

Paper No. 651: Towards Zero Energy Renovation: Ex-Post Building in Bolzano/Italy

Alexandra Troi¹, Michael Tribus², Andrea Costa¹, Walter Haberer³, Davide Parisi⁴,
Wolfram Sparber¹

EURAC Research, Drususallee 1, 39100 Bozen, Italy^{1}*
alexandra.troi@eurac.edu

Michael Tribus Architecture, Schießstandgasse 9, 39011 Lana, Italy²
Amt für Energieeinsparung, Mendelstraße 33, Bozen, Italy⁴
Technisches Studio dP, Carducci-Straße. 10, 39042 Brixen, Italy³

Abstract

For the relocation of the Environmental Department in Bolzano/Italy the three-storey ex-post building was enlarged with two storeys and refurbished with the goal to reduce heating demand from 200 to 7 kWh/m²a.

The envelope with small, regular window was refurbished as an ETIC system with 35cm of EPS-insulation. The window reveals were used for an aesthetically charming and at the same time functional solution, which enlarges lateral views and optimises daylighting and shading. This gives the façade a distinguished and lively appearance. The HVAC system guarantees optimum air quality also with closed windows (noise due to railway station and through road), whereas in each office the air can be thermally post-treated in order to take account of different locations and orientation. A green roof provides valuable unsealed surface in the city centre and mitigates summer climate in the last floor. The SE-facing staircase is covered with photovoltaic panels (26.7 kWp).

A monitoring system, registering heat, electricity and gas consumption for different floors and zones and discriminating electricity demand for different uses, allows not only to verify the overall performance, but also to analyse the influence of parameters as location, orientation and user behaviour. Evaluations of energy consumption, indoor temperature and humidity have been carried out and show satisfying results. Energy consumption is slightly above the design values but some optimisation measures could already be identified.

Keywords: energy refurbishment, indoor comfort, monitoring, post-occupancy evaluation

1. Building description

For the renovation of an existing institutional building built in 1954, two stories had to be added to the existing three stories. The heated surface – as calculated with the Passive-House-Planning-Package software – amounts to 2'841 m² for an inner volume of 12'817 m³. Due to the large wall insulation the net heated area can vary substantially if calculated with different software: in our case, it would amount to 3'366 m², if calculated according to the governmental regulation in force [1]. This is important for the comparison of the specific yearly heat demand.

The site between railway station and a through road asked for special attention to acoustic issues and severe microclimate in summer. The central location, however, makes the building highly visible and sort of a lighthouse for the reconciliation of architectural ambition, energy efficiency and innovation.

The building was certified as Klimahaus Gold according to the regional rating scheme, with a calculated energy demand of 7 kWh/m²a according Klimahaus calculation. Furthermore the

building has been calculated with PHPP (passive house planning programme, provided by Passivhausinstitut Darmstadt) to an energy demand of 10 kWh/m²a.

Two years for design and project completion were allowed by the contractor and the budget was set very tight, being the renovation paid by public funds.

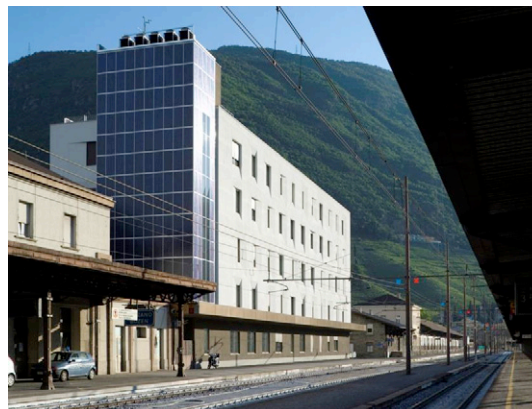


Fig 1. View of the refurbished building from the station

1.1 Building site

Bolzano is situated within the Alps in the north of Italy, at a height of 265m above sea-level. The climate is characterized by quite harsh winters but also hot summers. Heating days amount to 194, heating degree days to 2736 respectively [2]. In fig.2 the average monthly outdoor temperatures, both as long term mean and for the investigated period [3], as well as the average daily irradiation for each month [4] are shown.

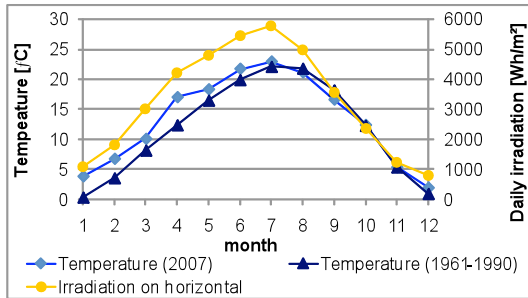


Fig.2 Average monthly temperatures (source [3]) and average daily irradiation (source PVGIS [4]) in Bolzano.

1.2 Building envelope

The building shell is designed as an ETIC system with 35 cm of EPS insulation, reaching a U-value of $0.08 \text{ W}/(\text{m}^2\text{K})$. The facade arrangement of the existing structure, with a low window fraction of 16 %, was kept for cost reasons, and was also extended to the added-on stories. The result of these two measures is a minimisation of transmission heat losses in winter and overheating in the summer. Technical and urban design-related issues in the existing building did not permit a substantial insulation of the foundation and the fire escape stairwell. However, this drawback did not compromise the overall performance of the envelope due to the large dimensions of the building.

The material thickness of the building insulation allowed an aesthetically charming play with the window reveals, also dictated by functional considerations. The latter are open diagonally to the side or upwards - depending on the position and orientation - in order to maximise the view or to optimize the incidence of light. In the upper stories, however, the upper reveals remain conventionally horizontal to provide the necessary shading and prevent overheating. Taking into account the loss of insulation material caused by the beveled reveals the walls are comparable with a straight wall with 28 cm insulation. The resulting U-value of $0.1 \text{ W}/(\text{m}^2\text{K})$ represents no significant weakening of the insulation shell.

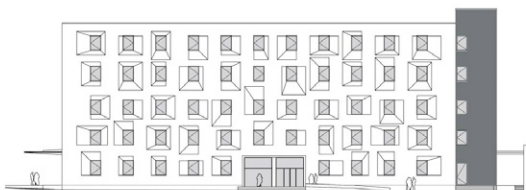


Fig 3. Concept of façade structure – play with window reveals



Fig 4. Detail of realised Façade

The windows are of the 3-pane type with plastic frame, insulated in the sunscreen plane with polyurethane. The result is passive-house suitable windows with a U-value of $0.79 \text{ W}/(\text{m}^2\text{K})$. Part of the southeast facade is plastered with 220 m^2 of photovoltaic panels with an output of ca. 27 kW peak. The yearly yield makes up for more than 10 % of the overall power consumption in the building.

The airtightness of $n_{50}=0.6$, as required for a passive house according to PHPP and Passivhausinstitut, was confirmed by blower door measurement.

A green roof provides valuable unsealed surface in the city centre and mitigates summer climate in the last floor.



Fig 5. Extensive green roof of the building

1.3 Daylighting

The interior of the building was gutted completely. An interior spacious lounge area, which serves as a waiting and reception area for the new agencies represent the core of each story and provides direct access to and between the individual offices. The receptionist offices on the front side are totally glazed to the interior. Daylighting of the building core is ensured by skylights implemented in the internal office walls and leads to energy savings for lighting especially in the upper stories. On the contrary, at evening the electric illumination of the hallways has a support function for the sensor-controlled illumination of the workplaces, thus reducing the overall electric load.

3. Results

The building was inaugurated in spring 2006. The measurement campaign started in July and is still ongoing. As described above, the emphasis was placed on energy consumption as well as on thermal comfort and air quality.

3.1 End-user demand

Fig 8 shows the overall yearly energy demand and consumption for heating and cooling broken down in monthly values.

Fig 8. Monthly energy demand and consumption for heating and cooling (2007)

The heating demand summed up to 69'851 kWh¹, which led to a specific consumption of 24.6 kWh/m²a. The cooling demand was covered by a central air dehumidification and a decentral air-cooling system. The former – performed by a compression cooling machine – amounted to 64'258 kWh², whereas the latter – provided by absorption chillers – reached 70'974 kWh³. The total specific energy demand for cooling summed up to 47.6 kWh/m²a.

The power consumption is depicted in Fig 9 but it must be noted in advance that the data for February had to be partly extrapolated due to the recording failure in the second half of the month. The consumption base load was formed by lighting⁴, ICT⁵ and DHW consumption with 69'811 kWh, 24'710 kWh and 3'817 kWh, respectively. Building services such as pumps, fans and control devices (126'441 kWh) were quite constant through the year but with increased demand in the winter months. Last, the dehumidification work accounted for 18'325 kWh⁶,

¹ measured with heat counter (mw216)

² not directly measured, but calculated from electricity counter (mw7), with COP of 3.5

³ not directly measured, but calculated from gas counter (c98), assuming 10 kWh_{th}/m³ and an average COP of 0.65. The sum of the cooling demand of the single fan-coils amounts, however only to 14'588 kWh. The high discrepancy can most probably neither be attributed only to losses in the cold storage and distribution, nor to a very low COP of the absorption chiller in part load behaviour, but will be subject to further analysis.

⁴ might include ICT, if not plugged to UPS

⁵ all appliances plugged to UPS

⁶ measured with electricity counter (mw7)

with the obvious concentration in the summer months. It has to be noted that for a primary energy discussion the dehumidification demand must be weighted with the conversion efficiency of a power plant; this is discussed further below. The total specific electric consumption resulted hence in 85.6 kWh/m²a.

Fig 9. Repartition of monthly electrical power consumption by uses (2007)

3.2 Primary energy consumption

The overall power consumption summed up to 243'103 kWh. The photovoltaic field has produced ca. 18'000 kWh. This value is calculated on the base of a façade-mounted system with 45° southwest orientation for the region of Bolzano. The purchased power was therefore reduced to 225'103 kWh. With an assumed conversion efficiency of 33.3 % for the power plant mix the consumption translates to 675'309 kWh of primary energy.

The natural gas consumption for heating was measured at 6'007 m³ whereas the consumption of the absorption chillers amounted to 10'919 m³. With an assumed energy content for natural gas of 10 kWh/m³ the corresponding primary energy consumption would be 169'258 kWh. Hence, the total primary energy consumption amounted to 844'567 kWh. The corresponding specific primary energy consumption results in 297 kWh/m²a.

3.3 Influence of indoor temperature on heating demand

The observed temperatures were throughout the monitoring period higher than the 20°C (assumed both in the PHPP and Klimahaus calculation). A recalculation of the heating demand with PHPP for the observed average temperature of 22.2°C leads to a 5 kWh/m²a higher heating demand.

3.4 Indoor comfort

As mentioned above temperature and relative humidity have been measured throughout the building. In order to quantify the level of comfort, those data have been plotted in temperature/humidity diagrams containing two “comfort windows” according to Leusden and Freymark [5]. The building shows a long and small shape (ratio: 3.3) along a northeast/southwest axis. Rooms on the southwest side were therefore compared to offices on the other side to detect possible effects due to orientation.

In winter no substantial differences were detected with all measurements within the boundaries of the comfort zone, as shown in Fig 10 temperatures ranged between 20.5°C and 23.5°C with the rel. humidity between 25 % and 50 %.

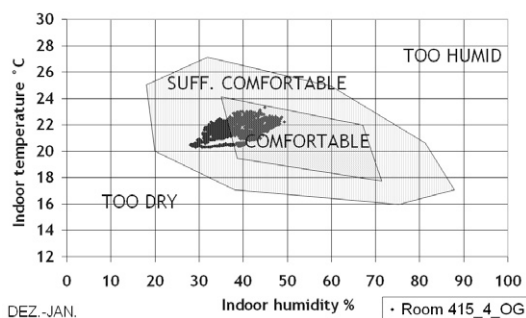


Fig 10. Temperature/humidity in winter, Room 415

The situation in summer is more diversified as shown in Fig 11 to 15 for some offices on the 4th floor. Room 415 is a large office with 4 co-workers, 2 server stations and 2 PCs. Due to the high internal loads the comfort could only be ensured for roughly half of the time, with temperatures reaching almost 27°C.

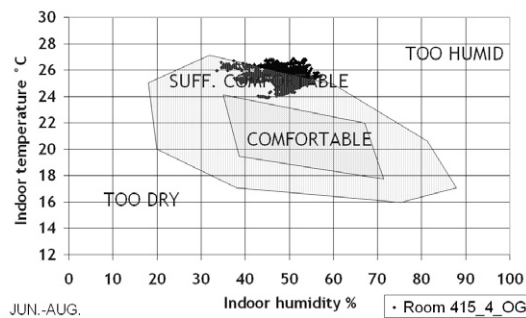


Fig 11. Temperature/humidity in summer, Room 415

Rooms 408 and 401 also show similar patterns with roughly 1/3 of the values outside of the comfort limits. The two rooms are situated on the southwest and northeast side, respectively, and give place to 2 and 3 people for a density of 11 m²/person and 9 m²/person, respectively. Also in this case it seems that the high internal gains are responsible for overheating rather than solar irradiation. Lastly, room 414 on the southwest side and room 403 on the opposite side are exemplary. Both show values completely within the comfort limits and both are single offices with a density of ca. 17 m²/person.

Fig 12-15. Temperature/humidity in summer, Room 408, 401, 414, 403

3.5 Indoor air quality

Additionally to the monitoring, the indoor air quality has been tested following a standard procedure by the governmental health care office of South Tyrol [6]. Several offices spread across the building have been randomly tested in December 2007. Temperature, humidity, carbon dioxide and bacterial charge have been examined. The average air temperature was with 22.8°C fully comfortable. Relative humidity was rather low (38.3%) but still in the comfort window. Carbon dioxide (707 ppm) and the two bacterial charges tested (106 and 38 UFC⁷) were rated as low, confirming the high efficiency of the air heat exchanger and the air filters used.

⁷ UFC: units forming colonies

4. Conclusion

4.1 Energy consumption

The design goal to attain a full passive house standard was not completely fulfilled, most probably due to the reduced insulation layer in the basement. Moreover the indoor temperatures chosen by inhabitants tend to be above design value. Nevertheless, the renovation represents more than a factor 8 in heating savings compared to the original building.

The cooling demand remains with 47.6 kWh/m²a (i.e. ca. 40 W/m² in the Bolzano climate) rather at conventional levels. This is not surprising due to the implementation of conventional cooling strategies and lacking passive or hybrid cooling strategies such as night ventilation or evaporative cooling. Also the rather high internal loads caused by conventional lighting and ICT have most probably contributed to the high cooling load. Further analysis will also explain the large discrepancy between gas consumption and cooling energy finally delivered by fan-coils – the consumption might result to be better than it now appears to be. Nevertheless, the successful implementation of passive-house suitable shading guidelines is demonstrated by the practically equal indoor temperatures measured in northeast and southwest office rooms.

The building overall energy consumption seems to be biased towards electric power consumption. Beside the high lighting load, also the consumption for technical services was quite high, with a surprising increase during the winter months. The rise was related to increased fan consumption in the AHU while operating in “heat recovery” mode, which in turn would suggest too high pressure drops in the AHU or, in other words, a too small AHU. These consumption facts reflect the decision of the investor to build very cost-efficiently, as discussed further below.

The primary energy consumption is with 297 kWh/m²a far above the limit set by the Passive House Institute (120 kWh/m²a). A reduction of a factor 2 in lighting and services consumption, the reduction of the heating demand to passive house levels (15 kWh/m²a) and a reduction of a factor 3 for cooling (down to 15 kWh/m²a) by means of lower internal loads and passive cooling techniques would lower the overall specific consumption to 130 kWh/m²a, thus not far from the objective. Whereas some of these options are realizable only with an early-stage integrated design planning of the building, others, such as low-energy lighting or ICT, or the introduction of manual or semi-automatic night ventilation procedures may be implemented at low cost with positive results. Particularly the adaptation of the system control on the basis of monitored data will allow for low-cost optimisation, as was shown for other buildings with complex energy systems [7].

4.2 Indoor quality and construction cost

The good indoor air quality has been confirmed by the monitored data as well as by the independent measurement of a governmental body. Merely the values for relative humidity in

winter were at times around 25 % and may be worth to be increased in the future by means of a stronger air humidification.

The net construction cost of the renovation, including monitoring, roof design, and photovoltaic unit, has been assessed to 241 €/m³ by the architect. Despite this exceptionally low specific investment the high-efficiency facade and heat recovery could be implemented, as well as a green roof and a 220 m² (27 kWp) photovoltaic field. The additional cost for the high-grade building envelope amounts to 3 % compared to a renovation according to the building code in force at the time of construction. The projected cost comparison – based on design values – show convincing results: A renovated building of this size in passive-house standard (assumed 10 kWh/ma) consumes heating energy for a corresponding annual cost of € 4,100. This compares with the 220 kWh/(m²a) average for heating of existing buildings, with corresponding savings in the order of € 86,000 per year. Related to the extra-cost for energetic refurbishment (3-pane windows instead of 2-pane windows, better insulation) of 190'000 €, these savings lead to pay back time of less than three years. Compared to the “Klimahaus C” standard of 70 kWh/(m²a) for heating, which has meanwhile become the minimum standard in South Tyrol, the incremental construction cost for the passive-house building would amount to € 130,000. However, with an estimated yearly energy savings of € 25,000 compared to a Klimahaus C, the passive house would pay back in 6 years.

Even with the measured, slightly higher heating energy demand, the back back time compared to Klimahaus C is still below 7 years – not taking into account, that (i) the higher demand is in part also due to indoor temperatures above design values, which would rise demand accordingly also in a Klimahaus C and (ii) the calculation has been done with 2007 energy prizes which are very likely to rise considerably. The renovation project can therefore be rated as a success from an economic standpoint of view, as well.

5 References

- [1] Ordinance for Energy savings, Nr. 341, 2004, Province of Alto Adige, Bozen 2004
- [2] Klimahaus-Berechnungsprogramm v2.1
- [3] Hydrografisches Amt, Autonome Provinz Bozen (2007), Klimareport 2007
- [4] PVGIS, online calculation of radiation re.jrc.ec.europa.eu/pvgis/apps3/pvest.php#,
- [5] Leusden, F. P. und Freymark, H.: Darstellung der Raumbehaglichkeit für den einfachen praktischen Gebrauch. GI 72, (1951)
- [6] Servizio igiene della Provincia Autonoma Bolzano (2007) relazione tecnica sul monitoraggio microbiologico dell'aria interna effettuato in data 7.12.2007 presso l'edificio passivo Exposta sito a Bolzano in via Renon 4
- [7] A. Napolitano, A. Troi, W. Sparber (2007). Monitoring activities for the optimization of a trigeneration plant including a solar heating and cooling system. 2nd Int. Conf. SolarAir-Conditioning Tarragona