range	% freq P1	% freq P2
A	19-21	16,35%	14,42%
B	18-22	75,96%	53,85%
C	17-23	100,00%	100,00%
U limit model			
class	range	% freq P1	% freq P2
A	19-21	99,04%	99,04%
B	18-22	100,00%	100,00%
C	17-23	100,00%	100,00%

Finally, a comparison between recorded and theoretical results highlights that common practise technologies are not able to guarantee an acceptable level of comfort during the heating period, which is instead performed by high insulated technologies and those suggested by Italian regulation.

HVAC SYSTEM BEHAVIOUR ANALYSIS

The analysis aims to evaluate VELUXlab envelope ability to preserve a specific thermal environment when indoor conditions are changed. Furthermore, a comparison between the recorded actual data and the theoretical data is proposed, in order to evaluate not only the differences between simulated and real data referred to the same technology, but also to underline the influence of different technological solutions on the envelope behaviour.

Temperature and humidity has been monitored from 18th February to 1st March by an electronic hygro–thermometer located in the centre of the west room (Figure 2) at about 60 cm above the floor (corresponding to a seated person centre height), every day from 7:30 am to 7:30 pm with 30 minutes time step.

On the 18th the heating system was switched-off until the minimum value of temperature was recorded; than the system was switch-on and data has been collected until ambient temperature reached 20°C value (set point temperature).

Theoretical data has been analysed trough dynamic simulations in three different situations:

- As built: based on the real construction (low transmittance, low inertia)
- Common practise: referred to the average identified in the building stock analysis (high transmittance, high inertia)
- U limit: based on the values identified in the code (good transmittance, high inertia)

The heating system was scheduled and modelled according to the real test method, with a switch-off of the HVAC system from February the 18th at 7:30am to February the 25th at 8:00am, and a new switch-on from February the 25th at 8:30am to March 1st at 7:00pm. During the 22nd, 23rd, and 24th of February the laboratory was closed, so no data were collected. The data show in Figure 9, illustrate the daily average indoor air temperature trend for the different models studied.

The analysis on real data shows that the indoor temperature quickly decrease to the minimum recorded value (12°C) in three days, but at the same time just one day is required to increase to 18°C and other three days to reach the set point value (about 20°C). A similar behaviour is observed on "As built" model: the low envelope inertia involves, on one side, a sudden decrease of the indoor temperature after the system is switched off but on the other side a fast increase, also guaranteed by its high resistivity, when it is switched on. "Common practice" reveals the worst behaviour: although common buildings are based on inertial technology, the transmittance values are very high and the envelope easy dissipates the heat stored. Finally, the "U limit" model seems to show the best behaviour: inertia allows ensuring a gradual decrease of temperatures and low transmittance preserves the heat stored inside. While for VELUXlab building and for the "As Built" model a radiant floor heating system was modelled, for the other two models an all-air HVAC system was modelled. Thus the results on the re-activation of the system have probably been influenced: air temperature increase quickly due to non-inertial heating system and higher specific heating power. For this reasons, apparently, the "Common Practice" model has a daily average air temperature on the 25th higher than the other two models. Results show interesting value of a dry technology construction compared to inertial technology buildings; however deeper analyses need to be conducted on this behaviour. Limits of these studies are indeed on the method adopted: simulations have been performed according to the real test and the system was scheduled to restart when it actually was switched on. Different results are expected performing simulations where the system is restarted only when the lowest temperatures are reached and with different HVAC system modelled. Due to the inertia of the envelope, a slow increase of the indoor temperature is expected, while VELUXlab results show a fast increase in just one day. Since the inertial envelope behaves as an energy store, while on one hand it allows to mitigate temperatures decrease, on the other hand, when the system is restarted, the energy provided will not have an instant influence on the indoor temperature but will be first stored in the envelope. **Further** studies need to be carried out in order to test also the heating power requested to re-set the internal comfort conditions and to model different HVAC systems on different realistic offices spaces occupancy schedules: as well as summer analysis are needed to complete the assessment.

CONCLUSIONS

The work presented is the first step of a deep research about nearly zero energy buildings in warm climate such as Milan (Italy). VELUXlab is the perfect prototype for this inquiry, because it is a real case study designed to be tested and monitored. The first results are really encouraging about its capability to answer well and instantly to the external thermal stress, furthermore, as it is shown in this paper, thermal comfort and energy savings are two different aspects but contribute harmoniously to the same purpose. Further analyses need to be carried out in order to compare summer monitored data with the simulated one and to obtain a more precise overview on the possible benefits in using a dry construction technology in Mediterranean climate. In addition it is necessary to compare also the monitored data of the HVAC system in order to understand better the real energy need of the building and the occupant interaction as well as the HVAC response in a warm climate with different construction technologies. This work can be considered as a basis for future analyses on the building, testing more dry construction technologies in warm climate.

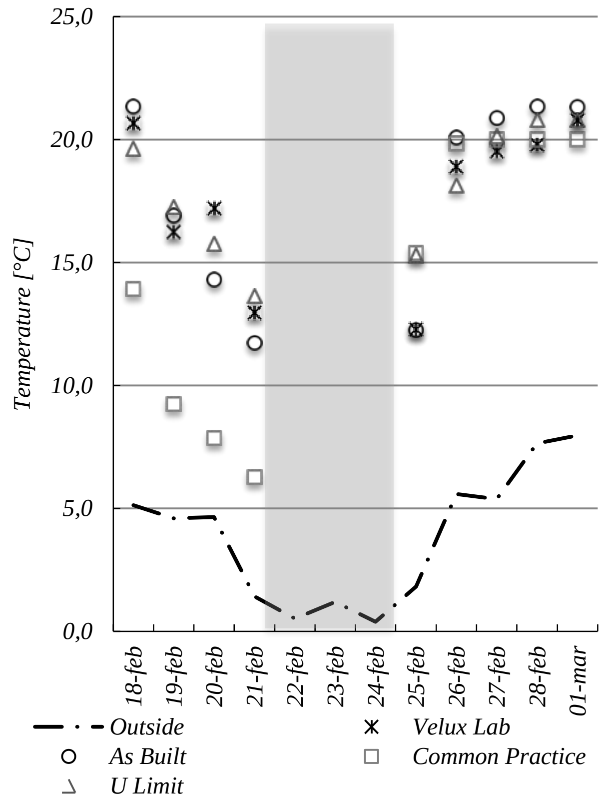

Figure 9: Indoor temperatures trend (average daily temperature): actual monitored data and theoretical data

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