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A case study of industrial building energy performance in a cold climate region in a developing country

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Abstract: Most industrial buildings in developing countries such as China have excessively high energy consumption, and the portion used by HVAC systems is significant. This investigation used a winery building in a cold region in northern China as a case study to analyze industrial building energy performance. A lack of communication, cultural differences in design requirements, and poor construction quality were the primary factors that led to excessive air leakage, insufficient building insulation, and poor indoor air distribution. This investigation developed a set of methods to evaluate building energy use, air leakage, condensation, thermal insulation, and indoor air distribution. A number of remedial measures were proposed, and some of them have been proven to be effective. In developing countries such as China, the lessons learned in this project will be useful for designing and constructing energy-efficient industrial buildings with desirable indoor environments.

CE Database subject headings: Industrial facilities; Energy consumption; Air leakage; Condensation; Insulation; Temperature distribution

Introduction

Both the number and construction speed of industrial buildings in China are among the highest in the world, especially in the last decade. The National Bureau of Statistics of China reported that the floor area of industrial buildings completed in 2012 was about 516,995,000m^2, nearly twice that of 2004 (National Bureau of Statistics of China,2013). Industrial buildings have consumed more than 7% of the total primary energy in China every year since 2006 (Xu, 2013; Wang et al., 2010). About50-55% of the energy (Wang et al., 2010; Zheng et al., 2005) was consumed by the heating, ventilating, and air conditioning (HVAC) systems of the buildings in providing a suitable indoor environment. The percentage in developed countries can reach 65% (Yaoet al., 2005;Lamet al.,2008) because of a much higher thermal comfort requirement. Similar problems can also be found in other developing countries. Therefore, both designers and building owners seek to reduce the energy consumption of HVAC systems while maintaining acceptable indoor environmental conditions. Buildings in China vary greatly in type, function, and size, and there are no national standards to serve as design guides for energy conservation in industrial buildings.

Most of the HVAC-related energy loss in industrial buildings is by infiltration and through the building envelope (Jokisaluet al., 2002). Kalamees (2007) estimated that infiltration accounted for about 25% of the heating loads in industrial buildings in the United States. Binamu (2002) found that this portion could be as high as 53%.Wu et al. (2010) determined that infiltration contributed 36.6% of the total heating load in an electrical equipment factory in Harbin, China. Infiltration can also cause condensation problems, as found by Lucaset al. (2002), which can lead to microbial growth in insulation materials and a sharp decline in their thermal resistance. Janssens and Hens (2003) concluded that, even if a roof design complied with condensation control standards, a light weight system could still be sensitive to condensation because of air leakage through discontinuities, joints, and perforations.

Because of poor quality in construction, heat loss through the building envelope was found to be four to five times higher in northern China than in developed countries with similar climates (Xiao et al., 2012). Xie (2009) measured the thermal resistance of a wall in a paper plant in Yueyang, China, to be 1.39 $m^2 \cdot K/W$ and that of the roof to be only 0.9 $m^2 \cdot K/W$ (without insulation). This was rather typical in China. In a study of eight factory buildings of cladded construction, Johns et al. (1987) estimated that missing insulation could result in an increase in heat loss of up to 7% for walls and 33% for roofs. Bolatturk (2006) found that the amount of insulation used is dependent on climate zone, and Aksoy (2012) showed that energy consumption decreases by 19-78% as a function of wall insulation thickness in the cold regions of Turkey. Yu et al. (2009) found that the use of insulation in Chinese buildings reduced life-cycle costs by $39.00 to $54.40 per square meter.

Because most industrial buildings contain large spaces, air distribution plays a very important role in the indoor comfort level and energy efficiency of a building (Demokritou et al., 2002; Huang et al., 2007). Furthermore, in long-span buildings a light structure is commonly used. Such a structure often creates air leakage and condensation problems. Jooet al. (2012) found that improper ventilation could result in heat loss of up to 70% and was often the source of energy usage problems. At the same time, by optimizing the air flow patterns in a large paper factory, Tanasićet al. (2011)

achieved energy savings of 5% and a reduction of 1140 t/year in CO_2 emissions. By analyzing the energy use in a natatorium in Shanghai, China, Wei (2009) found that an under-floor supply air distribution system used 9.2% less energy than an above-floor supply mode. Lau and Chen (2006) obtained similar conclusions when they compared the annual energy used in large industrial workshops with two different air distribution systems in five climate regions in the United States.

In recent years, many industrial buildings in China have been designed jointly by foreign and local Chinese designers. The foreign designers have typically used Western standards in their conceptual design, and the local Chinese designers have finalized the construction documents to comply with local construction codes. However, a lack of communication and significant cultural differences have resulted in improper design or design errors, and have been the major barriers in designing highly energy-efficient buildings with an acceptable indoor environment. In addition, a poorly trained labor force and a lack of supervision during construction have led to poor-quality industrial buildings with excessive energy use and other problems such as condensation. This paper reports the lessons learned in the areas of building infiltration, condensation, and air distribution in a winery building in northern China, which may be typical problems for industrial buildings throughout China. The objective of this investigation is to identify common energy-waste problems in industrial buildings in a developing country such as China and to evaluate building energy performance using a number of feasible methods.

Case Description

This investigation used a winery building located about 100 km north of Beijing as a case study. Figure 1 shows a bird’s-eye view of the winery, and Table 1 lists the room functions and floor areas.

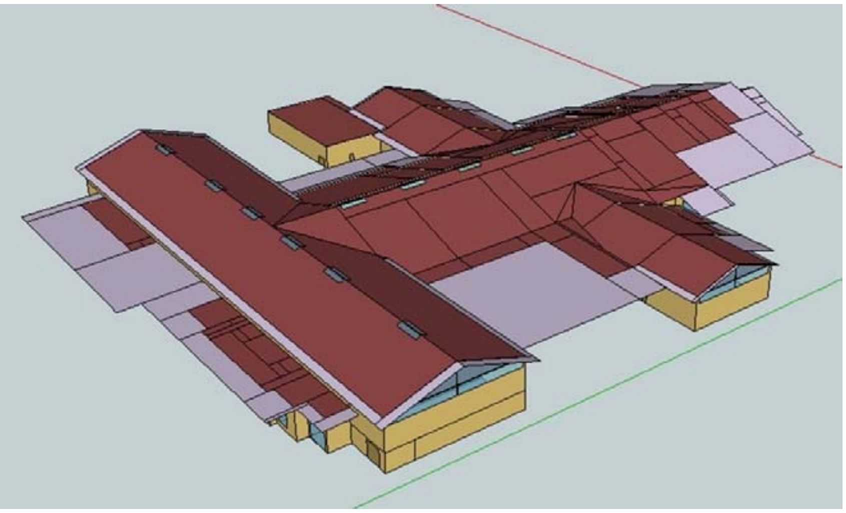


Figure 1. Bird’s-eye view of the winery building

Table1. Building functions and floor areas

Room	Area (m^2)
Administrative offices	1,583
Barrel rooms	3,755
Winery operations and bottling	2,149
Fermentation	3,396
Shipping and receiving	577
Crush pad	1,967
Total	13,427

The conceptual design of the winery was completed by a designer in California, using the California Code of Regulations (CCR), Title 24, also known as the California Building Standards Code. The code is one of the best in the United States for building energy conservation. The conceptual designer specified building materials and mechanical systems using products available from the U.S. market. The designer also considered several green features for the building, such as the use of night cooling and skylights.

The final construction document was completed by a Chinese designer in Beijing with some assistance from building envelope suppliers to comply with the local construction codes. The local designer specialized in cleanroom design and had no or little experience in winery design, although the firm had many architects and engineers. This local designer replaced the building materials and mechanical systems with products available from the local market. Thus, there were differences between the original specifications and the final products in terms of quality, physical properties, and capacities.

All the building elements were completed according to the design drawing as follows. The exterior walls were insulated sandwich panels composed of concrete with a core of extruded polystyrene board. The roof was composed of two layers of metal panels that sandwiched a layer of fiberglass batt insulation. The windows were made of dark brown coated Low-E insulating glass, and the outer doors were insulated steel doors or insulated shutter doors. The thermal conductivities of the walls, roof, windows, and doors were designed to be less than or equal to 0.299, 0.19, 2.0, and 1.70W/(m^2·K), respectively.

The local climate belongs to the continental monsoon region with very strong winds all year round. The outdoor design temperature in the winter was -14.3 °C, much colder than that in Beijing. Although the design had been intended to meet high standards, the building energy performance in the first year was disappointing. For example, when the outdoor air temperature was well above the design temperature from February 5 to 15, 2012, the indoor air temperature in the heated area, such as the barrel rooms, was far below the design temperature (15.6 ± 2.8°C), as shown in Figure 2. In some areas, the indoor temperature was even below the freezing point. Note that the total heat supply to the building differed from day to day so the temperature did not vary linearly with the outdoor air temperature. In addition, the barrel rooms experienced condensation problems during both the cold winter and warm summer, when the indoor relative humidity was maintained at approximately 80% to avoid evaporation of wine from the barrels to the room air.

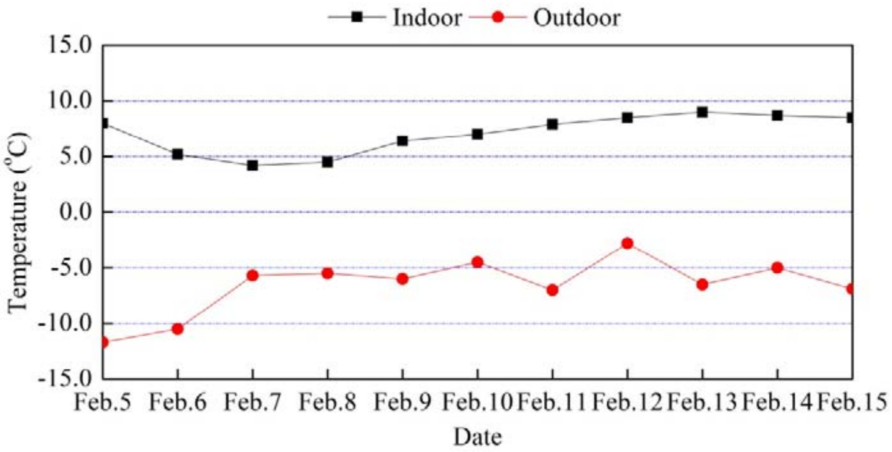


Figure 2. Indoor and outdoor air temperatures of the winery building as recorded between February 5 and 15, 2012

Identification of the Problems

In order to identify the problems in the winery, we thoroughly investigated the building leakage, envelopes, and mechanical systems. The following sections report the major findings from the investigation.

Air leakage through the building

In the building, a large number of emergency ventilators were located close to floor level in case the CO_2 level became too high in the winery during fermentation. The emergency ventilators had a fan and a simple damper that closed under the force of gravity, as shown in Figure 3(a). Strong local winds in the winter could easily push the damper to the open position. Both the number and capacity of the ventilators were greater than needed. In a discussion of the situation with the local designers, they argued that the ventilators were also used for natural ventilation. Indeed, the building was designed with natural ventilation capability, and there were many ventilation caps at roof level, such as the one shown in Figure 3(b). Because these openings were not closed by dampers, they would allow very severe infiltration in winter as a result of the chimney effect. A large opening, as shown in Figure 3(b), could account for 2% of the total heat loss in the winery. The perimeter of the winery building was greater than 1,000 m. There were numerous air leaks in the building, especially at the joints between the roof and the wall as shown in Figure 3(c). Heat loss through all leakage locations was estimated at 62% of the total heat loss.


(a) (b) (c)

Figure 3. Various leakage locations in the winery building: (a) emergency ventilator with a poor-quality damper, (b) roof ventilator cap without a damper, and (c) small leaks between the roof and wall.

The conceptual designer located in California designed the winery building that seems for warm or mild climate. For example, they designed the winery with natural ventilation and used light steel roof structure. In addition, they did not perform annual energy analysis so the energy performance of their design was not estimated. The local climate for the winery, in contrast, was harsh in winter with very strong wind and with a short shoulder season. The use of natural ventilation would only save 0.5% of the total energy. However, it was difficult to seal the emergency ventilators and roof ventilation caps to prevent leakage. Strong winds could brow snow through the ventilators into the building as far as 6 m. The local craftsmanship for light steel roof structure was very poor. They normally used heavy concrete roof. For the steel roof, they were not trained for carefully placing the insulation and making the joint between panels. The local designer in China was reluctant to communicate with the conceptual designer because of a poor command of English and could be afraid to challenge the expert design made by the California designer because they did not know much about winery design. Chinese building owners tend to trust the foreign designers rather than the local Chinese designers if the design was different. Therefore, these design deficiencies could not be corrected in the design phase. The problem led to very serious infiltration.

Condensation in the building

A steel roof system was used, with a light structure suitable for a long-span building such as the winery. However, because of design deficiencies and poor-quality construction, the roof allowed rain leakage and air infiltration/exfiltration. Various kinds of junctions are required for leakage prevention with a steel roof. The moisture barriers used to block summer moisture penetration from outside to inside, and winter moisture penetration from inside to outside, had failed because they were placed in the roof fragmentally. The design used a soft layer to support the moisture barrier, making continuous placement of the barrier impossible. Winter exfiltration of moist indoor air to the outdoor environment, and summer infiltration of moist outdoor air to cool indoor spaces, caused condensation in the insulation materials, as shown in Figure 4(a). The insulation would likely fail in a few years, and the rich nutritional content and yeast in the winery air would encourage mold growth in the roof structure. Another problem was the dripping of condensed water onto wine barrels, as shown in Figure 4(b).

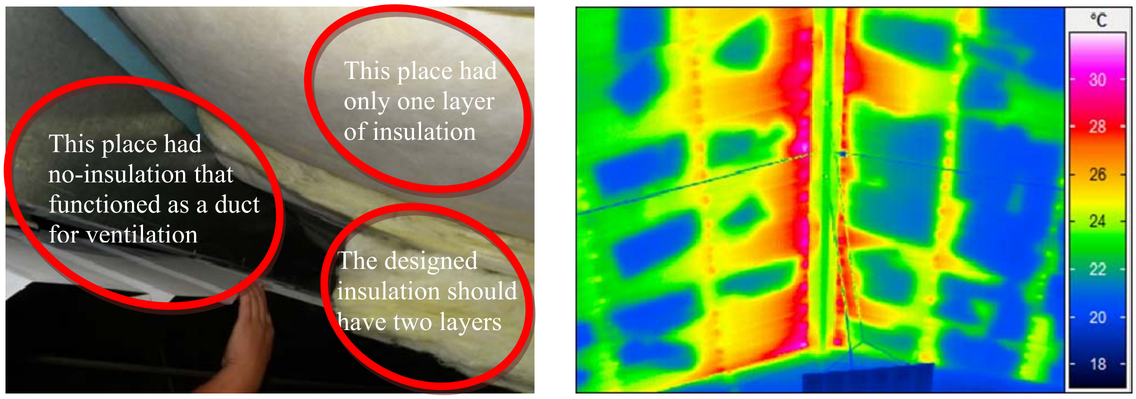
(a) (b)

Figure 4. Condensation problems found in the winery building: (a) condensation on a beam on the roof, and (b) condensed water dripping onto a barrel

Because the local designer had failed to complete all the construction documents, part of the roof joint design was completed by the steel roof supplier. In order to save money, the supplier did not break the thermal bridges, and Figure 4(a) shows the resulting condensation on a cold beam.

Poor insulation in the building roof

Figure 5(a) shows that insulation was insufficient or absent in some parts of the roof. The design had specified a very good insulation value for the roof in order to combat the cold winter and warm, humid summer. However, because of poor workmanship and lack of supervision during building construction, the insulation materials were not properly placed in many areas of the roof, and air could flow freely. Figure 5(b) shows the measurements of the interior surface temperature of the roof. The outdoor air temperature was about 29 ^{o}C at that time, but the exterior temperature of the top metal layer of the roof was as high as 72 ^{o}C due to solar radiation. The insulation value was finally estimated at only 70% of the design specification.



(a) (b)

Figure 5. A poorly insulated roof: (a) missing insulation materials in the roof and (b) the temperature of the interior roof surface as measured on a summer day by an infrared camera

Poor quality of the HVAC systems

Because the inspection of the winery building construction revealed poor quality in many places, we also suspected that the quality of the installed HVAC systems might not meet design specifications. Therefore, we tested one of the forced air heaters with reference to its design and the product catalog. Table 2 shows that the heating capacity of the heater was only 70% of that listed in the catalog, while the fan power input of 415 W was twice that listed in the catalog. The local designer had used lower-quality Chinese products to replace the U.S. products specified by the conceptual designer, perhaps because the specified products were not available locally. For example, the cooling coils in the original design were replaced by the direct expansion evaporator units typically used in cold storage. As a result, the direct expansion unit capacity was greater than needed, and the noise level from the direct expansion coils could reach 90 dB, which was higher than acceptable in a winery. The other observed deficiencies of the HVAC systems are not discussed here because of the limited space available in this paper.

Table2. Capacity evaluation of a forced air heater

Description	Catalog	Measured
Airflow rate (m^3/h)	4,434	4,217
Fan power input (W)	200	415
Inlet dry air bulb temperature (^oC)	15.6	15.6
Outlet dry air bulb temperature (^oC)	48.0	39.9
Water flow rate (kg/h)	3,540	3,531
Inlet water temperature (^oC)	93.3	93.3
Outlet water temperature (^oC)	(not available)	85.4
Air heating capacity (W)	45,700	32,197

Poor air distribution in the building

In the barrel rooms, the air temperature was supposed to be controlled at 15.6±2.8 ^oC. The rooms were cooled by fan coil units and heated by forced air heaters. The fan coil units were hung in the centers of two opposite walls about 6m above the floor, and the heaters were hung in two opposite corners, also about 6m above the floor. Because the fan coil units were positioned high above the floor, negative buoyancy allowed the cold air from the units to be distributed uniformly. However, the warm air from the heaters remained in the upper parts of the rooms because of positive thermal buoyancy. Figure 6 shows the air temperatures at different heights in a barrel room as measured on a winter day when the outside temperature was about -5^oC. During measurement, the room was almost empty, so the warm air could be easily circulated. However, the measured temperature stratification between 0.5m and 6.0m above the floor was 3K.

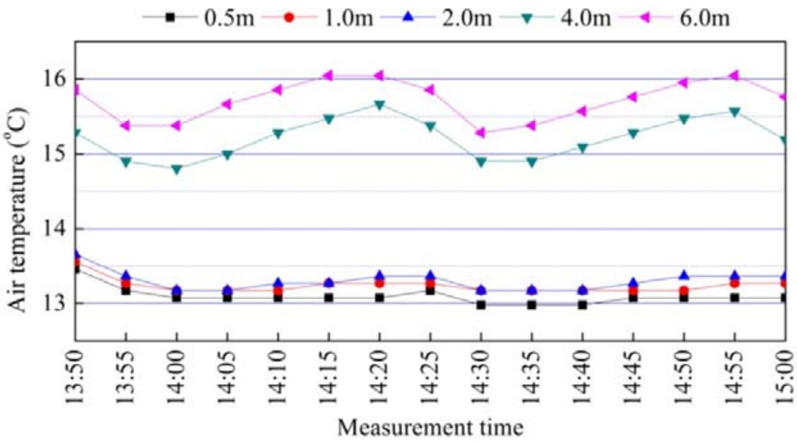


Figure 6. Indoor air temperatures at different heights as measured on a winter day

If the outdoor environment was at the design condition and the room was full of barrels, the temperature difference could be as large as 10K, as shown in Figure 7, which was simulated using a computational fluid dynamics (CFD) program, ANSYS Fluent (version12.1). The CFD program for indoor environment has been validated by our team by using different experimental data, such as Zhang et al. (2007) and Wang and Chen (2009). Due to limited space available, this paper did not provide the validation results. Figure 7 shows the temperature distribution at three representative sections, and the heaters were in the upper-left corner and upper-right corners of the room. The heaters supplied warm air at a 45° downward angle, but this air remained in the upper part of the room because of the buoyancy effect. The designers did not simulate the air temperature distribution in the barrel room and assumed that the air would be perfectly mixed by the forced air heaters. The assumption was obviously incorrect for this case.

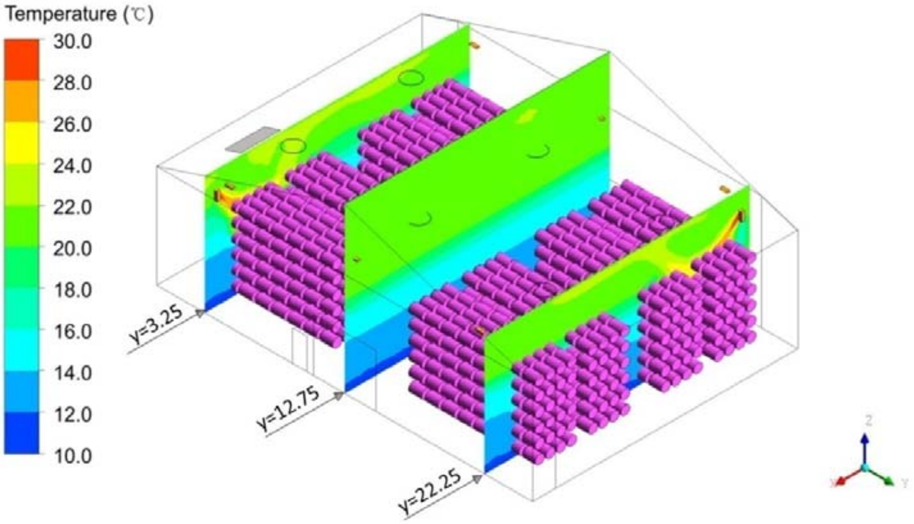


Figure 7. Air temperature distribution in three cross sections in a barrel room with two forced air heaters in opposite corners (where the cylinders represent wine barrels)

Despite the design deficiencies of the winery building as described above, not all parts of the building were inadequate. For example, the walls were of good quality. This investigation measured the thermal resistance of an exterior wall and found that its thermal conductivity was only $0.24W/(m^2\cdot K)$, lower than the design value of $0.299\ W/(m^2\cdot K)$. Not only was the thermal conductivity low, but the temperature distribution on the wall was uniform, indicating the high quality of the wall structure.

Lessons learned

In this investigation of the winery, we learned many useful lessons for the design and construction of industrial buildings in China. At the same time, a number of remedial measures for the winery were proposed, and some of them have been proven to be effective. Most of the methods we employed to identify and solve problems in the winery can be used to improve the design of other industrial buildings as well.

Air leakage through the building

The conceptual design was completed in California, where the climate is mild and where natural ventilation has been proven to be very effective in reducing energy consumption in buildings. In contrast, the winery building in China is in a cold climate region. If the conceptual designer had performed an energy analysis for natural ventilation design, such ventilation would not have been specified for the building. Using EnergyPlus, a building energy analysis program, we found that the use of natural ventilation would save only \$323 per year out of more than \$423,000 in total energy costs (Table 3). Even if the ventilation openings were sealed with high-quality fire dampers, there would still be leakage. In addition to the extra initial costs for the ventilators and dampers, the use of natural ventilation would mean high overall energy costs for this project.

Table3. Energy analysis of the building with and without natural ventilation

Operating mode	Energy consumption		Energy cost		Total energy costs
	Electricity (MWh)	Gas (m^3)	Electricity	Gas	
With natural ventilation	1150.4	360,053	\$185,548	\$238,100	\$423,648
Without natural ventilation	1152.4	360,053	\$185,871	\$238,100	\$423,971
Energy saved	2	0	\$323	\$0	\$323

The available labor force for construction in the winery area was not professionally trained.

Their skills were not up to the standards set by the winery owner and designers. Unfortunately, supervision of the construction process was extremely poor. Therefore, many obvious leakage locations were not sealed during construction. Although the walls were very thick, we could see light penetration through the joints between the walls and the roof when we switched off the indoor lighting. It is hard to find high quality labor because of the high demand for construction workers throughout China. However, the leakage problems would not be difficult to solve with basic training of the labor force and better supervision during the construction process.

Very few buildings are fully commissioned before they are turned over to the owners. Commissioning for air leakage can be done at the present time. This investigation used a blower-door pressurization test method, tracer-gas decay measurement method, and moisture condensation method to determine the air infiltration.

In the blower-door pressurization test method, a room is pressurized from 10 to 50Pa (Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD), 2009) or even up to 75Pa (ASTM International, 2006).The airflow rate through the blowers to maintain the pressure differences can be regressed to fit the following power law equation (Emmerich et al., 2005; Montoya et al., 2010):

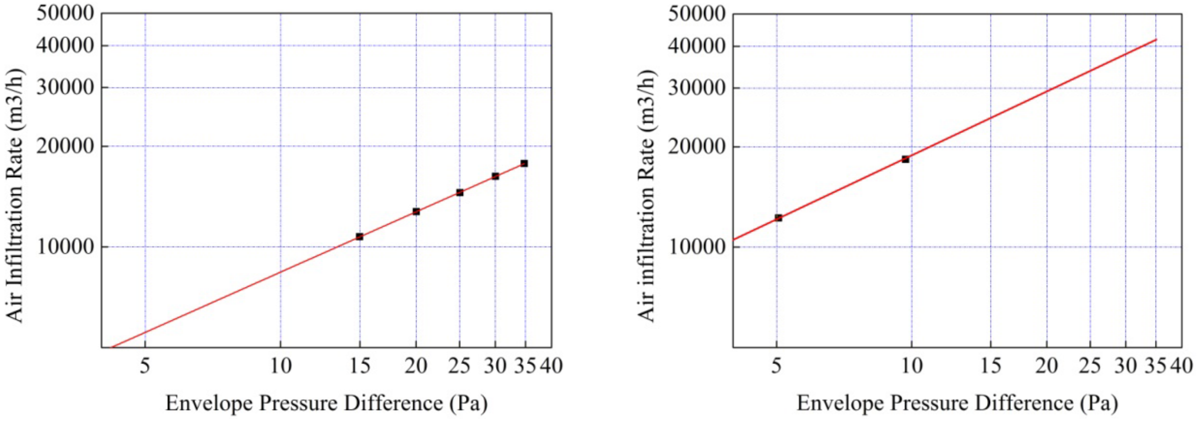
$$Q = C\left(\Delta P\right)^{n} \qquad (1)$$

where Q is the air leakage rate of the room, ΔP is the indoor-outdoor pressure difference of the room, C is the airflow coefficient, and n is the power law exponent. Once C and n have been obtained by curve fitting, Eq. (1) can be applied to predict the room air leakage at any given pressure difference.

Following standards JGJ/T 177-2009 and EN 13829, the investigation performed blower-door pressurization tests in two barrel rooms, an exterior room, and an interior room. Figure 8 illustrates the relationship between the measured infiltration rates and the pressure differences for the two rooms. Because of the large volume of the two rooms, the blowers were able to maintain a pressure difference of up to 35Pa in the exterior room and 10Pa in the interior room, as shown in Figure 8. However, the two curves were quite linear and could be extrapolated. The leakage rate and pressure difference for the two rooms can be determined from the test data as:

$$Q = 2332.5\left(\Delta P\right)^{0.574} \text{ for the exterior room} \qquad (2)$$

$$Q = 4259.4\left(\Delta P\right)^{0.650} \text{ for the interior room} \qquad (3)$$



(a) (b)

Figure 8. Relationship between infiltration rate and pressure difference: (a) exterior room and (b) interior room

When the rooms were pressurized to winter design conditions, the infiltration rate of the exterior room could reach 3.2 ACH (Air Changes per Hour), and that of the interior room could reach 3.0ACH, as determined by using Eqs. (2) and (3), respectively. Note that the infiltration rate for such a building is typically around 1.0ACH in China. Therefore, we can conclude that this winery building had a high level of leakage.

The blower-door pressurization method can tell us the extent of leakage in the building under summer or winter design conditions, but not the actual leakage at the time when the tests were performed. Therefore, the investigation attempted a further evaluation using the tracer-gas decay method. This method calculates air leakage by measuring the concentration decay rate of a tracer gas injected into the room. However, it was very challenging to mix the gas with the air in the winery building because the room volume was large. Without complete mixing of the tracer gas with the room air, the measured results cannot be trusted.

Therefore, we instead measured the moisture condensed from the cooling coil units in the winery building. As there was no fresh air supply system, operable windows, or moisture sources in the barrel rooms during the tests, moisture could be brought in or out of the room only by infiltration. The mass of condensed moisture from the cooling coils of the coolers in the barrel rooms is equal to that brought in by infiltration:

$$\dot{m} = \dot{Q}\left(d_i - d_o\right) \tag{4}$$

where $\dot{m}$ is the mass flow rate of the condensed moisture; $\dot{Q}$ is the air infiltration rate of the room; and d_i and d_o are the humidity ratios of the outdoor air and indoor air, respectively. Table 4 shows the air infiltration rates as measured by the moisture condensation method for four barrel rooms on a summer day.

Table 4. Infiltration in four barrel rooms in a summer day using the moisture condensation method

Room number	Indoor temperature (^{o}C)	Indoor relative humidity (%)	Indoor humidity ratio (g_{water}/kg_{air})	Water condensation rate (g/s)	Air infiltration rate (m^3/h)	Air change rate (h^{-1})
A	14.8	71.2	7.6	5.53	2197	0.44
B	14.9	82.2	8.8	4.25	2014	0.4
C	14	73	7.2	5.83	2449	0.34
D	15.6	77.3	8.6	5.83	2449	0.34

The moisture condensation method determines the actual infiltration rate at the moment of the test, but it cannot predict the level of leakage in the building under summer and winter design conditions. Combining the blower-door pressurization method and the moisture condensation method provides all the information needed. It should be noted that in this study we did not consider moisture transfer by diffusion through the building enclosure. The diffusion is a much slower process that would have minimal impact on the results.

Condensation in the building

Numerous leakage locations and poor insulation of the roof led to condensation in the winery building on both hot summer and cold winter days. The Chinese are capable of constructing high-quality concrete buildings but not light structures, which can suffer from severe condensation problems in cold climates. These structures usually have quite high infiltration, requiring very careful handling of moisture barriers and insulation materials. This is especially true when the roof has a complex structure. Furthermore, in cold climates it is essential to handle thermal bridges very carefully, as the conductivity of steel is very high. For a country such as China, with a labor force that is not well-trained, it is preferable to use only mature construction technologies.

Poor insulation in the building roof

This study found that the thermal performance of the building envelope varied significantly. The wall panels had very good performance, while the roof had very poor performance. The manufacturing of the wall panels was an automated process on factory production lines, where human errors were greatly reduced. The roof, on the other hand, was built on the construction site by workers with insufficient training and supervision. Furthermore, the construction team expected that the poor-quality work would not be discovered. An infrared camera should have been used during the construction process to inspect the roof and reveal defects. By using such a camera, we were able to provide evidence of poor insulation. Although our results were obtained after construction had been completed, the thermal images were still useful in identifying areas of the roof where repair work was needed.

Poor quality of the HVAC systems

Our study of the HVAC systems in the winery building concluded that the product catalog data for these systems was not reliable. The manufacturers probably copied the design from an imported product and never tested their product under the design conditions. For example, the heating capacity and fan power of the forced air heater tested were very different from those in the catalog. In the cooling coil units, a high noise level indicated that poor-quality fans had been used.

Poor air distribution in the building

As is typical in a winery building, the barrel rooms were in the basement. The ceiling height in the basement was quite low, so the air in the barrel rooms would normally be considered well mixed. However, for a large space, the usual wisdom of complete mixing of air does not hold. Because the winery designer did not perform an air distribution analysis, the design allowed for a considerable temperature gradient in the barrel room in winter. For a large indoor space, accurate air distribution analysis is not easy, but it should be conducted. The most popular and trusted method is probably CFD. The investigation used the RNG κ-ε model to simulate high Reynolds number turbulent flow because its performance in predicting indoor airflows has been validated by Zhang et al. (2007). Figure 7 shows a very significant stratification of air temperature. Using CFD, this investigation positioned six ceiling fans in the barrel room and moved the heaters to the centers of the two opposite walls to reduce stratification. Figure 9 shows that the ceiling fans would reduce the temperature stratification from 10 to 4 K for the barrel room with full barrels or to 1 K without barrels, which would meet the design requirements.

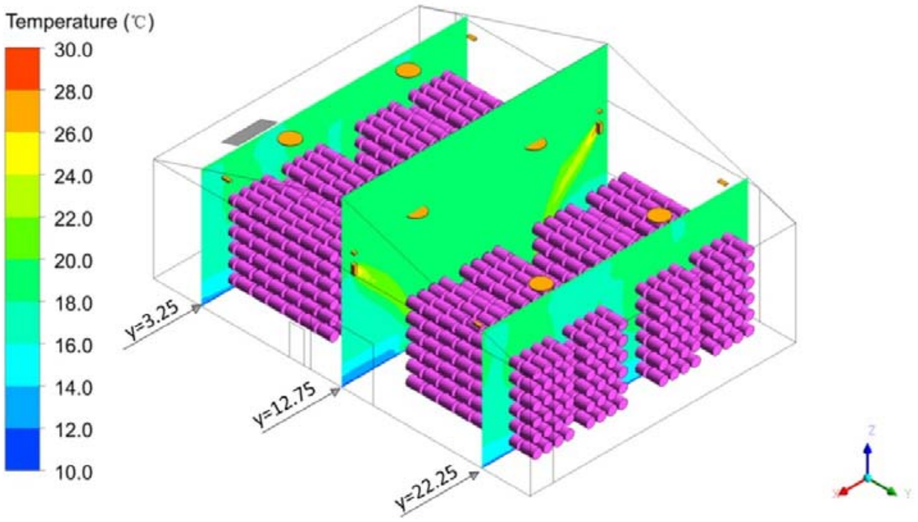


Figure 9. Air temperature distribution in three cross sections in a barrel room with two forced air heaters and six ceiling fans (where the cylinders represent wine barrels)

As a supplement to the CFD simulation results, the investigation measured the air temperatures at different heights in the barrel room when remedial measures were in place: the fans had been installed and the heaters had been relocated. Figure 10 shows the measured temperatures on another winter day when the outdoor temperature was very close to -5°C. All the fans were running, and the room was almost empty. The measured temperature difference between 0.5m and 6.0m above the floor was no more than 1K; thus, there was almost no stratification. This further proves that CFD would be a very useful tool for the design.

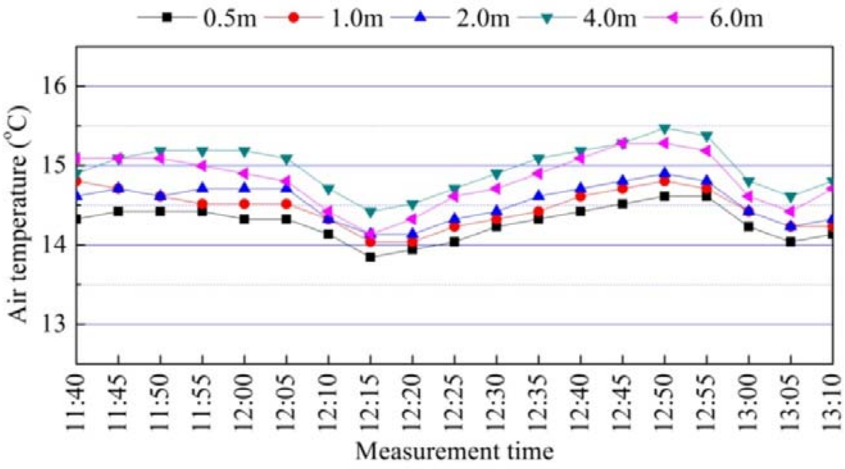


Figure 10. Indoor air temperatures at different heights with remedial measures in place

Conclusions

The investigation in the winery building found excessive air leakage, condensation, insufficient roof insulation, poor indoor air distribution, and poor-quality HVAC systems. These problems were caused by a lack of communication and significant cultural differences between the conceptual designers and local detail designers; poor construction quality; and low-quality products. In developed countries, the building deficiencies might have been discovered earlier. When designers from developed and developing countries work together, however, their cultural differences cause unique problems. This investigation recommends the use of an energy analysis program to evaluate different energy conservation measures, and the use of a CFD program to analyze air distribution in large indoor spaces. This study also recommends the blower-door pressurization method and moisture condensation method for the evaluation of air leakage, and the thermal imaging method with an infrared camera for the evaluation of thermal insulation. In addition, full commissioning of an industrial building is a very important step in ensuring proper operation.

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Table1. Building functions and floor areas

Room	Area (m^2)
Administrative offices	1,583
Barrel rooms	3,755
Winery operations and bottling	2,149
Fermentation	3,396
Shipping and receiving	577
Crush pad	1,967
Total	13,427

Table2. Capacity evaluation of a forced air heater

Description	Catalog	Measured
Airflow rate (m^3/h)	4,434	4,217
Fan power input (W)	200	415
Inlet dry air bulb temperature (^oC)	15.6	15.6
Outlet dry air bulb temperature (^oC)	48.0	39.9
Water flow rate (kg/h)	3,540	3,531
Inlet water temperature (^oC)	93.3	93.3
Outlet water temperature (^oC)	(not available)	85.4
Air heating capacity (W)	45,700	32,197

Table3. Energy analysis of the building with and without natural ventilation

Operating mode	Energy consumption		Energy cost		Total energy costs
	Electricity (MWh)	Gas (m^3)	Electricity	Gas	
With natural ventilation	1150.4	360,053	$185,548	$238,100	$423,648
Without natural ventilation	1152.4	360,053	$185,871	$238,100	$423,971
Energy saved	2	0	$323	$0	$323

Table 4. Infiltration in four barrel rooms in a summer day using the moisture condensation method

Room number	Indoor temperature (^oC)	Indoor relative humidity (%)	Indoor humidity ratio (g_{water}/kg_{air})	Water condensation rate (g/s)	Air infiltration rate (m^3/h)	Air change rate (h^{-1})
A	14.8	71.2	7.6	5.53	2197	0.44
B	14.9	82.2	8.8	4.25	2014	0.4
C	14	73	7.2	5.83	2449	0.34
D	15.6	77.3	8.6	5.83	2449	0.34